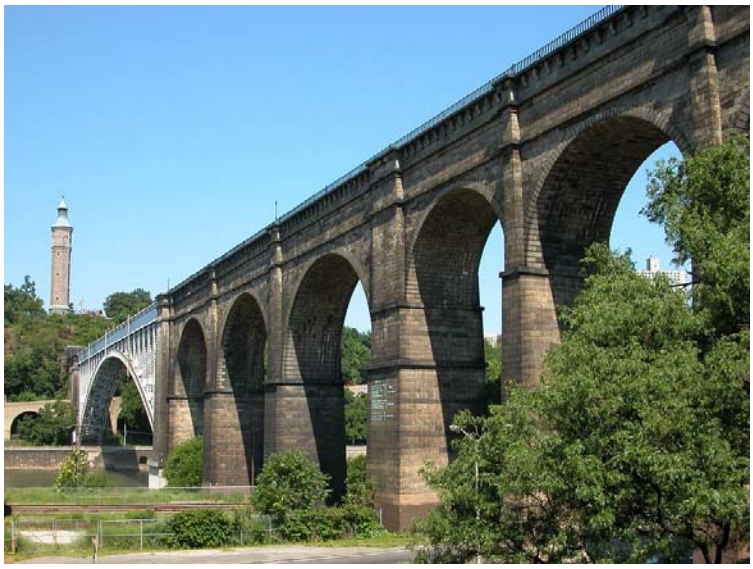
HISTORIC STRUCTURES REPORT FOR

HIGH BRIDGE

BRONX AND MANHATTAN, NEW YORK



PREPARED BY

LI • SALTZMAN ARCHITECTS, PC

LICHTENSTEIN CONSULTING ENGINEERS, INC.

MKW + ASSOCIATES, LLC

HISTORICAL PERSPECTIVES, INC.

ALTA PLANNING AND DESIGN

CHU AND GASSMAN INC

OCHSENDORF DEJONG & BLOCK, LLC

HORTON LEES BROGDEN LIGHTING DESIGN

ENVIRONMENTAL MANAGEMENT & PLANNING, INC.

APRIL 25, 2012

VOLUME I
CHAPTERS 1-14

Contents

VOLUME I.

1. EXECUTIVE SUMMARY
1.1. Identification of the Resource
1.2. Zones of Significance
1.3. Purpose, Scope, and Treatment Approach
1.4. Prior Preservation, Rehabilitation, Restoration or Reconstruction Efforts
1.5. Owners and Stewards, Current Operations and Maintenance Jurisdiction

2. INTRODUCTION
2.1. Statement of Significance
2.2. Project Team
2.3. Goals of HSR
2.4. Study Boundaries
2.5. Acknowledgments

PART I. DEVELOPMENTAL HISTORY

3. HISTORICAL BACKGROUND AND CONTEXT
3.1. Introduction
3.2. Croton Aqueduct Campaigns
3.3. Low Bridge or High Bridge (1837-1839)
3.4. Construction of the High Bridge Commences (1839-1848)
3.5. The Great Pipe (1860-1864)
3.6. Croton Waterworks Extension
3.7. New Croton Aqueduct
3.8. Demolition or Modification (1911-1923)
3.9. Steel Arch (1923-1928)
3.10. Land Transfers, Decommissioning and Post 1928 Maintenance Activity

4. ARCHAEOLOGICAL EVALUATION
Phase IA Archeological Documentary Study – Rehabilitation of the High Bridge in the Boroughs of Manhattan and the Bronx, New York by Historical Perspectives, Inc, April 2011

5. SITE AND LANDSCAPE EVALUATION
5.1. Introduction
5.2. Description of the Historic Landscape
5.3. Description of Vistas from the Bridge and On to the Bridge from Surrounding Parks
5.4. Existing Landscape Evaluation
5.5. Proposed Treatment Options
5.6. Construction Disturbance

6. ARCHITECTURAL AND STRUCTURAL EVALUATION
6.1. Survey Methodology
6.2. General Conditions

6.3. Masonry and Span Conditions
6.4. Steel Span Conditions
6.5. Aqueduct Pipes
6.6. Railings
6.7. Power and Lighting

Attachments

High Bridge Inspection Report by Lichtenstein Consulting Engineers, September 2010
Structural Analysis: Analysis of Stone Arch Span, Load Rating Analysis of Brick Arch Walkway, & Brick Arch Deck Strengthening Options , by Lichtenstein Consulting Engineers, August 31, 2010
Structural Analysis of Main 80' Masonry Arch Span, High Bridge, NYC, by John Ochsendorf, August 12, 2010
Structural Analysis of Brick Deck Arch, High Bridge, NYC, by John Ochsendorf, April 15, 2010

7. CODE, SAFETY, AND ACCESSIBILITY REVIEW

7.1. Methodology
7.2. Guidelines, Safety and Accessibility Review
7.3. Design Standards for Universal Access
7.4. Existing Conditions
7.5. Bridge Access Alterations and Recommendations
7.6. Design Scenarios

8. SYSTEMS EVALUATION

8.1. Methodology of Conducting Evaluation
8.2. Description of Existing Conditions, Including Evaluation of Integrity, Intactness, Damaged or Deteriorating Conditions
8.3. Proposed Treatment Recommendations

9. SUMMARY OF PROBES AND TESTING

9.1. General
9.2. Probe 1 – Steel Span Walkway Probe at Coping
9.3. Probe 2 - Steel Span Walkway Probe at Center
9.4. Probe 3 – 1864 Brick Walkway Probe
9.5. Probe 4 – Granite Step Probe
9.6. Probes 5 and 6 – 1928 Steel Span Floor Beam Bottom Flange Probe and Testing
9.7. Probes 7, 8, and 9 – 90 ½" Wrought Iron Pipe at Masonry Span
9.8. Samples Sent for Testing by JBCI and Professor Gordon
9.9. Mortar Samples
9.10. Coating Samples
9.11. Ironwork Samples

Attachments

Probe & Testing Locations Walkway Plans
Materials Analysis Report by JBCI, April 5, 2011
Brick Paving Coating Removal Memorandum by JBCI, January 7, 2011
Conservation Assessment of Selected Iron Elements, by CSI, November, 2010
Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report by Robert Gordon and Colin Thomas
Metallurgical Test Report by MSI Testing & Engineering, August 11, 2010

PART II. TREATMENT AND USE

10. TREATMENT PHILOSOPHY

11. USE AND INTERPRETATION OF THE RESOURCE
11.1. Proposed and Recommended Use
11.2. Interpretive Program

12. FEATURE TREATMENT RECOMMENDATIONS
12.1. Recommended Treatment for Each Area, Material, Element, or Feature

ADDITIONAL INFORMATION

13. BIBLIOGRAPHY
14. GLOSSARY

VOLUME II.

APPENDICES
A. Historic Designations
B. Historic Prints and Photographs
C. Detailed Chronology of Ownership, Construction, Alteration, Use and Significant Events
D. Landscape Chronology
E. Lighting Chronology
F. Drawings of Construction Chronology
G. Historic Documents
H. Historic Drawings

VOLUME III.

APPENDICES
I. Environmental and Hazmat Reports
    1. Limited Phase Environmental Site Assessment
    2. Draft Asbestos, Lead-Based Paint, Universal Wastes & Other Hazardous Materials Survey Report
J. Existing Conditions Photographs
K. Landmarks Preservation Commission Presentation Drawings
L. 1925 and 1926 High Bridge Reconstruction Scope Comparison
M. Value Engineering Report
N. Lighting Report
O. Interpretive Program

1. Executive Summary

1.1. IDENTIFICATION OF THE RESOURCE

1.2. ZONES OF SIGNIFICANCE

1.3. PURPOSE, SCOPE AND TREATMENT APPROACH

1.4. PRIOR PRESERVATION, REHABILITATION, RESTORATION AND RECONSTRUCTION EFFORTS

1.5. OWNERS AND STEWARDS, CURRENT OPERATIONS AND MAINTENANCE JURISDICTION

1. Executive Summary

1.1 IDENTIFICATION OF THE RESOURCE

1.1.1 Location

The High Bridge and approaches are located within Highbridge Park, Manhattan and Highbridge Park, Bronx. The High Bridge spans the Harlem River between Manhattan and the Bronx.

Manhattan cross streets: Amsterdam Avenue and 173rd Street. Bronx cross-streets: University Avenue and 170th Street.

Area of Potential Effect (APE): The Manhattan touchdown APE includes Block 2106, Lot 1 (in part), Lot 1; the Bronx touchdown APE includes Block 2533, Lots 22, 107, and 111 (in part). In addition to the previously cited blocks and lots, the High Bridge also touches lands that do not have a block or lot designation, including the river, roads and railroad tracks below the bridge.

Landmark site: Manhattan Block 2106, Lot 1. Bronx Block 2533, Lot 22.

Bridge Identification Number: BIN 2-24650-0

1.1.2 Overview

The High Bridge is the oldest bridge in New York City and connects the neighborhoods of Highbridge in the Bronx and Washington Heights in Manhattan. First opened in 1848 to deliver Croton water to Manhattan, the 1450'-0" long and 122'-0" high. The High Bridge was modeled on ancient Roman aqueduct bridges and is the most visible and monumental element of the Old Croton Aqueduct in New York City. In 1848, the bridge was designed to carry water in inverted siphon pipes located in a concealed gallery and featured fifteen (15) granite arches. Currently, the bridge features ten (10) granite arches (1860-1864), and a 466'-0" long, 3-hinge steel arch spanning the Harlem River (1926-1928).

Site features include the 118.75 acre Highbridge Park (West 155 and Dyckman Streets, Edgecombe and Amsterdam Avenue) on the Manhattan side, and the 0.82 acre Highbridge Park (West 170 Street, University Avenue and Highbridge) on the Bronx side of the Harlem River. Park holdings on the Manhattan side were assembled between 1867 and the 1960s, while the park holdings on the Bronx side were acquired in 1837 in conjunction with the construction of the Old Croton Aqueduct (1837-1842). Among the most striking features of both parks are the vistas of magnificent cliffs and large rock outcroppings, as well as sweeping views of the Harlem River.

The High Bridge was designated an individual New York City landmark in 1970, and listed on the National Register of Historic Places in 1972. In 1975, the American Society of Civil Engineers designated the Old Croton Aqueduct a National Historic Civil Engineering Landmark. In 1992, the north-most 26 miles of the Old Croton Aqueduct, including the High Bridge, were nominated as a National Historic Landmark.

1.1.3 Site History

The High Bridge was originally constructed between 1839 and 1848 and modified twice thereafter (1860-1864; 1926-1928). The Bridge was designed by Chief Engineer John B. Jervis (1795-1885), engineer of the Erie Canal, and constructed by contractors Samuel Roberts, Arnold Mason and George Law. The bridge was the critical link that enabled delivery of Old Croton Aqueduct water from the Croton Dam in Westchester to Manhattan.

Inspired by ancient Roman aqueduct bridges, the High Bridge was a civil engineering achievement. It was originally built with fifteen (15) granite arches of two widths, where the width of the arch either spanned the river or the land below. The eight arches over the Harlem River were wider (80 feet) and the seven arches over

land were narrower (50 feet). It carried two 36-inch-diameter wrought iron water pipes laid on a bed of gravel on the bridge deck. By 1860, the demand for water was so great the pipes had reached capacity. Commencing in 1860, a new 90 ½ inch iron main, which was installed atop 5'-0" tall cast iron standards, was set above the existing pipes in order to maintain the flow of water during construction. As part of this project, the side walls were raised approximately 6'-0", and the deck was paved with brick pavers in a herringbone pattern.

Following the construction of the Harlem Ship Canal in 1895, the frequency of shipping and the size of ships on the Harlem River grew and Bronx businessmen increasingly agitated for the removal of the bridge's central piers. The Army Corps of Engineers and the Secretary of War expressed concern that the bridge's river piers posed an obstruction to navigation. By 1921, New York City's Board of Estimate had approved alterations to the bridge, but two years later, reversed their decision and voted to demolish it in 1923. In response to a coordinated campaign led by architects, landscape architects, engineers, and others, this proposal was defeated and a compromise was brokered to replace five masonry arches with a single span. Construction commenced in 1926, and by 1928, the installation of a new 3-hinge steel arch, measuring 466'-0" long, was completed.

Although delivery of Croton water across the bridge had been temporarily halted at various times, the Croton delivery over the bridge was permanently discontinued in 1958 and, two years later, the Department of Water Supply, Gas and Electricity turned over jurisdiction of the High Bridge to the Department of Parks.

1.1.4 Surrounding Land Use

On its eastern terminus, the bridge touches down in the neighborhood of Highbridge, Bronx. The surrounding blocks in the immediate vicinity of the bridge are residential, with apartments typically ranging up to eight stories. New residential construction in the area is on-going. Several commercial corridors are a short distance away. The bridge approach consists of an approximately 1-acre Highbridge Park, which is fronted by University Avenue. The park features bench seating, game tables, lawns and a spray shower for children.

On its west side, the Bridge touches down in the neighborhood of Washington Heights, Manhattan. The surrounding neighborhood is a mixed use commercial district with residential occupancy.

Residential units vary in size from tenement style walk-ups to high-rise construction. The approach to the Bridge consists of the approximately 119-acre Highbridge Park, a long and narrow park extending along Amsterdam Avenue and Edgecombe Avenue, from 155th Street to Dyckman Street (200th Street). Park amenities include trails, sports courts, children's playgrounds, as well as the Highbridge Tower and the Highbridge Pool and Recreation Center.

The topography of the Harlem River Valley creates steep slopes in both the Bronx and Manhattan. The underlying bedrock (Manhattan Schist, Inwood limestone) is close to the surface, and is exposed in some locations. Stairs and ramps traverse the distance from street level to the Bridge entrances.

1.1.5 Dates of Construction and Major Alterations

1837-1842	Old Croton Aqueduct constructed
1839-1848	High Bridge constructed with 15 masonry arches conveying two 36-inch water pipes
1860-1864	Side walls of High Bridge raised to accommodate new 90 ½ inch pipe; New herringbone brick walkway and railings installed
1926-1928	Four piers and five masonry arches replaced with single 3-hinge steel arch to improve navigation on Harlem River
1958	Delivery of Old Croton Aqueduct water across High Bridge discontinued
1960	High Bridge reassigned from DWSGE to Department of Parks
1970	High Bridge designated an individual NYC landmark (LPC)

1972	High Bridge listed on National Register of Historic Places (SHPO)
1975	High Bridge designated a National Historic Civil Engineering Landmark (ASCE)
1992	Old Croton Aqueduct designated National Historic Landmark (including High Bridge)

1.2 ZONES OF SIGNIFICANCE

The High Bridge's exterior character-defining features include: granite masonry arches, piers and copings (1839-1848, 1860-1864); East and West abutments; (1839-1848; 1926-1928); 3-hinge steel arch and plates (1926-1928); walkway brick paving (1860-1864/herringbone and 1926-1928/running bond) and crown-shaped form; cast and wrought iron railings (1839-1848; 1860-1864; 1926-1928); light fixtures (1935); granite steps (Manhattan side 1860-1864; Bronx side 1860-1864); Gatehouses on Bronx and Manhattan sides (NIC); and Ventilators (NIC).

The High Bridge's interior character-defining features include: masonry brick attic (1860-1864); attic arches and structural system including iron tie rods, skewbacks, etc (1860-1864); Croton Aqueduct pipes, saddles and pedestals (1839-1848; 1860-1864; 1913); and pipe gallery and inspection walks (1926-1928).

1.3 PURPOSE, SCOPE AND TREATMENT APPROACH

The purpose of the project is (1) to respect the work of the 19th century visionaries who originally created the High Bridge and to restore the bridge's beauty, usefulness, and grandeur; (2) to restore the historic fabric of the bridge; (3) to restore the connection between the boroughs of the Bronx and Manhattan, and improve access to parks and park facilities; (4) to provide needed safety and accessibility improvements; and (5) to rehabilitate and reopen the High Bridge for pedestrians and bicyclists.

The scope of the proposed project is (1) to rehabilitate the masonry arch spans, steel arch span, walkway and deck, (2) to preserve the aqueduct pipe; (3) to provide barrier-free access and safety for pedestrian and wheeled users, (4) to rehabilitate historic railings, (5) to provide walkway and navigational lighting, and if funding allows, architectural lighting of the bridge's arches; and (6) to provide a visitor information system consisting of way-finding signage and aqueduct interpretative signage.

The primary treatment approach recommended for the High Bridge consists of rehabilitation, with preservation of historic fabric wherever possible. "Rehabilitation" is defined in *The Secretary of the Interior's Standards for the Treatment of Historic Properties (1995)* as: "The act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, and architectural values."

The historic features, form, and integrity of the High Bridge are largely intact; the intent of the proposed scope of work is to maximize retention of historic character, minimize the loss of historic fabric, and meet *The Secretary of the Interior's Standards for the Treatment of Historic Properties* while addressing the required program for the High Bridge, e.g., safety, security, and barrier-free access. Rehabilitation is an appropriate treatment for the High Bridge as it allows the historic character and most of the architectural and engineering features of the bridge to be retained and preserved, yet accommodates modern programmatic requirements.

Within the primary treatment of rehabilitation of the High Bridge, preservation of the form, integrity, and features of the bridge should be the preferred approach wherever possible. "Preservation" is defined in *The Secretary of the Interior's Standards* as: "The act or process of applying measures to sustain the existing form, integrity, and materials of a historic property."

1.4 PRIOR PRESERVATION, REHABILITATION, RESTORATION AND RECONSTRUCTION EFFORTS

The following summarizes critical dates in the construction and significant alteration history of the High Bridge:

1839-1848	High Bridge constructed with 15 masonry arches conveying two 36-inch water pipes
1860-1864	New 90 ½ inch Pipe installed; walls raised at masonry attic; walkway paved with herringbone brick; two 36-inch pipes retained for redundancy
1926-1928	Four piers and five masonry arches replaced with single 3-hinge steel arch; two 36-inch pipes removed from steel arch section
1935	New lighting installed on High Bridge deck (Department of Parks)
1939	Steel arch span and all iron work painted
1941	1,533 linear feet of 36-inch pipes removed (Works Progress Administration)
1958	Delivery of Old Croton Aqueduct across High Bridge discontinued (DWSGE)
1979	Rehabilitation work performed: stabilize railings, selective brick replacement at walkway (Coffey, Levine, Blumberg); fabricate/install two metal gates and fan guards at both ends of the Bridge (DPR); lighting contract
2007	Bronx Gatehouse repairs (DPR, Total Construction Corp.)

1.5 OWNERS AND STEWARDS, CURRENT OPERATIONS AND MAINTENANCE JURISDICTION

1.5.1 Owners and Stewards

1839-1960 High Bridge, Pipes, Lampposts, Gatehouses and Ventilators

Water Supply Commission (1833-1849) – the main duties of the five mayor-appointed commissioners were to identify a new source of water for the city, and then to investigate, plan and oversee construction of the new water works. Once projects were completed, they were handed over to the Aqueduct Board to be maintained and operated.

Aqueduct Board (1842-1849) – the Board was created after Croton water was first introduced into the city and was in charge of operating the city's municipal water supply system. The Board took charge of projects from the Water Supply Commission once they had been completed.

Croton Aqueduct Department (1849-1870) – the duties of the abolished Water Supply Commission and Aqueduct Board were transferred to the new Department. Water supply, distribution and preservation were all the domain of the Department, along with sewers, drainage and water rents.

Department of Public Works (1870-1898) – consisting of ten bureaus, the Department of Public Works (DPW) took over the duties of the abolished Croton Aqueduct Department as well as the Street Department. In addition, the DPW was responsible for the operation of projects completed by the Aqueduct Commission (est. 1883).

Department of Water Supply (1898-1901) - the Department of Water Supply (DWS) replaced the Department of Public Works when the city was consolidated by the Greater City Charter in 1898. The DWS took over the duties relating to water supply, distribution and preservation, as well as the collection of water rents and maintenance of all water supply structures.

Department of Water Supply, Gas and Electricity (1902-1955) – the Department of Water Supply, Gas and Electricity (DWSGE) took over the duties of its predecessor, the DWS, after the Amended Greater New York City Charter came into effect. The DWSGE had additional duties relating to the use and transmission of gas, electricity and steam. Of its various bureaus, its largest was the Bureau of Water Supply.

1960-present High Bridge

The Board of Estimate approved the release of the fee of the Old Croton Aqueduct Takings from West 155th Street in the Borough of Manhattan to University Avenue in the Borough of the Bronx, including the High

Bridge structure and High Bridge Tower, from the DWSGE to the Department of Parks (later renamed Department of Parks and Recreation.)

1960-present Pipes, Ventilators and Gatehouses

The Department of Water Supply, Gas and Electricity retained jurisdiction over the Old Croton Aqueduct, the 90 ½ inch pipe across the High Bridge, two 36-inch cast iron pipes across the High Bridge, a Gate House at Manhattan end of the High Bridge, and a Gate House at the Bronx end of the High Bridge. The DWSGE reserved the right to "enter at all times upon any this property for the purpose of operating and maintaining the structures remaining under its jurisdiction or to extend or improve the water supply system on said property."

Department of Water Resources (1968-1977) - the Department of Water Resources (a department of the Environmental Protection Administration) took over the duties of the abolished DWSGE.

Department of Environmental Protection (1977-present) - the Department of Environmental Protection (DEP) took over the duties of the Environmental Protection Administration.

1.5.2 Current Operations and Maintenance Jurisdiction

The High Bridge, in its present configuration, can accommodate the biennial inspection program and regular maintenance. The proposed rehabilitation and repairs to the bridge structure will not alter its configuration in any way or impede access for inspection or maintenance. The proposed manhole ladder replacements and installation of permanent lighting in the Attic will improve conditions for maintenance and inspection.

High Bridge Ownership – City of New York, assigned to Department of Parks and Recreation

High Bridge Pipe Ownership – City of New York, assigned to Department of Environmental Protection

High Bridge Daily Operations – responsibility of Department of Parks and Recreation

High Bridge Long Term Maintenance – Department of Parks and Recreation with the support of the Department of Transportation

2. Introduction

2.1. STATEMENT OF SIGNIFICANCE

2.2. PROJECT TEAM

2.3. GOALS OF HSR

2.4. STUDY BOUNDARIES

2.5. ACKNOWLEDGMENTS

2. Introduction

2.1 STATEMENT OF SIGNIFICANCE

2.1.1 Summary

The High Bridge is a distinctive civil engineering landmark in the United States which combines granite masonry arches with a three-hinged steel arch spanning the Harlem River. The monumental structure, measuring 1450'-0" long and 122'-0" high, originally featured fifteen (15) arches and was constructed between 1839 and 1848. The bridge was altered between 1860 and 1864 to accommodate the installation of a 90 ½" diameter pipe, and was subsequently altered between 1926 and 1928 when four contiguous river piers were replaced with a single steel arch.

2.1.2 Introduction

In 1970, the High Bridge, Aqueduct and Pedestrian Walk were designated as an individual landmark by the New York City Landmarks Preservation Commission (LPC). In 1972, utilizing the research of the LPC's staff, the High Bridge and Water Tower were listed individually on the National Register of Historic Places (NR). Between 1976 and 1978, the Old Croton Aqueduct, including the High Bridge, was documented by the Historic American Engineering Record (HAER). In 1992, in recognition of the outstanding national significance of the Old Croton Aqueduct, the surviving components of its northernmost 26.2 miles – including the submerged dam, sub-grade conduit and tunnels, culverts, ventilators, waste weirs, gatehouses and the High Bridge – was designated as a National Historic Landmark (NHL).[1]

This Historic Structure Report (HSR) is intended to supplement these earlier official recognitions of the High Bridge's significance by presenting an expanded discussion of the High Bridge's design, construction, modifications, and purpose-built use as a means of delivering the Croton's "pure and wholesome water" to the City of New York. This HSR does not elaborate on the general history of the Croton Aqueduct, except in instances that have direct bearing on an understanding of the High Bridge.

The period of significance of the Old Croton Aqueduct and the High Bridge are indentified in the NR and NHL nominations and HAER documentation as 1838 (commencement of Aqueduct construction) to 1870. Due to a fuller understanding of the High Bridge's history, this HSR proposes to expand the period of significance from 1836 (commencement of Bridge design) to 1928 (completion of the steel arch). The HSR also proposes new areas of significance and new contextual themes that were not identified in the earlier nominations. In recognition of the High Bridge's association with significant events (Criterion A), the new contextual themes include "Water for New York City," "Shipping and Transportation," "Historic Preservation," and "Expressing Cultural Values." In recognition of the High Bridge's distinctive characteristics (Criterion C), the new contextual themes include "Work of a Master," and "Distinctive Characteristics of a Type, Period and Method of Construction."

These themes relate principally to the construction of the Old Croton Aqueduct as a civil engineering and public infrastructure achievement (1836-1842), the arrival of abundant supplies of pure and wholesome water to New York City (1842), and the benefits to public health and safety, as well as urban growth and development, which the city's residents enjoyed as a result of Croton water's arrival (1842-1870).

2.1.3 Significance as Presented in the National Register and National Historic Landmark Nominations

The 1972 NR nomination's statement of significance notes that that the High Bridge was "An engineering triumph, unique in this country in its own time, [it] stand[s] today 'magnificent and lofty', as it was described shortly after its completion in 1848." The High Bridge, along with the adjacent Water Tower, are also noted in the NR nomination as "important visual landmarks of the upper Manhattan and Bronx skylines and illustrate the sculptural impressiveness of engineering structures."

The 1992 NHL statement of significance for the Old Croton Aqueduct notes: "Constructed between 1837 and 1842, this Aqueduct provided New York City with its first planned water supply system and served as a model for other cities. The eight-and-one-half foot tall, masonry-lined conduit ran 40 miles through undulating topography to central Manhattan; in a few places it is tunneled through solid rock or carried across valleys on bridges and berms, yet most of the aqueduct lies on a stone foundation immediately below ground." Although the concealed masonry conduit of much of the Old Croton Aqueduct is a significant aspect of this work of civil engineering, it was its largest and most expensive structure – the High Bridge, designed in the form of a Roman aqueduct bridge – that served from the inception of the great public works project as its often published and most visible symbol of the plan to bring water for drinking, fighting fires, and manufacturing into the city.

The 1972 NR nomination recognized the High Bridge's national significance as an engineering structure. In 1992 the NHL nomination expanded the national significance of the Old Croton Aqueduct by recognition of its association with events that have made a significant contribution to the broad patterns of American history and as the embodiment of distinctive characteristics of an historic period and method of construction . As a contributing resource of the Old Croton Aqueduct, the High Bridge can also be considered significant under these Criteria.[2]

The 1992 NHL nomination identified several contextual themes and sub-themes in which the Old Croton Aqueduct expresses its significance.[3] These contextual themes include Technology (Sub-Themes: Construction; Water & Sewerage; Fire, Safety, Sanitation and Pollution Controls) and American Ways of Life (Urban Life).

2.1.4 Proposed HSR Period of Significance (1836-1928)

This HSR presents a period of significance for the High Bridge distinct from but associated with the Old Croton Aqueduct: from 1836 (commencement of design) until 1928 (completion of the three-hinged steel arch). In addition to the themes stated above, this HSR presents new themes to illustrate the multivalent significance of the High Bridge that are not discussed in the LPC, NR, HAER, or NHL documents.[4] These themes include:

III. Expressing Cultural Values/Significance
V. Developing the American Economy
  K. Public Works (Water for New York City)
  T. Shipping and Transportation by Water
VII. Transforming the Environment
  A. Historic Preservation (1913-1924)

This HSR maintains that these additional themes and sub-themes are necessary to understand the history and context of the High Bridge, and are provided as a framework for expounding the High Bridge's significance.

2.1.5 HSR Proposed Significance: Association with Significant Events (Criterion A)

The High Bridge is historically significant at the municipal, state and national levels under Criterion A for its association with events that have contributed to the broad patterns of American history.[5]

Water for New York City

Though surrounded on all sides by three rivers – all tidal and non-potable – Manhattan's water for drinking, manufacturing use, and fighting fires came from springs, ponds, well and cisterns. Before the arrival of reliable and abundant sources of potable water from Westchester County, New York City was subject to recurrent epidemics of cholera, typhoid and plague, as well as repeated fires and property loss. The decimating impacts of these forces on resident populations fundamentally challenged health and well-being, but also undermined the city's long-term socio-economic and political stability.

In 1842, New York State Assemblyman (and future Columbia College President) Charles King delivered an address when the Old Croton Aqueduct was brought on-line, noting the wide-ranging significance, broad spectrum of public service benefits, and future value of the civic investment in waterworks infrastructure. Ultimately, King proclaimed that the Croton Aqueduct represented, "the crowning glory and surpassing achievement of the latter part of the half century."[6]

The High Bridge was the sole means by which Croton water was delivered into Manhattan from 1848 (completion of construction) until the completion of the New Croton Aqueduct tunnel under the Harlem River in 1890. After the New Croton Aqueduct's completion in 1895, and the operation of the Catskill Aqueduct in 1917, water delivery across the High Bridge was recurrently suspended. On December 2, 1958, water delivery across the High Bridge was permanently discontinued.

Shipping and Transportation by Water

The legislated dimensions of the High Bridge – at least 80'-0" wide between the piers and not less than 100'-0" clear under the arches – allowed large sailing ships to navigate up the Harlem River and facilitated commercial growth of properties on both sides of the river. During the late 19th century, several navigation improvement projects began to be planned to provide for clear and free passage of the increasingly larger ships that were entering the harbor. A municipally and federally funded "Improving Harlem River" plan, directed by the US Army Corps of Engineers, included projects such as the Harlem River Ship Canal (1895) which removed the circuitous shallow impediment at Spuyten Duyvil Creek, and the replacement of Harlem River Bridge with the Third Avenue Bridge (1898).[7] The last impediment to free navigation of the Harlem River were the 80'-0" wide openings between the river piers of the High Bridge, and the shallow draft around the piers.

In 1911 the Corps of Engineers formally notified the City that the bridge's river piers were an obstruction to navigation and must be removed. Thus began a heated debate within the city government and among professional and civic groups over how best to remove the piers and whether or not the High Bridge merited preservation and modification. A critical re-assessment of the High Bridge, which occurred between 1911 and 1924 from aesthetic, economic, and technical points of view, ultimately resulted in a proposal to modify the bridge in a manner that met the city's navigational needs and complied with national standards.

A wide range of options for allowing navigation of the river at the aqueduct crossing were examined, including replacement of the bridge with an aqueduct tunnel. Over time, a number of ambitious modification plans were presented by both private and municipal architects and engineers, culminating in the proposal to replace five contiguous arches with a single, three-hinged steel arch of 420'-0" span and 103'-0" rise above mean high water. The approved design, constructed between 1926 and 1928, provided "an unobstructed fairway from bulkhead to bulkhead," thus satisfying the Corps' requirements.

Historic Preservation (1913-1924)

The early 20th century campaign to preserve the High Bridge may evidence one of the earliest cases of bridge preservation campaigns in particular, and of preservation of 19th century civil engineering infrastructure in general, within the United States. The events leading up to and including the 1926-1928 remodeling of the High Bridge are instructive in that they illustrate how the bridge's fate fluctuated for over a decade before a compromise decision to modify the bridge was ultimately reached in 1923.

Between March and June 1923, the American Institute of Consulting Engineers, the American Institute of Architects, the American Society of Civil Engineers, the American Scenic and Historical Preservation Society, the Parks and Playgrounds Association, and the American Institute of Fine Arts persistently lobbied for the bridge's preservation. Advocates for remodeling urged the Board of Estimate and Apportionment to consider preservation strategies that respected the architectural, engineering and aesthetic value of the bridge but also improved river navigation. On June 29, 1923, the Board of Estimate and Apportionment voted to remodel the

High Bridge in a manner that would be cost-effective, structurally sound, and meet all War Department requirements for river navigation.

The narrative history of the bridge in the early 20th century illustrates how a unified voice, representing the disciplines of engineering, architecture, landscape architecture, and preservation, was instrumental in reversing the Board of Estimate and Apportionment's vote sanctioning the bridge's demolition to one in favor of selective modification. The early 20th century debate over the High Bridge ultimately resulted in the retention of the structure, as well as the aqueduct pipe within, and underscored early 20th century opportunities for modernizing historic infrastructure.

Expressing Cultural Values/Significance

In 1928, *The American Architect* ran an article on the bridge's newly-completed modification, which announced, "Of all the picturesque structures in the United States, few have been of greater inspiration to artists as a subject for etching, painting or sketching than what has been familiarly known as "High Bridge, New York."[8] Even before the bridge's construction was completed, a consciousness about the singularity of this structure in the American landscape began to manifest itself amongst technical/engineering audiences. For instance, Assistant Croton Aqueduct Engineer Fayette B. Tower (1817-1857) wrote in his book, *Illustrations of the Croton Aqueduct* (1843) that the High Bridge, "which, when completed, will be the most interesting work on the whole line of the Aqueduct, and in its appearance will rival the grandeur of similar works of the Ancient Romans." The bridge was popularized in commercial media such as prints and photographs, and guidebooks cited the bridge as a destination.

Printmakers Nathaniel Currier (1813-1888) and James Merritt Ives (1824-1895), whose firm "Currier and Ives Publishers of Cheap and Popular Prints" prepared numerous views of the High Bridge and made some of the first commercially-illustrated reproductions of the bridge available for purchase by the public, including *Highbridge at Harlem in New York* (1849; Appendix B, Figure 3), and *View on the Harlem River, NY* (1852). Professional photographers repeatedly chose to document the High Bridge. Successful Victorian photographer William England (?-1896, British) photographed the High Bridge during his mid-19th century tour of the U.S. and Canada for the London Stereoscopic Company (see Appendix B, Figure 6). Prominent photographer August Loeffler produced images such as the *Speedway near High Bridge* (1902, Appendix B, Figure 34). Illustrated guidebooks of New York featured images of the bridge, including Birseye Glover Noble and Charles F. Sterling's Nichols' *Illustrated New York: A Series of Views of the Empire City and its Environs; each Number containing six elegantly finished steel engravings, from original drawings, with explanatory descriptions* (1847) and James Miller's *New York As it Is: or A Stranger's Guide-book to the Cities of New York, Brooklyn and adjacent Places With Map and numerous illustrations* (1867).

By the last quarter of the 19th century, the bridge was known as a popular locale for day-tripping New Yorkers. A June 1877 *Scribner's Monthly* article noted: "Every resident of the City knows where the High Bridge is, no matter how dense his ignorance may be as to other points of the water service. It is one of the most popular resorts of the middle classes."[9] Illustrations which appeared in *Harpers Weekly*, such as *At High Bridge, Harlem River - "All Aboard"* (Appendix B, Figure 26) depicted the bridge and its environs as popular attractions.[10] During the first quarter of the 20th century, the bridge repeatedly became the subject of several American artists, including Frederick James Boston (1855-1932) and American Impressionist Ernest Lawson (1873-1939). Lawson produced three known paintings of the bridge, including *High Bridge, Harlem River* (1912; San Antonio Museum of Art), *Harlem River at High Bridge* (circa 1915, de Young Fine Arts Museums of San Francisco), and *Harlem High Bridge* (circa 1910, collection unknown).

2.1.6 HSR Proposed Significance: Distinctive Characteristics (Criterion C)

The High Bridge is historically significant at the national level under Criterion C for its embodiment of distinctive characteristics of a type, period, and method of construction and as the work of a master. In this respect, the High Bridge may be understood within pre-1993 NPS theme XVIII. Technology, sub-theme

Construction and current NPS CLI themes III. Expressing Cultural Values/Significance, sub-theme M. Landscape Architecture, and N. Other (Civil Engineering).

Distinctive Characteristics of a Type, Period, and Method of Construction

The High Bridge is unique and significant as an early arched stone bridge, preserved by the complex construction processes required to incorporate the monumental three-hinged steel arch into its river span.

The surviving original sections of the High Bridge illustrate the type of structure chosen by civil engineers from antiquity through the 19th century to carry water at a relatively level grade above a wide or deep valley. This type of structure came to be known as a Roman aqueduct, for the prominent ruins of tall multiple stone piers and arches carrying water channels that are found throughout the regions of the former Roman Empire. In the 18th and early 19th century British engineers adopted the aqueduct form to carry canals across river valleys during the flourishing era of British canal construction.

Although early American canal engineers built wooden bridges on stone piers to carry canals across intersecting streams and rivers, they turned to more durable stone bridges, based on British models. Jervis was familiar with the details of many of the aqueduct bridges constructed on the Erie Canal, such as at Little Falls (1825), Rochester (1825), and Schoharie Creek (1839-41).

Notably, no American aqueduct bridges were as long or as tall at the High Bridge. Its engineering context also includes a similar structure for crossing valleys, namely arched stone railroad viaducts. In the 1830s canals began to be overtaken by railroads as the preferred means of moving people and freight long distances. As railroads stretched out into the countryside valleys were crossed by embankments and culverts, where the crossing was shallow or short, and by tall stone pier and arch structures resembling the Roman style aqueducts. Both canals and railroads are relatively level structures, carrying heavy dynamic loads. Canals were required to maintain water levels to maintain ease of barge navigation, and railroads were required to limit steep grades due to the limited traction of locomotive engines. The design and construction of the High Bridge resembles the Thomas Viaduct of the B&O Railroad (1835), the Canton Viaduct of the Boston & Providence Railroad (1835), and the New York & Erie Railroad's Starrucca Viaduct (1848).

Long span hinged steel arch bridges were built where bearing conditions did not allow multiple spans, or where an open channel was required for navigation. Constructed from the mid-19th century of wrought iron, transitioning to steel in the 1880s, the hinged steel arch brides reached their apogee of length in 1930. Steel arch bridges generally ranged in length from 200 to over 1,500 feet in length, and are often monumental works spanning major rivers in American cities.

The steel section of the High Bridge is a relatively short hinged arch bridge, though it is unusual as a three-hinged steel arch with deck girder that is continuous across the mid-span hinge. Its design is imitative of the two-hinge steel arch Washington Bridge, completed in 1889, which spans 510 feet across the Harlem River just north of the High Bridge. It is also significant for reusing two of the original bridge piers, both founded on bedrock, as abutment piers with additional granite facing over reinforced concrete additions to the piers and foundations.

Work of a Master

The initial construction of the High Bridge is also significant as the work of civil engineer John B. Jervis, and its remodeling by master bridge builder, McClintic-Marshall Company.

John B. Jervis was selected by the Water Commissioners to build the Croton Aqueduct because of his success constructing canals and railroads, which presented similar problems of design, organization, and construction as the aqueduct. Jervis became one of the nation's early leading civil engineers in the design and construction of canals and railroads. During his active career as a civil engineer between 1819 and 1864, Jervis served as Chief Engineer of three major canal projects, designed and supervised the construction of numerous early railroads, designed the Stourbridge Lion – the first locomotive to run in the US, designed and constructed the

Croton Aqueduct, consulted on the design of the Boston Aqueduct, and founded an iron manufactory. Until his death in 1885 at the age of 86 Jervis actively consulted on civil engineering projects, including the enlargement of the High Bridge and the New Croton Aqueduct.

In addition to his civil engineering works, his influence on the profession of civil engineering cannot be understated. Following their work in the engineering corps of Jervis numerous engineers later became prominent in the profession, including Horatio Allen, Peter Hastie, Edward H. Tracy, and James Renwick, Jr.

Pittsburgh based McClintic-Marshall Company, contractor for the steel work for the 1926-1928 remodeling of the High Bridge, were builders of some of the most significant steel bridges in the country in the early 20th century, including, in the New York City area, the George Washington Bridge, Bear Mountain Bridge, Outerbridge Crossing, Goethals Bridge, and the approaches to the Hell Gate Bridge. McClintic-Marshall constructed numerous large and small railroad and road bridges throughout the US, as well as the structural steel for many prominent structures, such as the Chelsea Piers and the lock gates for the Panama Canal.

2.2 PROJECT TEAM

Lichtenstein Consulting Engineers, Inc., *Prime Consultant*
Joseph Pullaro, *Principal-in-Charge*; Gina Zamiskie, *Project Manager*; Michael Lahti, *Project Engineer*; Leo Fernandez, *Field Engineer*

Li/Saltzman Architects, PC, *Preservation Architect*
Judith Saltzman, *Principal-in-Charge,* John Favazzo, *Project Manager,* Zach Rice, *Senior Preservation Architect,* Meisha Hunter, *Senior Historic Preservationist,* Chian-Ju Ku, *Project Architect,* Pascale Montadert, *Research Assistant;* Rie Shoji, *Production Assistant*

MKW + Associates, LLC, *Landscape Architect*
John Williams, *Principal-in-Charge*; Linda Gumeny, *Design Principal*; Gaetano Romano, *Landscape Architect*

ALTA Planning and Design, *Bicycle Access and Interpretive Design*
Phil Goff, *Principal-in-Charge*; Steve Durrant, *Project Manager*

Chu and Gassman Inc., *Electrical Engineer*
Jon T. Chu, Principal-in-Charge, R. Keith Craven, *Senior Associate/Department Head*; Sam Perez, *Electrical Engineer*

Historical Perspectives, Inc., *Archeologist*
Cece Saunders, *Senior Archeologist*; Faline Schneidermann-Fox, *Researcher*

Ochsendorf Dejong & Block, LLC, *Structural Engineering Consultants*
Prof. John Ochsendorf, *Structural Engineer*

Jablonski BuildingConservation Inc., *Materials Testing and Analysis*
Mary Jablonski, *Prinicipal-in-Charge*

Prof. Robert Gordon, *Metallurgist*

Conservation Solutions, Inc., *Metals Conservators*
Mark Rabinowitz, *Vice-President/Senior Conservator;* Justine Posluszny Bello, *Conservator/Project Manager*

Horton Lees Brogden Lighting (HLB) Design
Barbara Cianci Horton, *President*; Brian Smith, *Lighting Designer*

Environmental Planning & Management, Inc.
Aphrodite Socrates, *Vice President*; Mike Aprahamian, *Environmental Engineer and NYSDOL Asbestos Inspector,* Darren Frank, *Environmental Scientist and NYSDOL Asbestos Inspector,* Christina Katsifas, *NYCDEP Asbestos Investigator*

2.3 GOALS OF HSR

The High Bridge Historic Structure Report (HSR) is intended (1) to provide a comprehensive description of the bridge's construction history and subsequent alterations over time, (2) to provide a multi-disciplinary evaluation of the bridge's existing conditions, (3) to critically assess the bridge's significance, and (4) to present a cogent treatment philosophy and recommendations that will guide the bridge's proposed rehabilitation and preservation.

2.4 STUDY BOUNDARIES

See Identification of Resource in Executive Summary, Section 1.1

2.5 ACKNOWLEDGMENTS

American Society of Civil Engineers, Heritage and History Section

Avery Library, Columbia University

Corbis Bettman Archive

Friends of the Old Croton Aqueduct

Hagley Museum and Library

Historic American Engineering Record

Jervis Public Library, John Bloomfield Jervis Papers

Library of Congress

Museum of the City of New York

National Archives

National Park Service

New York City Department of Design and Construction

New York City Department of Parks and Recreation

New York City Mayor's Office

New York City Department of Environmental Protection Archives

New York City Landmarks Preservation Commission

New York State Historic Preservation Office

New York City Municipal Archives, Bureau of Plant and Structures Collection

New York Historical Society

New York City Hall Library

New York Public Library

The New York Times Archives

Public Design Commission

ENDNOTES

1 While the HSR builds upon earlier research presented in the LPC designation and NR and NHL nominations, the HSR seeks to correct several discrete inaccuracies found within in these documents. These include: 1) the 1972 NR nomination states that the side walls of the Bridge were raised in 1850 rather than in 1860-64, and identifies Navy Engineers as having replaced the Bridge's river piers in 1923, rather than the Department of Plant and Structures engineers work in 1926-1928; and 2) the 1992 NHL nomination's reference to the construction of the steel arch over the Harlem River in 1937 instead of 1926-1928.

2 The 1992 NHL nomination lists the periods of significance for the Old Croton Aqueduct as 1842-1870 for Commerce, 1836-1842 for Engineering, and 1842-1870 for Health/Medicine, with 1842 as the significant date common to all three areas of significance. The High Bridge can also be considered a contributing resource to the Old Croton Aqueduct under these Criteria.

3 The thematic nomenclature and organization presented in the 1992 NHL nomination were based on NHL guidelines which preceded the 1993 revision of the NPS's thematic framework.

4 The themes are drawn from *Revision of the National Park Service's Thematic Framework*. History E-Library, National Park Service, 1994. http://www.nps.gov/history/history/categrs/thematic.htm

5 In this respect, the Bridge may be understood within pre-1993 NPS theme XVIII. Technology, sub-themes Construction, Water & Sewerage, Fire, Safety, Sanitation and Pollution Controls and theme XXX. American Ways of Life, subtheme Urban Life.

6 Lockwood, Charles. *Manhattan Moves Uptown*. Boston: Houghton Mifflin Company, 1976, 185.

7 The US Army Corps of Engineers had regulatory authority under the Rivers and Harbors Acts of 1890 and 1898 over the construction of bridges, wharves, piers, jetties, bulkheads, and similar structures in ports, rivers, canals, or other waterways used for navigation. These federal acts established of minimum standards for navigation of waterways and required removal of obstructions to navigation by owners of the obstructions. Beginning in the 1880s, and then under these federal acts the Corps began to systematically clear, widen, dredge, and remove impediments to navigation throughout New York Harbors, including the Harlem River.

8 Department of Plant and Structures. "Engineering and Construction: The Reconstruction of High Bridge, New York." *The American Architect*, Volume CXXXV, Number 2560, January 5, 1929, 55.

9 The landscape around the High Bridge and the vista from the High Tower were also praised, "The views from the windows (of the High Service Water Tower) are of surpassing beauty, revealing the Hudson reaching north and south between the Palisades, and into the Tappan Zee; Long Island Sound flashing in the east; the smoky city with its spires and roofs below, and the soft green pastures and woods of Westchester County undulating into the northward haze. The line of the Harlem, speckled with row-boats, sloops, schooners, and little steamers; the red-brick paved walk across the top of the bridge dotted with pigmy men and women, and the white houses, half hidden among the foliage on the banks, give a charming variety of the scene." *Scribners' Monthly*, June 1877, page 168.

10 *Scribners' Monthly*, June 1877, page 169.

3. Historical Background and Context

3.1. INTRODUCTION

3.2. CROTON AQUEDUCT CAMPAIGNS

3.3. LOW BRIDGE OR HIGH BRIDGE (1837-1839)

3.4. CONSTRUCTION OF THE HIGH BRIDGE COMMENCES (1839-1848)

3.5. THE GREAT PIPE (1860-1864)

3.6. CROTON WATERWORKS EXTENSION

3.7. NEW CROTON AQUEDUCT

3.8. DEMOLITION OR MODIFICATION (1911-1923)

3.9. STEEL ARCH (1923-1928)

3.10. LAND TRANSFERS, DECOMMISSIONING AND POST 1928 MAINTENANCE ACTIVITY

3. Historical Background and Context

3.1 INTRODUCTION

This section introduces the reader to the Croton Aqueduct and the High Bridge. A brief overview of the Croton Aqueduct's history and significance serves as a prelude to a comprehensive narrative of the High Bridge's physical and social evolution. The narrative chronology of the High Bridge's initial design, construction, and significant modifications commences with the request for proposals for the bridge in June 15, 1839 and terminates with the re-opening of the bridge after the completion of the steel span on October 27, 1928. It should be noted that the discussion is inclusive of alterations which were proposed but were never executed. A review of post-1928 modifications, including land transfers in the vicinity of and including the High Bridge, the discontinuation of water service at the High Bridge, and post-1928 repair and maintenance campaigns are also summarized.

3.2 CROTON AQUEDUCT CAMPAIGNS

"*The history of civilization is the history of infrastructure.*" - Oliver Schwaner-Albright[1]

Before the arrival of reliable and abundant sources of potable water, New York City was subject to recurrent epidemics of cholera, typhoid and plague, as well as repeated fires and property loss. The decimating impacts of these forces on resident populations fundamentally challenged health and well-being, but also undermined the city's long-term socio-economic and political stability.

3.2.1 Manhattan Company

New York City's first privately-held municipal water company was the Manhattan Company, founded by Aaron Burr (1756-1836) in 1799, and legislated by the State Senate and Assembly with the passage of "An Act for supplying the City of New York with pure and wholesome water." In addition to the bill's civic mandate, which essentially created the city's first public utility, an unusual paragraph in the bill granted the newly incorporated Company power to "employ all such surplus capital as may belong or accrue to the said company in the purchase of public or other stock, or in any other monied transactions not inconsistent with the constitution and laws of this state or of the United States, for the sole benefit of the said company."[2] Given unprecedented powers to provide both a municipal waterworks and perform banking operations, the Company's priority was generating income, rather than providing water. By the 1830's, there was a growing consensus among New York City residents that the Manhattan Company had violated its charter of incorporation, by providing only a portion of the City with an unreliable water supply rather than providing the entire City with a reliable water supply.[3]

3.2.2 New York State Water Commission

Responding to a March 1829 report about the inadequacy of the Company's water supply to meet fire-fighting needs, the Common Council took matters into its own hands and ordered the construction of a new reservoir, outfitted with a 233,000 gallon tank, at the north side of 13th Street east of Fourth Avenue. The Council then appropriated $1,000 in 1832 for an inquiry into providing fresh water – the report recommended that water be procured from the Croton River in Westchester County. In February 1833, the State Legislature passed "An Act for the Appointment of Commissioners in Relation to Supplying the City of New York with Pure and Wholesome Water" and authorized the creation of a New York State Water Commission.[4] Citing health and safety crises, New York City seized control over the fate of its water supply from the Manhattan Company in February 1835. The Common Council was bolstered by overwhelming public support in its agenda to control the water system's future: an April 1835 referendum garnered a 3 to 1 majority vote for the Croton water project. A devastating fire in 1835, which destroyed much of lower Manhattan and resulted in $20M in insurance claims, also catalyzed support for the Croton's construction.

The State legislature authorized $2.5 million in bonds to fund the ambitious campaign, which sought to tap the Croton River in Westchester.

3.2.3 First Croton Campaign (1833-1842)

By July 1835, pre-construction surveys under the direction of Major David B. Douglass (1790-1849) were underway. Douglass, a Yale graduate and one-time professor of natural philosophy, mathematics and civil engineering at West Point who served as the project's first chief engineer, planned the aqueduct's route and structures and established the aqueduct's hydraulic principles. Planning the route took four years, which commenced under Douglass and was taken over by engineer John B. Jervis (1795-1885) in 1837.

For the Croton Aqueduct, Jervis carefully studied Roman aqueducts, aqueduct bridges, in addition to contemporary civil engineering works, such as the first sub-aqueous tunnel (begun 1826, completed 1841) under the Thames River, designed by French engineer Marc I. Brunel (1769-1849).

Rome's ancient waterworks exerted a strong influence on engineers charged with realizing the Croton Aqueduct system. A concerted effort to better understand the civil engineering achievements of the past, in particular, ancient Roman hydraulic construction, is a recurrent theme in the memoirs of several key players tied to Croton's commission and design. Both New York State Assemblyman (and future Columbia College President) Charles King (1789-1867) and Assistant Engineer of the Croton Aqueduct, Fayette B. Tower (1817-1857) introduce their respective narrative histories of the Croton Aqueduct with detailed descriptions of ancient waterworks construction, and pay particular attention to Roman waterworks.

The construction of the Croton Aqueduct relied heavily upon immigrant Irish laborers, who were hired by the contractors responsible for each section of the line. Between 1837 and 1842, Irish laborers temporarily suspended work on the line and agitated for higher wages during two labor strikes in 1838 and 1840, respectively.

Jervis' Croton Dam (currently submerged inside of the New Croton Dam) consisted of bolder-filled, timber-cribbed aprons, keyed masonry and granite facing all using hydraulic mortar, and earth embankments. Jervis' unique design for the S-shaped profile of the Old Croton dam minimized the "destructive force of overflowing water" and became an industry standard for American dam design.[5] From the dam, water descended at a rate of 13 inches per mile for 33 miles in a gravity-fed, horseshoe-shaped, brick and hydraulic mortar lined channel (8'-6" high x 7'-6" wide). Seventy-two million gallons of water flowed through these masonry channels on a daily basis. Despite its high cost ($225,000), Jervis specified hydraulic Rosendale mortar throughout the Croton aqueduct.

Although primarily a sub-grade construction, the Croton Aqueduct featured several spectacular superstructures at topographically challenging locations or at junctures of water collection and distribution: the monumental masonry-arched Valley Crossing at Sing Sing Kill; the 1450'-0" long, 100'-0" high masonry-arcaded High Bridge over the Harlem River; the 1,900'-0" long, 50'-0" high Clendening Valley Crossing; the 31-acre, 190-million gallon York Hill Reservoir in Central Park; and the neo-Egyptian style, 24-million-gallon Murray Hill Distributing Reservoir at 42nd Street.[6] Single-story, utilitarian style gatehouses were constructed at 142nd, 135th, and 119th Streets, all in the middle of 10th Avenue (currently Amsterdam Avenue), whose function was to control and regulate the water supply. Six (6) waste weirs were constructed to allow discharge of surplus water from the aqueduct's masonry conduit to the sewer system (and thence to the Hudson River). Thirty-three (33) granite ventilators (14'-0" high) were constructed at regular mile intervals to bring fresh air into the Aqueduct. Every third ventilator (11 total) included a door and interior stair to access the aqueduct's conduit. Where the waste-weirs occurred, ventilators were omitted.

Charles King delivered the following address in 1842 in commemoration of the newly-operational Croton Aqueduct, where he noted the wide-ranging significance, broad spectrum of public service benefits, and future value of the civic investment in waterworks infrastructure.

> Of the valuable consequences which will be derived from this work some may not be developed until after successive years. The little experience already had points to many useful results that were not foreseen. Among its immediate and palpable benefits are its influences on domestic convenience and comfort, the promotion of sobriety and personal cleanliness, the purification of our streets, the consequent increase of public health, the facilities it will extend to mechanical and manufacturing industry, the vast increase of steam power among us to be employed in the arts, the supply to our mariners of a necessary element which will remain comparatively unaffected by change of climate, and pre-eminently the security it will afford against the dangers of conflagration. Each neighborhood uniting its inhabitants for purposes of mutual safety may promptly arrest the ravages of fire in its early stages and if such associations be numerously formed extensive fires need but rarely occur. Large as we may deem the expense of this vast structure we cannot but consider it as cheaply purchased when we reflect that the calamity of a night occurring when we were without the protection now afforded involved a destruction of property of twice this cost.[7]

The Croton Aqueduct's completion was a defining moment in the history of the City, evidencing the sustained commitment and joint efforts of Water Commissioners and legislators, engineers and surveyors, masons and laborers. Its' planning and construction had been initiated with a $2.5 million dollar bond act and a total investment of $8,575,000.[8] King's reference to the devastating fire of 1835 (whose flames demolished 700 buildings and prompted $20 million in insurance claims), and the waves of cholera and yellow fever which had claimed so many innocent lives, were reminders of the heavy price the City had paid for not having a reliable, abundant water supply.[9] In asserting the preciousness of Croton water and its tangible (improved public health and hygiene, sanitation, public safety, utility in industry, energy) and intangible (convenience, sobriety, perceived security) benefits, King's conviction of the Aqueduct's role of safeguarding the future of New York City was clear. Moreover, each granite block, each reservoir and each mile of conduit were designed and built with longevity in mind. The impregnable, fortified appearance and monumental presence of the above-ground structures associated with the Aqueduct communicated the value of the life-sustaining water within. The enormous civic enterprise which financed the Aqueduct's construction carried with it the expectation that the Croton would serve many generations of future New Yorkers.[10]

3.3 LOW BRIDGE OR HIGH BRIDGE (1837-1839)

Throughout the late 18th and early 19th centuries numerous plans were presented entrepreneurs, politicians, and civil engineers for providing the city with fresh water, and in each plan, in order to enter the city, the water was required to cross the Harlem River.[11] During the 1820s the Common Council and Legislature examined and dismissed plans by Erie Canal engineer Canvass White to provide water from the Bronx River, crossing the Harlem at Macomb's Bridge, where it would be pumped over the river and up to a reservoir. Following a deadly cholera epidemic in the summer of 1832, the Council's Committee on Fire and Water, at the urging of alderman and Board of Health treasurer Myndert Van Schaick, hired engineer Col. Dewitt Clinton, Jr., son of the late governor and champion of the Erie Canal builder, to examine sources of water. Clinton concluded that the Croton River was the best source of water, because of its capacity was greater than the Bronx River, and because its higher elevation allowed the city's reservoirs to be filled by gravity, without the use of pumps. However, the location of the dam to contain the Croton River required a very long and expensive aqueduct, with numerous, ravine, creek, river, and valley crossings, including the wide and deep Harlem River, which Clinton proposed to cross with a bridge 1,000 feet long, 138 feet above the river. Clinton estimated the aqueduct would cost $2.5 million and take 3 years to build. Clinton's report was received by the council on December 22, 1832 and its merits were debated alongside a renewed Bronx River plan late into the night. When questioned about the gravity fed crossing of the Harlem River by an advocate of the Bronx source Council President Henry Meigs explained, "Why, sir, we'll build a bridge of gold to let the silver stream pass over."[12]

Two months later newly elected Senator Van Schaick ushered a bill through the legislature, entitled "An Act for the Appointment of Commissioners in Relation to Supplying the City of New York with Pure and Wholesome Water." This act allowed for the establishment of the Water Commission. Following recommendations made by Van Schaick, in the spring of 1833 Governor William Marcy, a Democrat, appointed Stephen Allen, Saul Alley, William W. Fox, Benjamin M. Brown, and Charles Dusenberry, as the first Water Commissioners. The Water Commissioners were Democrats, with the exception of Whig Party member Fox. Former Mayor Stephen Allen was selected as Chairman.

The first order of business of the Water Commissioners was to hire two engineers to determine the best course for the aqueduct, Canvass White, who had been earlier engaged in plans for water for the city, and former West Point instructor Major David Bates Douglas, whose experience included surveys for canals and railroads, and was Chief Engineer on the Morris & Essex Canal.

White was unable to complete his surveys due to summer floods along the course of the Delaware and Raritan Canal where he was chief engineer.

Douglas began his surveys during June 1833, and reported to the Water Commissioners on two potential routes for the aqueduct, The Inland, or Saw Mill River Route, and The Hudson River Route. Both required crossing of the Harlem River, for which Douglas proposed a stone "aqueduct bridge, 18 chains, or 1,188 feet long, from abutment to abutment, and consisting of nine plain semicircular arches. . . . the height of the structure from water line to water line would be 126 feet, exclusive of hydraulic foundations, which would be from 10 to 25 feet more." [13]

Douglas noted the bridge would be a "considerable labor and expense, but by no means of paramount difficulty in either of these respects."[14] However, citing examples of much longer and taller aqueduct bridges – both modern and ancient – at Lisbon, Caserta (near Naples), Spoletto, Lucca, Pontcycylte (Wales), and Maintenon (France), Douglas stated: "With such examples of enterprise and skill before us, many of them undertaken for objects far less important than that of supplying the city of New-York with water, we may certainly look upon the design of the Harlem aqueduct without fear."[15]

In October 1836 Douglas was dismissed by the Water Commissioners, without leaving drawings or specifications for construction of any part of the aqueduct.

Chief Engineer John B. Jervis

Nine days after the dismissal of Douglas the Chief Engineer's position was taken up by canal and railroad engineer John B. Jervis, who began learning his trade as an axeman on the Erie Canal, clearing timber and cutting stakes for surveyors in the summer of 1817. By the summer of 1819 Jervis was resident engineer of a 17 mile stretch of the Erie Canal. Over the next six years, until 1825, Jervis ambitiously took on greater responsibility to become supervising engineer on a 50 mile stretch of the canal. Among Jervis's superiors were Canvass White, who discovered hydraulic cement in the US and also provided an early plan for the Croton Aqueduct, and Judge Benjamin Wright the Erie Canal's Chief Engineer, considered by the American Society of Civil Engineers to be the "Father of American Civil Engineering." Jervis's abilities and ambitions allowed him to rise within the ranks of the profession and lead to his appointment to increasingly complex projects, including the Delaware and Hudson Canal, where as Principal Assistant Engineer under Judge Wright, he organized the engineering department and supervised construction, his first position of authority in the construction of a large civil engineering project. Jervis next became Chief Engineer of the Mohawk and Hudson Railway, then the Chenango Canal, and then returned briefly to the Erie Canal as Chief Engineer of the eastern division, before being offered and accepting the position as Chief Engineer of the Croton Aqueduct.

Jervis quickly began to lay out the line of the new aqueduct, generally accepting the course selected by Major Douglas. By late December 1836, aided by a corps of assistant engineers, Jervis began to design the aqueduct, including its dam, tunnels, culverts, gatehouses, and valley crossings. By the end of February 1837 Jervis had

completed plans and specifications for public bidding for the first segments of the aqueduct, and construction began in May 1837, demonstrating Jervis's ability to take charge of a complicated engineering project and move it forward.

Of all the valley crossings, the crossing of the Harlem River was the most vexing political as well as technical challenge encountered in constructing the Croton Aqueduct. As costs on the aqueduct escalated and the national economy worsened following the Panic of 1837, the Water Commissioners sought to contain costs. They ordered Jervis to examine the costs and benefits of the plans for crossing the river.

A detailed description of the costs and benefits associated with crossing the Harlem River was laid out by Chief Engineer Jervis in his December 12, 1837 "Report of the Chief Engineer in relation to the Plan for crossing Harlaem River." In this report Jervis first outlined the previous proposals by consulting engineers for crossing the Harlem River by both low and high bridges, although he noted he only had general descriptions of the proposals, and no drawings. He next prepared detailed plans and estimates for a low and a high bridge, "to determine which, under all the circumstances, will most economically secure the desired object of passing the water over this valley."

Jervis noted that the first proposed crossing of the Harlem River, by canal engineer Canvass White in his 1826 plan to provide the city with water from the Bronx River, was by means of iron pipes on a "permanent stone bridge," about 80 feet above mean tide, located at Macomb's Dam. In 1832 Col. Dewitt Clinton, Jr. proposed crossing the Harlem River on a bridge 138 feet high, maintaining the aqueduct grade. In 1835 engineer John Martineau, consulting to the Water Commissioners, proposed crossing the Harlem River "by an 'inverted syphon,' made of wrought iron, 8 feet in diameter, and supported on a bridge, composed of one arch of 60 feet span, over the channel way, and the remainder by a stone embankment 30 feet high." This was the plan that became to be known as the "low bridge." The plan that Jervis inherited from Major Douglas was for the stone bridge 126 feet above the river, or the "high bridge."

Jervis ' detailed cost estimates and rendered drawings by draftsman Henry B. Pearson were presented showing for the first time both the inverted syphon Low Bridge and the High Bridge (Appendix H, Figs. 1 and 2).[16]

Jervis estimated that the High Bridge would cost $935,745 and the cost of the Low Bridge was $426,027, a difference of $509,718.

Jervis caveated the cost estimate for the High Bridge by stating that there was "no work that is *precisely* similar—that is, of the same magnitude; that from its elevation and inconvenience of access, will be as expensive in laying up; that requires so great a proportion of large stone, or the same exactness of execution; at the same time, there is sufficient resemblance [to other work] to constitute a guide, that with careful application, will not lead us materially astray in computing the expense."[17]

On October 12, 1838 the Water Commissioners awarded a contract to construct the lower cost option – the Low Bridge. With the letting of the Low Bridge contract the Water Commissioners met vociferous opposition from property owners along the Harlem River who were intent on increasing shipping along the Harlem River and insisted that the Low Bridge would not allow ships with tall masts to pass under the aqueduct. Bowing to political pressure from the property owners, the state legislature passed a law requiring construction of a tunnel under the river of an aqueduct bridge with arches 80 feet wide and 100 feet tall water to allow for free river navigation.

The Commissioners then abandoned the contract for the Low Bridge and Jervis prepared drawings and specifications for a "lofty bridge of masonry" – the High Bridge – which began construction on August 13, 1839 and was completed in late 1848.

3.4 CONSTRUCTION OF THE HIGH BRIDGE COMMENCES (1839-1848)

On June 15, 1839, the following advertisement appeared in the *New York Evening Post*:

> Croton Aqueduct.
>
> Notice- Sealed proposals will be received by the Water Commissioners of the City of New York until the 29th day of July next, at 9 o'clock, P.M. at their office in the city of New York, for the excavation, embankment, back filling, foundation and protection walls, a waste weir, pipe chambers, an aqueduct of stone and brick masonry, a bridge of masonry over Harlem river, and such other incidental work as may be required, on that portion of the Croton Aqueduct which is embraced in section 86.
>
> Some preparatory work has been done, such as procuring materials, erecting shantees, and preparing other buildings, a bill of which at specific prices will be presented at the office aforesaid, at which the same will be charged, as an advance on the contract and the same will then be the property of the contractor, for the use of the work.
>
> The prices for the work must include the expense of materials necessary for the completion of the same, according to the plans and specifications that will be presented for examination as hereinafter mentioned.
>
> The work to be completed by the first day of August, 1843.[18]

The advertisement summarizes the work to be done to bring the water of the Croton Aqueduct across the Harlem River by way of the "high bridge," and by mention of the "preparatory work," hints at the difficulties that the Democratic Water Commissioners, chaired by former mayor Stephen Allen, and their Chief Engineer, John B. Jervis, had encountered in trying to bring the Croton Aqueduct across its most difficult and river crossing in a economical manner. And, although Croton water was brought into the city across the Harlem River in the summer of 1842 by temporary iron pipes, it would take another six years to bring the High Bridge to its completion.

After placing most of the aqueduct under contract, the Water Commissioners advertised for the remaining, and most expensive, contracts for the aqueduct on September 7, 1838 for all the work on the "Island of New York," the lower half of the Fourth Division (Sections 86 to 97), including the Receiving and Distributing Reservoirs (Sections 96 and 97) and the crossing of the Harlem River by low bridge carrying an inverted siphon (Section 86). The Pennsylvania firm of Ellsworth, Mix & Co. successfully submitted the low bids of $360,000 on October 23, 1838 to construct a "low bridge" of inverted siphon of cast iron pipes, and $39,955 for the adjacent Section 87 which ran about 1/10 of a mile from the low bridge, and included what became known as the Jumel tunnel.[19]

In the face of vigorous opposition by landowners along the Harlem River who wanted the river to be navigable to large vessels, the legislature, passed on May 3, 1839 "An Act, Prescribing the Manner in which the Croton Aqueduct shall pass the Harlem River" which ordered the Commissioners to carry the Croton Aqueduct across the Harlem River by a bridge "with arches and piers; the arches . . . at least eighty feet span, and not less than one hundred feet from the usual high water mark of the river; or . . . by a tunnel under the channel of the river."[20]

On the 7th of May, 1839, the Commissioners then abandoned the contract for the "low bridge" inverted siphon with Ellsworth, Mix & Co. By that time the contractors purchased timber, cut stone, and other materials, and erected shantees, but had completed little work.[21]

On July 29, 1839 thirteen bids were received to construct a "lofty bridge of masonry".[22] The low bid of $737,755 was withdrawn by the bidder, and the contract was awarded to the next lowest bid to a firm

composed of Timothy N. Ferrell, George Law, Samuel Roberts, and Arnold Mason. Three of the members of the firm (Ferrell, Law, and Roberts) had been previously awarded contracts to construct sections of the aqueduct. Ferrell would later drop out of the firm, and it became known as Law, Roberts & Mason. A contract was signed on August 13, 1839 with Law, Roberts & Mason to construct the High Bridge for an estimated $755,130.[23]

Writing to the Water Commissioners on Christmas Eve, 1839, Jervis noted that the contractors "have not made as much progress as was expected" and that "three of the partners have been much occupied in finishing Sections for which they had previously contracted; which has doubtless operated to prevent that energetic and uniform course of proceeding, necessary in conducting such a work. They are now very considerably relieved from their previous contracts, and give strong assurances that no effort on their part shall be wanting, to carry forward the work with a progress commensurate with its importance."[24] By the end of March 1840 the contractors had constructed the cofferdam for the first pier on the Bronx side of the bridge (pier 3), and made preparations for driving piles for that pier and one other.[25]

The contractors would later report to the Water Commissioners that the reason for their slow start was because: "Few, if any contracts upon the public works in this country involved more pecuniary responsibility, or required greater accuracy and precision in its architectural and mechanical details" so that "much of the first few months after the commencement of the work, was necessarily devoted by the contractors in devising and preparing machinery, reducing to order and system the manner of operating, and in ascertaining the best and most effective means of obtaining materials.[26]

For more than eight years to come, Jervis would be urging the contractors of the High Bridge to engage in an "energetic and uniform course of proceeding." Indeed, the construction challenges faced by the contractors, who it appears had not ever built a structure even close to its size and complexity, were many:

Foundations

- Dredging soft mud from the river bottom with "a mud machine;"
- Sinking wooden cofferdam frames into the sand of the river bottom;
- Driving sheet piling into the river bottom around the cofferdam frames;
- Removing boulders encountered while driving sheet piling;
- Placing an embankment of puddled earth around the cofferdams;
- Pumping water out of the cofferdam with steam powered pumps to allow excavation of sand to expose the rock bottom;
- Within the cofferdams, cutting and leveling the rock bottom to lay stone foundations for the piers;
- Driving piles for eight foundations (four on land and four in the river) where rock bottom could not be reached;
- Cutting the pile tops level and laying two layers of planking spiked to the piles with treenails, and filling the spaces between the pile heads and planks with concrete;
- Constructing a small crane to raise, move, and place stones by steam power;
- Laying pier foundations of gneiss on the rock or planked piles to the height of the adjacent earth or high water level;
- Filling hollow spaces in each pier solid with concrete;
- Removing cofferdams from the river at completion of the work.

Piers and Abutments

- Constructing a large crane to raise, move, and place stones by steam power;
- Procuring steam engines to hoist the stones and move the arch centering;

- Procuring sufficient granite to construct the piers and abutments;
- Laying fourteen hollow stone piers, from 94 to 66 feet high, and capping them with impost blocks;
- Laying two abutments on bedrock.

Arches

- To lay up the arches, constructing centering of white oak and pine, bolted together, and resting on timber scaffolding;
- Procuring sufficient light gray granite to construct the arches;
- Laying fifteen cut stone rusticated light gray granite arches (seven of 50 foot diameter and eight of 80 foot diameter);
- Taking down and reinstalling the centering for each arch.

Spandrels

- Laying stone spandrel walls solid to twenty feet above the springline of the arches, then sloped upwards solid to the top of the arches;
- Procuring sufficient granite to construct the spandrels;
- Laying up three rough hammered stone interior haunch walls, parallel to the spandrels, bonded together with headers every twelve feet;
- Setting stone floor slabs, covered by two inches of concrete, laid on top of the haunch walls and bonded to the spandrels.

Parapets

- Installing almost 300 linear feet of granite water table and parapet walls and brick attic interior walls;
- Procuring sufficient granite to construct the parpets;
- Removing the temporary pipe from the river, and installation of two lines of 36 inch cast iron pipes on brick pedestals;
- Placing earth and sand fill over the pipes;
- Laying turf and flag stone paving over the fill.

Gatehouses

- Laying stone foundations on bedrock;
- Raising up granite exterior walls with door and window openings;
- Laying up brick ceiling vaults, with rubble fill;
- Constructing granite gate chambers, with iron gates;
- Connecting the gate chambers to the aqueduct;
- Paving the exterior plazas with bluestone flagging;
- Constructing a granite and brick waste weir from the Bronx gatehouse to the river;
- Installing slabs of greywacke stone for the roofs;
- Installing wrought iron railings on the gatehouse copings.

3.4.1 New Water Commissioners

On March 20, 1840, Gov. William S. Seward, leading a new Whig administration in Albany, replaced the first Water Commissioners with a new slate of Whig Water Commissioners, under the leadership of Samuel Stevens, who proceeded to investigate the bidding processes of the late Commissioners and Jervis for graft and collusion (they found none) and to seek economies in all aspects of the aqueduct, including re-thinking

the High Bridge. In their plan to lower costs for the aqueduct, rather than press forward with the High Bridge work, the new Water Commissioners proceeded to make requests to Jervis to analyze revisions to the High Bridge design already under contract and to the contractors to provide estimates for several new means of carrying the Croton water across the Harlem River, including: tunneling under the river; replacing seven arches on the Bronx side with a solid wall; constructing a bridge with arches fifty feet high, instead of 100 feet high, as mandated by the legislature; and to sink a raft in the river as a foundation for the bridge piers.[27]

Jervis made unfavorable reports to the Commissioners against each of these proposed changes. Law, Roberts, & Mason reported that these new projects "weakened their confidence in the stability and permanency of their contract, and to paralize [sic] their efforts in preparation, or vigor in the prosecution of the work."[28] The Commissioners continued to press for changes to the High Bridge throughout their years in office.

At the end of 1840, Jervis reported that the $91,000 of completed "work at the Harlaem River Bridges has not progressed as rapidly as could be desired. It is satisfactory, however, to be able to say, that so far as the work has progressed in preparing the foundations, the method of accomplishing it has succeeded as well as anticipated."[29]

The work of preparing the pier foundations in the river was a complex and time consuming affair, and one that had worried Jervis from the beginning of the project. To understand how other engineers had accomplished the task of sinking cofferdams and building bridge piers Jervis researched the topic by reading articles in journals and reports, and, in 1837, by visiting a similar project under construction, the Alexandria Aqueduct bridge that crossed the Potomac River at Georgetown, where he and Commissioner Allen met with the engineer in charge of the construction Maj. William Turnbull of the U.S. Army's Topographical Bureau. Jervis also acquired a copy of Maj. Turnbull's drawings for the cofferdam which were published as *Drawings Accompanying the Report of Captain Turnbull on the Survey and Construction of the Alexandria Aqueduct* (1838).[30]

For the piers on land and in the river where the bedrock was very deep, the contractors drove oak piles from 18 to 50 feet deep about 2½ feet on center, requiring more than 240 piles for some piers.

Before driving the river piles the mud, sand, and rock within the cofferdams were removed to a depth of 14 to 35 feet below the level of high water. The river piles were sawed off level, the earth removed from between the pile heads from two to four feet deep and successive layers of natural cement concrete placed between them. On top of the leveled pile heads timber grillage was begun by first spiking a layer of 12 x 12 white oak timbers into the pile heads with two inch thick white oak treenails, then placing concrete between the timbers, flush with the top. A second layer of 12 x 12 timbers was placed perpendicular to the first, with 3 inch spaces left between the timbers, which was filled with fine concrete. On top of the timber grillage a layer of 9 inch thick white oak planks were laid tight. On top of this platform the masonry piers were then laid.

For the land piles, pits were excavated before the piles were driven and the pile heads were cut level. No timber grillage was placed (as for the river piers), but a mass of 3 feet of concrete was placed in layers between the pile heads. On top of the grillage or piles the foundation stones were laid, of "suitable dimension to rest fairly over the heads of the piles, and form a proper bond in the successive course.[31]

At the end of June 1841 Jervis reported to the Water Commissioners that the foundation work "at Harlaem River proceeds but slowly." At the end of 1841 both Jervis and the Commissioners noted that progress was still not as rapid as had expected: for only some of the 15 piers had foundations been started, and for only five piers had the masonry work begun, with the piers raised from 4 to 21 feet above high water. Delays on the river foundations were becoming apparent. Rock bottom in the river was found to be much deeper than the engineers had believed. While dredging and driving sheet piles for piers 10 and 11 the contractors began to encounter large boulders that lay close together within a layer of mud and sand overlaying a stratum of sand and clay. The boulders were at a level that did not allow their removal by dredging or other means until after the cofferdams were placed. Jervis reported that due to the boulders "Yellow Pine sheeting timbers, 9 to 12

inches thick, were to a great extent driven to splinters, or broken on reaching the boulders, rendering them of little use for any work required below the surface of the boulder stratum."[32] For the cofferdam at pier 10 sheet piles had to be driven fifty feet below high water.[33] The largest boulders had confused the soundings of the river taken during the winter of 1838 by Jervis's young draftsman, T.J. Carmichael. From the soundings Jervis determined the types and depths of foundations required to cross the river, and his resident engineer, Peter Hastie had estimated bid quantities for dredging, excavation, rock removal, embankments, cofferdams, and sheet and bearing piles. Law, Roberts & Mason's contract was based on the designs and estimated quantities,[34] so as it became evident that the boulders were not bedrock and the depth of the excavations revealed that four of the river piers would have to be laid on pile foundations, the costs increased, as did the time of construction. The boulders had to be individually removed from the sand layer by cutting a slot in each boulder and inserting a lewis pin to allow them to be raised from the river by crane.

3.4.2 The Temporary Pipe

In addition to the difficulties encountered with providing foundations for the piers, progress on the bridge was slowed also by an addition to the contract for laying and supporting a temporary 36 inch diameter cast iron pipe across the river to connect the completed Westchester and Manhattan sections of the aqueduct so as to allow Croton water to flow into the city by July 1842. In order to support the temporary pipe the contractors had to complete work of installing the bridge pier cofferdams with their embankments for all of the piers, which, because of the closeness of the piers and depth of the river, created a nearly continuous earthen dam across the river. Jervis, in his December 31, 1841 "Report on the General State of the Croton Aqueduct" stated to the Commissioners that by early April 1842 the final embankment of the bridge pier cofferdams would be completed and, with a little additional work, the embankments would be ready to begin laying the temporary pipe.[35]

In early June 1842 the final work of laying the temporary pipe across the embankments was completed and the temporary pipe connected to the aqueduct on both sides of the river. At the lowest point of the temporary pipe a fountain was provided by connecting a one foot diameter branch pipe extending 80 feet south into the river. From the branch pipe a vertical fountain shot up – a "*jet d'eau*" – 115 feet high. To the fountain various size nozzles were attached. The Commissioners noted "This was done for the purpose of ascertaining by experiment what form and size will be best suited for fountains, which may be erected in the public squares, or other parts of the city, for convenience or ornament." [36]

First Assistant Engineer Fayette B. Tower, in his *Illustrations of the Croton Aqueduct* (1843), romantically proclaimed of the fountain:

> To those who had watched over the work during its construction and looked for its successful operation, this [fountain] was peculiarly gratifying. To see the water leap from this opening and rise upwards with such force and beauty, occasioned pleasing emotions and gave proof that the design and construction of the work were alike faultless, and that all the fondest hopes if its projectors would be realized.
>
> The scenery around this fountain added much to its beauty; there it stood,—a whitened column rising from the river, erect, or shifting its form, or waving like a forest tree as the winds swayed it, with the rainbow tints resting upon its spray while on either side the wooded hills arose to rival its height: all around was *nature*; no marble basin;—no allegorical figures, wrought with exquisite touches of *art* to lure the eye, but a fountain where nature had adorned the place with the grandeur and beauty of her rude hills and mountain scenery.[37]

The fountain remained in place to delight and entertain visitors at the High Bridge construction site until it was removed in 1848 when the permanent pipes were installed across the completed High Bridge. [38] See an engraving of the fountain from Tower's *Illustrations of the Croton Aqueduct* in Appendix B, fig. 2.

On Monday afternoon, June 27, 1842, Croton water flowed into the temporary pipe across the Harlem River and into the Receiving Reservoir at York Hill (now the Great Lawn in Central Park). A week later, at sunrise on July 4th, the water entered the Receiving Reservoir at Murray Hill.[39] On Friday, the 14th of October, 1842, the "Croton Celebration" was held throughout the city. Church bells pealed, cannon roared, as many as 250,000 people marched or watched a seven-mile long parade of government officials, firemen, Croton contractors and workmen, Croton engineers, civic, professional, and temperance societies and ordinary citizens. They marched from the Battery up Broadway, past the new fountains at City Hall Park and Union Square, then down The Bowery back to City Hall Park for a grand celebration of the introduction of "pure and wholesome" Croton water into the city.[40] Yet, the High Bridge was far from completion.

3.4.3 Construction Continues

Following the introduction of water into the city, construction continued at the High Bridge at a somewhat quickened pace. On September 10, 1842 the Water Commissioners removed the slow down order, which had delayed by one season the setting of stone on the piers that had completed foundations. During the fall of 1842 masonry on piers 1 to 10 and 14 was raised from seven to thirty-seven feet above high water. The piles for river pier 11 were driven and concrete placed around the heads. Half the piles for pier 12 were driven, generally 31 to 36 feet long, but with one 40 and another 49 feet long. Aided by a new steam engine, the work of pumping and hoisting out the mud from the cofferdam was begun on pier 13, the last river pier. Jervis was apprehensive about this pier, because on the south side rock ran steeply down into the river, and he knew it was possible that the soils were the same as the adjacent piers, would require very long and costly piles, and could result in an uneven foundation for the pier.[41]

3.4.4 The Old Water Commissioners Return

On February 8th, 1843, the original Water Commissioners were returned to their former positions by the new Democratic governor, William C. Bouck, long-time Erie Canal Commissioner. Under the leadership of Stephen Allen, the Democratic Water Commissioners ceded control of aqueduct operations on the island of New York (including reservoirs) to the city's Croton Aqueduct Board, with the exception of completion of the unfinished High Bridge.

Jervis reported to the Commissioners in July 1843 that the work had "progressed steadily," and that foundations for the abutments had begun, and all the river piers were above water, except pier 13, for which about three-fifths of the piles had been driven. He had hoped that the piles for pier 13 would have been completed by then, but the steam engine that kept water out of the cofferdams had required repairs. Jervis reported that counter to his earlier reports, the soils for pier 13 were better than expected, allowing fewer extra piles, and that the adjacent rock descended so steeply as to not interfere with obtaining a "uniform and substantial foundation." He expected the masonry of pier 13 to be above water by October 1st, two months after Law, Roberts & Mason's contract with the Water Commissioners to have completed the entire High Bridge. Regarding the temporary 36 inch pipe laid on top of the cofferdams of the piers, Jervis reported in July 1843 that excavation for the foundations of piers 12 and 13 had caused settlement of the pipe foundation, which "gave some apprehension for its safety," though none of the joints had been opened by the settlement. He noted that "it will be strictly watched and measures adopted to secure it should any indication of further settlement appear," but he was confident that as work was completed on the two piers the pipe would be out of danger.[42]

On the day after Christmas, 1843, Chief Engineer Jervis reported to the Commissioners that some of the piers had been raised nearly to their full height, and that pier 12 had been carried up above the water. The foundation of pier 13 had been completed in August and "it was expected the masonry would have been carried up above the high water level of the river before this time; but disappointments in obtaining stone for some for the lower courses, delayed the work." The contractors had procured granite from Maine and it did not arrive until the beginning of December – six weeks after the October 15th contractual deadline for laying masonry with mortar intended to prevent damage to the work from freezing. The contractors asked Jervis

that they be allowed to lay the stone so that they could fill the space between the emerging pier and the sides of the cofferdam with earth, and thereby reduce their costs for pumping water from the cofferdam in the spring. Jervis agreed, noting that the depth of the work surface would "render it secure from damage by freezing" and that filling around the pier would secure the temporary pipe from future settlement.[43]

Problems with obtaining granite for the bridge became a common refrain in Jervis's reports to the Commissioners. All the stone, delivered by water, came principally from quarries in the Hudson Highlands in Putnam County, New York, though at least ten quarries in total in New York, Connecticut, and Maine came to be worked to provide the all the stone required to build the High Bridge. Delays in delivery and quality at times slowed the work, as stone for lower courses would arrive late or would be rejected by the Resident Engineer, delaying installation of the courses above. In addition, progress on the masonry was slowed by rising labor and masonry costs, as the depression that had set in after the Panic of 1837 waned, and the national and local economy began to improve just as the contractors needed skilled stonecutters and thousands of cubic yards of granite and gneiss (for internal work) to complete the bridge.[44]

Jervis reported on Christmas Eve, 1844 that eleven of the piers were within a few courses of being ready to begin installation of the impost course and centering and laying the arches. As for the other three, and the abutments required an average of about 13 courses of stone to be laid before the arches could commence. During the winter of 1844 and spring of 1845 the contractors made preparations for installing the wooden centering for eight of the arches by driving piles for the scaffolding to support the centering.[45]

By the end of June 1845 the Water Commissioners reported that all the piers and abutments were complete to the last course before the impost, and some of the impost courses had been laid. Three centers had been installed and a fourth was in the process of installation. The ring stones were on site, and ready to be installed. The Commissioners believed at that time that the "work has the appearance of a more rapid progress than heretofore." Their confidence in the work was likely bolstered by a letter they had received in May from Law, Roberts & Mason in response to the Commissioners request for a formal explanation of their failure to complete the High Bridge by the contractual deadline of August 1843. The contractors' letter detailed their work from signing of the contract to that date. Principally, they claimed, the delay was the result of meddling by the previous Whig Water Commissioners. They assured the Commissioners that "if no untoward event occurs, the final completion may be expected in the course of the working season of 1846."[46]

Writing to the Commissioners in mid-December of 1845, Jervis stated that while good progress had been made, a large amount of work was still to be done, therefore, he could not see the bridge completed in 1846, as claimed by the contractors. By that report to the Commissioners the contractors had nearly completed all the piers and both abutments, two of the 50 foot span arches, and one 50 and one 80 foot arch was begun. The contractors would reuse the centering as the arches were completed, but to increase progress they had begun building more centers for the remaining arches. As the courses of the arches were completed the work of laying up the spandrel and haunch walls would follow the arches. Until all the arches, spandrels, and haunch walls were complete no work could begin on the parapets and brick pipe chamber lining. To supplement the temporary pipe which was to be moved to the bridge, Jervis requested that the Commissioners procure 1,500 feet of additional 36 inch cast iron pipe to lay on the bridge. He calculated that the two 36 inch pipes would be sufficient to supply the city for the next 30 years.[47]

At the end of 1846, the Commissioners reported that the contractors assured them that the work would be completed in 1847. By that reporting, ten of the fifteen arches had been completed (six of 50 foot span and four 80 foot span arches), with the spandrel walls complete to the tops of the arches, 400 feet of water table laid, and the parapets begun. Jervis noted that work on the arches would move more quickly if not for the time and care required to move and set the heavy centering at such a great height. The 80 foot center for the 12th arch was so racked and twisted out of shape by a severe gale on the night of November 19th, that he doubted if it could be used. Work on the north end of the bridge, including the gatehouse, had so far advanced that he believed they could begin to lay pipes in September of 1847.[48]

On May 1, 1847 the Water Commissioners received two bids for 600 feet of cast iron pipe, and awarded the contract, at $52 per ton, to the West Point Foundry, the same foundry which had supplied the temporary pipe.[49] Although the Commissioners had hoped the pipes could be laid that fall, the parapet walls were not completed and a layer of concrete was yet to be laid on the floor of the pipe chamber. Until that work was complete, the water would still be carried into the city by the temporary pipe.[50]

3.4.5 New Water Commissioners Again

Removed again by a change in administration in Albany, on February 14, 1848 the Water Commissioners presented their last report, in which they recounted the history of the Croton Aqueduct, their recommendation to carry the water across the Harlem River by inverted syphon, the Whig criticism of their administration of the project, and praised all of the project's engineers and contractors, and the Common Council for their prompt payments during the project. They noted that the work left to be completed on the High Bridge was "merely mechanical, and can as well be completed without the aid of commissioners, as with it." Their Whig successors, led by the elderly Philip Hone, were still left with the tasks of completing the parapets, laying the pipes, removing the remaining centers, and clearing the river of the cofferdams and embankments to allow navigation to return to the Harlem River.[51]

In addition to moving forward to complete the High Bridge, the new Commissioners also proposed a plan to alter the structure to make it a public thoroughfare for carriages. The Commissioners noted as a reason for the alteration was that the only means of access to the Westchester (now the Bronx) side of the High Bridge by carriages was by crossing over Macomb's Dam into Westchester and utilizing a private toll road. The Commissioners' proposal was reviewed by Chief Engineer Jervis, and an estimate of $15,189 was prepared by Resident Engineer Hastie for altering the High Bride to accommodate carriages. Jervis noted that the best carriageway access to the High Bridge on the Manhattan side was on the west side of the gatehouse, which Jervis stated would require an iron bridge of two spans bearing on an abutment and a pier. He noted that on the Manhattan side some rock removal and an embankment would be required to connect the iron bridge to the top of the new carriageway which would run on top of the aqueduct. On the Westchester end of the bridge the plan required an earth embankment and retaining wall approach to the bridge for the carriageway. The plan also required cutting into the High Bridge parapet at both ends, paving the earth fill over the cast iron pipes with cobbles, and installing an iron railing on the parapets for safety.[52] It is not clear how this proposal was received by the Mayor or Common Council, however the carriageway plan was not implemented.

3.4.6 The High Bridge Completed

The first line of water pipe was laid during the spring of 1848 and water began to flow through it on the 30th of May. By June 30, 1848 Jervis noted that they were moving the temporary pipe from the river to the bridge, and that the masonry was essentially complete. Work to be done included covering the pipes with sand and earth to protect them from freezing, and installation of an iron railing around the gatehouses. Jervis also noted that a railing had not been planned to be installed on the bridge parapets, because for maintenance of the aqueduct pipes railings were not necessary, but he argued that "it is probable numerous visitors will pass along it, and there may be those who will not exercise the care necessary in walking at so great a height. Doubtless many will walk on the coping of the parapets, and without a railing serious accidents may occur. . . [T]he great resort, indicated by the numerous visitors to the work during its construction, induces the belief that such protection will be necessary for those that will hereafter visit it, . . ." [53] Jervis recommends that the Commissioners consider a parapet railing, as well as enclosing the grounds on the Bronx side of the bridge with suitable fencing and grounds about the gatehouses "leveled off, and put in something like regular shape, so as to give a proper finish to the work."[54] During the last months of 1848 the contractors covered the pipes with sand and earth, finished with turf and flagging. The masonry retaining wall on the north side of the Manhattan gatehouse was altered and extended, by day's labor. Provisions were made for installation of a wrought iron railing around the gatehouses, but not on the bridge, though the railing was not installed until

1850. The final work of making the river navigable – the *raison d'être* for the High Bridge, rather than the Low Bridge – was removal of the cofferdams, which proved to be a much more onerous and expensive task than the engineers had anticipated.[55]

The final cost of the High Bridge was $963,427.80.[56]

3.4.7 The Croton Aqueduct Department

On April 11, 1849, with the High Bridge complete, the office of Water Commissioners was abolished and its duties merged with those of the Croton Aqueduct Board into the Croton Aqueduct Department, which took over maintenance of the aqueduct, reservoirs, supply pipes, and the High Bridge. Former Aqueduct Board President, Nicholas Dean, reporting as President of the Croton Aqueduct Department, noted in his first Annual Report that the only section of the aqueduct not completed was the "westerly end of the bridge, over Harlem river. To enable the public to conveniently visit this stupendous structure, without passing off the island, commodious and safe stone stairs should be built down the steep and rocky declivity, from the present termination of One hundred and seventy-third street, to the top of the embankment on the aqueduct, and an iron railing placed on the coping of the wall supporting the embankment, from then to the bridge."[57] In addition Dean, writing on December 31, 1849, noted that they had recently accidently learned, that the later Water Commissioners had ordered the railing, but it had not been delivered. He also noted that the river required dredging between the bridge piers to allow navigation, or the extreme expense of constructing the bridge, rather than the inverted syphon, "would be useless."[58] The following year two of the channels between the piers were dredged to a depth of 8 feet at low water.[59]

With their second annual report, for 1851, the Aqueduct Department commissioners began a campaign to increase the capacity to both store and supply water for the city. They took to task "their predecessors in the office" and criticized the inverted syphon of "two lines of small pipes" on the High Bridge, and could find no valid excuse, not even the stated costs savings, for the loss of head and the bottleneck created by the 36 inch pipes at the High Bridge. They stated that the masonry aqueduct should have been carried directly across the Harlem, with the bridge raised up another fourteen feet, and lined with iron, as at the Sing-Sing Kill and Glendenning Valley bridges. The commissioners noted that before any new reservoirs could be constructed in the city the capacity of the aqueduct over the Harlem River must be increased. To address this they proposed constructing an extension of the aqueduct over the High Bridge, while leaving the pipes in place.[60] Presumably the intent was a masonry aqueduct, lined with iron, however, in 1853 the Department planned to install an additional 4 ½ foot diameter pipe, if an appropriation had been forthcoming from the Common Council.[61] It does not appear that the funds were released. The following year work was begun to install a new 4 foot diameter cast iron pipe, 4,087 feet long in Tenth (Amsterdam) Avenue. The Department believed it was the largest water pipe in the country.[62] The new pipe increased the flow into the reservoirs sufficiently enough to delay need for a larger pipe over the High Bridge for a few years, until the new Receiving Reservoir was completed in 1863 in Central Park as part of what was known as the "Croton Water Works Extension."

In 1858 Chief Engineer and Commissioner Alfred W. Craven went to Albany to prevent the legislature from converting the High Bridge into a public or private road.[63] Ten years earlier the Water Commissioners had also thwarted an attempt to convert the top of the High Bridge into a public thoroughfare. Had a road been constructed on top of the High Bridge at either time it would have been much more difficult to lay additional pipes across the bridge, as had been anticipated by Chief Engineers Jervis and Craven. Not until the 1889 opening of the Washington Bridge just north of the High Bridge was the Harlem River crossed at the northern end of Manhattan by a public street.

3.5 THE GREAT PIPE (1860-1864)

On November 23, 1859 the "plans for bringing an additional quantity of water across the High Bridge" were submitted to consulting engineers James P. Kirkwood and William J. McAlpine for their opinion "as to the best mode of bringing the full capacity of the Aqueduct to the City."[64] The opinion of Kirkwood and

McAlpine was not recorded, however on April 25, 1860, the Croton Aqueduct Board approved Andrew W. Craven's plan to bring an extra supply of water over the High Bridge. The water was to be brought over in a galvanized wrought iron pipe 90½ inches in diameter:

> Said pipe to be placed in the centre of the bridge, and two feet from the present pipe, and that the walls be carried up to a proper height, coped and an iron railing placed thereon in accordance with plan shown. The pipe to be arched over and pavement laid in cement between the said walls so as to make the same water tight, the estimated cost thereof $188,500.[65]

The contract for the 648,000 pounds of wrought iron plate and 100,144 pounds of flange iron plate for the pipe was awarded on August 8, 1860 to Horace Abbott & Sons Canton Rolling Mills, in Baltimore. By January 1861 nearly all the iron had been delivered to Greenpoint, Brooklyn, the shipyard and ironworks of Samuel Sneden and Thomas F. Rowland, who had been awarded the contract to fabricate and install the pipe. By January 1861 Sneden & Rowland had placed 1,100 feet of the pipe on the bridge and joined together and installed about 350 feet of pipe.[66] The 90½ inch diameter pipe was constructed of wrought iron plates, eight feet by six feet, ½ inch thick, which were joined together by horizontal and transverse plates 9 inches wide and ½ inch thick. The pipe sections were fastened with 4 rows of ¾ inch rivets (from Burden's Troy Iron Nail Works) which were countersunk on the interior of the pipe to provide a smooth flowing surface for the water. The pipe was supported on cast iron pedestals 4'-9 ½" tall placed about 12 feet apart between the original 36 inch cast iron pipes. The top surface of the pedestals was planed smooth to allow cast iron rollers to freely move to accommodate expansion and contraction of the pipe. The pipe rested on cast iron saddles, which in turn rested on top of the rollers. Both ends of the pipes were fitted with a cast iron ring faced with brass plate, into which fit a cast iron cylinder, also faced with brass, to allow expansion and contraction movement of the pipe. The pipe, inside and out, and its supports were given two coats of Prince's Metallic Paint as a protective coating.[67]

The pipe was shipped up the Harlem River from Sneden & Rowland's Greenpoint shop aboard lighters or scows. At the High Bridge each 12 foot long section of pipe, weighing 4 tons, was raised 122 feet from the river to the bridge by a boom derrick operated by a 20 horse-power steam engine. The derrick and engine were mounted on a platform with wheels which ran along iron rails resting on the bridge coping stones. With this derrick each section of pipe was raised, three per day, from the river in about seven minutes, and then placed on the bridge where the pipe sections were moved into placed from a trussed platform which also ran on the iron rails. From the trussed rail platform the pipe sections were rolled into place and lowered onto the cast iron pipe supports.[68]

In order to allow the new pipe to be connected to the aqueduct without stopping the flow of water into the city, using their own forces, the Croton Aqueduct Department re-routed the two 36 inch cast iron pipes from direct exit and entrance from the gate chambers to the north side of each gate chamber. This was done by constructing wood cofferdams within each chamber to allow removal of a section of the north walls and installation of two new by-pass pipes around the outside of each gatehouse and to re-enter the bridge under the new pipe. This was performed one pipe at a time, without stopping the flow of water through the aqueduct. After the pipes were re-routed the masonry front of the gate chamber was dismantled and reconstructed to fit the wrought iron pipe into the gate houses. This work was superintended by engineers George S. Greene and W. L. Dearborn "by day's work" because the Commissioners believed it "could not be done without extreme risk of accident and consequently incalculable damage" under a special 1860 law that empowered the Commissioners to construct difficult projects without outside contractors.[69] The pipe was ready to receive the water near Thanksgiving 1861.

By January 1862 the Aqueduct Commissioners reported that all the work of installing the pipe was completed, with the raising of the parapet walls to begin in the spring.[70] By the following January the Commissioners reported that the brick and granite sidewalls had been carried up and the brick arch

completed. Additionally they noted that the first course of brick had been laid up in coal tar and Trinidad lake asphalt, but the final course of paving brick was not completed before winter weather forced suspension of the masonry work. They also noted that: "The paving, while forming a covering and protection to the arch over the pipe, will also perform a perfectly uniform foot-walk for visitors to the Bridge; the rise in the arch being too slight to cause any inconvenience."[71]

Resident Engineer W. L. Dearborn described the construction and waterproofing of the arch in a paper presented to the American Society of Civil Engineers in 1870: The brick arch was laid in an arc 26 feet 6 inches radius 17 feet wide. The 12 inch thick arch is constructed of "the best hard-burned brick" laid in mortar of one part "hydraulic cement of New York" (Rosendale natural cement) and two parts sand. The arch bears on cast iron skewbacks 10 feet long, which are restrained by wrought iron tie rods, and 1 7/8 inches in diameter. The top of the arch was coated with ½ inch of a hot coal tar and Trinidad lake asphalt, and the next brick course was dipped in the hot asphalt, laid flat, after which the joints were filled with hot asphalt. On top of this waterproofing course of brick and asphalt was laid the paving course of pressed brick, laid in natural cement mortar. George S. Greene commented on Dearborn's paper that:

> [in] the plan for working the asphalt with the brickwork, the object was to avoid depending on a large, continued surface of asphalt, as usual in covering arches, which very frequently cracks from the greater contraction of the asphalt from that of the masonry with which it is in contact, the extent of the asphalt on this work being only about one-quarter of an inch to each brick. This is deemed to be an essential element in the success of the impervious covering.[72]

The work of raising the parapets and constructing the brick arch and paving was done by contractor John P. Cumming, who had successfully bid on several Aqueduct Department projects. Additional work included cutting two arched doors in the sides of the Bronx abutments to allow for access for repairs to the pipes, installation of thirteen glazed cast iron vault lights for daylighting of the attic, and construction of two granite ventilators for the new pipe. The light gray granite of the exterior of the raised parapets and the ventilators was supplied by Simon Stevens, from his Spruce Head Quarry in Maine. The same granite was supplied by Stevens for the gatehouses of the new Receiving Reservoir in Central Park.[73]

Possibly at the end of 1863 plaques, probably bronze, were installed on the bridge side of both gatehouse to commemorate the work with the following inscription:[74]

The improvement of this bridge by adding the large
pipe, raising of the side walls and covering the whole
work with an arch was commenced October, 1860.
The new pipe was put in operation December 1861.
The masonry completed in 1863.
Croton Aqueduct Board.
Thos. Stephens
President Commissioner
Thos. B. Tappen Rob't Darragh
Assistant Commiss'r to Dec. 4, 1862 Assistant Commiss'r from Dec. 4, 1862
Alfred W. Craven
Commissioner and Engineer in Chief
Engineers
Geo. S. Greene Wm. L. Dearborn
Engineer in Charge to Jan. 31, 1862 Engineer in Charge from Feb. 1, 1862
Contractors
Thos. F. Rowland for the pipe J. P. Cumming for the masonry

In the spring and summer of 1864 the work of installation of the iron railing by the Architectural Iron Works Company was completed. The final work at the bridge included grading and terracing the Bronx side and repairing the grounds around the bridge damaged during the work.[75]

By the end of 1865 the interior of the pipe "was found to be affected by rust much more rapidly than was anticipated." The pipe had been given two coats of Prince's Metallic Paint, but small rust blisters began to be observed during the first annual inspection of the pipe. By 1865 almost the entire interior of the pipe was covered by the blisters, which were on average ½ inch in diameter and ¼ inch deep.[76]

In what must be one of the earliest experiments with cathodic protection, based on a paper by French scientist, M. Becquerel, the Aqueduct Department installed within the pipe plates of pure zinc which were screwed to a 60 foot long section of the pipe.[77] The intent was to use the zinc as a sacrificial anode and reduce rusting of the iron. The results of the experiment do not appear to have been reported by the Aqueduct Department.

3.6 CROTON WATERWORKS EXTENSION

Soon after the first Croton Aqueduct was completed, soaring population growth which tripled between 1840 and 1870, rapid real estate development, wastage of available water, and developments in plumbing significantly increased the pressure on New York City's over-extended system.[78] Arguably, the City's rapid population growth was solely due to the supply of abundant, reliable and potable water. According to Croton Aqueduct National Historic Landmark author Robie Lange, "this extraordinary early public works project played a somewhat obscure yet essential role in New York City's growth and development during the 19th century. The successful design and construction of the Croton Aqueduct not only made the city's rise to prominence possible, but it served as a model for other municipal water supply systems."[79]

On April 11, 1849, the Croton Aqueduct Department was established, charged with constructing sewers and paving roads, and overall water system operation and maintenance. The changes required by the Croton Aqueduct Department to improve the system, and to allow it to evolve to meet new demands and to incorporate improvements and new components, came to be known as the Croton Waterworks Extension. Extension projects included the construction of the 96-acre, 1-billion gallon capacity New Receiving Reservoir in Central Park (1858-1863) and the installation of a 90 ½ inch main across the High Bridge to increase capacity (1860-1864). Croton Waterworks Extension, High Service Works at Carmansville was constructed above the High Bridge to provide water pressure to buildings higher in elevation than the new reservoir in Central Park. The High Service Works included a 7-acre 10,794,000 gallon capacity Reservoir (1866-1872) with two gatehouses, a boiler house, and engine to pump water from the High Bridge up to the reservoir and tower, and an inclined plane for raising coal from a new wharf in the Harlem River. The final and most prominent structure of the High Service Works was the 185 foot tall Water Tower (1868-1872), with a 53,600 gallon wrought iron tank.

In 1875, when 100 mgd (million gallons daily) coursed through the Aqueduct's channel and water was exceeding the height of the flow line, the masonry conduit was modified with the addition of one or more brick rings above the arches to accommodate higher water levels. A new 48-inch main was laid under Fifth Avenue, in addition to the two pre-existing 36-inch diameter pipes which connected the Receiving Reservoir with the Distributing Reservoir at 42nd Street. In addition to these enhancements, ongoing maintenance and water leakage issues led engineer Benjamin S. Church (1836-?) to advocate for a new Aqueduct in his lecture before the American Society of Civil Engineers in 1876.[80]

In 1870 the Croton Aqueduct Department was abolished and its duties assumed by the Department of Public Works (DPW) until 1898, when the five boroughs were consolidated into New York City, and the aqueduct came under the jurisdiction of the new Department of Water Supply. When the Amended Greater New York Charter came into effect in 1902 the operation and maintenance of the aqueduct, and the High Bridge, were transferred to the newly created Department of Water Supply, Gas and Electricity.

3.7 NEW CROTON AQUEDUCT

While the Croton had curbed future onsets of epidemic disease, and had greatly reduced the incidence of devastating fires, there was one challenge it could not meet: over-extension. By the 1870's, some New Yorkers agitated for the construction of a new aqueduct. Apologists for water conservation, metering systems and a new 36-day capacity reservoir, were set against a costly new municipally financed aqueduct campaign. In his address to the Municipal Society in 1876, George B. Butler Esq. (1809-1886) appealed to reason and the business acumen of his audience when he argued: "the first step towards rendering the service of water equal (between Fort Washington and Murray Hill) is to stop all waste, as the waste is supposed to amount to nearly one half of the whole quantity supplied" and further that, "as it costs to pay interest on the outlay for the aqueduct and its appurtenances about $6,000 per day, it needs no argument to support the proposition that a system which permits such waste to be indulged in by 1,000,000 inhabitants is radically bad and ought not to stand."[81] In the end, however, a campaign to expand the earlier aqueduct was approved. An "Act to Facilitate the Acquisition of Lands for A New Reservoir" was passed in 1883. The 1886 *Report of the Aqueduct Commissioners* resolved: "We are of the opinion…that the health, security and growth of this city imperatively require an increased supply of pure and wholesome water, and that such measures should be immediately taken by the Legislature as will enable the city to secure and provide such increased and sufficient supply at the earliest day practicable.[82] Legislated in 1883, the New Croton Aqueduct was operational by 1890 (while still under construction) serving 1.5 million people. The campaign's completion was memorialized by assistant engineer of construction Edward Wegmann in his technical survey, *The Water-Supply of the City of New York 1658-1895,* who included a detailed description of the New Croton Aqueduct. [83]

3.8 DEMOLITION OR MODIFICATION (1911-1923)

The events leading up to and including the 1926-1928 remodeling of the High Bridge are instructive in that they illustrate how the bridge's fate fluctuated for over a decade before a compromise decision to modify the bridge was ultimately reached in 1923. While navigational and security-driven forces at the federal and regional levels initiated a re-examination of the bridge's river piers, the protracted debate over the bridge's future largely occurred at the municipal level. A diverse array of city agencies, civic groups and private firms proposed a broad spectrum of design options, inclusive of substituting multiple river piers with one or more arches, modifying the bridge for vehicular traffic, demolishing the bridge, and replacing the bridge with an aqueduct tunnel under the Harlem River. Over time, modification plans became increasingly ambitious, ranging from removing two alternating piers, to removing several (two or three) contiguous piers, and culminating in the bold proposal to replace four contiguous piers and five arches with a single steel arch. The narrative history also illustrates how a unified voice, representing the disciplines of engineering, architecture, landscape architecture, and preservation, was instrumental in reversing a vote sanctioning the bridge's demolition to one in favor of selective modification. The debate over the High Bridge ultimately resulted in the retention of the structure, as well as the aqueduct pipe within, and underscored early 20th century opportunities for modernizing, rather than demolishing, historic infrastructure.

3.8.1 Laying of Additional Pipe

In 1911, the Department of Water Supply, Gas and Electricity (DSWGE) considered plans to augment the supply of Croton water delivered by the existing 90 ½-inch pipe with the addition of either a 12-inch or a 20-inch main. In January 1912, the DWSGE requested that a contract for furnishing, delivering and laying a 12-inch main across High Bridge be prepared. However, concerns about the potential damage which the new main could cause to the Bridge in case of leakage or breakage, the anticipated destruction of the Bridge's easterly steps, and the new main's estimated cost ($10,000) prompted a year-long debate within the Department, where ultimately, this option was eliminated. The 12-inch main's comparatively smaller size and lower estimated cost ($6,500), and the relative ease of accessing and maintaining the existing 90 ½" main as well as the new main within the physically tight confines of the masonry attic, led the Department to approve it. Bids were issued in December 1912, and a contract was executed in June 1913.[84] Notably, this work was

ultimately not performed, as indicated by "Note: 12" Main Not Laid" dated December 13, 1935 which was subsequently added to the 1913 contract drawing (Appendix H, Fig. 18). [85]

3.8.2 Controversy

A combination of security, public safety and commercial concerns for unobstructed river navigation documented as early as 1911 prompted careful assessment of the High Bridge's river piers (Piers 10-13). Arguably, the volume of river traffic and the size of vessels had increased in the years following the completion of the Harlem River Ship Canal in 1895. In 1911, the Corps of Engineers, U.S. Army, issued a letter to the City of New York, calling attention to the concerns expressed by the Taft Administration's Secretary of War and the United States Engineers' Office for the First District over the obstruction to navigation caused by the bridge's river piers.[86] Operators of boats, tugs, and other vessels complained that the bridge's river piers proved increasingly difficult to navigate without accident (collision or sinking) since the 80'-0" spans between these piers, and the footings of these piers (which extended out under the water's surface) resulted in a clear waterway which equaled about 40'-0". Navigation on the Harlem was also challenged by the swift flow of the river's current.[87]

3.8.3 Menace to Navigation

In 1915, the *New York Times* reported that the Wilson Administration's Secretary of War, Lindley Miller Garrison (1864-1932), determined the High Bridge's river piers were obstructions to navigation on the Harlem River, and in response, the Board of Estimate and Apportionment authorized its Chief Engineer and the Municipal Consulting Engineers to evaluate the feasibility of removing one or more river piers. The report presented to the Board of Estimate sought to distinguish between bridges constructed to carry vehicular traffic from those designed to carry aqueducts: "while the bridge crosses a navigable stream…it is an aqueduct rather than a bridge…it is not a highway bridge in the ordinary sense of the word."[88]

The Secretary of the Municipal Consulting Engineers, Charles E. Gregory (president of the Municipal Engineers Society), admitted that, "while [the High Bridge] is one of the most remarkable of our various public works…it is of very little practical use even for the purpose for which it was built." Gregory criticized the Bridge's negligible role within the municipal water supply system, the "undue" expense of retaining the bridge as a footpath between two parks, and the challenges associated with converting the bridge for vehicular traffic use.[89] The Chief Engineer's report argued that "The High Bridge's removal or the serious mutilation of its appearance would be a public misfortune, and should only be considered in case it was shown that it forms a serious obstruction to navigation which could not be removed or mitigated except by taking out one or more of the piers."[90]

3.8.4 Vehicular Traffic

Coinciding with the rising popularity of the automobile, recurrent references were made both in the popular press as well as in professional journals about the possibility of converting the bridge from pedestrian to vehicular traffic. As early as 1919, public critiques of this scheme noted the steep-stepped Manhattan approach to the Bridge and highlighted the difficulty of introducing vehicular ramps both for approaching and exiting the Bridge.[91] An essay published in 1921 by *The American Architect* noted that the bridge could become a highway bridge with the construction of "an effective roadway approximately 20'-0" wide with a sidewalk on either side supported by brackets and an effective connection made with the street system on the Manhattan side."[92]

3.8.5 Remodeling Schemes Commence

While multiple remodeling schemes were considered, the Chief Engineer and the Consulting Engineers proposed the removal of two river piers and the construction of a reinforced concrete rib arch (with a 218'-0" span), with material enlargement of the abutment piers, as the design solution which offered "the best appearance as well as the greatest economy…while preserving as much as possible of the old bridge." The proposed design was conservatively estimated at $300,000.[93] The Chief Engineer of the Board of Estimate and

Apportionment recommended to the Board that "no action be taken looking to the removal of one or more {river} piers of the bridge until other obstructions in the waterway at this point have been removed, and until the conditions have been materially improved at both ends of the Harlem River."[94] Other possible solutions to improving navigability included dredging the river's channels, and constructing tidal locks between the High Bridge's river piers. In an editorial entitled "High Bridge in Danger," the *Times* questioned whether "the modern demands of commerce must sweep {High Bridge} out of existence?" and urged that, despite the real challenge of improving navigability on the Harlem, engineers studying the issue ought to be "up-builders, not destroyers, and to be capable of solving difficult problems."[95]

3.8.6 Temporary Suspension of Water Service

The critique of the High Bridge's river piers coincided with temporary suspension of Croton service north of the 135th Street Gatehouse (including the High Bridge) beginning on February 3, 1917. Security concerns for New York's water were heightened with the United States' declaration of War against Germany and entry into World War I (April 6, 1917). According to Lieutenant Colonel Merritt H. Smith, who served as Chief Engineer of the Department of Water Supply, "We had four aqueducts bringing water into New York City, three aqueducts and a pipe line. It was easier and safer to patrol two aqueducts than it was four, and if any devil had tried to destroy any part of any one of those aqueducts the principal damage would have been done by the rush of water, not by the bomb, and for that reason…on February 3, 1917 the old aqueduct was closed down by my orders."[96] Temporary suspension of Croton water delivery into Manhattan via the High Bridge could not have been feasible were it not for the existence of two tunnels, delivering Croton and Catskill water respectively, under the Harlem River. The New Croton Aqueduct featured a seven-mile (11 km) long inverted siphon under the Harlem River tunneled with diamond drill borings that descended to a depth of 300 feet (91 m) below the surface (constructed 1885-1895). Additionally, while still under construction, the Catskill system's water arrived into Manhattan via City Water Tunnel #1, completed in 1917. According to the 1920 DSWGE Annual Report, "introduction of Catskill supply made use of this {old Croton} aqueduct temporary unnecessary."[97] The service suspension of the old Croton was prompted by increased consumption of new Croton water in Manhattan. Leakage in the masonry conduit had been observed between the Jerome Park reservoir in the Bronx and the 135th Street gatehouse in upper Manhattan, and repairs were performed after which the aqueduct was filled. At the end of 1920, the Department anticipated the restoration of old Croton aqueduct service into Manhattan early the following year.

3.8.7 Public Hearings Convene

In June 1919, a Board of Conference Hearing to further investigate concerns over the High Bridge river piers and the Harlem River's navigability was convened. The Board of Conference consisted of an amalgam of four appointed officials, representing the Superintendent of Public Works, the State Engineer and the Commissioner of Docks and Director of the Port of New York, appointed by Governor Al Smith (1873-1944) under provisions of the Dowling-Healey Measure.[98] A June 1919 *New York Times* editorial entitled, "Plans to Improve Harlem River: Picturesque High Bridge may be Destroyed in Interest of Better and Safer Navigation," argued that "the High Bridge has outlived its usefulness…the bridge no longer serves as a necessary water carrier…the bridge, therefore, serves only an aesthetic purpose." The bridge's temporary loss of purpose-built use as an aqueduct bridge extended until April 1920, when another *New York Times* editorialist referred to the High Bridge as having "formerly carried a huge water main over the Harlem River."[99] Cumulatively, the temporary suspension of water delivery across the bridge, increased agitation from business and shipping interests for unhampered river navigation, and initial cost estimates which indicated that remodeling would exceed demolition by $100,000, all cast a growing shadow of uncertainty over the Bridge's future.

3.8.8 Peremptory Order from Secretary of War

Tensions over the fate of the High Bridge continued to mount in 1920. On March 1st, Secretary of War Newton Diehl Baker, Jr. (1871-1937) formally served a peremptory order on New York City's Board of

Estimate and Apportionment. Specifically, the Secretary called for the removal within one year of two alternate piers at the High Bridge which interfered with "safe and free navigation" of the Harlem River: "The Secretary of War having good reason to believe that the bridge over the Harlem River, New York City, known as 'High Bridge' is an unreasonable obstruction to free navigation of said river, on account of insufficient clearance between piers, it is proposed to require the following changes to be made in the bridge within one year from the date of service of order by the War Department, to wit: Two alternate piers be removed, and a vertical clearance of at least 100 feet above mean low water to be provided in each of the proposed widened spans."[100] Arguably, the intent of the Secretary's peremptory order was to enforce compliance with the Rivers and Harbors Act of 1890 (as amended by the Rivers and Harbors Appropriation Act of 1899), which governed the removal of obstructions in navigable waters.[101] The Secretary's order was referred to the Department of Plant and Structures, War Department for deliberation and reply.

3.8.9 Additional Remodeling Schemes Proposed

According to the 1920 DSWGE Annual Report, "several plans for altering the structure were proposed" by two municipal agencies, namely, Plant and Structures and Bureau of Water Supply, as well as "engineering societies and other organizations and persons interested in retention of High Bridge."[102] On March 30, the New York Harbor Line Board – composed of officers of the U.S. Army Engineering Corps - held a hearing at which the removal of two alternate piers was proposed.[103] Following the recommendation of the Harbor Line Board, the Department of Plant and Structures prepared plans for the removal of two alternating piers and the construction of two spans of steel, where the steel girders were proposed to be clad in concrete to give the impression of a masonry arch. The aqueduct line on the bridge was to be maintained, and the cost of the work was estimated at $630,000.[104]

On April 17, 1920, the Board of Estimate and Apportionment hosted a public hearing regarding the High Bridge at which Charles Paff, of Charles Paff & Co. Architects and Engineers, and Henry G. Tyrrell, of the Tyrrell Engineering Company, presented their proposal for remodeling the bridge. After conducting a survey, Paff and Tyrell proposed a plan which called for removal of three river piers, while retaining the attic and deck above, and constructing a reinforced concrete arch with a flat ellipse profile. The two men claimed that the new arch would offer approximately 200'-0" of clearance, at a height of 65'-0" to 70'-0" and that its cost would not exceed estimates for the Bridge's demolition.[105] In early May, DPS Commissioner Grover A. Whalen (1886-1962) presented plans for the remodeling of the High Bridge to the Board of Estimate and Apportionment, with an anticipated price tag of $650,000.[106]

In January 1921, *The American Architect* published a series of renderings illustrating the reconstruction of the High Bridge produced by the DPS, the New York architectural firm of Carèrre and Hastings, the New York Chapter of the American Institute of Architects (NYC-AIA) and the American Institute of Consulting Engineers, and the DWSGE. The renderings, which accompany an article entitled, "The Fate of High Bridge: Do the Facts in the Case Warrant its Reconstruction or Demolition?" depict multiple remodeling options for the bridge. Five of these renderings were photographed by Ernest Roericht and are part of the collections of the DEP Archives.

The Plant and Structures renderings (Appendix H, Fig. 19 and 25) illustrate several schemes where two alternating piers (10 and 12)[107] were to be removed, two new arches were to be constructed (spanning between piers 9-11, and 11-13 respectively), and the abutments were to be materially enlarged (piers 9, 11, 13). The first design featured two elliptical arches (Appendix H, Fig. 19) where the steel girders were clad in masonry to evoke solid masonry arches. The second DPS design, which featured two trabeated arches (Appendix H, Fig. 25), was criticized by the article's author as one "which literally carries out the order of the War Department, {where} steel girders would span the widened openings. Economical, but ugly."[108] The rendering prepared by Carrère and Hastings (Appendix H, Fig. 20) proposed the removal of two contiguous piers (10 and 11), and the construction of a single masonry arch with an elliptical profile. Two new subsidiary arches, shown in groups of three, were proposed to flank the new masonry arch spanning the river. These two

arcades, which were to rise to a height terminating below the spring lines of the bridge's main arches, spanned between piers 8 and 9, and between piers 12 and 13, respectively.[109]

The DWSGE prepared three proposed schemes (Appendix H, Fig. 21, 22, 23) where different combinations of contiguous piers were removed and replaced with single masonry arches. The first design (Appendix H, Fig. 21) illustrated the removal of piers 10 and 11, the construction of a single masonry arch, and the material enlargement of abutments at piers 9 and 12. The second DPS design (Appendix H, Fig. 22) called for the removal of piers 11 and 12, and the construction of a single masonry arch span. One of the two most ambitious remodeling schemes (Appendix H, Fig. 23) which survives in the DEP Archives but was not published in *The American Architect* article called for the removal of three contiguous piers (10, 11, 12), the enlargement of piers 9 and 13, and the construction of a new masonry arch span featuring vertical openings in the spandrels of the arch.

The final scheme illustrated in *The American Architect* article was jointly authored by the NYC-AIA and the American Institute of Consulting Engineers (Appendix H, Fig. 26). This design, which also featured the removal of three contiguous piers (10, 11, 12) the material enlargement of piers 9 and 13, and the construction of a simply articulated single span, was praised by the article's author as one which "shows the best treatment of any of the schemes so far suggested."[110] On June 2, 1920, a letter in support of remodeling the High Bridge was submitted by Colonel William J. Wilgus (of the Municipal Art Commission; 1865-1949), on behalf of the Committee of the American Institute of Consulting Engineers (AICE) and the New York Chapter of the American Institute of Architects (NYC-AIA). The cost of the joint AICE/NYC-AIA Committee proposal was estimated at $830,000.[111] After reviewing the design proposal of Paff & Tyrell, and the design proposal and cost estimate of the joint AICE/NYC-AIA Committee, Commissioner Whalen challenged the $830,000 estimate as being too low. He proposed a revised sum of $1,250,000 for remodeling the bridge.

3.8.10 Call for Demolition

Later that month, Whalen formally requested the Board to sanction demolition: "In the matter of improving the navigation facilities on the Harlem River, in the vicinity of the High Bridge, the various plans for the treatment of the High Bridge submitted to the Board of Estimate and Apportionment have been given full consideration, and it appears to me that the proper action to be taken by the Board of Estimate and Apportionment is the removal of this bridge."[112] Whalen's objections to remodeling were based on structural concerns, higher cost, low vertical clearance above mean high water, and insufficient compatibility with planned Harlem River improvements. Structurally, Whalen noted, "The driving of additional piles at Pier 12 and the attaching of new masonry to the present pier masonry, which will mean additional and eccentric loading on this pier, have elements of uncertainty that might entail failure. In the removal of two alternate piers, no piles have to be driven and the loads on the various piers are decreased." Since no record drawings documenting how the pile foundations were constructed were available to him, Whalen was also concerned that, in order to properly design the reconstruction of Pier 12, probing and examination of the pilings using cofferdams would be required.[113] Whalen proposed a cost estimate of $500,000 for demolition, which was significantly less than the previous estimates for remodeling ($630,000 and $830,000). He also criticized the remodeled High Bridge's relatively low vertical clearance of 101'-0" above mean high water as significantly lower than the clearances at the Washington Bridge and all East River bridges (135'-0"; excluding Hell Gate Bridge 140'-0"), which would perpetually be a limiting height for vessels navigating around Manhattan. Lastly, Whalen argued that "the proposed work of straightening the Harlem Ship Canal at Spuyten-Duyvil and the dredging at the Harlem Kills connecting the River directly with the Long Island Sound, as a matter of business policy, should mean the removal of this bridge." In conclusion, Whalen argued that, "the Engineers of this Department {DPS} have fully considered this entire question and I believe that the only proper action to be taken by your Honorable Board is the entire removal of this bridge." In response, the {New York} Society of Architects (est. 1906) requested that the Board postpone acting on Whalen's proposal for two weeks. The delay would in fact extend far longer than two weeks - the Board would not vote on the fate of the bridge until January of the following year.

In a rebuttal to Whalen recorded in its *Annual Report*, the DSWGE offered a reasoned argument for the bridge's retention: "The department is opposed to removal of High Bridge, as it is in every sense an aqueduct and was designed as such, and its removal would necessitate construction of a tunnel in lieu thereof."[114] The *Report's* authors argued that the bridge's retention was advisable from the perspective of Croton aqueduct capacity and overall water system effectiveness: "(a) the capacity of the new Croton aqueduct south of Jerome Park reservoir is only 225 mgd {million gallons daily} as compared with 290 mgd from Croton Lake to Jerome Park reservoir; (b) the level at which water is delivered at Jerome Park reservoir and at 135th Street gatehouse through the new Croton aqueduct is 4'-0" and 4'-6" respectively, higher than delivery of water at the same points through the old Croton aqueduct. Therefore, water delivered from Croton Lake to Jerome Park to 135th Street gatehouse through the old aqueduct could not be delivered from Jerome Park to 135th Street gatehouse through the new aqueduct except by seriously lowering the level in the 135th Street gatehouse, (c) the maximum draft of Croton water in Manhattan during the past year on a monthly basis has been equal to fill normal capacity of the new aqueduct, (d) the use of Croton water within Manhattan will increase until introduction of the Schoharie Reservoir {completed 1924} when there will be a decrease, followed however, by a gradual increase in amount of Croton water delivered, that under existing conditions the Croton aqueduct forms a useful link in the delivery system required to supply Manhattan in the future, and (e) in the very near future the old aqueduct will be a necessary link if the Croton water is to be utilized most effectively. It is impossible to foretell accurately the future conditions as to the water supply system of the city. About every twenty years an additional supply, at least equal in volume to that of the Catskill system, will have to be developed. The present Croton system always will be an important portion of the city's supply and in the future the High Bridge section of the old Croton aqueduct may and probably will be a very necessary part of the transportation system to utilize economically the water from Croton Valley."[115]

3.8.11 Modification of Bridge Approved

On January 21st, 1921, the Board of Estimate and Apportionment held a public hearing "on the question of alteration or removal of High Bridge." As described by the DSWGE's *Annual Report* authors (1921), the remodeling plan, which was subsequently approved by the War Department, called for the replacement of two river piers with a single steel span.[116] The Board authorized the issuance of $900,000 in corporate stock for the remodeling of High Bridge to improve navigation conditions.[117] Advocates for the High Bridge viewed the Board's vote as a victory.[118]

In addition, the Board authorized the DSWSGE's Bureau of Water Supply to form a new group dedicated to the bridge's reconstruction, consisting of two assistant engineers and five support-staff assistants (DSWGE *Annual Report*, 1921). Since the Bureau did not have adequate staffing for the High Bridge project at that time, the Bureau submitted a schedule to the Board requesting a consulting architect and consulting engineer, as well as full-time engineering and support staff, since "both the engineering and architectural problems connected with the reconstruction of this bridge were considered sufficiently difficult to receive the most expert treatment."[119] The Bureau's request was turned down by the Board of Estimate, who suggested that the DPS staff be engaged instead.

A few months after the Board of Estimate's public hearing in New York, the Secretary of War convened a public hearing on March 21, 1921 regarding the High Bridge at the Army Building in Washington DC. A group of Bronx businessmen who travelled to the nation's capital testified in favor of either removing two river piers that obstructed navigation, or demolishing the Bridge. Critics claimed the Bridge's river piers "hampered industrial progress of the districts above the bridge."[120] Petitions supporting either modification or demolition were filed by the Bronx Board of Trade, the Harlem Board of Commerce, the New York Piano Manufacturers Association, the Piano Club of New York, the Bronx County Property Owners Association, the Claremont Heights Taxpayers Association, the South Bronx Property Owners Association, and the Taxpayers Alliance of the Borough of the Bronx.

3.8.12 Survey and Testing

At the same time, (March 1921), a joint committee of engineers and architects inspected the bridge, after which they determined it to be structurally sound.[121] The scope of the survey and the specific results of the investigation, as well as the identity of the joint committee members are unknown at this time. A DSWGE survey of the bridge, with particular emphasis on the foundations of the river or channel piers, was commenced in October. In addition, an October 1921 DSWGE study of the Harlem River channel found that the channel area would be doubled after the bridge was reconstructed.[122]

By 1922, the Bureau of Water Supply had taken the lead on the remodeling project, and the DPS was appointed the project consultant.[123] According to DSWGE, the execution of the Board of Estimate's directive {to remodel the bridge} was "carried out under adverse conditions, the work performed being grouped under borings, investigation of the structure, and plans for the proposed structure."[124] In addition to the Bureau's staffing and procurement issues, the progress of the work was interrupted by the Board of Estimate who took a month to approve the engineer-in-charge's $3,920 salary. Progress was further aggravated by the DPS, whose staff were directed by the Board of Estimate to advise the Bureau on remodeling designs and costs, but provided "very little assistance…to aid in solving problems that were encountered."[125]

DWSGE prepared a contract for borings to investigate the character of bedrock at the High Bridge and the Harlem River, estimated at $30,000, the funding for which was approved by the Board of Estimate a year later.[126] In January 1922, the War Department gave permission to make borings in the Harlem River, and on March 14, 1922, the contract was awarded to the Scranton, PA, firm of Sprague & Henwood.[127] Work began on March 25th, and by July 20th a total of 21 holes had been bored (total length 2,424 linear feet) at a cost of $13,692. According to DWSGE engineers, no unusual geological conditions were discovered. However, "the disintegration of rock where the Inwood limestone joins the Manhattan schist on the west side of the valley was again shown by these borings."[128] In August, soundings were taken by the DWSGE engineers (Appendix H, Fig. 32). A Federal plan to widen the Harlem River's channel, and perform dredging to deepen the channel's 12'-0" depth, was placed on hold until the remodeling of the bridge was completed.[129]

Despite the Bureau of Water Supply's initial claim of inadequate staffing, the Bureau launched a "careful investigation" of all available High Bridge construction documents and records, and a physical survey of the bridge itself: "It was necessary to check thoroughly the information given on the drawings by measurements of the structures and soundings in the river."[130] Findings from the 1922 survey concluded that "a settlement had evidently taken place in the foundations of piers 10, 11, 12 and 13, causing a sag in the bridge deck, which reached its maximum of about 0'-2" of a foot between piers 11 and 12," and that "a high loading on the piles forming the foundations for piers 10 and 13 was found, the maximum loading per pile being about 43 and 40 tons respectively."[131] Department engineers proposed to materially strengthen the remaining piers in the river: "the removal of two piers to provide more room for future navigation will throw additional weight upon the other piers and the borings will determine where the foundations can best be made for this purpose."[132] Department engineers studying the bridge's foundations and loading potential deduced that if river piers 10 and 11 were eliminated, vertical loads would be carried on rock foundation cylinders independent of existing pile foundations.[133] Ultimately, piers 10, 11, 12, and 13 would be removed, and substituted with a single steel arch span in the 1926-28 reconstruction project.

3.8.13 Designs for Remodeling

In addition to surveying the bridge, and performing soundings, DSWGE engineers also prepared schematic designs for the reconstruction of the High Bridge. Numbered in what appear to have been a series (Designs 1 thru 7; only five are extant) and prepared between March and May 1923, the proposals illustrate the removal of either two or three contiguous river piers, and arches of varying materials, channel spans and vertical clearances. When considered in conjunction with the 1920 schemes discussed earlier, it is evident that the DWSGE drawings prepared in 1923 advance the earlier conceptual schemes illustrating single rounded and elliptical arch spans, while eliminating the multiple-arch and trabeated schemes.

In Designs 1 and 2, piers 10 and 11 were to be removed, and a new arch, either constructed of reinforced concrete (Appendix H, Fig. 35) or granite (Appendix H, Fig. 36), were proposed. Pier 12 was to be materially enlarged, with concrete struts driven into the clay and gravel riverbed. In these designs, the new arch would permit a clear channel span of 221'-4", with a vertical clearance of 100'-3" above mean high water. These DWSGE designs bear close visual relationships with two 1920 renderings prepared by Carèrre and Hastings, and the DWSGE, respectively (Appendix H, Fig. 20).

In Designs 3, 4 and 7, three adjacent piers (10, 11, 12) were to be removed, and a new arch, either constructed of structural steel with granite cladding (Appendix H, no. 37), reinforced concrete (Appendix H, Fig. 38), or exposed structural steel in a two-hinged arch configuration (Appendix H, Fig. 39) permitted either 320'-0" (Design 3 and 4) or 317'-0" (Design 7) channel spans across the Harlem River. These designs called for either a 100'-3" (Designs 3 and 4) or a 102'-0" (Design 7) vertical clearance above mean high water.[134] Designs 3 and 4 suggest that the DWSGE acknowledged the jointly-authored 1920 NYC-AIA and American Institute of Consulting Engineers rendering of a single span. Design 7 illustrates what may have been the first documented scheme of a round-arched exposed steel span flanked by the bridge's masonry arches.

As part of their due diligence effort, DSWGE engineers conducted materials testing, with particular emphasis on how the new materials would function in conjunction with the bridge's existing materials. The engineers investigated stresses in an elastic arch rib of reinforced concrete faced with granite, where the granite was specified to be of the same texture as found on the existing structure and the proposed arch would provide a clear channel span of 210'-0". The results of these material tests are unknown at this time.

Planning for the High Bridge remodeling project came under close scrutiny in January 1923, when the Board of Estimate demanded a status update from the Bureau of Water Supply. The Bureau reported its preliminary survey findings, particularly, that the foundations of two piers (11 and 12) had settled by approximately 0'-2", resulting in sagging in the middle of the bridge. Additionally, structural defects had also been observed at either end of the bridge. Just as he had done two years earlier, DPS Commissioner Whalen advocated against remodeling the bridge and urged the Board to support demolition on aesthetic and structural grounds. "High Bridge will lose its chief value, its scenic beauty," he argued, "when the middle columns are replaced by larger, central columns, breaking the regularity of the present structure, so there is no reason to preserve it at great expense." According to Whalen, the settling of piers 11 and 12 had occurred due to construction on pile reinforced foundations and he suggested that the estimate for remodeling ($900,000) would need to be more than doubled, offering a revised figure of $2,000,000. Whalen charged that the removal of the bridge's river piers would "present engineering difficulties, as the arches were hollow and removal of the stones from them would endanger the stability of the structure." Further, he expressed concern that the Federal government's plan to dredge the Harlem River could further compromise the river piers, and that protecting the pier foundations during the channel dredging project would be an onerous financial burden for the municipal government to bear.[135] In support of his position, Whalen anticipated cooperation from Mayor John F. Hylan (1868-1936), as well as the Water Department – who, according to *The New York Times* - was expected to recommend replacing the aqueduct pipes carried aloft with a new aqueduct tunnel under Harlem River. Demolition was also advocated by commercial interest groups, including the Harlem Board of Commerce, the Bronx Board of Trade, the New York Piano Manufacturers Association, Piano Club of New York, Bronx County Property Owners' Association, Claremont Heights Taxpayers Association, South Bronx Property Owners Association, and the Taxpayers Alliance of the Borough of the Bronx, all of whom had previously filed petitions advocating either remodeling or demolition with the War Department three years earlier.[136]

3.8.14 Decision to Demolish (March 1923)

On March 12, 1923, the High Bridge remodeling project was abruptly terminated when the Board of Estimate, "sitting as a Committee of the Whole" sanctioned the High Bridge's demolition.[137] Costs for demolishing the bridge and constructing a new tunnel under the river were estimated at $1,600,000. The Board of Estimate eliminated the staff division at the Bureau of Water Supply assigned to the High Bridge

remodeling project, and resolved that "the work of reconstruction be undertaken by the Department of Plant and Structures."[138] The change in nomenclature of the project's title is noteworthy – specifically, the project was no longer referred to as "bridge remodeling" but as "aqueduct pipe reconstruction." That year, an additional appropriation of $325,000 in corporate stock was authorized by the Board of Estimate for the "Reconstruction of the Croton Aqueduct at High Bridge."[139] The DSWGE was charged by the Board of Estimate to prepare plans for the aqueduct tunnel under the river.[140]

3.8.15 Opposition to Demolition

In response to the potential loss of the bridge, a consortium of "prominent architects and public-spirited citizens" called the demolition of the High Bridge "nothing short of a calamity from the engineering, architectural and historical point of view" and joined forces to spearhead an intensive, three-month long campaign to save the bridge.[141] As evidenced by a series of articles in *The New York Times* and *Scientific American* written between March and June, 1923, apologists for remodeling on both aesthetic and practical grounds used the platforms of the popular press and professional journals to openly challenge the Board of Estimate's vote, since the Board had made its decision to raze the bridge without inviting public commentary. "It is not only from a utilitarian standpoint that this structure should be considered," urged a memorandum jointly prepared by the AIA and the Civil Engineers, "this bridge is one of the city's most striking monuments in marking the inauguration three quarters of a century ago of the Croton water supply."[142] Preservation advocates were incredulous that the Board could have decided on demolition, especially since the same Board had determined remodeling to be feasible only two years earlier.

On March 16, 1923, only four days after the Board's vote, representatives of the American Scenic and Historic Preservation Society, the American Institute of Architects, the New York Section of the American Society of Civil Engineers, the American Society of Consulting Engineers, and the Park and Playground Association were granted the opportunity to present their "last stand" defense before the Board of Estimate Committee of the Whole.[143]

In response to the petitions of its Advisory Committee, as well as letters in support of the bridge's preservation submitted by multiple professional and civic groups, the Board made the following motion, "Whereas the Commissioner of the Department of Water Supply, Gas and Electricity in a…communication dated February 27, reports, "My engineers have prosecuted further studies on this problem and the chief engineer reports to me that an arch can be built, spanning the Harlem River and removing three piers in the river. Therefore, be it resolved that the Commissioner of the Department of Plant and Structures be and he is hereby requested to re-examine, investigate and report with all convenient speed."[144] Rather than take a vote, the Board tabled the issue of the bridge's remodeling or demolition.

The public outcry over the possibility of losing the bridge gained momentum as the American Institute of Consulting Engineers, the American Institute of Architects, the American Society of Civil Engineers, the American Scenic and Historic Preservation Society, the Parks and Playgrounds Association, and the American Institute of Fine Arts continued to advocate for its preservation. Supporters for remodeling urged the Board to consider preservation strategies that respected the architectural, engineering and aesthetic value of the bridge but also improved river navigation. A May 1923 *Scientific American* editorial entitled "Municipal Vandalism", which hailed the High Bridge as "the only work of its kind that may be compared to the famous aqueducts for the supply of the City of Rome," called the proposal for demolition "an act of vandalism without precedent in the history of our country."[145]

3.8.16 Decision Reversed (June 1923)

On June 29, 1923, the Board of Estimate and Apportionment voted to remodel the High Bridge in a manner that would be cost-effective, structurally sound, and meet all federal requirements for river navigation. Consistent with its previous efforts supporting the retention of the High Bridge, the DWSGE certified to the Board that the bridge's retention was necessary since it bore three mains carrying water from the old Croton

Aqueduct.[146] The Board's Advisory Committee of Engineers and Architects proposed design consisted of removing three river piers and constructing a singular steel arch over the river, which would be visually sympathetic with the steel arches of the Washington Bridge located immediately to the north. The rendering of the proposed design, which was published in *The New York Times* the day after the hearing, featured an elegant but utilitarian single steel arch over the Harlem, which met the enlarged abutments on either side, and framed a view of the Washington Bridge's steel arches in the distance. According to the Advisory Committee's estimate, the remodeling scheme would cost $716,000, whereas demolition of the bridge and the construction of a new aqueduct tunnel was estimated to cost $1,700,000. The Board determined the cost of remodeling would be chargeable to the DWSGE, and that "money required would be derived from revenues and not {from} next year's budget or require a bond issue."[147]

3.9 STEEL ARCH (1923-1928)

3.9.1 Design for Modification (1923-1926)

Between July 1923 and March 1924, the DPS engineers, in conjunction with members from the Board of Estimate's Advisory Committee, feverishly prepared plans for and sought preliminary review from agencies including the DWSGE for a proposal to substitute four masonry piers (10, 11, 12, 13) with a single 3-hinged steel arch.[148] Notably, the most ambitious of all previously-documented schemes to-date had called for the removal of three contiguous piers, the DPS scheme was the first to depict the substitution of *four* contiguous piers with a single arch.

On April 12, 1924, the DPS submitted a presentation drawing and a rendering of the proposed design to the Municipal Art Commission. The proposal, consisting of "a steel arch of 420 feet span and 103 feet rise to be erected above the Harlem River at High Bridge," would provide "an unobstructed fairway from bulkhead to bulkhead. The steel arch will be sprung from rock to rock and there will be a clearance of 103 feet at mean high water. The {3-hinged} steel arch will have a span of 420 feet."[149] According to Commissioner Whalen, the construction methodology would involve constructing the new (3-hinged) steel arch as a cantilever, "thereby eliminating all obstruction to navigation during the prosecution of the work by the erection of false work. The present piers which are to be removed (10, 11, 12, 13) will not be disturbed until the new steel arch is in place. The steel arch will then be utilized very effectively in the removal of the masonry arches and piers."[150] The Art Commission's recommendation of approval was formally adopted on April 24, 1924, conditional on the receipt of large scale detail drawings at a later date.[151]

Between April 1924 and July 1925, while DPS engineers were engaged in preparing bid documents for the High Bridge reconstruction, Commissioner Whalen stepped down and was succeeded by William Wurt Mills. Plans for the High Bridge's reconstruction were subsequently re-examined and revisions made under the direction of Colonel Francis W. Perry and Chief Engineer Edward A. Byrns.[152] An updated submission, represented in seven (7) presentation drawings and a model, was approved by the Municipal Art Commission on July 14th.[153] The Board of Estimate and Apportionment formally approved the $1,100,000 contract to reconstruct the High Bridge (June 7, 1924) and on August 19, 1924, the War Department offered its approval.

Although DPS had prepared the drawings and specifications for remodeling and would supervise the work, the DWSGE held jurisdiction over the bridge (and the aqueduct within) and advised that the Croton aqueduct's 90 mgd flow across the bridge not be interrupted during the reconstruction project. The DPS Commissioner and the DWSGE Commissioner differed in their opinions regarding the requirement for maintaining water service across the High Bridge's siphon. According to Commissioner Albert Goldman (DPS), the DSWGE's requirement would add $200,000 to the cost of the reconstruction work. Conversely, a representative of the DSWGE argued that if the summer of 1926 was dry, and water demand could not be met by the Catskill supply, then the Old Croton aqueduct delivery would be critical.[154] Despite the anticipated higher cost, the Board of Estimate supported DWSGE's recommendation and mandated that water delivery across the High Bridge during reconstruction work be maintained.

3.9.2 First Bid Set Issued (1925)

By December 1925, the DPS had finalized bid documents for "The Reconstruction of High Bridge over the Harlem River between Boroughs of Manhattan and the Bronx."[155] The maintenance of the aqueduct's operation across the High Bridge, the avoidance of any obstruction to river or speedway traffic, and the aggressive one-year timeframe to complete the work cumulatively posed logistical and scheduling challenges for prospective bidders. In order to avoid disruption to the delivery of Croton water, the aqueduct siphon was to be underpinned in place, from which the new steel arch {supported by false-work} would be suspended from the underpinning until the arch could be joined at mid-span and swung on its own abutments.[156] In order to avoid obstructions to navigation, "the old bridge will be tied lengthwise at the spring line against progressive collapse, leaving 60'-0" clear headroom in the channels {and} each old arch will be carried on {a} steel frame and towers."[157] Bids were solicited on December 27, 1925 and fee proposals were received the following day. Arguably in response to the complex nature of the project and the requirements stated above, the submitted bids far exceeded the amount allocated by the Board of Estimate. The lowest bid ($1,481,000) was $381,000 higher than the Board's anticipated projected cost. On January 12, 1926, the bids were rejected.

3.9.3 Second Bid Set (1926)

By June 1926, just seven months after the initial set of plans and specifications had been issued for bid, the DPS "revised and simplified" their contract documents to eliminate the requirement of maintaining water delivery across the bridge during reconstruction (Appendix H, 40-55). The modified CDs also permitted bidders to propose alternate methods for deconstructing piers 9 thru 13. The DPS's updated plans and specifications were approved by the Board of Estimate on June 7th and by August 20th, both the Municipal Art Commission and the War Department had issued their approvals. Bids were solicited in September 1926, and opened on September 16, 1926.[158] The lowest bid was $1,190,300, which when compared to the 1st round of bids opened in December 1925, this figure constituted a savings of $290,700. A contract was executed on October 15, 1926, with the successful bidder, the Patrick J. Cox Construction Company, and work commenced on October 26, 1926.[159] Although the 1926 contract called for a one-year construction schedule, the work would in fact require two years to complete.

It is instructive to compare the 1925 bid set (drawings and specifications) and 1926 bid set (drawings only), since the former set was more complicated and more costly, and the latter was simpler and anticipated to be less expensive to construct (Appendix L). The effort to simplify scope and cut construction costs resulted in the following critical changes, where the 1926 bid set called for: (1) the suspension of water service during construction and the temporary dismantling, removal and reinstallation of the 90 ½ inch conduit pipe at Section 3B only, (2) the installation of walkway paving in a running bond pattern above the new steel arch, in lieu of a herringbone pattern; and (3) elimination of scope items outside of Section 3B (Steel Arch) from the Contract.

3.9.4 Construction Commences (1926)

During construction, anticipated cost-saving measures such as salvaging and reinstalling granite masonry from the deconstructed attic above piers 10 through 13 proved to be "an intricate engineering problem." The salvaged bridge masonry was reused in the Riverdale Avenue retaining wall (still extant). Ultimately, new masonry was used for the abutments, which was "like that used in the old work in size and kind, so that after it has weathered the marked difference between the old and new will not be noticeable in appearance as at present."[160]

In addition to budget issues, the issue of hostile inter-agency relations between DWSGE and DPS protracted critical path decisions. For instance, a new lighting system was to be installed in conjunction with the remodeling project. Poor coordination between the DPS and the DWSGE restricted the design and integration of the lighting system into the plans for the bridge. According to the DWSGE Annual Report for 1926, "{DPS} plans for the work had progressed so far before being submitted to us that we were restricted to

the use of short posts, as no means had been provided for proper anchorage of large standards. The contract was let and work is under way, but it will probably be two years before the same is completed." In 1929, DPS prepared a post-completion project summary, illustrated with annotated photographs taken by staff photographer Eugene de Salignac, entitled, "Engineering and Construction: The Reconstruction of High Bridge, New York" which was published by *The American Architect* in 1929 (Appendix G). The article offers an insightful review of the decision-making challenges confronted by the engineers during the course of the reconstruction effort, including the deconstruction of the piers, the enlargement of the abutments, and the construction of the new steel span.

3.9.5 Bridge Re-Opens (1928)

Water was restored to service across the High Bridge on April 15, 1928, and ceremonies commemorating the re-opening of the "modernized structure" were held on October 27th as 2,500 pedestrians thronged the bridge after a two-year hiatus. The new steel span, and the unobstructed river navigation it offered, was praised as a means of opening up the Harlem as a "great artery of commerce."[161](Appendix B, Fig. 67) Addresses were made by elected officials, commissioners of municipal agencies, and leaders of civic organizations, including William J. Flynn, Bronx Commissioner of Public Works, Joseph V. McKee, President of the Board of Aldermen, Albert Goldman, Commissioner of the Department of Plant and Structures, Joseph Johnson, Manhattan Commissioner of Public Works, Albert Liebenau, Deputy Commissioner of the Department of Water Supply, Gas and Electricity, George P. Nicholson, Corporation Counsel, and Frederick A. Wurzbach, President of the Bronx Board of Trade. During the proceedings, DPS Commissioner Goldman returned the bridge to the custody of DWSGE Deputy Commissioner Liebenau. A *New York Times* editorial hailed the "metamorphosed bridge" as "a triumphant compromise between art and utility, between the needs of today and tomorrow and those of yesterday…as the steel span symbolizes the future, so the old arches stand as a link with the past."[162] Two weeks after the opening, the Municipal Art Commission's Assistant Secretary, Dr. Hall, inspected the bridge (November 14, 1928) and authorized the issuance of final payment.

3.10 LAND TRANSFERS, DECOMMISSIONING AND POST 1928 MAINTENANCE ACTIVITY

3.10.1 Land Transfers

During Robert Moses' tenure as Commissioner of the Parks Department (1929-1965), the DWSGE was repeatedly petitioned for lands adjacent to, and ultimately, including the High Bridge. Until 1954, each discrete land transfer request was initiated by Parks, reviewed by DWSGE, and approved by the Commissioners of the Sinking Fund. The Sinking Fund was comprised of the Mayor, Deputy Comptroller, Recorder, City Chamberlain and Chairman of the Finance Committee of the Board of Assistant Aldermen.[163] Once approved, former DWSGE property was surrendered to the Sinking Fund and subsequently re-assigned to the Department of Parks. In 1954, the Sinking Fund Commission's role in granting approvals for public land transfers was taken over by the City Planning Commission, subject to final approval by the Board of Estimate's Committee on Acquisition and Disposition of City Property and the Mayor.[164] The Board of Estimate's Committee consisted of the Mayor, the City Council President, and the City Comptroller. Since Parks was granted surface rights to former DWSGE holdings only, Parks was required to submit proposals for alteration of lands and property to the DWSGE for review and approval.[165] Over the course of twenty-six years (1934-1960), the Parks Department initiated, and ultimately was successful in acquiring, surface rights to acreage and structures, from the DWSGE at the High Bridge, including the Reservoir, Tower, park lands on the Manhattan and the Bronx sides, and finally the bridge itself.[166]

The protracted, multi-agency review, approval and jurisdictional transfer process commenced in 1934 when the DWSGE surrendered the High Bridge Reservoir to the Commissioners of the Sinking Fund, who in turn transferred control of these properties to the Parks Department (Appendix H, Fig. 57).[167] Commissioner Moses' request for and Parks' acquisition of the Reservoir in April 1934 was quickly followed by DWSGE's surrender of the lands around the reservoir and tower in July 1934 (Manhattan).[168] The reservoir was subsequently demolished in part to accommodate the construction of the High Bridge Playcenter on the same

site, formally opened in the summer of 1936.[169] Later that year, Commissioner Moses made an additional request that the DWSGE release land holdings on University Avenue north of the bridge (Bronx) to the Sinking Fund. However, DWSGE was not supportive of the request, claiming that the site was in use as a store yard by the Works Progress Administration (WPA) and that it would be "inadvisable to release this property at this time."[170] In 1937, DSWGE submitted a formal request to the Sinking Fund Commission in response to Commissioner Moses' request for the release and re-assignment of DWSGE lands to Department of Parks, which was approved.[171]

On September 20, 1945, the pedestrian stairway (Bronx) adjacent to High Bridge was surrendered from the DWSGE to the Board of Estimate.[172] By 1949, a plot consisting of an unoccupied, two-story Engineer's dwelling and adjacent lands on University Avenue (parcel 143; Bronx) were released to the Sinking Fund.[173] In 1951, the Sinking Fund Commission approved the transfer of High Bridge Tower (unused since 1950; Manhattan) from DWSGE to the Parks Department.[174] The same year, the demolition of the High Bridge Pumping Station (Manhattan) was announced, and Highbridge Park (Manhattan) was cleared to make way for the Highbridge Expressway Interchange.[175] As envisioned by City Construction Coordinator and arterial road planner Robert Moses, the interchange was proposed to connect the Major Deegan Expressway (1935-1939) and Cross-Bronx Expressway (1948-1972).[176] The High Bridge Interchange would also connect the Harlem River Drive (opened 1964), the Trans-Manhattan Expressway (1957-1962), the Alexander Hamilton Bridge (opened 1963) and the Washington Bridge (opened 1889).

Discussions regarding the future transfer of the High Bridge are documented as early as 1954 during a boat tour of the Harlem River in July. The purpose of the tour was to discuss the proposed 2 ½ mile long East River Drive between 125th and 164th Streets. The tour party included Manhattan Borough President Hulan E. Jack, Marine and Aviation Commissioner Vincent A.G. O'Connor, DWSGE Commissioner Arthur C. Ford, Parks Commissioner Moses, Public Works Commissioner Frederick H. Zurmulehn, and Edward J. Smith, chief designer of the new East River Drive segment. According to a *New York Times* article entitled, "Span is swapped on City boat ride," Commissioner Ford complained of the High Bridge's serious maintenance and vandalism issues and suggested that "the Parks Department would really be in a better position to take care of it."[177] Moses indicated his Department would be willing to accept the bridge, so long as the lands on either side of the span were surrendered by DWSGE to his department, as well as his interest in the High Bridge tower. Commissioner Ford accepted.

Ultimately, it would take six years before the DPR release request for the High Bridge and Tower, DWSGE's surrender, Sinking Fund Commission approval, and re-assignment to DPR reached conclusion.[178] Notably, the Board of Estimate Committee's re-assignment of the Tower to Parks authorized DWSGE to retain jurisdiction over the 90 ½ inch aqueduct pipe, and the Gatehouses on each side of the High Bridge.[179]

3.10.2 Decommissioning

In the decade between 1955 and 1965, DWSGE decommissioned the Old Croton Aqueduct and began to de-water the conduit, during which time multiple temporary suspensions of the Aqueduct's flow into the City occurred, Parks contemplated not only the acquisition but also the demolition of the High Bridge, and legal complications arising from the potential loss of aqueduct lands by reversion were debated.[180] Delivery of Old Croton Aqueduct water across the High Bridge and into Manhattan's 135th Gatehouse was finally terminated on December 2, 1958.[181] That year, as the Board of Estimate's Committee was reviewing the re-assignment of the High Bridge to the Parks Department, the Department of Public Works was asked by the Director of the Budget to prepare a cost estimate for the demolition of the bridge.[182] The cost estimate for demolition, $1,750,000, was finalized in March 1960.[183] Months later, on August 25, 1960, the Planning Commission and the Mayor finally approved the transfer of the Bridge and the Tower to the Parks Department, while the DWSGE retained the right of entry to maintain structures still under its jurisdiction.[184] Since the bridge's maintenance and vandalism issues had been criticized by DSWGE Commissioner Ford in 1954, it is possible

that the cost estimate for demolition was simply an exercise that would provide a benchmark against which to compare rehabilitation costs.

3.10.3 Significant Maintenance Activity (post 1928)

During the Great Depression, the bridge appeared to suffer from lack of cyclical maintenance, and in 1934, only six years after the High Bridge was reopened, DWSGE proposed a recommended maintenance program. The recommended scope included painting structural steel work and railings at the steel arch span, and caulking and pitching of joints between brick pavement and steel coping of the promenade. The cost of the proposed maintenance work, which was restricted to the 1926-1928 portion of the bridge, was estimated at $12, 038. It is unknown whether this work was performed. Other DWSGE documents from 1934 indicate that painting of railings and wire protection on the High Bridge would be performed by the Works Division of the Department of Public Welfare.[185] In 1935, a fence was installed in front of a pillar supporting the High Bridge on Sedgewick Avenue south of Undercliff Avenue by DSWGE on recommendation of the Police Department Commissioner.

In 1939, the DWSGE received a complaint from a civic group called the Building Industry League to the effect that "metalwork at High Bridge is in an unsightly condition" and requested that the agency repaint the steel. This correspondence may indicate that the maintenance work recommended in 1934 was not carried out. The DSWGE's request for $8,795 in funding to perform the repainting of the High Bridge's steel arch section and all iron work in fiscal 1939 was approved and the work was completed.

In 1940, DWSGE replaced wooden coverings on the steps and landings at the Bronx end of the High Bridge (Bid for labor given to Martin J. Lyons Contracting Co.). Later that year, the Parks Department requested the installation of benches on the "floorway" of the High Bridge. In addition, Parks requested the installation of ramps at each end of the bridge to facilitate the wheeling of baby carriages on and off the bridge's deck. Parks' request for benches sparked an inter-agency disagreement between the Department of Parks and DWSGE. DSWGE engineers were concerned about life safety, and disproved of placing benches in close proximity with the existing 3'-6" deck railing, which was considered in need of repair. It is unknown whether the deck ramps were installed.

DWSGE refused to grant permission to the Parks Department for the installation of benches on the High Bridge until the promenade fence was "high enough." In 1941, the DWSGE approved drawings prepared by the Department of Parks for a new fence and ramps to be installed on the deck of the High Bridge which would allow the bridge to be used for recreational purposes. The approval also included new benches, and the maintenance for these new installations would be the responsibility of Parks.[186] In that year, the DWSGE submitted a request to the Federal Works Agency Works Project Administration (FWAWP), which urged the Agency to "undertake the reclamation of 1,533 linear feet of 36" cast iron pipe in a gallery in Highbridge."

By the mid 20th century, the steel arch structure evidenced deterioration and the bridge in general was a locus for acts of vandalism.[187] In particular, the west expansion joint on the 90'-0" steel main crossing was cracked across the top and resulted in leaking onto the Harlem River Speedway. Increased vandalism prompted the performance of lighting repairs. As a preventative measure, the entrance door at the Bronx end of the Bridge was sealed with brick. In 1960, the High Bridge closed to pedestrian traffic. Although the exact date of closure is unknown, a July 1, 1960 letter to Mayor Wagner, protested the inconvenient closure of the bridge.[188] Conversely, anecdotal knowledge from residents who lived near the High Bridge in the 1960s suggests that the Bridge may not have been permanently closed to pedestrian traffic in 1960.[189]

In 1974, the Art Commission granted Preliminary Approval to the Department of Parks for the bridge's estimated $318,500 rehabilitation. The proposed scope included: "Rehabilitation of Aqueduct and Pedestrian Walk over Harlem River including rehabilitation and/or replacement of existing bridge railing, rehabilitation of pavement, construction of seating areas, and entrance ramp, and painting of steel bridge arch and lighting."[190] Five years later, the Department of Parks received approval for a reduced scope of work,

estimated at $296,400, from both the Landmarks Preservation Commission and the Art Commission. The LPC approved scope included: "Stabilizing the bridge, repaving, restoration of the bridge iron railing, resetting and caulking of the cap stones and granite stairs, and the fabrication and installation of two wrought iron gates and fan guards at each end of the bridge; steel span shall be cleaned and painted in the original paint color" (Landmarks Preservation Commission LP 0539). The Art Commission's Final Approval included the following scope: "Rehabilitation of the Bridge, repaving, restoration of the iron bridge railing, resetting and caulking of the cap stones and granite stairs, and fabrication and installation of two wrought iron gates and fan guards at each end of the Bridge" (Art Commission Series 1273-S Certificate 13316). Although the five year period (1974-1979) of regulatory approvals is well documented in LPC and Art Commission records, the construction dates for the rehabilitation work are unknown. Based on 2010 physical inspections of the Bridge, the following scope approved in the 1970's appears to have been performed: selective repaving of running bond and herringbone patterned brick, selective repair of the historic railings, and installation of security gates at the Manhattan and Bronx ends of the promenade. Numerous proposed scope items were not installed, most notably, four raised seating "pods," and a 1'-0" top rail vertical extension above the historic railings.

3.10.4 Lighting/Electrical Upgrades

Refer to Lighting Chronology (Appendix E).

3.10.5 Croton Aqueduct and New York City's Water Supply Today

Despite changes to and decommissioning of the Old Croton Aqueduct, some of the system remains intact. Notably, in 1986, a three and one-half mile segment of the Old Croton's masonry conduit was re-opened for the Village of Ossining, the only community to presently utilize the Old Croton Aqueduct in its water supply system. The Department of Environmental Protection currently manages the New Croton Aqueduct, which continues to deliver 10% (250 mgd) of the City's drinking water supply.

In 1966, Governor Rockefeller announced plans for a 32-mile long Croton Aqueduct Trail for hikers and bicyclists along the right-of-way of the Croton Aqueduct extending south from the Croton Dam in Westchester to include High Bridge parks in Manhattan and the Bronx. Following the purchase of land above the aqueduct from New York City in 1968, the north-most 26.2 miles of the Aqueduct (from Croton Dam to Van Cortlandt Park at the Bronx County/City of Yonkers border) were placed under the jurisdiction of the New York State Department of Parks, Recreation and Historic Preservation and named the Old Croton Aqueduct State Historic Park. This linear park, which corresponds to the course of the sub-grade aqueduct, it is still in active use today.[191]

ENDNOTES

1 Oliver Schwaner-Albright, "Design Challenge: Fend Off Disaster," *The New York Sun,* July 22, 2008.

2 *Laws of the State of New York*, 22nd sess., ch. 134:816.

3 David Church, *A Short History of Water Supply and Waste Disposal in New York City with reference to Wall Street. Cultural Resources Survey Testing and Mitigation Phases, 60 Wall Street Site, New York City*, Section X: Appendices A-F, Binder 1, B14. An 1830 Common Council special committee, chaired by Alderman Samuel Stevens, concluded that the Manhattan Company was not complying with its charter of supplying the City with "pure and wholesome water." In State Supreme Court, Democratic Attorney General Greene C. Bronson sued the Manhattan Company in October 1830 in an attempt to dissolve the Company's charter, arguing that the surplus capital gained from water customers and diverted to banking operations could not be applied to purposes other than water because the Company had failed to provide sufficient water in the first place.

4 *Report of the Commissioners under an Act of the Legislature of this State Passed May 2, 1834 Relative to Supplying the City of New York with Pure and Wholesome Water (*February 1835): 324.

5 Kevin Bone, *Water-Works: The Architecture and Engineering of New York Water Supply (*New York: Monacelli Press, 2006*):* 40.

6 "The imposing Egyptian Revival style structure, whose 45-foot high granite walls dominated the busy intersection of Fifth Avenue and 42nd Street, was designed by James Renwick, Jr." from Gerard Koeppel, *Water for Gotham: A History* (Princeton, New Jersey: Princeton University Press, 2000), 275-276. A visiting German engineer noted that, "at 119 feet above the level of the sea, it commands a complete view of . . . Manhattan Island, as well as the south part of the City with New York bay, and, at a greater distance, the Atlantic Ocean. The view is exceedingly beautiful, and may be called one of the finest in the world" from Theopholus Schramke, *Description of the New York Croton Aqueduct in English, German and French* (New York and Berlin: T. Schramke, 1846).

7 Charles King, *A Memoir of the Construction, Cost, and Capacity of the Croton Aqueduct*, *Compiled from Official Documents Together with an Account of the Civic Celebration of the Fourteenth October 1842, on Occasion of the Completion of the Great Work* : *Preceded by a Preliminary Essay on Ancient and Modern Aqueducts* (New York: King, 1843.)

8 Schramke, *Description of the New York Croton Aqueduct*, 59.

9 Without indoor plumbing, or modern sewerage systems, effluvia was discharged into the streets, canals, and the East and Hudson Rivers. These unsanitary conditions provided the perfect breeding ground for waves of yellow fever, cholera and typhoid outbreaks, which claimed thousands of lives in the year 1798 alone. Faced with such a health crisis, New York City could not afford to avoid the water issue. Epidemic disease registered as a disruption in mercantile operations with shuttered businesses, the flight of merchants to Harlem or Greenwich, and the decimation of immigrant labor forces. Additionally, not having reliable and sufficient water was dangerous, as fires wrecked havoc by destroying precious imported and local goods, jobs, businesses, and valuable real estate, prompting costly insurance claims. Reports differ on concise numbers of lives lost during the 1798 cholera outbreak. Gerard Koeppel, in his book *Water for Gotham*, includes a number exceeding 2,000. Edwin Burrows and Michael Wallace, in *Gotham: A History of New York City to 1898*, cites 2,086. For the reference regarding insurance claims in the 1835 fire, see Kevin Bone, *Water-Works: The Architecture and Engineering of New York Water Supply,* 6.

10 Diarist Philip Hone wrote of the enormous expense of the aqueduct: "Political spouting has given place to waterspouts, and the free current of water has diverted the attention of the people from the vexed question of the national currency . . . how cheerfully our citizens acquiesce in the enormous expense which will burden them and their posterity with taxes to the last generation." Philip Hone. *The Diary of Philip Hone: 1828-1851.* Vol. 2:(New York: Dodd, Mead and Company, 1889):150.

11 Unless specifically cited, the general chronology and history of the design and construction of the High Bridge is taken from several sources, all which rely on the Reports of the Water Commissioners and Chief Engineer as primary sources: Koeppel, *Water for Gotham;* Larry D. Lankton, "Old Croton Aqueduct'" Historic American Engineering Record NY-120 (1976); F. Daniel Larkin, *John B. Jervis: An American Engineering Pioneer* (Ames: Iowa State University Press, 1990); F. Daniel Larkin "The New York Years of John B. Jervis, A Builder of Nineteenth Century America" (PhD diss., State University of New York at Albany, 1976); Edward Wegmann, *The Water Supply of the City of New York, 1658-1895* (New York: John Wiley and Sons, 1896).

12 *New York Evening Post* (March 18, 1845), Meigs quoted in Keoppel, *Water for Gotham*:154.

13 "Engineer's Report" (November 1, 1833) from "Report of the [Water] Commissioners" *Documents of the Assembly of the State of New-York*, Document No. 15 (January 8, 1834): 37-8.

14 Ibid.

15 Ibid.

16 The Water Commissioners note in their report on the crossing of the Harlem River that they "directed a contracted plan of the two methods of crossing the Harlaem River, to be prepared by Charles B. Pearson, Esq., an architectural draftsman, now in the employ of the Commissioners, which are herewith submitted for the inspection of your honorable body; . . ." "Semi-Annual Report of the Water Commissioners," *Documents of the Board of Alderman of the City of New York*, Document No. 55 (January 4, 1838): 371.

17 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 55: 394.

18 "Croton Aqueduct Notice," *New York Evening Post*, June 15 1839.

19 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 25 (December 31, 1838): 238.

20 An Act, Prescribing the manner in which the Croton Aqueduct shall pass the Harlem River. (Passed May 3, 1839). The People of the State of New York, represented in Senate and Assembly, do enact as follows:

§1. The Water Commissioners shall construct an aqueduct over the Harlem River, with arches and piers; the arches on the channel of said river shall be at least eighty feet span, and not less than one hundred feet from the usual high water mark of the river; or they may carry the water across said river by a tunnel under the channel of the river, top of which tunnel shall not be above the present bed of the said channel.

21 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 10 (July 1, 1839): 7.

22 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 42 (January 6, 1840): 442.

23 Ibid., 442 and 471. George Law's contract at Mill River was the only unfinished section between the Croton Dam and the Harlem River in June 1841, but Jervis expected it complete in August. "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 17 (July 12, 1841): 97-8.

24 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 42 (January 6, 1840): 471.

25 "Supplemental Report of the Later Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 65 (March 30, 1840): 643-4.

26 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 9 (June 30, 1845): 90-1.

27 Ibid.

28 Ibid.

29 Description of pile foundations from "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 39 (January 11, 1841): 551.

30 Description of Jervis's research on cofferdams and visit to Washington, DC from: Larkin, *John B. Jervis*, 69; and Lankton, "Old Croton Aqueduct," Jervis's acquisition of Turnbull's Drawings of the Alexandria Aqueduct is cited in Lankton, 136, n. 5. The reports on the arduous task of sinking cofferdams for the piers of the Potomac Aqueduct were published in the *Congressional Record* in 1838 and 1841 and republished in 1873 as William Turnbull, *Reports on the Construction of the Piers of the Aqueduct of the Alexandria Canal across the Potomac River at Georgetown, District of Columbia, 1835-1840* (Washington: GPO, 1873).

31 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 39 (January 11, 1841): 551.

32 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 47 (January 3, 1844): 623.

33 Description of problems with cofferdam construction from "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 47 (January 3, 1844): 623.

34 Baker Engineering, NY, Inc., *Condition and Assessment Report*, (November, 1999): Appendix G, from Jervis Papers. "Approximate Quantities for Section No. 86, including Aqueduct Bridge across Harlæm Valley." Resident Engineer Peter Hastie certified that the notice on quantities was posted on the door of the Water Commissioners office for bidders from July 23 to 31, 1839.

35 Description of the temporary pipe across the nearly continuous cofferdam embankment in Schramke, *Description of the New York Croton Aqueduct*, 43; and, "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 55 (January 17, 1842): 381.

36 Description of "jet d'eau" from F.B. Tower, *Illustrations of the Croton Aqueduct* (New York, London: Wiley and Putnam, 1843): 111-2 and pl. XX; and, quotation from the Commissioners in "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 9 (August 8, 1842): 77.

37 Quotation from Tower, *Illustrations of the Croton Aqueduct:*112.

38 Removal of the fountain from "Our Weekly Gossip: High Bridge Fountain," *The Harbinger,* June 24 1848: 62.

39 Koeppel, *Water for Gotham:*275.

40 Koeppel, *Water for Gotham*:279-83.

41 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 75 (January 30, 1843): 764-5, 775-7.

42 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 12 (July 7, 1843): 117-19, 121, and 125-7.

43 "Report of the Water Commissioners," *Docs. Bd. Ald.,* Doc. No. 47 (January 3, 1844): 621-3.

44 On granite and labor: Ibid., 617 and 625-6; Doc. No. 8 (July 1, 1844):137; and Doc. No. 43 (January 6, 1845): 425.

45 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 43 (January 6, 1845): 426-7.

46 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 9 (June 30, 1845): 87-93.

47 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 28 (January 5, 1846): 450 and 455-9.

48 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 25 (January 4, 1847): 254-5 and 259-60.

49 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 5 (July 1, 1847): 69-70.

50 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 29 (January 3, 1848): 454-5.

51 "Supplemental Report of the Late Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 39 (February 14, 1848): 577-94.

52 "Communication from the Water Commissioners in Relation to the Aqueduct Bridge," *Docs. Bd. Ald.*, Doc. No. 5 (June 5, 1848): 75-84.

53 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 7 (July 24, 1848): 102.

54 Ibid., 98 and 101-6.

55 "Report of the Water Commissioners," *Docs. Bd. Ald.*, Doc. No. 32 (January 15, 1849): 616 and 619-24.

56 Final cost of the High Bridge from Wegmann, 56.

57 "Report of the Croton Aqueduct Department," *Docs. Bd. Ald.*, Doc. No. 2 (January 7, 1850): 27-8.

58 Ibid., (January 7, 1850): 28.

59 "Report of the Croton Aqueduct Department," *Docs. Bd. Ald.*, Doc. No. 81 (December 31, 1851): 1398-9.

60 Ibid., 1411-13.

61 *Annual Report of the Croton Aqueduct Department* (January 3, 1853): 16.

62 *Annual Report of the Croton Aqueduct Department* (January 3, 1855): 12.

63 Department of Water Supply, Gas and Electricity, *Minutes of the Croton Aqueduct Board of the City of New York, July 18, 1849 to April 9, 1870* (New York: Mail and Express Company): 67.

64 *Minutes of the Croton Aqueduct Board*:84.

65 *Minutes of the Croton Aqueduct Board*:94.

66 Croton Aqueduct Board, *Annual Report of the Croton Aqueduct Department* (January 7, 1861): 17-18. Beginning in 1858 Prince's Metallic Paint was a reddish brown colored iron oxide paint manufactured from iron ore mined in Carbon County, Pennsylvania. Other manufacturers offered iron oxide "metallic paint" using ore from the same vein of iron ore. Metallic paint was commonly used for coating roofing and industrial structures, and was advertised and cited in industrial and farm journals and publications throughout the late 19th century. See legal case in Prince Manufacturing Co. v. Prince Metallic Paint Co., 47 N.Y., 99 (1893).

67 Description of pipe from 1862, Doc 2:23-4; "The New Croton Pipe over High Bridge," *New York Herald*, November 24 1861:4; "The Great Croton Pipe, *New-York Daily Tribune*, September 8 1860:10.

68 Description of raising and laying the pipe from "The Laying of the New Croton Mains Over High Bridge," *New York Herald*, November 3 1860:10.

69 Description of re-routing of 36 inch cast iron pipes by day's work in: *Annual Report of the Croton Aqueduct Department for the Year 1861*, in *Documents of the Board of Alderman of the City of New York*, Document No. 2 (January 6, 1862): 26-7.

70 *Annual Report of the Croton Aqueduct Department* (January 6, 1862): 22.

71 *Annual Report of the Croton Aqueduct Department* (January 5, 1863): 10. Robert Donnell was authorized by the Croton Aqueduct Board on June 14, 1862 to be paid $60 for use of his tugboat to deliver skewbacks and [tie] rods to the High Bridge. *Minutes of the Croton Aqueduct Board*:126.

72 William Dearborn, "Experiments for Making Brick Masonry Impervious to Water Tried on the Walls of the Back Bays of the Gate Houses of the New Croton Reservoir in New York, and on the Brick Arch of High Bridge in 1863" Paper read before the ASCE, May 4, 1870 in *Transactions of the American Society of Civil Engineers* (1870): 206-8.

73 *Annual Report of the Croton Aqueduct Department* (January 7, 1861): 15.

74 The plaques on both gatehouse are now missing, probably taken by vandals. The plaque inscription is quoted in: J. Thomas Scharf, *History of Westchester County, New York, including Morrisania, Kings Bridge and West Farms which have been annexed to New York City,* vol. 1, pt. 2, (Philadelphia: L. E. Preston & Co., 1886): 791; and, Edward Hagaman Hall, *The Catskill Aqueduct and Earlier Water Supplies of the City of New York*, 2nd ed. (New York: The Mayor's Catskill Aqueduct Celebration Committee, 1917): 61.

75 *Annual Report of the Croton Aqueduct Department* (January 4, 1864): 11; (January 9, 1865): 8; Corporation of the City of New York, *Annual Report of the Comptroller,* (1863): 202.

76 *Annual Report of the Croton Aqueduct Department* (January 1, 1866): 9 and 11.

77 Ibid: 10-12.

78 American Society of Civil Engineers, Met Section, "The Croton Water Supply System, "American Society of Civil Engineers, http://www.ascemetsection.org/content/view/341/875/

79 National Park Service, History Division, *Croton Aqueduct: National Register Nomination*, Robie S. Lange, 1991, 12-13.

80 Benjamin Church, "Notes and Suggestions on the Croton Water Works and Supply, for the Future," paper read before the ASCE, February 2, 1876, in *Transactions of the American Society of Civil Engineers 5*, (1876): 16 and 20.

81 George B. Butler Esq. to the Municipal Society on the occasion of the opening of their new building at 87 Madison Avenue (Dec. 21, 1876, published 1877), Collection of the Columbia University Archives. Butler's comparison of New York and London's water supply: "London has reached a population of nearly 4,000,000 without having more than one third of the quantity for each inhabitant which our aqueduct can furnish. With the London supply, fires are put out without difficulty, hundreds of miles of sewers are washed clean, her manufacturers are abundantly accommodated, and no limits have yet been imposed on her growth. Water there is less freely used in houses that in ours, but the great difference results from our enormous waste and their prevention of waste. It would seem, so long as we can appeal to such experience, that it would be wild extravagance to mortgage our property to procure water when by enforced economy in its use we may have enough. When the capacity of the aqueduct shall be fully met at all seasons, and the requisite care shall be taken to prevent either waste or misappropriation of the water, then conviction will be quite general that such supply as we would then have, maintained with constancy, is not only ample but liberal, and that our deepest gratitude is due to those who planned and those who executed a work which bestows the greatest benefits upon the city."

82 *Report of the Aqueduct Commission* (1886): 29.

83 The Legislature passed "An Act to provide new reservoirs, dams, and a new aqueduct, with the appurtenances thereto, for the purpose of supplying the City of New York with an increased supply of pure and wholesome water," (Chapter 490 of the Laws of 1883) on June 1, 1883. See Edward Wegmann, *The Water Supply of the City of New York 1658-1895* (New York: John Wiley and Sons, 1896):110.

84 Final contract "G.E.M. 13" for "furnishing, delivering and laying a 12-inch water main and appurtenance across High Bridge, Manhattan and the Bronx." Correspondence, (signature illegible), Chief Engineer, Department of Water Supply, Gas and Electricity to Mr. J. W. F. Bennett, Deputy and Acting Commissioner, June 12, 1912. DEP Archives, Subject Files, Water and Sewer Operations, 1911-1913.

85 The 1925 specifications describe the siphon as consisting of: two 36 inch internal diameter cast iron conduits, one 90 ½ inch internal diameter wrought iron conduit, a 6 inch internal diameter cast iron pipe service line and a wire circuit located within the attic story of the bridge. No date of installation is provided for the 6 inch pipe. Form of Proposals for Bids, Bid, Contract, Bond and Specifications, Department of Plant and Structures for the Reconstruction of High Bridge over Harlem River between the Boroughs of Manhattan and the Bronx, City of New York Department of Plant and Structures for the Department of Water Supply, Gas and Electricity, 1925, pgs. 33 and 38.

86 "Fate of High Bridge," *The American Architect*, January 12, 1921. While the Corp of Engineers, U.S. Army letter to the City of New York is referenced in the American Architect article, there is no specificity about which Secretary of War expressed prior concern over the obstruction caused by the bridge's river piers. The two individuals who served in the post of Secretary of War in the Taft Administration were Jacob McGavock Dickinson and Henry Louis Stimson.

87 Charles Gregory and Eugene Stern, "Proposed Reconstruction of the High Bridge: An Informal Discussion," *Municipal Engineers Journal* 3, no. 1, 1917.

88 "The Fate of High Bridge," *The American Architect*, January 1921.

89 Gregory and Stern, "Proposed Reconstruction of High Bridge," 1917.

90 "The Fate of High Bridge", *The American Architect*, January 1921.

91 "Plans to Improve Harlem River: Picturesque High Bridge May Be Destroyed in Interest of Better and Safer Navigation," *The New York Times*, June 29, 1919.

92 "The Fate of High Bridge." The futuristic vision of a modified High Bridge which carried cars continued as late as 1925 by which time plans and specifications for remodeling the bridge had been prepared. DPS Commissioner Whalen (confirm) admitted that such use would not be precluded in future since "the new steel arch…will be capable of carrying vehicle traffic. See "Plans to Rebuild High Bridge Ready," *The New York Times,* December 27, 1925.

93 Gregory, "Proposed Reconstruction of High Bridge," 1917.

94 Gregory, "Proposed Reconstruction of High Bridge," 1917.

95 "High Bridge in Danger," *The New York Times,* November 13, 1916.

96 "The Fate of High Bridge," *The American Architect*, Jan 1921.

97 Department of Water Supply, Gas and Electricity, *Annual Report*, (1920): 66.

98 "Plans to Improve Harlem River," *The New York Times*, June 29, 1919. Dowling-Healey Measure was passed in the legislature to consider definite plans for improving navigation of the Harlem River.

99 "Plan to Save High Bridge Demolition", *The New York Times,* April 18, 1920.

100 Department of Water Supply, Gas and Electricity, *Annual Report*, (1920): 66.

101 Section is from Act Mar. 3, 1899, popularly known as the 'Rivers and Harbors Appropriation Act of 1899' which states: "The creation of any obstruction not affirmatively authorized by Congress, to the navigable capacity of any of the waters of the United States is prohibited; and it shall not be lawful to build or commence the building of any wharf, pier, dolphin, boom, weir, breakwater, bulkhead, jetty, or other structures in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines, or where no harbor lines have been established, except on plans recommended by the Chief of Engineers and authorized by the Secretary of the Army; and it shall not be lawful to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of, any port, roadstead, haven, harbor, canal, lake, harbor or refuge, or enclosure within the limits of any breakwater, or of the channel of any navigable water of the United States, unless the work has been recommended by the Chief of Engineers and authorized by the Secretary of the Army prior to beginning the same." See Mar. 3, 1899, ch. 425, Sec. 10, 30 Stat. 1151; July 26, 1947, ch. 343, title II, Sec. 205(a), 61 Stat. 501.

102 Department of Water Supply, Gas and Electricity, *Annual Report*, (1920): 66.

103 "The Fate of High Bridge," *The American Architect*, January 1921.

104 Ibid.

105 "Plan to Save High Bridge Demolition," *The New York Times,* April 18, 1920.

106 "Mayor Makes Plain that His Namesake is a Seagoing Tug," *New York Tribune,* May 8, 1920.

107 The High Bridge pier numbering system referenced herein utilizes the numbering system enumerated on Drawings titled "High Bridge Reconstruction over the Harlem River between the Boroughs of Manhattan and the Bronx," June 1, 1926, prepared by the Department of Plant and Structures. Historic (19th and 20th century) identification of the High Bridge's land and river piers commenced at the east-most pier 1 on the Bronx side and continued in ascending numeric order towards the west-most pier 14 on the Manhattan side. This identification system corresponded to the direction of flow of water within the aqueduct pipe. Currently, the pier numbering commences at the west (Manhattan) and continues in ascending numeric order towards the east (Bronx).

108 "The Fate of High Bridge," *The American Architect,* Jan 1921.

109 Note that the design Carèrre & Hasting's elliptical arch appears visually similar to that proposed by DWSGE as shown in Design No. 1, March 1923.

110 "The Fate of High Bridge," *The American Architect*, Jan 1921.

111 Ibid.

112 Ibid.

113 Ibid.

114 Department of Water Supply, Gas and Electricity, *Annual Report*, (1920): 14.

115 Ibid.: 66-67.

116 It is not known which river piers were referred to in the remodeling plan.

117 Department of Water Supply, Gas and Electricity, *Annual Report*, (1920): 35 and 58. The DSWGE's *Progress Report for the Quarter Ended March 31, 1922* indicated that the High Bridge reconstruction was advertised on February 4, 1922, that bids were opened on February 16, 1922 and that the bid award occurred on February 23, 1922.

118 "High Bridge has been Saved," Current News, *The American Architect*, February 9, 1921.

119 Department of Water Supply, Gas and Electricity, *Annual Report,* 1921.

120 "Pleas for High Bridge Changes Made to U.S.: Bronx Business Men Want the Structure Removed or Two Alternate Piers Demolished," *New York Tribune*, March 31, 1920.

121 The DSWGE's *Progress Report for the Quarter Ended March 31, 1922* indicated that notification to begin work on the High Bridge reconstruction occurred on March 21, 1922; that work was to commence on March 25, 1922, and that field work was to commence on March 30, 1922.

122 Department of Water Supply, Gas and Electricity, Bureau of Water Supply, *High Bridge Reconstruction: Progress Report for the Quarter Ended March 21, 1922*, Yates, W. H., New York, 1922.

123 DSWGE *Annual Report*, 1922:32.

124 Ibid.

125 Ibid.

126 DSWGE *Annual Report*, 1921, 61; "Remove Two Piers of High Bridge," *The New York Times*, January 22, 1922.

127 DSWGE *Annual Report*, 1922, 32; Boring Drawings.

128 DSWGE *Annual Report*, 1922, 32.

129 "Remove Two Piers of High Bridge," *The New York Times*, January 22, 1922.

130 DSWGE Annual Report, 1922.

131 Ibid.

132 "Remove Two Piers of High Bridge," *The New York Times*, January 22, 1922.

133 DSWGE, *High Bridge Reconstruction Progress Report*, W.H. Yates (March 1922); New York City Department of Environmental Protection Archives.

134 High Bridge Reconstruction Designs 1, 2, 3, 4, 7, dated March – May, 1923, DEP Archives. Note these drawings were turned over to the Department of Plant and Structures in 1924, after DWSGE was no longer leading the reconstruction effort.)

135 "High Bridge May Go, New Defect Found: Structure Has Sagged Badly and the Cost of Remodeling is Prohibitive," *The New York Times*, January 26, 1923. It is unknown whether the Army Corps was the federal agency which would be responsible for the proposed Harlem River dredging project.

136 "Open Fight to Save Historic High Bridge," *The New York Times,* March 14, 1923.

137 "High Bridge Razing Officially Voted," *The New York Times,* March 13, 1923.

138 DSWGE Annual Report 1923-1924.

139 DSWGE Annual Report 1923-1924.

140 "Municipal Vandalism," *Scientific American*, May 1923.

141 "Open Fight to Save Historic High Bridge," *The New York Times,* March 14, 1923.

142 "Open Fight to Save Historic High Bridge," *The New York Times,* March 14, 1923.

143 "Save High Bridge Campaign Grows," *The New York Times,* March 15, 1923. The Advisory Committee, chaired by E. S. Jarett of the ASCE-NY Section included fellow ASCE-NY Section members Ralph Chambers, Daniel E. Moran, Lincoln Bush, J. Vipond Davies, and Ralph Modjeski ; Reginald Pelham Bolton, Dr. Edward Hagaman Hall, N. Taylor Philips, and Colonel Henry L. Sackett of the American Scenic and Historic Preservation Society; Donn Barber of the American Institute of Architects; and Colonel William J. Wilgus of the Municipal Art Commission. "Will Appeal Today to Save High Bridge," *The New York Times*, March 16, 1923.

144 "Won't Tear Down High Bridge at Once," *The New York Times* March 17, 1923.

145 "Municipal Vandalism," *Scientific American*, May 1923.

146 "Huge Steel Arch in High Bridge Plan," *The New York Times,* April 20, 1924.

147 "High Bridge Saved: To Be Remodeled," *The New York Times,* June 30, 1923.

148 "Reconstruction of High Bridge over Harlem River Between Boroughs of Manhattan and the Bronx," March 1, 1924, prepared by Department of Plant and Structures. Collection NYC Public Design Commission.

149 "Huge Steel Arch in High Bridge Plan," *The New York Times,* April 20, 1924. (See drawing dated March 1, 1924.)

150 "Huge Steel Arch in High Bridge Plan," *The New York Times,* April 20, 1924.

151 Art Commission, Submission 3032, Series 1273 Exhibit A, Certificate 2961.

152 "High Bridge Remodeled," *The New York Times,* July 16, 1925.

153 "High Bridge Reconstruction over Harlem River (Location Plan, Channel Span, Steel Superstructure, East Abutment Pier Section 1, East Abutment Pier Section 2, West Abutment Pier Section 1, West Abutment Pier Section 2), prepared by DPS, dated June 1925; Art Commission Exhibits 1273-E through N.

154 "To Rebuild High Bridge," *The New York Times*, June 8, 1926.

155 Department of Plant and Structures, DWSGE. *Form of Proposals for Bids, Bid, Contract, Bond and Specifications for the Reconstruction of High Bridge over the Harlem River between the Boroughs of Manhattan and the Bronx*. New York, 1925.

156 "Plans to Rebuild High Bridge Ready" *The New York Times,* December 27, 1925.

157 Ibid.

158 The date of the bid solicitation is unknown at this time.

159 "$291,000 is Saved on High Bridge Bids," *The New York Times*, September 17, 1926; *Department of Plant and Structures Annual Report,* 1926.

160 "Engineering and Construction: The Reconstruction of High Bridge, New York," *The American Architect* 135, no. 5, 1929.

161 "High Bridge Opens as a Single Span," *The New York Times*, October 28, 1928.

162 "High Bridge Transformed," *The New York Times*, October 30, 1928.

163 "The Sinking Fund," *The New York Times*, October 31, 1871.

164 Notably, Robert Moses served as Commissioner of City Planning, however the dates of his tenure at DCP are unknown at this time.

165 DEP Archives (1931-1934) 1371, Folder 16. "The land shall be transferred to the Dept. of Parks 2) the HB Tower and the water mains connected thereto which are left in service and included within the area released shall remain under the jurisdiction of the Dept. of WSGE (...) 3) All new work of constructing on and/or alteration in surfaces of lands released which is undertaken by the Dept. of parks, its successors or assigns shall be subject to the approval of the commissioner of WSGE and for his determination as to whether such work or alteration of surfaces will affect and require changes in the structures on the property remaining under his jurisdiction. (...).

166 Although transfer of acreage and buildings from the DWSGE to Department of parks occurred, the total acreage and the total number of buildings which were transferred are unknown at this time.

167 DEP Archives Box 1371, Folder 16.

168 DEP Archives, Box 1371, Folder 16.

169 *Highbridge Play Center.* Landmarks Preservation Commission Designation Report, Designation list 395, LP 2237, August 13, 2007.

170 Memo, M. F. Quinn, Division Engineer, Real Estate Division, to Joseph Goodman, Chief Engineer, in DEP Archives, Box 1351, Folder 19. Moses requested Land on Segwick Avenue bounded on the north by Commerce Avenue, on the south by 154 ft. south of High Bridge, on the east by Sedgewick Avenue, on the west by New York Central Rail Road; site was occupied as a store yard for materials by Works Progress Administration.

171 Joseph Goodman, Commissioner, to L.F. Lang, Secretary, Commissioners of the Sinking Fund, in DEP Archives Box 1351, Folder 19. Lands at E. 170th Street, High Bridge Avenue and Aqueduct Avenue, Borough of the Bronx; Map 26192-X, part of parcel 143, Block 2533, Lot 22 in part.

172 Correspondence, President of the Borough of the Bronx, Board of Estimate, Office of the Mayor and Department of Water Supply, dated April 9, 1945, May 9, 1945, January 8, 1946 and September 7, 1946, in DEP Archives Box 3383, Folder 6. Release of Land (Bronx, 1885 Stairway {a pedestrian highway} extending from University Avenue to Sedgwick Avenue south of High Bridge.

173 DEP Archives Box 3384, Folder 2. "The property is no longer of use to the DWSGE and it is suggested to be disposed of."

174 "High Bridge Water Tower Saved as City Landmark," *The New York Times*, November 24, 1951.

175 Although the announcement of the proposed demolition of the High Bridge Pumping Station is documented in correspondence on file at the DEP Archives, the actual date(s) of the demolition of the station is unknown at this time. Similarly, the actual date(s) of the clearing of Highbridge Park (Manhattan) to accommodate the construction of the High Bridge Interchange is unknown at this time. Please refer to DEP Archives, Box 3373, Folder 8.

176 "Tunnels and Ramps to Speed Traffic," *The New York Times*, January 18, 1952; DEP Archives Box 3373, Folder 8.

177 Lawrence O'Kane, "Span is 'Swapped' on City Boat Ride," *The New York Times*, July 8, 1954.

178 Ibid.; DEP Archives Box 3393, Folder 1: Land transfer (3 ½ acres on Bronx Side, westerly of University Avenue and Sedgewick Avenue; 7 acres on Manhattan Side from the Bridge to West 158th Street; Tower) from DWSGE to Parks.

179 Letter, Board of Estimate Calendar No 149, October 29, 1954, in DEP Archives, Box 3064, Folder 3.

180 DWSGE Annual Report (1955): 49. Flow to Manhattan stopped (October – December 1955), closure of sluice gates at Highbridge and opening of the blow-off to discharge leakage in old Croton Aqueduct.; 1956 Annual Report of DWSGE, p. 51Old Croton Aqueduct not in service during the entire year to Borough of Manhattan; water in the Aqueduct wasted into the Harlem River at the High bridge blow-off. Along the line, the Aqueduct was shut down from August 20 to December 7; High bridge blow-off closed on July 2, however Old Croton Aqueduct delivered water to Manhattan for the rest of the year. The first six months of the year, aqueduct used solely to supply water to several up-state communities. DWSGE *Annual Report* (1957): 45.

181 DEP Archives Box 3070, Folder 18. After April 8, 1958, the Old Croton Aqueduct was used solely to provide surplus water to upstate communities with surplus flow wasted into Harlem River through the Blow-off at High Bridge. 1958 *Annual Report* of the DWSGE: 45. As of December 2, 1958, no water from the Old Croton Aqueduct is delivered in Manhattan (end at blow-off at the Bronx end of Highbridge).

182 DEP Archives Box 3370, Folder 18.

183 DEP Archives Box 3063, Folder 14.

184 "River Landmarks to be Park Units: Plan Board Transfers Span and Tower at High Bridge From Water Department," *The New York Times,* January 20, 1955.

185 DEP Archives, Box 1353, Folder 9 (High Bridge Reconstruction, 1931-34).

186 Letter to James Dawson, Park Director, Department of Parks from Patrick Quilty, Commissioner, Bureau of Water Supply, October 30, 1941. DEP Archives, Box 1240, Folder 15.

187 "Boys Stone Boat, Hurt Sight Seers: 4 on Excursion Craft Hit as Youths Hurl Objects from High Bridge in Bronx." *The New York Times*, April 21, 1958.

188 DEP Archives Box 3064, Folder 3.

189 Anecdotal knowledge regarding High Bridge possibly being opened to pedestrian traffic during the 1960s was provided by NYC Department of Parks and Recreation staff.

190 Art Commission Submission 12817 Series 1273-Q Certificate 12817.

191 Will Lissner, "Trail to Run Along Croton Aqueduct; History of Aqueduct," *The New York Times*, September 25, 1966; David Bird, "A 32-Mile-Long Swath of Green From the Country to the City," *The New York Times*, October 27, 1968, Resorts and Travel Section.

4. Archaeological Evaluation

Phase IA Archaeological Documentary Study – Rehabilitation of the High Bridge in the Boroughs of Manhattan and The Bronx, New York by Historical Perspectives, Inc., April, 2011

PHASE IA ARCHAEOLOGICAL DOCUMENTARY STUDY

REHABILITATION OF THE HIGH BRIDGE IN THE BOROUGHS OF MANHATTAN AND THE BRONX, NEW YORK

CITY OF NEW YORK, DEPARTMENT OF PARKS & RECREATION

PHASE IA ARCHAEOLOGICAL DOCUMENTARY STUDY REPORT

REHABILITATION OF THE HIGH BRIDGE
IN THE BOROUGHS OF MANHATTAN AND THE BRONX, NEW YORK

CITY OF NEW YORK, DEPARTMENT OF PARKS & RECREATION

Prepared for:

Li/Saltzman Architects, PC
62 White Street
New York, NY 10013-3593

Prepared by:

Historical Perspectives, Inc.
P.O. Box 3037
Westport, CT 06880

Authors:

Faline Schneiderman-Fox, RPA
Julie Abell Horn, RPA

April 2011

TABLE OF CONTENTS

EXECUTIVE SUMMARY
I. INTRODUCTION....1
II. STATEMENT OF SIGNIFICANCE....1
III. RESEARCH DESIGN AND METHODOLOGY....2
IV. RESULTS OF RESEARCH....3
Manhattan APE....3
Bronx APE....7
High Bridge APE....10
V. ARCHAEOLOGICAL POTENTIAL....11
Manhattan APE....11
Bronx APE....11
High Bridge APE....12
VI. CONCLUSIONS AND RECOMMENDATIONS....12
BIBLIOGRAPHY....13
FIGURES
PHOTOGRAPHS
APPENDIX A: High Bridge historic plans

FIGURES

1. U.S.G.S. Topographic Map: Central Park, NY Quadrangles.
2. Manhattan APE and Photograph Key on *Insurance Maps of the City of New York* (Sanborn 2008).
3. Bronx APE and Photograph Key on *Insurance Maps of the City of New York* (Sanborn 2008).
4. High Bridge Existing Conditions (Baker Engineering 2006).
5. *New York City Soils Reconnaissance* (U.S.D.A. 2005).
6. *Topographical Map of the City and Country of New York, and the Adjacent Country* (Colton 1836).
7. *Map of Westchester County, New York* (Sidney and Neff 1851).
8. *New York City and Manhattan Island* (U.S.C.S. 1854-5).
9. *Map of Lands in the County of Westchester Belonging to Richard F. Carman, John Lowery, and Archibald H. Lowery* (Nicholson 1857).
10. *High Bridge During Construction of the Large Main: Viewed from the New York Side Looking Northeast* (top) *and Viewed From the West Gate House Looking East* (bottom) (ca. 1860-1862, reproduced in HAER-NY- 119).
11. Two images of High Bridge During Construction of the Large Main (ca. 1860-1862). Top image from New York Public Library, bottom image from Bone (2006).
12. *Plan of New York City, from the Battery to Spuyten Duyvil Creek* (Harrison 1867).
13. *Atlas of New York and Vicinity* (Beers 1868).
14. *High Bridge and High Service Works & Reservoir* (1871).
15. *Topographical map made from surveys by the commissioners of the Department of Public Parks of the city of New York...* (Grant 1874).
16. *Atlas of the city of New York: Borough of Manhattan* (Bromley 1879a).
17. *Atlas of the 23rd Ward, City of New York* (Bromley 1879b).
18. *Atlas of the City of New York* (Robinson 1885).
19. *Insurance Maps of the City of New York* (Sanborn 1891).
20. *Maps or plans and profiles, with field notes and explanatory remarks...* (Topographical Bureau 1895).
21. *Insurance Maps of the City of New York* (Sanborn 1900).
22. *High Bridge, New York City* (Detroit Publishing Company 1900).
23. *Insurance Maps of the City of New York* (Sanborn 1913).
24. *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans* (Bromley 1923).
25. Reopening of High Bridge for Pedestrian Traffic (1928).
26. High Bridge [Spanning the Harlem River, and connecting the Bronx at about 170th Street to the Manhattan Highbridge Park at 174th Street] (Sperr 1940).
27. *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans* (Bromley 1942).
28. *Insurance Maps of the City of New York* (Sanborn 1951).

PHOTOGRAPHS

Locations shown on Figures 2 and 3

1. Manhattan terminus of High Bridge, with Harlem River Drive and Harlem River at base of slope. View looking northeast from south side of APE.

2. Manhattan terminus of High Bridge, with Harlem River Drive and Harlem River at base of slope. View looking east from north side of APE.

3. Manhattan terminus showing north side of bridge with exposed bedrock and a level area with low cement walls and fencing. Note bricks and architectural debris on ground surface. View looking northwest from bridge.

4. Manhattan terminus showing detail of an arch supporting the Harlem River Drive. View looking east from bridge approach on north side of APE.

5. Manhattan terminus showing area south of the bridge touchdown with a set of stairs that originate at the paved terrace and extend downward into another relatively level area now in the woods. View looking southeast from bridge touchdown.

6. Manhattan terminus showing Gate House and approach to bridge. View looking west from bridge.

7. Manhattan terminus showing detail of Gate House. View looking northeast from bridge approach.

8. High Bridge and Manhattan terminus showing the area east of the Gate House including a steep incline with exposed bedrock that rises up to Highbridge Tower and a recreation area with a pool (formerly a reservoir for the OCA). View looking west from bridge.

9. High Bridge with Bronx APE in background. View looking east from bridge.

10. Bronx terminus showing ashlar block stair street immediately to the south of the bridge touchdown. View looking southeast from bridge.

11. Detail of ashlar stair street south of Bronx touchdown. Note stone wall marking southern edge of property. View looking south from bridge.

12. Bronx terminus showing wooded and brushy slope on north side of APE in background. View looking east from bridge.

13. Bronx terminus showing detail of wooded and brushy slope on north side of APE. View looking southwest from bridge approach.

14. Bronx terminus showing an alignment of stones protruding from the dirt amidst the brush on the north side of the APE, suggesting either a crude retaining wall or prior structure once stood in this location. View looking west from bridge approach.

15. Bronx APE showing detail of park on south side of bridge. The foundation represents remains of the former office building that was once in this location. View looking southeast.

16. Bronx APE showing additional detail of park on south side of bridge. The foundation represents remains of the former office building that was once in this location. View looking southwest.

MANAGEMENT SUMMARY

SHPO Project Review Number (if available):

Involved State and Federal Agencies:

Phase of Survey: **Phase IA Archaeological Documentary Study**

Location Information
- Location: **High Bridge spans the Harlem River between Manhattan and the Bronx. The Manhattan touchdown APE includes Block 2106, Lot 1; the Bronx touchdown APE includes Block 2533, Lots 22, 107, and 111.**
- Minor Civil Division: **06101, Manhattan and 00501, Bronx**
- County: **New York and Bronx**

Survey Area
- Length: **varies**
- Width: **varies**
- Number of Acres Surveyed: **ca. 1**

USGS 7.5 Minute Quadrangle Map: **Central Park**

Archaeological Survey Overview
- Number & Interval of Shovel Tests: **N/A**
- Number & Size of Units: **N/A**
- Width of Plowed Strips: **N/A**
- Surface Survey Transect Interval: **N/A, urban area**

Results of Archaeological Survey
- Number & name of precontact sites identified: **Possibly NYSM 4066**
- Number & name of historic sites identified: **None**
- Number & name of sites recommended for Phase II/Avoidance: **None**

Report Authors(s): **Faline Schneiderman-Fox, RPA and Julie Abell Horn, RPA, Historical Perspectives, Inc.**

Date of Report: **April 2011**

EXECUTIVE SUMMARY

The proposed New York City Department of Parks & Recreation's proposed renovation of High Bridge for pedestrian passage over the Harlem River between Manhattan and the Bronx requires environmental review. As part of the environmental review process, a Phase IA Archaeological Documentary Study has been prepared by Historical Perspectives, Inc. (HPI) for Li/Saltzman Architects. The specific locations of ground disturbance by proposed upgrades at two ramp pier locations near existing touchdowns of the bridge, and where scaffolding will be temporarily installed for the repair of the masonry surfaces define the Area of Potential Effect (APE); HPI's report addresses the archaeological sensitivity of the APE. Also included in the APE are portions of the historically significant High Bridge and the Old Croton Aqueduct (OCA), which it carries between the two boroughs, and which would be modified to accommodate pedestrian access.

The historically significant High Bridge is a designated New York City Landmark and is listed on the State and National Register (S/NR) of Historic Places. The entire Old Croton Aqueduct (OCA) system, of which High Bridge is a component, also maintains S/NR designation. It is also a National Historic Civil Engineering Landmark, as well as a National Historic Landmark. High Bridge, being a part of the OCA system, maintains these same National designations. Historic American Engineering Record (HAER) recordation of High Bridge has been completed.

The preliminary assessment of archaeological potential for the High Bridge APE suggests that neither the Manhattan nor the Bronx portions of the project site have the potential to contain precontact resources due to the naturally steep slope and the extent of historical disturbance. The construction of High Bridge coupled with other 19th and 20th century improvements to the project site would negate the possibility of encountering any intact precontact deposits.

With regard to historical archaeological resource potential, map and atlas research to date suggests that the Manhattan project site APE may be potentially sensitive for the footprint of a former Pump House associated with the Croton water distribution system. The Pump House once stood northwest of the High Bridge Gate House, and there is an extant retaining wall immediately north of the Gate House. The Bronx project site may be archaeologically sensitive for the remains of a mid-19th century dwelling that once stood northeast of the Gate House, although imprecise mapping may have erroneously placed the dwelling in the APE.

For those portions of the APE that are found to be potentially sensitive for archaeological resources, but would not undergo any subsurface disturbance, no archaeological testing would be warranted. However, if future plans are revised to entail subsurface disturbance to these sensitive areas, then testing would be recommended.

High Bridge and the OCA are of industrial archaeological significance; the Historic American Engineering Record (HAER) for both resources is recognition of this status. Although the HAER reports are at the Library of Congress, they were filed in 1984 and are more than 25 years old. An updated photographic record to current HAER standards of both High Bridge and OCA features prior to any proposed changes is recommended. HPI will assist in documentation with the industrial archaeological component as requested.

I. INTRODUCTION

The New York City Department of Parks & Recreation's proposed renovation of High Bridge for pedestrian passage over the Harlem River between Manhattan and the Bronx requires environmental review. As part of the environmental review process, a Phase IA Archaeological Documentary Study has been prepared by Historical Perspectives, Inc. (HPI) for Li/Saltzman Architects. The specific locations of disturbance to the ground surface by various activities related to improvements to High Bridge define the Area of Potential Effect (APE); HPI's report addresses the archaeological sensitivity of the APE. Also included in the APE are portions of the historically significant High Bridge and the Old Croton Aqueduct (OCA), which it carries between the two boroughs, and which would be modified to accommodate pedestrian access.

II. STATEMENT OF SIGNIFICANCE

The historically significant High Bridge over the Harlem River is New York City's oldest extant bridge, and was designated a New York City Landmark in 1970 (Site No. LP-0639). The nearby Old Croton Aqueduct (OCA) Water Tower in Highbridge Park was designated a City Landmark in 1970 (Site No. LP-0319). Both were listed on the State and National Register of Historic Places (S/NR) in 1972 (Site No. 72001560). The entire Old Croton Aqueduct (OCA) system, of which High Bridge is a component, was listed on the S/NR in 1974 (Site No. 74001324), and was designated as a National Historic Civil Engineering Landmark (NHCEL) by the American Society of Civil Engineers in 1975. The OCA was also designated as a National Historic Landmark (NHL) in 1992. High Bridge, being a part of the OCA system, maintains these same National designations. Historic American Engineering Record (HAER) recordation of High Bridge and the OCA was completed in 1984 (HAER NY-119 and HAER NY-120).

High Bridge was constructed between 1839 and 1848 as part of the original Croton Aqueduct System, now referred to as the OCA. Plans for an aqueduct into Manhattan from points north were proposed from 1833 onward, with construction commencing in 1837. Originally designed by Major David Douglass, who proposed a horseshoe shaped tunnel to carry water to the City, the design was later modified by engineer John Bloomfield Jervis who was hired to replace Douglass after he had been fired. As per the 1984 HAER documentation of the OCA, and, more specifically, the original engineering drawings, the aqueduct was built as a brick and mortar lined tunnel with stones and mortar along the exterior sides. Much of the aqueduct was supported above surrounding grade by a stone pediment and then backfilled with soil and reinforced with cement bracing. This ensured support of the conduit, and helped to prevent degradation.

When planned, the OCA was to be carried over the Harlem River in "two three feet pipes at present…[in the future] they are to be taken up and replaced by four feet pipes" (The Morning Herald, July 18, 1839). The High Bridge was designed to carry the OCA across the river, and was originally built with fifteen arches, eight with an eighty foot span, and seven with a fifty foot span (Ibid). In 1861-1862, a 90-inch main was installed between the original two three-foot pipes to increase water flow to Manhattan. However, even with the increased capacity, the OCA soon proved inadequate for the City's fast-growing population, and thus the New Croton Aqueduct (NCA) was constructed in the 1890s. The mains traversing High Bridge continued to carry a reduced water flow to Manhattan until 1955, supplementing water from the NCA (HAER 1984).

The OCA was considered an important engineering feat in the mid 19th century, serving internationally as a model for urban water supply. Its significance has been recognized through its multiple historic designations. The NHL nomination form for the OCA reports:

> Constructed between 1837 and 1842, this aqueduct provided New York City with its first planned water supply system and served as a model for other cities. The eight-and-one-half foot tall, masonry-lined conduit ran 40 miles through undulating topography to central Manhattan; in a few places it is tunneled through solid rock or carried across valleys on bridges and berms, yet most of the aqueduct lies on a stone foundation immediately below ground (NHL 1992).

Extensive documentation pertaining to High Bridge and the OCA's planning, construction, use, and discontinuation of use are provided in the NR and NHL Registration Forms prepared in conjunction with their historical designations. These documents, along with an extensive collection of original engineering drawings and a detailed construction history prepared for HAER documentation of the overall OCA and, more specifically, High Bridge, provide a broad diversity of information on these historically significant structures.

III. RESEARCH DESIGN AND METHODOLOGY

This Phase IA Archaeological Documentary Study is designed to satisfy the requirements of both State Environmental Quality Review (SEQR) and City Environmental Quality Review (CEQR), and to comply with the standards of the New York State Office of Parks, Recreation and Historic Preservation (NYSOPRHP) and the New York City Landmarks Preservation Commission (LPC) (New York Archaeological Council 1994, NYSOPRHP 2005; LPC 2002; CEQR 2001). Where guidelines for the archaeological evaluation and report format of the LPC and the NYSOPRHP varied, those of the LPC, which specifically address New York City conditions and resources, took precedent.

This study specifically addresses those land areas within the proposed project site that will be subject to direct subsurface disturbance activities, which define the APE (see Figures 2 and 3). The Manhattan APE for the proposed ramp pier (Ramp Pier) includes the land approximately 100 feet to the west of the extant Gate House, and approximately 35 feet to the north and south of the existing bridge fascia (Figure 2). East of the proposed Ramp Pier, the APE is 25 feet on either side of the north and south fascia of the bridge where scaffolding would be erected to allow for repair of masonry surfaces (Figure 2). This temporary scaffolding would have timber mat foundations that would not penetrate the ground by more than two feet. Upon completion of repair work, the ground will be restored. Where the bridge crosses above extant roads, temporary lift equipment would be placed at grade rather than installing scaffolding. The staging area for proposed work would be within the plaza to the west of the extant Gate House on previously graded and paved land, and is not part of the archaeological APE as there is no potential subsurface impact.

The Bronx Ramp Pier APE includes the land east of the extant Gate House to the western edge of University Avenue, and approximately 35 feet to the north and the south of the existing bridge fascia (Figure 3). West of the proposed Ramp Pier, the APE is 25 feet wide on either side of the north and south fascia of the bridge where temporary scaffolding would be erected to allow for the repair of masonry surfaces (Figure 3). Impacts would be no more than two feet below grade for the timber mat foundations. Where the bridge crosses above the Major Deegan Expressway, the railroad right-of-way, and local streets, work in these areas would be limited to lift equipment for access to the sides of the bridge. The staging area for proposed work would be within the plaza to the east of the extant Gate House on previously graded and paved land, and is not part of the archaeological APE as there is no potential subsurface impact.

In addition to the east and west Ramp Pier and scaffolding locations, potential impacts to High Bridge and the historically significant OCA within High Bridge are also addressed.

Sufficient information was gathered to assess the subsurface disturbance record of the APE, both horizontally and vertically, and to establish the potential for precontact period and historical archaeological resources, as well as industrial archaeological resources. This was accomplished by undertaking an intensive cartographic analysis of the project site through time in order to identify areas of sensitivity as well as areas unlikely to produce archaeological materials due to prior disturbance. At the High Bridge APE, disturbances were caused by bridge construction, excavations for underground utilities, extensive landscape manipulation, and several episodes of bridge, aqueduct, and park improvements.

Review of Primary and Secondary Sources

Primary and secondary source material was researched in order to document the prior usage of the project site. These resources included pertinent archaeological reports as well as local and regional source material for data on prehistoric and historical settlements, and manuscripts and newspaper articles held by the New York Public Library, the New-York Historical Society, the New York City Municipal Archives and various online archival sites including the Library of Congress American Memory collection, and the New York Public Library Digital Image collection. Previously completed archaeological assessments of nearby locations were reviewed, and work efforts completed for those reports were not duplicated.

Of note, a number of archival resources normally consulted for a Phase IA Archaeological Documentary Study in New York City were not used, because either they were not relevant or did not include coverage of High Bridge. Specifically, because the project site has been municipally owned since construction of High Bridge in the 1830s, no deeds were reviewed. Additionally, the few Department of Buildings records on file for the APE were not deemed useful. Census and city directory data also were not pertinent due to the inability to precisely locate any individuals within the APE and its vicinity during the 19th century using these sources.

Cartographic Analysis

Historical maps and atlases were obtained from the Map Division of the New York Public Library, the New York Historical Society, the Manhattan Borough President's Office, and various online sources including the New York Public Library, Digital Images collection, DavidRumsey.com, and the Perry-Castañeda Library Map Collection. These were compared for early and later land use, topography, historical events, and documented subsurface disturbance episodes. Early maps helped to provide an account of land-use modifications and episodes of construction over the course of the last two centuries.

Late 19th and 20th century atlases and Sanborn Fire Insurance Maps were reviewed to establish construction episodes, building locations in relation to the APE, and the presence of basements, which are indicators of subsurface disturbance. Cartographic comparisons were critical in demonstrating site-use changes over the last 150 years.

Site Review

A walkover of the High Bridge APE and a photographic record of the current conditions were completed on March 31, 2010. At the time, plants were defoliated and visibility was excellent. Anomalies and areas of obvious ground disturbance were photographed and noted on the site sensitivity map.

IV. RESULTS OF RESEARCH

Manhattan APE

Geological Conditions: The prehistory and history of Manhattan was in part shaped by the topography, ecology, and economic conditions that prevailed at various times. Understanding the city's geologic history aids in understanding the land-use history. During the Pleistocene period, ice advanced in North America four times. In the last 50,000 years, the Wisconsonian period, ice was 1,000 feet thick over Manhattan. Gravel and boulders deposited at the ice sheet's melting margin formed Long Island about 15,000 years ago (Kieran 1982:26). Briefly, Manhattan was largely covered by a glacial lake. Glacial Lake Flushing occupied broad, low-lying areas when deglaciation of the region produced vast volumes of meltwater. Higher elevations of Manhattan may have been marginal to this lake (Church and Rutsch 1984:6). By 12,000 years ago the lake drained and sea levels have gradually risen as glaciers retreated.

The project area is within the embayed section of the Coastal Plain which extends along the Atlantic Coast and ranges from 100 to 200 miles wide. The Manhattan prong, which includes southwestern Connecticut, Westchester

County and New York City, is a small eastern projection of the New England uplands, characterized by 360 million year old highly metamorphosed bedrock (Schuberth 1968:11). The Manhattan ridge generally rises in elevation toward the north, and sinks toward the south.

The prevalent gneissoid formation is known as Hudson River metamorphosed rock. The city is characterized by a group of gneissoid islands, separated from each other by depressions which are slightly elevated above tide and filled with drift and alluvium. Historical development has altered many of the natural topographic features that once characterized Manhattan (Gratacap 1909:5). Soil within Manhattan is mostly glacial till, clay, sand, gravel, mud, and assorted debris (Kieran 1982:24). The groundwater level fluctuates with tidal variations in the river.

Soils: The USDA soil survey for New York City (Figure 5) indicates that the Manhattan APE falls within an area mapped as "Chatfield-Charlton complex, 15 to 50 percent slopes." These soils are described as:

> Moderately steep to very steep areas of bedrock controlled hills and ridges modified by glacial action that are relatively undisturbed and mostly wooded; a mixture of moderately deep and deep gneissic till soils; located in Manhattan and the Bronx (USDA 2005:17).

Properties of the two soil series are described in the table below.

Name	Soil Horizon Depth	Color	Texture, Inclusions	Slope %	Drainage	Landform
Chatfield series	A: 0-2 in AB: 2-8 in Bw: 8-25 in 2R: 25 in	VDkGryBrn DkBrn Brn	Lo Lo GrlSiLo Bedrock	15-50	Well	Bedrock controlled hills and ridges
Charlton series	A1: 0-5 in A2: 5-10 in AB: 10-14 in Bw1: 14-24 in Bw2: 24-33 in C1: 33-45 in C2: 45-72 in	VDkGryBrn DkBrn DkYelBrn StrBrn DkYelBrn YelBrn LtOlBrn	Lo Lo Lo SaLo SaLo StoLoSa StoLoSa	15-50	Well	Till plains and hills

Key: Color: V-Very, Dk-Dark, Gry-Gray, Brn-Brown, Yel-Yellow, Str-Strong, Lt-Light, Ol-Olive
Soils: Lo-Loam, Sa-Sand, Si-Silt
Other: Grl-Gravel, Sto-Stony

Current Conditions: The Ramp Pier APE in Manhattan is predominantly situated on a slope along the Harlem River, while the scaffolding APE includes both the slope down to the river, and manmade land to the east (Figure 2). The terminus of the bridge is on a terrace elevated high above the Harlem River Drive. To the north and south of the bridge, the APE is steeply sloped with mature trees and brush extending down to the Highbridge Interchange, which linked the George Washington Bridge, the Cross Bronx Expressway, and the Harlem River Drive (Photographs 1-2). Immediately to the north of the bridge is exposed bedrock, as well as a level area with low cement retaining walls and fencing (Photograph 3). Bricks and architectural debris are strewn across the surface in this area. Below the slope is the Harlem River Drive (Photograph 4). South of the bridge touchdown is a stepped stone buttress that originates at the paved terrace and extends downward into another relatively level area now in the woods (Photograph 5). A Gate House is visible at the Manhattan touchdown, and the area to the east is paved (Photographs 6, 7). The OCA runs through the Gate House, and veers to the southwest, protected by a retaining wall that serves to create the paved terrace. Further west of the Gate House is a steep incline with exposed bedrock that rises up to Highbridge Tower and a recreation area with a pool (formerly a reservoir for the OCA) (Photograph 8).

Prior to construction of the OCA, the APE was steeply sloped down to the Harlem River. In the 19th century, fill was added along the shoreline to the east of the Ramp Pier APE, extending the shore eastward further into the Harlem River, and both a highway (the Harlem River Drive) and an access ramp (Highbridge Interchange) were constructed beneath the westernmost piers of High Bridge.

Precontact Use: Research conducted at the NYSOPRHP, the LPC, and the library of HPI revealed that there are a number of archaeological resources mapped within a one mile radius of the Manhattan APE, including a village site mapped by the NYSOPRHP as within a broad area along the Harlem River from 169th to 185th Avenues. These precontact sites are detailed in the table below.

Site Number	Site Description	Location	Time Period
NYSM#4065	Village	West 155th Street and the Harlem River	Unknown precontact
NYSN#4066	Village	Broad area from 169th to 185th Streets, from the Harlem River west to Broadway	Unknown precontact
NYSM#4068	Village	Fort George area	Unknown precontact
NYSM#8370	Camp	Fort George area	Unknown precontact

Based on proximity to the archaeological sites along the Harlem River on the Manhattan shore, the NYSOPRHP GIS database (which indicates sensitivity for areas within one mile of known resources) indicates that the Manhattan APE is within an area of archaeological sensitivity.

Historical Use: Although Dutch trading expeditions had already been visiting the Hudson River for many years, the first settlement in New Netherland was not undertaken until 1624, under the authority of the Dutch West India Company (Brodhead 1853:150-151). New Amsterdam had been settled for 13 years before the first attempt was made to establish a village at the northern end of the island. Jan Dyckman settled the area in 1661. Roger Morris - whose home was temporarily used as a headquarters by General Washington during the American Revolution in the fall of 1776 and during the Battle of Harlem Heights - eventually owned the land in the vicinity of High Bridge, but lost it after the American Revolution, being a Tory. His estate and surrounding land was conveyed to Stephen Jumel in 1810 (Riker 1904). Although the surrounding area saw extensive occupation and military action during the American Revolution due to the strategic importance of northern Manhattan, no maps or military surveys from that period depict structures or earthworks in proximity to the APE (Stevens 1900; Johnston 1897).

During the 1860s, dredging for the Harlem River Canal generated tons of fill material when much of the river bottom was removed to create a deep channel for easier shipping (Murphy 1860). In the early 19th century, the majority of Manhattan north of 125th Street was a mix of residential, agricultural, and industrial use, while by the late 19th century it was shown as residential, commercial, and unimproved land. Northern Manhattan, or what is now considered Washington Heights, was dotted with grand family estates. Presumably agriculture had largely been abandoned in this area by that time (NYCLPC Neighborhood Maps 1983: 1815-1829, 1855-1879).

Historical Land Use in APE and immediate vicinity: The 1781 Taylor Skinner map shows the Manhattan APE at the top of a bluff and devoid of any structures, whereas the Randel 1811 map just shows a vacant shoreline. Several small farms and estates dotted the northern portion of Manhattan during the early 19th century, with the project APE falling in the Stephen Jumel lot (Sackersdorff 1868 [depicting 1815]). No buildings or roads were mapped near the project site until after the construction of the OCA.

When a survey of the Harlem River shoreline was completed in 1835, it also depicted the Manhattan APE as a vacant bluff along the western side of the river High Bridge had not yet been completed (M'Neill 1835). By 1836, the route of the OCA was mapped crossing the Harlem River, but since the bridge was still not yet completed, it was not portrayed on the map (Colton 1836, Figure 6). The 1837 USCS survey failed to show the aqueduct at all, either crossing the river or along the shoreline (USCS 1837).

In 1849, High Bridge was mapped crossing the Harlem River, and the Manhattan APE was portrayed at the top of a bluff and a slope down to the river, and devoid of structures (Sidney 1849). When Dripps created his map of

Manhattan in 1851, he depicted several structures around the Manhattan touchdown of the bridge, but details of their location in relation to the current APE are difficult to discern (Dripps 1851). To the northwest, and far outside of the APE, stood a hotel on what was formerly the Jumel landholding.

By 1855, a coastal survey showed two Gate Houses present; one at either end of the bridge (USCS 1854-55, Figure 8). Because of the dark shading on the map directly along the river's edge to indicate a steep slope, it is unclear if any other structures are present in the Manhattan APE. A road had been laid out east-west across upper Manhattan, terminating just south of the Gate House. In 1857 the APE appeared to only contain the extant Gate House, and a road was clearly laid out to the south of the Gate House and above the route of the OCA as it meandered along the top of the bluff heading south to lower Manhattan (USCS 1857). Two years later, the Gate House was clearly mapped in the APE (Nicholson 1857, Figure 9).

When a new 90.5" pipe over the two original OCA pipes in High Bridge was constructed in 1861-1862 so as to increase water capacity, it became necessary to provide a mechanism to increase water pressure in northern Manhattan where elevations were higher than the pipes coming over the Harlem River. To address this, a reservoir was built to the west of the Gate House within what is now Highbridge Park, and water was mechanically pumped from it into an elevated storage tank at the top of a new water tower. A contract was issued for the construction of a reservoir, wharf, and coal house in 1866, and a pump and boiler house in 1867. Construction of the High Service Tower and Reservoir was completed in the early 1870s, and the tower remains on the landscape today. The coal house and wharf were built to the east of the APE on the Harlem River, with coal delivered through a tunnel under what is now Harlem River Drive, and coal conveyor built immediately north of the Gate House within the APE. Coal was hoisted up the conveyor to service a pump house or pumping station (also called an engine and boiler house) that stood to the immediate northwest of the Gate House also in the APE (Wegmann 1896; Bone 2006; Sanborn 1893, 1900 [see Figure 22], 1913 [see Figure 24]; City of New York Department of Plant and Structures 1926, see Appendix A of this report)

By 1867, both the High Service Tower and the Reservoir were mapped even though they were still under construction, but none of the other features were (Harrison 1867, Figure 12). An 1871 image of the site shows the new High Service Tower, Reservoir, coal house, wharf, and coal conveyor as they appeared upon completion of construction (Figure 14). By 1874, the tower, reservoir, and engine house were depicted cartographically, and the site appears unchanged in 1879 and 1885 (Grant 1874 [Figure 15], Bromley 1879a [Figure 16]; Robinson 1885 [Figure 18]). A ca.1900 photograph of the Manhattan touchdown of High Bridge shows the pump house to be a two-story structure with a basement and chimney stack that architecturally mimics the more ornate High Service Tower to the west (Figure 22).

Late 19th and early 20th maps and atlases show variations on the descriptive name of the pump house (pumping station, boiler house, engine house), and the newly created Harlem River Speedway, where horses and carriages were raced, on manmade land along the Harlem River shoreline (Sanborn 1893, 1900 [Figure 22], 1913 [Figure 23]; Bromley 1916). Eventually, this became the Harlem River Drive. In 1926, long after the New Croton Aqueduct had been put into service, the coal conveyor and tower were to be removed, and the coaling tunnel that was out of the APE was to be sealed at both ends. Simultaneously, the 36" siphon conduits in the Gate House were to be discontinued, and the 6" pipe service lines were to be removed (City of New York Department of Plants and Structures 1926; see Appendix A of this report). A 1934 topographic map of Highbridge Park shows the placement of all of the structures and the surrounding topography at the time. While the coal conveyor and tower had been removed, the pump house was still standing in the APE (City of NY Dept of Parks 1934; see Appendix A of this report). Most of the land in the APE was either steeply sloped, or developed with structures and features affiliated with the OCA and High Bridge.

The APE was again modified in the 1950s with the construction of the Trans-Manhattan Expressway that opened to traffic in 1962 (Sanborn 1936, 1951, 2008; compare Figures 2 and 28). More specifically, construction of the Highbridge Interchange, which linked the George Washington Bridge, the Cross Bronx Expressway, and the Harlem River Drive, caused extensive changes to the landscape of Highbridge Park. An access ramp to the Harlem River Drive was constructed to the north and east of the Manhattan Ramp Pier APE, running beneath High Bridge.

Despite the fact that the pump house is portrayed on insurance maps as late as 2008, the structure is no longer standing in the APE (Sanborn 2008, Figure 2; see Photograph 8)

Bronx APE:

Geological Conditions: The borough of the Bronx also lies within the Hudson Valley Region and is considered to be part of the New England Upland Physiographic Province, which is a northern extension of the Great Appalachian Valley (Schuberth 1968). Situated within the Manhattan Prong, the region has a landscape of rolling hills and valleys. Underlying bedrock include metamorphic rocks that resist erosion and thus make up the hills (Isachsen et al 1991).

During the most recent period of glacial activity, the Wisconsin episode, the Bronx was covered by ice. Following deglaciation, postglacial Lake Hudson covered much of the Hudson Valley below the Highlands including the project site. When it receded, smaller water courses were left, scouring the landscape into what it is today. The adjacent Harlem River, underlain by easily abraded Inwood Marble, was created through these actions. Although many fresh water tributaries once fed the Harlem River, it is essentially a tidal strait (Kieran 1982).

Soils: The USDA soil survey for New York City (Figure 5) indicates that the Bronx APE falls within an area mapped as "Pavement & buildings-Chatfield-Greenbelt complex, 15 to 50 percent slopes." These soils are described as:

> Moderately steep to very steep urbanized areas of bedrock controlled hills and ridges modified by glacial action, that have been substantially cut and filled, mostly for residential use; a mixture of moderately deep gneissic till soils and anthropogenic soils, with 50 to 80 percent impervious pavement and buildings covering the surface; located in Manhattan and the Bronx (USDA 2005:17).

Properties of the two soil series are described in the table below.

Name	Soil Horizon Depth	Color	Texture, Inclusions	Slope %	Drainage	Landform
Chatfield series	A: 0-2 in AB: 2-8 in Bw: 8-25 in 2R: 25 in	VDkGryBrn DkBrn Brn	Lo Lo GrlSiLo Bedrock	15-50	Well	Bedrock controlled hills and ridges
Greenbelt series	A: 0-3 in Bw: 3-13 in C: 13-57 in Ab: 57-58 in BwB: 58-65 in	Brn YelRd RdBrn DkBrn YelRd	Lo Lo GrlLo Lo Lo	15-50	Well	Anthropogenic urban fill plains

Key: Color: V-Very, Dk-Dark, Gry-Gray, Brn-Brown, Yel-Yellow, Rd-Red
Soils: Lo-Loam, Sa-Sand, Si-Silt
Other: Grl-Gravel

Current Conditions: The Bronx APE for archaeological resources includes the footprint for the Ramp Pier, which is situated on a slope at the base of a bluff that rises above the Harlem River, where a Gate House and park are located (Figure 3; Photograph 9). The APE for the scaffolding includes both the slope and the land to the west, exclusive of roadways and railroad right-of-way. Immediately to the south of the bridge touchdown is an ashlar block stair street that was constructed in the 19th century to allow access from the top of the bluff to Sedgwick Avenue (formerly Undercliff Avenue) below (Photograph 10). It appears that the terraces created by the zigzagging stair street were once landscaped, and a stone and cement wall demarcates the southern boundary of the planted area (Photograph 11). To the north of the touchdown is a wooded and brushy slope located below the park above

(Photographs 12 and 13). An alignment of stones protruding from the dirt amidst the brush suggests either a crude retaining wall or prior structure once stood in this location (Photograph 14).

A park surrounds the north, south, and east sides of the Gate House, and is tiered up to the level of University Avenue to the east (Photograph 15). Within the park to the immediate south of the Gate House are the remains of a foundation for an office building that stood on the site in the late 19th and early 20th centuries (Photographs 15, 16).

Precontact Land Use: The presence of Native Americans in the Bronx for the Early Archaic through Late Woodland Periods has been documented, although some periods are more abundantly represented than others. Archaeologist Eugene Boesch undertook the task of creating a model of precontact land use in the Bronx based upon the knowledge of existing precontact sites and their topographic locations coupled with an understanding of the precontact environmental conditions (Boesch 1994). His generalized sensitivity map for the borough indicated that the current project site has a high sensitivity for precontact period resources (Ibid.). Boesch specifically called out the north to south extending ridge overlooking the Harlem River as an area that "may have been the location of numerous hunting camps" (Ibid.). However, it should be noted that Boesch's assessment was generalized, and was not intended to account for prior disturbance, which is essential to establish in order to determine if any potential archaeological resources may have retained their integrity.

Research conducted at the NYSOPRHP, the LPC, and the library of HPI revealed no archaeological resources specifically mapped within the Bronx APE, and no precontact sites recorded within a one mile radius of the project site in the Bronx, although the four precontact noted for the Manhattan APE have been recorded within a one mile radius in Manhattan. These sites are detailed in the table below.

Based on proximity to the archaeological sites along the Harlem River on the Manhattan shore, the NYSOPRHP GIS database (which indicates sensitivity for areas within one mile of known resources) indicates that the project site is within an area of archaeological sensitivity. Additionally, a Native American trail has been documented in the project site vicinity, along the approximate location of modern Jerome Avenue (Grumet 1981). Last, Boesch's study of the Bronx identifies the top of the ridgeline at the Bronx APE eastern terminus as within a moderately archaeologically sensitive area for precontact resources (Boesch 1994).

Historical Land Use: The Bronx APE vicinity falls within the original Fordham Manor grant, initially obtained by John Archer in the 1660s. Fordham Manor encompassed some 1,250 acres, extending from the Bronx River on the east to the Harlem River on the west, and roughly between present Kingsbridge on the north to the Manor of Morrisania on the south (about West 169th Street) (Scharf 1886). The lands of the manor including the project site were mortgaged by John Archer in 1676, and later passed to the Dutch Reformed Church. In 1683 the County of Westchester was formed, extending from Putnam County to the north, south to the Harlem and East Rivers. What is now the Borough of the Bronx, including the project site, was included in this tract (Jenkins 1912:1). In 1759, local landowner Lewis Morris purchased a large portion of the former Fordham Manor, including the project site, but through a series of transactions the land ended up back with the Archer family in 1766. In 1788, Westchester County was reorganized, and the Town of Westchester expanded westward to include the lands of the former Manors of Fordham, Morrisania, and the settlement of West Farms, basically all of the Bronx between the Bronx and Harlem Rivers. The Town of Westchester, along with all lands in the Bronx west of the Bronx River, was annexed by New York City in 1874 and became part of the 24th Ward. In 1898 the Borough of the Bronx was formed (Jenkins 1912:7).

Historical Land Use in APE and immediate vicinity: Prior to construction of High Bridge in the Bronx, the area along what was then the Westchester County shoreline that would become the APE was devoid of any structures, as shown on the 1781 Taylor Skinner map. The nearest roadway was Macombs Dam Road, which ran along the ridgeline several blocks to the east, from Fordham near modern day University Heights to Macombs Dam Bridge. By at least the 1830s, the line of what is now known as Undercliff Avenue had been laid out west of the APE, as shown on the 1836 Colton map (Figure 6) and the 1837 U.S.C.S. map. Undercliff Avenue began at Macombs Dam Road and ran southwest along the shoreline, under the bluffs along the bank to the river's edge, just west of the APE. No buildings were mapped near the APE site until after the construction of the OCA.

As noted above, the OCA was built between 1837 and 1842. The land including the Bronx APE was acquired in 1837. When a survey of the Harlem River shoreline was completed in 1835, it depicted the Bronx APE as a vacant bluff along the eastern side of the river as the bridge had not yet been completed (Hall 1835). By 1836, the route of the OCA was mapped crossing the Harlem River, but since High Bridge was not yet completed, it was not portrayed on the map (Colton 1836, Figure 6). The 1837 USCS survey failed to show the aqueduct at all, either crossing the river or along the shoreline (USCS 1837). However, both the 1836 and 1837 maps did illustrate the route of Undercliff Avenue.

In maps made in 1849 and 1851 by Sidney and Neff, High Bridge was mapped crossing the Harlem River, and the route of the OCA was shown making a turn from High Bridge to the northeast. The 1849 map shows a structure on the northwest side of this angled turn, and the 1851 map shows a second structure on the southeast side of the turn. The 1851 map illustrates a hotel to the southeast of the APE, accessed from Undercliff Avenue to the west (Figure 7). It is unclear what the unmarked structures represent, and based on the scale of the mapping, whether they were even located within the APE. Review of slightly later maps indicates that there were no structures immediately adjacent to the OCA within the APE that might have corresponded to those shown on the Sidney and Neff maps. For example, by 1855, a coastal survey showed only the Gate House (within the line of the bridge, and not adjacent to it) and the hotel just off the APE (USCS 1854-55, Figure 8). In 1857 the APE appeared to only contain the Gate House; the hotel is not shown nearby, although few buildings were included on this map (USCS 1857). The same year, another mapmaker showed the Gate House clearly within the APE, the hotel was shown just outside the APE, and another unnamed stone structure was shown to the northeast of the APE, within the overall project site (Nicholson 1857, Figure 9). Thus, it is possible that the Sidney and Neff maps were showing structures further away from the APE, such as the hotel to the southeast, and/or the structure shown on the Nicholson map (which was shown on later maps and images to be a dwelling, as described below) but imprecisely located. There does not seem to be any evidence that there were additional structures within the APE during this period.

As noted above, in 1861-1862 a new 90-inch conduit was installed along the top of High Bridge, to increase the carrying capacity of the aqueduct. Construction of this new pipe was documented by a number of illustrations (Figures 10 and 11), some of which are included in the HAER documentation of the OCA. These lithographs, which generally showed the bridge looking east from the Manhattan side, also included some details for the Bronx APE. In particular, these images show that the building to the northeast of the APE within the overall project site was a two-story structure with a hipped roof, perched on the top of the ridgeline and oriented with its entrance to the southwest. Although none of the maps or images identify its occupants, because it was located on land owned by the city and used for OCA purposes, it is likely that the building was a house for OCA-related personnel.

Maps made during the 1860s and 1870s often did not show enough detail to confirm use of the Bronx APE (e.g. Beers 1868 [Figure 13], 1876, Viele 1874). The 1868 Beers map showed a long structure on the northeast side of the OCA where it meets High Bridge, but based on other maps, this unnamed building appears to have been located off the APE. For example, the 1874 Grant map (Figure 15) shows this building as a long structure just outside the APE and the 1879b Bromley map, also showing it just bordering the APE, attributes it to "Kart" (Figure 17). Both the 1874 and 1879b maps illustrate the Gate House at the end of High Bridge and the dwelling to the northeast of the APE, partially within the modern footprint of University Avenue. The hotel, shown to the southeast of the APE on earlier maps, is no longer depicted by the 1870s.

During the 1880s, there were a number of modifications made within the Bronx APE. The 1891 Sanborn map (Figure 19) shows that by this time, a two story stone office building had been constructed just south of the Gate House, and an extensive stair street had been constructed leading from the top of the bridge down to the base of the hill, accessing what is now known as Sedgwick Avenue. The steep area between the stairs and the bridge was landscaped. The 1891 Sanborn map also confirms that the dwelling shown to the northeast of the Bronx APE within the overall project site on earlier maps was two stories high with a front porch on the southwest and a one story rear extension on the back, or northeast (Figure 19). There were two outbuildings northeast of the dwelling, one of which was octagonal shaped and may have been a gazebo or tower. Additionally, a series of six small structures was shown within the line of what is now University Avenue to the east of the Bronx APE. The structure just outside the APE on the north was a one, two, and three story, large building attributed to "J. Kart." A walkway extended from the Gate House within the APE to this property. The 1893 Bromley map provided further details

about these buildings, showing that the Kart structure was a hotel. Interestingly, the Bromley map did not show any buildings within the modern line of University Avenue. The 1895 Topographic map showed some of the details from the other maps as well (Figure 20).

Maps made during the early 20th century show additional details about the Bronx APE, although few changes. The 1904 Bromley map and the 1909 Sanborn map both indicate similar conditions as their earlier editions, although the 1909 Sanborn map notes both the hotel and the structure to the northeast of the APE as dwellings, but indicates at least a part of the former hotel was vacant at this time). The dwelling is shown next to the hotel and not within the roadway anymore. It appears that the roadway was narrowed to accommodate the house.

By the publication of the 1923 Bromley map (Figure 24), both the former hotel and the dwelling described above had been demolished, and the area north and northeast of High Bridge was vacant. There was no change shown on the 1932 Bromley map update, although High Bridge itself had been reconstructed in the 1920s. Drawings from the bridge reconstruction show that the area north of High Bridge, including the location once containing the dwelling, was now noted as landscaped (City of New York Department of Plants and Structures 1926; see Appendix A of this report). The bridge reopened in 1928 (New York Times 10/30/1928, Figure 25). In 1931, reconstruction plans were made to upgrade the stairs adjacent to the Bronx APE with new treads, cleats, and hand rails (City of New York Department of Water Supply, Gas and Electricity 1931; see Appendix A of this report). In the 1930s, the Major Deegan Expressway (Route 87) was built beneath the eastern end of High Bridge in the Bronx, west of Undercliff Avenue. A photograph from 1940 shows the stair street with the office building at the top of the hill in the APE (Sperr 1940, Figure 26).

In 1941, the Carmelite Sisters Monastery, a brick two story complex, was built on the property just north of the APE, where the former Kart hotel once stood. The 1942 Bromley map (Figure 27) shows the building and the 1952 Sanborn map confirms that the monastery had been built in 1941. The area northeast of the APE was noted in 1952 as a park, and was separated from the monastery property and University Avenue by retaining walls.

Maps made during the remainder of the 20th century showed no change to the current configuration of the Bronx APE (Hyde 1969, Bromley 1978). By issuance of the 2008 Sanborn map (Figure 3), the office building south of the Gate House had been removed; today this area contains the former building's stone foundation walls. A renovation to the park portion northeast of the APE was completed in 2001.

High Bridge APE:

Plans for an aqueduct into Manhattan from points north were proposed from 1833 onward, with construction of the OCA dating between 1837 and 1842. Originally designed by Major David Douglass, it was later modified by engineer John Bloomfield Jervis who was hired to replace Douglass. When originally built, it was undecided if the aqueduct would pass over the Harlem River on a low bridge – over a relatively low embankment with one low arched passage for boats - or at grade level, crossing high above the river over a bridge of towering Roman arches (Bone 2006). The High Bridge, or grade option, was ultimately chosen and construction began in 1839; the bridge was ready for use in 1848, six years after the completion of the OCA. During the interim, the aqueduct was carried across the Harlem River via a pipe siphon on a low embankment (Ibid.). When completed, the OCA was carried across High Bridge in two 36" diameter iron pipes.

In 1859 plans were made to lay a new 90.5" pipe over the two original OCA pipes in High Bridge so as to increase water capacity (Bone 2006). Several historic images show this construction underway (Figures 10 and 11),with work completed between 1861-1862. At that time, the top of the bridge was covered with a masonry arch that served to both protect the piping beneath, and to provide a pedestrian surface. This increased the quantity of water that could pass over the bridge.

The OCA was considered an important engineering feat in the mid 19th century, serving internationally as a model for urban water supply. As previously stated, there is extensive documentation pertaining to High Bridge and the OCA's planning, construction, use, and discontinuation of use provided in the NR and NHL Registration Forms

prepared in conjunction with their historical designations. These documents, along with an extensive collection of original engineering drawings and a detailed construction history prepared for HAER documentation of the overall OCA and, more specifically, High Bridge, provide a broad diversity of information on these historically and industrially significant features.

In the 1920s High Bridge was reconstructed, with the most dramatic change being the replacement of the central spans with a single steel span. Piers 10 through 13 that stood in and adjacent to the Harlem River were removed to allow the passage of larger vessels (see Appendix A). Upon completion of the renovations, the bridge reopened in 1928 (New York Times 10/30/1928; Figure 25).

V. ARCHAEOLOGICAL POTENTIAL

Manhattan APE

As presently defined, the APE for the Manhattan Ramp Pier includes the area measuring approximately 100 feet to the west of the Gate House and 35 feet on either side of the bridge fascia, while the scaffolding APE extends out 25 feet from the bridge fascia above fast land to the east, exclusive of existing paved roads (Figure 2).

Based on the modifications to the landform to support High Bridge and the OCA on the western portion of the APE, and the steep topography and exposed bedrock on the northern and southern portions of the APE, precontact archaeological sensitivity is low. Although a NYSM precontact village site has been mapped broadly as overlapping the APE, the landform of the APE suggests that this would not have been a favorable location for a precontact village. It is probable that the site was located further inland, on more level terrain, and the mapping is imprecise.

Prior to construction of High Bridge and the OCA, there was no historical development within the APE. Potential historical archaeological resources associated with High Bridge and the OCA includes any remains of the former pump house/engine house that was located northwest of the Gate House, a retaining wall to the north, and the pipes and conduits of the OCA itself. The Scaffolding APE lacks archaeological potential as it extends across land that was extensively modified with the construction of the Harlem River Drive and an access ramp built as part of the Highbridge Interchange. These construction activities caused extensive changes to the predevelopment landscape of the APE, rendering it too disturbed to yield any potential intact resources.

Bronx APE

As presently defined, the APE for the Bronx Ramp Pier includes the area from the Gate House east to University Avenue and the area approximately 35 feet on either side of the bridge fascia for the area east of Sedgwick Avenue. To the east of this, the scaffolding APE extends out 25 feet from the bridge fascia west to the river, exclusive of roads and railroad right-of-ways (Figure 3).

As with the Manhattan Ramp Pier APE, based on modifications to the landform to support High Bridge, the OCA, and the former late 19th century office building and stair street, combined with the steep topography on the north and south sides of the bridge, precontact archaeological sensitivity within the APE is low.

Prior to construction of High Bridge and the OCA, there was no historical development within the APE. Potential historical archaeological resources in the Bronx APE include the pipes and conduits of the OCA itself. The visible foundation of the former office building (from ca. 1880s-late 20th century), located south of the Gate House, is preserved in the current parkland and is part of the historical OCA landscape, but is not assumed to have archaeological research potential given its late date (post-dating municipal sewer and water availability). Although just outside the present APE, any remains associated with a former 19th century dwelling located at the northeastern corner of the park within the overall project site (from ca. 1857-1923) would also be archaeologically sensitive, but no impacts are anticipated in this location. There is also the possibility that remains from possible unidentified structures shown on the 1851 Sidney map (Figure 7) located on the northwest and southeast side of the OCA alignment could be located with the Ramp Pier APE. However, the identity and precise location of these possible

structures could not be confirmed and it is equally possible that the map was in error and that the structures in question were located outside the APE and were imprecisely mapped.

High Bridge APE

Both High Bridge and the OCA have industrial archaeological significance in their own right. As noted above, High Bridge is New York City's oldest extant bridge. It has been listed as a New York City Landmark and on the S/NR. The entire OCA system, of which High Bridge is a component, also is listed on the S/NR and is a National Historic Civil Engineering Landmark (NHCEL), a NHL, and is nationally renowned by both engineers and laymen alike. High Bridge, being a part of the OCA system, maintains these same National designations.

Because of the industrial archaeological significance of the bridge and the OCA, HAER recordation was completed in 1984 (HAER NY-119 and HAER NY-120). Any potential changes to the structural or mechanical elements of either the bridge or the OCA would constitute an impact to the fabric of these features as they exist today.

VI. CONCLUSIONS AND RECOMMENDATIONS

HPI has determined that portions of the Manhattan and Bronx APEs may be archaeologically sensitive for resources associated with High Bridge and the OCA. The Manhattan Ramp Pier APE may be sensitive for historical resources identified northwest of the Gate House, and the Bronx Ramp Pier APE may be potentially sensitive for ca.1851 mapped historic dwellings – although the imprecise nature of the mapping makes it just as likely that these resources were outside of the APE. For those portions of the APE that are found to be potentially sensitive for archaeological resources, but would not undergo any subsurface disturbance, no archaeological testing would be warranted. However, if subsurface disturbance is anticipated in these sensitive locations, then testing would be recommended.

High Bridge and the OCA are of industrial archaeological significance; the Historic American Engineering Record (HAER) for both resources is recognition of this status. Although the HAER reports are at the Library of Congress, they were filed in 1984 and are more than 25 years old. An updated photographic record to current HAER standards of both High Bridge and OCA features prior to any proposed changes is recommended. HPI will assist in documentation with the industrial archaeological component as requested.

BIBLIOGRAPHY

Baker Engineering NY, Inc.
2006 *High Bridge, General Plan and Elevation*.

Beers, Frederick W.
1868 *Atlas of New York and Vicinity.* F. W. Beers and Company, New York.

1876 *Map of 23d Ward, New York City, from Official Records and Surveys, Compiled and Drawn by F.W. Beers*. J.B. Beers and Co., New York.

Boesch, Eugene J.
1994 *Archaeological Evaluation and Sensitivity Assessment of the Bronx, New York.* Prepared for the New York City Landmarks Preservation Commission.

Bone, Kevin, editor
2006 *Water-Works : the Architecture and Engineering of the New York City Water Supply*. Monacelli Press, New York.

Brodhead, John R.
1853 *History of the State of New York*. Harper and Brothers, New York.

Bromley, George W. and Walter S.
1879a *Atlas of the City of New York: Borough of Manhattan from actual surveys and official plans*. G.W. Bromley, Philadelphia.

1879b *Atlas of the 23rd Ward, City of New York.* G. W. and W. S. Bromley and Company, Philadelphia.

1882 *Atlas of the 23rd Ward, City of New York.* G. W. and W. S. Bromley and Company, Philadelphia.

1893 *Atlas of the City of New York, 23rd and 24th Wards.* G. W. Bromley and Company, Philadelphia.

1904 *Owners Names of the City of New York, Borough of the Bronx.* G. W. Bromley and Company, Philadelphia.

1923 *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans.* G. W. and W .S. Bromley and Company, Philadelphia.

1932 *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans.* 1923 edition corrected to 1932. G. W. and W .S. Bromley and Company, Philadelphia.

1942 *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans.* G. W. and W .S. Bromley and Company, Philadelphia.

1950 *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans.* 1942 edition corrected to 1950. G. W. and W .S. Bromley and Company, Philadelphia.

1955 *Manhattan Land book of the City of New York*. New York, G. W. Bromley.

1974 *Manhattan Land book of the City of New York*. New York, G. W. Bromley, 1970 [corrected to ca. 1974].

1978 *Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans.* 1923 edition, corrected to 1978. G. W. and W .S. Bromley and Company, Philadelphia.

Church, David E. and Edward S. Rutsch
1984 "Stage 1A Documentary Cultural Resources Survey for the 184 East 70th Street Proposed Construction Site, Borough of Manhattan, New York City." Historic Conservation and Interpretation, Inc. Prepared for Trafalgar House Real Estate, Inc., New York.

City Environmental Quality Review (CEQR)
2010 *City Environmental Quality Review Technical Manual*. City of New York, Mayor's Office of Environmental Coordination. May 2010.

City of New York Department of Plant and Structures
1926 *High Bridge Reconstruction over Harlem River.* City of New York Department of Plant and Structures, June 1, 1926.

Colton, J. H.
1836 *Topographical Map of the City and Country of New York, and the Adjacent Country.* David H. Burr. J.H. Colton and Company, New York.

Detroit Publishing Company
1900 *High Bridge, New York City*. Image 53644. Detroit Publishing Co., Detroit. On file at the Library of Congress Prints and Photographs Division, Washington, D.C.

Dripps, Matthew
1851 *City And County Of New - York North Of 50th St*. M. Dripps, New York.

Grant, William H.
1874 *Topographical map made from surveys by the commissioners of the Department of Public Parks of the City of New York of that part of Westchester County adjacent to the City and County of New York embraced by Chapter 534 of laws of 1871 as amended by Chapter 878 of laws of 1872*. Department of Public Parks, the City of New York.

Gratacap, L. P.
1909 *Geology of the City of New York.* Second Edition. Irving Press, New York.

Grumet, Robert Steven
1981 *Native American Place Names in New York City*. Museum of the City of New York.

HAER
1984 *Old Croton Aqueduct, Harlem River Crossing, Spanning Harlem River, Bronx, Bronx County, NY. HAER NY-119 and Old Croton Aqueduct, Bronx, New York, and Westchester Counties, New York. HAER-NY-120.* Historic American Engineering Record, National Park Service, Department of the Interior, Washington, D.C.

Harrison, J.F.
1867 *Plan of New York City, from the Battery to Spuyten Duyvil Creek*. New York.

Hyde, E. Belcher
1969 *Atlas of the Borough of the Bronx, City of New York.* 1907 edition, corrected to 1969. E. Belcher Hyde Map Company, New York.

Isachsen, Y.W., E. Landing, J.M. Lauber, L.V. Rickard and W.B. Rogers, eds.
1991 *Geology of New York: A Simplified Account.* Educational Leaflet No. 28. The New York State Museum/Geological Survey, The University of the State of New York. The State Education Department, Albany, New York.

Jenkins, Stephen
1912 *The Story of the Bronx*. G. P. Putnam's Sons, New York.

Johnston, Henry P.
1897 *The Battle of Harlem Heights.* Macmillan and Company, London.

Kieran, John
1959 *Natural History of New York City.* Fordham University Press, New York.

Landmarks Preservation Commission (LPC)
1970 *High Bridge, Aqueduct, and Pedestrian Walk, LP-0639.* Landmarks Preservation Commission, November 10, 1970.

1983 "DRAFT: New York City Pilot Study for New York State's Resource Planning (RP3) Protection Process Program." Funded by the New York State Department of Parks and Recreation-Historic Preservation Division.

2002 *Landmarks Preservation Commission Guidelines for Archaeological Work in New York City*.

M'Neill, William Gibbs
1835 *Topographical Delineations of Haarlaem River & Spitieng Duyvel Cr[eek].* Available at New-York Historical Society.

The Morning Herald
1839 *The Croton Aqueduct.* July 18, 1839.

National Historic Civil Engineering Landmark
1975 *Croton Water Supply System.* American Society of Civil Engineers.

National Historic Landmark
1992 *Croton Aqueduct (Old).* National Historic Landmarks designation form, National Park Service.

National Register of Historic Places
1972 *High Bridge Aqueduct and Water Tower.* Structure - #72001560. National Register of Historic Places Nomination Form, National Park Service.

1974 *Old Croton Aqueduct.* Structure - #74001324. National Register of Historic Places Nomination Form, National Park Service.

New York Archaeological Council (NYAC)
1994 *Standards for Cultural Resource Investigations and the Curation of Archaeological Collections.* New York Archaeological Council.

New York State Office of Parks, Recreation, and Historic Preservation (NYSOPRHP)
2005 *Phase I Archaeological Report Format Requirements.* Prepared by the New York State Historic Preservation Office (NYSHPO), April, 2005.

New York Public Library
1871 *High Bridge and high service works & reservoir.* Digital Images, available at: http://digitalgallery.nypl.org. Site accessed May 4, 2010.

nd *Photograph Files.* Local History Room, New York Public Library, New York.

New York Times
1928 *High Bridge Transformed*. October 30, 1928.

Nicholson, Francis
1857 *Map of Lands in the County of Westchester Belonging to Richard F. Carman, John Lowery, and Archibald H. Lowery*. Map No. 45.

Randel, John Jr.
1811 *A map of the City of New York by the commissioners appointed by an act of the legislature passed. April 3rd 1807, also The Randel Survey, or commissioners' map.*

Riker, James
1904 *Revised History of Harlem*. New Harlem Publishing Co., New York.

Robinson, Edward.
1885 *Atlas of the City of New York: embracing all territory within its corporate limits from official records, private plans & actual surveys*. Prepared under the supervision of E. Robinson & R.H. Pidgeon, civil engineers. New York: E. Robinson.

Sackersdorff, Otto
1868 *Maps of Farms, Commonly Called the Blue Book, 1815.* Map Division, New York Public Library.

Sanborn Map Company
1891-2008 *Insurance Maps of the City of New York.* Sanborn Map Co., New York.

Scharf, J. Thomas
1886 *History of Westchester County, New York, including Morrisania, King's Bridge, and West Farms.* Volume I. L. E. Preston & Co., Philadelphia.

Schuberth, Christopher J.
1968 *The Geology of New York City and Environs.* Natural History Press, Garden City, New York.

Sperr, F.L.
1940 *High Bridge [Spanning the Harlem River, and connecting the Bronx at about 170th Street to the Manhattan Highbridge Park at 174th Street.]* On file at the New York Public Library.

Sidney & Neff
1849 *Sidney's Map of Twelve Miles Around New-York.* On file at the New York Public Library.

1851 *Map of Westchester County, New York.* Newell S. Brown, White Plains, New York.

Stevens, B.F.
1900 *B.F. Stevens facsimile of the unpublished British headquarters coloured manuscript map of New York & environs (1782).* Reproduced from the original drawing in the War Office, London. London, B.F. Stevens, 1900.

Taylor, George and Andrew Skinner
1781 *Map of New York & Staten Islands and Part of Long Island*. Surveyed by order of Sir Henry Clinton. On file at the New York Public Library.

Topographical Bureau
1895 *Maps or plans and profiles, with field notes and explanatory remarks, showing the location, width, grades, and class of streets, roads, avenues, public squares and places, located and laid out by the Commissioner of Street Improvements of the 23rd and 24th wards of the city of New York : under authority of Chapter 545 of the laws of 1890*.

United States Coastal Survey (U.S.C.S.)
1837 *Manhattan Island, Northern Part of New York City to West Farms, New York.*

1854-5 *New York City and Manhattan Island.*

1857 *Shores of Harlem River and Spuyten Duyvel Creek with Adjacent Topography, New York*.

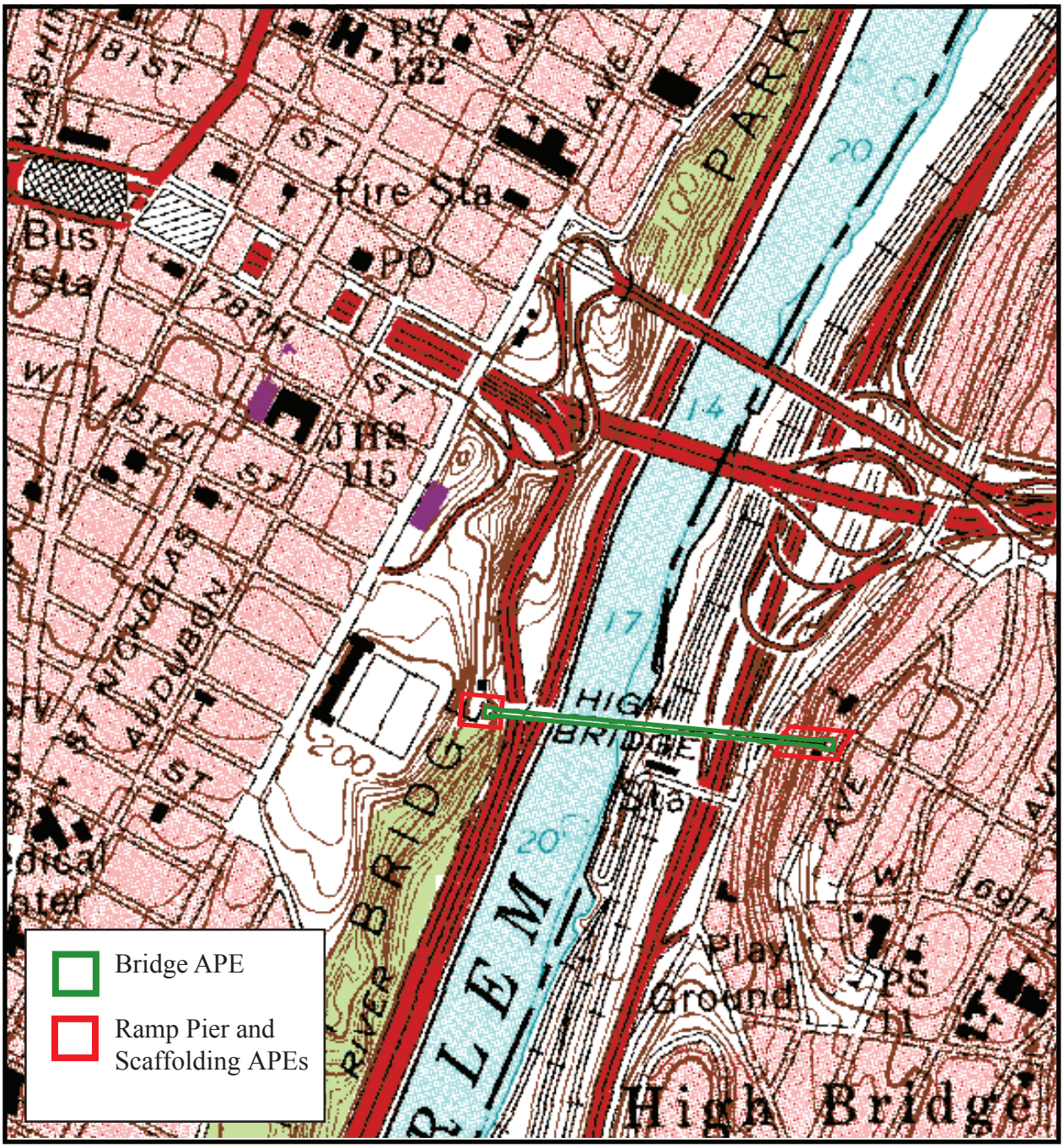
United States Department of Agriculture (U.S.D.A.)
2005 *New York City Reconnaissance Soil Survey*. United States Department of Agriculture, Natural Resources Conservation Service, Staten Island, NY.

United States Geological Survey (U.S.G.S.)
1891 *Harlem, N.Y.-N.J. Quadrangle.* United States Geological Survey, 15 Minute Series.

1979 *Central Park, N.Y.-N.J. Quadrangle.* United States Geological Survey, 7.5 Minute Series.

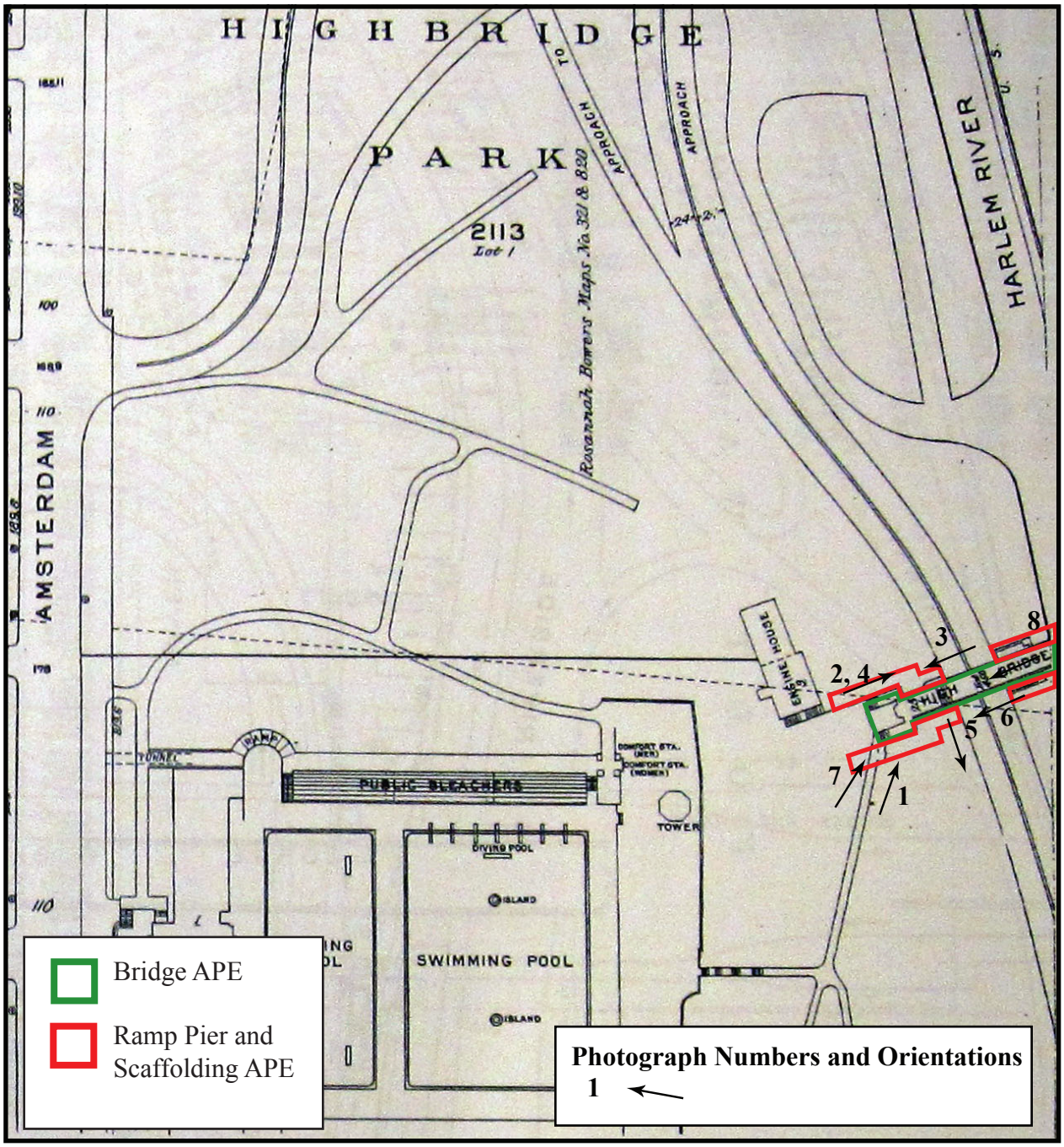
Viele, Egbert
1874 *Topographic Atlas of the City of New York. Section IV.* Egbert Viele, New York.

Wegmann, Edward
1896 *The Water Supply of the City of New York, 1858-1895.* John Wiley and Sons, New York.



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

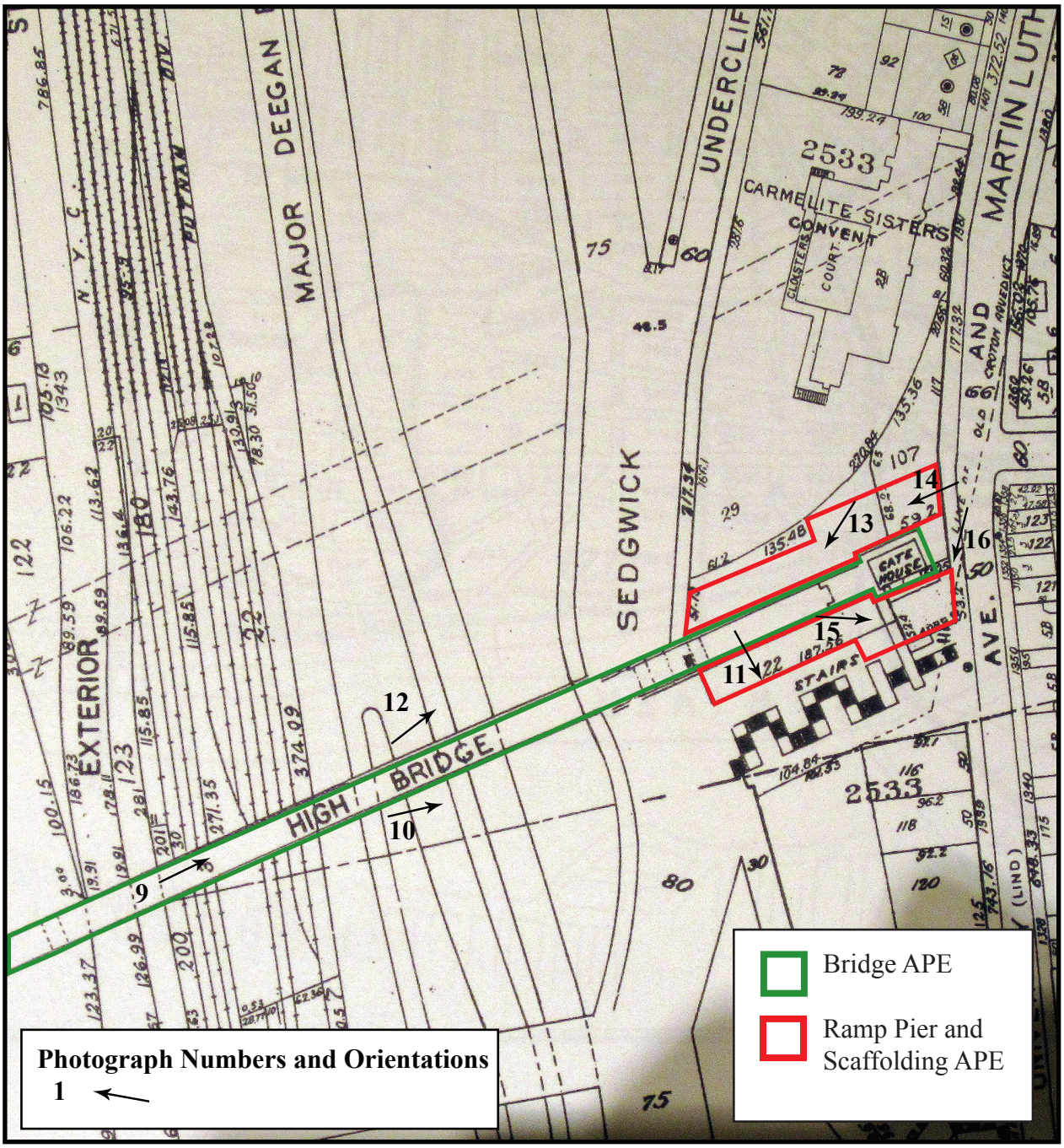
Figure 1: *Central Park, N.Y.-N.J.* 7.5 Minute Quadrangle (U.S.G.S. 1979).



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 2: Manhattan APE and Photograph Key on *Insurance Maps of the City of New York* (Sanborn 2008).

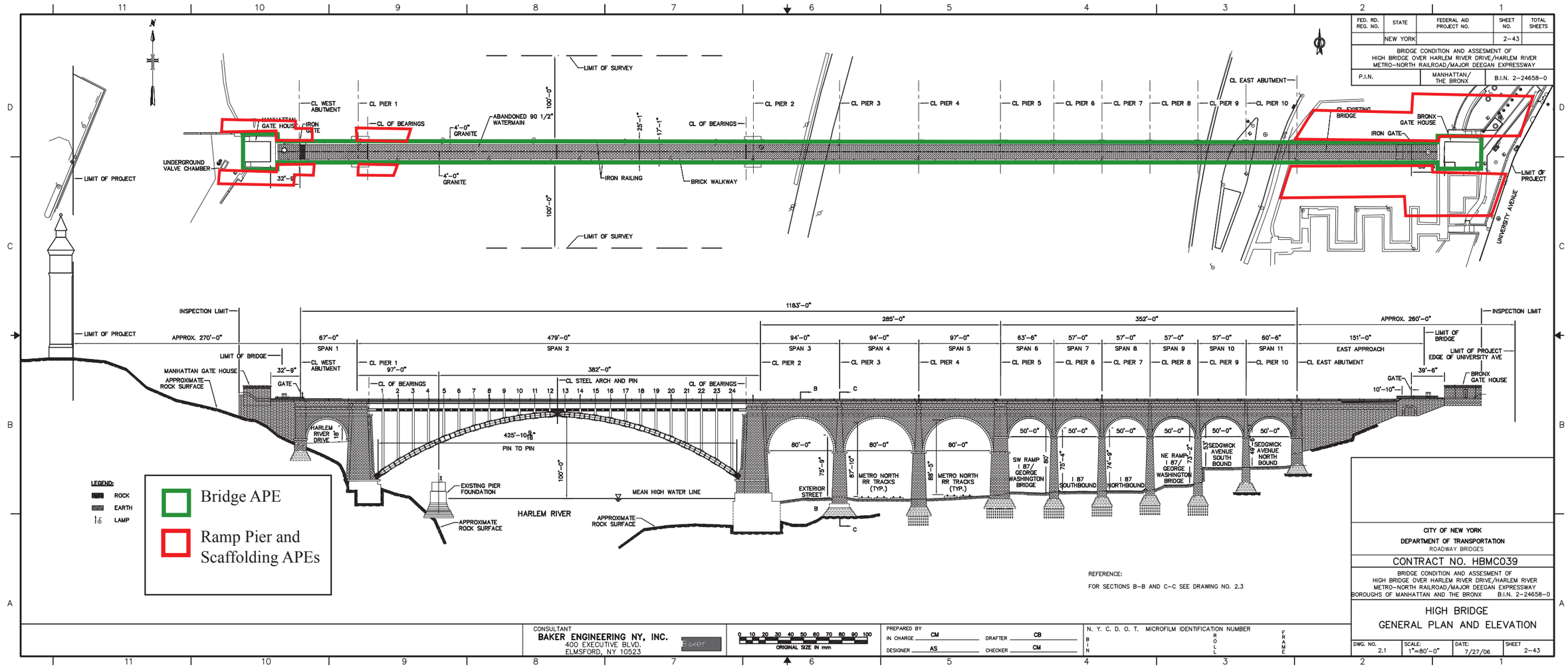
0 100 200 300 400 500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 3: Bronx APE and Photograph Key on *Insurance Maps of the City of New York* (Sanborn 2008).

0 100 200 300 400 500 FEET



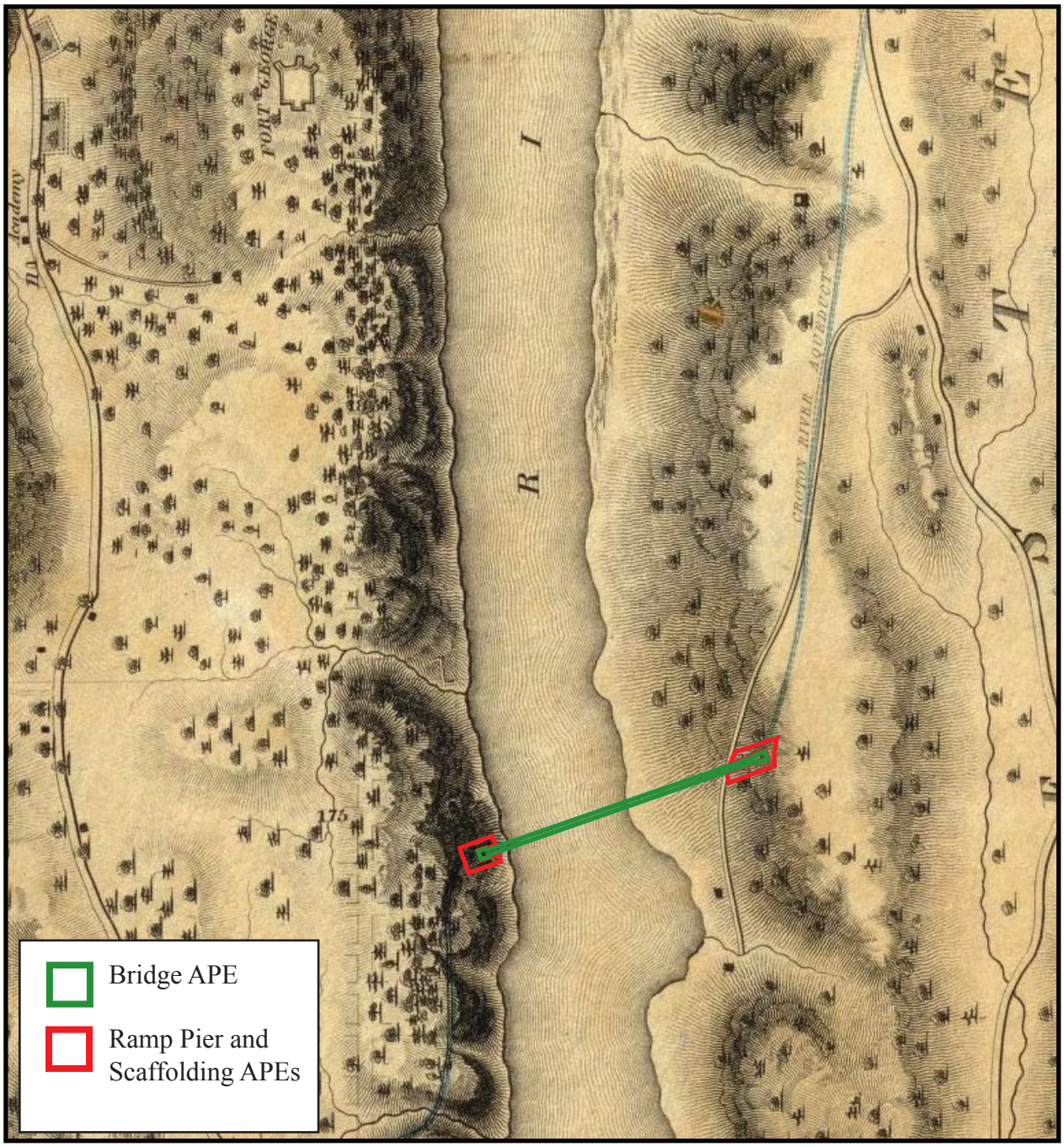
Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 4: High Bridge Existing Conditions (Baker Engineering 2006).



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 5: ***New York City Reconnaissance Soil Survey*** **(U.S.D.A. 2005).**

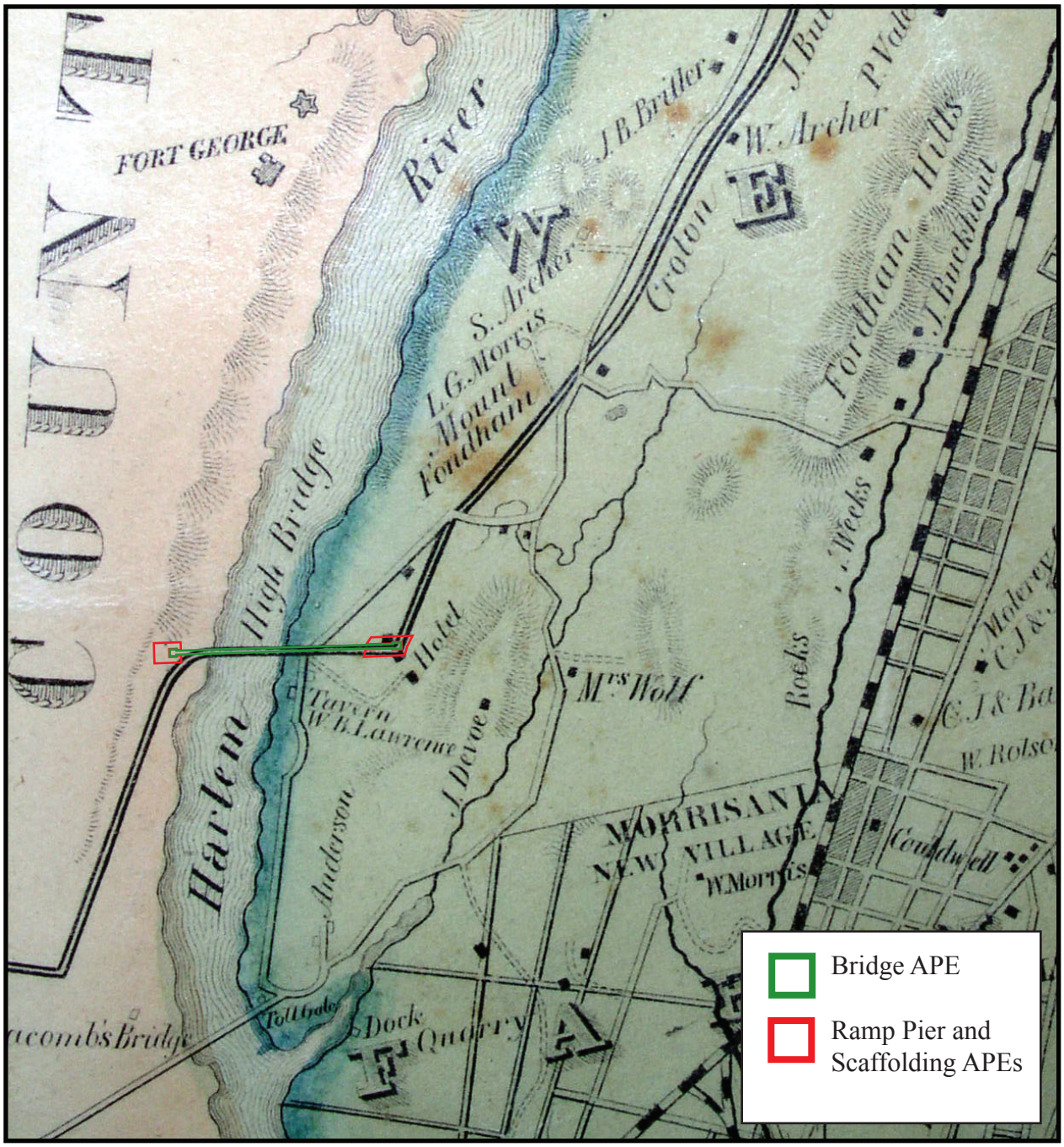


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 6: ***Topographical Map of the City and Country of New York, and the Adjacent Country*** **(Colton 1836).**

N

0 400 800 1200 1600 2000 FEET

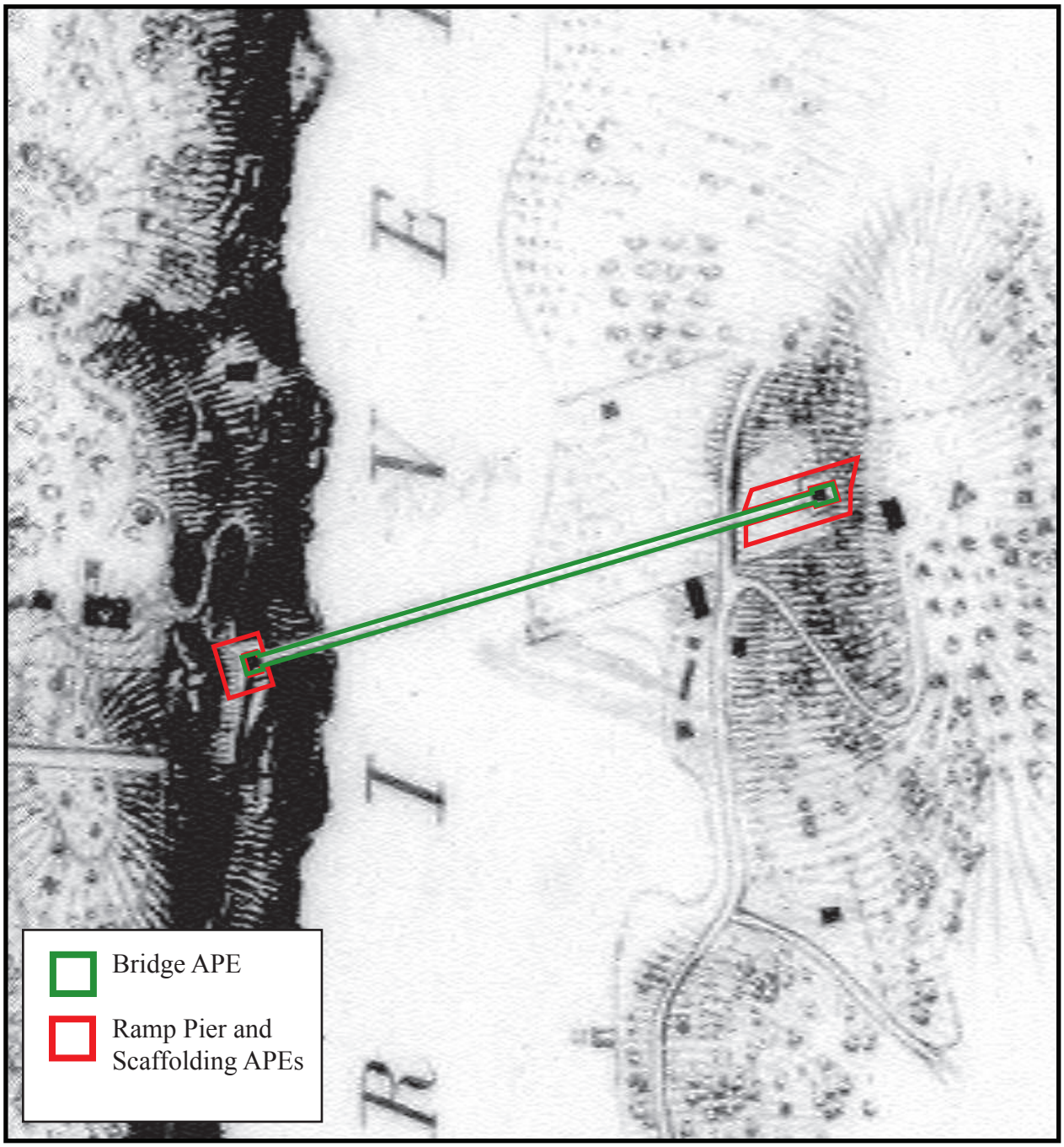


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 7: ***Map of Westchester County, New York*** **(Sidney and Neff 1851).**

N

0 600 1200 1800 2400 3000 FEET

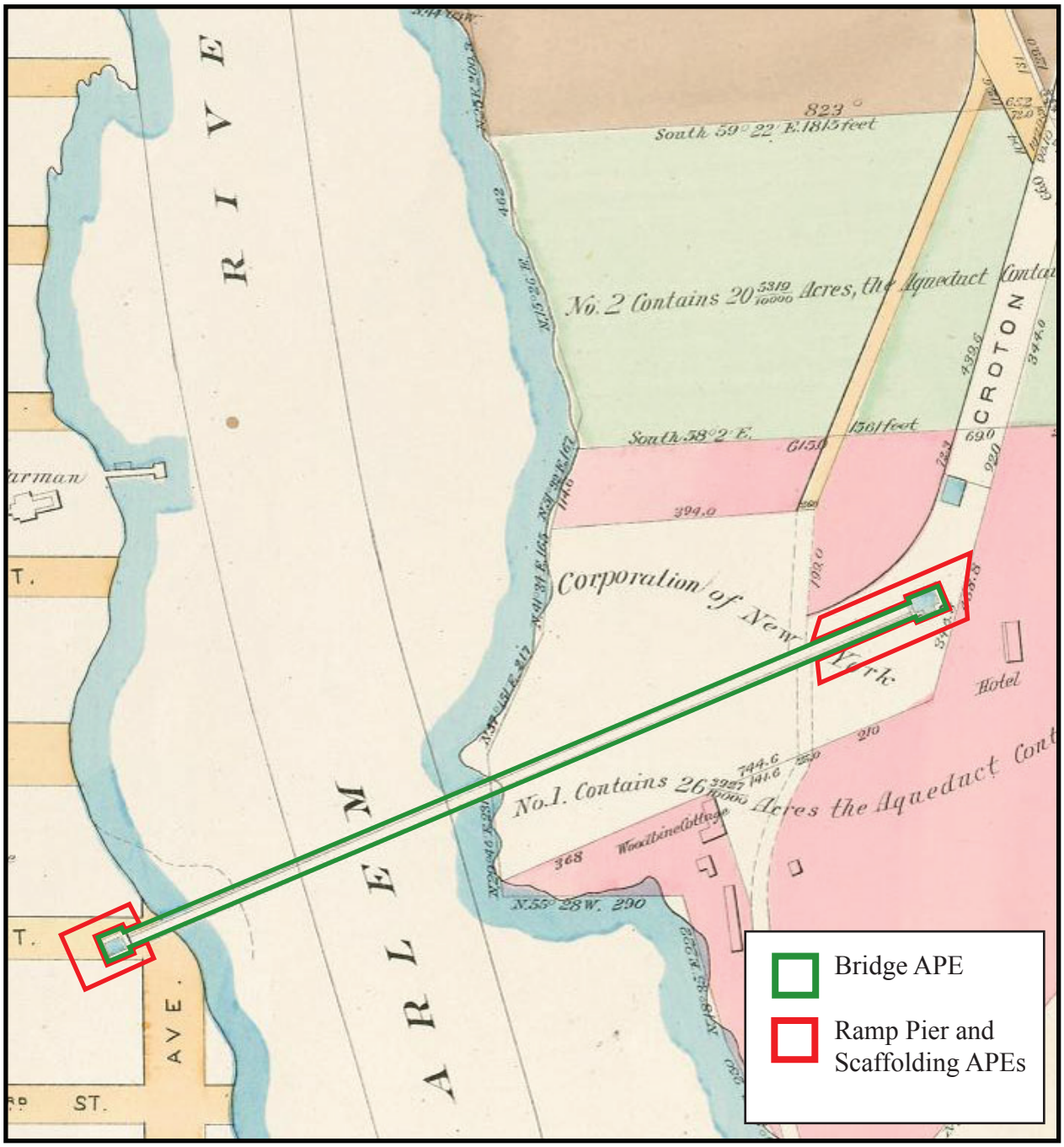


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 8: ***New York City and Manhattan Island*** **(U.S.C.S. 1854-5).**

N

0 200 400 600 800 1000 FEET

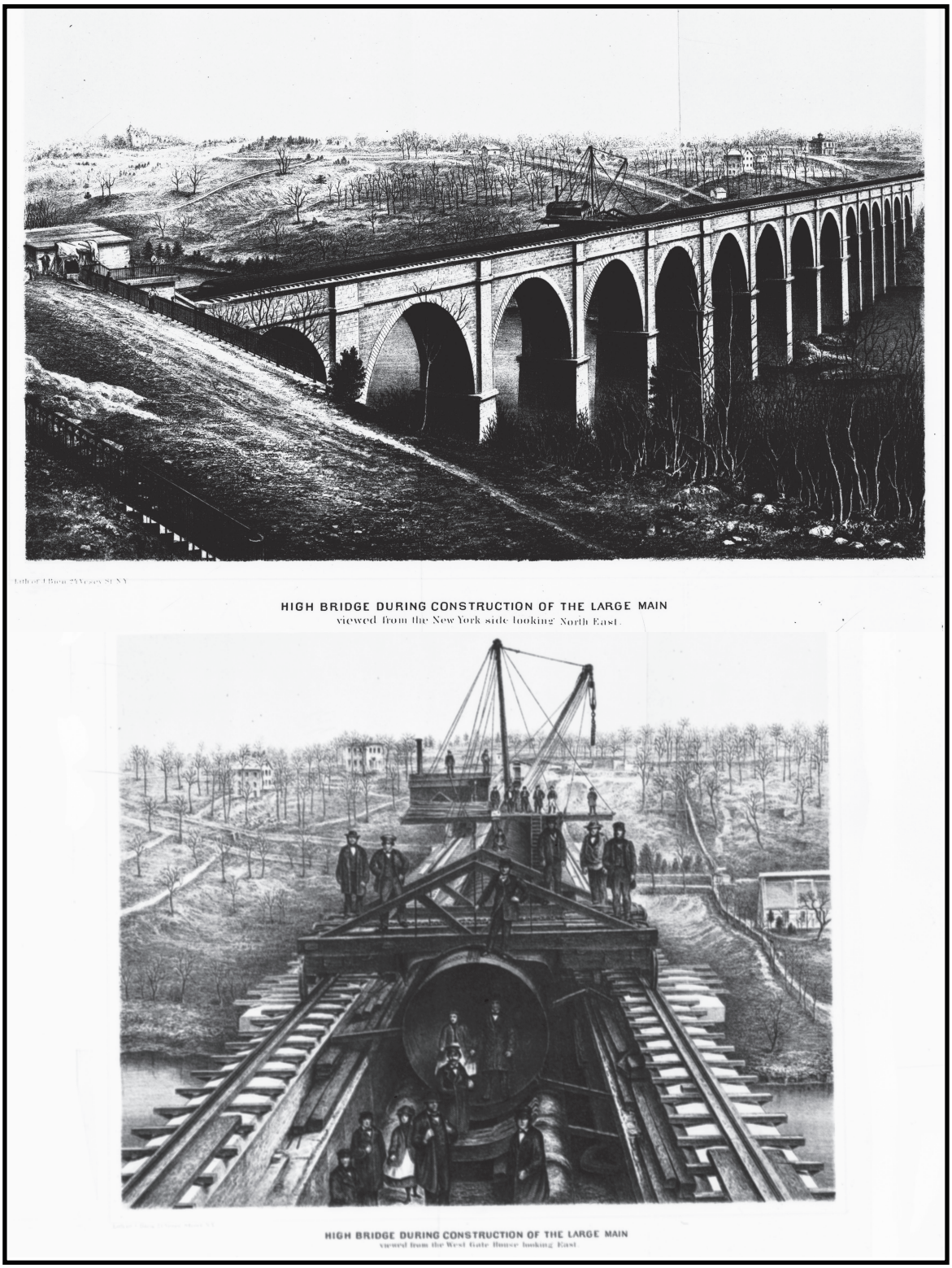


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 9: ***Map of Lands in the County of Westchester Belonging to Richard F. Carman, John Lowery, and Archibald H. Lowery*** **(Nicholson 1857).**

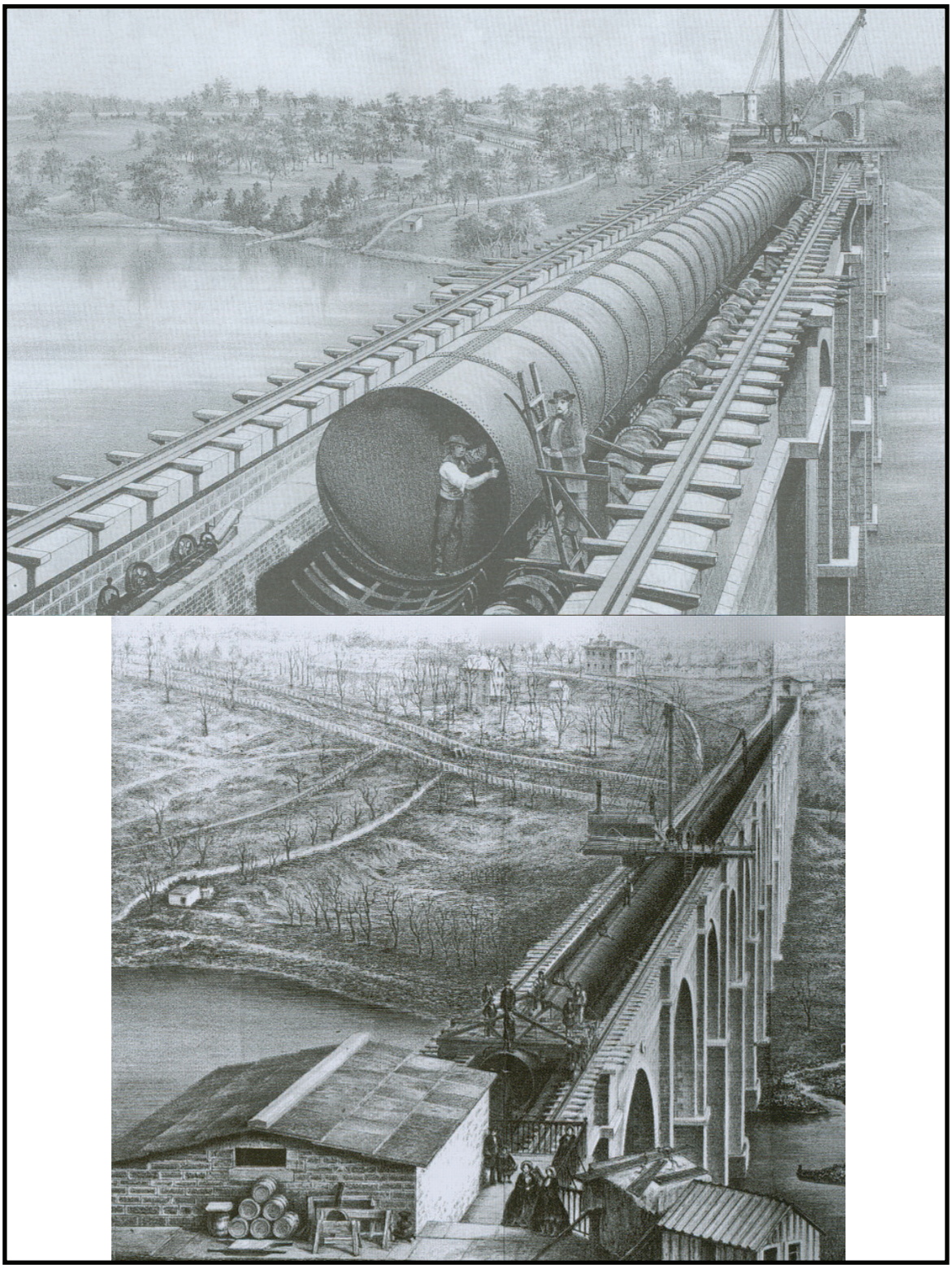
N

0 200 400 600 800 1000 FEET



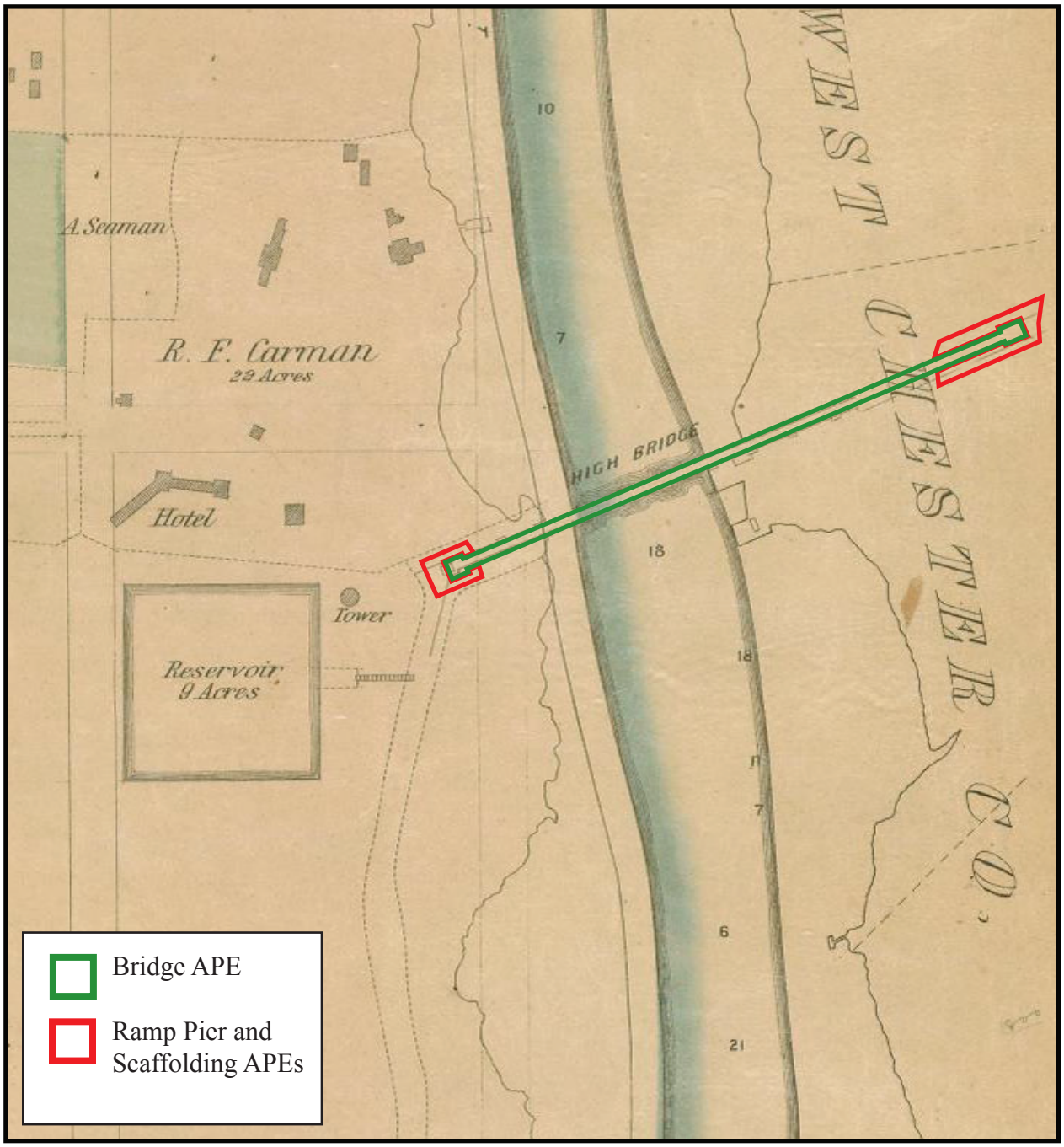
Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 10: ***High Bridge During Construction of the Large Main: Viewed from the New York Side Looking Northeast*** **(top)** ***and Viewed From the West Gate House Looking East*** **(bottom) (ca. 1860-1862, reproduced in HAER-NY- 119).**



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

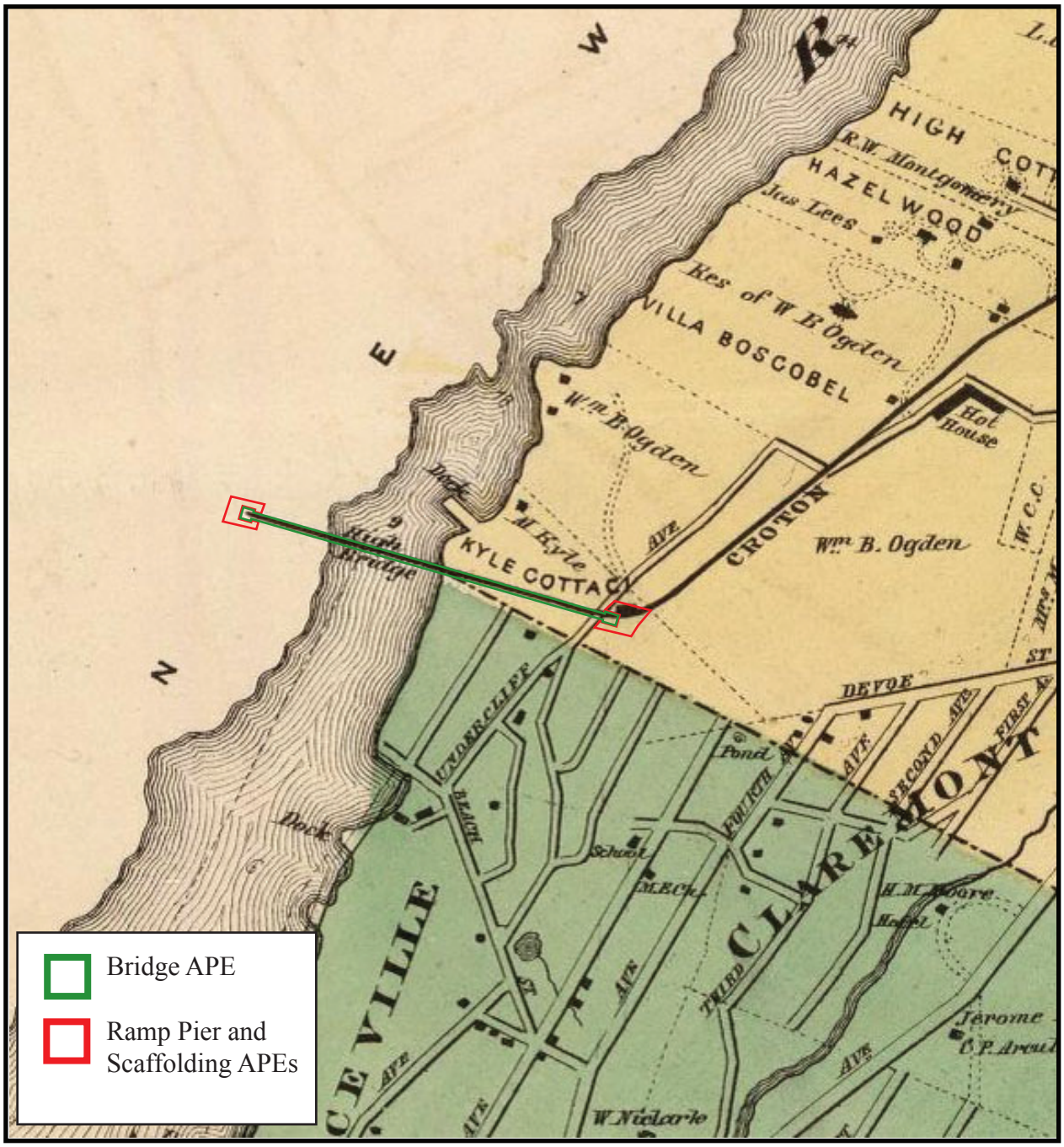
Figure 11: Two images of High Bridge During Construction of the Large Main (ca. 1860-1862). Top image from New York Public Library, bottom image from Bone (2006).



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 12: ***Plan of New York City, from the Battery to Spuyten Duyvil Creek*** **(Harrison 1867).**

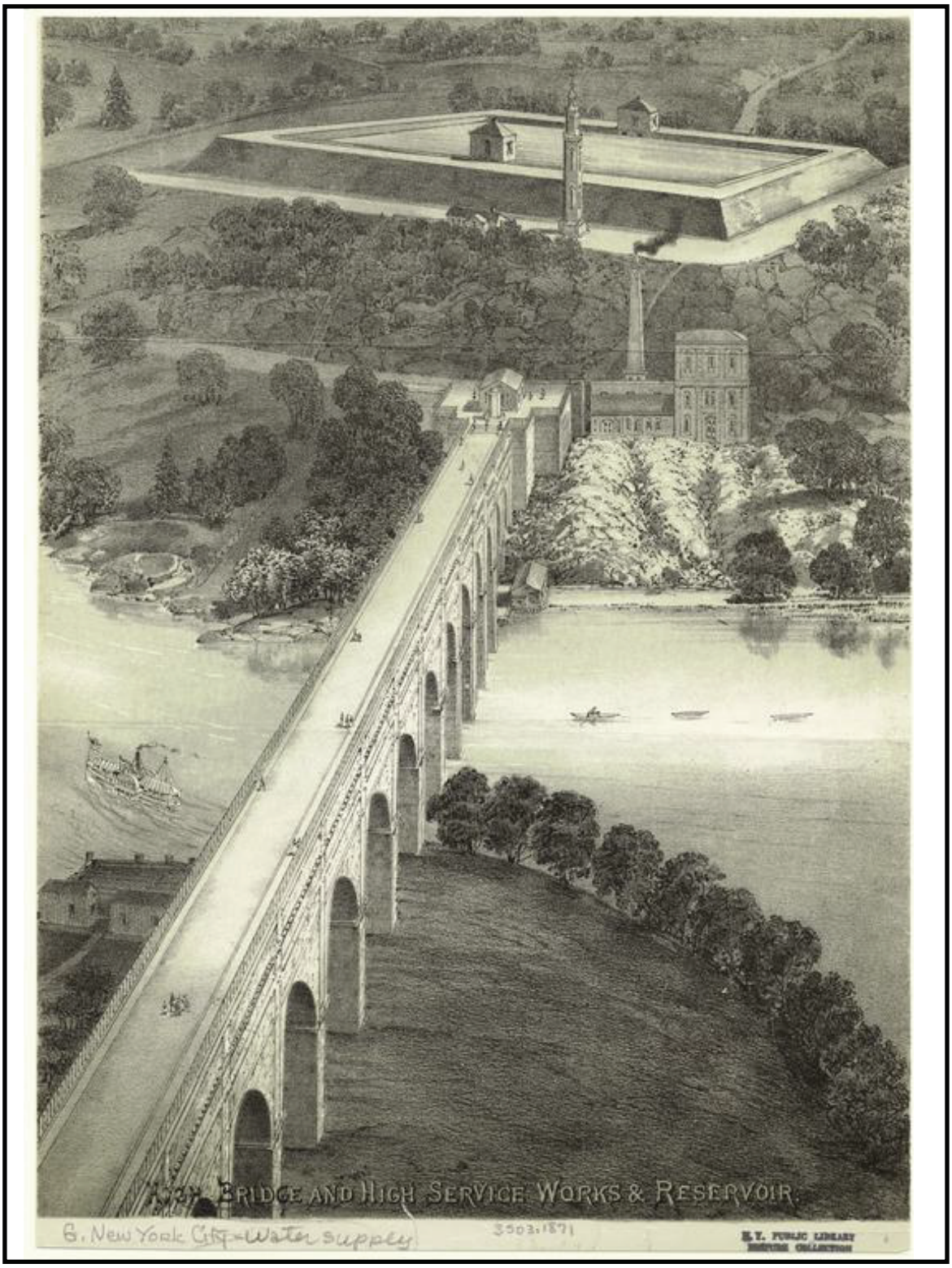
0 200 400 600 800 1000 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

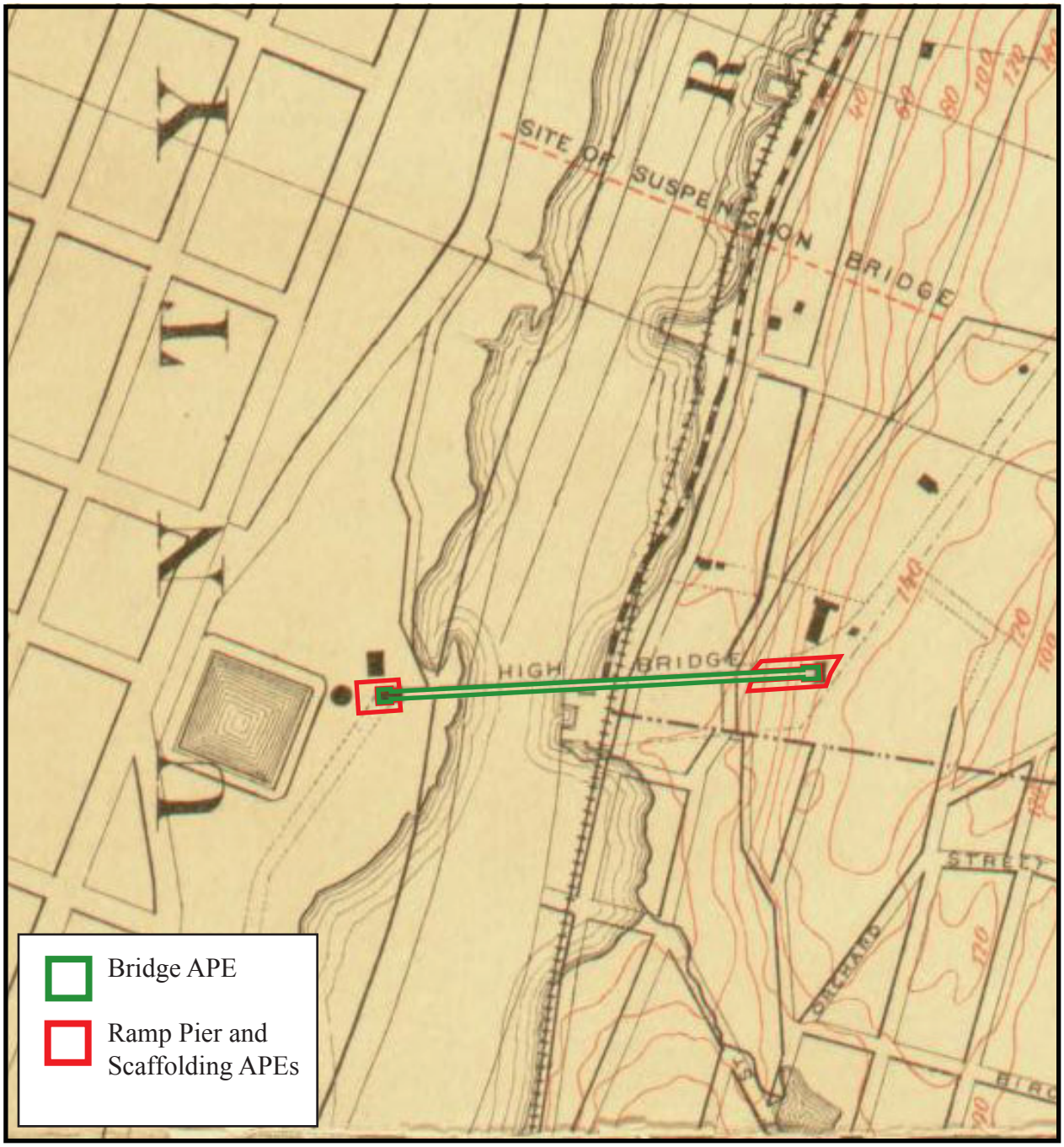
Figure 13: ***Atlas of New York and Vicinity*** **(Beers 1868).**

0 300 600 900 1200 1500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 14: ***High Bridge and High Service Works & Reservoir*** **(1871).**

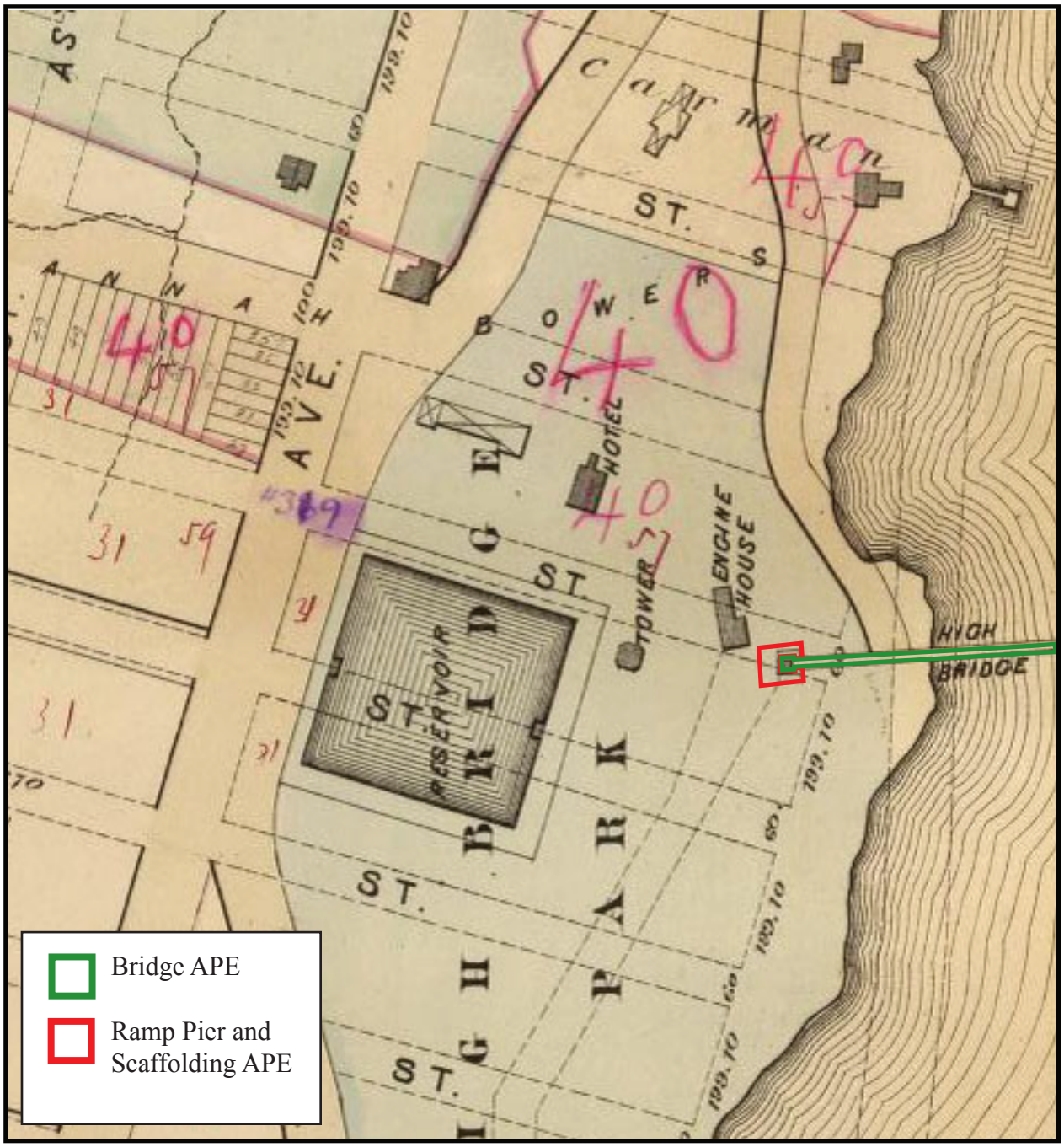


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 15: ***Topographical map made from surveys by the commissioners of the Department of Public Parks of the city of New York...*** **(Grant 1874).**

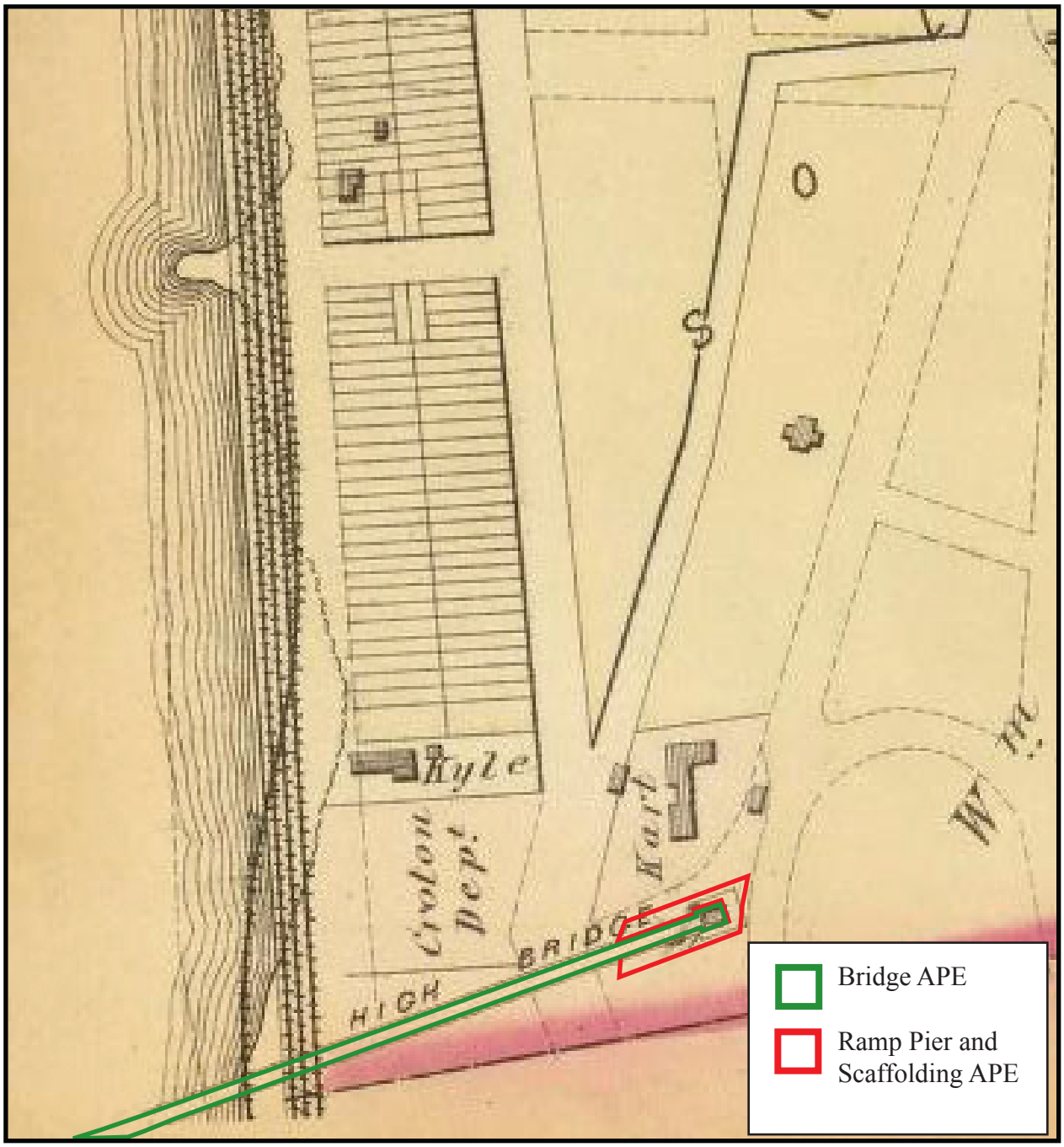
N

0 300 600 900 1200 1500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 16: ***Atlas of the city of New York: Borough of Manhattan*** **(Bromley 1879a).**

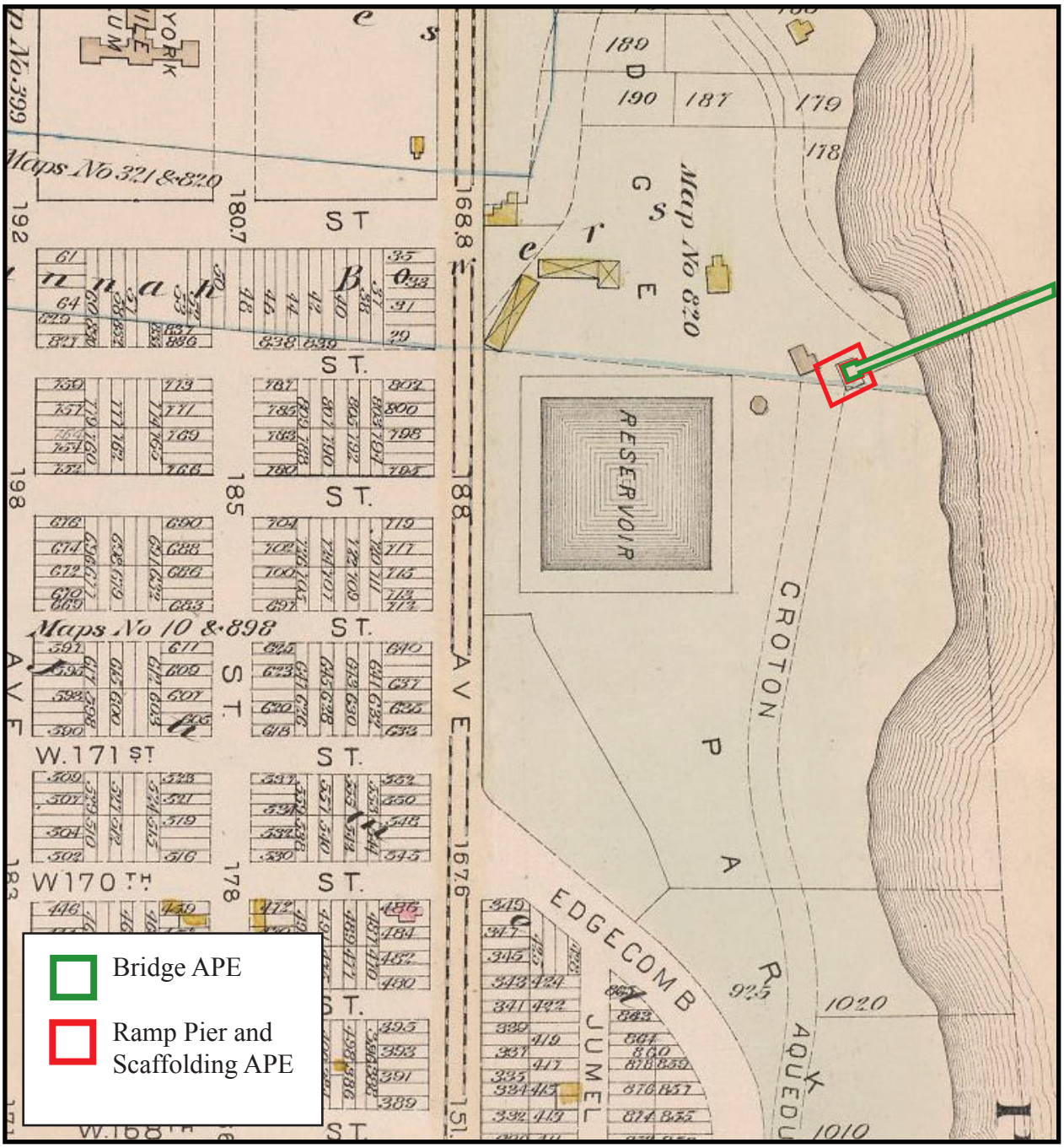


Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 17: ***Atlas of the 23rd Ward, City of New York*** **(Bromley 1879b).**

N

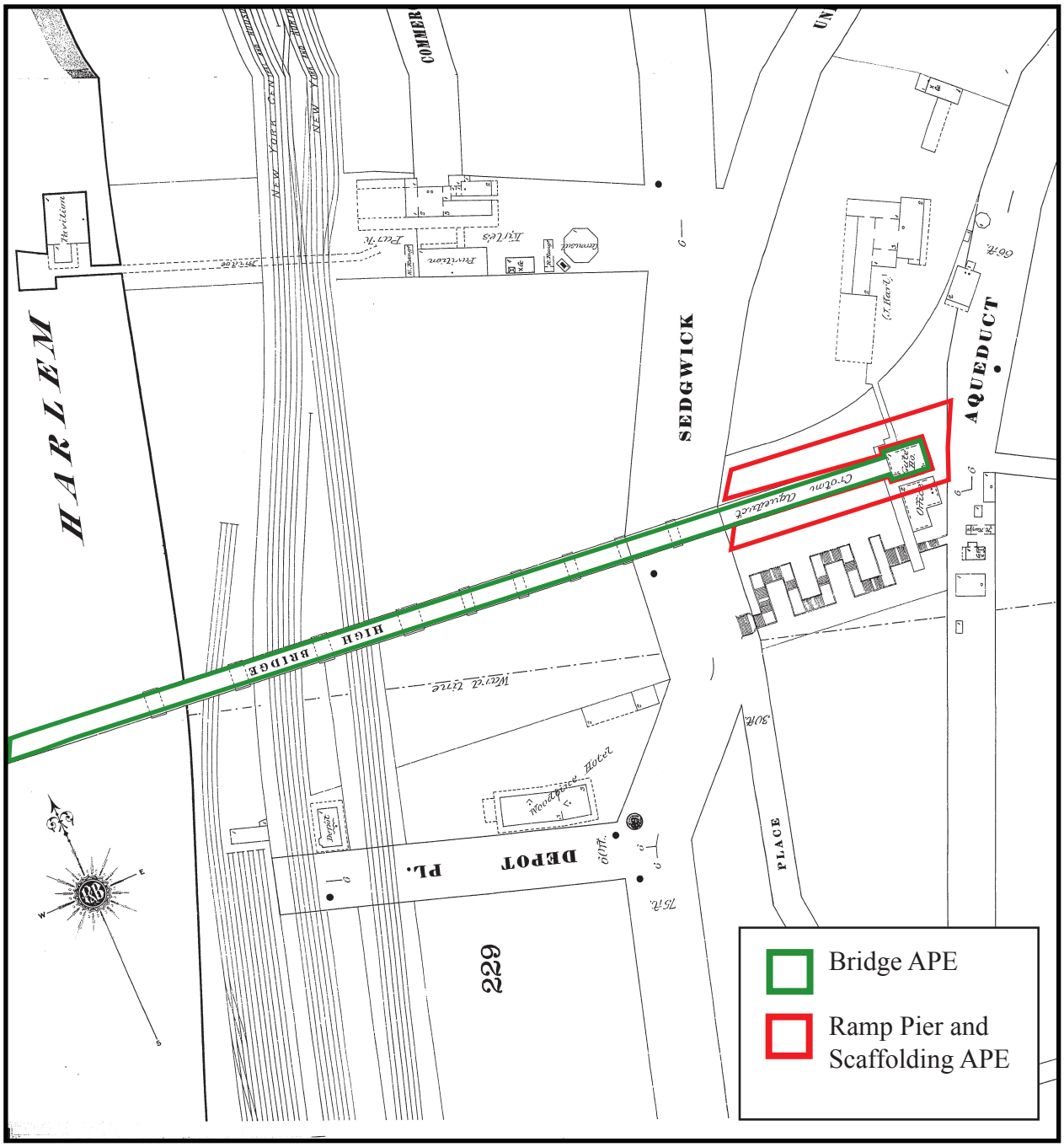
0 150 300 450 600 750 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 18: ***Atlas of the City of New York*** **(Robinson 1885).**

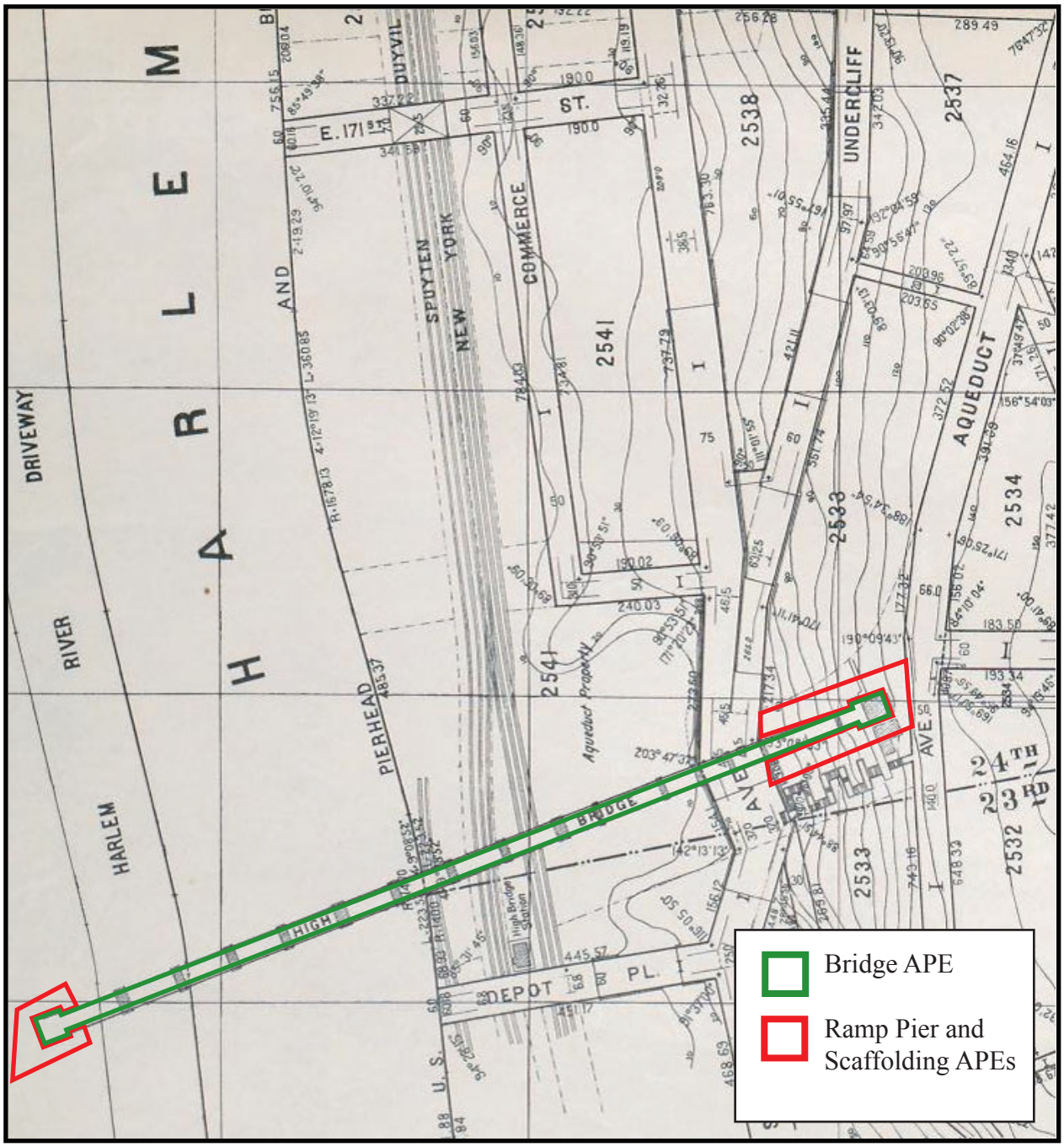
0 200 400 600 800 1000 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 19: ***Insurance Maps of the City of New York*** **(Sanborn 1891).**

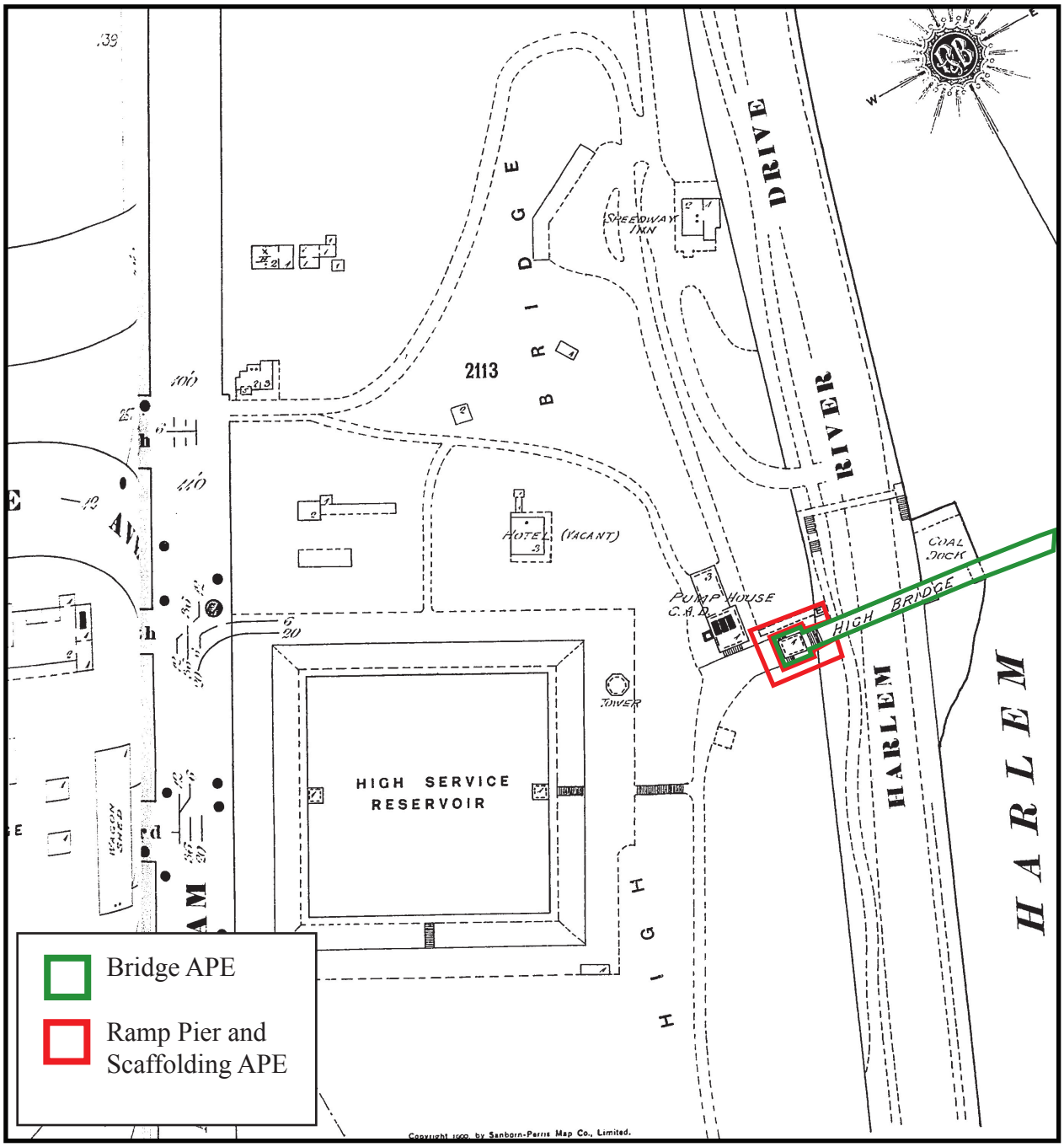
0 100 200 300 400 500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 20: ***Maps or plans and profiles, with field notes and explanatory remarks...*** **(Topographical Bureau 1895).**

0 200 400 600 800 1000 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

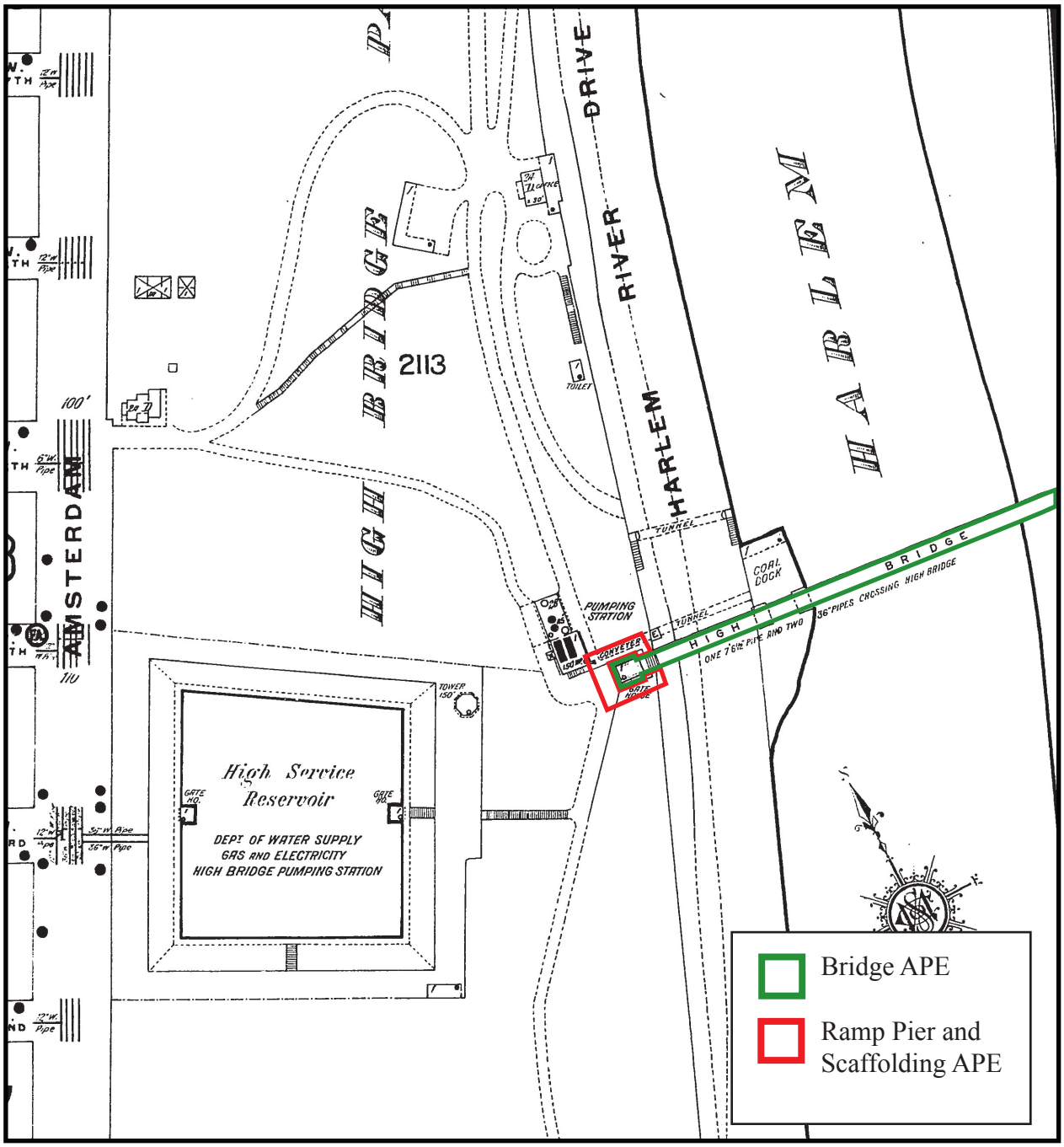
Figure 21: ***Insurance Maps of the City of New York*** **(Sanborn 1900).**

0 100 200 300 400 500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

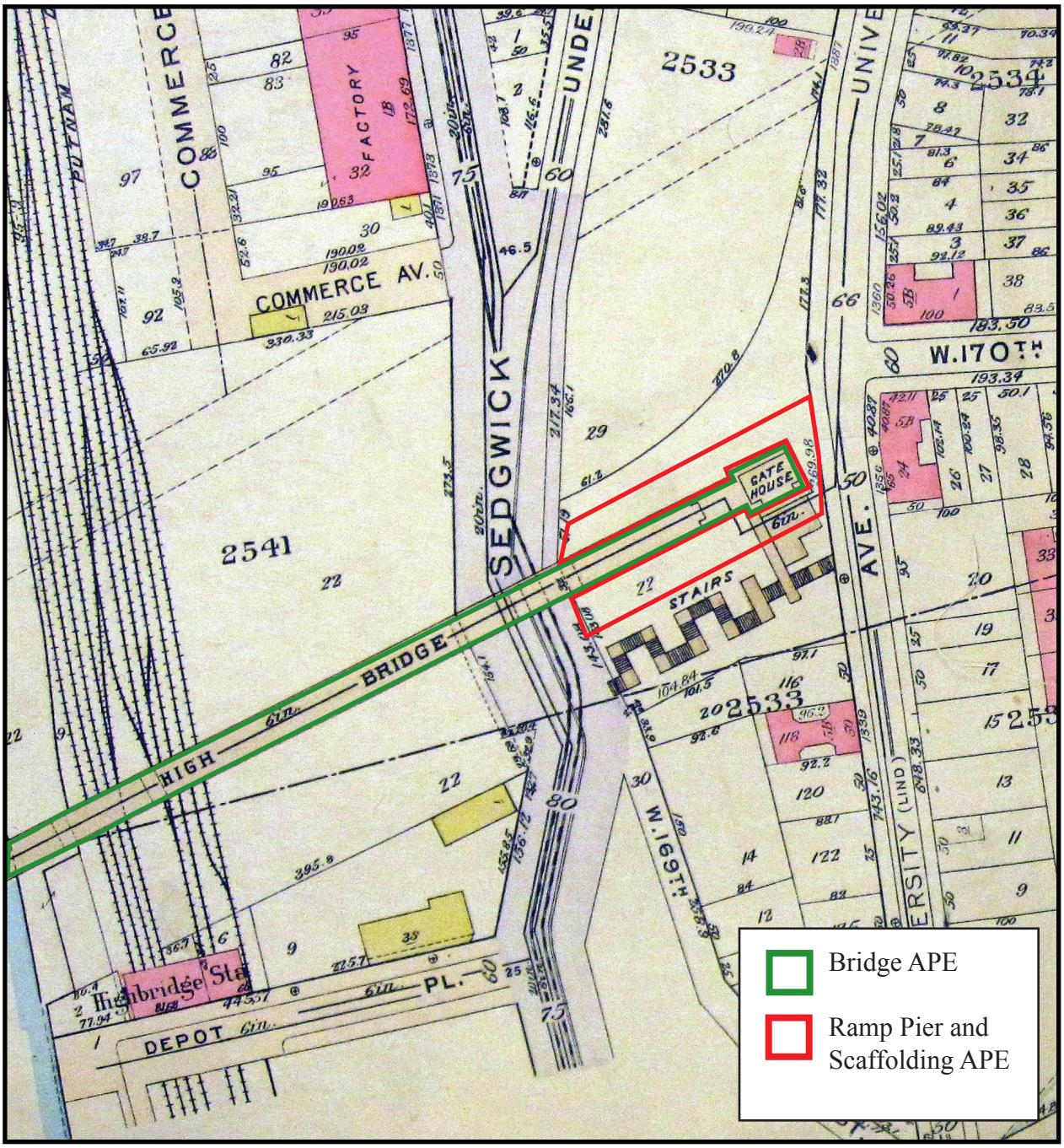
Figure 22: ***High Bridge, New York City*** **(Detroit Publishing Company 1900).**



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 23: ***Insurance Maps of the City of New York*** **(Sanborn 1913).**

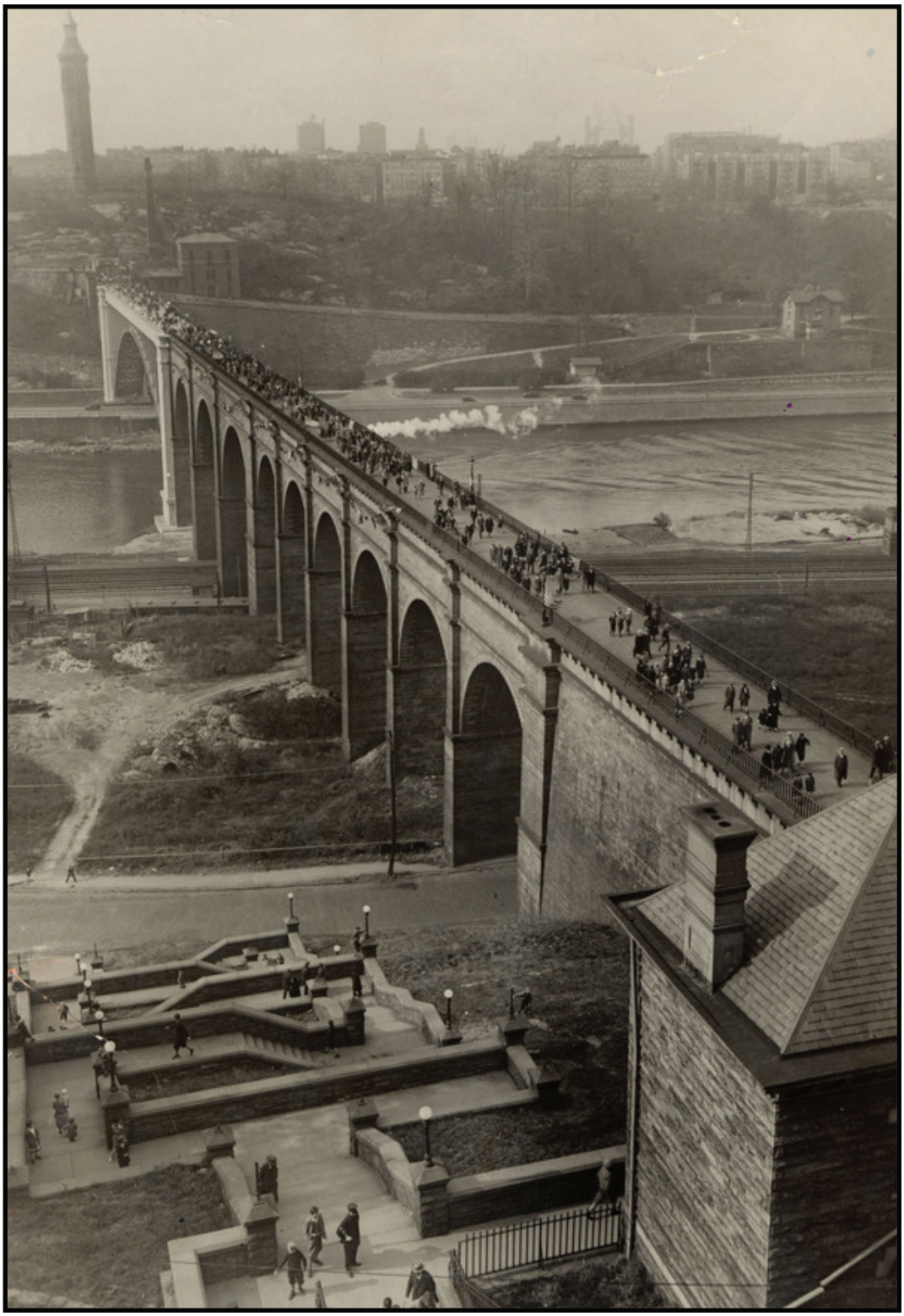
0 100 200 300 400 500 FEET



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 24: ***Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans*** **(Bromley 1923).**

0 100 200 300 400 500 FEET



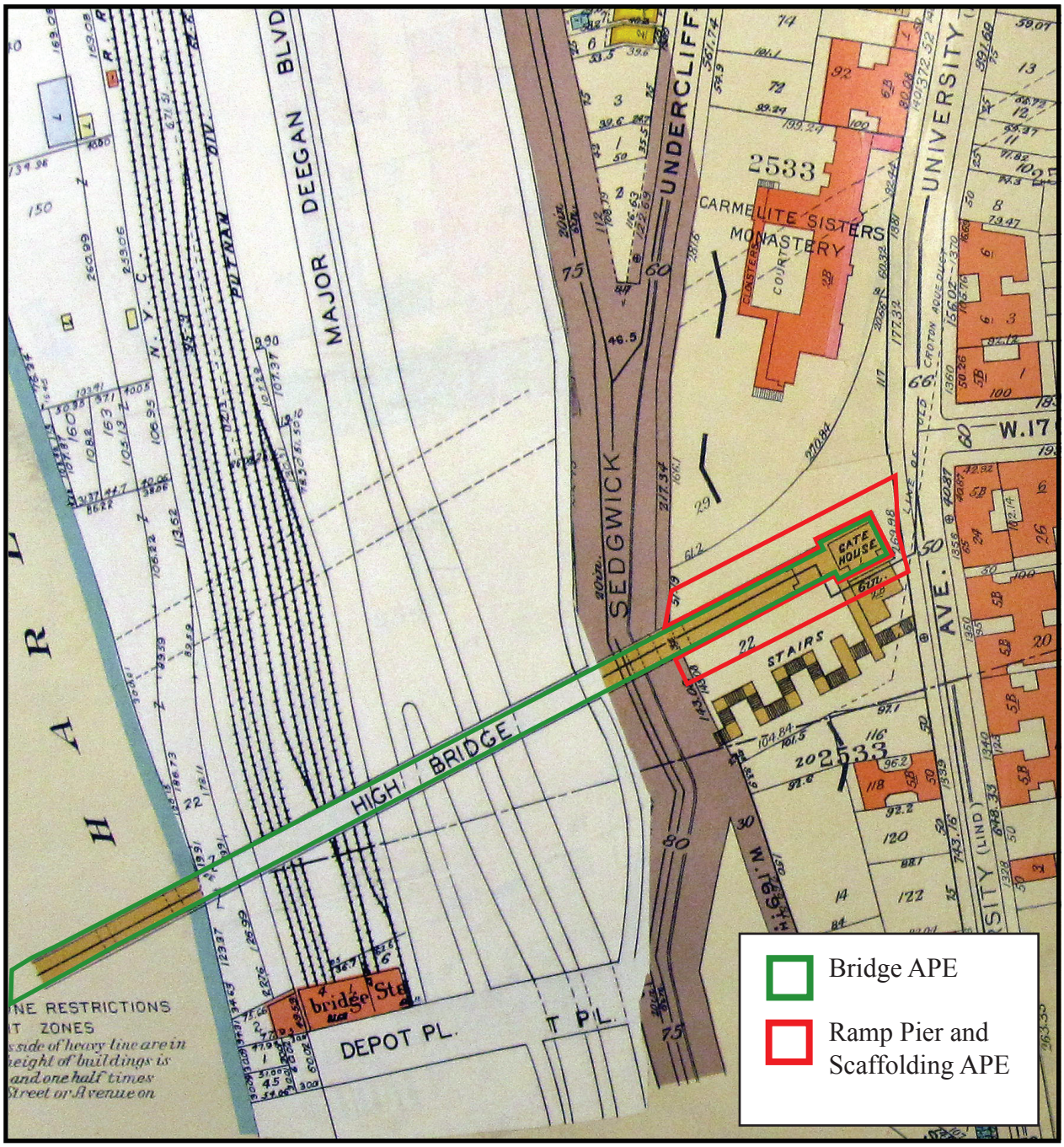
Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 25: Reopening of High Bridge for Pedestrian Traffic (1928). (Note: stair street down to Sedgewick Avenue and office building at lower right)



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 26: ***High Bridge [Spanning the Harlem River, and connecting the Bronx at about 170th Street to the Manhattan Highbridge Park at 174th Street]*** **(Sperr 1940).**
(Note: stair street in foreground and office building in background, in front of apartment complex)



Phase IA Archaeological Documentary Study
High Bridge, Manhattan and Bronx, New York

Figure 27: ***Atlas of the City of New York, borough of the Bronx, from actual surveys and official plans*** **(Bromley 1942).**

0 100 200 300 400 500 FEET

5. Site and Landscape Evaluation

5.1. INTRODUCTION

5.2. DESCRIPTION OF THE HISTORIC LANDSCAPE

5.3. DESCRIPTION OF VISTAS FROM THE BRIDGE AND ON TO THE BRIDGE FROM SURROUNDING PARKS

5.4. EXISTING LANDSCAPE EVALUATION

5.5. PROPOSED TREATMENT OPTIONS

5.6. CONSTRUCTION DISTURBANCE

5. Site and Landscape Evaluation

5.1 INTRODUCTION

An understanding of the documented historic landscape around the High Bridge provides valuable information both for the Historic Structure Report as well as the current design effort. The site, as defined by the Area of Potential Effect (APE) reflects 162 years of landscape evolution from a pastoral mid-19th century landscape dominated by the monumental High Bridge, to a densely developed, urban landscape of the 21st century. The landscape surrounding the High Bridge has been influenced by a rich and layered history of transportation infrastructure construction, real estate development, and increasing industrialization in addition to a series of modifications to the Bridge itself. The landscape chronology (see Appendix D) commences in 1848 with the earliest surviving illustrations of the Bridge and the surrounding landscape (APE and outlying landscape on Manhattan and Bronx sides), and vistas from the High Bridge and onto the bridge from surrounding parks. In addition, the report includes an evaluation of current conditions, and concludes with a discussion of proposed treatment options and potential construction related disturbances.

5.2 DESCRIPTION OF THE HISTORIC LANDSCAPE

Immediately following the completion of the bridge, mid-19th century maps illustrate the vicinity around the High Bridge as being sparsely populated with farms and private estates.[1] The earliest illustrations of the bridge and the surrounding landscape, such as Fayette B. Tower's 1843 rendering *Croton Aqueduct at Harlem River* (Appendix B, Fig. 1) and Nathaniel Currier and James Merritt Ives' 1849 print, *The High Bridge at Harlem N.Y.* (Appendix B, Fig. 3) depict a pastoral landscape dominated by the bridge's monumental masonry arcade. In these images, both taken from points south of the bridge, the landscape consists of pristine, verdant hills rising up along both banks of the Harlem River and a tree canopy unbroken by development. In his *Illustrations of the Croton Aqueduct* (1843), Tower's description of the backdrop to the 115-foot high, temporary fountain located 80 feet south of the bridge, provides a romantic description of the scene:

> "The scenery around this fountain added much to its beauty; there it stood,—a whitened column rising from the river, erect, or shifting its form, or waving like a forest tree as the winds swayed it, with the rainbow tints resting upon its spray while on either side the wooded hills arose to rival its height: all around was *nature*; no marble basin;—no allegorical figures, wrought with exquisite touches of *art* to lure the eye, but a fountain where nature had adorned the place with the grandeur and beauty of her rude hills and mountain scenery."[2]

Not long after the completion of the High Bridge, the surrounding landscape bore signs of change. The 1851 Sidney and Neff map indicates a tavern and hotel on the Westchester (later Bronx) side (HSR/Archaeological Evaluation, Fig. 7). In 1859, British photographer William England's photographs of the High Bridge, including *Riverbank View of Arched Bridge* (Appendix B, Fig. 6), document not only the wooded cliffs and craggy outcroppings (Manhattan side), but also a building and pathways situated close of the riverbank south of the bridge, and limited real estate development near the crest of the hill (Westchester/later Bronx side).[3]

A Department of Environmental Protection (DEP) Archives rendering from 1860-1861, *High Bridge during Construction of the Large Main* (Appendix B, Fig. 11), depicted the High Bridge and surrounding landscape in a state of transition. While a mechanical traveler situated mid-way across the bridge's span hoists new sections of pipe up from the river to the attic, the slope of the hill on the Manhattan side is covered in low-lying vegetation but is almost completely devoid of trees. The Westchester (later Bronx) side depicts sparsely-situated, single and multi-story buildings and roads at the crest of the hill. Like the Manhattan side, the area around the bridge on the Westchester (later Bronx) side appears to have been almost completely de-forested. The clearing of vegetation permitted unobstructed views of the bridge's land piers, and east and west abutments, on both sides of the river.

A circa 1861 rendering (Appendix B, Fig. 13) in the collection of the New York Public Library illustrated the laying of the great main on the bridge's deck, and the Westchester (later Bronx) side of the Harlem River beyond. The landscape south of the bridge was developed with several multi-story structures near the base of the wooded slope, all of which appear to have been oriented towards the river, while a pier and moored steamboat were situated on the riverbank itself. In a circa 1860s view of the Manhattan side, the wooded cliffs, craggy outcroppings and low-lying vegetation of the Manhattan slope were punctuated by a masonry embankment wall aligned with the course of the aqueduct as it continued south (Appendix B, Fig. 14). A large, multi-story building situated immediately north of the bridge dominated the Manhattan ridgeline.[4]

In 1864, the *Annual Report of the Croton Aqueduct Department made to the Common Council of the City of New York* noted landscaping work which had been performed during the extension of the Croton Aqueduct on the Westchester (later Bronx) side: "The slope of the river on the north or Westchester side has been terraced, and the grounds about the bridge, which during the work at this point have necessarily been disfigured, have been put in proper order."[5]

In 1863, the New York State Legislature passed an Act authorizing the construction of a High Service Works, including a water-tower, reservoir, and associated structures, to supply the more elevated portions of Manhattan.[6] In June 1866, a contract was issued for the construction of a wharf, reservoir and coal house, and in 1867 a contract was issued for the construction of pump and boiler houses, all on the Manhattan side. The majority of these structures were sited to the bridge's north, including the water tower, pump and boiler houses, coal house and wharf. Notably, the High Bridge was most often depicted from the south looking north in commercial prints and photographs, while the view from the north of the bridge looking south was less commonly represented. Coal was delivered through a tunnel under what is now Harlem River Drive, and was raised vertically up a coal hoist built immediately to the north of the Manhattan gatehouse. The Reservoir was constructed in 1870, and the High Service Tower was constructed in 1872. Cumulatively, these structures contributed to the increasing industrialization of the landscape on the Manhattan side of the bridge.

Almost twenty years after the High Bridge was completed, and only three years after the installation of the great pipe, the City of New York began assembling Highbridge parklands on both sides of the Harlem River in 1867. This activity continued through the 1960s. As noted in its 1894 *Annual Report*, the Department of Public Parks continued to acquire lands at High Bridge Park on the Manhattan side of the bridge: "Proceedings are pending in court to acquire title {including} lands at High Bridge Park."[7] According to the Department of Parks and Recreation, the majority of Highbridge Park lands were assembled through condemnation between 1895 and 1901.[8] Under Robert Moses' administration of the Department of Parks, both land holdings and buildings were transferred from the Department of Water Supply, Gas and Electricity to the Department of Parks.

The last quarter of the 19th century witnessed multiple railroad infrastructure projects which continued to industrialize the formerly rural/bucolic landscape; the railroad also brought day-tripping passengers and commuters to the High Bridge. The New York and Boston Railroad was chartered May 21, 1869 to construct a line from the High Bridge on the Harlem River in New York heading upstate to Brewster. The New York and Putnam Railroad (later Putnam Division), was leased to the New York Central and Hudson River Railroad system circa 1874. When both lines merged, the line became the Putnam Division of the NY&HR. Passengers could transfer at High Bridge station to the Hudson Division (of the Spuyten Duyvil and Port Morris Railroad) to reach Grand Central Terminal or continue to the 155th Street terminal.[9]

As part Upper Manhattan's increasing population growth and northward expansion/development, trains linking lower and upper portions of the island were organized, financed, and constructed. In 1875, the Rapid Transit Commission granted the New York Elevated Railway Company the right to construct a railway from Battery Park to the Harlem River along the Bowery and Third Avenue. In 1878, the I.R.T. trolley (former Third Avenue El) was erected, and its northern terminus reached High Bridge Park on the Manhattan side.[10] Some forty years hence, the railroad building boom near the High Bridge was captured in a 1922 photograph

in the collection of the New York Historical Society, which illustrated increasing industrialization and a proliferation of railroad tracks on the Bronx side of the river, coupled with long lines of passenger and freight cars (Appendix B, Fig. 41).

By the late 1870s, the vicinity around the High Bridge was praised as "one of the most popular resorts of the middle classes" in *Scribners' Monthly*: "The line of the Harlem, speckled with row-boats, sloops, schooners, and little steamers; the red-brick paved walk across the top of the bridge dotted with pigmy men and women, and the white houses, half hidden among the foliage on the banks, give a charming variety of the scene."[11] Between 1885 and 1886, a monumental stepped street was constructed by the Department of Public Works on the Bronx side immediately south of the bridge, connecting the top of the bluff to Sedgwick Avenue below (Appendix B, Fig. 28).[12] In 1895, the Fort George Amusement Park was opened just north of 190th Street on the Manhattan side, which featured amusement rides and attractions. To accommodate the avid cyclists eager to traverse the linear path above the Croton Aqueduct, an 1895 State Senate and Assembly Bill called for a bicycle path extending from High Bridge to the Croton Dam in Westchester.[13] Finally, between 1897 and 1898, the $3M Harlem River Speedway – consisting of a 95'-0" wide unpaved thoroughfare for horse-traffic, bounded by two narrower, pedestrian walkways lined with trees - was constructed parallel to the riverbank on the Manhattan side. The construction of the Harlem River Speedway significantly changed the Manhattan shoreline of the river by building out a hard, bulkheaded edge for its entire 1½-mile length. (Appendix B, Fig. 29).[14]

The landscape around the High Bridge and Highbridge Parks was radically transformed in the 20th century with the arrival of the automobile. On October 12th, 1922, the Harlem River Speedway was "rechristened" the Harlem River Driveway and formally opened to vehicular traffic, as a ceremonial motorcade drove on the newly-paved concrete roadway.[15] Under City Construction Coordinator and arterial road planner Robert Moses, multiple highways, interchanges, and viaducts were constructed in the vicinity around the High Bridge, including the Major Deegan Expressway on the eastern shore of the Harlem River (formerly Major Deegan Boulevard, initiated 1935, completed 1956), the Trans-Manhattan Expressway (initiated in the 1950s, opened to traffic in 1962), and the Highbridge Interchange, which linked the George Washington Bridge, the Cross-Bronx Expressway, and the Harlem River Drive. A Harlem River Drive viaduct was erected to the north and east of the bridge on the Manhattan side (running beneath the bridge), while another HRD roadway was situated on a raised thoroughfare adjacent to the river (project initiated 1941). The Alexander Hamilton Bridge was also constructed 1960-1963.

In the 20th century, landscape maintenance and improvement campaigns were proposed at the High Bridge on both sides of the Harlem River. In December 1912, the DWSGE proposed landscaping work for both the Manhattan and Bronx sides of the bridge. The scope for the Manhattan side included trimming the slope uniformly at a ratio of 2:1 (minimum fill at top of slope; maximum fill at bottom of slope). The scope for the Bronx side called for trimming the slope to uniform grade (fill to elevation 21.5-22).[16] Landscaping work also occurred at Highbridge Park in Manhattan circa 1936, coinciding with the opening of the High Bridge Play Center (later renamed High Bridge Pool and Recreation Center). According to the Department of Parks *Annual Report* for 1934, playgrounds at High Bridge (at 163-165th Street and 180th Street) were to be redesigned in 1935.[17]

In July 1975, the Department of Parks proposed grading and planting work at the Bronx side of the High Bridge. The scope included landscaping a rectangular bed located immediately to the south of the Bronx gatehouse.[18] In 1989, the Department of Parks and Recreation proposed landscaping work at Highbridge Park on the Manhattan side of the Bridge.[19] In 2002, the Department of Parks and Recreation completed landscaping work at Highbridge Park on the Bronx side of the Bridge. Scope items included removals (remove and salvage 562 LF of 4'-0" steel panel fence; remove and salvage 7 light poles; remove benches), and construction (hardscaping, softscaping, ADA ramp, fencing, benches, and interpretive markers).[20] On the Manhattan side, the High Bridge access project was completed in 2008, including rehabilitation of a stair and

pathway leading from the upper level plaza to the High Bridge. Recent and current efforts for both the Manhattan and Bronx parks include restoring and naturalizing the 1930s planting plan, removal of volunteer trees, scrub and vines, and re-opening of sightlines.

5.3 DESCRIPTION OF VISTAS FROM THE BRIDGE AND ONTO THE BRIDGE FROM SURROUNDING PARKS

Vistas from the High Bridge evidence the High Bridge parks on both sides of the Harlem River as parkland oases situated amidst densely urbanized, commercially and residentially developed, and infrastructure-rich portions of the Bronx and Manhattan.

Bronx side road and rail infrastructure:

- Exterior Street,
- Metro-North railroad,
- Cross Bronx Expressway,
- Major Deegan Expressway,
- Depot Place,
- Sedgwick Avenue,
- Undercliff Avenue, and
- Dr. Martin Luther King Boulevard.

Bronx side parks, landscape and architecture:

- steep wooded slope and Highbridge Park at eastern terminus of bridge,
- stepped street immediately south of the bridge,
- low-scale commercial buildings and a hotel situated at the base of the hill,
- low-scale apartment buildings to the east of the bridge, and
- Carmelite Sisters Convent to the north of the bridge.

Manhattan side parks, landscape and architecture:

- steep wooded cliffs and rock outcroppings,
- Highbridge Park at western terminus of bridge,
- High Service Tower and Highbridge Recreation Center at the crest of the hill, and
- low-scale mixed use apartment and commercial buildings to the west of the bridge.

Manhattan side road and rail infrastructure:

- Harlem River Driveway.

Vistas onto the bridge deck and of the piers from the Highbridge Park (Manhattan side) are frequently obscured by densely overgrown vegetation and tall trees. Vistas onto the bridge deck and piers from the Highbridge Park (Bronx side), on the whole afford more panoramic views of the bridge itself.

From a sensory perspective, it should be noted that the western spans of the bridge have a modest connection to nature as it crosses over the Harlem River and into Highbridge Park, while the eastern spans traverse noisy modern infrastructure. The river itself is frequently active, where commonly observed traffic includes Circle Line tour boats and crew boats.

5.4 EXISTING LANDSCAPE EVALUATION

The High Bridge connects two distinct parks, namely the 118.75 acre Highbridge Park in Manhattan and the 0.8 acre Highbridge Park in the Bronx. Wooded cliffs and large rock outcroppings characterize the parkland immediately adjacent to the bridge.

In 2008, a new pathway was constructed on the Manhattan side providing much-needed access for pedestrians and cyclists between the park, surrounding neighborhood, and the bridge. The cast-iron stairway with wood risers, which connects the High Bridge to the historic High Service Tower, was also reconstructed. Mountain bike trails were constructed in 2007.

In 2001, improvements were made on the Bronx side with the addition of an accessible ramp to the gatehouse, new seating, and chess tables. Low vegetation on the slope immediately adjacent to the ramp, and a steep gradient beyond allows open views of the bridge and Water Tower from this vantage point.

South of the bridge on the Bronx side, a grand stone staircase, built in 1885-1886, connects University Avenue to Sedgwick Avenue below. The steps are overgrown with vegetation, in disrepair and are slated for restoration in the future. Invasive plants, predominantly poison ivy, are still prevalent on the masonry piers and bridge railings on the Bronx side. On the Manhattan side, recent forest restoration efforts have included invasive plant removal, erosion control and new tree planting.[21]

5.5 PROPOSED TREATMENT OPTIONS

The proposed treatment options for the landscape and site will include:

- Clearing and Grubbing: This is proposed to occur on the north side of the bridge in both Manhattan and Bronx boroughs.
- Selective Tree Removal: Existing trees within the footprints (plus some distance) of the proposed ramps will be removed, and trees outside the footprints will be preserved and protected. Large invasive trees, i.e., mulberry, which have grown close to, and in some cases, within the masonry of the High Bridge itself, will be removed.
- Vine and Poison Ivy Removal: Invasive vine and poison ivy growth will be removed from the bridge.
- Bare Soils: Bare soil that results from clearing and grubbing operations will be protected from erosion and scouring by soil conservation methods and materials. These will be maintained in place during the course of construction, until permanent means of vegetating the side slopes (such as seeding, groundcovers, mulching) are installed. Native vegetation, including small tree species suitable for the slopes, will be utilized.

The landscaping component of the High Bridge project will contribute to larger, long-term goals: reducing invasives and planting native plant species, improving the overall health and habitat value of the ecology, improving the aesthetic value of the landscape, and opening sightlines. Permanent construction changes at the High Bridge will have a visual impact on the surrounding landscape, such as the construction of the new access ramps on the Manhattan and Bronx approaches. Additionally, the installation of architectural lighting will enhance the visibility of the bridge, as well as the surrounding landscape, at night.

5.6 CONSTRUCTION DISTURBANCE

The existing landscape on both Manhattan and Bronx sides of the High Bridge will be impacted during construction, primarily due to the construction of the new exterior access ramps. Clearing and grubbing on the north side of the bridge in both boroughs will be necessary to allow for staging and mobilization of equipment. Existing trees within the footprints (plus some distance) of the new ramps will necessarily be removed, and trees outside the footprints will be preserved and protected. Several large invasive trees have grown close to the High Bridge, and in some cases, into the masonry itself. Removal of these trees to enable

construction and cleaning will also allow for greater visibility of the bridge from both sides, but will also improve some of the views and vistas possible from on the High Bridge itself.

After the completion of construction, permanent means of vegetating the side slopes (such as seeding, groundcovers, mulching) will be installed. Native vegetation, including small tree species suitable for the slopes, will be utilized. With 2-3 years, the slopes will start to recover, and will soften the visual impacts of the ramp supports.

---

1 Please see the following maps from Historical Perspectives' PHASE IA ARCHAEOLOGICAL DOCUMENTARY STUDY REHABILITATION OF THE HIGH BRIDGE IN THE BOROUGHS OF MANHATTAN AND THE BRONX, NEW YORK: Map of Westchester County, New York (Sidney and Neff 1851; Figure 7); New York City and Manhattan Island (U.S.C.S. 1854-5; Figure 8); Map of Lands in the County of Westchester Belonging to Richard F. Carman, John Lowery, and Archibald H. Lowery (Nicholson 1857; Figure 9).

2 Quotation from Tower, F.B., *Illustrations of the Croton Aqueduct,* 112.

3 The building situated close to the riverbank on the Westchester (later Bronx) side may be the tavern, and one of the buildings at the crest of the hill may be the hotel, as noted on Map of Westchester County, New York (Sidney and Neff 1851). Historical Perspectives' PHASE IA ARCHAEOLOGICAL DOCUMENTARY STUDY, Figure 7.

4 This building may be the hotel shown in Plan of New York City, from the Battery to Spuyten Duyvil Creek by Harrison 1867.

5 *Annual Report of the Croton Aqueduct Department made to the Common Council of the City of New York, October 10, 1864, for the year 1864*. Board of Aldermen, January 9, 1865, Document No. 3, page 8.

6 See Wegman, Edward. *The Water Supply of the City of New York 1658-1895*. New York: John Wiley and Sons, 1896, 76, and *Annual Report of the Croton Aqueduct Department made to the Common Council of the City of New York,* 1866.

7 *City of New York Department of Public Parks, Report for 1894*, pages 3, 6.

8 See DPR website for Highbridge Park http://www.nycgovparks.org/parks/highbridgepark/highlights/7732

9 See "New York and Putnam Railroad" in http://en.academic.ru/dic.nsf/enwiki/1036270

10 Stern, Robert A. M., et al. *New York 1900*. New York: Rizzoli, 1983, 45.

11 "Croton Water." *Scribner's Monthly* Volume XIV, No. 2, June 1877, 168.

12 Due to DWSGE's lack of maintenance funds, this stepped street was later proposed to be released from the Department of Water Supply, Gas and Electricity to the Board of Estimate, who in turn would release the stepped street to the President of the Bronx. See DEP Archives, Box 3383, Folder 6 and DEP Box 3384, Folder 12.

13 "Bicyclers Get Impatient: They Urge the Passage of the Aqueduct Path Bill." *New York Tribune*, April 24, 1895.

14 According to the authors of New York 1900, the completion of the Harlem River Speedway "realized the continuous carriage route to the Island's northern tip which {Frederick Law] Olmsted had initially envisioned, enabling one to proceed through either Riverside Drive or a chain of parks (Central, Morningside and St. Nicholas parks) and back by a route lined with greenery and little traffic to interfere. CKG Billings' stable (c. 1903) at the Speedway [near 197th Street] was a temporary haven for the horses and carriages of travelers of wished to dismount or "park" their carriages while they took a walk in the still open countryside." Stern, Robert A. M. et al., *New York 1900.* New York: Rizzoli, 1983, 57.

15 "Harlem Driveway Opened to Autos: Speedway Formerly Sacred to Horse-Drawn Vehicles Scene of Celebration." *The New York Times*, October 13, 1922. At the opening ceremonies for the Driveway, Manhattan Borough President Julius Miller announced plans for a belt-line parkway (extending from Riverside Drive and 72nd Street, to Dyckman Street, to the Harlem River Driveway, to 7th Avenue, to either the east or west drive of Central park, to 72nd Street), which, once completed, would be "a [parkway belt] unequalled anywhere else in the world." The concrete paved roadway cost $235,934.

16 "DWSGE Boroughs of Manhattan and Bronx, Contract Drawing for Filling, Grading and Soiling and Seeding the grounds owned by the city between Sedgwick Ave and the NYC&HRRR at High Bridge Borough of Bronx." DEP Archives, Drawing 2152-X. Appendix E, Fig. 16.

17 Department of Parks, *Annual Report* (1934): 73, 75.

18 City of New York, Department of Parks, "Rehabilitation of the High Bridge Aqueduct, a Pedestrian Walk over the Harlem River, Borough of Manhattan and Bronx," prepared by Coffey Levine Blumberg Architects, Sheet 4. Appendix E, Figure 74.

19 City of New York, Parks and Recreation, "Reconstruction of High Bridge Park Phase III between West 155th and 173rd Streets Harlem River Drive to Edgecombe and Amsterdam Avenues, Borough of Manhattan" Miceli Kulik and Associates. Sheets 11 (removals) and 15 (reconstruction) are missing from the set received by LSA, and the final as-built scope and construction dates are unknown.

20 City of New York, Parks and Recreation, "The Reconstruction of the Entrance walk and Seating Area at University Avenue and West 170th Street in Highbridge Park, Borough of Bronx," DPR Drawing. Appendix E, Figs 87-102.

21 "Parks Plants Trees and Restores Highbridge Park In MillionTrees NYC Effort." *The Daily Plant*, December 2, 2008.

6. Architectural & Structural Evaluation

6.1. SURVEY METHODOLOGY

6.2. GENERAL CONDITIONS

6.3. MASONRY AND SPAN CONDITIONS

6.4. STEEL SPAN CONDITIONS

6.5. AQUEDUCT PIPES

6.6. RAILINGS

6.7. POWER AND LIGHTING

ATTACHMENTS

High Bridge Inspection Report by Lichtenstein Consulting Engineers, September 2010

Structural Analysis: Analysis of Stone Arch Span, Load Rating Analysis of Brick Arch Walkway, & Brick Arch Deck Strengthening Options , by Lichtenstein Consulting Engineers, August 31, 2010

Structural Analysis of Main 80' Masonry Arch Span, High Bridge, NYC, by John Ochsendorf, August 12, 2010

Structural Analysis of Brick Deck Arch, High Bridge, NYC, by John Ochsendorf, April 15, 2010

6. Architectural Evaluation

6.1 SURVEY METHODOLOGY

To evaluate the structural condition of the High Bridge an inspection of the bridge structure was performed during several separate site visits from March to August 2010 by Lichtenstein Consulting Engineers (LCE). The LCE inspections included the masonry piers, arches, spandrels, abutments, attic, brick walkway and arch, wrought iron tie rods, attic, steel span, and water main gallery. See the LCE "High Bridge Inspection Report" included in this section of the HSR for a detailed description of structural conditions, including photographs.

Between April and September 2010 Li/Saltzman Architects, P.C. (LSA) examined the railings, walkway, steps, masonry attic, and iron pipes of the High Bridge. During August and September 2010 LSA performed a limited examination of the piers and arches from a platform lift in association with LCE during their inspections.

During May and June 2010, under the direction of LSA, probes were performed and samples taken of selected areas of the walkway, steps, wrought pipe, by PreConLogStrat (PCLS). All probes were documented by LSA, and observed by LCE. The probes consisted of the removal of parts of the structure to allow documentation of the assemblies and materials and adverse conditions. Samples of brick, mortar, coatings, and metals were taken for testing by Jablonski Building Conservation Inc. (JBCI) and Prof. Robert Gordon at Yale University. The wrought iron pipe was examined by Conservation Solutions, Inc. (CSI) during August 2010. Samples of the wrought iron pipe were taken by PCLS during September 2010 and delivered to Prof. Gordon for metallographic testing. The description and results of the probes, samples, and testing are included in Section 9 of the HSR.

The purpose of the LCE inspection was to verify the overall condition of the structure and to identify structural and non-structural deficiencies that may have changed since the previous inspection, performed by Baker Engineering NY, Inc., and completed in 2006 (see Baker Engineering NY, Inc. "Bridge Condition and Assessment Report: High Bridge," 4 vols. August, 2006). LCE found that the overall condition of the High Bridge is fair, and that no conditions requiring immediate action or repair were found during their inspection.

The purpose of the examination of the bridge by LSA, and the probes and testing, was to supplement inspections performed by LCE, specifically the railings, lamps, brick walkway construction, granite steps, and wrought iron pipe, and to provide documentation of materials and assemblies for the HSR.

6.2 GENERAL CONDITIONS

Typical conditions noted during the inspection include: deteriorated bricks and vegetation growth at the brick walkways, light to moderate rust at the railings, bent and broken sections of railing, non-functioning bridge lights, dampness with cracked brickwork, efflorescence, and mortar loss at attic side walls and structural brick arch above, heavy efflorescence with cracks and spalls at attic concrete walls at Piers 1 and 2, detrimental environmental conditions within the attic, pervasive corrosion of the wrought iron pipe, tilted cast iron pipe supports, heavy corrosion with section loss at ends of roof floor beams at the water main gallery, crevice corrosion at gusset plates in the steel arch span, heavy corrosion on the tie-rods supporting the deck at the masonry arch spans, and staining and mortar loss at the masonry piers and arches.

LCE concluded that the overall results of the 2006 Baker Engineering in-depth inspection have not significantly changed, except that LCE did not find active leaking into the attic and found that section loss of horizontal steel plates was less than observed by Baker. LCE found that, in general, deterioration of the bridge has not increased, and that the Baker Report findings may be relied upon for design of the proposed rehabilitation of the High Bridge, as updated by LCE.

6.3 MASONRY SPAN CONDITIONS

6.3.1 Stone Piers, Arches, and Abutments

LCE found that the granite piers, arches, and abutments are in fair condition. Typical conditions include thick vegetation growth, heavy stains, loss of mortar, heavy efflorescence, cracks and spalled stones near the base of the piers. The overall condition of the granite is similar to that described in the 2006 Baker Report, and has not changed significantly.

A linear elastic finite element analysis model analysis of the stone arch spans preformed by LCE shows tensile stresses present in the arches, which do not meet AASHTO requirements of zero tension. LCE also peformed a limit analysis which found compressive stresses within the arches much smaller than AASHTO compressive stress limits, indicating that the load bearing capacity of the arches is generally sufficient. For a detailed description of LCE's analysis of the stone arch spans see their report in this section of the HSR.

A limit analysis by Prof. John Ochsendorf, PhD of Ochsendorf DeJong & Block. LLC (ODB) found that for two critical loading conditions, full live load and asymmetrical live load, purely compressive solutions exist with low stresses in the masonry arches. OBD found that stone arches, together with the spandrel and haunch walls provide more than enough load capacity to ensure that the arch is stable with reserve capacity for significantly higher loading conditions than can be expected for its use as a pedestrian bridge. OBD noted that they were not concerned about the predicted tensile stresses from the linear elastic finite element analysis performed by LCE, because an elastic analysis makes a number of assumptions for unreinforced masonry that are not applicable, leading to predicted tensile stresses that are not a meaningful prediction of the safety of the structure. For a detailed description of OBD's analysis of the stone arches see the OBD report in this section of the HSR.

Piers 1 and 2, which were altered to serve as abutment piers for the steel span in 1928 by the thickening of the piers with reinforced concrete clad in a gray granite, exhibit heavy efflorescence at the top section just below the water main gallery. The granite cladding was laid in and pointed with a Portland cement mortar. Efflorescence is more significant on the faces of the piers under the steel span, but efflorescence is also present on the sides of the piers.

At Pier 1, a 1" gap with deep loss of mortar was noted at the joint between the between the granite-faced reinforced concrete section and the original granite pier at both the north and south faces.

At the base of Pier 2, which is located in the Harlem River, transverse cracks were noted along the joint between the the granite-faced reinforced concrete section and the original granite pier at both the north and south sides. LCE found a total of four vertical cracks on the south face, five vertical cracks on the north face and nine vertical cracks on the west (river) face. The cracks also extend into the granite pier base. Baker's underwater inspection found significant loss of mortar between the granite units, and cracks in the granite below water. (See Baker Report, Appendix I, Underwater Inspections).

For the original unaltered piers (3 to 10) and arches LCE found loss of mortar as a typical condition, with depth of loss ranging from less than ¾" at the piers up to 12" at the vertical joints of the intradoses of the arches. The granite is laid in a natural cement. The intradoses of the arches exhibit heavy efflorescence and stains and mortar loss due to water movement into the haunches from the attic. Generally, mortar loss is significant and in many areas complete, at all upward facings joints, such as impost blocks, string courses, pier tops, and copings.

The granite of the piers, arches, and spandrels was found to be in good condition, except at several of the Bronx piers, where isolated areas of spalled masonry stones were noted at or just above the base of the piers. These spalls were likely caused by impact or exposure to fire.

The bronze commemorative letters attached to the south face of Pier 5 are in good condition.

Both the Bronx and Manhattan abutments are covered with heavy vegetation growth. Vines are growing on the granite of both abutments and the roots are penetrating the mortar joints. Very large poison ivy vines are growing in the joints of the south side of the Manhattan abutment, and have caused movement of facing stones and coping stones. All coping stones around the Manhattan gatehouse have shifted from a combination of water infiltration and plant growth, causing mortar joints to open, which are allowing water to enter the abutments, and has also caused cracking and bending of the wrought iron railings (see below). Water has also entered the Manhattan abutment through gaps between the bluestone paving slabs, which are also cracked in many locations.

Small trees have begun to take root in both sides of the Manhattan abutment. At the base of the northeast corner of the Manhattan abutment, there are cracks up to ¼" wide, and mortar loss was pervasive and significant on all sides of the Manhattan abutment due to water infiltration from the gatehouse plaza and coping stones above.

The granite is generally soiled from more than 150 years of atmospheric pollutants. The piers and arches at the highways and railroad are heavily stained due to exposure to vehicle and locomotive emissions. Brown paint has been applied to the bottoms of all the highway and street piers to cover graffiti, up to 10' high. Gray paint has been applied to the lower section of Pier 2, the river pier to cover graffiti. The bottom of the piers within the MetroNorth fence has moderate graffiti.

There are large white epoxy drips on three sides of the bridge below the coping stone from installation of replacement tie rods following probes and samples taken by Baker Engineering.

6.3.2 Foundations

No inspections of the foundations were undertaken for this project. Four borings were taken by Baker Engineering to establish bedrock. Findings from the borings and historic documentation indicate that the piers are either bearing directly on bedrock, or are on deep wood pile foundations that are continually below ground water level, and that the abutments are founded on bedrock. Baker noted that they found no evidence of settlement of the piers and abutments. (See summary of foundations in Baker Report, p. 1-4).

6.3.3 Structural Brick Deck Arch

The general condition of the structural brick deck arch is good, with minor loss of brickwork and cracking observed in the attic below. Water penetration through the arch was observed at the steps at both ends and at the Bronx gate penetrations. Bricks tested by Baker Engineering indicated compressive strengths lower than expected results, however they are more than adequate for the applied compressive loads.

A load rating analysis of the brick deck arch and wrought iron tie rods by LCE indicate that the brick arch is slightly under required capacity, while the tie rods are adequate. LCE recommended additional tie rods to increase the capacity of the deck. For a detailed description of LCE's analysis of the structural brick deck arch, and their recommendations, see their report in this section of the HSR.

A structural analysis by ODB indicates very low compressive stresses in the brick arch, and also demonstrated an inherent stability in the arch with the existing wrought iron tie-rods. For a detailed description of the structural brick deck arch see the OBD report in this section of the HSR.

6.3.4 Wrought Iron Tie Rods

The wrought iron tie rods exhibit light to heavy corrosion and section loss, due principally to condensation. Some deterioration of the tie rods can also be attributed to leaks in the walkway above, but the principal cause of deterioration is condensation, exacerbated by water infiltration. Water infiltration is most pronounced under the steps at the two ends of the bridge, and section loss of the tie rods is greatest beneath the steps. The tie rods were originally 1-7/8" (47 mm) in diameter. A selected examination of the tie rods indicates a section loss from approximately 1-5/8" (41 mm) to 1-1/8" (28.5 mm) in the most severe areas under the steps.

Testing of samples of the tie rods for Baker Engineering by Lehigh University's Center for Advanced Technology for Large Structural Systems found an average yield strength of 27.7 ksi and an average tensile strength of 46.5 ksi, which Lehigh indicated as consistent with 19th century wrought iron. (See Baker Report, Appendix H, Tie-Rod Testing Report.)

Testing by Prof. Gordon indicates that corrosion attack at the surface of the tie rod has formed pits and detached layers of metal as scales, and the continuation of this process has resulted in the eventual loss of the undercut metal, and the formation of a groove in the surface, causing the fibrous texture of the corroded surface. The strength data and chemical analysis of the sampled tie rod fall within the range usually found for wrought iron used in structures. Corrosion is expected to continue on the exposed sections of the rods unless the scale is removed and the surface protected. See Prof. Gordon's description of the tie rods in Section 9 of the HSR.

6.3.5 Cast Iron Skewbacks

During Probe 3 (see Section 9 of the HSR) about 8' of the top edge of a cast iron skewback was exposed, and found to have only surface rust and minor pitting. The skewback was fully embedded in natural cement mortar. A sample of the skewback was tested by Prof. Gordon and the corrosion was found to penetrate to a depth of about 0.2 mm and he concluded that the minor penetration is because graphite flakes do not make a continuous path into the metal interior. Prof. Gordon noted that the cast iron is mechanically sound and the rate of corrosion sufficiently slow as not to degrade the strength of the casting for the foreseeable future. See Prof. Gordon's description of the cast iron skewbacks in Section 9 of the HSR.

6.3.6 Brick Underlayment and Waterproofing

Probe 3 (see Section 9 of the HSR) revealed that the attic brick underlayment and waterproofing under the brick walkway is an integral system of bricks dipped in hot asphalt and coal tar waterproofing and laid on top of ½" layer of the waterproofing, which matches the description of by Resident Engineer William L. Dearborn in his paper read before the ASCE in 1870 (see copy of paper in Appendix G). The waterproofing on top of the structural brick arch and between the brick underlayment (see below) was found to be loose and friable, with plant roots growing throughout. No testing of the waterproofing was done, except to confirm that it does not contain asbestos (see Appendix I) .

6.3.7 Brick Paving and Granite Steps

Typical conditions observed at the brick walkway on the masonry spans and gatehouse plazas include medium to wide cracks, broken and chipped edges of bricks of up to 1" wide, bricks with holes in their upper surfaces, spalled bricks, mortar loss, moss and small plant growth. The conditions of the brick walkway are consistent with the Baker Report and the deterioration has not increased significantly.

The bridge and gatehouse plazas are paved with approximately 23,355 SF of brick, of which approximately 15,360 SF are laid in a herringbone pattern over the masonry span and gatehouse plazas, the remaining approximately 7,995 SF are laid in a running bond pattern laid over the steel span (see below). The majority of the herringbone pattern brick is original brick, installed in 1864, with the exception of the Bronx gatehouse plaza and selected areas of the bridge, such as at original vault lights, which were replaced circa 1979 with a wire cut brick.

Most of the original brick walkway exhibits surface holes, broken bricks, moss and vegetation growth, and loss of mortar. The red bricks are blackened from nearly 150 years of atmospheric pollutants, and possibly from a coating.

The original brick paving of the masonry span is a hard-burned red paving brick set in herringbone pattern laid on a natural cement mortar bed directly on top of the underlayment bricks. The walkway joints were also pointed in natural cement mortar, and the mortar was found in Probe 3 (see Section 9 of the HSR) to be extremely well adhered to the brick.

There are longitudinal cracks at the center and quarter points of most of the walkway, indicating a hinging movement from expansion and contraction of the walkway. These cracks appear in most early photographs of the bridge and have been repointed numerous times over the years with Portland cement mortar. Typically there is vegetation and moss growth along the mortar joints between the stone coping and brick. Based on Dearborn's 1870 paper, the Baker Report notes that grooves were installed in the brick at these three points to prevent cracking of the brick. During the exploratory probe phase, no evidence of these grooves was found.

The circa 1979 wire cut brick was installed over original vault light openings, set on either a corrugated steel pan or plywood. Piles of original brick paving and underlayment brick can be found under each vault light opening in the attic below. The original iron vault light framing is visible from the attic, and fragments of the vault lights can be found in several locations in the attic.

It was found in Probe 4 (see Section 9 of the HSR) that the Bronx gatehouse plaza paving was replaced circa 1979 with wire cut bricks laid over a sand bed. The original brickwork sloped towards the granite steps, but the rebuilt plaza was laid without a slope, and the granite steps raised and laid with much thicker bed joints (approximately 1"). The Bronx granite steps are cracked in several locations and have open mortar joints. The Bronx plaza brick and structural arch are pierced by the steel gate posts installed circa 1979, which is the principal direct source of water infiltration into the attic at the Bronx end. The Manhattan gatehouse steps have open mortar joints and the steel gate braces are bolted to the steps in two locations.

6.3.8 Mortar

Based on historic documentation all mortar used for both granite and brickwork on the original 1848 construction and the 1864 alteration was a natural cement, tan in color. Natural cement was confirmed by petrographic examination by John J. Walsh. See Baker Report, Appendix B, Material Sampling Reports.

6.3.9 Vault lights

There were thirteen cast iron vault lights with glass lenses set into the structural brick arch of the masonry span to provide daylight into the attic. Two vault lights were located in the Manhattan plaza and eleven on the bridge, alternating sides at each pier. All of the original thirteen vault lights were removed circa 1979. Three were replaced with manholes for access into the attic, and the other ten were covered with wire cut brick (see above). The vault lights and manholes have historically leaked and deterioration of the wrought iron pipe is greater below the vault light openings.

6.3.10 Attic

Typical conditions found in both ends of the masonry span attic include cracking of brickwork, mortar loss, efflorescence, accumulation of rust and brickwork debris on the floor, active leaks through the walkway above and the Bronx end gate post, high humidity, lack of ventilation, condensation on the underside of the walkway arch above, brick sidewalls, and wrought iron pipe, which freeze into ice sheets in the winter. The conditions found in the attic are consistent with those described in the Baker Report, with the exception of an understanding of the severity of the cracks in the brick sidewall arches at the Bronx end.

Active leaks were observed under both sets of granite steps, where plant roots have grown down through the walkway, steps, and structural brick arch, and at the Bronx gate steel posts that penetrate the walkway structural brick arch.

Efflorescence covers up to 70% of the walls, and moisture from condensation was observed over all brick surfaces of the attic. A white coating on the surface of the attic chamber walls was tested by JBCI and found to be whitewash.

At the base of the sidewalls there are intermittent small piles of eroded mortar and efflorescence. There is a general loss of mortar at the base of the wall of ½" to 1" depth, and an erosion or spalling of the brick surfaces in the same areas, all caused by water movement through the wall cavity causing efflorescence.

The sidewall brickwork of the attic exhibits horizontal and diagonal cracking at the mortar joints in several locations, generally in the area of the joint between the 1848 and 1864 construction. Some cracks are as long as 25' and range from hairline to ½" wide. The cracks do not appear to be recent and are likely caused by old differential movement of the two eras of construction, possibly in relation to slight settlement of the pile supported piers.

At the Bronx end of the attic there are two cracking conditions of note: wide cracks at the sloped "ceiling" where three walkway structural arches intersect, and cracks and brick loss at both sidewall opening arches, which were included as a "Flagged Bridge Report" item in the Baker Report Appendix J – Flag Reports.

The walkway structural arch at this point consists of three intersecting segmental arches – with one sloped to provide structure for the Bronx end steps. The walkway arch is 12 inches thick constructed with the same cast iron skewbacks and wrought iron tie rods in tension as the remainder of the walkway. The sidewall brick opening arches are 3 wythes thick, in a 4-plus wythe thick wall that was cut away to allow sliding doors to fully retract. At some point the larger opening was infilled with granite to provide a smaller door opening, which is now infilled with CMU. The brick wall is laid up against the granite exterior abutment walls.

There are two cracks at the ceiling at the intersections of the three walkway structural arches. These cracks are at the bottom of the Bronx steps. The lower one is more than 1" wide, and has a thick crust of efflorescence indicating a long-term leak. The masonry in this end of the attic is almost always wet and saturated from leaks and condensation. It appears that cyclical freeze-thaw of water in the crack is exacerbating the cracking.

There are also cracks at the west side of the sidewall opening arches, and missing bricks towards the center of the sidewall opening arches on the underside. The area of the missing bricks is approximately 4 square feet and up to 6 inches deep at identical locations in both arches.

Both locations of cracks at the Bronx end are most likely due to thermal expansion and contraction forming a natural expansion joint in the masonry. There is no evidence that overloading is a cause of the cracking at the Bronx end.

At the Bronx end sidewall opening iron doors exhibit heavy corrosion with significant section loss, and are falling off the iron frames. There are stone and mortar blocks behind the iron doors which were used to seal the entrance into the attic from the outside

Conditions at the Manhattan end of the attic are similar to the Bronx end, except that the construction varies in that structure supporting the steps is different, and there are no sidewall openings, so the cracking problems found on the Bronx end are not present.

Throughout the attic there is a thick accumulation of dust and debris, consisting of lead paint flakes, rust shards and flakes from wrought iron tie-rods and the wrought iron pipe, mortar, brick, efflorescence, and trash from former work in the attic. There are also piles of brickwork beneath each closed vault light, and piles of fragments of broken cast iron pipe at both ends of the attic. At the Bronx end there are also piles of brick and stone from sections of steps that have been partially demolished.

6.4 STEEL SPAN CONDITIONS

6.4.1 Steel Arch

LCE observed that the steel arch span is in good condition and that no conditions were present requiring immediate action or that can be categorized as priority or safety repairs. See the LCE "High Bridge Inspection Report" included in this section of the HSR for a detailed description of steel arch structural conditions, including photographs.

General conditions observed at the ribs, spandrel columns, lower lateral system, spandrel columns, transverse vertical bracing, upper lateral system, hinges, and roller nest bearing include paint loss, minor to heavy rust,

isolated areas of pitting, debris accumulation and crevice corrosion at elements close to horizontal or where water collects as the bottom angles and gusset plates, isolated areas of section loss.

Of note are the conditions of the four roller nest bearings, which are in poor condition, with anchor bolts and nuts exhibiting section loss. Additionally, the bearing plates showed heavy corrosion, loss, and heavy rust and pitting. LCE observed that contrary to the Baker Report the section loss of the steel plates in this same area was observed to be up to 25% material loss and that the material loss was found at isolated areas within each individual plate and is not as severe as previously reported in the Baker Report, which noted several steel plates that exhibit 30% to 70% section loss at areas close to the middle of the span where the plates are near horizontal.

6.4.2 Water Main Gallery

LCE found that deterioration of the steel of the water main gallery has been caused by water infiltration through the walkway and roof plates, indicated by heavy efflorescence at the leaks, and that the condition of the structure ranges from fair to poor. LCE found that conditions are consistent with those presented in the Baker Report. See the LCE "High Bridge Inspection Report" included in this section of the HSR for a detailed description of the water main gallery structural conditions, including photographs.

Typical conditions at the water main gallery include paint loss, minor to heavy rust, guano and debris accumulation and corrosion at crevices and isolated areas of section loss.

Extensive section losses were found in the deck supporting members, largely due to water leakage through the joints and several cracks in the coping plates. The roof plates are in fair condition, with inspections from below and at Probes 1 and 2 indicating typical deterioration, which includes loss of paint, surface rust, cracks at the splice plates of the coping and efflorescence due to water leakage from the brick walkway through the joints of the roof plates.

Typical conditions at the built-up roof floor beams include heavy efflorescence, rust, paint loss and heavy section loss at the web, top and bottom flanges, and substantial rivet head loss. The most extensive corrosion occurs in areas close to where the outer stringers frame into the floor beams and at the floor beam ends. In some locations, the section loss at the floor beam flanges measures up to 100% along the edges. There is also evidence of heavy crevice corrosion at the bottom flanges with floor beam web section loss of 50% to 75%. The top and bottom angles also exhibit substantial section losses to the rivet heads where the outer stringers frame into the floor beams.

The outer roof stringers are in worse condition compared to the inner stringers. Most of the stringer deterioration is located at the area where they frame into the floor beams. Typical deterioration of the outer roof stringers includes section losses to the web and flanges, heavy efflorescence, rust, and extensive paint loss. In several locations, the web has rusted through.

There are deep accumulations of pigeon guano from pigeons nesting in the laced beams and roosting throughout the gallery. The access platforms are covered with guano, lead paint, and rust which conceals most of the walkway. At the south walkway, section loss with holes were noted on the edges of the plate at mid-span

6.4.3 Brick Paving and Steel Coping Plates

Typical conditions observed at the brick walkway on the steel span includes efflorescence, heaved sections of brick up to 1 ½" high, mortar loss, raised and depressed bricks at the edge of the steel coping, moss and small plant growth. The conditions of the steel span brick walkway are consistent with the Baker Report and the deterioration has not increased significantly.

The steel span is paved with approximately 7,995 SF of red pressed running bond pattern brick, installed in 1928. As uncovered in Probes 1 and 2, the brick is pointed with what appears to be a white Portland cement

and are set on a one inch sand setting bed, on an approximately 2" thick reinforced mortar slab, with 2"x2" WWM. A bituminous expansion joint material was found at the joint between the brick and coping and brick and transverse steel plate. All details appear to match the 1926 "High Bridge Reconstruction" construction drawings.

At most of the steel span the brick surface is higher than the adjacent steel coping plates by approximately 1½". The movement appears to be a result of frost heave of the brickwork from water leaching into the sand and mortar bed. There is heavy moss and vegetation growth at the joint with the coping plates. The coping plates have isolated areas with minor rust, 1/8" pitting, minor to moderate paint loss and corrosion within 5" of the walkway edge. The utility access covers at some of the locations on the steel coping plates are missing bolts.

There are three steel expansion joints in the deck, corresponding to the location of the three steel span hinges. At the east end of the span, bricks adjacent to the expansion joint are spalled and dislodged where the steel plates moved during thermal expansion. Similar conditions exist, but not as severe, at the other two expansion joints, which are located mid-span and at the west end. There are also eight relief joints in the brick paving of the steel span. There is evidence of vegetation and moss growth through the joint at some locations but they are generally in good condition

6.4.4 Concrete Transition Between Masonry And Steel Sections

At both Piers 1 and 2, conditions noted by LCE include cracks with heavy efflorescence, areas of hollow-sounding concrete, and concrete spalls. The encasement of the roof beams also exhibit concrete spalls, exposed rebar, cracks with efflorescence and hollow-sounding areas. These findings are consistent with the Baker Report. See the LCE "High Bridge Inspection Report" included in this section of the HSR for a detailed description of the concrete conditions, including photographs.

6.5 AQUEDUCT PIPES

An inspection of the supports for the wrought iron pipe was completed by LCE, and an examination of the conditions of the wrought iron and cast iron pipes was undertaken by LSA and CSI. See the LCE "High Bridge Inspection Report" included in this section of the HSR for a detailed description of the pipe supports, including photographs, and CSI's "Conservation Assessment of Selected Historic Iron Elements of the High Bridge" for a detailed description and photographs of the pipe conditions, and Prof. Robert Gordon's "Metallurgy or the Croton Aqueduct, High Bridge Iron, First Report," for metallographic analysis of the iron, both included in Section 9 of the HSR.

6.5.1 90 ½" Wrought Iron Pipe and Pedestals

The cast iron pipe supports and saddles exhibit pervasive surface rust and loss of paint. The pipe supports and saddles were originally painted with Prince's Metallic Paint, an iron oxide protective coating. Numerous parts of the pipe saddles have broken off, although the capacity to support the pipe has not been impinged. A fragment of a pipe support was examined by Yale University metallographer Prof. Robert Gordon, who found it to be made of slightly mottled pearlitic gray cast iron, with a moderate phosphorous content, and a discontinuous chill margin of pearlitic gray iron 0.65 mm thick at the surface of the casting. Corrosion has undercut metal on the surface due to the structure of the chill margin, however due to the thickness of the castings the corrosion is insignificant to the stability of the pipe.

LCE noted that all the roller bearings are rusted and do not move as intended. Approximately 25% of the pipe supports have a misaligned cradle or bearings, are missing supports or have tilted support pedestals. The remainder of the supports are frozen and not functioning as designed. The pipe is unsupported due to a missing cradle at the roller bearing near Pier 1. The concrete at the base of the pedestals is spalled in some locations. LCE has noted that the condition of the pipe supports is consistent with the Baker Report.

LSA and CSI observed that the environmental conditions in the attic are a significant cause of corrosion of the pipe and its supports, including: overhead leaks allowing the acidic rainwater to drip on the pipe, high relative humidity and resultant condensation, condensation dripping on the pipe from tie rods spaced five feet on center, and condensation dripping on the pipe from the bottom of the structural arch above.

The interior and exterior surfaces of the pipe have lost approximately 1/8" to 1/4" of iron from corrosion, which is most obvious in the approximately 3" thick layer of iron oxide flakes and paint that have accumulated inside the pipe and on the attic floor. In the attic section large delaminated sheets of iron bonded together by paint remain on the upper exterior surface. The pipe was originally painted on the interior and exterior with Prince's Metallic Paint. The delaminating sheets are not present on top of the pipe in the steel span because the pipe was removed and reinstalled during the 1928 construction and the delaminations were removed at that time. No additional rust sheets have formed due to the air circulation and lack of condensation at this section of the pipe.

Deterioration of the pipe at the 1928 steel span section differs from that seen within the attic spaces, including a greater incidence of surface pitting rather than flaking, and the accumulation of significant calcite runs from leaks in the walkway above, as well as bird guano.

Samples of the wrought iron were taken by PCLS in three locations for testing by Yale University metallographer Prof. Robert Gordon. Measurements of the three samples by LSA indicates that on average the pipe retains approximately 1/4" to 3/8" of the original 1/2" of metal, with loss of thickness from corrosion of the inside of the pipe slightly less than the outside. Even though there is loss of material on both sides of the pipe throughout its length, resulting in holes in numerous locations, the pipe is generally sound.

CSI noted that deterioration of both interior and exterior pipe surfaces is most obviously visible as widespread delamination of thin fragments or layers of iron, which become detached in flakes of varying sizes. The surfaces also exhibit pervasive blistering and cratering, with holes in many locations, mostly in the top sections of the pipe. Since the metal structure is the same at both the outside and inside surfaces of the pipe, the difference in corrosion attack originates in the different corroding environments on the inside and outside.

The holes originated as cratered corrosion at the interior, caused by wetting of the iron after more than 90 years of active use as a water main. The craters were first noticed in the late 1860s by Croton Aqueduct engineers soon after the pipe was placed in service, and an attempts were made to arrest the corrosion by painting the interior of the pipe and installing zinc plates with the mistaken belief that they would function as sacrificial anode. The corrosion of the exterior of the pipe from condensation and leaks caused the final loss of material resulting in the holes on the upper sections of the pipe.

Testing of three samples of the wrought iron pipe by Prof. Gordon indicate that the original manufacturing process of the wrought iron and fabrication of pipe have contributed to its corrosion. Prof. Gordon found that the wrought iron has a high concentration of slag inclusions, far in excess of that in even the most ordinary grades of wrought iron. All of the slag inclusions are fully shattered by fractures, probably from the cold rolling process used in fabrication of the pipe from puddled iron sheets. Where pits have penetrated to slag fibers the attack has followed the fibers into the metal interior. Since the slag fibers are approximately parallel to the surface this results in undercutting of the metal, causing the isolated metal to eventually corrode completely and flake off. This may be the cause of the craters found on the interior of the pipe soon after it was placed into service.

6.5.2 36" Cast Iron Pipes

Fragments of broken sections of the original 36" cast iron pipes are stacked at both ends of the attic and two runs of pipe, approximately 50' long, remain in place at the Manhattan end of the attic. Paint analysis by JBCI found that the cast iron pipes were also coated with an iron oxide paint, probably the same Prince's Metallic Paint that coated the wrought iron pipe and supports. Prof. Gordon found that the pipe is made of ferritic

gray cast iron and that corrosion has attacked the inside surface of the pipe to a depth of 0.6 to 0.7 mm. The corrosive attack started as pits and propagated inward along the graphite flakes, and because the graphite makes a continuous path into the metal's interior, the penetration is relatively deep. The iron at the outside surface of the pipe has a chill margin of pearlitic gray iron 0.6 mm thick, and corrosion of this surface proceeds primarily by solution of the ferrite constituent of the pearlite, and would have advanced more slowly than on the inside surface since the pearlite does not afford easy channels to the interior metal. Because the cast iron has large section thicknesses it will last for a prolonged time without attention.

6.6 RAILINGS

Both sides of the brick walkway and the gatehouse plazas have braced iron railings. Wrought iron railings with cast iron posts were installed in 1850 around the gatehouse plazas, and cast iron railings and posts were installed in 1864 on the sides of the masonry span, and in 1928 on both sides of the steel span. All of the railings have been repaired and altered by the installation of additional braces over the years, with the last significant repairs completed by the Parks Department in circa 1979. The railings are in fair condition and LCE notes that the conditions of the railings are consistent with the Baker Report.

Typical conditions for all the railings includes: surface rust, general paint loss, cracked castings, bent top rails and balusters, missing cast sections of the railings, as well as finials and fasteners, and inappropriate repairs and braces. The top of the railing ranges from 3'-4" to 3'-6" high. The open space between the balusters ranges from 5" to 8" depending on era of construction and location.

In general the wrought iron sections of the 1850 railing are in the best condition, exhibiting only bent and repaired sections from movement of the Manhattan gatehouse plaza coping stones. In several locations the cast iron posts of the 1850 railing have cracked bases, missing side panels, and most finials have been broken off, with the notable exception of three locations on the Bronx side where the original finials remain. One section of 1850 railing on the Bronx side has been replaced with steel angles.

The 1864 railings are in fair condition, with notable conditions including bent sections in plan, due to lack of expansion provisions. Because of this movement and probably a general lack of stability of the railing, steel braces were installed circa 1979 and later, on both sides of the railing, anchored into the granite coping and the brick walkway. The inboard braces pose a tripping hazard. The original outboard railing braces were set in lead in holes in the granite coping stones, but have been removed and cut flush with the granite. The brace remnants are rusting and causing the coping to crack in numerous locations. The bottom rail, which was presumably originally cast iron, was replaced circa 1979 with a steel channel. The bottom rail was originally braced by U-shaped iron brackets set into the coping, but they were cut down flush to the coping, presumably when the steel bottom railings were installed. Two cast iron S-scroll brackets at the Bronx steps are missing, though one is lying in the brush at the bottom of the abutment. All the original finials on the 1864 railings have been replaced.

The 1928 cast iron posts on the steel span are in the worst condition, generally cracked at the bottom from rust jacking of the bottom rails which are inserted into the posts. The railing breaks to provide expansion joints at the steel span hinge joints, where the baluster spacing changes drastically and the arches become pointed. The finials on the 1928 railings appear to have been replaced during the circa 1979 work.

6.7 POWER AND LIGHTING

There is no active power or lighting on the High Bridge, although a non-functional temporary power line connects to a street light along the Harlem River Drive, which was installed for the inspections by Baker Engineering. The cast iron bridge lighting, installed in 1935, has missing electrical connections and broken luminaires. The cast iron sections of the fixtures are intact, exhibiting flaking paint and surface rust. The conduit for the bridge lights is surface mounted on the granite and steel copings. The navigational lights do not have power and are not well attached to the steel span. Light fixtures installed in the attic, possibly for the

Baker Engineering inspection, are not functioning and some have been vandalized over the years and are damaged or missing.

High Bridge Inspection Report

BIN: 2-24658-0

Boroughs of Manhattan and The Bronx, New York



Lichtenstein Consulting Engineers

The Empire State Building

350 Fifth Avenue

Suite 924

New York, NY 10118

Phone: 212-244-1600

Fax: 212-244-4488

September, 2010

Lichtenstein
Consulting Engineers

Executive Summary

Lichtenstein Consulting Engineers, P.C. performed an inspection of the High Bridge (BIN 2-24658-0) over the Harlem River from March to August 2010 as part of the design for the rehabilitation of the bridge and in association with the City of New York Department of Parks and Recreation and the NYC Department of Design + Construction (Contract #M037-707M PlaNYC). The purpose of the inspection was to verify the overall condition of the structure and to identify any structural and non-structural deficiencies that may have changed since the previous inspection, performed by Baker Engineering, completed in 2006.

The overall condition of the High Bridge is fair. No conditions requiring immediate action or repair were found during this inspection.

The top of deck and attic area was inspected by means of walking and using an extension ladder. The steel span was inspected using industrial rope access provided by CAN USA. The masonry arch spans were inspected using a 120 ft. manlift and lane closures with MPT provided by Metro Traffic Safety Corp.

Typical conditions noted during the inspection include: deteriorated bricks and vegetation growth at the top of deck, light to moderate rust at the railings, non-functioning bridge lights, dampness with cracked bricks and mortar loss at attic walls and ceilings, heavy efflorescence with cracks and spalls at concrete walls atop Piers 1 & 2, heavy corrosion on water main pipe and supports, tilted water main pipe supports, heavy corrosion with section loss at ends of roof floorbeams at the water main gallery, crevice corrosion at gusset plates in the steel arch span, heavy corrosion on the tie-rods supporting the deck at the masonry arch spans, staining and mortar loss at the masonry piers and arches.

These noted conditions are consistent with the Baker report from August 2006 except for the following items:

The Baker report noted that “The Attic is subject to water infiltration from both the gatehouses and from the bridge surface, especially in locations close to the gatehouses. Rainwater penetrates through the mortar gaps on the granite steps, along the roots of the shrubs that have sprouted at both sets of steps, and around the posts that support the wrought iron gates.” Although the ends of the attic, under the gatehouses, have more moisture, dampness and efflorescence compared to other sections, no active leakage was observed during this inspection.

At the steel span, the Baker report noted several steel plates that exhibit 30% to 70% section loss at areas close to the middle of the span where the plates are near horizontal. During this inspection, the section loss of the steel plates in this same area was observed to be up to 25% material loss. We note that this material loss was exhibited at isolated areas within each individual plate and not as severe as previously reported.

The overall results of the 2006 in-depth inspection have not significantly changed, except as noted, and the deterioration has not increased. The previous findings may be relied upon for design of the proposed rehabilitation.

Table of Contents

	Section	*Page*
	Executive Summary	ii
	Table of Contents	iii
	Introduction	iv
I.	Top of Deck	1
	• Masonry Arch Spans (Spans 1 & 3-11)	4
	• Steel Arch Span (Span 2)	7
II.	Railing	9
III.	Bridge Lights	12
IV.	Attic Walls and Ceilings	12
	• East Attic (Bronx Side)	13
	• East Attic Roof	19
	• West Attic (Manhattan Side)	20
V.	Concrete Walls at Piers 1 and 2	22
	• Pier 1	22
	• Pier 2	24
VI.	Utilities	25
VII.	Water Main and Supports	27
VIII.	Water Main Gallery	29
	• Roof Plates	30
	• Roof Floorbeams	31
	• Roof Stringers	33
	• Laced Beams	34
	• Column and Knee Bracing	34
	• Access Platform	35
	• Fascia Plates	35
IX.	Steel Arch Span	36
	• Ribs	36
	• Lower Lateral System	37
	• Spandrel Columns	38
	• Transverse Lateral Bracing	39
	• Upper Lateral System	40
	• Hinges	40
	• Roller Nest Bearings	41
X.	Masonry Piers and Arches	42

Introduction

The High Bridge is a multiple span arch structure, with a height of almost 140 feet over the Harlem River, connecting the New York City Boroughs of Manhattan and the Bronx. The bridge also crosses what are now Metro North Railroad, Major Deegan Expressway, Harlem River Drive and local roads. It is the oldest surviving bridge in New York City.

The bridge was built as part of the Croton Aqueduct, which supplied the city with water, and was placed in service in 1848. It was designed by the aqueduct's engineering team led by John B. Jervis. James Renwick, Jr., who later went on to design New York's landmark Saint Patrick's Cathedral on Manhattan's Fifth Avenue, participated in the design.

Originally designed as a fifteen span stone arch structure, the High Bridge had the appearance of a classical Roman aqueduct. Construction was started in 1837, and completed in 1848. The bridge was primarily composed of coursed ashlar granite masonry. It has a length of about 1,283 feet measured from abutment to abutment. There are retaining wall sections on both the Bronx and Manhattan approaches, totaling about 170 feet, where the elevation of the slope no longer requires an extended span. Gatehouses with additional retaining structures of similar construction extend beyond the approaches. The stone piers and abutments of the bridge are supported by timber mat foundations, founded on timber piles or carried to rock. The clear span of the masonry arches varies from 50 feet to 80 feet and is semicircular in shape. The total width of the deck is 28'-6".

Pier columns are rectangular in shape with three internal voids. There is a decorative coping between the top of pier column and the arch springline. The closed spandrel walls terminated about six feet above the crown of arch and floor in the 1847 construction, forming an open trough to carry two three foot diameter water pipes. The concrete floor was supported on internal longitudinal ribs within the spandrel walls, which were lined with brick masonry. The trough was backfilled with gravel over the pipes and paved for pedestrian use. There was no provision for thermal expansion or contraction in the structure, it was monolithic from one end to the other and did not require joints.

In the early 1860's, the High Bridge aqueduct was enlarged to carry a 7.5 foot diameter pipe. The stone masonry spandrels and their brick lining were extended about six feet higher and covered with a 12 inch thick brick arched slab, which formed a roof to the pipe chamber. This feature of the bridge is called the "Attic". The Attic is about 13.75 feet wide and height of about 15.5 feet. The minimum depth of an arch span at its centerline is approximately 20 feet, with a depth of either 41 feet or 60 feet at the piers.

The arch slab was strengthened by means of closely spaced wrought iron tie rods, embedded within the upper portion of the spandrel walls and at right angles to the aqueduct. Underlayment, waterproofing and herringbone patterned brick paving were placed on the slab. The enlarged arches and new deck were monolithic over their entire length, as the original structure was.

An iron handrail was installed on the new coping to ensure safety for pedestrians crossing over the river.

The 7.5 foot diameter wrought iron water main is supported by cast iron stanchions with saddle assemblies to allow for differing thermal expansion between iron and masonry. Stanchions are spaced at about 12 feet in stone masonry spans and 18 feet in the steel arch. Some are anchored together with rods near the midpoint of the structure to provide a fixed point.

During the early 1920's, the War Department tried to force the demolition of the High Bridge to improve navigation clearances over the Harlem River. A clearance of 100 feet above mean high water was required. After a campaign by numerous public and private parties, the bridge was preserved with modifications.

Five of the stone arches over the Harlem River were demolished and replaced by a three-hinged steel arch span, typical in style to many arch highway bridges of the early 20th century. Two steel deck arch structures with similar features are located just north of High Bridge, also spanning the Harlem River.

The arch has a span length of 426 feet and is comprised of ribs spaced at 21 feet between centers. The ribs are doubled, six foot deep, built up plate girders. The arch is hinged at both ends where it attaches to the piers and at its center by means of 17 inch or 14 inch diameter pins. The entire steel structure can rotate about the pins to accommodate thermal movement. Spandrel columns varying in length from about 3 feet to 70 feet extend upward to carry the deck at the correct elevation. Arches and deck structure are connected together with substantial lateral bracing and cross bracing.

The piers from the original stone pier construction were extended toward the river and strengthened to withstand the large horizontal forces needed to support a long span arch.

The pipe gallery is comprised of steel plate girders on crossbeams spanning between steel spandrel columns, extending up from the arches to support the bridge deck, water main and access walkways. The deck is made up of steel floorbeams framed into fascia girders that are also supported by the spandrel columns, I-beam stringers and steel plating, with running bond brick paving over a mortar bed. Width of the span at deck level is 28'-6".

Transitions between the brick and steel decks are concrete slabs. Three expansion joints are placed in the deck to accommodate the hinge rotations from thermal movements.

There have been no significant modifications or major maintenance of the High Bridge structure since the installation of the steel arch, except for repairs to the paving and handrails and painting the steelwork. The aqueduct was taken out of service during the 1950's and the bridge closed to the public during the 1970's.

The High Bridge was evaluated as a structure according to current engineering practice for transportation facilities. The structure was physically inspected to determine the extent, location and severity of deterioration. A ground survey of the bridge and its connections to the parks on both sides was performed. Samples were taken of the various materials making up the bridge and tested in the laboratory. An analysis of the different structural systems was conducted to ascertain their capacity to

carry the intended existing and new loadings. Finally, an evaluation was performed to confirm that the needed rehabilitation and strengthening were feasible.

The evaluation of the structure was conducted in two phases. An in-depth inspection and extensive material testing program was performed circa 2006 by Baker Engineering for the New York City Department of Transportation. This was accompanied by an analysis of the steel arch, stone masonry arches and brick deck slab.

The inspection findings at that time indicated that the structure was in good condition, overall, but had some areas of significant deterioration. The bridge was reinspected by Lichtenstein Consulting Engineers in 2010 as part of the rehabilitation contract. No significant changes to the previous findings have been found. Some additional material sampling and testing was performed to supplement the previous testing program.

I. TOP OF DECK

The bridge deck surface is comprised of a brick pedestrian walkway that crosses over the Harlem River Drive, the Harlem River, Metro-North Railroad, Major Deegan Expressway and local streets. The total span length is 1,183'. The Manhattan approach has a length of 28' and the Bronx approach has a length of 151'. The out-to-out width is 28'-7" on the masonry spans at the piers and 25'-1" at all other locations. On the steel span, the width is 28'-6". The brick walkway measures 17'-1" wide and the remainder of the width is taken up by either granite coping stones on the masonry arch spans or steel coping plates on the steel arch span on both sides of the walkway. The surface of the brick walkway has a crown, varying from 3.5" to 4" high.

There are two arrangements of brick patterns on the top surface; herringbone and running bond. The herringbone pattern, installed in 1862, consists of dark red bricks, measuring 3½" x 7 ¾" x 2" deep. This pattern discontinues at approximately 14' from the end of span 1, giving way to a new running bond brick pattern installed in 1927 **(See Photo 1).**



Photo 1: Running Bond bricks installed in 1927.

This new brick pattern is composed of a 3" layer of mortar containing a 2"x2"x⅛" wire mesh covered with a single layer of paving bricks, reddish in color and set on edge. The running bond pattern continues through span 2 (steel arch span) and terminates at the beginning of span 3 **(See photo 2).**



Photo 2: Running Bond bricks end.

The herringbone pattern resumes from there for approximately 72’ into span 3, replacement brick is used that differs in composition and color than the original paving. At this point, the original brick begins again and carries on for the remainder the bridge **(See photo 3).**



Photo 3: Herringbone pattern bricks continue.

There are currently three existing manholes enabling access to the attic from the top of deck. One is located at Pier 2 on the north side of the walkway **(See photo 4)**.



Photo 4: Access manhole at Pier 2.

The other two manholes were installed after the 2006 inspection at Pier 5 on the south side of the walkway and at Pier 10 on the north side of the walkway **(See photos 5 & 6)*,*** respectively. New replacement brick was initially placed at all these locations prior to the installation of these new manholes as shown in the 2006 inspection report. In addition, there are several locations of brick patches of varying sizes at different areas along the top of deck **(See photo 7*).***



Photo 5: Access manhole at Pier 5.



Photo 6: Access manhole at Pier 10.



Photo 7: Existing patch on top of deck, TYP.

At each pier, there are patches of brick of varying sizes that do not match the original bricks. At some point in time, the manholes located in these areas were partially removed. The upper portions were completely removed and the remaining manhole sections, contained within the brick arch, were covered with wood/metal plates and the spaces above them were filled with mortar and surface bricks. These areas are located at the north section of the walkway at the

even-numbered piers and at the south section for the other piers. Some portions of the original manholes can be seen from inside the attic space **(See photo 8).**



Photo 8: Access manhole blocked.

Typical deficiencies that were noted during the inspection of the brick walkway on the masonry and steel spans included efflorescence/leakage, medium to wide cracks, broken and/or chipped edges of bricks of up to 1" in diameter, bulging and depressed bricks up to 1 ½" deep, bricks with holes in their upper surfaces, spalled bricks and mortar, depressed bricks at edge of coping up to 1 ½" deep, deep surface scaling, missing mortar or loss of mortar up to 1" deep, moss and vegetation growth.

- <u>Masonry Arch Spans (Spans 1 & 3-11)</u>

  Most of the brick walkway in these spans exhibits surface holes, broken bricks, moss and vegetation growth, and loss of mortar **(See photos 9 & 10).**



Photo 9: Surface holes & missing mortar.



Photo 10: Surface holes, broken bricks & vegetation growth.

There is occasional vegetation and moss growth along the mortar joints between the stone coping as well as the interface between the granite coping and brick surfaces **(See photo 11*).***



Photo 11: Vegetation growth.

Longitudinal cracks propagate for several feet in length, in certain areas, indicating that the walkway surface has settled, possibly due to frost heave action **(See photo 12)**. The stone coping also exhibits cracks at random locations **(See photo 13)**. There are numerous areas where longitudinal mortar joints between bricks opened up and were repaired. These repair areas are conspicuous due to their much lighter color that contrasts with the surroundings **(See photo 14)**. There are also numerous areas on the deck surface that are bulging and/or depressed **(See photo 15)**, most likely due to vegetation growth through the joints pushing up against the bricks and frost heave action.

The findings for the top of deck in the stone masonry spans during this inspection are consistent with the Baker report from August 2006 and the noted deterioration has not increased significantly.



Photo 12: Longitudinal cracks on top of deck.



Photo 13: Stone coping exhibits cracks on top of deck.



Photo 14: Mortar repair and brick replacement creating unique pattern on top of deck.



Photo 15: Bricks bulging due to vegetation on top of deck.

- Steel Arch Span (Span 2)

  In span 2, the brick surface is higher than the coping plates by approximately 1½" and there is heavy moss and vegetation growth at the interface with the plates. The steel coping plates flank the brick walkway on the north and south sides. They exhibit isolated areas with minor rust, 1/8" pitting, minor to moderate paint loss and corrosion within 5" of the walkway edge (**See photo 16)**.



Photo 16: Brick surface 1 ½" higher than coping plates.

The utility access covers at some of the locations on the steel coping plates are missing bolts (**See photo 17)**.



Photo 17: Utility access covers missing bolts.

There are three steel expansion joints in the deck, corresponding to the location of the three hinges. At the end of the span near pier 2, bricks adjacent to the expansion joint are spalled and dislodged where the steel plates moved during thermal expansion (**See photo 18)**.



Photo 18: Bricks at expansion joint dislodged due to thermal expansion.

Similar conditions exist, but not as severe, at the other two expansion joints, which are located at begin and mid-span. There are also eight (8) relief joints in span 2. There is evidence of vegetation and moss growth through the joint at some locations but they are generally in good condition **(See photo 19).** There is also evidence of mortar repair at the joints **(See photo 20).**

The findings for the brick paving in the steel arch span noted during this inspection are consistent with the Baker report from August 2006.



Photo 19: Relief joint approximately 365' from Manhattan stairs.



Photo 20: Typical mortar repair.

II. RAILING

Running the entire length of the bridge and the approaches are decorative railings that are a combination of wrought iron and cast iron parts. These railings have support bars with varying spacings and designations. The support bars are anchored into the deck in two different ways. Some are fastened to the deck with bolts and others are embedded into the deck. The original (1864) bars are anchored into the stone coping **(See photo 21).** In addition, several sections of the railing on the south side of the bridge, from the Bronx stairs to the abutment have support bars that extend into the walkway, posing a tripping hazard **(See photo 22).**



Photo 21: Typical railing support anchored into stone coping.



Photo 22: Railing supports intrude into walkway pose tripping hazard.

Some new supports are bolted into the coping stone as shown over the Major Deegan Expressway **(See photo 23).**



Photo 23: Typical railing supports bolted into stone coping.

The railing support bars vary in pattern at numerous locations throughout the length of the bridge. For example, some locations have the bars inside the railing, **(See photo 24);**



Photo 24: Typical supports at interior of railing.

some have the bars located outside the railing **(See Photo 25)** and some areas have the bars on both the interior and exterior **(See Photo 26).**



Photo 25: Typical supports at exterior of railing.



Photo 26: Typical supports at interior and exterior of railing.

Many of the ornamental features were missing. Several of the finials which are located on the top of the railing posts were missing **(See photo 27)** and two of the decorative S-shaped sections are missing from the Bronx end of the railings on the south side **(See photo 28).**



Photo 27: Typical missing finial at top of post.



Photo 28: Decorative S-Shaped sections missing.

Other typical deteriorations include missing bolts and a few broken cast iron details on the posts and pickets. In addition, the railings located at both sides of the walkway exhibit minor to moderate rust and paint loss **(See photo 29).**

The condition findings for the bridge rails noted during this inspection are consistent with the Baker report from August 2006.



Photo 29: Typical broken cast iron detail and areas of rust.

III. BRIDGE LIGHTS

There are no working lights on the High Bridge. The existing light standards are decorative, painted green, and missing electrical wiring connections. The paint is flaking with surface rust, and the glass globes are no longer present **(See photo 30).** This condition was also found during the 2006 inspection.



Photo 30: Typical non-functional lighting standard on bridge deck.

IV. ATTIC WALLS AND CEILINGS

The bridge superstructure consists of 10 masonry arches and one steel arch. Both types contain a longitudinal chamber that carries the aqueduct pipe. The chamber inside the masonry arch is referred to as the "Attic" in this report, while the chamber in the steel span is referred to as the "Water Main Gallery". The Attic is the area located above the masonry piers and is made up of brick walls, a plain concrete floor and a brick arch roof which serves as the structural support for

the walkway. Contrary to the findings noted on the Baker report from August 2006, the ends of the Attic, under the gatehouses, exhibit more moisture, dampness and efflorescence compared to other sections, but there is no active leakage. Other than that, findings are similar to the 2006 report. There is condensation clinging to the attic surfaces, and in the winter a thin sheet of ice coats the inner walls and brick arch areas. The moisture cycling causes salts to leach and mortar to erode from the brick walls. There is an opening, referred to as an "alcove", in the wall at each pier location (**See Photo 31*l***.



Photo 31: Typical alcove at pier location.

These openings vary slightly in size, but in general measure 18" wide, 53" high, and 19" deep. This alcove allows access to the south "hance" space located below the Attic floor.

- <u>EAST ATTIC (Bronx Side)</u>

  At the Bronx approach, the attic roof slopes upwards starting from the east abutment to the location under the walkway stairs above, where it reaches a height of 19'-8" (measured at the wall), an increase of 4 feet **(See Photo 32).**



Photo 32: Attic roof sloping upward under walkway stairs above.

Additionally, the width of the Attic increases as well. The north and south sidewalls have inner steel doors that exhibit heavy corrosion with holes. They have disconnected from the steel frame and are starting to fall apart. There are stone and mortar blocks behind the steel doors which were used to seal the entrance into the attic from the outside **(See photo 33).**



Photo 33: Steel doors at longitudinal arches in east attic.

There are two longitudinal arches within the brick inner walls **(See photo 34).**



Photo 34: Typical longitudinal arch at east end attic north side.

These arches are 26'-6" long and 10'-8" high, measured from the ledge located at the bottom of the doors and the arches. These arches support the Attic roof and both have cracks and missing bricks towards the center of the arch on the underside. The area of the missing bricks is approximately 4 square feet and up to 6 inches deep at identical locations in both arches **(See Photo 35).**



Photo 35: Heavy spalled area under longitudinal arch.

The presence of efflorescence indicates that water leakage is present and is contributing to the deterioration of the arches **(See photo 36).**



Photo 36: Evidence of water leakage through longitudinal arch.

The ledge is 6' above the Attic floor, and 1'-8" wide, and is similar at both the north and south walls. The ledges are topped by 3" thick slate slabs **(See Photo 37).**



Photo 37: Typical ledge above attic floor at east end attic.

There is a similar ledge, topped by slate, along the transverse end wall. There are stairs leading to the north ledge from the Attic floor **(See photo 38).**



Photo 38: Stairs leading to north ledge from attic floor.

Below the ledge is the rim of a cut-off 36" pipe, totally filled in with brick masonry **(See photo 39).**

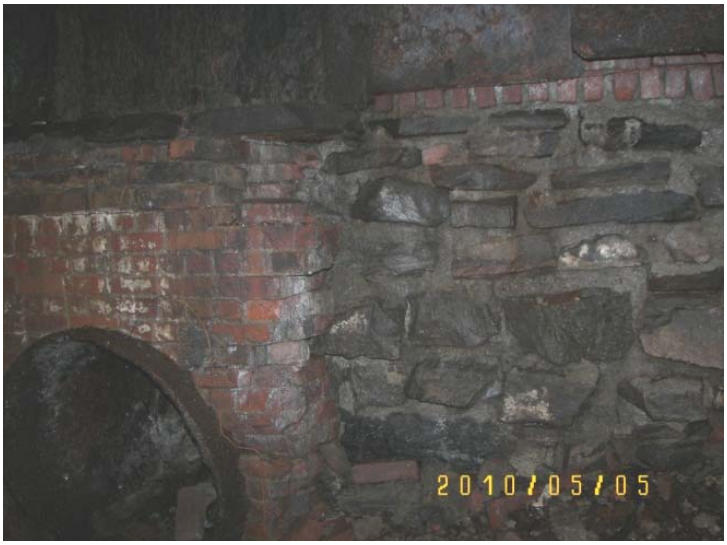


Photo 39: 36" cut-off pipe below north ledge.

Based on historical drawings, this is one of the two original pipes that were abandoned after the 90.5" water main was installed. Coating material on the surface of the attic chamber walls was tested and found to be whitewash **(See photo 40).**



Photo 40: Typical white substance on surface on attic chamber walls.

There is also a fine crystalline powder that covers the wall mostly along the base. These are salts that leach out during the cycles of moisture and dryness in the walls. The powder deposits collect at the bottom of the wall **(See photo 41).**



Photo 41: Typical salt leaching out on to surface of walls.

A 6” section of the brick wall located approximately 6’ above the floor, for the top 14”, contains hollow sounding bricks. The loss of mortar ranges from ½” to 1” deep in scattered areas throughout the brick walls (**See photo 42*)***. Many individual bricks are chipped and spalled, mostly at the lower portions of the walls.



Photo 42: Typical loss of mortar.

There is a ½" wide crack in the south wall 40’ east of Pier 2 **(See photo 43).**



Photo 43: A ½” wide crack with missing bricks.

The crack travels diagonally for 7 ½’ and several horizontal 1/16" wide cracks propagate from it. Two bricks in this area are missing. This crack extends east horizontally for roughly 25’ along the center of the wall. Five feet below, there is another horizontal crack, ¼” wide, that propagates from the same area and runs parallel to the one above it for about 20’. All the other bricks in the surrounding area are delaminated. At the same location, but on the North Wall, there are a number of short diagonal cracks and one 14' long longitudinal crack. The cracks range from ⅛” to ½" wide **(See photo 44).**



Photo 44: Typical crack on east attic wall.

Additionally, there is a 25' long horizontal crack along the mortar, ⅛” wide, in the south wall and a 14’ long and ⅛” wide diagonal crack was found in the north wall of Span 4 **(See photo 45).**



Photo 45: Typical crack on east attic wall.

Efflorescence covers up to 70% of the walls and moisture is evident over the entire Attic surface **(See photo 46).**



Photo 46: Typical efflorescence on east attic wall.

- EAST ATTIC ROOF

The brick arch that forms the Attic roof and supports the pedestrian walkway has several transverse cracks, moisture over 90% of the entire area, mortar loss up to ¼" deep over 20% of the entire area, and isolated areas of broken bricks near the north and south wall. The tie rods exhibit light to heavy corrosion (***See photo 47)***.



Photo 47: Typical tie rods on attic roof exhibit corrosion.

In addition, there is a 1" wide transverse crack near the end of the Attic adjacent to the Bronx gatehouse **(See photo 48).**



Photo 48: A 1" wide transverse crack near east end of Attic.

- WEST ATTIC (Manhattan Side)

The west attic is similar to the east attic except for the difference in elevation of the ceiling at certain points. The section towards the end of the bridge, underneath the walkway stairs, is slightly higher. The height of the Attic is 16'-8" (measured at the walls from the west end) for the first 8'-6" in length, and decreases by 2'-2" to a height of 14'-6" towards Pier 1, where the Attic ends and the Water Main Gallery begins.



Photo 49: End wall at west attic chamber.

There are steps that lead into the west attic from the water main gallery. There are two manholes in the roof of the west attic that have been covered with bricks at the surface **(See photo 49)**.

The general conditions are similar to the east attic. Typical conditions at both north and south walls include loss of mortar, signs of water leakage, heavy moisture, efflorescence, broken bricks, hollow and delaminated areas **(See photos 50 & 51).**



Photo 50: Upper section of west attic wall bulging out.



Photo 51: Lower section of west attic wall bulging out.

The north wall exhibits a ⅛" crack approximately 20' long and 6' above ground level near midspan **(See photo 52)**.



Photo 52: 20' x 1/8" longitudinal crack at north wall of west attic.

The end wall at the Manhattan gatehouse exhibits a ¼"crack above the water main pipe **(See photo 53)**.



Photo 53: End wall in west attic has full width x ¼" crack near top.

The surface of the attic chamber walls exhibits a white substance which was tested and found to be whitewash **(See photo 54)**.



Photo 54: Remains of waterproofing on west attic end wall.

The findings during this inspection for the east and west attics are consistent with the Baker report from August 2006, except that there is no active leakage observed at the ends of the attic.

V. CONCRETE WALLS AT PIERS 1 AND 2

There are 12' long transitional sections at Piers 1 and 2 located between the Attic and the Water Main Gallery. They consist of reinforced concrete walls at each pier with an opening to allow the water main pipe to pass through. The walls support concrete-encased transverse I-beams and a 12" thick reinforced concrete slab roof.

- PIER 1

At Pier 1, the north and south walls and ceiling consist of concrete and brick masonry sections. Conditions noted include several cracks with heavy efflorescence, areas of hollow-sounding concrete, and concrete spalls **(See photo 55).**



Photo 55: Cracks with efflorescence on north wall pier 1.

The encasement of the roof beams also exhibit concrete spalls, cracks with efflorescence and hollow-sounding areas (**See photos 56 & 57)**.



Photo 56: Roof beam encasement with concrete spalls and cracks.



Photo 57: Concrete ceiling exhibits cracks with efflorescence.

The brick masonry ceiling also has spalls, missing/broken bricks exposing the concrete roof slab, dampness and signs of water leakage **(See photo 58).**



Photo 58: Brick ceiling with missing and broken bricks at pier 1.

The brick masonry ceiling also exhibits loss of mortar up to ½" deep at the joints. The transverse concrete wall exhibits heavy efflorescence, hollow sounding areas, and map cracking on both faces and a 1' x 8"x ½" deep spall **(See photo 59).**



Photo 59: Spall on lower section of transverse concrete wall at pier 1.

- PIER 2

At Pier 2, the transition area consists of concrete walls and ceiling. Conditions noted include several cracks with heavy efflorescence and hollow sounding concrete ***(See photo 60)***.



Photo 60: Numerous cracks with efflorescence at south wall pier 2.

The ceiling shows concrete spalls with exposed rebar, cracks with efflorescence, and hollow-sounding areas. The bottom encasement of the transverse beams that support the ceiling slab also show concrete spalls, cracks and hollow-sounding areas. At one location, a 5' long section of the I-beam encasement is completely delaminated **(See photo 61).**

The findings for pier 1 and 2 walls noted during this inspection are consistent with the Baker report from August 2006.



Photo 61: I-beam concrete encasement spalled pier 2.

VI. UTILITIES

The bridge carries one inactive 90½" diameter water main pipe and six inactive electrical ducts, including non-functioning navigation lights. The water main pipe is installed along the centerline of the bridge superstructure **(See photo 62),** while two of the electric ducts are positioned on top of the bridge, one along each railing. These electric ducts used to supply power to the lighting standards **(See Photo 63)**.



Photo 62: Inactive water main in bridge superstructure.



Photo 63: Typical electrical duct positioned on top of bridge along railing.

There are temporary lights inside the bridge attic that was installed by NYCDOT prior to the start of the 2006 inspection. The light fixtures are attached to the inside walls of the attic, alternating between the north and south walls. A temporary power line that connects to a street light along the Harlem River Drive powers the lights. These light fixtures are currently non-functional, but were operational during the previous inspection. **(See photo 64).**



Photo 64: Typical light fixture inside east attic.

There are four electrical ducts inside the steel span water main gallery, two ducts on each side. These steel conduits are in fair condition and their u-bolt hangers are intact. However, all the junction boxes are heavily deteriorated with missing covers, disconnected conduits and exposed wires **(See photo 65)**.

The findings during this inspection are consistent with the Baker report from August 2006.



Photo 65: Typical deteriorated junction box and disconnected conduits.

VII. WATER MAIN AND SUPPORTS

The 90 ½" diameter wrought iron water main pipe consist of sections that are riveted at 6' intervals. The pipe was originally ½" thick and is supported on both expansion and fixed bearings that are placed on cast iron pedestals 5'-6" high and on average 12' apart. The expansion bearings consist of a roller nest assembly with three rollers inside. On top of the bearings there are single **(See photo 66)** and triple **(See photo 67)** cradles that wrap around the

bottom of the pipe. They follow a pattern of two triple cradles followed by a single cradle, except for a 48' long section at the center of the bridge that comprises of all triple cradles. This is the fixed section of the water main located in Span 4. At each end of the fixed section are three metal pipes that serve as thrust supports and bracing for the water main pipe.



Photo 66: Typical single cradle wrap.



Photo 67: Typical triple cradle wrap.

One vertical and two diagonal pipes, 17' long, anchor the pedestals to the attic floor **(See photo 68)**.



Photo 68: Three metal pipes for thrust support.

Approximately 25% of the water main supports exhibit misalignment of the cradle, misalignment of the bearings, missing support or tilted support pedestals **(See photos 69 & 70)**. The remainder of the supports are frozen and not functioning as designed. The rivets on the water main and its supports show over 50% section loss.



Photo 69: Misalignment of bearing.



Photo 70: Tilted pedestal.

The pipe is unsupported due to a missing cradle at the roller bearing at the beginning of span 2 near pier 1 **(See photo 71)**.



Photo 71: Roller bearing missing cradle to support water main.

The concrete at the base of the pedestals are spalled in some locations **(See Photo 72)**.

The condition of the water main noted during this inspection is consistent with the Baker report of August 2006.



Photo 72: Typical spalled concrete pedestal for water main support.

VIII. WATER MAIN GALLERY

The water main gallery is enclosed on the north and south sides with steel fascia plates ½" thick **(See photo 73)**. There are two access platforms, consisting of ⅜" steel checkered plate 4' wide, running the full length of the steel span. The platforms have steel pipe railings and are located adjacent to the water main **(See photo 74)**. Forming the roof structure above the water main is a framework of floorbeams and stringers. Above the floorbeams and stringers are ⅜" thick steel roof plates that are butt spliced a foot and a half past each panel point **(See photo 75)**. They are 18' long and 5'-5 ¾" wide. Longitudinally, there is a splice plate under each butt joint and a stiffener angle every 3'. The roof floorbeams are riveted, built up sections, flat at the bottom and curved along the top, giving the roof an arched configuration. The rivets measure 7/8" in diameter at the framing, and ¾" at the fascias, roof plates, copings, and inspection walks. Extensive section losses were found in the deck supporting members, largely due to water leakage through the joints and several cracks in the coping plates.



Photo 73: Typical steel fascia plate.



Photo 74: Typical steel pipe railing inside steel arch span.



Photo 75: Butt-spliced steel roof plate.

- ROOF PLATES

The roof plates were inspected from the access platforms below. Typical deterioration observed include loss of paint, surface rust, cracks at the splice plates of the coping **(See photo 76)** and efflorescence due to water leakage from the brick walkway through the joints of the roof plates **(See photo 77).** Their condition was found to be in fair.



Photo 76: Crack at the splice plate.



Photo 77: Efflorescence due to water leakage through joints of roof plates.

- ROOF FLOORBEAMS

The built-up roof floorbeams exhibit various degrees of deterioration. Typical conditions found include heavy efflorescence, rust, paint loss and heavy section loss at the web, top and bottom flanges, and substantial rivet head loss. The most extensive corrosion occurs in areas close to where the outer stringers frame into the floorbeams and at the floorbeam ends (***See photo 78).*** The deterioration is due to water leakage through the brick walkway, as indicated by the presence of heavy efflorescence in the surrounding areas. In some locations, the section loss at the floorbeam flanges measure up to 100% along the edges (***See photo 79)***.



Photo 78: Heavy floorbeam corrosion at outer stringers.



Photo 79: 100% section loss to bottom flange of floorbeam.

There is also evidence of heavy crevice corrosion at the bottom flanges **(*See photo 80)***. The floorbeam web exhibits 50% to 75% section loss **(*See photo 81)***. The top and bottom angles also exhibit substantial section losses to the rivet heads where the outer stringers frame into the floorbeams **(*See photo 82)***.



Photo 80: Heavy crevice corrosion on bottom flanges.



Photo 81: Heavy corrosion of web.



Photo 82: Section losses to rivet heads at bottom of web.

- ROOF STRINGERS

The outer roof stringers are in worse condition compared to the inner stringers. Most of the stringer deterioration is located at the area where they frame into the floorbeams. Typical deterioration includes section losses to the web and flanges, heavy efflorescence, rust, and extensive paint loss **(See photo 83).** In several locations, the web has rusted through similar to the condition in panel point 1 **(See photo 84).**



Photo 83: 100% section loss to bottom flange of stringer.



Photo 84: 100% section loss to web of stringer.

- LACED BEAMS

The top chord channels connecting the columns consist of lacing bars at the top and bottom allowing for nesting of pigeons. As a result, the space inside contains large quantities of bird droppings **(See photo 85)**. This is a typical condition throughout the entire span on both sides.



Photo 85: Laced beam contains heavy pigeon debris.

- COLUMNS AND KNEE BRACING

The columns inside the water main gallery exhibit paint deterioration and efflorescence with minor section loss. The columns support the knee bracing that connects to the floorbeams. Typical conditions noted include surface rust, paint deterioration and crevice corrosion between the two angles **(See photo 86)**. The flange of the knee brace at panel point 4 exhibits a 3" diameter hole **(See photo 87)**.



Photo 86: Typical deteriorated knee brace.



Photo 87: Hole in top flange of knee brace.

- ACCESS PLATFORMS

  The inspection platforms inside the Gallery consist of 3/8" thick checkered plates supported by two 6" beams. The platforms are located on both sides of the water main pipe. They are covered with layers of rust and debris which conceals most of the walkway. At the south walkway, section loss with holes were noted on the edges of the plate at mid-span **(See photo 88)**. The platform railings are in good condition.



Photo 88: Holes in access platform.

- FASCIA PLATES

  There are built-up steel fascia plates on both sides of the steel arch span. They block lateral forces such as wind from blowing through the water main gallery and affecting the water main. The steel fascia plates exhibit widespread paint deterioration and surface rust on the inside faces, but minimal section loss.

  The condition findings noted during this inspection for the water main gallery are consistent with the Baker report of August 2006.

IX. STEEL ARCH SPAN

The steel arch span is 448’ measured from centerline of end bearings at the upper lateral system. Measured from the bottom hinges of the ribs, the span length is 425’-11”. The steel arch consists of 2 pairs of 6’ deep ribs, a lower lateral system, 48 spandrel columns, 14 transverse vertical bracings, an upper lateral system, 6 hinges, and 4 roller nest bearings. Supported above the upper lateral system is the water main gallery structure. The steel arch span is in good condition. There were no conditions requiring immediate action or that can be categorized as priority or safety repairs **(See Photo 89)**.



Photo 89: Steel Arch Span-Elevation.

- <u>RIBS</u>

The 2 pairs of 6’ deep ribs are in fair to good condition and exhibit minor surface rust **(See photo 90).** Isolated areas of pitting were noted on the top surface of the ribs near the centerline of the span where the plates are close to horizontal **(See photo 91).** There was no significant section loss observed on the rib elements.



Photo 90: Ribs exhibit minor surface rust (Typ).



Photo 91: Isolated areas of pitting (Typ).

- LOWER LATERAL SYSTEM

  The lower lateral system is in fair condition and exhibits minor to heavy rust, debris accumulation and crevice corrosion. These conditions were noted at elements that are close to horizontal or allowed water to collect such as the bottom angles **(See photos 92 & 93).**



Photo 92: Heavy rust with debris accumulation at bottom angles (Typ).



Photo 93: Crevice corrosion at bottom angles (Typ).

- SPANDREL COLUMNS

The 48 spandrel columns are in good condition with no significant section loss noted. Typical conditions include paint deterioration, minor crevice corrosion, minor surface rust and debris accumulation along the base at the connection to the ribs **(See photo 94 & 95).**



Photo 94: Spandrel Column with light rust (Typ).



Photo 95: Debris accumulation at the base of spandrel column (Typ).

- TRANSVERSE VERTICAL BRACING

The 14 transverse vertical bracings are in fair to good condition. Typical conditions noted include light to heavy rust, paint deterioration, crevice corrosion at the corners of gusset plates, and isolated areas of section loss at horizontal lacing bars **(See photos 96 & 97).**



Photo 96: Crevice corrosion at corners of gusset plates (Typ).



Photo 97: Section loss at horizontal lacing bars (Typ).

- UPPER LATERAL SYSTEM

The upper lateral system is in good condition and exhibits paint deterioration and minor surface rust **(See photo 98).**



Photo 98: Upper lateral system (Typ).\

- HINGES

The 6 hinges, 1 in each of the 4 ends of the ribs of the steel arch span, and 2 along the centerline of the span are in good condition with only minor surface rust noted **(See photos 99 & 100)**.



Photo 99: Bottom hinge with minor surface rust (Typ).

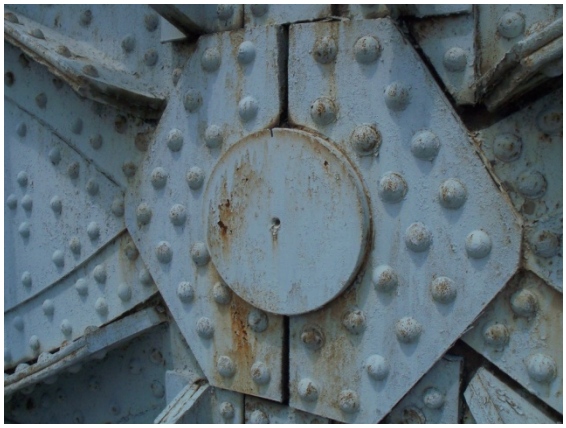


Photo 100: Mid-span hinge with minor surface rust (Typ).

- ROLLER NEST BEARINGS

The 4 roller nest bearings are in poor condition. The anchor bolts and nuts exhibit section loss. Additionally, the bearing plates showed heavy corrosion with the southeast bearing at pier 2 missing one side plate entirely **(See photo 101)**. The northeast bearing at pier 2 has section loss on 3 of 4 anchor bolts. In addition, the sole plate exhibits heavy rust and pitting **(See photo 102)**.



Photo 101: Side plate missing.



Photo 102: Sole plate exhibits heavy rust and pitting.

The 2006 Baker report noted several steel plates that exhibit 30% to 70% section loss at areas close to the middle of the span where the plates are near horizontal. During this inspection, the section loss of the steel plates in this same area was observed to be up to 25% material loss. We note that this material loss was exhibited at isolated areas within each individual plate and not as severe as previously reported.

X. MASONRY PIERS AND ARCHES

The High Bridge consists of 10 masonry piers and 2 abutments. All piers and abutments date back to the 1840s except for piers 1 and 2 which were reconstructed in the 1920s when the steel arch span was built to allow for larger vessels to pass through. The original piers now numbered 1 & 2 were built outward to support the steel arch span.

The existing masonry piers and arches are in fair condition. Typical conditions include vegetation growth, heavy stains, loss of mortar, heavy efflorescence, cracks and spalled stones near the base of the piers.

Piers 1 and 2 exhibit heavy efflorescence at the top section just below the attic/water main gallery **(See photo 103)**.



Photo 103: Heavy efflorescence (Typ).

At the base of Pier 2, transverse cracks were noted along the interface between the built-up section and the original pier at both north and south side **(See photo 104)**. A total of four vertical cracks were noted on the south face, 5 vertical cracks on the north face and 9 vertical cracks on the west face.



Photo 104: Cracks at the base of Pier 2 (Typ).

The arch soffits are generally in fair condition with heavy efflorescence and stains due to moisture leaking from the attic **(See photo 105).**



Photo 105: Heavy efflorescence and stains at arch soffits (Typ).

Throughout the bridge, loss of mortar is a typical condition ranging from ¾" deep at the piers up to 12" along the arch stones **(See photo 106).**



Photo 106: Loss of mortar (Typ).

At the Bronx piers, isolated areas of spalled masonry stones were noted at or just above the base of the piers. These spalls may have been due to impact damage or heat induced due to exposure to fire at one point in time **(See photo 107 & 108).**



Photo 107: Spalled masonry stones (Typ).



Photo 108: Spalled masonry stones (Typ).

At the abutment areas, the piers and walls exhibit heavy vegetation growth **(See photo 109).**



Photo 109: Vegetation growth (Typ).

At the piers directly above the highways and the railroad, heavy stains due to constant exposure to vehicle and locomotive emissions were noted **(See photo 110).**



Photo 110: Heavy stains at piers (Typ).

The copper letters of the bridge sign at the south face of Pier 5 are intact and in good condition **(See photo 111).**



Photo 111: Bridge sign letters (Typ).

At Pier 1, a 1” gap with loss of mortar was noted along the interface between the built-up section and the original pier at both north and south face **(See photo 112).**



Photo 112: 1 inch gap at Pier 1 (Typ).

At the north wall of the Manhattan (West) Abutment, cracks up to ¼” wide were noted at the masonry stones **(See photo 113)**. Also, widespread loss of mortar was observed throughout the abutment due to water infiltration originating from the top of deck around the Manhattan Gatehouse **(See photo 114)**.



Photo 113: ¼” Crack at masonry stone – Manhattan Abutment Wall



Photo 114: Widespread loss of mortar at Manhattan Abutment

The overall condition of the stone masonry piers, soffits and fascias is similar to that noted during the 2006 Baker inspection and has not changed significantly.

CITY OF NEW YORK DEPARTMENT
OF PARKS & RECREATION

STRUCTURAL ANALYSIS

- BRICK ARCH DECK STRENGTHENING OPTIONS
- LOAD RATING ANALYSIS OF BRICK ARCH WALKWAY
- ANALYSIS OF STONE ARCH SPAN



HIGH BRIDGE

BOROUGHS OF MANHATTAN
AND THE BRONX, NEW YORK

August 31, 2010

The Empire State Building

350 Fifth Avenue
Suite 924
New York, NY 10118
Phone: 212-244-1600
Fax: 212-244-4488

Lichtenstein
Consulting Engineers

ANALYSIS OF STONE ARCH SPAN

Introduction & Analysis Methodology

The high Bridge located between the boroughs of Manhattan and the Bronx consists of ten stone masonry semi-circular arches and a steel parabolic arch. The continuous stone masonry spans have 9 arches and are approximately 637 ft. long. The out-to-out width of the top bridge surface is 28'-7" at the piers and 25'-1" at all other locations. The superstructure of the bridge has an enclosed attic that houses an inactive 90 ½ in. diameter cast iron water main. The brick walkway topping the body of the arch measures 17'-1" wide and the difference is taken up by granite coping stones on both sides of the walkway. The clear spans of the three west arches are 80 ft. and the clear spans of the reminder are 50 ft. The maximum height of the stone masonry of the arch is 59'-9½" and the minimum height of the stone masonry of the arch is 19'-9½".

Nine spans (Spans 3 through 11) of stone masonry arch described above were analyzed. The 3-D structural model was generated using STAAD Pro V8i software. A stress analysis was conducted to determine the line of action of axial force within the barrel of the arch and locate any areas of tensile stress within the load carrying section.

The structural model (see Figure 1) consists of the brick arch walkway, two spandrel walls, stone arch, and nine pier columns (Piers 2 through 10). The brick arch walkway, spandrel walls, and stone arch were modeled using shell elements and the piers were modeled using beam elements. The connections between piers and arch spans were rigidly modeled using the slave/master option. The bottoms of the piers and the side of span 11 were modeled as fixed boundary conditions. Three different materials were used. The walkway was modeled with brick material and the unit weight was assumed to be 135 pcf. The side walls, stone arch, and piers 3 through 10 were modeled with granite material and the unit weight of it was assumed to be 165 pcf. Pier 2 was modeled with concrete material and the unit weight of it was assumed to be 150 pcf.

The dead loads were automatically calculated in the program using the unit weight and section dimensions. Additional dead loads applied to the top of stone arch manually are the weights of the stone floor, haunch walls, and siphon supports. The following three live load conditions were considered: (1) Pedestrian/Bicycle loading – 85 psf., (2) One police "Cushman" vehicle loading – applied two point loads for rear axle (each point load is 1000 lbs. and 3.5 ft. apart.) and one

point load for front axle (750 lbs.), and (3) Combined effect of pedestrian and Cushman vehicle loading. Note that "Cushman" vehicle loading was applied as moving load.

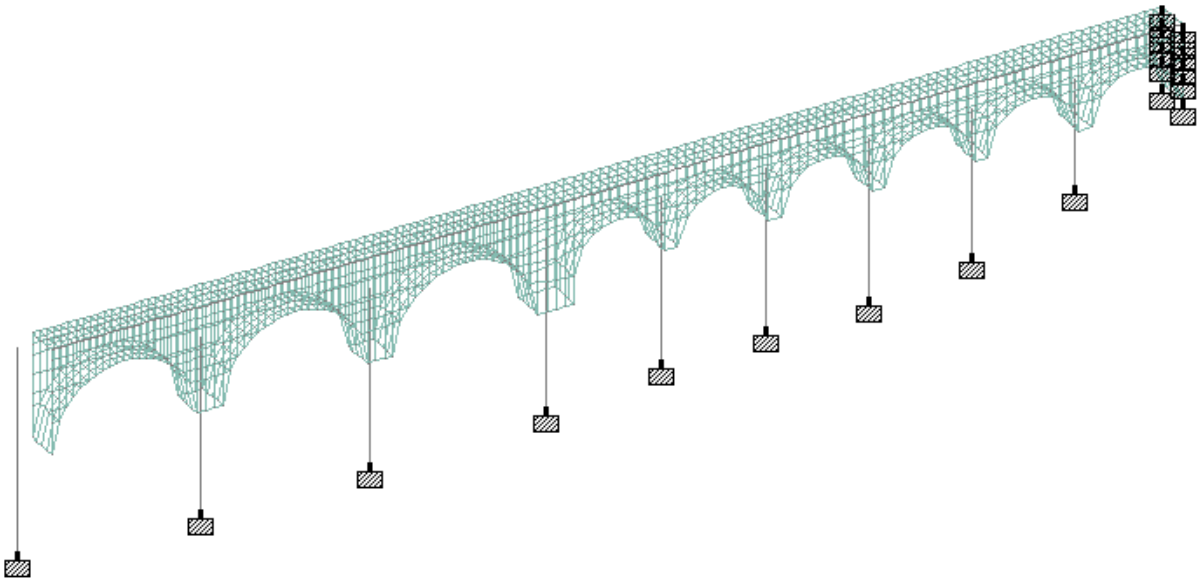


Figure 1. 3-D Structural Model

Computation of Stresses – Allowable Stress Method

Allowable stresses were determined from the AASHTO Manual for Bridge Evaluation (2008). The inventory compressive limit is 720 psi, assuming granite ashlar masonry with type M mortar. The tensile stress limit is taken as zero, assuming that the mortar has no ability to resist tension.

Combined stresses of axial force and bending moment were calculated by the program at the top and bottom of the stones for dead and live loads in longitudinal and transverse directions and the corresponding rating factors were computed. Table 1 shows the longitudinal and transverse stresses under dead and live loads. A tensile (negative) stress indicates that the line of action does not lie within the kern (middle third) of the masonry voissoirs.

		Stress (psi)			
		Top		Bottom	
		DL	LL	DL	LL
Longitudinal Direction	Max. Compression	158.0	2.8	167.6	5.0
	Max. Tension	-25.4	-0.8	-36.5	-2.2
Transverse Direction	Max. Compression	43.8	1.3	51.5	2.2
	Max. Tension	-38.7	-2.5	-65.6	-0.5

+: compression

Table 1. Stress Analysis Results

Computation of strength / Load Rating – Strength Method

As the working stress methodologies frequently do not demonstrate that masonry structures have sufficient carrying capacity, limit state methods have been developed for load rating purposes.

The procedure shown in this section was taken from "Load Rating of Masonry Arch Bridges", Boothby, ASCE Journal of Bridge Engineering, 2001. It is analogous to interaction diagrams for strength design of reinforced concrete columns.

The strength of the stone masonry arch was determined analytically by constructing a moment/axial force interaction diagram. The interaction diagram, based on limit states analysis, incorporates the assumption that the masonry reaches a peak compressive stress, followed by a limited softening behavior under the combined action of axial force and bending. The failure envelope is defined by the equation as follows:

$$\frac{1}{4}\left|\frac{M}{M_o}\right| - \left(\frac{P}{P_o}\right) + \left(\frac{P}{P_o}\right)^2 \leq 0$$

where $P_o = bh\sigma_o$; $Mo = 0.125bh^2\sigma_o$; and σ_o = peak stress in the masonry. The peak stress was assumed to be 720 psi.

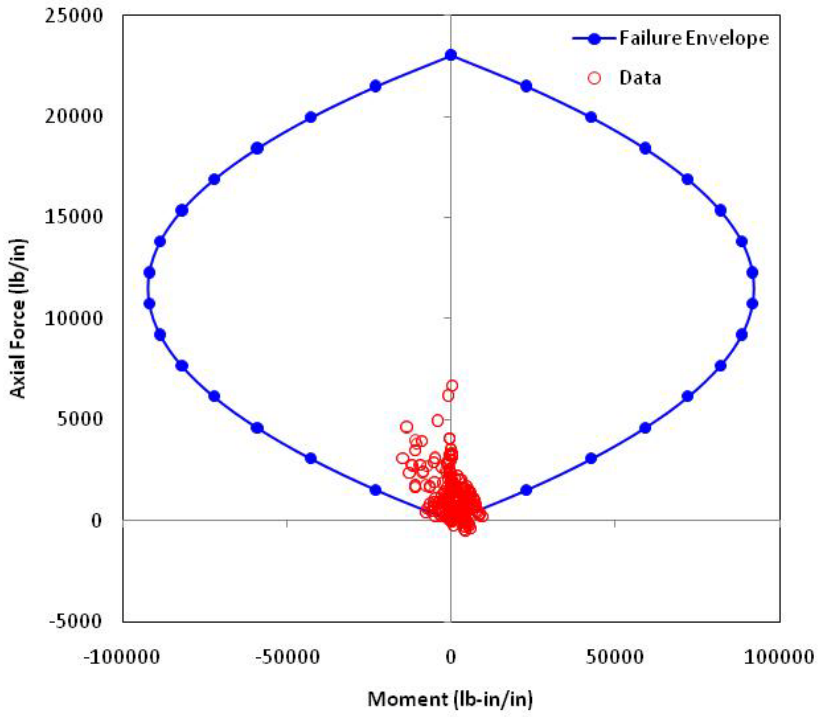


Figure 2. Moment/Axial Force Interaction Diagram in Longitudinal Direction

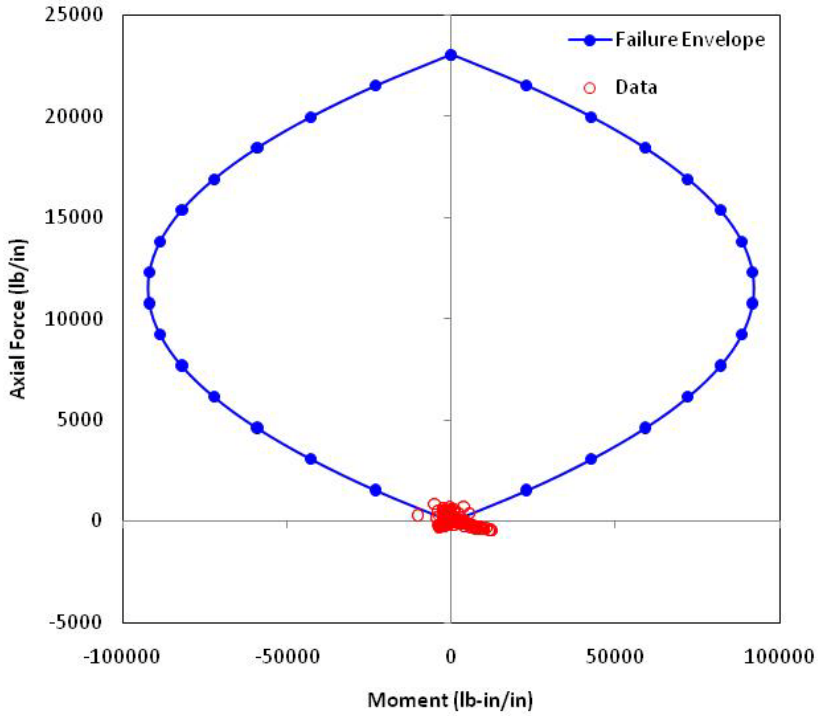


Figure 3. Moment/Axial Force Interaction Diagram in Transverse Direction

Discussion

The following observations were made from the analysis:

- The longitudinal tensile stress in the bottom of the stone arch under dead load was observed at the crown of arch span generally and the maximum tensile stress is 36.5 psi. The observed tensile stress is relatively low, but does not meet the requirement of zero tension.
- The longitudinal tensile stress in the top of the stone arch under dead load was observed at the quarter location of arch span generally and the maximum tensile stress is 25.4 psi. The observed tensile stress is relatively low, but does not meet the requirement of zero tension.
- The transverse tensile stress in the bottom of the stone arch under dead load was observed at the interior parts of arch span generally and the maximum tensile stress is 65.6 psi. The observed tensile stress is relatively low, but does not meet the requirement of zero tension.
- The transverse tensile stress in the top of the stone arch under dead load was observed at the exterior parts of arch span generally and the maximum tensile stress is 38.7 psi. The observed tensile stress is relatively low, but does not meet the requirement of zero tension.
- The tensile stresses observed in the stone arch are often noted in semi-circular arches with shallow backfill. The depth of cover is insufficient to force the arch into a purely compressive state and the departure of the semicircular shape from a parabolic form causes eccentricity of the line of action and corresponding bending stress.
- The maximum compressive stresses under dead load and live load are 167.6 psi and 5.0 psi respectively and were observed in the bottom of the stone arch in the longitudinal direction. These stresses are much smaller than the compressive stress limit.
- The findings of the strength method indicate that the load bearing capacity is generally sufficient. The scatter diagram of combined, factored axial forces and bending moments fits approximately within the ultimate strength envelope.

It is noted that the referenced ultimate strength method of analysis and rating is not part of the AASHTO Standard Specifications. Unreinforced stone masonry is no longer used for bridge

applications and there are no current criteria or specifications for its analysis and design. Load rating requirements only consider its use as bearing elements, not as flexural members.

LOAD RATING OF BRICK ARCH WALKWAY

The load rating analysis was prepared according to the guidelines given in the AASHTO Manual for Bridge Evaluation (2008) for the brick arch walkway and the wrought iron tie-rods. Live load capacity ratings were calculated for both as-built and as-inspected conditions. For the brick arch walkway, the load rating was calculated at the inventory level only. For the wrought iron tie-rods, however, the load rating was computed at both inventory and operating levels. The working stress method was used for this analysis.

The brick arch forms the attic roof and supports the pedestrian walkway; the wrought iron tie-rods reinforce the brick arch. The total length and clear span length of the brick arch is 17'- 1" and 13'- 9", respectively. The brick arch is 12 inches in depth. The diameter of the wrought iron tie-rod is 1 7/8 inches and they are spaced at 5 ft intervals.

The structural model was generated using STAAD Pro V8i software. The effective span length was assumed to be 16'- 6" and the rating was computed for a unit width of 1 foot. The brick arch and tie-rods were modeled using beam elements. Two different models were generated, based on the boundary conditions. The first model assumes a two hinged arch, supported by the masonry walls. The second model is also a two hinged arch, but assumes a released roller boundary condition on one end. For the first model, no forces are transferred into the tie-rod, because all horizontal forces are carried by the walls. The tie-rod, therefore, was rated based on the calculated horizontal reaction forces.

The self weight of the brick material was assumed to be 135 pcf. The following three live load conditions were considered for the rating: (1) Pedestrian/Bicycle loading – 85 psf., (2) One police "Cushman" vehicle loading – applied two point loads for rear axle (each point load is 333 lbs. and 3.5 ft. apart.) , and (3) Combined effect of pedestrian and Cushman vehicle loading. The vehicle axle was assumed to be carried by three feet of deck.

The allowable stresses for brick masonry are 200 psi and 0 psi for compression and tension, respectively, and the allowable stresses for wrought iron are 14,600 psi and 20,000 psi for inventory and operating rating, respectively. Testing of the brick material indicated average compressive strength over 4500 psi.

Based on these assumptions, the rating factors for the brick arch (first model) and the wrought iron tie-rods are as follows:

Component	Load Rating Factor (Allowable Stress Method)					
	As-Built Condition		As-Inspected Condition			
	Inventory	Operating	Inventory		Operating	
Brick Arch	0.92	*	0.92		*	
Tie-Rod	1.12	2.34	Min. SL	Max. SL	Min. SL	Max. SL
			0.79	-7.53	1.89	-7.35

Note: Negative value indicates that dead load demands are larger than capacities.

It was observed from the results of the second model with the roller support that it is not adequate to model the behavior of the brick deck. Under dead loads only, the maximum compressive stresses in the brick arch were significantly larger and tensile stresses were present. Tie rod forces were less than those of the first model and were insensitive to changes in its section properties.

BRICK ARCH DECK STRENGTHENING OPTIONS

The original stone masonry span decks of the High Bridge consist of a 12 inch deep brick arch with a 13.75 foot clear span, which is covered with variable depth brick underlayment and brick pavers. The deck is supported by the attic walls. Tensile forces generated by the arch are resisted by wrought iron tie rods, 1.75 inches in diameter, connected to cast iron skewbacks embedded in the attic walls. Tie rods are spaced at 5 foot intervals, for a total of 175.

Design Loading:

The design loading for the bridge deck is 85 psf pedestrian uniform loading, in accordance with AASHTO standard specifications. A small service vehicle, approximately 2000 pounds, will also utilize the bridge, but is a not a design consideration as the pedestrian loading will govern.

Inspection Summary:

Structural Arch
The brick structural arch is in very good condition, requiring only minor repair in isolated locations Such as small spalled areas, isolated missing pointing and fine cracks. There were two transverse structural cracks near the Bronx end. All defects should be repaired. The deck paving and waterproofing will require rehabilitation or replacement.

Tie Rods
The tie rods all have some loss of section due to corrosion, varying from 5 to 90 percent. Three tie rods had section losses exceeding 75 percent, with 17 tie rods experiencing losses over 50 percent. However, 90 of the 175 tie rods had loss of section above 25 percent. These section losses were predominately near the intersection with the brick deck.

Structural Analysis:

A structural analysis of the deck was performed by the finite element method, considering it to be a two hinged arch. Horizontal support reactions were provided by the tie rods. The results for the as-built condition, with an 85 psf live load, indicate that the brick arch itself is slightly under required capacity, while the tie rods are adequate. Rating factors are .92 and 1.12, respectively. Application of controlled tensile force to the tie rods can be used to increase the brick arch rating factor to 1.0. Rating factor is defined as the fraction of the design loading that the structure can carry without exceeding the allowable stresses. A check of the as-inspected condition indicates that the tie rods are not of sufficient strength to provide the required load carrying capacity. The as-inspected tie rod rating factors varied from .79 to zero. The brick arch rating factor was unchanged for the as-inspected condition.

A second structural analysis by means of the equilibrium method was also performed. This methodology is relatively new and it has not been extensively used in the US. Its results demonstrate that the brick arch and tie rods are adequate for the design loading in their as-built state, with 85 psf pedestrian load, but that approximately one quarter of the tie rods have section losses that necessitate strengthening. Both

analyses considered both continuous and partial applications of loading, to encompass the worst case. In any case, current AASHTO design codes will be utilized for the work.

Rehabilitation Alternates:

Additional support or replacement of all tie rods is necessary, based on the finite element analysis. The equilibrium analysis method would require replacement of 45 to 50 of the 175 tie rods.

As assurance cannot be given that cleaning and attempting to protect those tie rods that are in good condition can be attained, it is recommended that the entire brick deck be strengthened with either new tie rods or new support beams. There is no practical method to strengthen the existing tie rods.

Two methods are available: removing each tie rod and replacing it with new material at the same location or leaving the existing tie rods in place and adding new members in between them.

From a construction standpoint it will be very difficult and costly to replace the tie rods or install beams at the same locations. The spandrel walls of the arch would need to be opened up on the fascia side to remove the end of the tie rod and its nut, possibly resulting in damage to the walls. Steel frames and jacking would be necessary to allow the tie rods to be replaced and tensioned. Only one location in an area could be under construction at any time. Additionally, from a historic standpoint, this would involve removal of original fabric that is still working, although not to the desired capacity.

An easier and less costly procedure would be to leave the tie rods in place, clean and preserve as much as possible and add new members in between to carry the design loads. In this manner there would be little to no dependence on the existing tie rods and the new members would be distinguishable from the existing in accordance with the "Secretary of the Interior's Standards".

Two alternatives to increase the strength of the brick deck have been developed:
Option 1: Support Beams
Option 2: Supplemental Tie Rods.

OPTION 1 SUPPORT BEAMS

Description of Work:
-Place W8 rolled beams, curved to follow the soffit of the brick arch, at 7.5 foot intervals, midway between all tie rods, at a total of 120 locations. This would result in an uneven spacing of old and new members.
-The structural action of the deck would be altered to some extent, using flexural stresses rather than axial stresses to carry load.
-Drill and grout anchor bolts into the attic wall to attach clip angles, bolted to the ends of the beams.
-Cast a 3 inch deep concrete haunch to allow the deck to bear against the beams.

Critical Issues, Pros and Cons:
-A total of 120 new beam assemblies would be required for the masonry spans of the bridge.

-Closely spaced beams provide structural redundancy and eliminate fracture-critical members.
-Beams conform to current AASHTO design codes for flexural members and there would be no issues with tensile forces in unreinforced masonry.
-The beam assemblies are quite different in appearance from the existing tie rods.
-Installation would be relatively straight forward, except for moving the materials into place.
-The new beams would carry the live load and a portion of the existing dead load. This is acceptable as the existing structure can carry these loads. Should any transfer of load occur, the new members would be of more than sufficient capacity.

Estimated Cost:

The projected cost for the beam option is $3,000,000.

Construction Duration:

The time required for construction is estimated to be 8 months.

OPTION 2 SUPPLEMENTAL TIE RODS

Description of Work:
-Place new, two piece high strength tie rod assemblies at 10 foot spacing, midway between every other original tie rod, for a total of 90 locations. Tie rods will be sized to carry the entire tensile force of two existing tie rods. As there are full length skewbacks embedded within the structure, the fundamental behavior of the deck would be unaffected.
-Core drill through brick arch and cast iron skewback to anchor ends of rods.
-Expose rear of skewback from top to attach beveled plates and nuts, while deck and underlayment are removed for rehabilitation. Should the existing deck be retained and repaired, it would be necessary to cut holes for attaching the new tie rod anchorages.
-Embed new tie rod ends within masonry and connect to skewback, no need to expose fascia.
-Tighten connecting sleeve nut between rod sections to tension rod to carry existing dead load forces.

Critical Issues, Pros and Cons:
-Supplemental tie rods are very similar in appearance to the original construction.
-The equilibrium method utilized for analysis is not well known or extensively used in the US.
-Correctly locating the cored holes will be troublesome and require working simultaneously from top and bottom. Reliably anchoring the tie rods to carry the tensile forces will require engaging the existing skewbacks.
-Space behind the skewbacks for installation is limited.
-New members are light in weight and easily transported to location.
-Calibrated tensioning of the tie rods can be easily accomplished via strain gauges.
-Construction cost of the supplemental tie rods will be less than that of support beams.

Estimated Cost:

The projected cost for the supplemental tie rod option is $2,000,000.

Construction Duration:

The time required for construction is estimated to be 5 months.

Recommendation:

The supplemental tie rods are the recommended option. This recommendation is based on two factors: the projected construction cost is than the support beam option and the supplemental tie rods are very similar in appearance to the existing tie rod system.

OCHSENDORF DEJONG & BLOCK, LLC
Structural Engineering Consultants

Michael A. Lahti, PE
Assistant Vice President
TranSystems
Empire State Building
350 Fifth Ave, Ste. 924
New York, NY 10118-0110

August 12, 2010

Re: Structural Analysis of Main 80' Masonry Arch Span, High Bridge, NYC

Dear Mike,

Please find attached the report which summarizes our analysis of the stability of the 80 ft main arch spans of High Bridge.

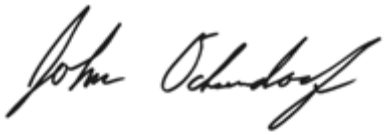
We demonstrate that the stone arch is stable for the expected vertical dead and live load. The stone arch proper, together with the spandrel and haunch walls provide more than enough load capacity to ensure that the arch is stable with reserve capacity for significantly higher loading conditions than will be expected when it re-opens as a pedestrian walkway.

We have also looked at the analysis which was performed by TranSystems, and we are not at all concerned about the predicted tensile stresses from the linear elastic finite element analysis. Such an elastic analysis makes a number of incorrect assumptions for unreinforced masonry, namely that the material can resist significant tension, that the material properties are homogeneous, that the support conditions can be known precisely, and that the elastic solution represents the one true state of the structure. In short, the tensile stresses predicted by the finite element model are not a meaningful prediction of the safety of the structure.

Although we are confident that the main span is stable based on our analysis thus far, a more complete three dimensional analysis of the main span arch and piers could be conducted if desired. However, this is beyond the scope of our current agreement.

Please don't hesitate to contact me with any questions or concerns.

Yours sincerely,



John Ochsendorf, PhD
Partner | Structural Engineer
jao@odb-engineering.com

Title: Structural Analysis of Main 80' Masonry Arch Span, High Bridge, NYC
Date: August 12, 2010

Introduction

This report describes the analysis of the main 80' masonry arch span of the High Bridge. We show that for two critical loading conditions, full live load and asymmetrical live load, purely compressive solutions exist with low stresses in the masonry arch. The approach outlined below is based on limit analysis, following the theory developed by Professor Jacques Heyman of Cambridge University.[1] In short, the safety of historical masonry structures is typically governed by stability and not by material failure due to excessive stresses. Thus, we first seek a safe equilibrium solution for the applied loads, and then confirm that stresses are below material capacity. Our analysis assumes that the material is strong in compression but has zero tensile capacity.

Geometry and Loading

The analysis considers the main masonry arch and overlying structure, spanning 80'-0" between bridge piers. To facilitate an approximate equilibrium solution, the arch geometry was simplified and the idealized main arch span and corresponding loads are shown below [Fig. 1]. In addition to its own weight, the main arch supports the weight of the pipe gallery, the spandrel and haunch walls, and the stone wedges at the bridge piers. The load from the siphon supports was determined to be less than 5psf and is considered negligible.

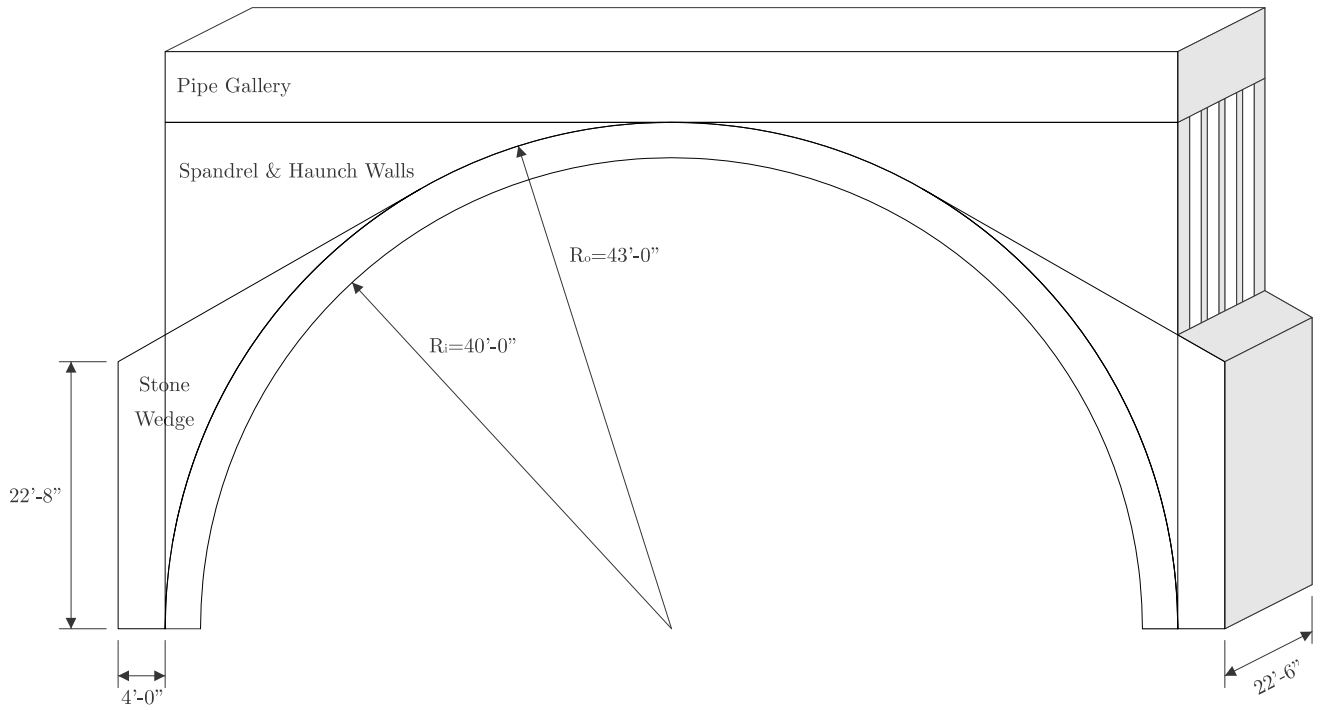


Figure 1. View of geometry for idealized main arch span

[1] Heyman, J. The Stone Skeleton: Structural Engineering of Masonry Architecture. Cambridge University Press, 1995.

Dead Load:

- The semicircular arch is 3'-0" thick with an average width of 22'-6" and stone density of 165 pcf.

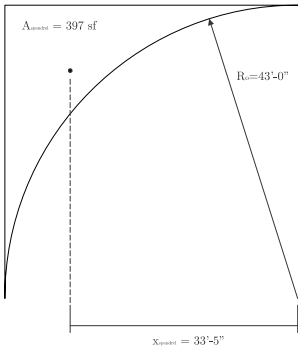
  Total arch self-weight ≈ 11.1 kips/ft ≈ 1,450 kips

- The pipe gallery is modeled as a 950 psf uniform load (sum of the attic and stone floor loads from the Baker Report) applied along the length of the arch with a width of 22'-6".

  w_{pipe} = 950 psf · 22'-6" = 21.4 kip/ft

  Total pipe load ≈ 1,840 kips

- The spandrel and haunch walls are modeled as a distributed load applied along the length of the arch with a width of 9'-6" and a stone density of 165 pcf. The 9'-6" width accounts for 2 spandrel walls with a thickness of 2'-0" and 3 haunch walls with a thickness of 1'-10".

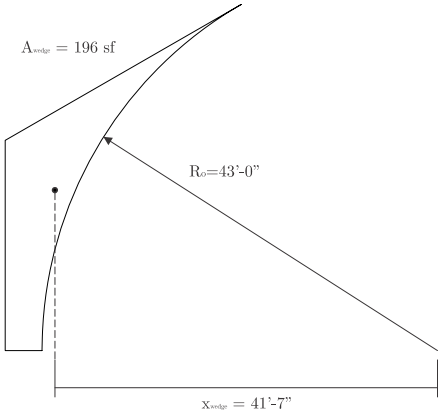


$w_{spandrel} = (R_o - \sqrt{R_o^2 - x^2}) \cdot 9'\text{-}6" \cdot 165$ pcf

Therefore, $w_{spandrel}$ varies from 0 kip/ft to 6.74 kip/ft

Total spandrel load ≈ 620 kips

- The stone wedge is modeled as a point load applied at the center of gravity of the idealized geometry below, with a width of 13'-0" and a stone density of 165 pcf. The 13'-0" width is determined by subtracting the width of the spandrel and haunch walls from the total width.



$P_{wedge} = A_{wedge} \cdot 13'\text{-}0" \cdot 165$ pcf
= 420 kip

The total dead load is approximately 4,330 kips.

Live Load:

Two live loading conditions will be considered:

1) Load case 1: uniform pedestrian live load of 85 psf applied over the entire span,
2) Load case 2: uniform pedestrian live load of 85 psf applied over one half of the arch only.

These loads represent the extremes of uniform and asymmetrical loading which can be expected. For the 22'-6" width of the main arch, this corresponds to a distributed load of 1.92 kip/ft. For Load Case 1, the total live load is approximately 165 kips. Thus, the live load is ~3.8% of the total dead load. Thus, it is immediately evident that the live load will have a relatively small effect on the stability of such a massive structure.

(Note: All loads are unfactored.)

Analysis Method

To demonstrate the stability of the arch under dead and live loads, we construct compressive thrust lines, which represent a possible load path within the structure. These thrust lines indicate equilibrium solutions which balance the applied loads. If a thrust line solution exists which lies within the geometry of the masonry structure, then the structure is in equilibrium and the arch is stable. We assume that all thrust lines terminate at the bridge piers, which are required to carry both the horizontal thrust of the arch and the weight of the arch itself.

Compressive thrust lines in an arch can be constructed in several ways, including:

1) Using numerical computing software such as MATLAB to compute the coordinates and forces of the equilibrium solution, as described in the PhD dissertation by Ochsendorf (2002);
2) Writing a closed form equilibrium solution, for example the horizontal thrust in an arch with uniform load *w*, span *L*, and depth *d*, is $H=wL^2/8d$; or
3) Using graphic statics to find a vector-based equilibrium solution.

In this analysis, the first method is used due to the nature of the loading. A MATLAB code has been written to determine the minimum thrust state of the arch based on the geometry and loading described above. The code operates by taking geometry and loading inputs, generating thrust lines based on both global and local equilibrium of an arch segment [Fig. 2], and then searching all admissible thrust lines to determine the state of minimum thrust. Equation 1 ensures moment equilibrium of the arch segment that subtends the angle ϕ and allows us to find the location of the thrust line at ϕ. Equation 2 is produced by converting (x_ϕ , y_ϕ) to the polar coordinates (r , ϕ) and solving for r. This allows for an easy comparison between the thrust line and the geometric constraints of the arch.

$$H(rise - y_\phi) = V_{crown}x_\phi + W_{segment}(x_\phi - \overline{x}_{segment}) + wR_o\sin(\phi)\left(x_\phi - \frac{R_o\sin(\phi)}{2}\right) + P_1(x_\phi - x_{P_1}) + P_2(x_\phi - x_{P_2}) + \ldots + P_i(x_\phi - x_{P_i}) \quad (1)$$

$$r = \frac{W_{segment}\overline{x}_{segment} + \frac{wR_o^2}{2}\sin^2(\phi) + P_1x_{P_1} + P_2x_{P_2} + \ldots + P_ix_{P_i} + H\cdot rise}{V_{crown}\sin(\phi) + W_{segment}\sin(\phi) + wR_o\sin^2(\phi) + P_1\sin(\phi) + P_2\sin(\phi) + \ldots + P_i\sin(\phi) + H\cos(\phi)} \quad (2)$$

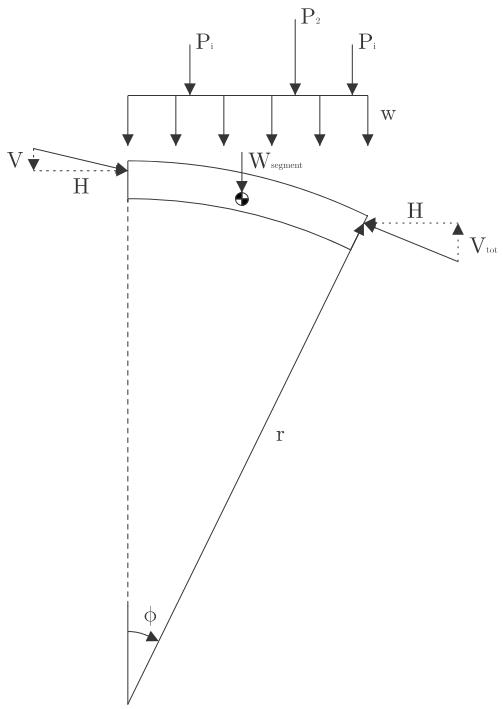


Figure 2. Local equilibrium of arch segment for MATLAB script

Analysis Assumptions

According to the Lower Bound Theorem, or "Safe Theorem" of limit analysis, if a thrust line exists which lies within the geometry of the structure, and does not exceed the strength of the material, then the structure is in equilibrium and the arch is stable. Two scenarios are considered for each load case described previously:

Scenario 1:

In the first scenario, the thrust line is required to remain within the middle third of the arch, except that the thrust line is allowed to exit the arch proper at the springing. This deviation from the arch at the springing is acceptable because the thrust line still remains within the stone wedge which can carry the thrust from the arch to the pier.

The middle third solution ensures that for a triangular stress distribution, compression is maintained over the entire thickness of the arch. It should be clearly noted that the middle third solution is extremely conservative. Limiting the thrust line to the middle third is equivalent to enforcing a geometric safety factor of 3. If the thrust-line exits the middle third, tension would begin to develop in the arch, but this is not a problem. Since tension cannot be sustained, a triangular stress distribution can be assumed over part of the thickness of the arch and no force would be transferred over the remaining thickness.

This extremely conservative scenario is used to evaluate the safety of the structure under the expected live load outlined previously.

Scenario 2:

In reality, the structure can sustain a much larger live load than predicted with the middle third limitation. To investigate the maximum capacity of the structure, a second scenario is considered. In this scenario, the thrust line is allowed to exit the middle third, and additional live load is added to the arch.

To avoid a singularity where large forces are transferred over infinitely small areas, we constrain the thrust line to remain at least 2 inches from the intrados of the arch. Again assuming a triangular stress distribution, the total force would be transferred over the inner 6 inches of the arch. The maximum stress can then be calculated and checked against the capacity of the stone.

Results

Load Case 1: Live load over whole span

For scenario 1, where the thrust-line is constrained to remain within the middle-third of the arch, the compressive thrust line solution is shown in Figure 3. The thrust-line clearly lies within the masonry over the entire arch span, and it enters the stone wedge at the springing. This confirms that the arch is stable.

While the thrust line demonstrates stability, it is still necessary to confirm that the corresponding stresses are indeed low compared to the compressive strength of granite. Typically the compressive strength of granite is on the order of 30 ksi. The force in the arch increases from the crown to the supports symmetrically and is shown in Table 1. The maximum force in the arch, 3,023 kips, occurs at the supports. This force can be transferred over the large area of the stone wedge, so the stress at this location is not an issue. However, the maximum stress must be checked at $\alpha = 50^{o}$, where the thrust line is at the inner middle-third. Assuming a triangular stress distribution along the 3'-0" thickness of the arch and a uniform distribution along the 22'-6" width of the arch, the compressive stress in the stone is:

$$\sigma_{axial} = 2 \cdot F_{axial} / (3'\text{-}0'' \cdot 22'\text{-}6'') \qquad (3)$$

At $\alpha = 50^{o}$, the maximum stress is approximately 0.38 ksi, or 380 psi. This stress is well below the compressive strength of granite (~30 ksi). This is also a highly conservative estimate of the stress because it assumes that only the arch is supporting the loads, when in reality, the stonework above the arch also functions as part of the load-carrying structure, but it is neglected here.

At the supports, the horizontal thrust can be resisted by the adjacent arches, but the vertical reaction must be taken by the pier. The total vertical reaction per pier for the two adjacent arches is ~ 5,540 kips. This can be distributed over an area of 22'-6" x 14'-0", which yields a stress of ~0.12 ksi or 120 psi, which is again very low for the masonry.

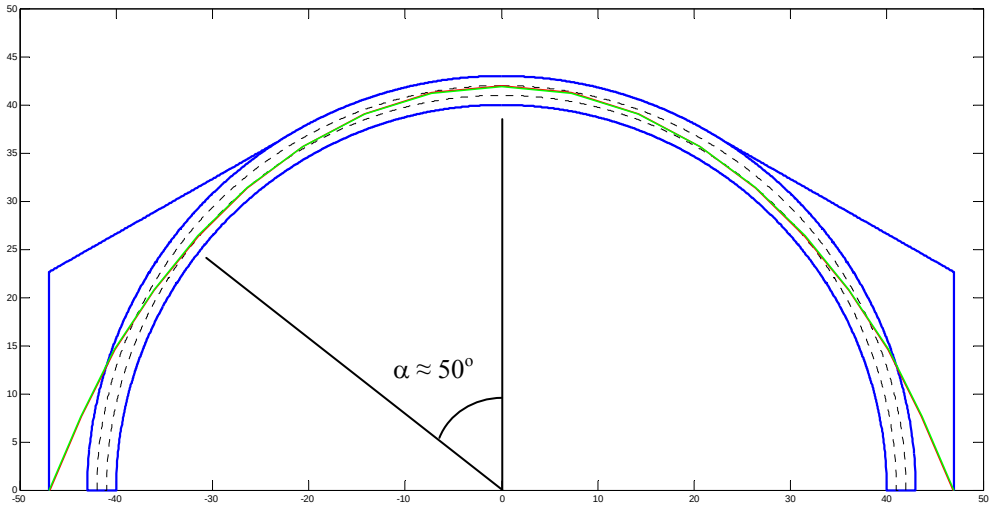


Table 1. Internal Arch Forces and Stresses

α (°)	F_{axial} (kip)	σ_{axial} (ksi)
0	1,212	0.25
±10	1,239	-
±20	1,320	-
±30	1,456	-
±40	1,640	-
±50	1,861	0.38
±60	2,101	-
±70	2,333	-
±80	2,900	-
±90	3,023	-

Figure 3. Masonry arch under full dead and live load with the compressive thrust line equilibrium solution. The dashed lines represent the middle third of the arch proper.

For scenario 2, where the thrust line is allowed to exit the middle-third, the compressive thrust line solution for a uniform live load of 3,500 psf (approximately 40x the expected live load of 85 psf) is shown in Figure 4. The solution confirms that the capacity of the structure is well above the expected live load. Furthermore, it should be noted that because adjacent arches are able to resist the lateral thrust, additional loading could even be sustained if the thrust line were allowed to exit the side of the stone wedge (it is currently constrained to the bottom of the wedge).

Again the stresses must be checked for this scenario where the thrust-line touches the intrados ($\alpha \approx 50^o$). Assuming a triangular stress distribution over the inner 6" of the arch thickness and a uniform distribution along the 22'-6" width of the arch, the compressive stress in the stone is:

$$\sigma_{axial} = 2 \cdot F_{axial} / (6" \cdot 22'\text{-}6") \quad (4)$$

At $\alpha \approx 50^o$, $F_{axial} \approx 5{,}050$ kips, and the maximum stress is approximately 6.2 ksi. This stress is still well below the compressive strength of granite (~30 ksi).

At the supports, the horizontal thrust can be resisted by the adjacent arches, but the vertical reaction must be taken by the pier. The total vertical reaction per pier for the two adjacent arches is ~ 12,150 kips. This can be distributed over an area of 22'-6" x 14'-0", which yields a stress of 0.27 ksi. The safety even with an impossibly large live load of 3,500 psf demonstrates that the arch is not in danger from uniform live loading.

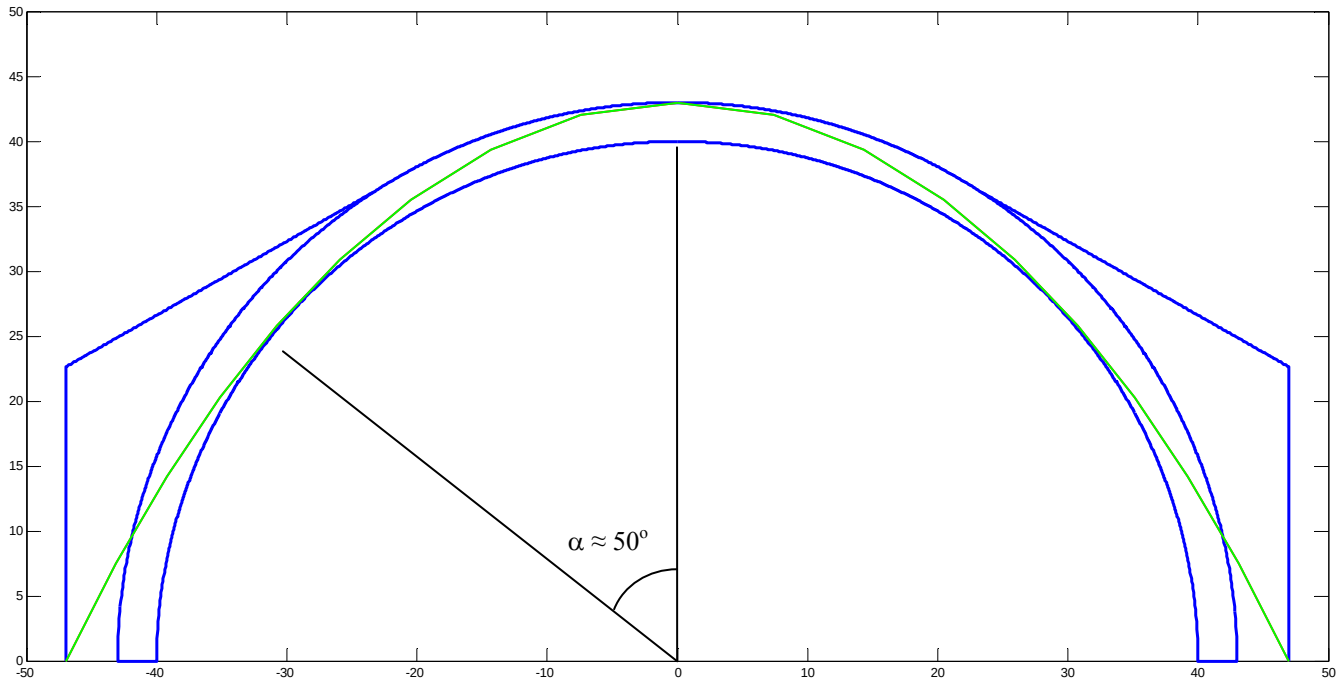


Figure 4. Masonry arch under full dead load and 3,500 psf uniform live load with the compressive thrust line equilibrium solution.

Load Case 2: Asymmetrical live load

For scenario 1, where the thrust-line is constrained to remain within the middle-third of the arch, a compressive equilibrium solution lying within the middle third of the arch is shown in Figure 5. Again, the thrust line exits the arch proper at the springing, but the surrounding stonework can easily accommodate the compressive thrust values. The arch is again determined to be stable.

The force in the arch increases from the crown to the supports and is shown in Table 2. The asymmetric forces within the arch reflect the asymmetric loading with slightly higher values on the half of the arch where the live load is applied. However, because the live load is very small compared to the dead load of the structure (as mentioned previously), the asymmetric loading has a relatively small effect.

Again, the stress at $\alpha \approx \pm 50^{o}$, should be checked using Equation 3. At $\alpha \approx -50^{o}$, $F_{axial} \approx 1{,}833$ kips which is less than before, so stresses remain low and compressive failure is not an issue.

Table 2. Internal Arch Forces

α (°)	F_{axial} (kip)
-90	2,924
-80	2,803
-70	2,241
-60	2,016
-50	1,785
-40	1,574
-30	1,402
-20	1,278
-10	1,206
0	1,184
10	1,209
20	1,289
30	1,425
40	1,610
50	1,833
60	2,074
70	2,307
80	2,876
90	3,000

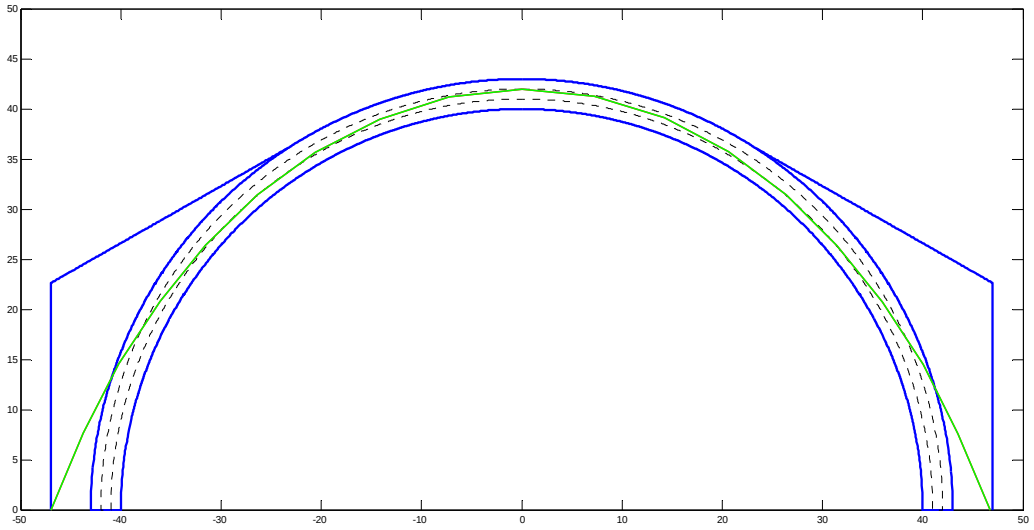


Figure 5. Thrust line solution for the masonry arch under full dead load and 85 psf asymmetric live load. Dashed line represents the middle third of the arch.

For scenario 2, where the thrust line is allowed to exit the middle-third, a second thrust line solution which corresponds to an applied live load of 850 psf along one half of the arch is shown in Figure 6.

Although the maximum capacity is significantly less than 3500 psf found for symmetric loading, it is still 10 times greater than the specified live load. Again, the capacity is limited by the assumption that the thrust line must exit the bottom of the stone wedge, which is not necessarily the case. Again, this solution is constrained to lie within the base of the pier, so even higher solutions are possible.

In this case, the stresses must be checked at $\alpha \approx 60^{o}$ where the thrust-line touches the intrados. Again, assuming a triangular stress distribution over the inner 6" of the arch thickness and a uniform distribution along the 22'-6" width of the arch, the compressive stress in the stone is found using Equation 4.

At $\alpha \approx 60^{o}$, $F_{axial} \approx 2{,}580$ kips, and the maximum stress is approximately 3.2 ksi. This stress is lower than that found for the symmetric case. And as before, the stress conservatively assumes that none of the masonry above the arch ring assists in supporting the load.

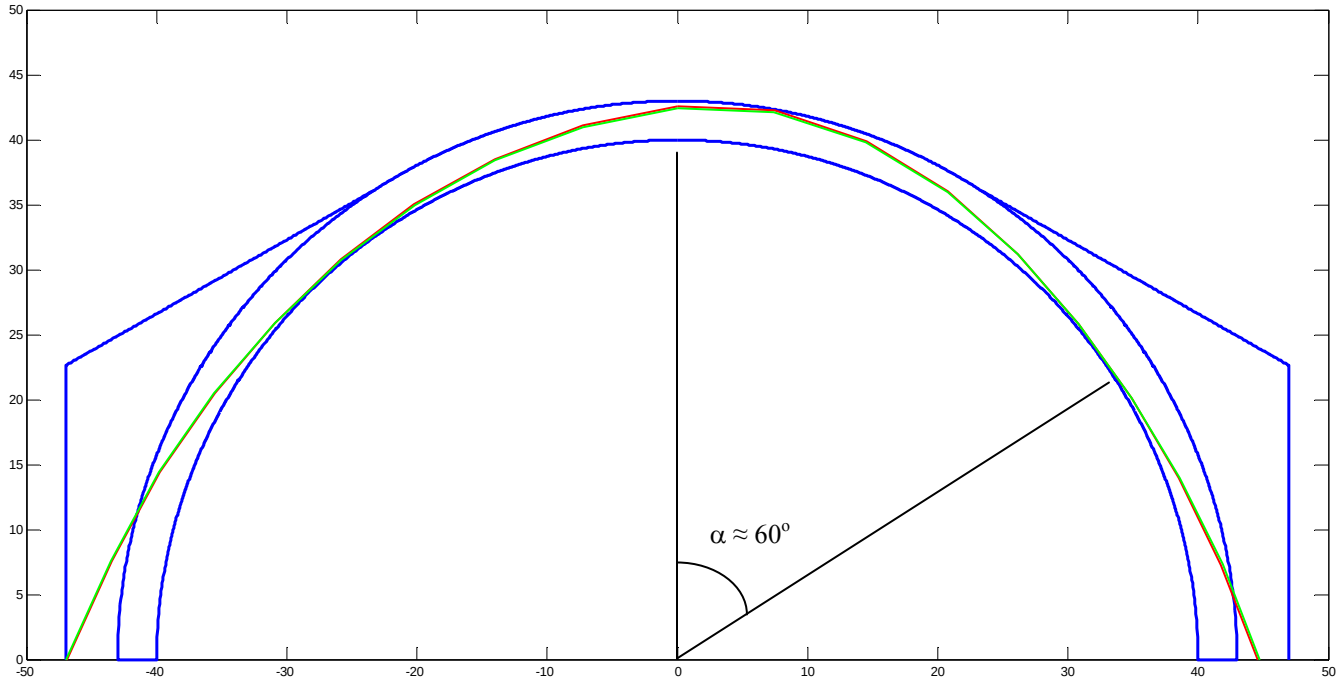


Figure 6. Masonry arch under full dead load and 850 psf asymmetric live load. The compressive thrust line is asymmetric due to the asymmetric live load.

Conclusions:

This analysis has demonstrated that the safety of the main arch span under vertical loading is not a concern. Thrust line solutions can be found within the middle third of the arch for both uniform and asymmetrical loading, ensuring a high safety factor for the stone arch spans. Additionally, the stresses within the structure are small relative to the strength of granite, so compressive material failure is not a concern.

The analyses show that the thrust lines exit the arch proper above the arch springing but the stone wedge provides a path for the thrust to pass from the arch to the piers. Adjacent arch spans would provide significant lateral restraint which would stabilize the structure even further. Therefore, the arch is concluded to be safe under the specified loading.

In conclusion, the expected live loads are extremely small compared to both the self-weight and the capacity of the structure, confirming the stability and durability which the structure has demonstrated over more than 150 years. The re-introduction of pedestrian loads or vehicle loads is not a cause for concern for the primary stone arches.

Appendix A: Background on Stability Analysis versus Finite Element Analysis

To further clarify the value of the assessment methods used in this report, this appendix seeks to emphasize the importance of a stability analysis in place of a linear elastic finite element analysis. Take, for example, the simple two block structure shown in Fig. A1a. What is the magnitude of *P* required for collapse (the top block to fall)? What is the collapse mechanism? Will the block slide first and then fall? Will the block simply overturn about point *A* without sliding when the magnitude of *P* is sufficient? Linear elastic finite element modeling is not capable of answering these questions.[2]



Figure A1. Example of stability analysis for a simple two block structure.

The load *P* necessary for collapse is clearly a question of stability, not stress. Of course stress plays a role when the entire load is focused at point A at collapse [Fig. A1b]. But in most cases of historical masonry construction, the working stress is two orders of magnitude below the compressive strength. Therefore, it is the instability of the structure, not insufficient compressive strength, which causes collapse. This simple example illustrates the value of a stability analysis and demonstrates the necessity of such an analysis for unreinforced masonry structures.

The limit analysis approach used in this report can be further contrasted with elastic analysis as described by Block et al. (2006).[3] Consider two semi-circular arches [Fig. A2], one with a thickness to radius (*t/R*) ratio of 0.08 and one of 0.16, loaded only by self-weight and supported on rigid foundations. A linear elastic finite element analysis (FEA) can be used to predict stresses in a masonry arch due to its own weight [Fig. A2]. By treating the arch as an elastic continuum on rigid supports, the output is similar to a fixed-fixed beam, and predicts tensile stresses (which can be interpreted as bending moments at the supports and at midspan.) The FEA outputs of the two arches are very similar and it is difficult for the elastic FE analyst to note any significant difference between the two arches of Fig. A2. A simple thrust line analysis immediately reveals the major difference between the two arches. The arch with a thickness to radius ratio of 0.08 is too thin to contain a thrust line and therefore, would not stand under its own weight unless the arch material had some appreciable value of tensile capacity, which is not the case for masonry. Therefore, the linear elastic finite element analysis gives an unsafe and deceptive result for the thinner arch by assuming that the material is capable of resisting tension. According to a linear elastic analysis, no masonry arch ever built is capable of standing without significant tension. Indeed, a linear elastic analysis would predict significant tensile stresses in a historic Roman aqueduct, and could lead to the conclusion that the structure is unsafe, despite 2,000 years of service.

[2] DeJong, M.J. "Seismic Assessment Strategies for Masonry Structures," Doctor of Philosophy in Building Technology, Massachusetts Institute of Technology, June 2009.

[3] Block, P., Ciblac, T., and Ochsendorf J.A. (2006). Real-time limit analysis of vaulted masonry buildings, *Computers and Structures* **84**(29-30), 1841-1852.

The power of the simple thrust line is clearly shown in the arch example below. While the FEA shows one possible stress state in the material, a linear elastic analysis does not say anything about the stability or collapse of the arch. The analysis of masonry arches is a long-standing problem in structural engineering, and this example immediately shows how difficult it is to draw conclusions from stress analysis, even for simple two-dimensional problems. The possible equilibrium configurations illustrated by the thrust line analysis give a clearer understanding of the problem. The thrust line gives more information about collapse than conventional elastic analysis and provides an immediate check for the stability of historic masonry structures.

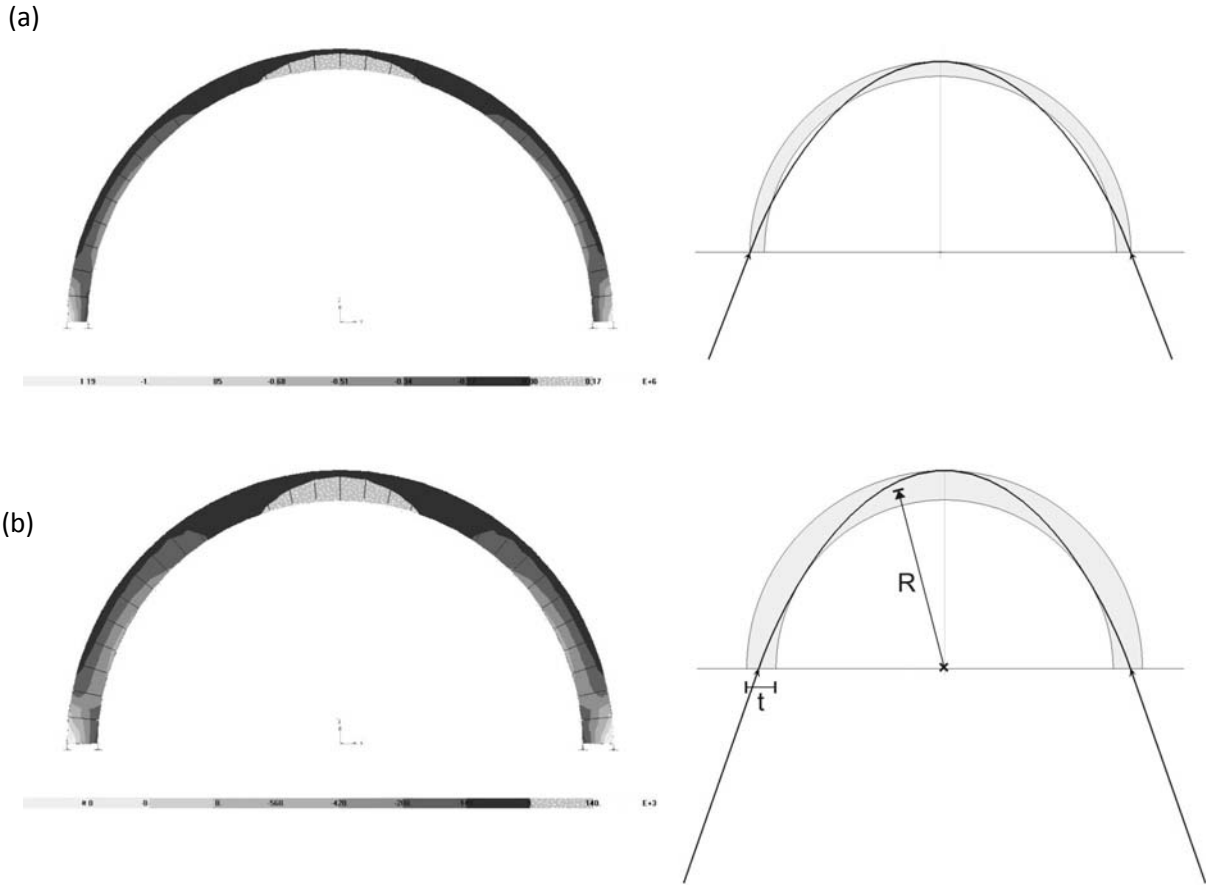


Figure A2. Elastic finite element analysis (left) versus limit state analysis (right) for arches with *t/R* ratios of (a) 0.08 and (b) 0.16.

OCHSENDORF DEJONG & BLOCK, LLC
Structural Engineering Consultants

Michael A. Lahti, PE
Assistant Vice President
TranSystems
Empire State Building
350 Fifth Ave, Ste. 924
New York, NY 10118-0110

April 15, 2010

Re: Structural Analysis of Brick Deck Arch, High Bridge, NYC

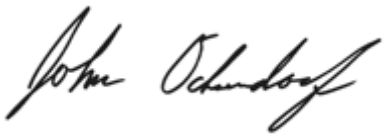
Dear Mike,

I am pleased to submit this preliminary report demonstrating the stability of the original brick arch for the deck of High Bridge. This is one of the most historically significant civil structures in the United States and it is a real pleasure to study it.

Our analysis shows that the arch is stable and has substantial reserve capacity for any loading which could be applied to it. The key question is the strength of the wrought iron tie bars. To keep with the original structural function of the deck, which has served well for 150 years, I recommend a full inspection to assess the strength of the remaining ties and to replace or supplement the wrought iron ties where necessary. The new ties could be carried out in stainless steel to differentiate the original construction from the current upgrade. Furthermore, as much original iron work should be maintained as possible. To understand the connection detail where the wrought iron ties meet the cast iron skewback, I recommend inspecting this junction at a location where the tie is likely to require complete replacement.

Please do not hesitate to contact me with any questions or concerns.

Yours sincerely,



John Ochsendorf, PhD
Partner | Structural Engineer
jao@odb-engineering.com
617.233.3648

Cc: Zach Rice, Li/Saltzman Architects

Title: Structural Analysis of Brick Deck Arch, High Bridge, NYC
Date: April 15, 2010
Project Engineer: John Ochsendorf
Report Number: 10-04-15

Introduction

This report describes the analysis of the brick masonry arch supporting the deck of the pedestrian walkway over High Bridge. We show that for two critical loading conditions, full live load and asymmetrical live load, purely compressive solutions exist with low stresses in the brick arch. The approach outlined below is based on limit analysis, following the theory of Professor Jacques Heyman of Cambridge University.[1] In short, historical masonry structures are predominantly a problem of stability and not stress analysis, and we seek a safe equilibrium solution for the applied loads.

Assessment of Brick Arches

The analysis considers the radial brick arch and overlying fill, spanning 13'-9" between walls, for a 5-foot-wide strip, corresponding to the 60" spacing between tie rods [Fig. 1]. To facilitate an approximate equilibrium solution, the arch was divided into ten equal-length segments of 16.5" (1/10 of the span), and the loads were assumed to act at the horizontal midpoint of each segment. (In reality, the center of gravity of each of these sections will vary only slightly from the assumed 8.25" centroid.) Dead loads were calculated by considering a rectangular prism, with the height at the midpoint, length of 16.5", width of 60" and a brick density of 120 pcf. Due to the increasing thickness of the arch at the haunches, the self weight of each segment varies from 1.5 kips (1500 pounds) nearest the support to 1.1 kips at midspan.

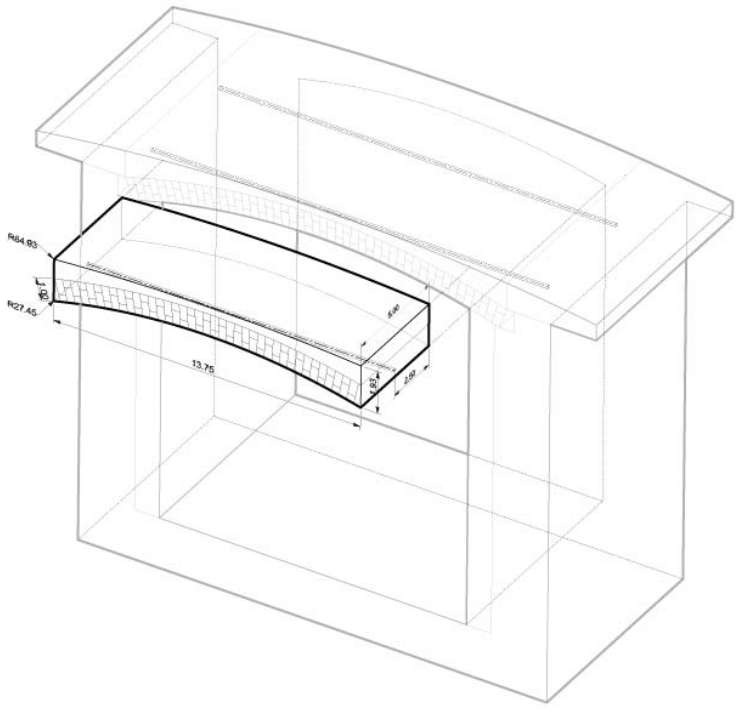


Figure 1. View of geometry and idealized five-foot wide strip of brick deck arch

[1] Heyman, J. The Stone Skeleton: Structural Engineering of Masonry Architecture. Cambridge University Press, 1995.

We consider two loading conditions: a uniform live load of 85 psf applied over the entire span, and the same loading applied on one half of the arch only. These loads represent the extremes of uniform and asymmetrical loading which can be expected. For the five foot wide strip, this corresponds to a distributed load of 425 lbs/ft, or 584 lbs per each 1/10 segment of the span due to live loading. (All loads are unfactored.)

Live loading = (85 psf)(5')(16.5"/segment)(1ft/12in) = 584 lbs/segment = 0.6k/segment

To demonstrate the stability of the arches under dead and live loads, we construct compressive thrust lines, which represent a possible load path within the structure. These thrust lines are pure equilibrium solutions, sometimes called funicular arches, which are found from the applied loads. To be extremely conservative, we assume that the thrust lines must lie within the middle third of the arch to maintain the entire brick section in compression. In reality, thrust lines are not confined to the middle third, which is a purely elastic assumption for a rectangular section. Most arches exist in a state of "passive" or "minimum thrust" in which the thrust line assumes the deepest possible rise within the arch to minimize the value of horizontal thrust on the supports. We also assume that all thrust lines terminate at the level of the iron ties, which are required to carry the horizontal thrust of the arch.

Compressive thrust lines in an arch can be constructed in one of three simple ways:

1) Using an excel spreadsheet to compute the coordinates and forces for the funicular arch;
2) Writing a closed form equilibrium solution, for example the horizontal thrust in an arch with uniform load w, span L, and depth d, is $H=wL^2/8d$; or
3) Using graphic statics to find a vector-based equilibrium solution.

The simplest method of calculation is graphic statics, which was used historically to analyze masonry arches, particularly in the late 19th and first half of the 20th century, and has been revived recently by the Masonry Research Group at the Massachusetts Institute of Technology.[2] We use custom software to construct the graphical solutions, which yields no rounding errors.

[2] Ochsendorf, J. and Block, P., "Designing Unreinforced Masonry," *Form and forces*, Chapter 8. E. Allen and W. Zalewski (Eds.), John Wiley & Sons, 2009, pp. 215-245. See also http://web.mit.edu/masonry for a list of related publications.

Results, Full live load:

For the arches under full live load and dead load, a compressive equilibrium solution is found within the middle third of the arch [Fig. 2]. The maximum force in the arch at the supports is 27.2 kips (27,200 pounds) at the support. Assuming this force acts over the entire section of the radial brick arch (12”x60”), the maximum compressive stress in the brick is 38 psi. Alternatively, conservatively assuming that the resultant force acts at the third point of the cross-section yields a triangular stress distribution with a maximum compressive stress of 76 psi. These stresses are well within acceptable limits for historical brick masonry. This equilibrium solution corresponds to a maximum tension force in the tie bar of 25.5 kips, which overestimates the expected bar force for reasons to be explained below.

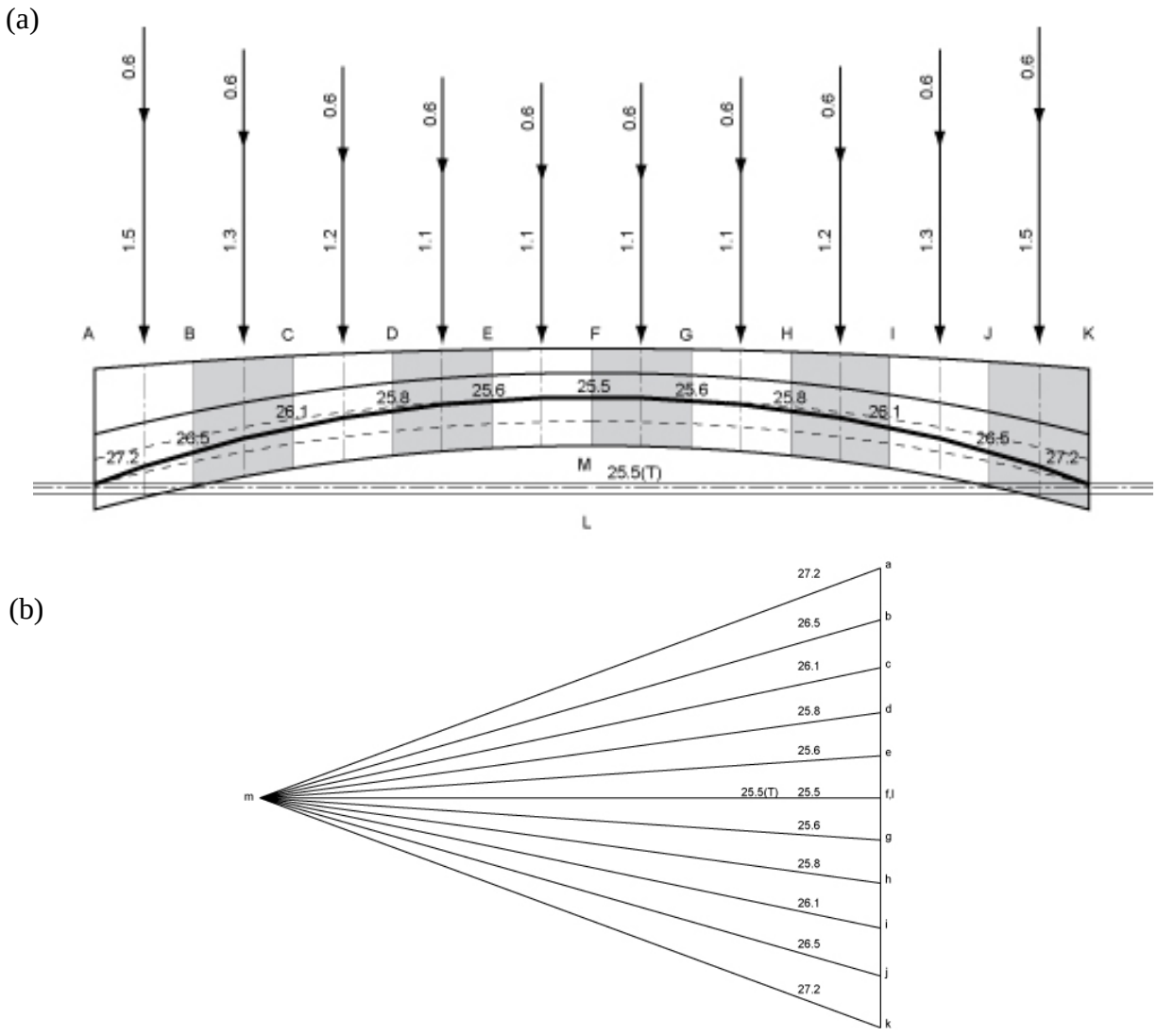


Figure 2. (a) Brick arch under full dead and live load. The compressive thrust line (darkest) is assumed to lie within the middle third of the arch. (b) The force polygon (labeled with Bow’s notation), which is a scaled drawing illustrating all of the forces in equilibrium. Segment *ab* on the force polygon represents the applied load of 2.1k near the left support, and the vectors *ma* (27.2k) and *bm* (26.5k) create a closed triangle of vectors in equilibrium.

Results: Asymmetrical live load

For the arch under half live load plus dead load, a compressive equilibrium solution is also found within the middle third of the arch [Fig. 3]. With a lower live load, the stresses in the brick and force in the tie bar are lower than those which occur under full live load (above).

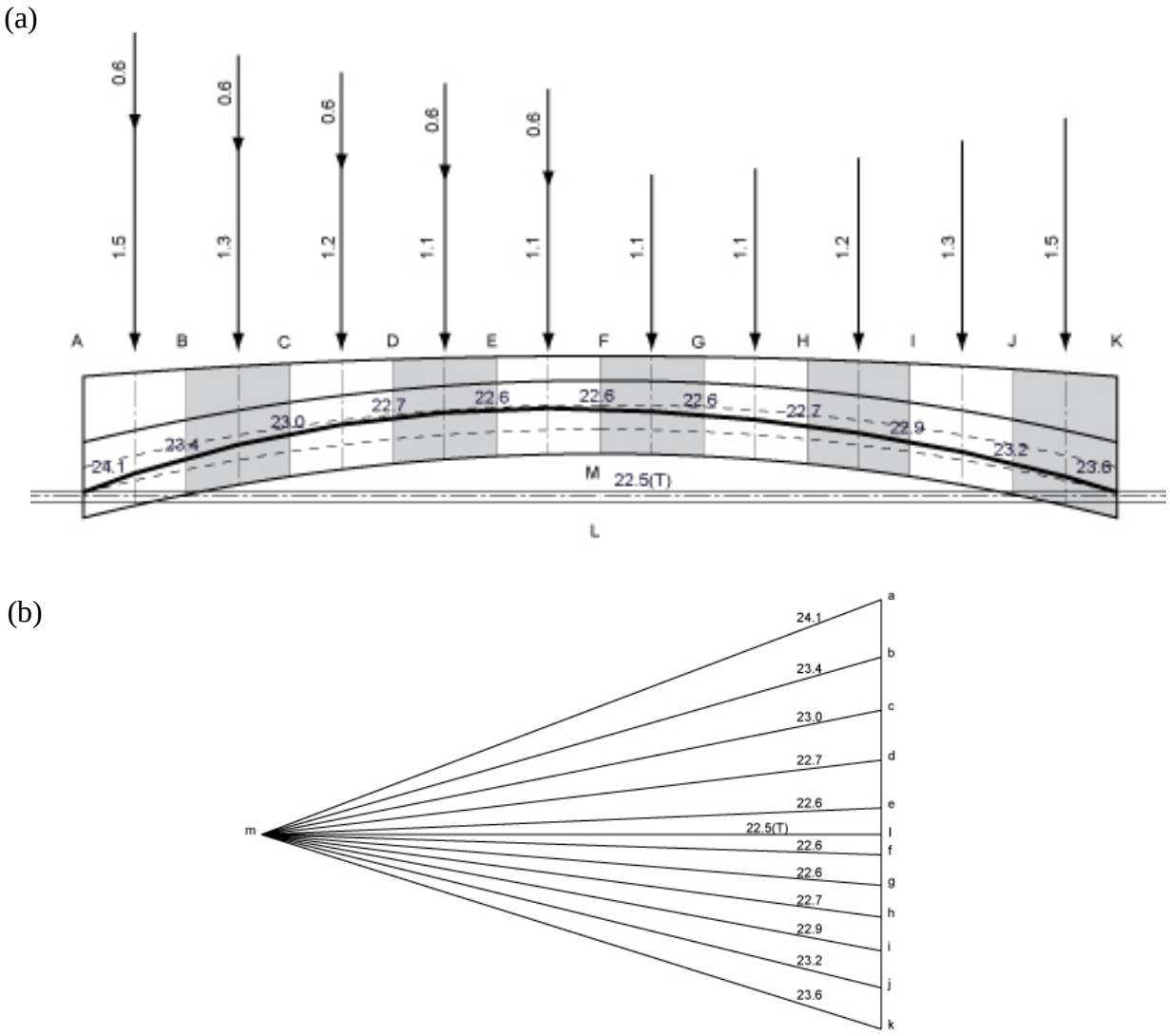


Figure 3. Brick arch under full dead and half live load. (a) The compressive thrust line skews slightly in the direction of the applied live load due to the asymmetry. (b) The corresponding force polygon is also asymmetric due to the loading.

Assessment of tie bars

To maintain the arch in equilibrium under the maximum expected live load, a tension tie must be applied at the base of the brick arch along the length of the bridge, as designed by the original engineer. The calculated value of 25.5k is higher than the rods will experience in reality. Under a full live load, the active thrust line will occur near the crown of the arch, increasing the rise of the thrust line arch by an additional 4", which will reduce the horizontal thrust in the arch and the tension force in the tie rod to approximately 20 kips. If necessary, we will be pleased to produce an additional drawing demonstrating this equilibrium state, which allows the compressive region to leave the middle-third of the arch section. This approach is similar to a strut-and-tie model, or truss model, which is commonly used in the design of reinforced and prestressed concrete structures.

Baker's report on the testing of the wrought iron showed a minimum yield strength of 27 ksi and a minimum ultimate strength of 45 ksi. The original 1.875" diameter wrought iron ties had a yield strength of approximately 74 kips for an original area of 2.76 square inches. Thus, the original ties were substantially overdesigned for the expected maximum load of 20 kips. To maintain a safety factor of 2.0 against yielding of the wrought iron, which is an acceptable measure of safety by today's code, each tie would therefore need a yield strength of 40 kips. For the historical wrought iron at 27 ksi yield strength, a reasonable safe cross-sectional area is therefore approximately 1.5 square inches, which corresponds to an effective diameter of 1.4 inches. These values are open to discussion of course.

This is still a conservative solution because the brick and granite walls supporting the brick arches also have significant lateral capacity. For the arch to collapse, multiple tension ties would have to fail and the supporting walls would need to overturn. Even if three or more adjacent ties were to fail suddenly, the brick arch would not collapse due to this reserve capacity and the excess capacity of adjacent ties. A full collapse analysis of the brick arch is beyond the scope of this report, but could be carried out if necessary.

Recommendation

Any bar which has less than an effective diameter of 1.4 inches at any point within its exposed length should be reinforced with new stainless steel ties whose placement is to be determined. As much original material should be maintained as possible, and these new bars should be kept to a minimum throughout the length of the bridge. They do not need to occur at closely spaced intervals and could be used very sparingly. They should also be designed in a manner that is reversible, if future engineers need to replace or remove them. The first step should be to identify which of the existing ties are not able to safely provide a tension force of 20 kips. To design a new anchorage system, it is recommend to inspect the connection between the existing wrought iron tie and the cast iron skewback at a place where the existing tie is missing or insufficient.

Appendix A: Background on Stability Analysis versus linear elastic Finite Element Analysis

To further clarify the value of the assessment methods used in this report, this appendix emphasizes the importance of a stability analysis in place of a linear elastic finite element analysis. Take, for example, the simple two block structure shown in Fig. 1a. What is the magnitude of force *P* required for collapse (the top block to fall)? What is the collapse mechanism? Will the block slide first and then fall? Will the block simply overturn about point *A* without sliding when the magnitude of *P* is sufficient? Linear elastic finite element modeling is not capable of answering these questions.[3]



Figure 4. Example of stability analysis for a simple two block structure.

The load *P* necessary for collapse is clearly a question of stability, not stress. Of course stress plays a role when the entire load is focused at point A at collapse [Fig. 1b]. But in most cases of historical masonry construction, the working stress is two orders of magnitude below the compressive strength. Therefore, it is the instability of the structure, not insufficient compressive strength, which causes collapse. This example illustrates the value of a stability analysis and demonstrates the necessity of such an analysis for unreinforced masonry structures.

The limit analysis approach used in this report can be further contrasted with elastic analysis as described by Block et al. (2006).[4] Consider two semi-circular arches [Fig. 5], one with a thickness to radius (*t/R*) ratio of 0.08 and one of 0.16, loaded only by self-weight and supported on rigid foundations. A linear elastic finite element analysis (FEA) can be used to predict stresses in a masonry arch due to its own weight [Fig. 5]. By treating the arch as an elastic continuum on rigid supports, the output is similar to a fixed-fixed beam, and predicts tensile stresses (which can be interpreted as bending moments at the supports and at midspan.) The FEA outputs of the two arches are very similar and it is difficult for the elastic FE analyst to note any significant difference between the two arches of Fig. 5. A thrust line analysis based only on static equilibrium immediately reveals the major difference between the two arches. The arch with a thickness to radius ratio of 0.08 is too thin to contain a thrust line and therefore, would not stand under its own weight unless the arch material had some appreciable value of tensile capacity, which is not the case for unreinforced masonry. Therefore, the linear elastic finite element analysis gives an unsafe and deceptive result for the thinner arch by assuming that the material is capable of resisting tension. It also incorrectly predicts significant tension throughout perfectly stable arches. According to a linear elastic analysis, no masonry arch ever built is capable of standing without experiencing tensile stresses. Indeed, a linear elastic analysis would predict significant tensile stresses in a historic Roman aqueduct, and could lead to the conclusion that the structure is unsafe, despite 2,000 years of service.

[3] DeJong, M.J. "Seismic Assessment Strategies for Masonry Structures," Doctor of Philosophy in Building Technology, Massachusetts Institute of Technology, June 2009.

[4] Block, P., Ciblac, T., and Ochsendorf J.A. (2006). Real-time limit analysis of vaulted masonry buildings, *Computers and Structures* **84**(29-30), 1841-1852.

The power of the thrust line approach is clearly shown in the arch example below. While the FEA shows one possible stress state in the material, a linear elastic analysis does not say anything about the stability or collapse of the arch. The analysis of masonry arches is a long-standing problem in structural engineering, and this example immediately shows how difficult it is to draw conclusions from stress analysis, even for simple two-dimensional problems. The possible equilibrium configurations illustrated by the thrust line analysis give a clearer understanding of the problem. The thrust line gives more information about collapse than conventional elastic analysis and provides an immediate check for the stability of historic masonry structures.

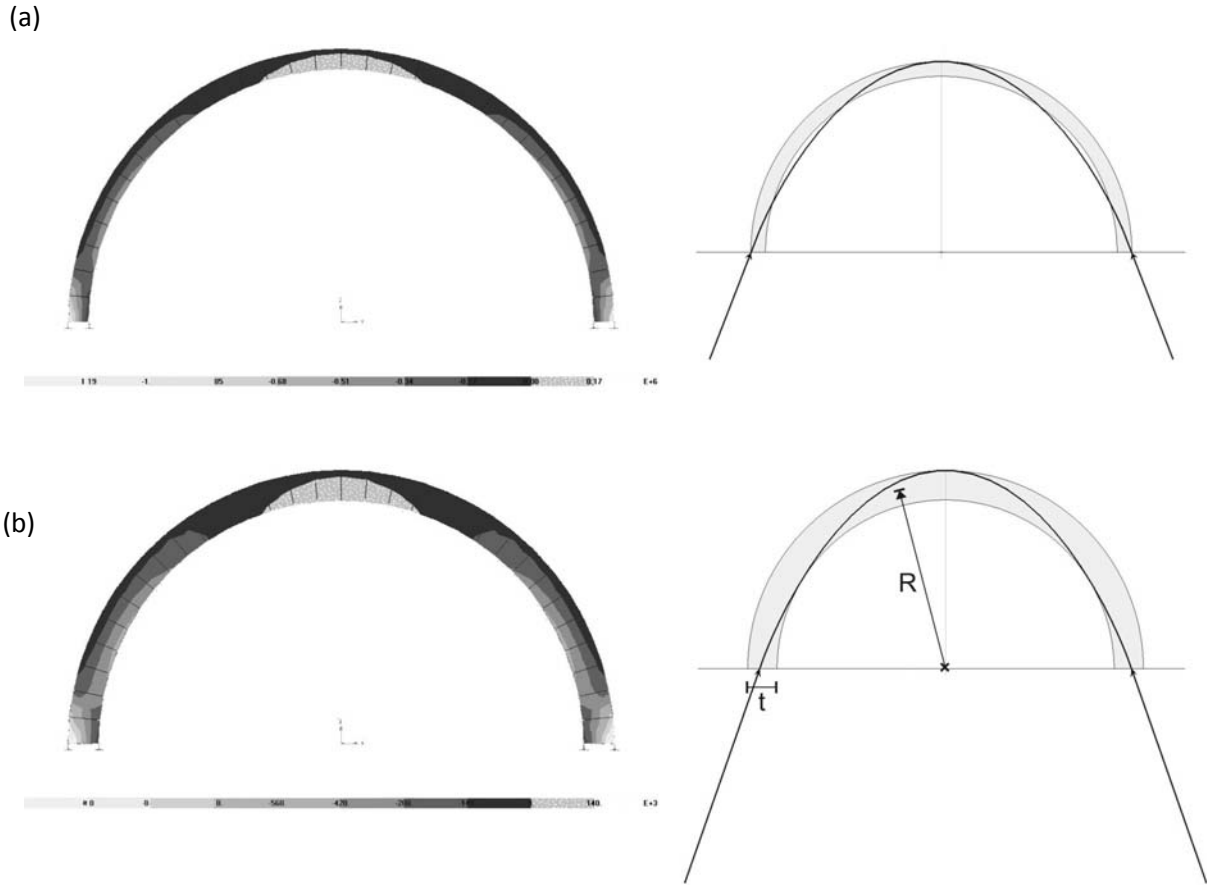


Figure 5. Elastic finite element analysis (left) versus limit state analysis (right) for arches with *t/R* ratios of (a) 0.08 and (b) 0.16.

7. Code, Safety and Accessibility Review

7.1. METHODOLOGY

7.2. GUIDELINES, SAFETY AND ACCESSIBILITY REVIEW

7.3. DESIGN STANDARDS FOR UNIVERSAL ACCESS

7.4. EXISTING CONDITIONS

7.5. BRIDGE ACCESS ALTERNATIVES AND RECOMMENDATIONS

7.6. DESIGN SCENARIOS

7.1 Code, Safety and Accessibility Review

7.1 METHODOLOGY

This section was developed using an initial code and accessibility study prepared by Alta Planning and Design. The study employed on-the-ground field work on foot and by bicycle, discussions with stakeholders and research into prevailing city, state and national policies and guidelines as the basis for its analysis and recommendations. Li/Saltzman Architects, Lichtenstein Consulting Engineers, and MKS Landscape Architects, in consultation with the NYC Department of Parks and Recreation, collaborated in developing the initial study into an interdisciplinary overview that addresses architectural, historic preservation, bridge engineering and landscape design issues for the High Bridge rehabilitation project. This section provides a summary of key opportunities and challenges, along with references to key factors in balancing the issues of mobility, access and safety within the context of the existing historic structure in the development of the proposed design concepts for the High Bridge.

7.2 GUIDELINES, SAFETY AND ACCESSIBILITY REVIEW

At the state and federal levels, there are existing guidelines that apply to shared-use paths, and pedestrian/bicycle facilities. While these documents are not absolute standards, many public agencies, including the New York City Department of Transportation (NYCDOT) and the New York State Department of Transportation (NYSDOT) require projects to follow the guidelines whenever feasible for key dimensions including slope, horizontal and vertical clearances, and surface condition, signage, and pavement markings. Key documents were reviewed to help inform the design of the High Bridge as a linear park linking the Bronx and Manhattan sides of Highbridge Park, and forming a critical component of the Old Croton Aqueduct Greenway with accommodations for commuting travel, recreational activities, tourism, and special events. The relevant documents include; The American Association of State Highway and Transportation Officials (AASHTO) Guidelines for the Development of Bicycle and Pedestrian Facilities, the NYC Greenways Plan and Streets Design Manual, the Manual of Uniform Traffic Control Devices (MUTCD), Chapters 17 and 18 of the NYS Highway Design Manual (HDM) and the NYS Bridge Manual (BM). The Americans with Disabilities Act (ADA) is civil rights legislation and requires consideration as well.

The High Bridge is an individually designated New York City landmark and is listed on the National Register of Historic Places (NR). The Old Croton Aqueduct, including the High Bridge, was documented by the Historic American Engineering Record (HAER) and the surviving components of its northernmost 26.2 miles – including the submerged dam, sub-grade conduit and tunnels, culverts, ventilators, waste weirs, gatehouses and the High Bridge are designated as a National Historic Landmark (NHL). The standards and guidelines of the New York City Landmarks Preservation Commission (LPC), the New York State Historic Preservation Office (NYSHPO), and the Secretary of the Interior's Standards for the Treatment of Historic Properties were also considered in evaluating alterations and additions to the bridge to address accessibility and code compliance.

Because Federal funds are being used to help rehabilitate the High Bridge, all of the standards and guidelines mentioned above must be taken into consideration.

7.2.1 Pedestrian Use as a Design Consideration

The High Bridge will function as a pedestrian link between the Bronx and Manhattan for commuting and other practical travel and will generate recreational movement between the two NYC parks it connects. The bridge is a cultural and historic artifact that will attract tourist activity, as will the scenic views from the bridge of the surrounding area. Consideration must be made for pedestrians, including the elderly and children, whose attention may be focused on social activities and observation of the site and surrounding scenery. Opportunities for gathering, sitting, and passive viewing should be accommodated to create a safe environment for these users.

7.2.2 Park Maintenance and Security as Design Considerations

The NYCDPR utilizes Gem E2 park maintenance vehicle for basic maintenance, including cleaning, trash collection, and minor repairs. Therefore the route of access on and off the bridge should accommodate this vehicle. Similarly, the NYPD scooter access must be accommodated for general monitoring and emergencies.

7.2.3 The Bicycle Use as a Design Consideration

Bicyclists and their bicycles come in a variety of sizes and configurations. This variation can take the form of the variety in types of vehicle (such as a conventional bicycle, a recumbent, tandem, bike with trailer, tricycle, etc.), or the behavioral characteristics and comfort level of the bicyclist riding the vehicle.

The operating space and physical dimensions of a typical adult bicyclist are shown below. Clear space is required for the bicyclist to be able to operate within a facility; this is why the minimum operating width is greater than the physical dimensions of the bicyclist. Although four feet is the minimum acceptable operating width, five feet or more is preferred.

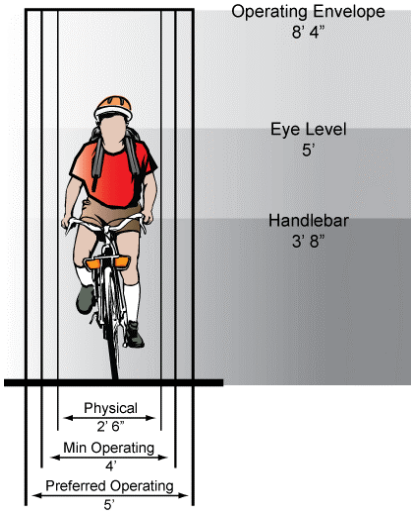


Figure 13: Operating Space and Physical Dimensions of a Cyclist *(Source: adapted from AASHTO Guide for the Development of Bicycle Facilities, 3rd Edition, 1999)*

+

7.2.4 Shared-Use Path Width

Shared-use path design criteria are based on the needs and characteristics of pedestrians, wheelchair users, strollers, and bicyclists. The focus was on meeting the requirements of the American Disabilities Act (ADA), coordinated with addressing safety for pedestrians, bicyclists and minimizing visual and physical impact on the historic bridge. The minimum paved width for a two-directional shared use path set forth by the AASHTO Guide and New York State DOT Highway Design Manual is 10 feet (§17.4.9). NYC has used wider cross sections for shared use paths (16' or greater) on the City's Greenway system but this width is not required where conditions do not permit. AASHTO also recommends an additional one-foot offset to hand rails or railings on ramps. The existing 17'-1" width of the High Bridge deck meets the criteria listed above. In locations where benches are planned, a 12'-1" clear pathway meets the guidelines as well.

For shared use the bridge path and access ramps should be designed to meet the minimum guidelines set forth by the AASHTO Guidelines, i.e. 10 feet minimum plus offsets where appropriate. However, due to the configuration of existing retaining walls at the Bronx approach as well as the desire to minimize intrusions to the landmark structure, the proposed access ramp widths and alignment have been kept to a minimum to fit

within the context of the historic bridge and accommodate the NYCDPR standard Gem cart maintenance vehicle. The clear ramp deck width (between handrails) is 8'-2" on the Manhattan ramp and 7'-4" on the Bronx ramp.

The NYSDOT design manual suggests the use of signage that instructs cyclists to dismount and walk along path or ramp facilities where adequate width is not provided. For High Bridge access, permanent signs will be placed at the entrances to the access ramps to instruct bicyclists to dismount and walk their bikes on the ramps or on the stairs. The ramps will be for the primary use of pedestrians and persons in wheelchairs. Further measures to direct cyclists away from the less-than-ten-foot ramps include the placement of thermoplastic pavement markings that will help lead cyclists to the stair approaches to the High Bridge. In a similar manner, thermoplastic pavement markings will be placed at the plaza approaches to lead persons with disabilities to the access ramps. A general slowing-down of all users is likely to occur at the entrances to the bridge, where visitors will get their bearings and negotiate the "funneling" of pedestrians, cyclists, and other users past the gates, stairs and ramps.

7.2.5 Cross Slope

Shared-use paths designed to be fully ADA accessible must meet the ADA's guidelines for maximum cross slope of 2%. In cases where a bike path is designed to be independent of an accessible route (i.e. ADA-accessible sidewalk or path is immediately adjacent), the maximum cross slope recommended is 5%, according to section 5.2.7 of the 2010 AASHTO draft. While the High Bridge will not have an independent bike route, the shared-use path will have cross slope ranging from a 2% pedestrian accessible route (PAR) to a maximum of 7% for the full width of the path. (See Bridge Deck Recommendation section below for a detailed description.)

7.2.6 Railings

Protective railings on either side of a shared-use path should be a minimum of 42-inches high to meet the AASHTO and NYS Bridge Manual guidelines. Section 5.2.10 of the 2010 Draft AASHTO Bike Guide recommends a 48-inch railing height where there are hard corners or sharp curves on a given path, particularly on bridge approaches, as is the case at the ends two of the proposed new access ramps to the bridge deck, due to the 90-degree turn required at the top and bottom of the ramp. In addition to providing a 48" railing at the ramps, cyclists will be required to dismount on the bridge access ramps. Also, an 8-foot high safety fence will be installed at the 90-degree turns to protect against potential vaulting from a crashing bicycle. The bridge span will have 42-inch historic railings with an 8-foot high safety fence offset 1-foot behind the historic railing. The fence design will be fully compliant with AASHTO design requirements.

7.2.7 Lighting

Fixed-source lighting reduces conflicts between different types of users along paths and at intersections, allowing them to see the path direction, surface conditions, obstacles, and other users. Path lighting is recommended in §17.4.10.3 of the NYS Highway Design Manual. Average maintained horizontal illumination levels of five lux to twenty-two lux should be considered. Where special security problems exist, higher illumination levels may be considered.

Bridge lighting will be installed along the full length of the bridge and ramp approaches. NYCDOT standard type "B" pole (12-foot high) provides the appropriate pedestrian scale lighting and the recommended horizontal and vertical clearances have been met.

7.3 DESIGN STANDARDS FOR UNIVERSAL ACCESS

7.3.1 Background

The United States Access Board has developed design guidelines to implement regulations established by the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990 (collectively referred to here as ADA). New York State regulations enacted in response to the ADA observe similar guidelines.

Implementation of ADA began with addressing the most obvious physical barriers obstructing mobility such as stairs, curbs, steep slopes, narrow passageways, rough or soft surfaces, doorways and gates that were difficult or dangerous to traverse in a wheelchair, with crutches or with another mobility assistance device. The ADA now also addresses accommodations for individuals with sight, hearing and other disabilities, which are beyond the scope of this technical memo.

7.3.2 Accessible Rights of Way for Bridges

There are no absolutes in implementing ADA. The agencies and courts have recognized that some sites and situations make accommodations extremely difficult, or conflict with other resource, right-of-way or use challenges. The law generally requires new construction or alterations incorporate accessibility standards. In general, the accessibility guidelines applicable to the High Bridge surface include the following: a *Pedestrian Accessible Route* (as defined by the US Access Board; see Table 1) shall include:

- the running slope (parallel to travel) cannot exceed 5% (1:20) unless railings are provided *(existing condition complies)*
- the cross-slope cannot exceed 2% (1:50) *(existing condition does not comply)*
- the two-way Pedestrian Accessible Route (PAR) not less than 64" wide *(existing condition does not comply)*
- the surface must be stable, firm and slip resistant *(existing condition does not comply)*

The proposed walkway along the bridge deck will provide a pedestrian accessible route (PAR) that is centered on the walkway crown but will most likely be slightly less than 64" due to the existing slope of the crown. At the edge of the PAR, three viewing platforms (one facing north and two facing south) will accommodate universal access with a 2% cross-slope to allow full access to the edge of the bridge for maximum scenic-viewing opportunities. (See Bridge Deck Recommendation section below for a detailed description.)

7.4 EXISTING CONDITIONS

7.4.1 Access to High Bridge from Washington Heights

The High Bridge is located mid-slope from Amsterdam Avenue to the Harlem River in Highbridge Park . The most direct access route is a recently-reconditioned stairway (fig 1) from the upper terrace adjacent to the community pool and historic water tower. The south end of the terrace is the most direct route from the Highbridge Park Recreation Center and adjacent neighborhood, roughly in alignment with West 173rd Street. An alternative route is a pathway that circles the recreation center and pool to the north, intersecting Amsterdam Avenue at West 174th Street (fig 2).

A Pedestrian Accessible Route (ie. compliant with ADA) connects the bridge to Edgecombe Avenue by way of a recently built multi-use trail (fig 3) and ramps to/from a sunken playground at West 167th Street (fig 4). The multi-use trail continues south, culminating in a steep segment (fig 5) that exceeds accessibility guidelines connecting to Edgecombe Avenue in the Adventure Playground near West 165th Street. The approximately 1,800 foot-long multi-use trail follows the historic alignment of the Old Croton Aqueduct.

7.4.2 Access to High Bridge from the Bronx

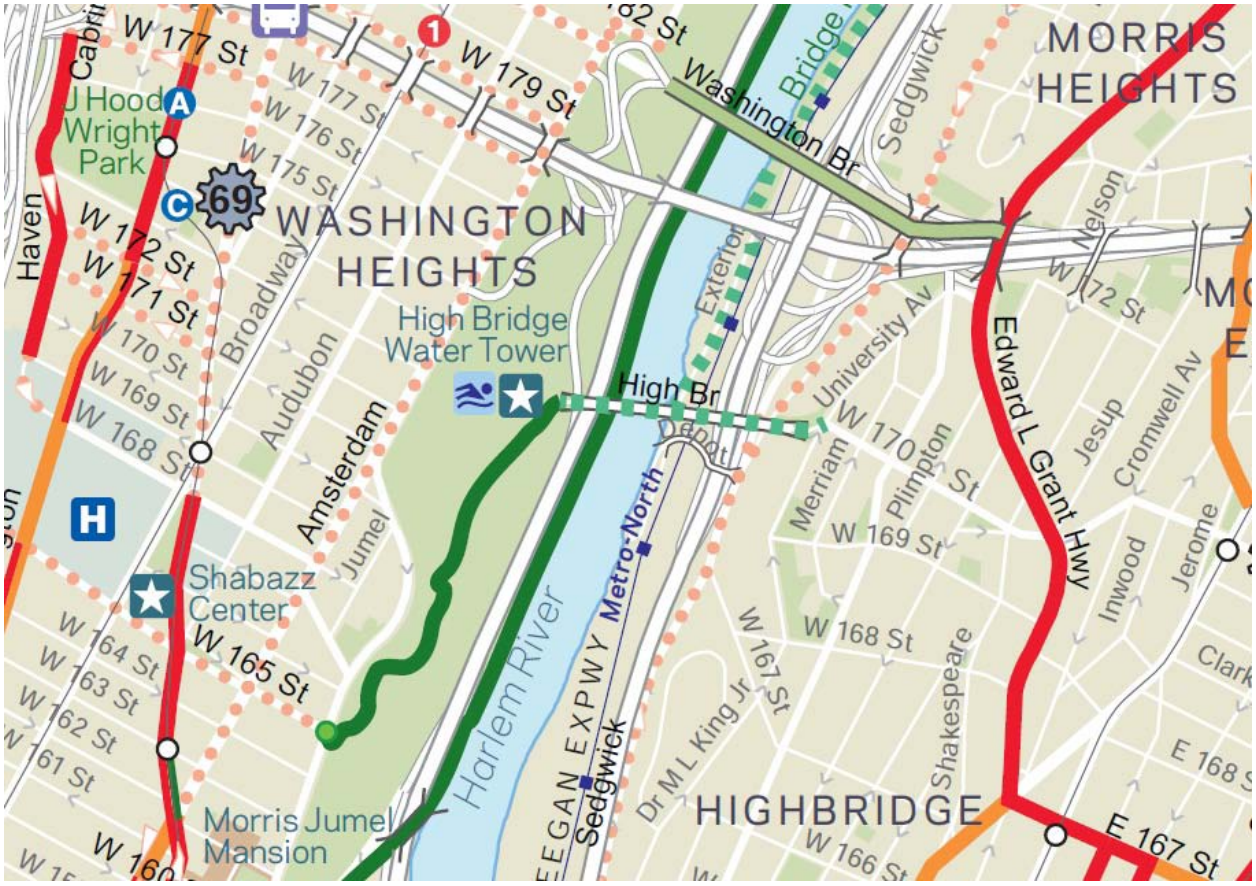
Highbridge Park in the Bronx was improved in 2001, including ramps, lighting, pathway, railings and seating (fig 6 and 7). The Pedestrian Accessible Route connects to Dr. Martin Luther King Jr. Boulevard/University Avenue approximately 270 feet from the end of the bridge, north of West 170th Street. There is also a stair way from MLK Blvd. to the gatehouse that sits just south of the West 170th Street intersection.

7.4.3 Access to the High Bridge deck

Both ends of the High Bridge have stairways down from the site to the bridge deck spanning the width of the bridge. The Washington Heights end has five risers whereas the Bronx end includes seven risers (fig 8). The Washington Heights end has an additional 6 step stairway from the site to the small plaza (fig 9) that sits just west of the gatehouse and at the far north end of the path connection to Edgecombe Avenue.

7.4.4 Access to the Harlem River Greenway

Access from the High Bridge to the Harlem River is circuitous at both ends. At the Bronx (east) end, an historic stairway (fig 10), now overgrown and in disrepair but funded for restoration, connects the bridge to Sedgwick Avenue (fig 11). The Depot Place Approach and Exterior Street provide access to the water's edge. The Parks Department recently acquired five acres of waterfront property immediately north of the High Bridge. While funding is still to be secured for their improvements, the City has long-term plans for open space improvements that would eventually connect to Roberto Clemente State Park. On the Washington Heights (west) side, a sidepath (fig 12) along the Harlem River Drive on/off ramp connects from Edgecombe Avenue and West 155th Street to the river.



Map 1 – Map of the areas adjacent to the High Bridge. *(New York City Department of Transportation Cycling Map – 2012)*

Figures 1 – 12 (see following pages)



FIGURE 1. *Stair from Highbridge Park Pool area, Manhattan*



FIGURE 2. *Path to Amsterdam Avenue, Manhattan*



FIGURE 3. *Multi-use path from Edgecombe, Manhattan*

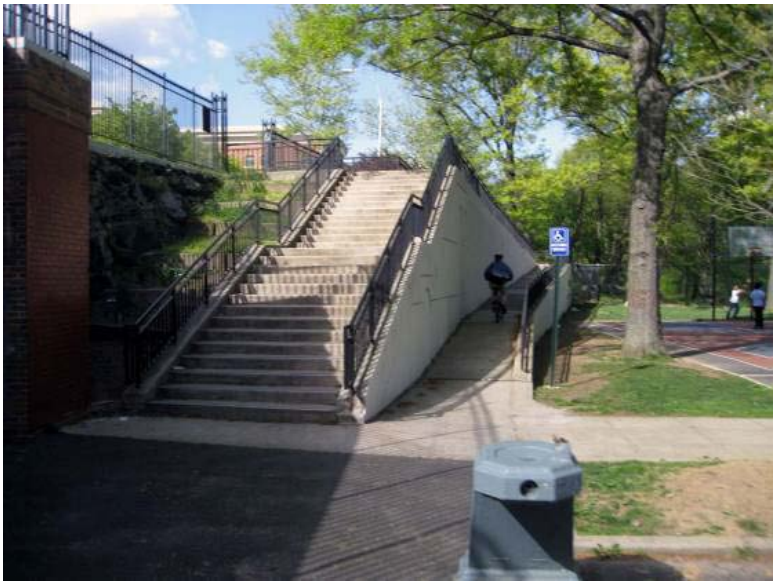


FIGURE 4. *ADA-accessible ramp to Edgecombe, Manhattan*



FIGURE 5. *Steep grade on path from 165th Street, Manhattan*

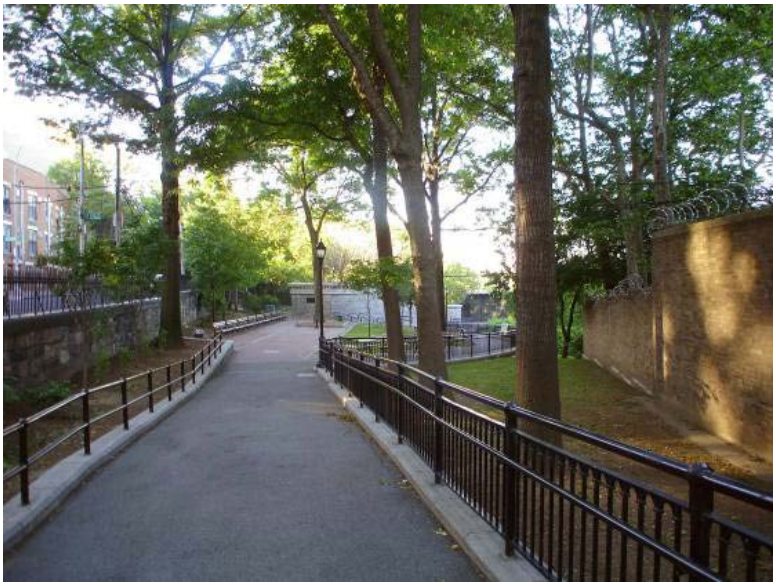


FIGURE 6. *Access path from MLK Jr. Blvd, Bronx*



FIGURE 7. *Ramp from terrace to gatehouse area, Bronx*



FIGURE 8. *Stairs on the east end of bridge, Bronx*



FIGURE 9. *Stairs next to gatehouse on west end, Manhattan*



FIGURE 10. *Stair connection to Sedgwick Ave, Bronx*



FIGURE 11. *Base of stair at Sedgwick Ave, Bronx*



FIGURE 12. *Sidepath to Harlem R. Greenway, Manhattan*

According to the survey performed for this project, the overall width of the top bridge surface is 28'-7" on the masonry spans at the piers and 25'-1" at the masonry arches. On the steel span, the width is 28'-6". The brick walkway measures 17'-1" wide and the difference is taken up by either 3'11" granite coping stones (on the stone spans) or 5'11" steel coping plates (on the steel span) on both sides of the walkway.

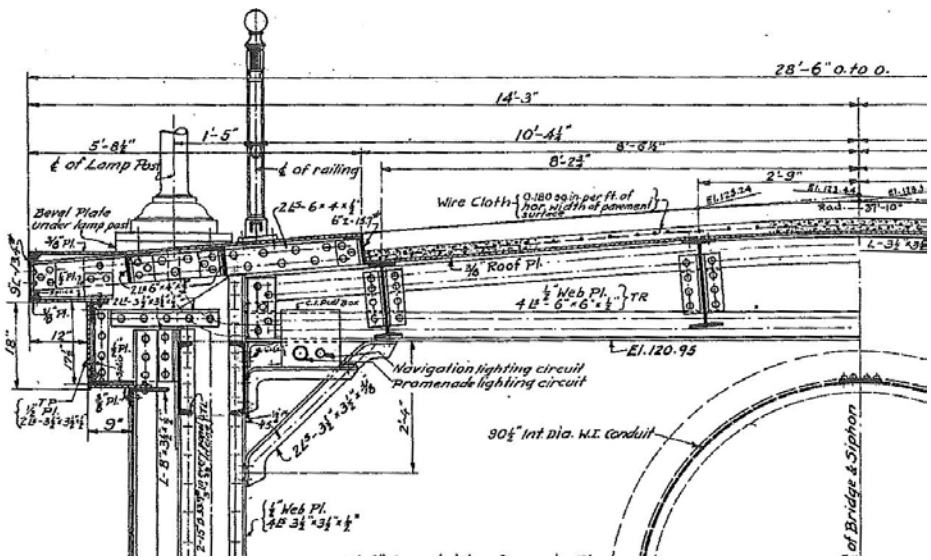


FIGURE 13. *Engineering drawings for the steel span segment of the High Bridge give precise dimensions for the width, slope and* curvature of the surface.

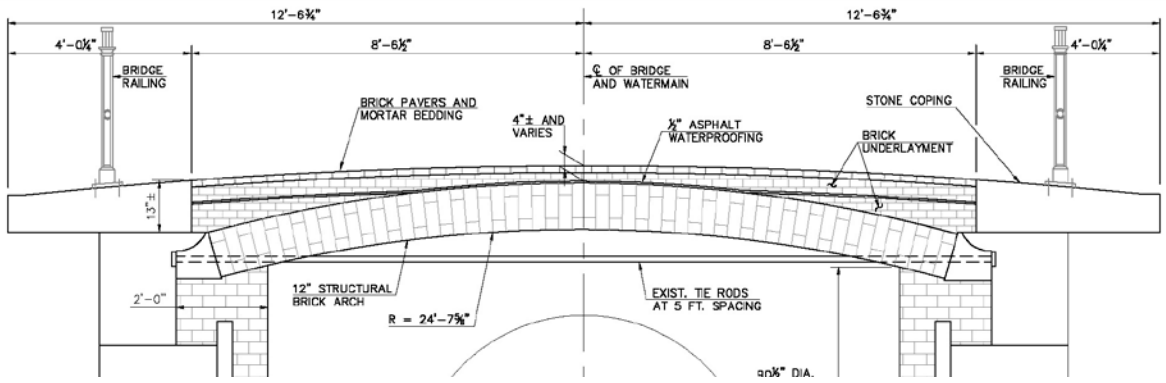


FIGURE 14. *Section of the bridge showing the masonry arches.*

Figure 13 and 14 above illustrate the existing condition on the surface of the High Bridge at the steel and masonry spans, respectively. The walking surface is 21 feet wide and composed of clay brick laid in a running bond pattern over the 1928 steel arch span and herringbone pattern on the original deck built in the 1860's. Both are edged with granite or steel plate as noted above. Above the masonry arch spans, the existing surface drops approximately 7.44 inches from the center to the edge of the bridge, a cross slope of 7%. Above the steel arch span above the Harlem River, the existing deck surface drops approximately 5.16 inches from the center to the edge of the bridge, a cross slope of 5%.

7.5 BRIDGE ACCESS ALTERNATIVES AND RECOMMENDATIONS

Short stairways lead down from the Manhattan and Bronx gatehouse plazas to the bridge deck. The Manhattan end of the bridge has additional short stairways adjacent to the gatehouse. Ramps are required to provide ADA compliant (see matrix on last page of memo) access past these barriers. Ramps sloped between 5% and 8% require hand rails and intermediate landings for each 30" of rise. As stated above, due to existing structural and constraints and the desire to minimize visual intrusions on the High Bridge structure, the access ramps will be narrower than 10 feet in clear width. Bicyclists will be instructed to dismount and walk their bicycles along the ramps.

7.5.1 Manhattan Access

The Gatehouse Plaza at the Manhattan end of the bridge is accessible from the Highbridge Park neighborhoods by way a ¾ mile multi-use path and ADA accessible route from the Sunken Playground at Edgecombe Avenue and 167th Street, or a slightly steeper route from Edgecombe Avenue and 165th Street. Pedestrians are able to connect directly from the Highbridge Park Pool area and the Water Tower plaza down to the bridge via the recently-renovated stair structure, at approximately 173rd Street.

Multiple variations on a few basic configurations were considered for locating an access ramp or ramps access from the Manhattan bridge plaza level (west of the gatehouse) to the vent plaza level (east of the gatehouse) and ultimately to bridge deck level (see Bridge Access Plans for Manhattan at the end of this section):

- One ramp on the north side of the bridge providing access from the bridge plaza to the vent plaza , combined with a second ramp on the bridge providing access from the vent plaza to the bridge deck (see Bridge Access-Manhattan Option 1, 1A, 1B, & 2)
- One ramp on the north side of the bridge providing access directly from the bridge plaza to the bridge deck (see Bridge Access-Manhattan Option 3)
- One ramp on the south side of the bridge providing access from the bridge plaza to the vent plaza, combined with a second ramp on the bridge providing access from the vent plaza to the bridge deck (see Bridge Access-Manhattan Option 4, 5, 6, & 7)
- One ramp on the north side of the Gatehouse providing access from the bridge plaza to the vent plaza, combined with a second ramp on the bridge providing access from the vent plaza to the bridge deck (see Bridge Access-Manhattan Option 8)
- One ramp running through the Gatehouse providing access from the bridge plaza to the vent plaza, combined with a second ramp on the bridge providing access from the vent plaza level to the bridge deck (see Bridge Access-Manhattan Option 9)

Based on convenience and accessibility, park maintenance vehicle access, bicycle access, feasibility of construction, impact on the historic fabric, and visual impact on the bridge, the option for one ramp on the north side of the bridge providing access from the bridge plaza to the vent plaza level, combined with a second ramp providing access from the vent plaza level to the bridge deck was selected and developed (similar to Manhattan Access - Option 1B).

7.5.2 Bronx Access

The east end of the bridge is accessible by way of a short multi-use path from Dr. Martin Luther King Jr. Boulevard to the Gatehouse Plaza.

Multiple variations on a few basic configurations were considered for locating an access ramp or ramps for access from The Bronx bridge plaza level (east of the gatehouse) to the vent plaza level (west of the gatehouse) and ultimately to bridge deck level (see Bridge Access Plans for The Bronx at the end of this section):

- Utilizing the existing access ramp from the bridge plaza to the vent plaza, combined with one ramp on the bridge providing access from the vent plaza level to the bridge deck (see Bridge Access-Bronx Option 1 & 1A)
- One ramp on the north side of the bridge providing access from the bridge plaza to the vent plaza, combined with a second ramp on the bridge providing access from the vent plaza to the bridge deck (see Bridge Access-Bronx Option 1B)
- Utilizing existing access from the bridge plaza to the vent plaza level, combined with one ramp on the north side of the bridge providing access from the vent plaza to the bridge deck (see Bridge Access-Bronx Option 2, 2A, & 2B)
- One ramp on the north side of the bridge providing access directly from the bridge plaza to the bridge deck level (see Bridge Access-Bronx Option 3)

Based on convenience and accessibility, park maintenance vehicle access, bicycle access, feasibility of construction, impact on the historic fabric, and visual impact on the bridge, the option for utilizing existing access from the bridge plaza level to the vent plaza level, combined with one ramp on the north side of the bridge providing access from the vent plaza level to the bridge deck level was selected and developed (similar to Bronx Access - Option 2).

7.6 DESIGN SCENARIOS

During the Schematic Design phase of the project, five design options were explored for the High Bridge deck. These included:

- **Option 1** – retains the existing crown of the bridge and includes ADA-accessible viewing platforms (at a 2% slope) in three locations (graphic not shown)
- **Option 2** (Fig. 15) – the Center Panel Rebuild option provides a flatter surface in the center of the bridge and includes ADA-accessible viewing platforms (at a 2% slope) in three locations (graphic not shown)
- **Option 3** (Fig. 16) – Outside Lanes provides flatter surfaces at the edges of the bridge
- **Option 4** (Fig. 17) – Full Deck raises the edges
- **Option 5** (Fig. 18) – Drop Full Deck reduces the side slope across the entire surface by lowering the crown.

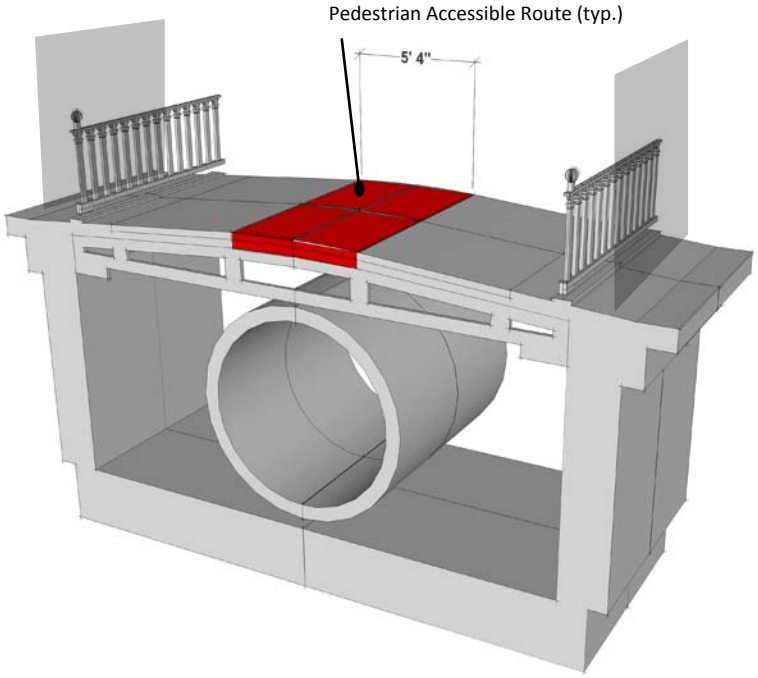


FIGURE 15. ***Option 2: Center Panel Rebuild Pedestrian Accessible Route (PAR).*** *This alternative replaces a center portion of the bridge surface with a 64" wide PAR that does not exceed 2% for its entire width. Rebuilding the central portion of the crown at no more than a 2% slope would likely result in a steeper slope than currently exists between the PAR and the edge of the bridge, however.*

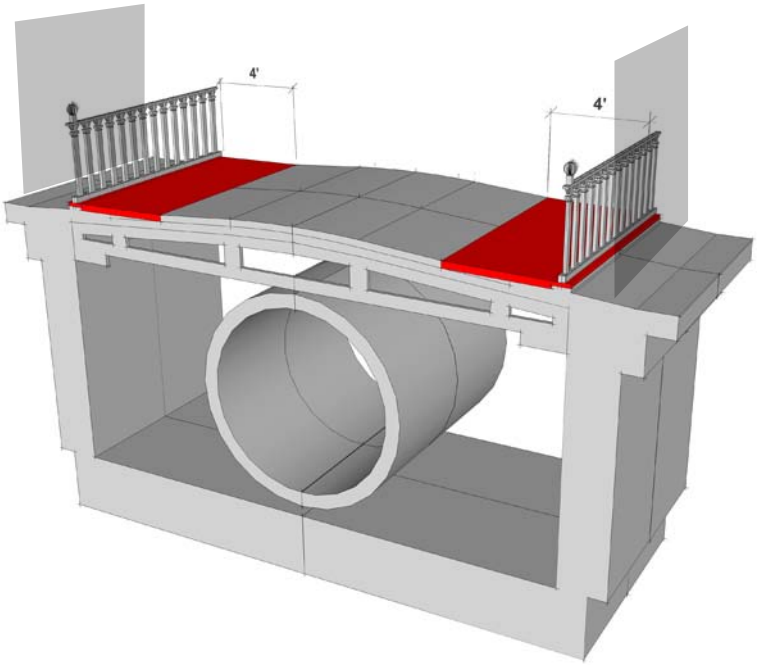


FIGURE 16. ***Option 3: Outside Lanes Pedestrian Accessible Route.*** *This alternative replaces a portion of the outer areas of the walking surface and provides a minimum of a 48" (recommended 72") Pedestrian Accessible Route in each direction. This option requires raising the curb supporting the railings and will lead to a 1.5" curb on the steel span and a 3" curb on the masonry span.*

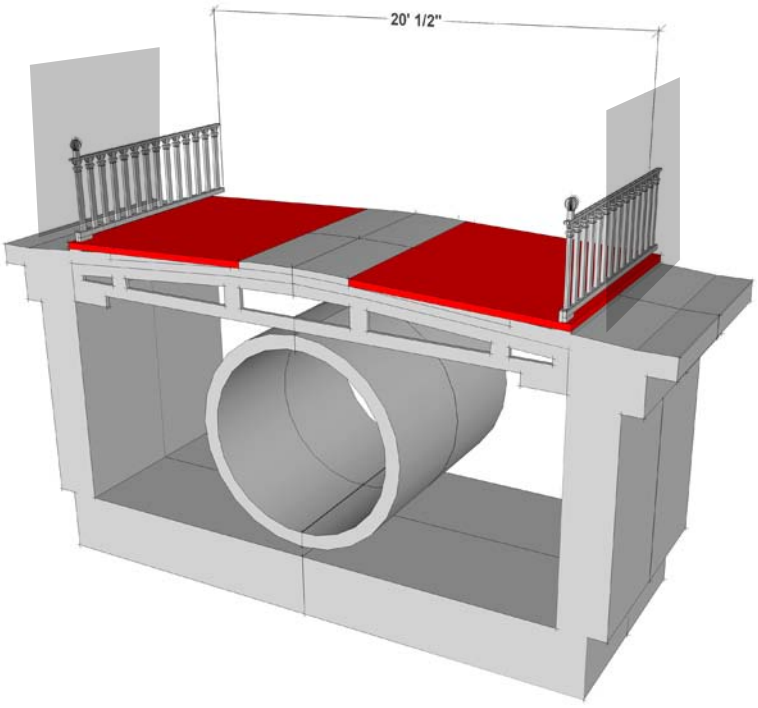


FIGURE 17. ***Option 4: Full Deck Pedestrian Accessible Route.*** *This alternative replaces a broader portion of the walking surface by raising the edges, making the whole deck a Pedestrian Accessible Route. This option requires raising the curb supporting the railings and will lead to a 3" curb on the steel span and a >5" curb on the masonry span.*

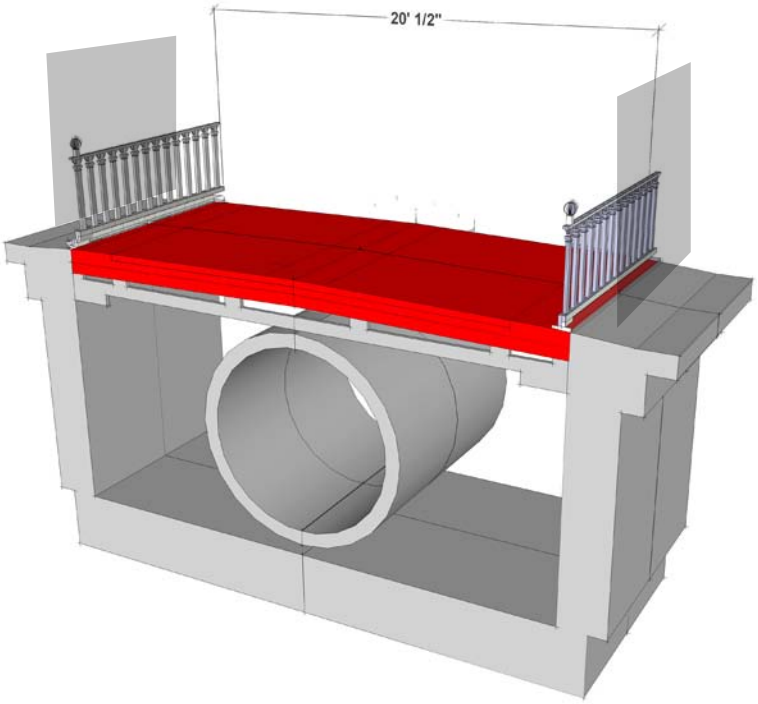


FIGURE 18. ***Option 5: Drop Full Deck Pedestrian Accessible Route.*** *This alternative replaces the entire walkway deck, drops the crown and maintains the edge elevations, making the whole deck a Pedestrian Accessible Route. It was determined that this option was not possible due to numerous structural complications.*

7.6.1 Bridge Deck Discussion

Option 1 has the least impact to the historic deck surface by visually impacting the existing crown in only three locations where the viewing platforms will be located. While the curvature of the crown creates a cross-slope slightly greater than 2% at the edges of the central 64" portion of the bridge deck, the center of the bridge becomes the designated Pedestrian Accessible Route with an average cross slope of less than 2%. Option 2 creates a 64" PAR where no section of the route exceeds a 2% cross-slope, leading to slightly steeper cross-slopes outside of the PAR, an undesirable change. Option 3 provides good access to the railings for viewing and resting. However, it has a significant impact on the historic fabric by creating visible curbs that will run for the full length of the bridge. Option 4 provides a full-width PAR but requires the greatest modification to the existing structure and shape. Option 5 requires replacement of the supporting structure. Given that there is only 3" of concrete slab on the steel span over the plate and less on the masonry span, Option 5 was completely ruled out.

7.6.2 Bridge Deck Recommendation

After evaluating the design options, the consensus of the team was to select Option 2. The proposed walkway along the bridge deck will provide a pedestrian accessible route (PAR) that is centered on the walkway crown but is less than 64" due to the existing slope of the crown. While the center of bridge is flat, the gentle curvature of the crown, in all likelihood, exceeds 2% within portions of the 32" off-set area from the center line of the bridge. During the relaying of the brick walkway, attempts will be made to "flatten out" the top of the bridge crown, but the shallow depth of the bridge superstructure precludes a more significant change to the High Bridge's crown. At the edge of the PAR, three viewing platforms (one facing north and two facing south) will accommodate universal access with a 2% cross-slope to allow full access to the edge of the bridge for maximum scenic-viewing opportunities. Outside of the PAR, the remaining portions of the bridge walkway will have a variable cross slope that exceeds 2%, up to 7% maximum. Railings and safety fence will both be provided to each side.

7.6.3 Ramp Geometry Discussion

- **Turning Radius to accommodate minimum bicycle speeds**

  For bicyclists to maintain their balance while turning corners, a minimum turning radius is typically required, based on anticipated speed of bicycle travel. Because of the potential use of the bridge by pedestrians and cyclists, an average design speed of 12 mph is anticipated for cyclists approaching the ramps to the High Bridge deck from either side. Page 38, tables 1 and 2 of the 1999 AASHTO guide recommends a turning radius of 30-36' in this scenario, while section 5.2.5 of the 2010 Draft recommends a 27' turning radius.

- **Safe stopping distance for minimum bicycle speeds**

  An issue for consideration with a straight ramp design for access to the High Bridge is safe stopping distance for cyclists. In order to make a 90-degree turn at the base of a sloped surface, considerable space is required for cyclists to negotiate the turn. Both page 42/Figure 19 of the 1999 AASHTO Guide and section 5.2.8 of the 2010 Draft update recommend a distance of at least 90 linear feet to accommodate a safe stop for cyclists moving 12 mph on a ramp of 8% grade.

It is the consensus of the design team that the access ramps have a small a profile as possible, and the selected design is straight with 90-degree corners. The consequence of this design element is that it could be difficult for cyclists to navigate the corners at the top and bottom of the ramp, especially if other users are present at these corners and the full width is not free. Due to the potential risk of collision, the access ramp design will require bicyclists to dismount when ascending or descending the ramp. Under these conditions, signs and thermoplastic pavement markings directing cyclists to dismount will be installed at both approaches to the bridge's access ramps.

TABLE 1: HIGH BRIDGE MATRIX OF RELEVANT DESIGN GUIDELINES AND STANDARDS

A. Bridge Approaches and Access

Element	Standard per Applicable Code	Existing Condition	Sub-Standard*	Proposed/Necessary Action for Code Compliance
Running slope (trail, plaza and bridge surface)	Max. 5% (ADAAG)	Stairs between gatehouse plazas and bridge deck. Other surfaces less than 5%.	Yes	Install ramps for ADA accessibility to bridge deck
Ramp slope to bypass stairs	Max. 8% with railings and landings at 30" vertical (ADAAG)	No existing ramps. Stairs between gatehouse plazas and bridge deck	Yes	Construct ramp with < 5% slope OR with <8% slope, landings and railings
Ramp landings	Min. 60" long, min. width equals ramp with, min. 60" x 60" if ramp changes direction at landing (ADAAG)	No existing ramps	N/A	Ramp landings will be at least 60" x 60"
Railing height at ramp landings	For multi-use paths, railing at landings must be min. 42", 48 recommended where high speed, steep-angled bicycle crashes could occur, lateral offset min. 12" (AASHTO)	No existing ramps	N/A	Ramp railings at off-bridge ramps will be 48" and 8'-0" safety fence will be provided at 90-degree turns to protect against vaulting from crashing bicycles or wheelchairs
Ramp width	Min. 60" for 2-way wheel chairs (ADAAG, NYSDOT)	No existing ramps	N/A	Min. 60" ramp for two-way ADA access.
Multi-use trail width	10-14 (min. 10-14' in constrained situation) for 2-way bicycles with min. 1' clearance on either side of path (AASHTO, NYSDOT) 12-16' for 2-way shared use path, including 2' buffer between path and surrounding (MWGMP) 8-14' for 1-way bike path (NYCSDM)	Existing trails accessing site and bridge deck comply	No	While existing trails and bridge deck comply, the proposed treatment will not comply. Ramp width will be 8'-2" on the Manhattan ramp and 7'-4" on the Bronx ramp
Signage	Standard greenway signs will be used on greenways throughout the city (MWGMP) Dimensions: 12" wide, 21-26" high, edge of sign align with edge of path, installed 7' above finished grade (MWGMP)	NY Greenway signs mark approaches	No	All signage will comply with MWGMP and client standards

B. Bridge Deck

Element	Standard per Applicable Code	Existing Condition	Sub-Standard*	Proposed/Necessary Action for Code Compliance
Cross slope Pedestrian Access Route (PAR)	Max. 2% (ADAAG, NYSDOT)	24" PAR at crown of bridge deck. Cross slope varies up to 7%	Yes	Proposed treatment will not provide a compliant PAR. Two mid-span viewing platforms provide ADA access to bridge railings.
Ramp railings	Height 34-38" (ADAAG), 36" recommended (NYSDOT) Rub-rail recommended for the area 36-42" high on a railing (AASHTO)	No existing ramp railings	N/A	Railing height will be 48" and will not include a rub-rail
Trip hazards	Max. ¼" vertical change in surface, max. ½" with beveled edge (NYSDOT)	Numerous trip hazards exist	Yes	Rebuilt bridge deck will conform to the standard
Slip hazards	Static coefficient of friction is 0.8 (ADAAG)	Clay brick surfaces may include slip hazards	Yes	Reconstruction may include resetting existing paving materials or replacement in kind.

* Substandard = Existing condition does not comply with the standard per the applicable code.

TABLE 2: HIGH BRIDGE MATRIX OF RELEVANT BRIDGE DESIGN GUIDELINES AND STANDARDS

Element	Standard per Applicable Code	Existing Condition	Sub-Standard*	Proposed/Necessary Action for Code Compliance
Bridge Deck Arches	Live Load = 85 lbs./SF AASHTO Standard Specifications for Highway Bridges, 17th Edition (See Reference Noted 2)	Brick Deck Arches do not rate for pedestrian live load	Yes	Strengthening of the brick arches with the installation of supplemental tie rods in the recommended action
Historic Pedestrian Railing – Capacity Longitudinal Elements Post Elements Anchorage	See Reference Note 1 & 2 50 lbs./LF vertically and transversely, acting simultaneously plus a point load of 200 lbs. applied in any direction at any point 200 lb transverse live load plus 50L rail element reaction applied at the upper element	Combined picket fencing capacity adequate Post adequate with bracing elements Inconsistent, cannot be analyized	No No Yes	Railing shall have new anchorages designed to resist loads as specified under each element. Grouted anchor bolts or chemical adhesive system are recommended with proof testing for adequate bond with granite coping. Means to provide expansion with the reinstallation shall be provide.
Historical Pedestrian Railing – Geometry Total Height Clear Opening	See Reference Note 3 3'-6" (42-inch) 6-inch sphere bottom 27-inch height 8-inch sphere top 27-inch height	3'-5" (41 –inch) 8-inches 8-inches	Yes Yes No	Reinstall pedestrian railing with base plate anchorage at posts to achieve 42-inch total height. Installation of a safety fence out board of the railing will mitigate the substandard railing opening.

* Substandard = Existing condition does not comply with the standard per the applicable code.

Table 1 Reference Sources

1. ADA Accessibility Guidelines for Buildings and Facilities (ADAAG), www.access-board.gov/adaag/html/adaag.htm

2. NYSDOT Highway Design Manual (NYSDOT) https://www.nysdot.gov/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_17.pdf

   https://www.nysdot.gov/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_18.pdf

3. AASHTO Guide for the Development of Bicycle Facilities (AASHTO) www.design.transportation.org/Documents/DraftBikeGuideFeb2010.pdf

4. NYC Manhattan Waterfront Greenway Master Plan (MWGMP) http://www.nyc.gov/html/dcp/html/mwg/mwghome.shtml

5. NYC Streets Design Manual (NYCSDM) http://www.nyc.gov/html/dot/downloads/pdf/nycdot_streetdesignmanual_ch2.pdf

6. New York State Manual of Uniform Traffic Control Devices (NYS MUTCD) https://www.nysdot.gov/divisions/operating/oom/transportation-systems/traffic-operations-section/mutcd

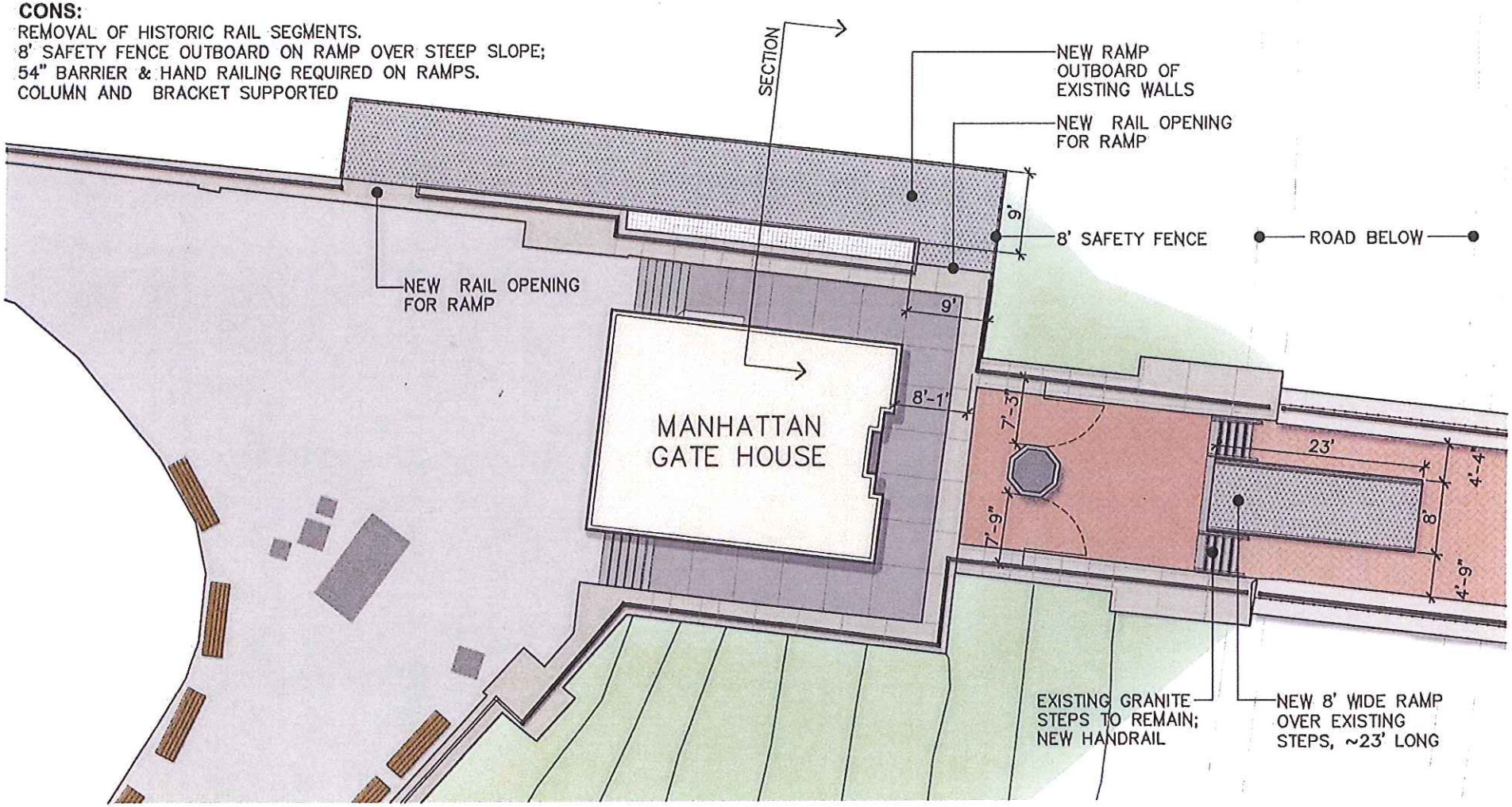
Table 2 Reference Notes:

1. The applicable structural design code for the railing capacity analysis is the *17th Edition of the AASHTO Standard Specifications for Highway Bridges*. In accordance with the *NYSDOT Design Manual Section 6 Bridge Railing*, specifically subsection 6.8.5.2 Upgrading the Bridge Railing – the design loads shall be as specified in the latest edition of the AASHTO LRFD Bridge Design Specifications, Section 13.
2. Design methodology is allowable strength design (ASD) design.
3. Geometric Design Requirements will utilize the *AASHTO LRFD Bridge Design Specifications, Section 13*.

BRIDGE ACCESS - MANHATTAN
OPTION 1

PROS:
HANDICAP, BIKE, AND VEHICLE ACCESSIBLE - GEM CARTS & NYPD SCOOTERS ONLY.

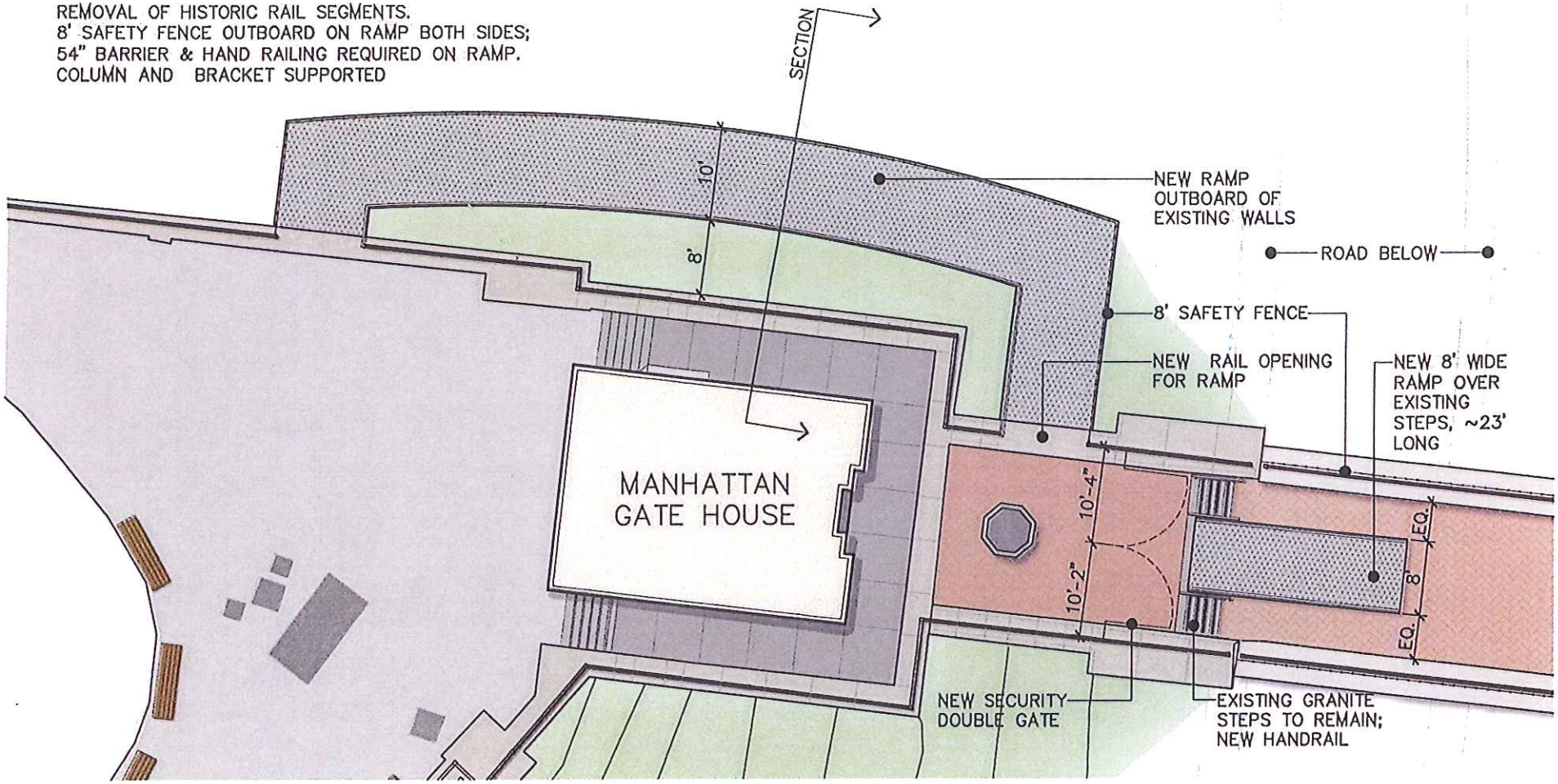
CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS.
8' SAFETY FENCE OUTBOARD ON RAMP OVER STEEP SLOPE;
54" BARRIER & HAND RAILING REQUIRED ON RAMPS.
COLUMN AND BRACKET SUPPORTED



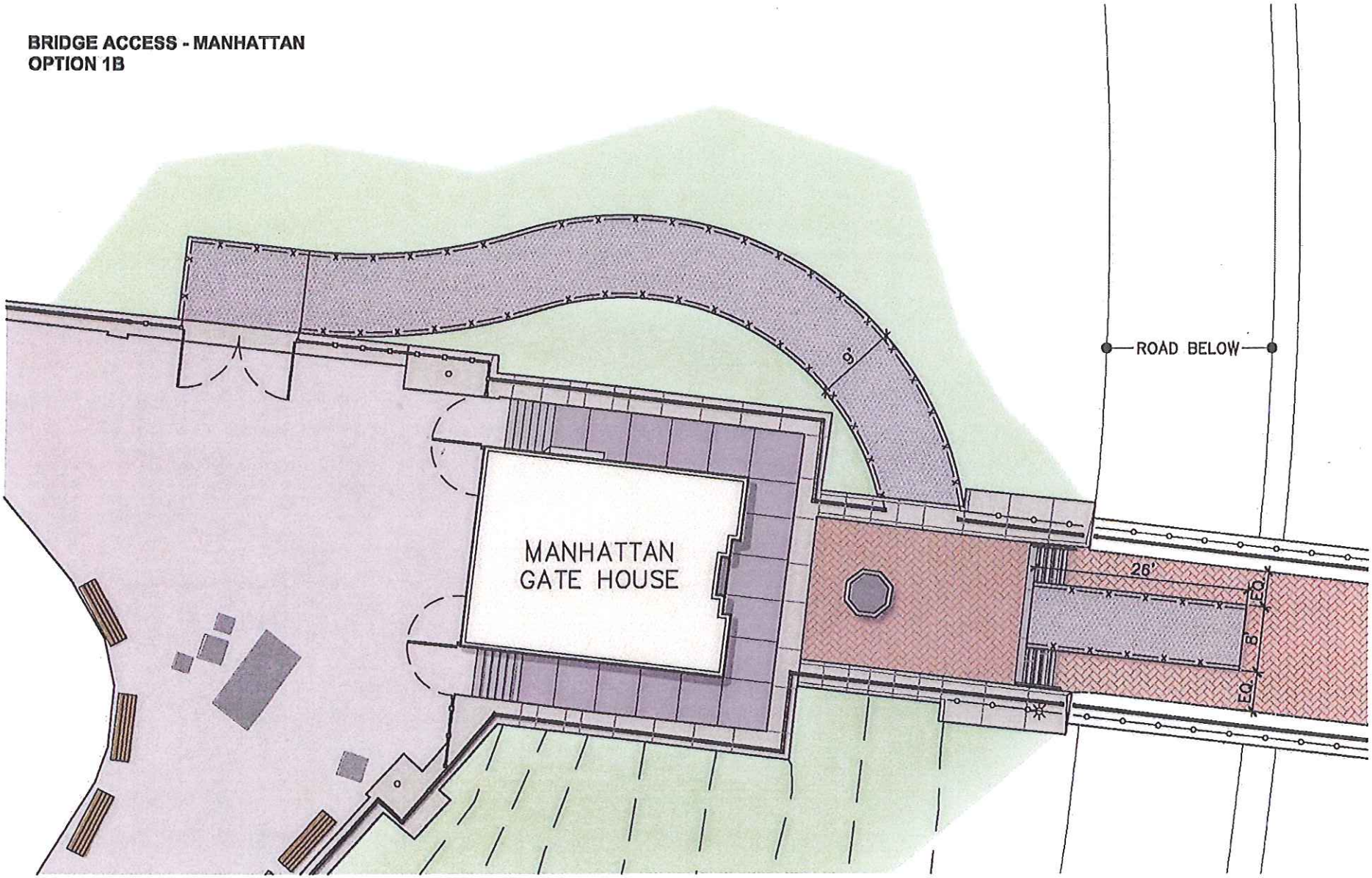
BRIDGE ACCESS - MANHATTAN
OPTION 1A

PROS:
HANDICAP, BIKE, AND VEHICLE ACCESSIBLE - GATORS, GEM CARTS & NYPD SCOOTERS

CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS.
8' SAFETY FENCE OUTBOARD ON RAMP BOTH SIDES;
54" BARRIER & HAND RAILING REQUIRED ON RAMP.
COLUMN AND BRACKET SUPPORTED



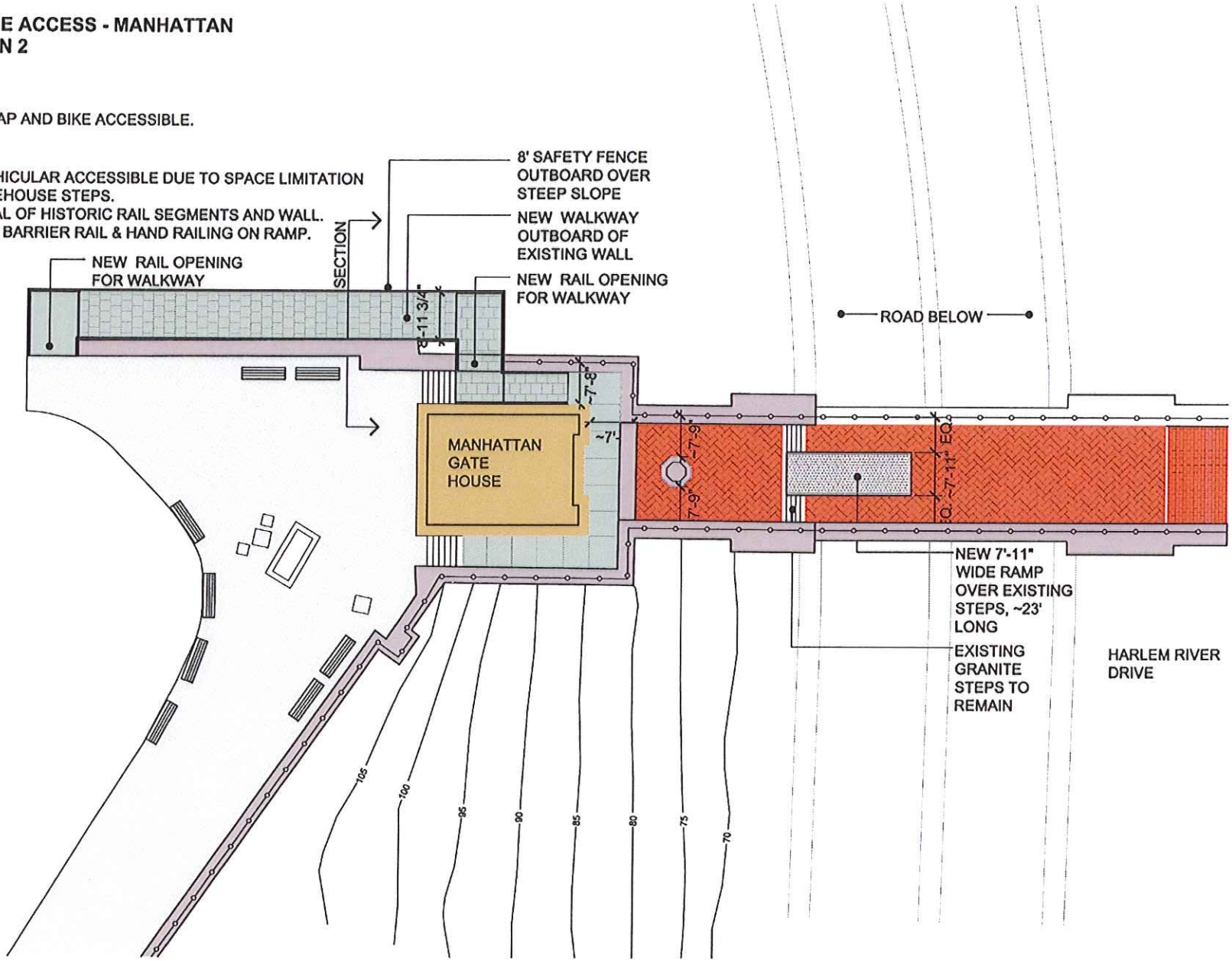
BRIDGE ACCESS - MANHATTAN
OPTION 1B



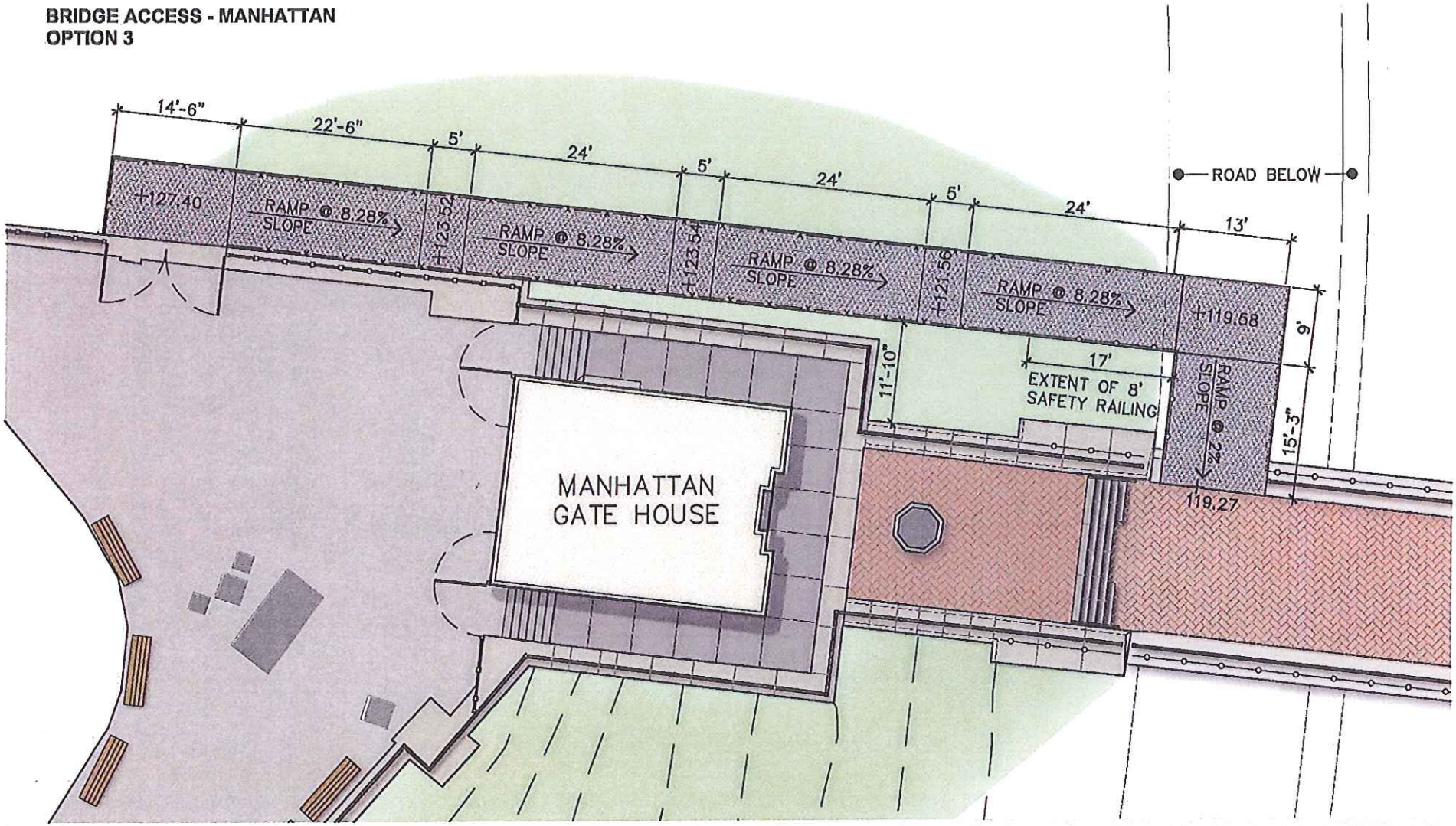
BRIDGE ACCESS - MANHATTAN
OPTION 2

PROS:
HANDICAP AND BIKE ACCESSIBLE.

CONS:
NOT VEHICULAR ACCESSIBLE DUE TO SPACE LIMITATION AT GATEHOUSE STEPS.
REMOVAL OF HISTORIC RAIL SEGMENTS AND WALL.
NEW 54" BARRIER RAIL & HAND RAILING ON RAMP.



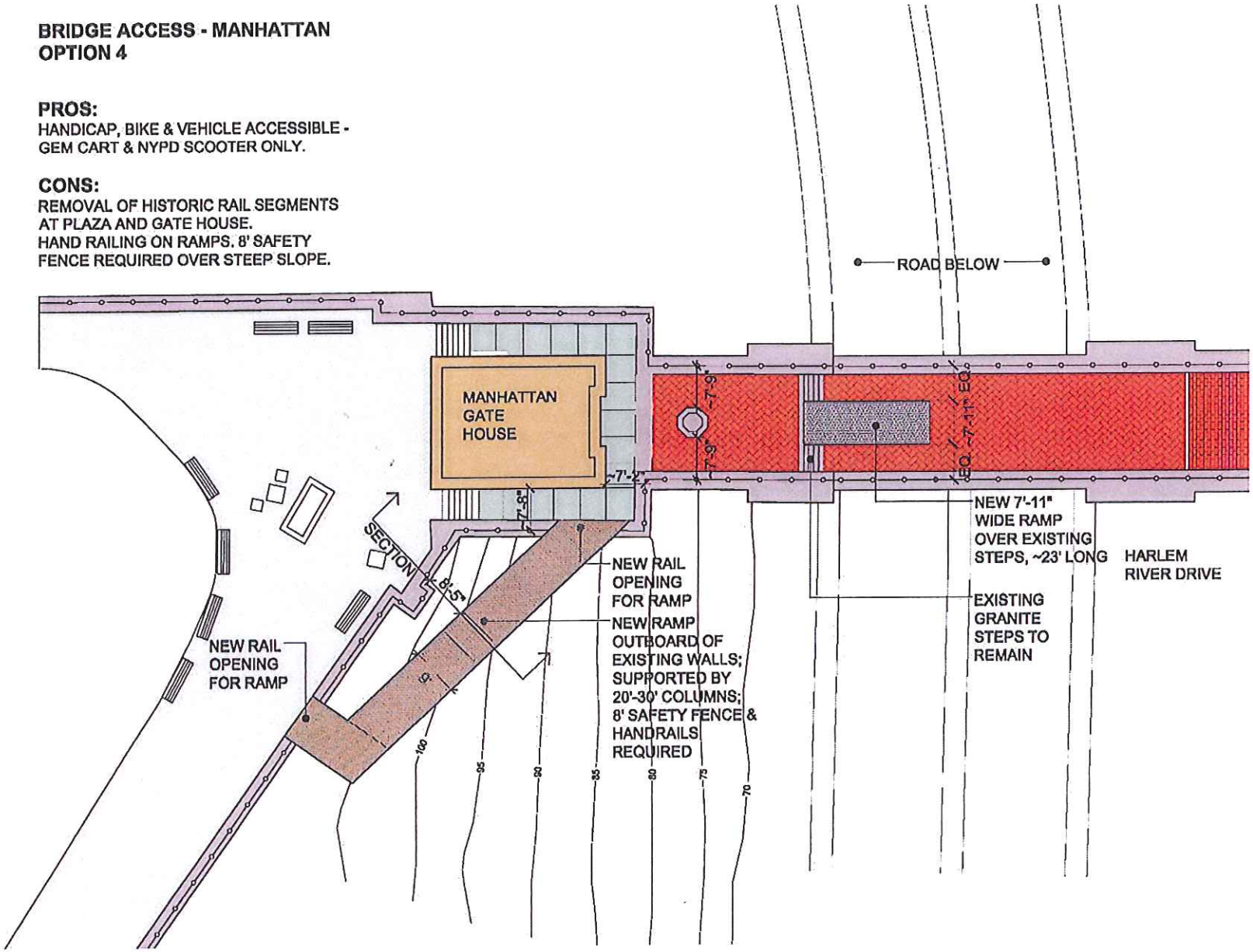
BRIDGE ACCESS - MANHATTAN
OPTION 3

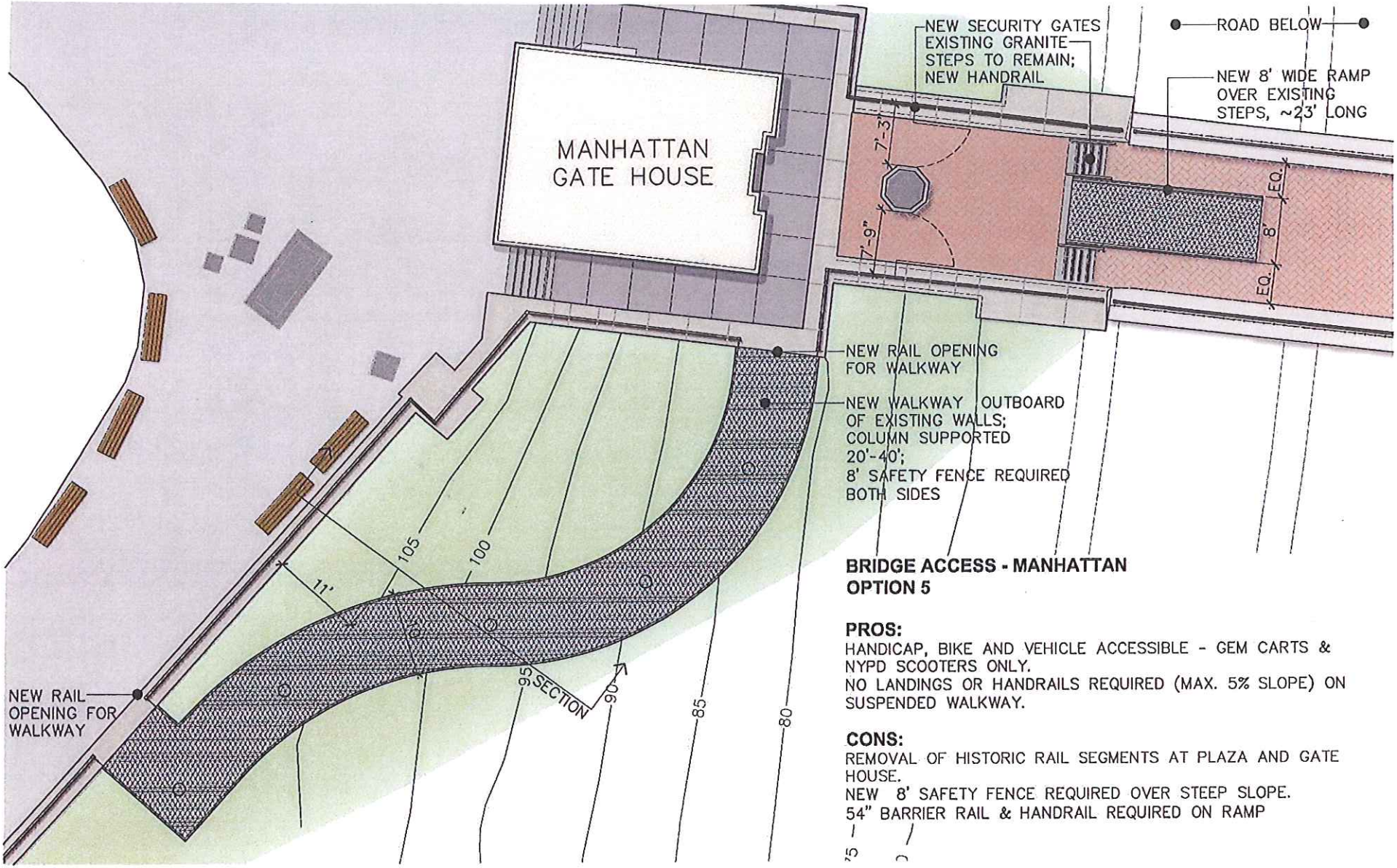


BRIDGE ACCESS - MANHATTAN
OPTION 4

PROS:
HANDICAP, BIKE & VEHICLE ACCESSIBLE -
GEM CART & NYPD SCOOTER ONLY.

CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS
AT PLAZA AND GATE HOUSE.
HAND RAILING ON RAMPS. 8' SAFETY
FENCE REQUIRED OVER STEEP SLOPE.

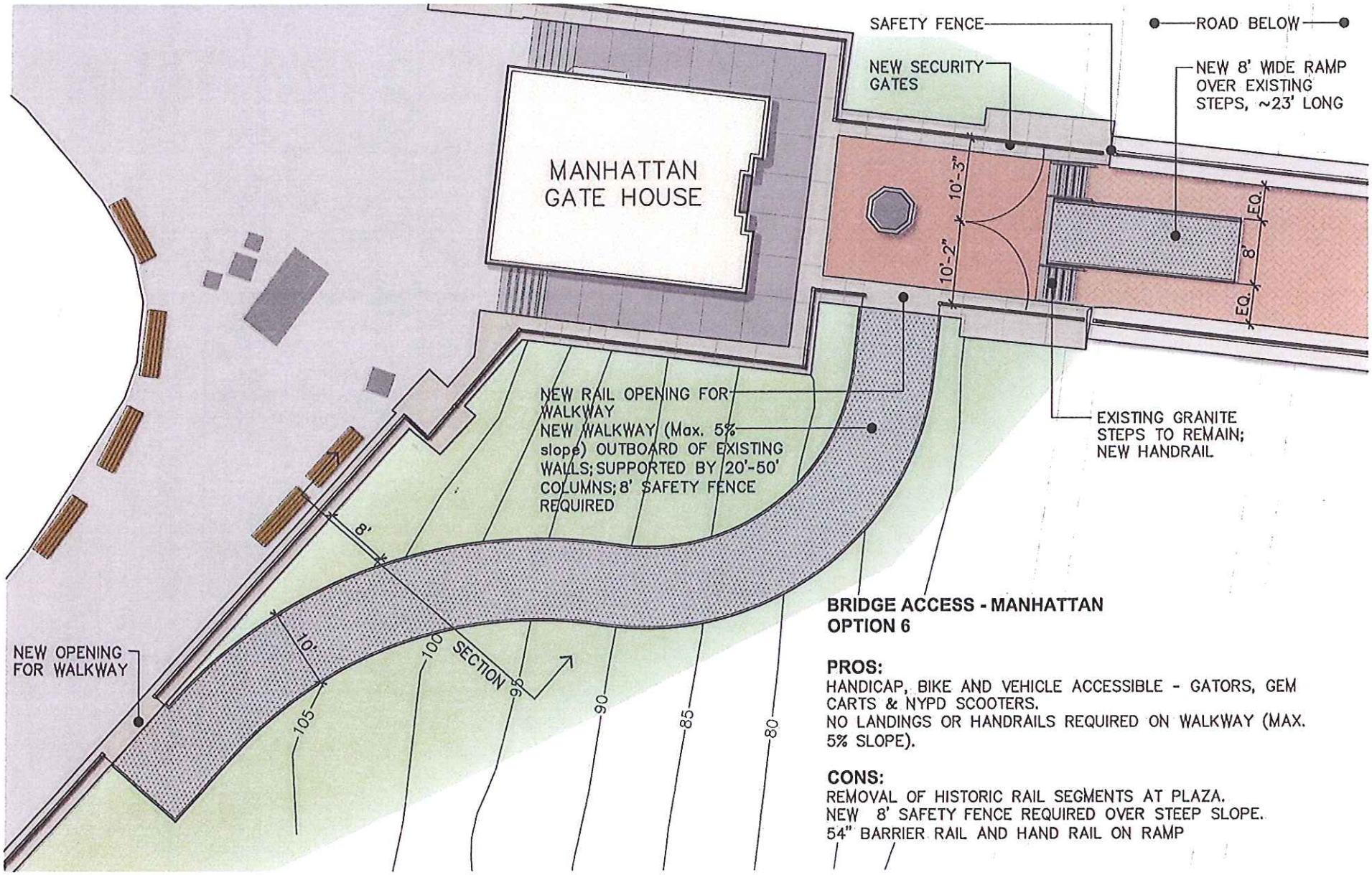




BRIDGE ACCESS - MANHATTAN
OPTION 5

PROS:
HANDICAP, BIKE AND VEHICLE ACCESSIBLE - GEM CARTS & NYPD SCOOTERS ONLY.
NO LANDINGS OR HANDRAILS REQUIRED (MAX. 5% SLOPE) ON SUSPENDED WALKWAY.

CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS AT PLAZA AND GATE HOUSE.
NEW 8' SAFETY FENCE REQUIRED OVER STEEP SLOPE.
54" BARRIER RAIL & HANDRAIL REQUIRED ON RAMP



BRIDGE ACCESS - MANHATTAN
OPTION 6

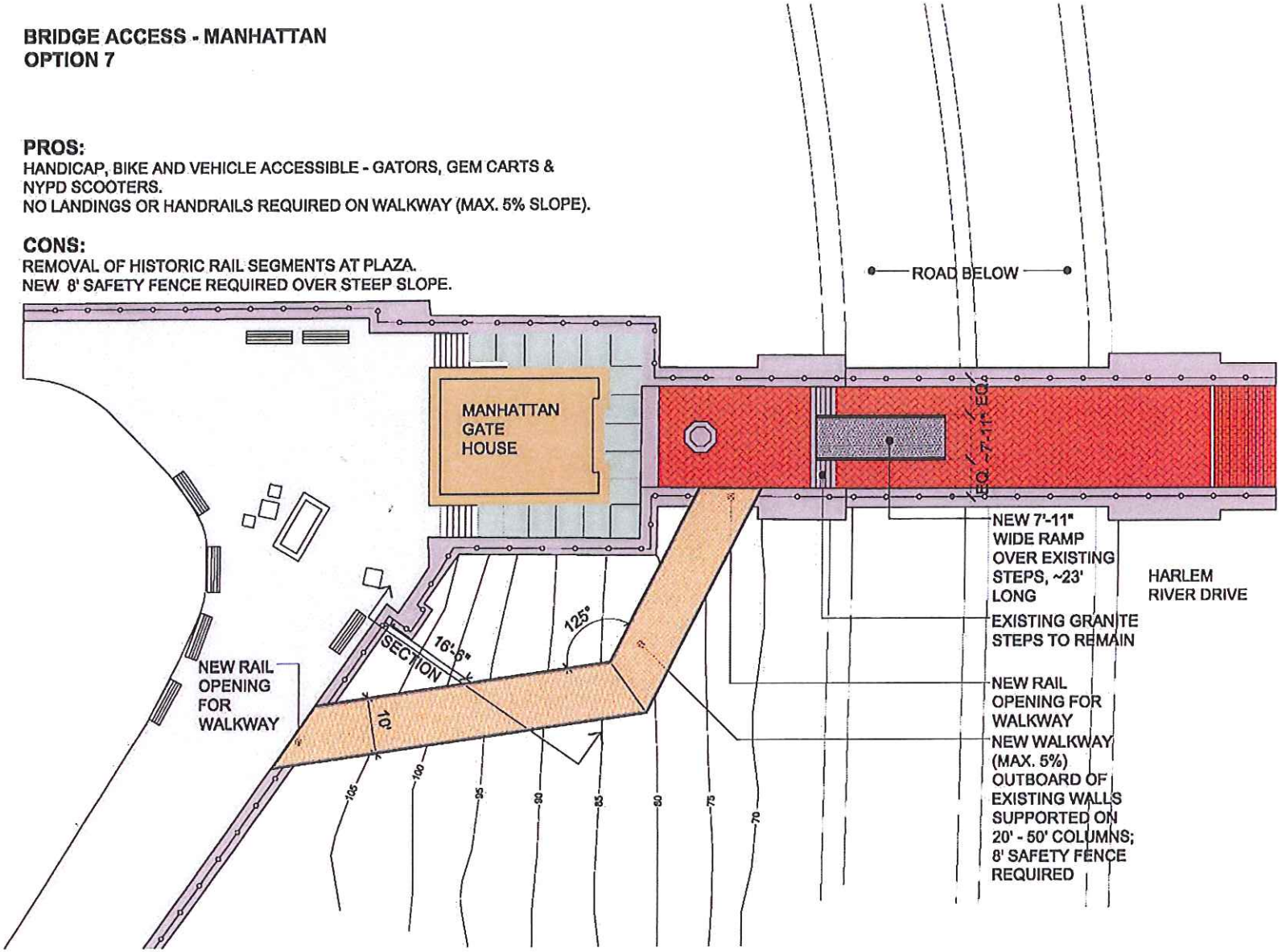
PROS:
HANDICAP, BIKE AND VEHICLE ACCESSIBLE - GATORS, GEM CARTS & NYPD SCOOTERS.
NO LANDINGS OR HANDRAILS REQUIRED ON WALKWAY (MAX. 5% SLOPE).

CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS AT PLAZA.
NEW 8' SAFETY FENCE REQUIRED OVER STEEP SLOPE.
54" BARRIER RAIL AND HAND RAIL ON RAMP

BRIDGE ACCESS - MANHATTAN
OPTION 7

PROS:
HANDICAP, BIKE AND VEHICLE ACCESSIBLE - GATORS, GEM CARTS & NYPD SCOOTERS.
NO LANDINGS OR HANDRAILS REQUIRED ON WALKWAY (MAX. 5% SLOPE).

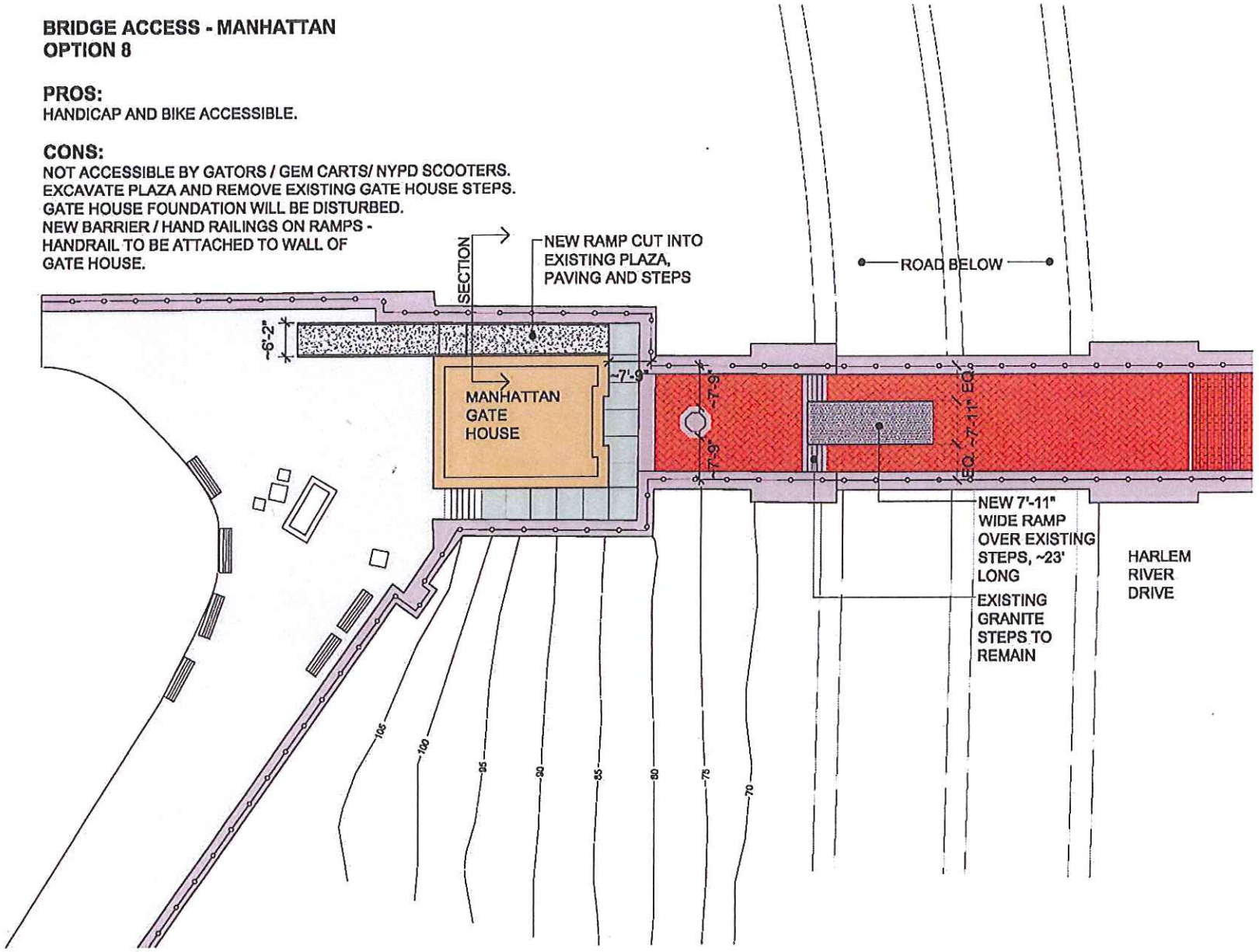
CONS:
REMOVAL OF HISTORIC RAIL SEGMENTS AT PLAZA.
NEW 8' SAFETY FENCE REQUIRED OVER STEEP SLOPE.



BRIDGE ACCESS - MANHATTAN
OPTION 8

PROS:
HANDICAP AND BIKE ACCESSIBLE.

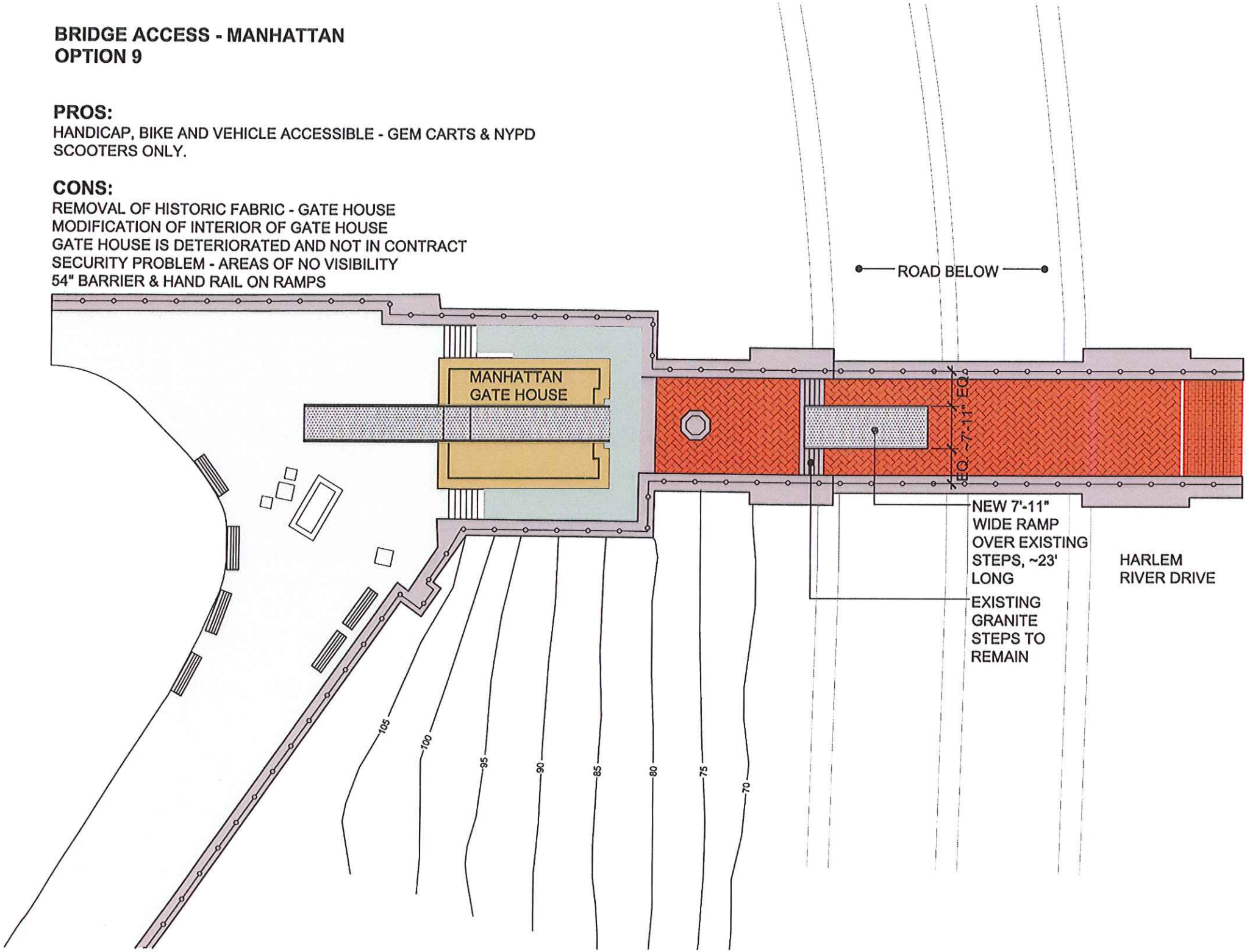
CONS:
NOT ACCESSIBLE BY GATORS / GEM CARTS/ NYPD SCOOTERS.
EXCAVATE PLAZA AND REMOVE EXISTING GATE HOUSE STEPS.
GATE HOUSE FOUNDATION WILL BE DISTURBED.
NEW BARRIER / HAND RAILINGS ON RAMPS -
HANDRAIL TO BE ATTACHED TO WALL OF
GATE HOUSE.



BRIDGE ACCESS - MANHATTAN
OPTION 9

PROS:
HANDICAP, BIKE AND VEHICLE ACCESSIBLE - GEM CARTS & NYPD SCOOTERS ONLY.

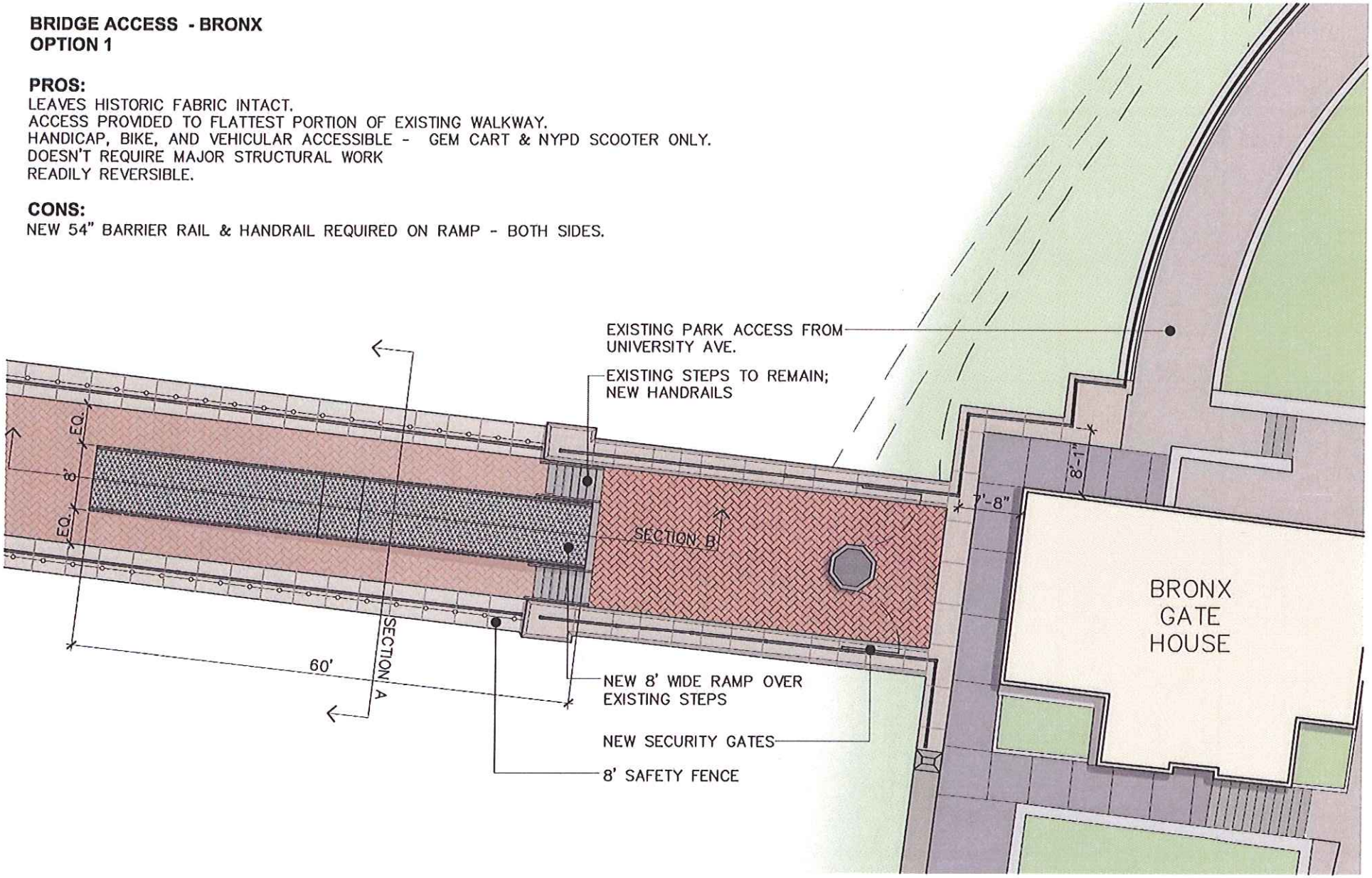
CONS:
REMOVAL OF HISTORIC FABRIC - GATE HOUSE
MODIFICATION OF INTERIOR OF GATE HOUSE
GATE HOUSE IS DETERIORATED AND NOT IN CONTRACT
SECURITY PROBLEM - AREAS OF NO VISIBILITY
54" BARRIER & HAND RAIL ON RAMPS



BRIDGE ACCESS - BRONX
OPTION 1

PROS:
LEAVES HISTORIC FABRIC INTACT.
ACCESS PROVIDED TO FLATTEST PORTION OF EXISTING WALKWAY.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GEM CART & NYPD SCOOTER ONLY.
DOESN'T REQUIRE MAJOR STRUCTURAL WORK
READILY REVERSIBLE.

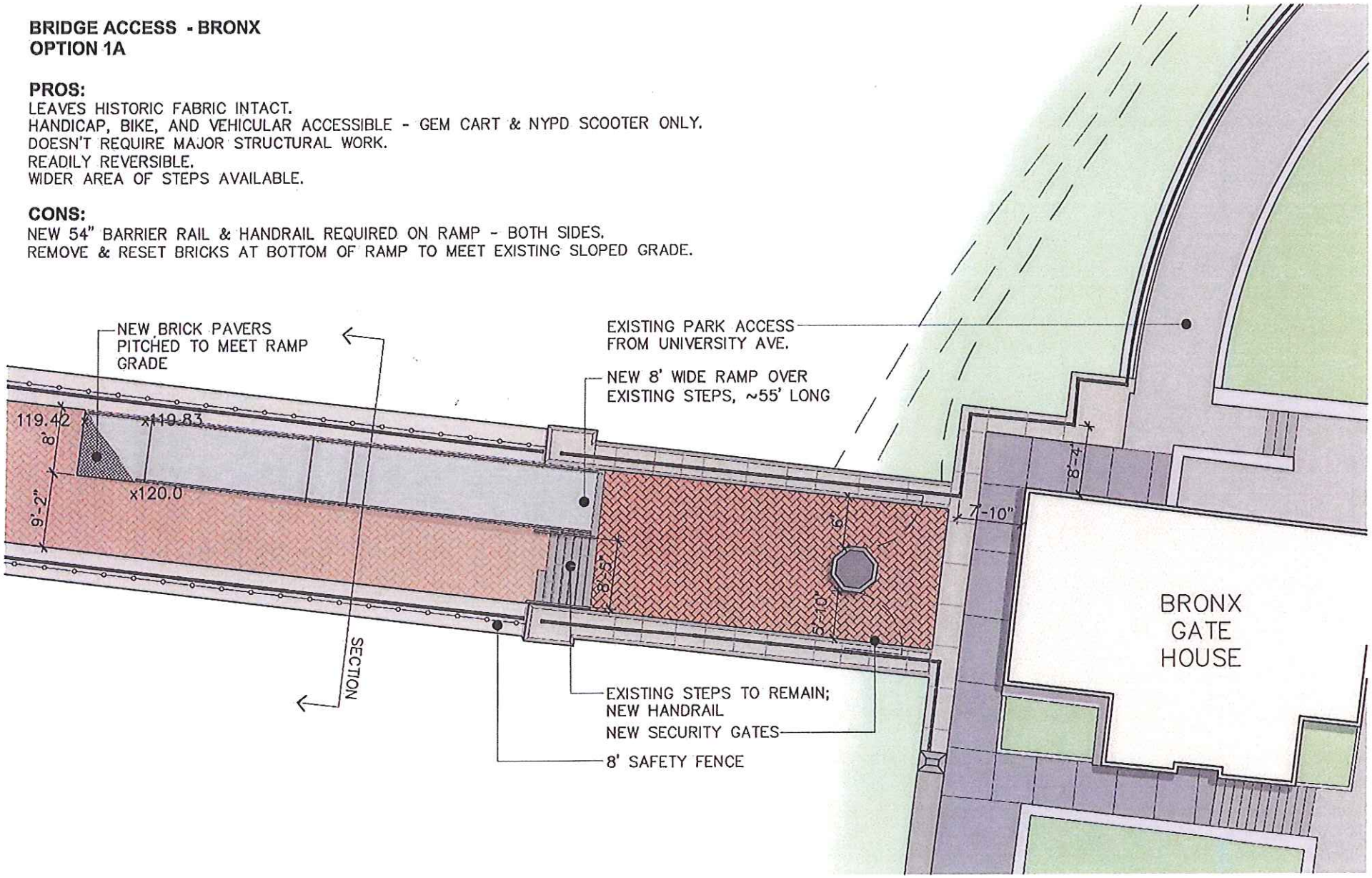
CONS:
NEW 54" BARRIER RAIL & HANDRAIL REQUIRED ON RAMP - BOTH SIDES.



BRIDGE ACCESS - BRONX
OPTION 1A

PROS:
LEAVES HISTORIC FABRIC INTACT.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GEM CART & NYPD SCOOTER ONLY.
DOESN'T REQUIRE MAJOR STRUCTURAL WORK.
READILY REVERSIBLE.
WIDER AREA OF STEPS AVAILABLE.

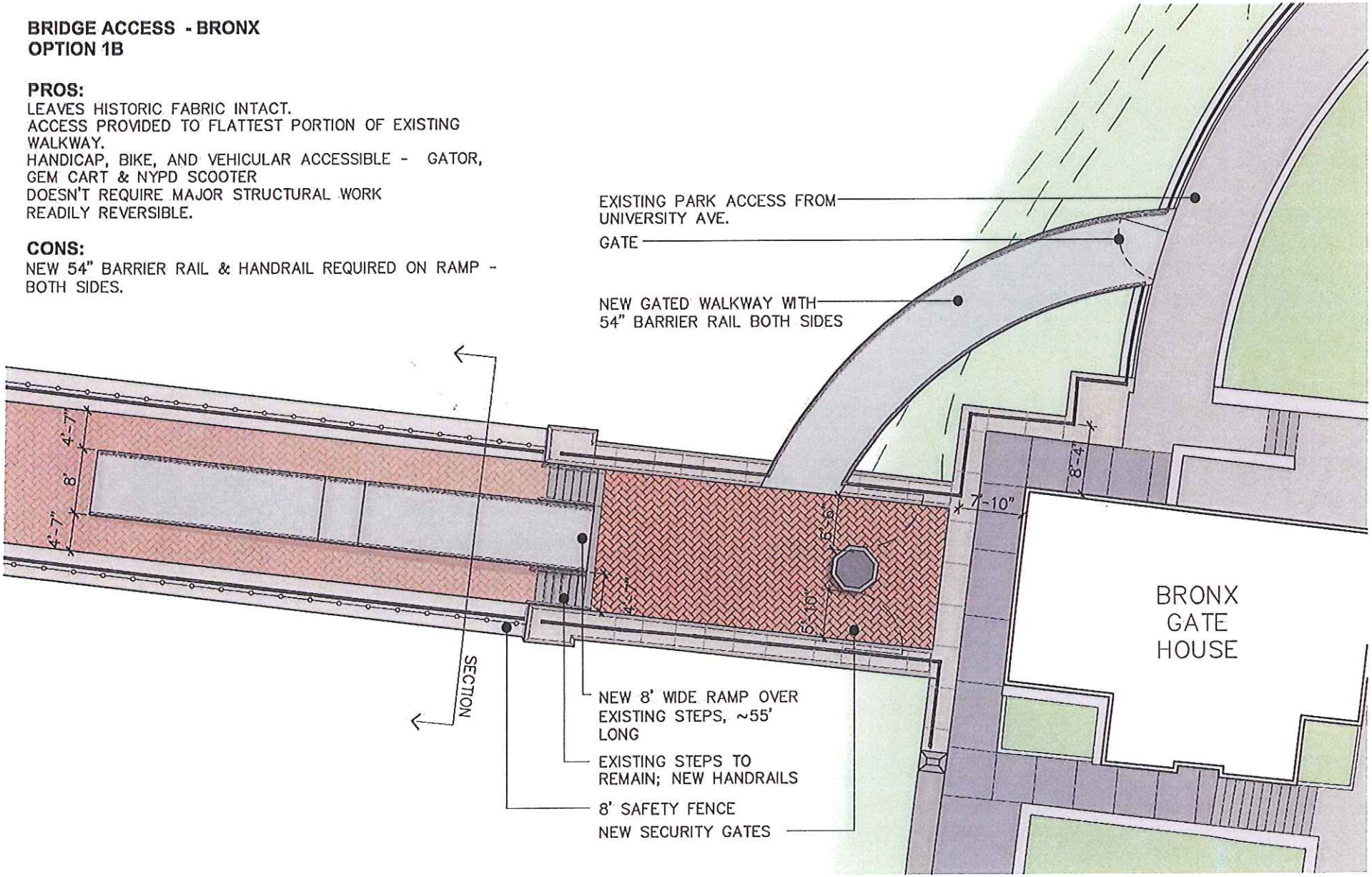
CONS:
NEW 54" BARRIER RAIL & HANDRAIL REQUIRED ON RAMP - BOTH SIDES.
REMOVE & RESET BRICKS AT BOTTOM OF RAMP TO MEET EXISTING SLOPED GRADE.



BRIDGE ACCESS - BRONX
OPTION 1B

PROS:
LEAVES HISTORIC FABRIC INTACT.
ACCESS PROVIDED TO FLATTEST PORTION OF EXISTING WALKWAY.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GATOR, GEM CART & NYPD SCOOTER
DOESN'T REQUIRE MAJOR STRUCTURAL WORK
READILY REVERSIBLE.

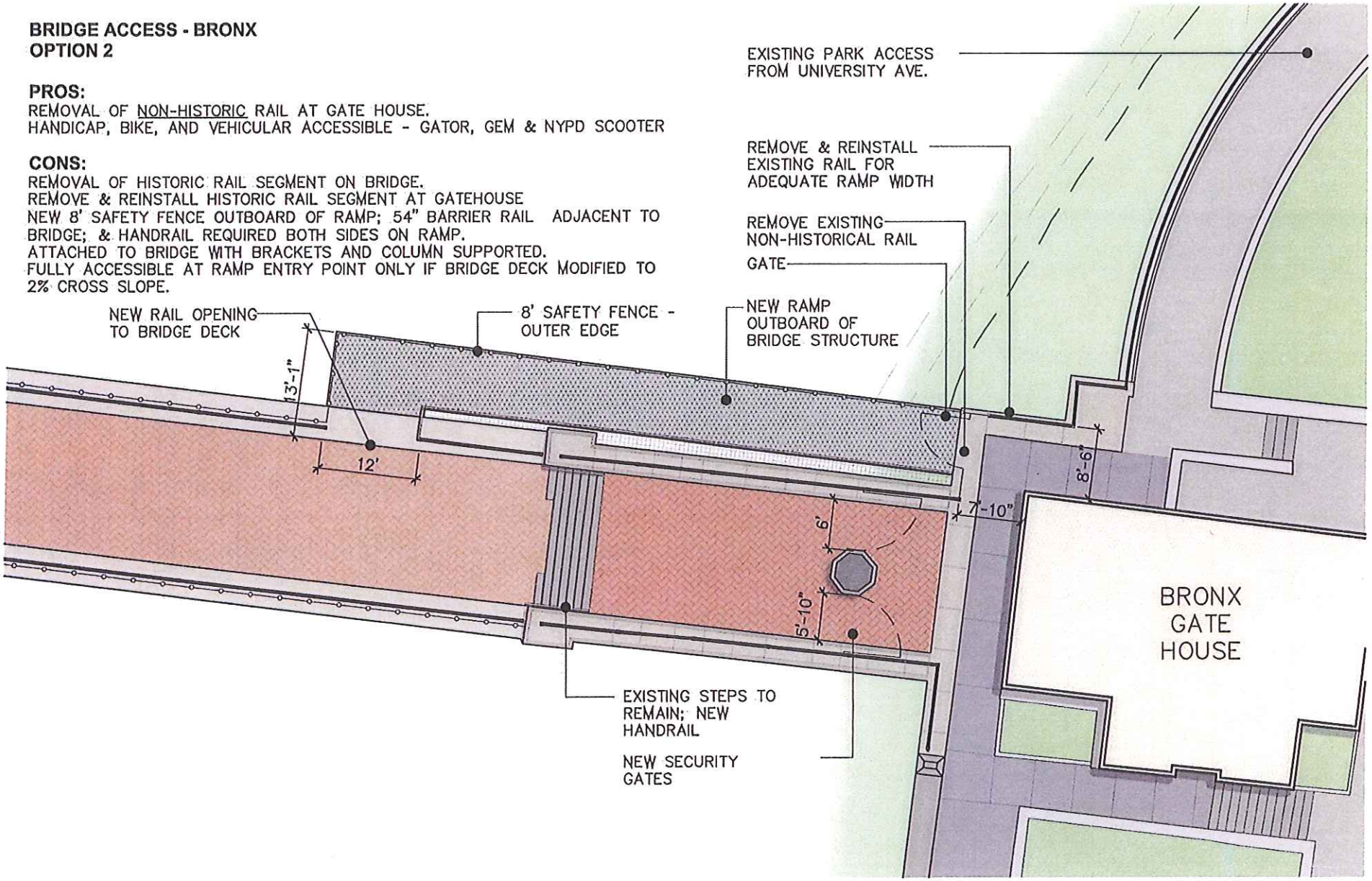
CONS:
NEW 54" BARRIER RAIL & HANDRAIL REQUIRED ON RAMP - BOTH SIDES.



BRIDGE ACCESS - BRONX
OPTION 2

PROS:
REMOVAL OF NON-HISTORIC RAIL AT GATE HOUSE.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GATOR, GEM & NYPD SCOOTER

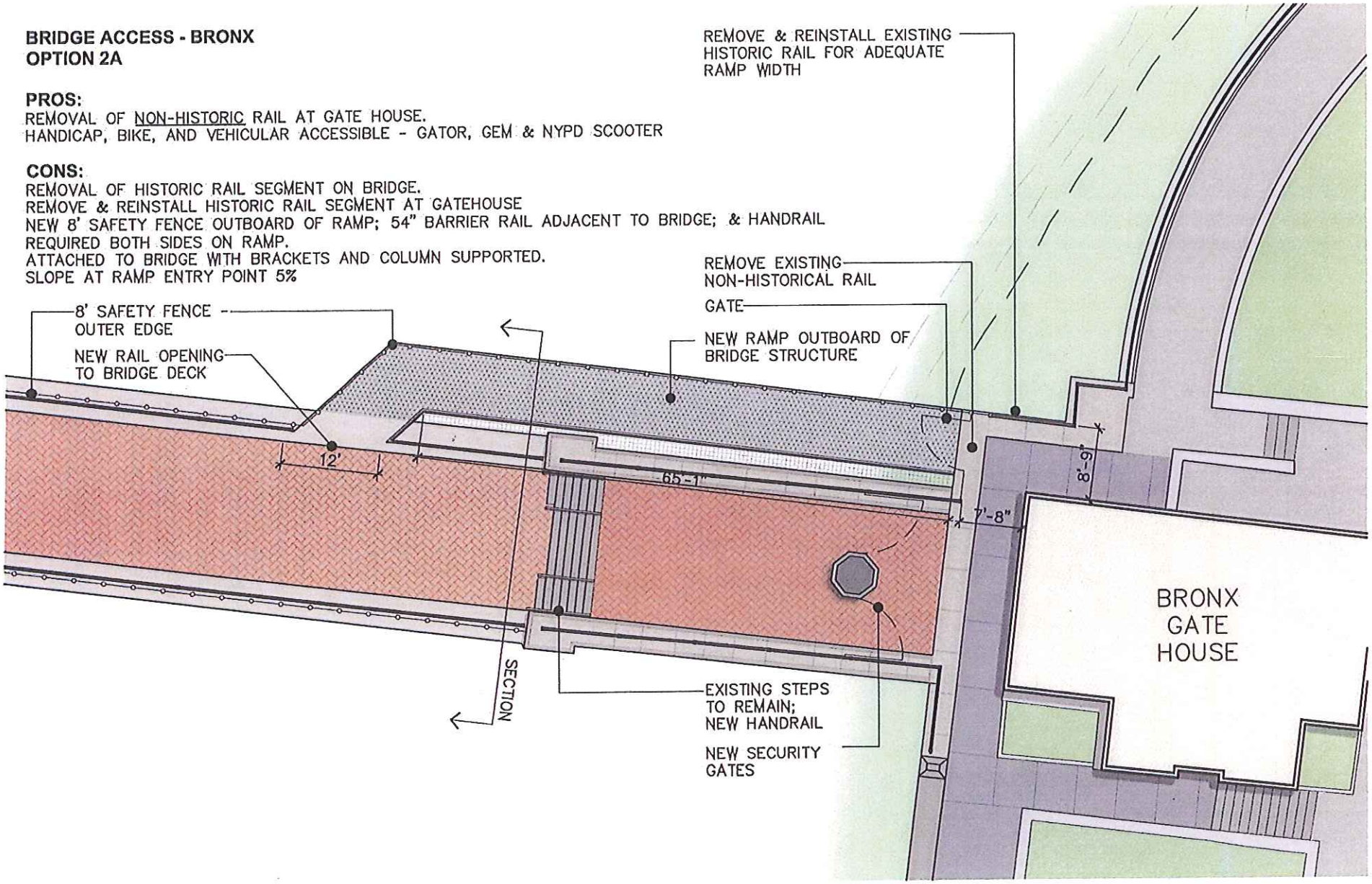
CONS:
REMOVAL OF HISTORIC RAIL SEGMENT ON BRIDGE.
REMOVE & REINSTALL HISTORIC RAIL SEGMENT AT GATEHOUSE
NEW 8' SAFETY FENCE OUTBOARD OF RAMP; 54" BARRIER RAIL ADJACENT TO BRIDGE; & HANDRAIL REQUIRED BOTH SIDES ON RAMP.
ATTACHED TO BRIDGE WITH BRACKETS AND COLUMN SUPPORTED.
FULLY ACCESSIBLE AT RAMP ENTRY POINT ONLY IF BRIDGE DECK MODIFIED TO 2% CROSS SLOPE.



BRIDGE ACCESS - BRONX
OPTION 2A

PROS:
REMOVAL OF NON-HISTORIC RAIL AT GATE HOUSE.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GATOR, GEM & NYPD SCOOTER

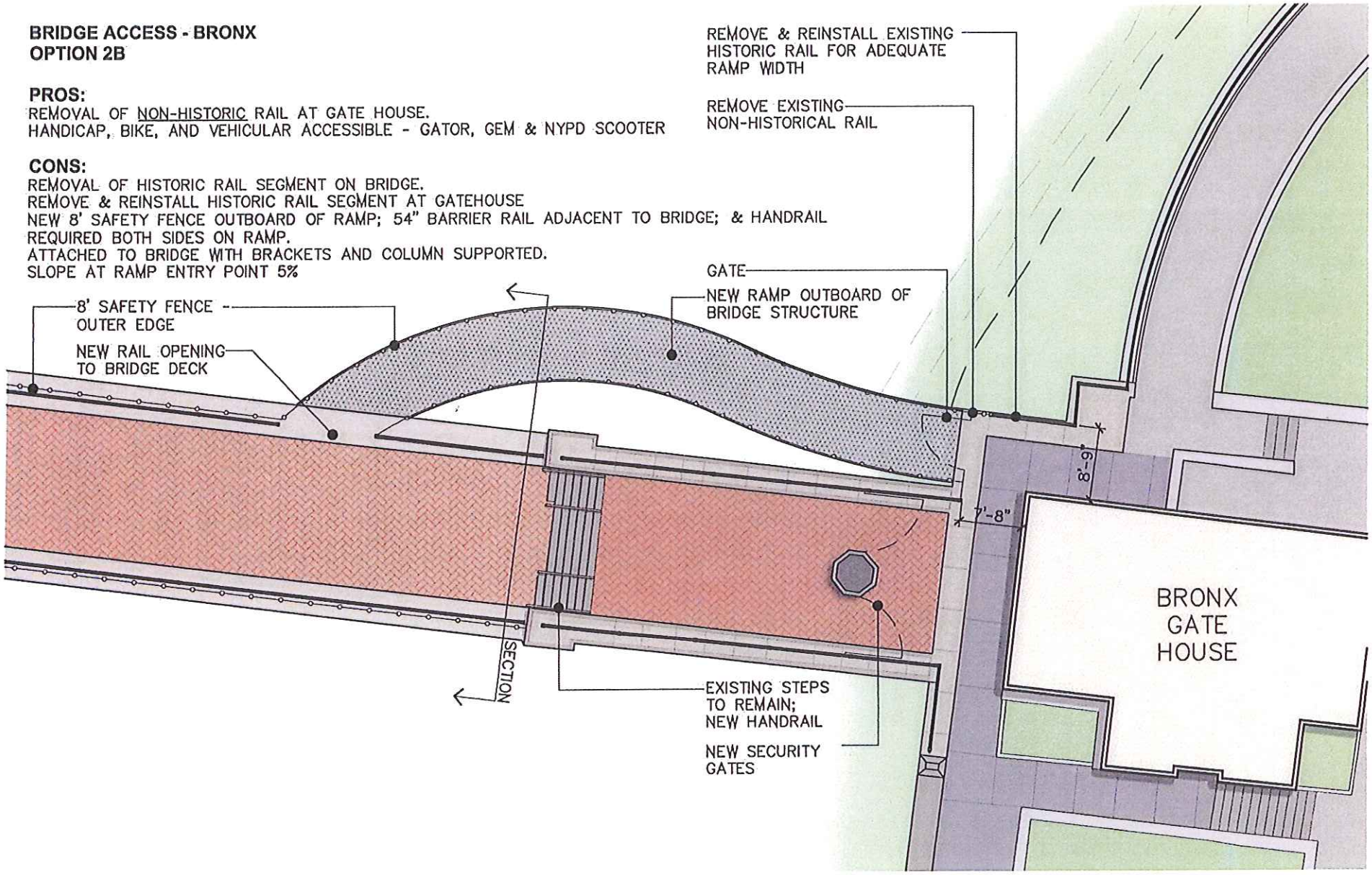
CONS:
REMOVAL OF HISTORIC RAIL SEGMENT ON BRIDGE.
REMOVE & REINSTALL HISTORIC RAIL SEGMENT AT GATEHOUSE
NEW 8' SAFETY FENCE OUTBOARD OF RAMP; 54" BARRIER RAIL ADJACENT TO BRIDGE; & HANDRAIL REQUIRED BOTH SIDES ON RAMP.
ATTACHED TO BRIDGE WITH BRACKETS AND COLUMN SUPPORTED.
SLOPE AT RAMP ENTRY POINT 5%



BRIDGE ACCESS - BRONX
OPTION 2B

PROS:
REMOVAL OF NON-HISTORIC RAIL AT GATE HOUSE.
HANDICAP, BIKE, AND VEHICULAR ACCESSIBLE - GATOR, GEM & NYPD SCOOTER

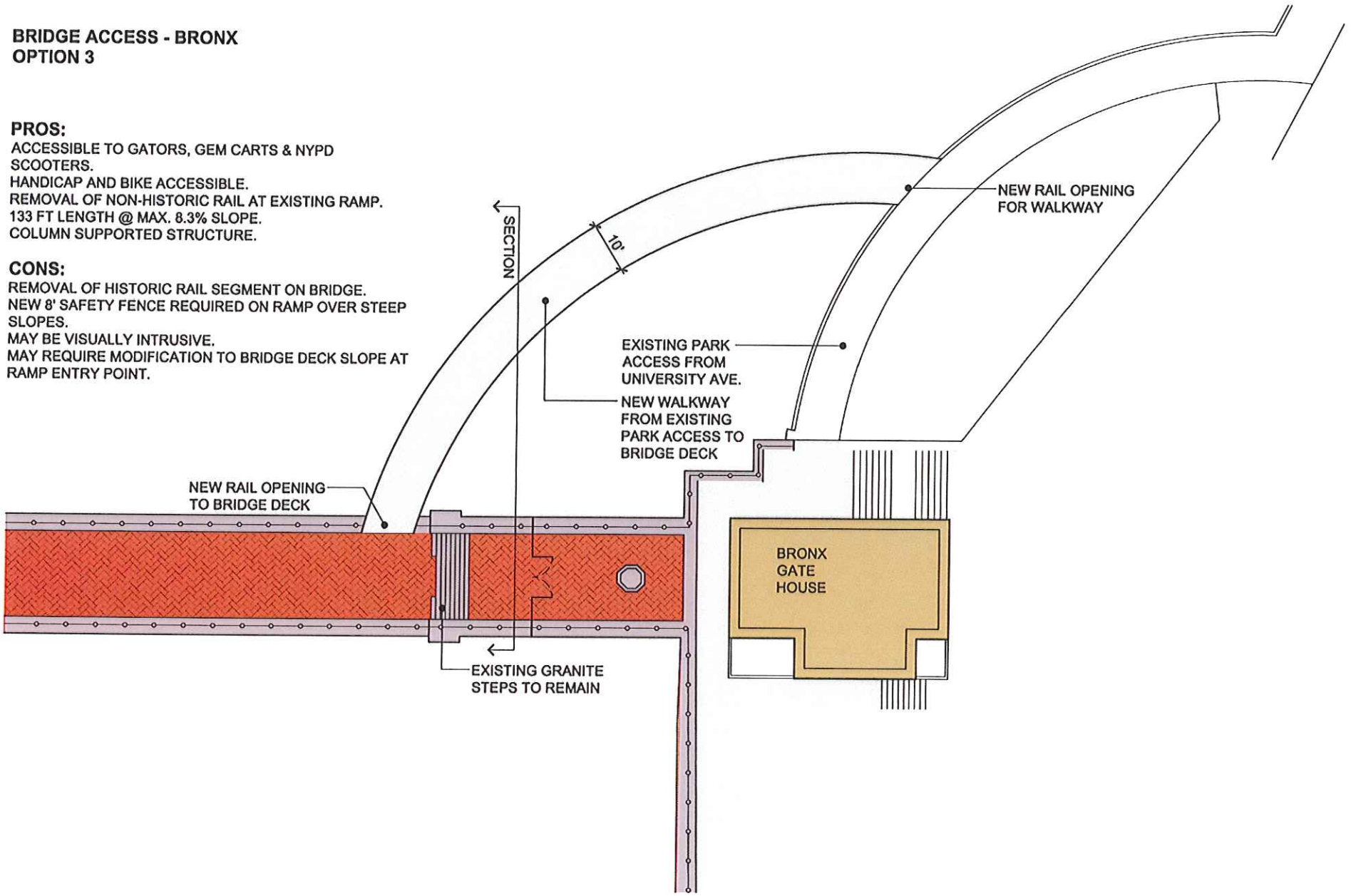
CONS:
REMOVAL OF HISTORIC RAIL SEGMENT ON BRIDGE.
REMOVE & REINSTALL HISTORIC RAIL SEGMENT AT GATEHOUSE
NEW 8' SAFETY FENCE OUTBOARD OF RAMP; 54" BARRIER RAIL ADJACENT TO BRIDGE; & HANDRAIL REQUIRED BOTH SIDES ON RAMP.
ATTACHED TO BRIDGE WITH BRACKETS AND COLUMN SUPPORTED.
SLOPE AT RAMP ENTRY POINT 5%



BRIDGE ACCESS - BRONX
OPTION 3

PROS:
ACCESSIBLE TO GATORS, GEM CARTS & NYPD SCOOTERS.
HANDICAP AND BIKE ACCESSIBLE.
REMOVAL OF NON-HISTORIC RAIL AT EXISTING RAMP.
133 FT LENGTH @ MAX. 8.3% SLOPE.
COLUMN SUPPORTED STRUCTURE.

CONS:
REMOVAL OF HISTORIC RAIL SEGMENT ON BRIDGE.
NEW 8' SAFETY FENCE REQUIRED ON RAMP OVER STEEP SLOPES.
MAY BE VISUALLY INTRUSIVE.
MAY REQUIRE MODIFICATION TO BRIDGE DECK SLOPE AT RAMP ENTRY POINT.



8. Buildings Systems Evaluation

8.1. METHODOLOGY OF CONDUCTING EVALUATION

8.2. DESCRIPTION OF EXISTING CONDITIONS, INCLUDING EVALUATION OF INTEGRITY, INTACTNESS, DAMAGED OR DETERIORATING CONDITIONS

8.3. PROPOSED TREATMENT RECOMMENDATIONS

8. Systems Evaluation

8.1 METHODOLOGY OF CONDUCTING EVALUATION

The systems evaluation was undertaken by Sam Perez, Electrical Design Engineer of Chu and Gassman, and consisted of field visits to the High Bridge to assess the existing conditions to review proposed electrical installations with the client and design teams. Follow up communication with Con Edison was also performed to ascertain lighting electrical loads.

An initial site visit was conducted by Chu and Gassman on April 19, 2010 to determine the condition of the bridge's electrical distribution system. Site visit participants included Sam Perez, Electrical Design Engineer. In addition to evaluating the bridge's electrical systems, this site visit was also an opportunity for the Chu and Gassman staff to obtain an understanding of the bridge structure itself.

A second site visit was conducted on October 7, 2010 to open discussions with the client and the design teams, and to propose and discuss possible locations for the new electrical distribution equipment and associated conduit/wire runs. Site visit participants from Chu and Gassman included R. Keith Craven, Department Head – Electrical, and Sam Perez, Electrical Design Engineer. During this visit, a better understanding of the complexities associated with placing electrical equipment and the running of conduit/wire was achieved.

Communication was established with Con Edison (NYC-Electrical Power Utility) and a Load Letter was submitted on November 15, 2010. The Load Letter is a request for information from Con Edison for the connection of new utility power for the bridge structure's proposed lighting. Calculated lighting electrical load is at 22.8 kW or 70 amperes at the requested voltage system of 208Y/120 volts, 3 phase, 4 wire.

8.2 DESCRIPTION OF EXISTING CONDITIONS, INCLUDING EVALUATION OF INTEGRITY, INTACTNESS, DAMAGED OR DETERIORATING CONDITIONS

Presently, there is no electrical power running to the High Bridge structure lighting. This includes both the existing lighting fixtures and poles on the bridge deck and the lighting in the attic space below the deck. At one time in the past, there was electrical service power, however, this service power has long since been disconnected. There is old conduit running exposed on the bridge deck (located on each side of the granite coping; outboard of the existing railings). Most of the associated existing wiring has been removed. The conduit is in poor and un-usable condition. This holds true for the existing junction boxes associated with the exposed conduit runs.

In the attic space, there are some remains of exposed wiring, however, this wiring is no longer connected to any power source. The existing wiring, for the most part, is not installed in conduit and is haphazardly run throughout the attic space. The existing lighting fixtures are in poor condition and need to be replaced.

On the Bronx side of the bridge, there are remnants of the old underground power supply however, all existing wiring has been removed. There is some left-over conduit associated with the historic lighting that is fragmented and in poor condition. The condition of the existing underground electrical run is unknown.

On the Manhattan side, there is a left-over power circuit that has been disconnected (cut) and abandoned in place. Looking from under the steel arch structure (at street level), some electrical conduits which run vertically into the steel arch span can be observed. The origins of these electrical runs are unknown and do not seem to be used. It is possible that one run provides power to the bridge-mounted navigation lighting, however, the function of this lighting is unknown as well.

There does not seem to be any electrical power running either to the Manhattan or the Bronx gatehouses, nor to the granite staircase located adjacent to the bridge structure on the Bronx side. Presently there are no lighting control provisions associated with the existing bridge lighting.

Based on the poor condition of the existing bridge-mounted electrical components, there is nothing that can be salvaged or re-used for the new design.

8.2.1 Chronology of Alteration and Use

Please see Appendix E: Lighting Chronology.

8.2.2 Capacity to adequately support recommended treatment, use, and interpretive programs

As discussed in Section 2.2 above, the capacity for the existing system to power the new proposed lighting is non-existent. In order to provide for the proposed bridge lighting a new utility power source and electrical distribution system will be required. The new system will be designed to the required capacity on the proposed lighting system. This includes all controls and voltage drop issues. Since the NYC-DOT and NYC-DPR will be listed as responsible parties for the maintenance and operation of the new lighting, the electrical design will reflect the needs of both agencies.

8.3 PROPOSED TREATMENT RECOMMENDATIONS

8.3.1 Recommendations and Alternatives

New Power Service and Distribution: The proposed electrical design will provide for a new Con Edison electrical service. This new service will include the following components: a property line manhole/hand hole/junction box (required by Con Edison), revenue metering, main distribution panelboard (possibly two), multiple control cabinets, disconnect switches, and conduit/wire runs. There are three possible options which have been identified as potential locations for the incoming and initial power and control equipment. These include:

a. Manhattan side – below the bridge structure, on NYC-DPR lands, adjacent to and on the west side of the Harlem River Drive.

b. Manhattan side – on the grassy area just to the west of the "approach" walkway and park area near the gatehouse structure.

c. Manhattan side – inside the gatehouse itself.

The final location will be determined based on input from the client and design teams, and Con Edison,

It should be noted that there are two NYC agencies associated with maintenance of the High Bridge, namely Department of Transportation (DOT) and Department of Parks and Recreation (DPR). The DOT power and control equipment will be provided via an un-metered Con Edison power source. This new equipment must be installed in an exterior location which can be easily accessible by DOT personnel.

The DPR power and control equipment will be provided via a metered Con Edison power source. This power source can either be installed at an exterior location or internally within a DPR owned structure. The final equipment locations remain to be determined.

Conduit and Junction Boxes**:** There were multiple discussions during Progress Review Meetings as well as a October 7, 2010 field meeting to review the options for the locations of the conduit and junction boxes; the client's preference was to surface-mount the conduit and junction boxes on the bridge deck, due to concerns related to core drilling the granite coping stones and the potential for leaks into the attic.

8.3.2 Impacts of Proposed Recommendations

Running of Conduit and Junction Boxes

Options for locating the conduit and junction boxes - either surface mounted on the bridge deck, or in the attic with stone coring through the granite coping - were reviewed. The benefits and liabilities for each option were analyzed, including the visual and physical impact on the historic fabric, and constructability, waterproofing and maintenance issues. A decision was made to surface mount the conduit and junction boxes

on the bridge deck, subject to on-site mock ups during the construction phase, which will provide a clear understanding of the visual impact and mounting requirements for the selected option.

The proposed conduit runs are as follows:

a. Bridge Deck: The conduit for the proposed pathway lighting will be run exposed on top of the granite and steel copings, directly behind the historic railing. The conduit will need to be run on both sides of the bridge deck. The conduit will be rigid steel/PVC coated and will be a color to blend with the surrounding historic material. The design proposes to run and connect the new conduit into the base of each pole. Each light pole will be fitted with a small "transformer" base which will act as a termination point for both the conduit as well as a splice/junction point for the required power wiring. Each fixture pole will also be fitted with a grounding lug for grounding of the light poles per the National Electrical Code.

b. Architectural Lighting on Steel Arch Span: The proposed architectural lighting on the steel span will be installed if funding allows. The conduit will be run exposed on the steel. In order to reduce visual impact of the surface-mounted conduit, the conduit can be painted to match the steel.

c. Architectural Lighting on Masonry Arches: The proposed architectural lighting on the masonry arches will be installed if funding allows. The conduit will be run exposed on the granite piers to uplight the arches. Multiple conduit runs will be required to power all fixtures. The recommended conduit will be rigid steel/PVC coated and will be gray in color, to match the historic granite. Multiple junction boxes, also PVC coated; gray in color, will need to be installed to allow for the proper routing of the new conduit. The conduit sizes will be kept to a minimum and run as "best as is practical" to harmonize with, rather than detract from, the landmark structure.

d. Incoming Service Power: The conduit will need to run exposed, along the bridge to the proposed light fixtures. Multiple conduit runs will be required to meet the both the NYC-DOT and NYC-DPR requirements for power and control. All conduit (PVC Coated) will run exposed and will be gray in color.

e. Conduit Diameter: It is estimated that the diameter of the proposed conduit will range from 1" to 1-1/2" in size.

f. Attic: Rigid Steel/PVC coated conduit will be run exposed in the attic space to pick up the required lighting fixtures. The color will be selected to blend with the adjacent materials to the full extent possible.

Impacts of Proposed Recommendations

The impact of the proposed recommendations will essentially be visual. The power conduit runs will be seen. It is understood that the visual and aesthetic aspects of this project are very important and every effort will be made to minimize the visual impact to the landmark by careful placement, detailing, and color selection.

8.3.3 Specific Interventions: Mechanical, Electrical, Plumbing, Fire Protection

Proposed electrical equipment will include:

- Power Panel (2)(4'h x 3'w x 12"d)
- Control Panels (2)(4'h x 3'w x 12"d)
- Meter and Meter Pan (1) 12" x 12" x 12"
- Conduit 2" RGS/PVC – 1000 LF
- Conduit 1-1/2" RGS/PVC – 2400 LF
- Conduit 1-1/4" RGS/PVC – 1850 LF
- Conduit 1" RGS/PVC – 3600 LF
- Junction Boxes (Approx. 6" x 6" x 6")(PVC Coated) - 136

9. Summary of Probes and Testing

9.1. GENERAL

9.2. PROBE 1 – STEEL SPAN WALKWAY PROBE AT COPING

9.3. PROBE 2 - STEEL SPAN WALKWAY PROBE AT CENTER

9.4. PROBE 3 – 1864 BRICK WALKWAY PROBE

9.5. PROBE 4 – GRANITE STEP PROBE

9.6. PROBES 5 AND 6 – 1928 STEEL SPAN FLOOR BEAM BOTTOM FLANGE PROBE AND TESTING

9.7. PROBES 7, 8, AND 9 – 90 ½" WROUGHT IRON PIPE AT MASONRY SPAN

9.8. SAMPLES SENT FOR TESTING BY JBCI AND PROFESSOR GORDON

9.9. MORTAR SAMPLES

9.10. COATING SAMPLES

9.11. IRONWORK SAMPLES

ATTACHMENTS

- *Probe & Testing Locations Walkway Plans*
- *Materials Analysis Report* by JBCI, April 5, 2011
- *Brick Paving Coating Removal Memorandum* by JBCI, January 7, 2011
- *Conservation Assessment of Selected Iron Elements*, by CSI, November, 2010
- *Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report* by Robert Gordon and Colin Thomas
- *Metallurgical Test Report* by MSI Testing & Engineering, August 11, 2010

9. Summary of Probes and Testing

9.1 GENERAL

The purpose of probes and testing for the High Bridge was to understand and document the bridge's assemblies and materials, and to understand adverse conditions and processes of deterioration for use in designing the Rehabilitation the High Bridge (New York City Department of Parks & Recreation Contract No. M037-607M PlaNYC). In addition, the probes and testing was undertaken to confirm an understanding of assemblies and materials developed by historic research for the HSR, such as annual reports (fig. 1), newspaper clippings, and photographs (fig. 2). The probes and testing were also performed to confirm findings presented in Baker Engineering NY, Inc's four volume "Bridge Condition and Assessment Report: High Bridge" (August, 2006).

The probes consisted of removal of parts of the structure allowing documentation of the construction and of adverse conditions. Probes were undertaken of the walkway at the steel and masonry spans, the Bronx granite steps, the steel span floor beams, and the wrought iron pipe. Samples were taken of brick, mortar, coatings, steel, cast iron, and wrought iron and tested to answer specific questions about the materials to aid in the rehabilitation of the High Bridge, and to document the materials for the HSR.

Probes and testing work was performed under the direction of Li/Saltzman Architects, PC (LSA), working as a consultant to Lichtenstein Consulting Engineers (LCS).

9.1.1 Probes and Testing Summary

Probes into the walkway and steel span of the High Bridge were begun on Monday, May 31, 2010, by PreConLogStrat (PCLS), a restoration contractor working for Jablonski Building Conservation Inc (JBCI), conservation sub-consultant for the design team. The probes work continued on Tuesday, June 1st and Wednesday, June 2. On June 1, JBCI took samples of coatings and mortar for historic properties testing. JBCI submitted a "Materials Analysis Report" on mortar and paint on April 5, 1011, which is included this section of the HSR.

Michael Aprahamian from Environmental Planning & Management (EPM) took samples of expansion joint and waterproofing materials for hazmat testing (see EPM's report in Appendix I of the HSR).

PCLS returned on June 17th to reinstall brick, and again on June 25th, at the request of DPR, to replace the brick paving infill materials adjacent to the Manhattan ventilator.

PCLS delivered sample materials to JBCI, including brick, steel coupons, and sections of cast iron pipe, cast iron saddle, and cast iron skewback. Additional sample materials of delaminating wrought iron pipe and waterproofing layer taken by LSA and a wrought iron tie rod and nut transmitted to LSA by Ellen Macnow of DPR were delivered to JBCI on July 16th.

The historic ironwork was delivered on August 1st to Prof. Robert Gordon, metallographer and emeritus professor of Geophysics and Applied Mechanics at Yale University, for metallographic analysis. Prof. Gordon's analysis provides provide historic context of the metals for the HSR, and data required to understand the mechanical properties of the metals that will be reused (such as the skewback) and for conservation (such as the wrought iron pipe). Prof. Gordon's analysis is presented in his "Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report" (October 21, 2010) included in this section of the HSR.

The wrought iron pipe was examined in situ by Conservation Solutions, Inc. (CSI) during August 2010 and their findings and recommendations are presented their "Conservation Assessment of Selected Historic Iron Elements of the High Bridge" (November 2010), included this section of the HSR.

Samples of the wrought iron pipe were taken by PCLS on September 18, 2010 and delivered to Prof. Gordon for metallographic testing, along with a sample of zinc plate taken by LSA, and the results are included in his "Metallurgy of the High Bridge Iron."

9.2 PROBE 1 – 1928 STEEL SPAN WALKWAY PROBE AT COPING

The 1928 steel span walkway was probed at the edge of the steep coping and adjacent to a transverse deck joint (fig. 3). The mortar joints were fully cut by PCLS with a masonry saw and then the bricks removed to reveal a sand bed and reinforced mortar bed (fig. 4). The reinforced mortar bed was removed with an air hammer.

The bricks are a hard burned red pressed paving brick and the mortar appears to be a white Portland cement. The bricks are laid with stretchers exposed in a running bond and are set on a one inch sand setting bed, which rests on a reinforced mortar slab (without large aggregate), approx. 2¼" thick with 2"x2" WWM reinforcing (fig. 7). The probe exposed the steel deck and rivets and side of the steel "coping" and the side of a transverse steel plate joint (fig. 5). No waterproofing is present. The steel is coated with a red lead primer. A bituminous expansion joint material was found at the joint between the brick and coping and brick and transverse steel plate. All details appear to match the 1926 "High Bridge Reconstruction" construction drawings.

In general the bricks were easily removed, the mortar is readily removed from the bricks with a chipping hammer. The mortar reinforcing slab was sound, but hollow in several areas of the probe. The WWM was in generally good condition with only moderate rust. The only steel rust of note is at the side of the steel coping where the steel was in contact with dirt, grass, and moss. All other exposed steel shows only surface rust, and the primer coat of paint is generally present and well adhered. The only other condition of note is the upward movement of the brickwork, generally about one inch at the edges (where dirt and plants have accumulated). The movement appears to be a result of frost heave of the brickwork from water leaching into the sand and mortar bed.

Three brick samples were taken by PCLS and delivered to JBCI. One brick was taken back to LSA for use in locating matching replacement brick. No testing was undertaken on the 1928 walkway brick.

9.3 PROBE 2 – 1928 STEEL SPAN WALKWAY PROBE AT CENTER

A probe was taken in the middle of the 1928 steel span walkway where the brick had heaved and there was excessive plant growth (fig. 6). This probe indicates the same materials and conditions as found in Probe 1 (figs. 7 and 8), except that the probe was taken a few feet from the edge of the walkway and not near a joint, so that no expansion joint material was present.

9.4 PROBE 3 – 1864 BRICK WALKWAY PROBE

To understand the waterproofing system and condition and ease of removal of the paving brick a probe was taken of the 1864 masonry span brick walkway from the center line of the walkway to the coping (approx. 2' wide x 8'-6" long) and along the coping (approx. 2' x 6') to uncover the cast iron skewback (fig. 9).

Mortar joints in the 1864 paving brick were partially cut with a masonry saw by PCLS, and then drilled to free the bricks (fig. 10). The paving bricks are set in a natural cement mortar bed on top of a second course of brick underlayment laid flat in a running bond pattern (fig. 12). The second course of bricks are laid in and set directly on top of an asphaltic waterproofing course, approximately ½ inch thick (figs. 12 and 13). Roots from grass and other plants were found growing through the pavers and into the waterproofing (fig. 13). At the center of the walkway the waterproofing is laid directly on top of the structural brick arch, but at about 4'-3" the edge of the granite coping it is laid on top of a brick haunch that tapers in thickness from zero to 7½ inches at the coping (fig. 14). This is contrary to the drawings in the Baker report, which indicate waterproofing directly on the top of the 12" structural arch and not on the brick haunch.

At the edge of the coping brick paving, underlayment and haunch were removed to expose the upper part of the cast iron skewback and the end joint between two skewbacks (fig. 15 and 16). The skewback was fully embedded in natural cement mortar. The skewback is about 10 inches down from the top of the coping and about 2 inches from the back of the coping. A small section of the structural brick arch was also removed to expose the top of a wrought iron tie rod, which is about 6½" below the top of the skewback (fig. 17). We verified that the web and ribs of the skewback are 1 inch thick, and the ribs are 15 inches on center, which corresponds with a ca. 1860 drawing of the skewbacks in the DEP archives. (See Figure 13 in Appendix H.) The flange was not visible.

Due to the bricks being laid flat in a herringbone bonding pattern, the fragility of the paving brick, and the tenacity of the original natural cement mortar that bonds the bricks together, it was very difficult to remove brickwork without damage to the bricks, and a significant percentage (approx. 25%) of the bricks were chipped or cracked during the removal process. Removal of the natural cement mortar from the paving brick requires use of a masonry saw (fig. 18). However, in general the paving bricks were easily removed from the bedding mortar. The second course of brickwork is very easily removed from the waterproofing layer. The waterproofing is generally loose and friable, with an occasional small bleb of hard asphaltic material present. The brickwork of the structural arch is sound, with no cracks or loose mortar observed. The approximately 4'-3" wide tapered brick haunch fill on top of the structural arch is sound and very well adhered to the arch and required an impact hammer for removal.

The cast iron skewback exhibited no rust. A sample was cut from the skewback for testing by Prof. Gordon to determine its mechanical properties (see his report). The rust was found to penetrate to a depth of about 0.2 mm. Prof. Gordon concluded that the minor penetration is because the graphite flakes do not make a continuous path into the metal interior. Prof. Gordon noted that the cast iron is mechanically sound and the rate of corrosion sufficiently slow as not to degrade the strength of the casting for the foreseeable future.

Three brick samples were taken by PCLS and delivered to JBCI. One brick was taken back to LSA for use in locating matching replacement brick. JBCI investigated removal of the dark surface color of the brick's walking surface, which may be due to an asphaltic coating. (See JBCI January 7, 2011 memo in this section of the HSR.)

9.5 PROBE 4 - GRANITE STEP PROBE

A loose granite step at the Bronx end was removed to determine the condition of its underlayment (fig. 19). The area of walkway from the top of the steps to the gatehouse was relaid with wire cut brick in ca. 1979 and the slope removed, so that the walkway is presently flat. The steps were also relaid, with a much fatter bed joint (approx. 2" thick in some areas. This area is also the location of active leaking and cracks in the structural brick walkway arch in the attic below.

On June 17, 2010, PCLS removed a section of the top granite step on the Bronx side (figs. 20). The step was laid with a bed joint about 2 inches thick in order to compensate for raising the plaza level. Grasses and young woody plants were growing between the step and the granite cheekwall and the adjacent brickwork, and under the step and brickwork (fig. 21). The step was laid on mortar, which had deteriorated to soil. Deteriorated wood (probably 2x4s) were also present under the step and imbedded in the mortar (fig. 22).

9.6 PROBES 5 AND 6 – 1928 STEEL SPAN FLOOR BEAM BOTTOM FLANGE PROBE AND TESTING

Two approximately 4 inch square steel coupons were removed from the bottom flanges of two different floor beams by PCLS with a grinder (fig. 23). The samples were sent by JBCI to MSI Testing & Engineering, Inc. for Carbon Equivalent Base Chemistry test to determine if the metal can be welded based on carbon content. See the MSI testing report in this section of the HSR.

Chemical testing by MSI following ASTM E415, ASTM A370 and ASTM E8 found carbon equivalence of 0.17 and 0.18 for the two coupons. MSI noted they met AISI steel grades 1006, 1008, and 1010, and that the

samples would exhibit good weldability. The samples also exhibited tensile strengths of 51,500 and 54,500 psi.

9.7 PROBES 7, 8, AND 9 – 90 ½ INCH WROUGHT IRON PIPE AT MASONRY SPAN

Following the site visit and an initial findings memo by CSI, probes were made of the 90 ½ inch wrought iron pipe to provide samples for testing by Prof. Gordon. Two samples were taken where the metal was thin and holes had developed in the pipe, and one at a riveted flange plate. All three samples were approx. 4" x 4" and cut out by PCLS with a grinder and reciprocating saw.

See Prof. Gordon's "Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report" (October 21, 2010) included in this section of the HSR for a description of findings on the wrought iron pipe.

9.7.1 Probe 7 - Wrought Iron Pipe at Masonry Span

The first sample of wrought iron pipe was cut high up on the pipe (fig. 24). The sample location was chosen with a hole located directly under a wrought iron tie rod (figs. 25 and 26) and just below a line of paint that is well bonded (fig. 27 and 28). The sample ranged in thickness from ¼" to 3/8" but also has a hole in it (fig. 29).

9.7.2 Probe 8 - Wrought Iron Pipe at Masonry Span Riveted Flange Plate

A sample of a riveted flange plate was taken to see how the rivets were constructed and to confirm thickness of the plates (figs. 30 to 32), which ranged from ½" to ¼".

9.7.3 Probe 9 - Wrought Iron Pipe at Steel Span Pipe Gallery

The third sample of pipe was cut in the steel span pipe gallery (fig. 33). The pipe in this area had been removed and reinstalled in 1928 when the steel span was constructed, and presumably the rust was knocked off the pipe, so the exterior is not as rough as the masonry span pipe and does not have the thick layer of rust bonded to paint on the top of the pipe, however, it does have streaks of pigeon guano and efflorescence from leaks in the walkway and deck above (fig. 34). The interior of the pipe is similar in condition to the pipe on the masonry span.

9.8 SAMPLES SENT FOR TESTING BY JBCI AND PROF. GORDON

9.8.1 Sample Log

The following is a log of samples taken by JBCI for testing:

Sample No.	Sample Type	Location/Description
HBM-01	Mortar	1864 brick paver mortar
HBM-02	Mortar	1864 Manhattan abutment stone mortar
HBM-03	Mortar	1864 Manhattan abutment stone mortar
HBM-04	Mortar	1848 attic brick mortar – Niche 4
HBM-05	Mortar	1848 attic brick mortar – Niche 4
HBP-01	Paint	1850s wrought iron railing outside Manhattan entrance
HBP-02	Paint	Cast iron railing scrollwork near Bronx entrance (North elevation)
HBP-03	Paint	Cast iron railing post – at missing arch ornament (North elevation)
HBP-04	Paint	Lamp post at Manhattan entrance (South elevation)
HBP-05	Paint	Cast iron railing scrollwork near Manhattan entrance (South elevation)
HBP-06	Paint	Steel span railing – top rail (North elevation)
HBP-07	Paint	Lamp post at Bronx entrance (North elevation)
HBP-08	Paint	Cast iron railing post – near missing brace
HBP-09	Paint	Cast iron pipe – West end (in attic on Manhattan side)

Sample No.	Sample Type	Location/Description
HBP-10	Paint	Saddle for wrought iron pipe – West end (in attic on Manhattan side)
HBP-11	Paint	Saddle for wrought iron pipe – at pipe support 18
HBP-12	Paint	Wrought iron pipe – at pipe support 18
HBP-13	Paint	Pedestal for wrought iron pipe - at pipe support 18
HBP-14	Paint	Saddle for wrought iron pipe near spandrel beam (East side of arch)
HBP-015	Paint	Steel span beam below pipe (East side of arch)
HBP-016	Paint	Steel span bottom flange of spandrel beam (East side of arch)
HBP-017	Paint	Brick coating – Attic North wall at #53
HBF-01	Metal	1840's cast iron pipe
HBF-02	Metal	1860's cast iron pipe saddle for wrought iron pipe
HBF-03	Metal	Nut from wrought iron tie rod
HBF-04	Metal	Cast iron skewback
HBF-05	Metal	Delaminated wrought iron pipe, Manhattan end, interior of pipe
HBF-07	Metal	Delaminated wrought iron pipe, Bronx end, exterior of pipe
HBF-08	Metal	Wrought iron tie rod

9.9 MORTAR SAMPLES

Ca. 1864 mortar was taken from locations of Probe 3 and from the west face of the Manhattan abutment near the ground level. Ca. 1848 mortar was taken from the attic niche of Pier 4.

JBCI performed wet chemical analysis of the mortars to understand the type of mortar and to determine aggregate type for use in replication mortar. JBCI found that all mortar used on the bridge in the 1848 and 1864 eras of construction is the same natural cement mortar. This matches petrographic analysis performed in 2003 by John Walsh for Baker Engineering which describes the mortar as a natural cement consistent with the historic record of Rosendale cement being used at the High Bridge. See JBCI "Materials Analysis Report."

JBCI recommends a mortar mix of 1 part ASTM C10 natural cement to 3 parts sand composed of 2 parts Schofield "125" and 1 part Schofield "219." This mix and aggregate type will be reviewed with the cement manufacturer.

9.10 COATINGS SAMPLES

Seventeen samples of coatings (see log above) were taken from the ironwork (lamps, railings, pipes, steel span) and attic brickwork to determine types of coatings and chromochronology. Most coatings were severely deteriorated and it was difficult in many cases to confirm original primers and complete finish sequences. See JBCI "Materials Analysis Report."

9.10.1 Wrought and cast iron railings

The railings date from 1850, 1864, and 1928. The earliest finish, which may be a primer, found on the railings is a dark grayish reddish brown (between Munsell 10R 2/2 and 2.5YR 2/2), which was coated with black (Munsell N1) on all railings.

9.10.2 Lamps

The lamps were installed in ca. 1935, and the earliest finish, which is likely a primer, found on the lamps is a dark grayish reddish brown (between Munsell 10R 2/2 and 2.5YR 2/2). Subsequent, and likely final, coatings were dark green.

9.10.3 Steel span

The steel span was completed in 1928. Painting specifications from 1925 required the steel to be primed with two shop coats of red lead primer, the first coat tinted with lampblack, then spot primed over damaged surfaces on site with red lead primer. The finish coat specified in 1925 was a combination of white lead, burnt umber, and Chinese blue pigment in linseed oil. JBCI found two layers of orange primer that appear to correspond with the specified red lead primer, and that the finish coating of the steel span was a pale blue gray (Munsell 10BG 7/1).

9.10.4 Attic brickwork

JBCI found that the interior brick walls of the attic were finished with whitewash.

9.10.5 Wrought Iron and Cast Iron Pipes

The cast iron pipes date from ca. 1848 and the wrought iron pipe and cast iron supports date from 1860. All were originally coated with a dark grayish reddish brown paint, with iron oxide pigment (Munsell 10R 2/2), then coated with several layers of black paint. The original iron oxide pigment coating is consistent with the historic documentation which describes the wrought iron pipe as being coated with Prince's Metallic Paint. (See Section 3.5 The Great Pipe (1860-1864) for citations for Prince's Metallic Paint.)

9.11 IRONWORK SAMPLES

Broken sections of 36 inch cast iron pipe and cast iron pipe saddle were removed from the attic of the Manhattan abutment by PCLS and delivered to JBCI's office. A section of cast iron skewback was taken by PCLS from Probe 3. A sample of a tie rod and a nut taken by Baker Engineering were transmitted by Ellen Macnow of DPR to LSA. All ironwork samples were then delivered to Prof. Gordon for metallographic examination.

See Prof. Gordon's "Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report" (October 21, 2010) included in this section of the HSR for a description of findings on the iron pipe, cast iron skewback, and wrought iron tie rod.

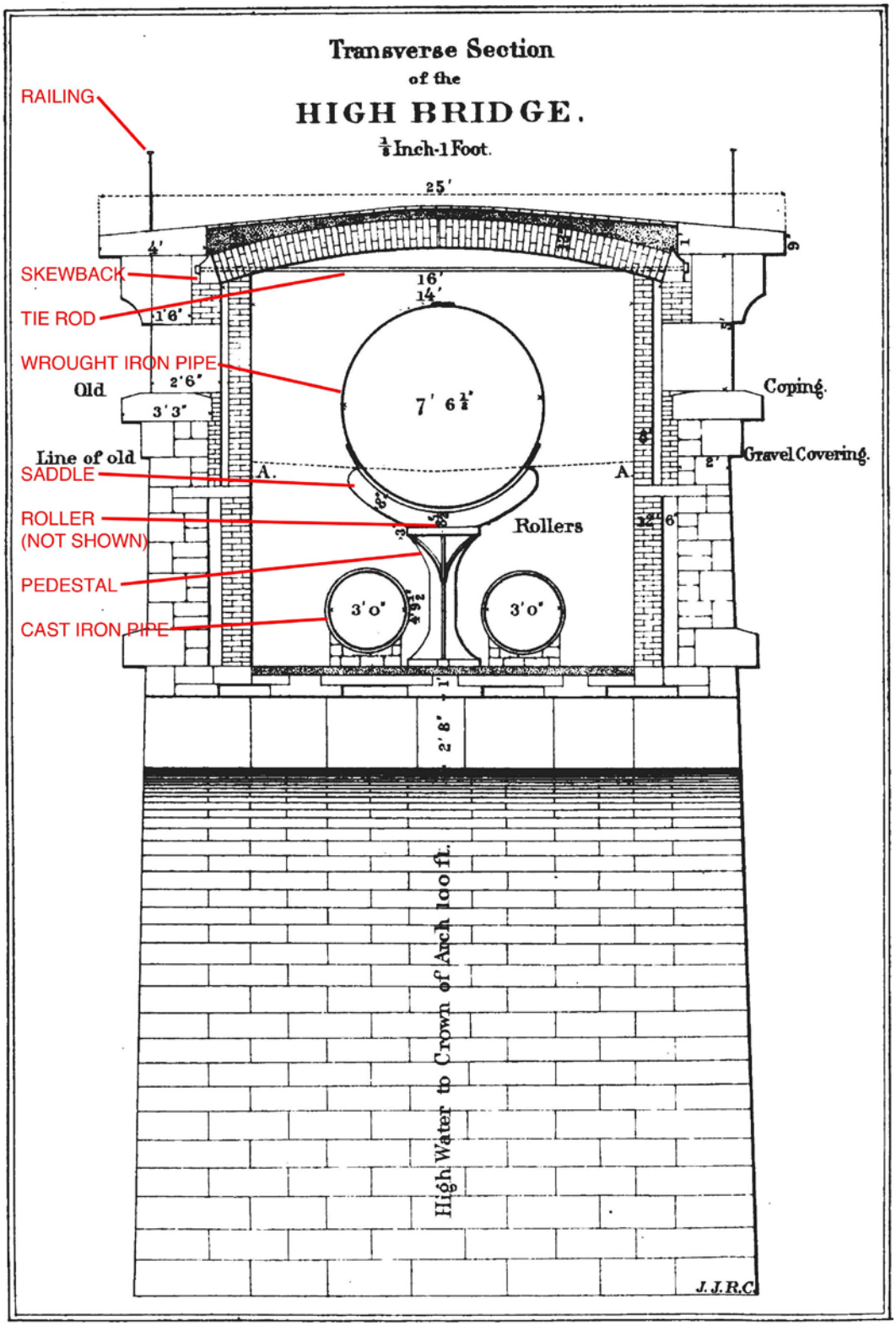


FIGURE 1. *Probes were performed to confirm details of construction as indicated in annual reports, such as* Transverse Section of the High Bridge, *showing original masonry construction and cast iron pipes and masonry and wrought iron pipe added between 1860 and 1864. From* Annual Report of the Croton Aqueduct Department *(1861).*

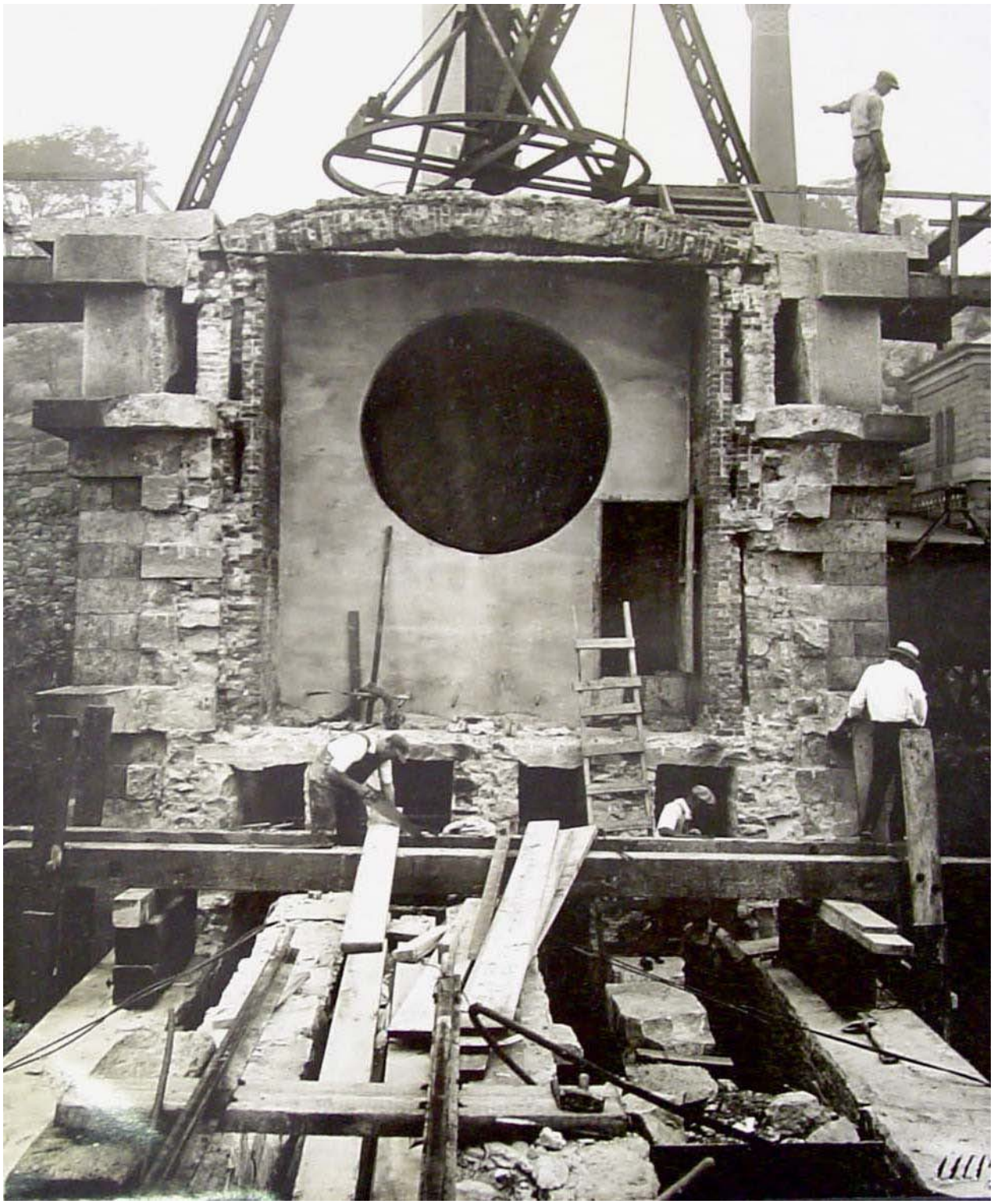


FIGURE 2. *Probes were performed to confirm details of construction as indicated in historic photographs, such as Eugene de Salignac's* High Bridge Showing Masonry Attic. *(August 22, 1927). New York City Municipal Archives. BPS 11112.*



FIGURE 3. *Probe 1 of steel span walkway.*



FIGURE 4. *Probe 1 of steel span walkway, with brick and sand setting bed removed.*



FIGURE 5. *Probe 1 of steel span walkway completed. See fig. 8 for details.*

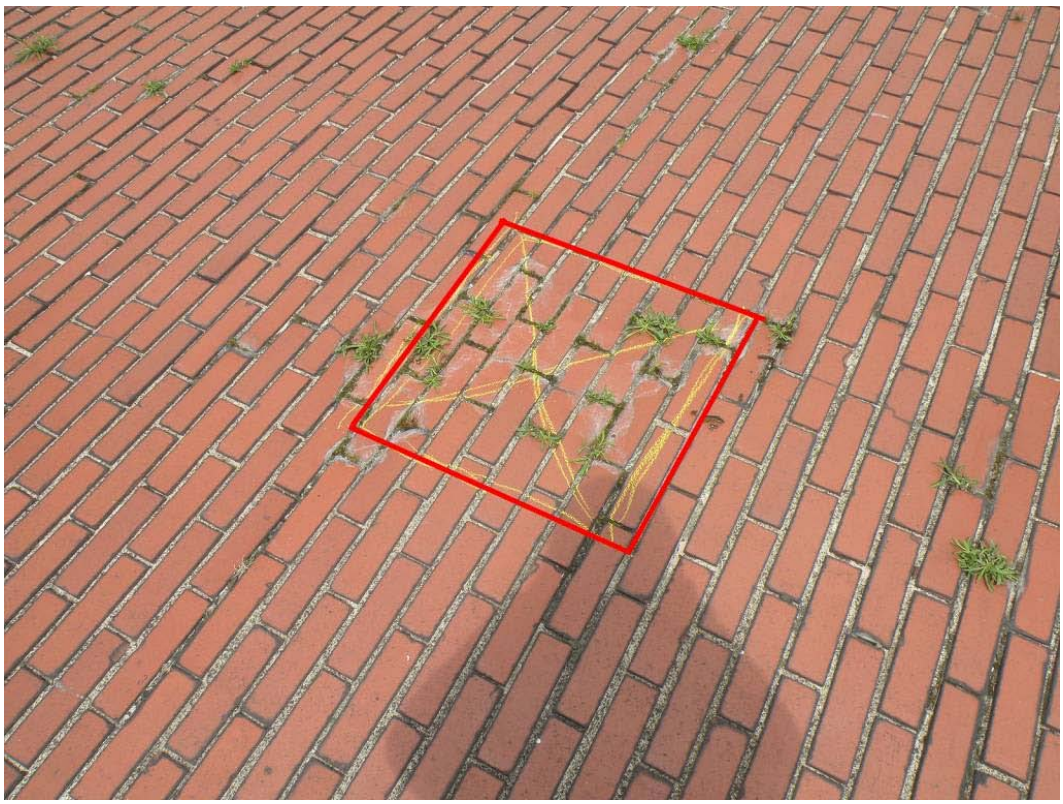


FIGURE 6. *Probe 2 of steel span walkway.*



FIGURE 7. *Probe 2 of steel span walkway completed. See fig. 8 for details.*



FIGURE 8. *Probe 2 of steel span walkway. Construction similar in Probe 1.*



FIGURE 9. *Probe 3 of masonry span walkway.*



FIGURE 10. *Probe 3 of masonry span walkway. Mortar was removed with chipping hammer, grinders, and circular saws.*

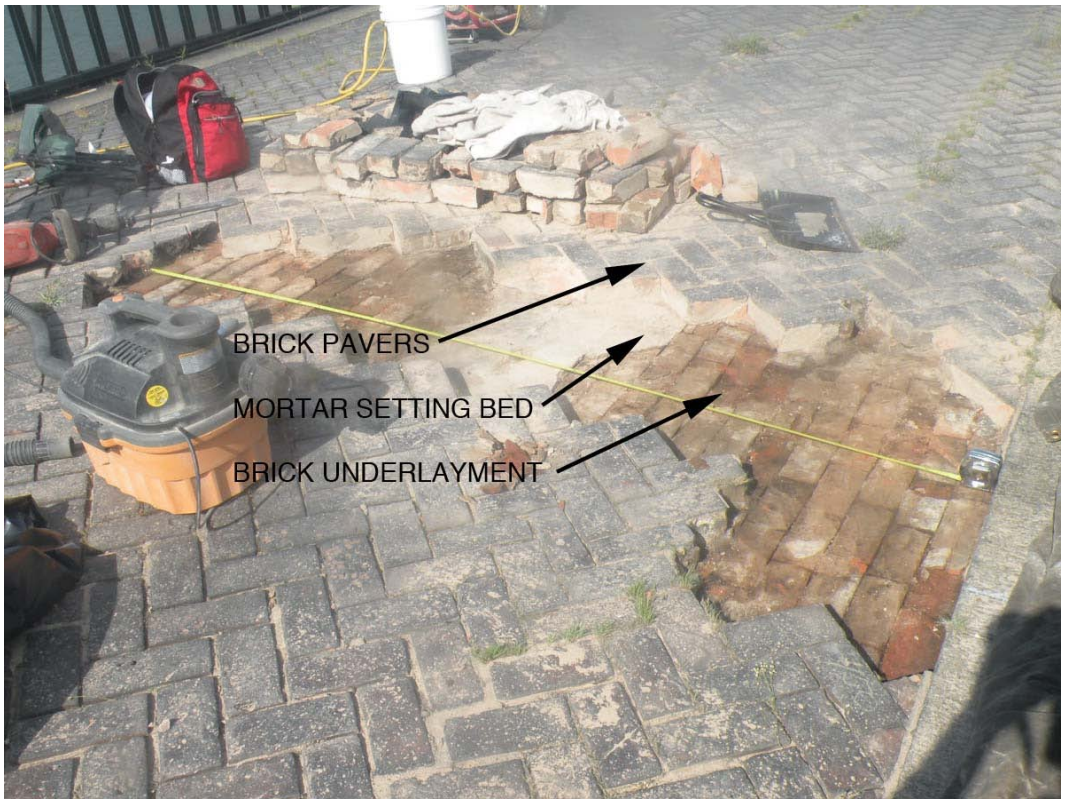


FIGURE 11. *Probe 3 of masonry span walkway following removal of brick pavers.*



FIGURE 12. *Probe 3 of masonry span walkway following removal of brick pavers and brick underlayment.*

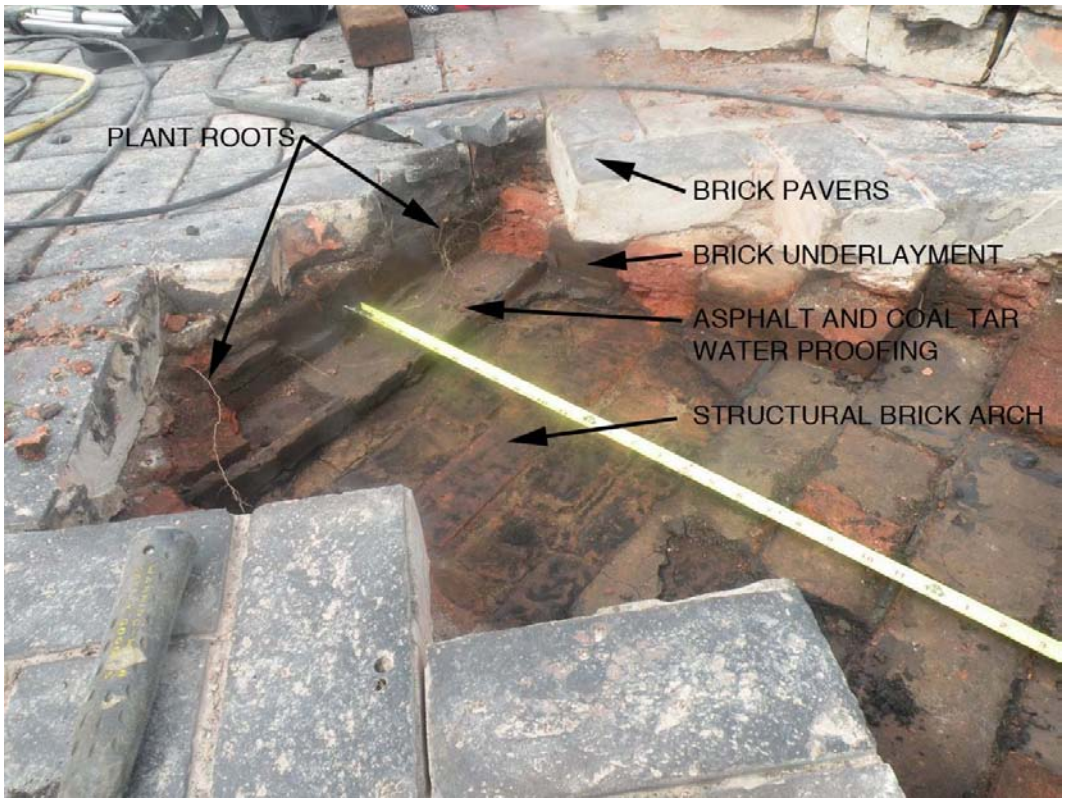


FIGURE 13. *Probe 3 of masonry span walkway.*



FIGURE 14. *Probe 3 of masonry span walkway.*



FIGURE 15. *Probe 3 of masonry span walkway.*



FIGURE 16. *Probe 3 of masonry span walkway.*



FIGURE 17. *Probe 3 of masonry span walkway. A sample of the cast iron skewback was taken for testing from this location.*



FIGURE 18. *Removing natural cement mortar from brick pavers.*



FIGURE 19. *Probe 4 of Bronx step. Note thick bed joint below the second step, which is typical.*



FIGURE 20. *Probe 4 of Bronx step showing step removed.*



FIGURE 21. *Probe 4 of Bronx step showing soil and plant growth in joints and under step.*

*



FIGURE 22. *Probe 4 of Bronx step.*



FIGURE 23. *Location of Probe 5 of steel span floor beam bottom flange. Probe 6 similar.*



FIGURE 24. *Cutting Probe 7, sample of wrought iron pipe.*



FIGURE 25. *Exterior of wrought iron pipe at location of Probe 7.*



FIGURE 26. *Interior of wrought iron pipe at location of Probe 7.*



FIGURE 27. *Probe 7 or wrought iron pipe in direct light.*



FIGURE 28. *Probe 7 of wrought iron pipe in raking light showing texture of exterior surface.*

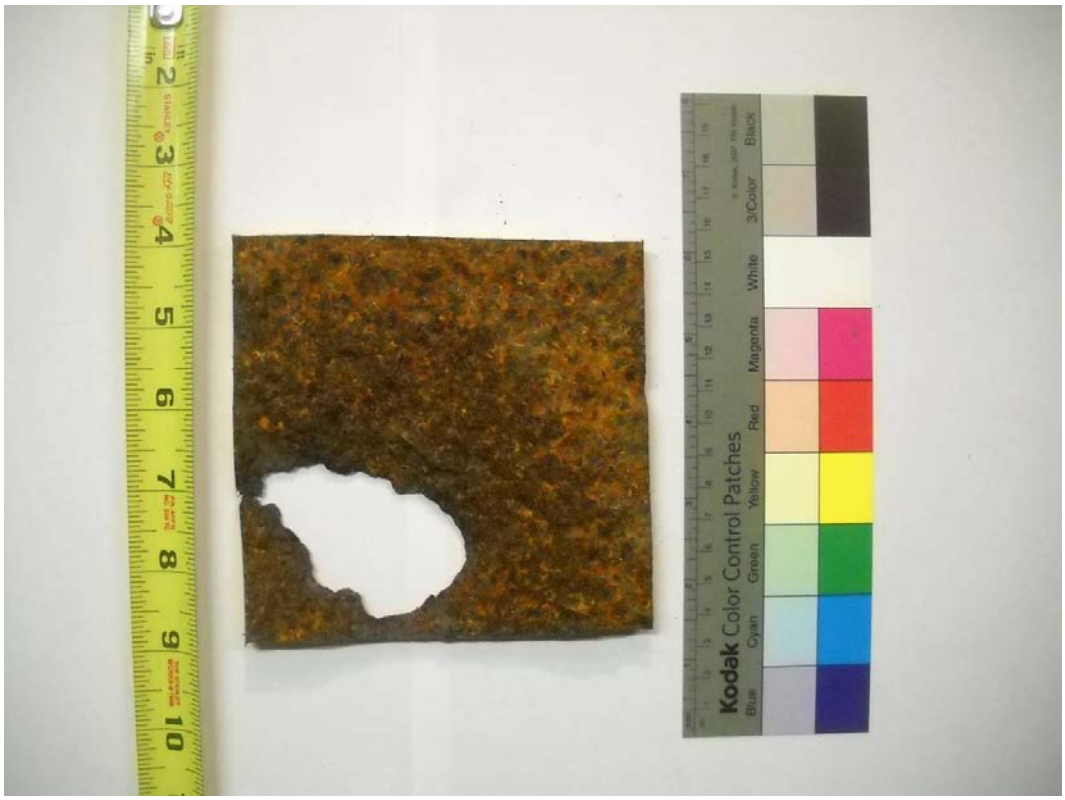


FIGURE 29. *Sample from Probe 7 of wrought iron pipe.*



FIGURE 30. *Location of Probe 8 of wrought iron pipe at riveted splice plate.*



FIGURE 31. *Location of Probe 8 of wrought iron pipe at riveted splice plate.*



FIGURE 32. *Sample from Probe 8 of wrought iron pipe at riveted splice plate.*



FIGURE 33. *Cutting Probe 9 of wrought iron pipe in steel span pipe gallery.*



FIGURE 34. *Exterior of wrought iron pipe at Probe 9 in steel span pipe gallery.*



FIGURE 35. *Interior of wrought iron pipe at Probe 9 in steel span pipe gallery.*



FIGURE 36. *Sample from Probe 9 of wrought iron pipe in steel span pipe gallery.*



FIGURE 37. *Interior of wrought iron pipe at Manhattan end showing zinc plate.*

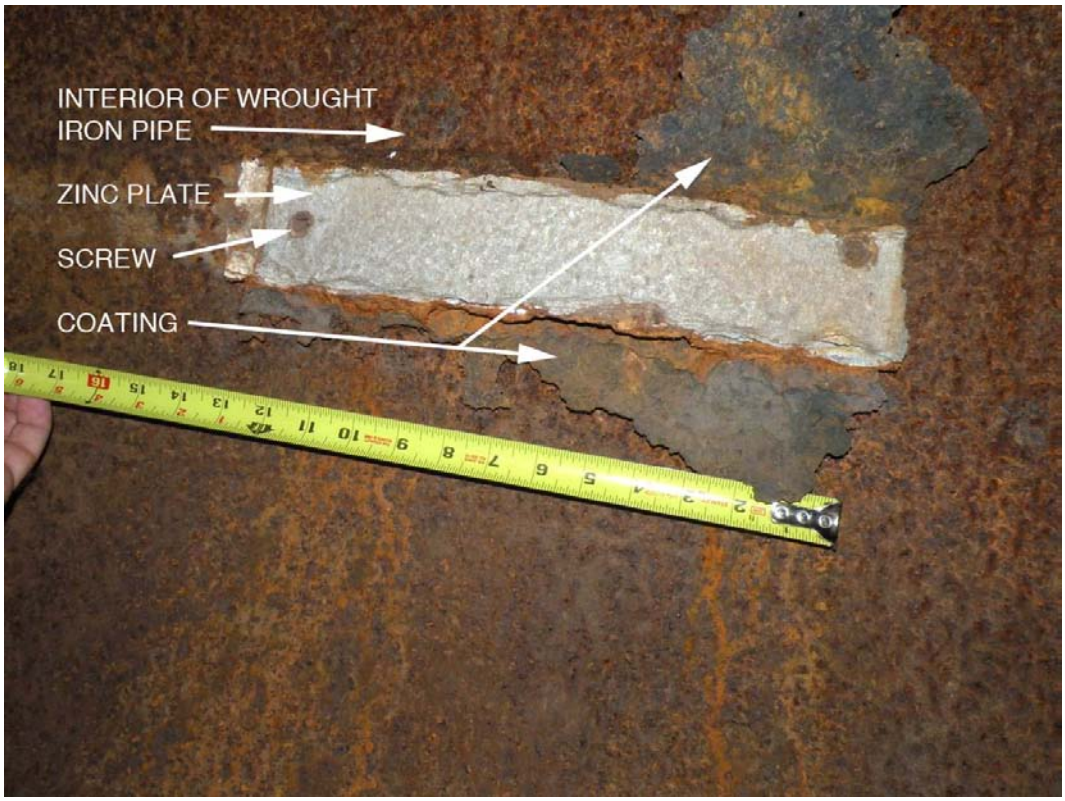
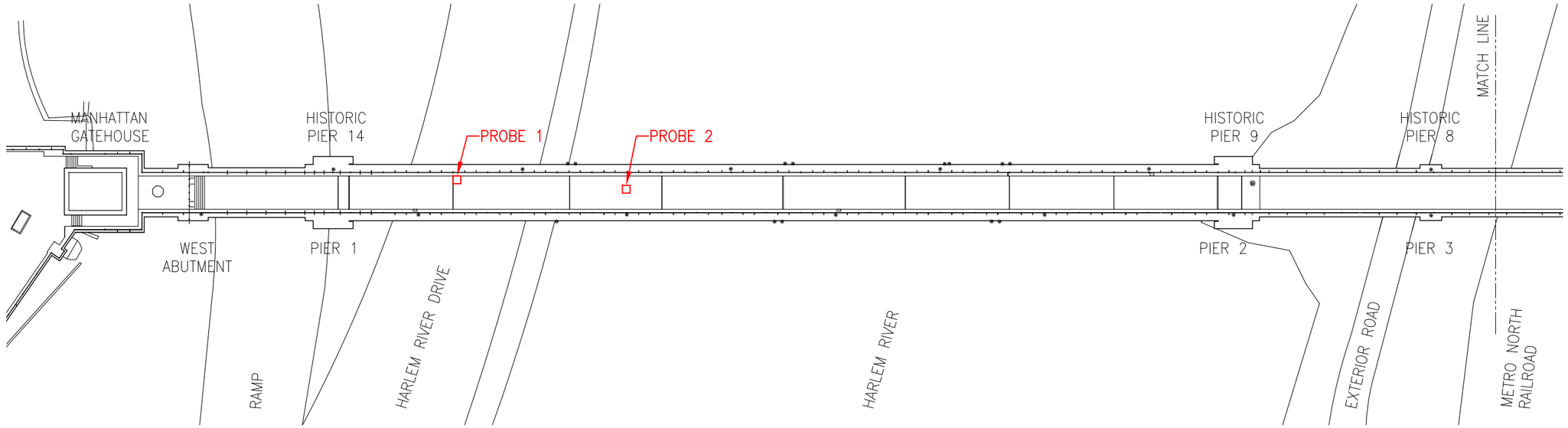
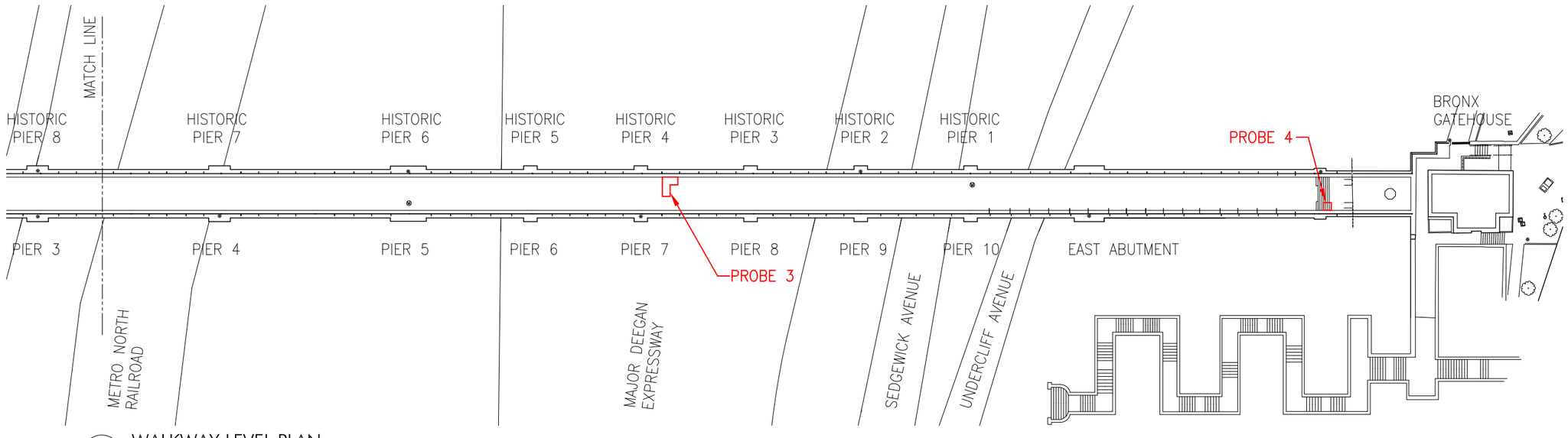


FIGURE 38. *Typical zinc plate taken as sample for testing.*



1 WALKWAY LEVEL PLAN

SCALE: 1"=60'-0"



2 WALKWAY LEVEL PLAN

SCALE: 1"=60'-0"

0 15' 30' 60'

HIGH BRIDGE RESTORATION

The Bronx, NY
New York, NY

NYC DEPARTMENT OF PARKS & RECREATION

NEW YORK CITY DEPARTMENT OF DESIGN + CONSTRUCTION

PROJECT ID: P-3PNYC01

LI • SALTZMAN ARCHITECTS, P.C.
ARCHITECTURE AND PRESERVATION
62 WHITE STREET NY, NY 10013.3598
TEL : 212.941.1838 FAX : 212.941.1834

ENGINEERS
STRUCTURAL ENGINEER
LICHTENSTEIN CONSULTING

LANDSCAPE ARCHITECT
MKW + ASSOCIATES, LLC

INTERPRETIVE CONSULTANT
ALTA PLANNING + DESIGN

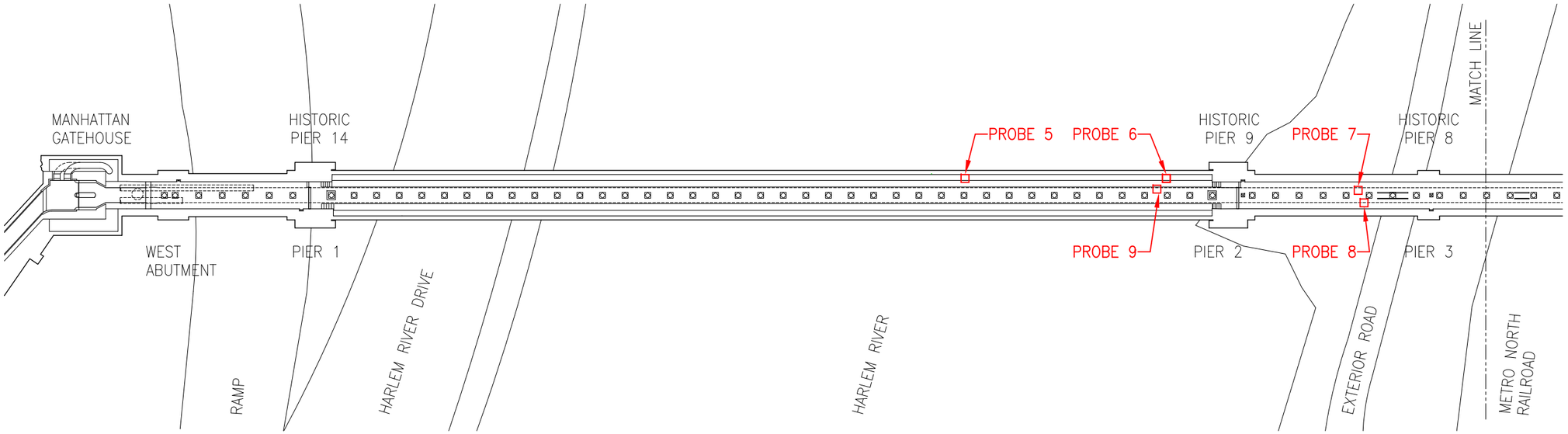
No.	Date	Issue

SEAL:

DRAWING TITLE:
PROBES & TESTING LOCATIONS WALKWAY PLAN

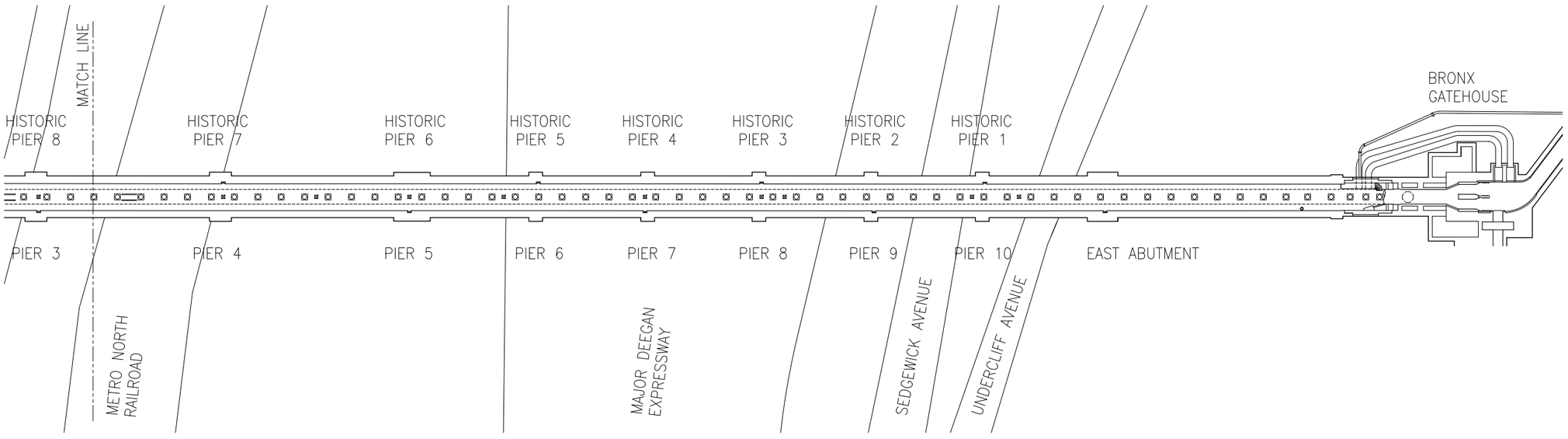
SCALE: 1"=60'
DATE: 01/10/2011

DRAWING NO:
HB-01



1 ATTIC LEVEL PLAN

SCALE: 1"=60'-0"



2 ATTIC LEVEL PLAN

SCALE: 1"=60'-0"

0 15' 30' 60'

HIGH BRIDGE RESTORATION

The Bronx, NY
New York, NY

NYC DEPARTMENT OF PARKS & RECREATION

NEW YORK CITY DEPARTMENT OF DESIGN + CONSTRUCTION

PROJECT ID: P-3PNYC01

LI • SALTZMAN ARCHITECTS, P.C.
ARCHITECTURE AND PRESERVATION
62 WHITE STREET NY, NY 10013.3598
TEL : 212.941.1838 FAX : 212.941.1834

ENGINEERS
STRUCTURAL ENGINEER
LICHTENSTEIN CONSULTING

LANDSCAPE ARCHITECT
MKW + ASSOCIATES, LLC

INTERPRETIVE CONSULTANT
ALTA PLANNING + DESIGN

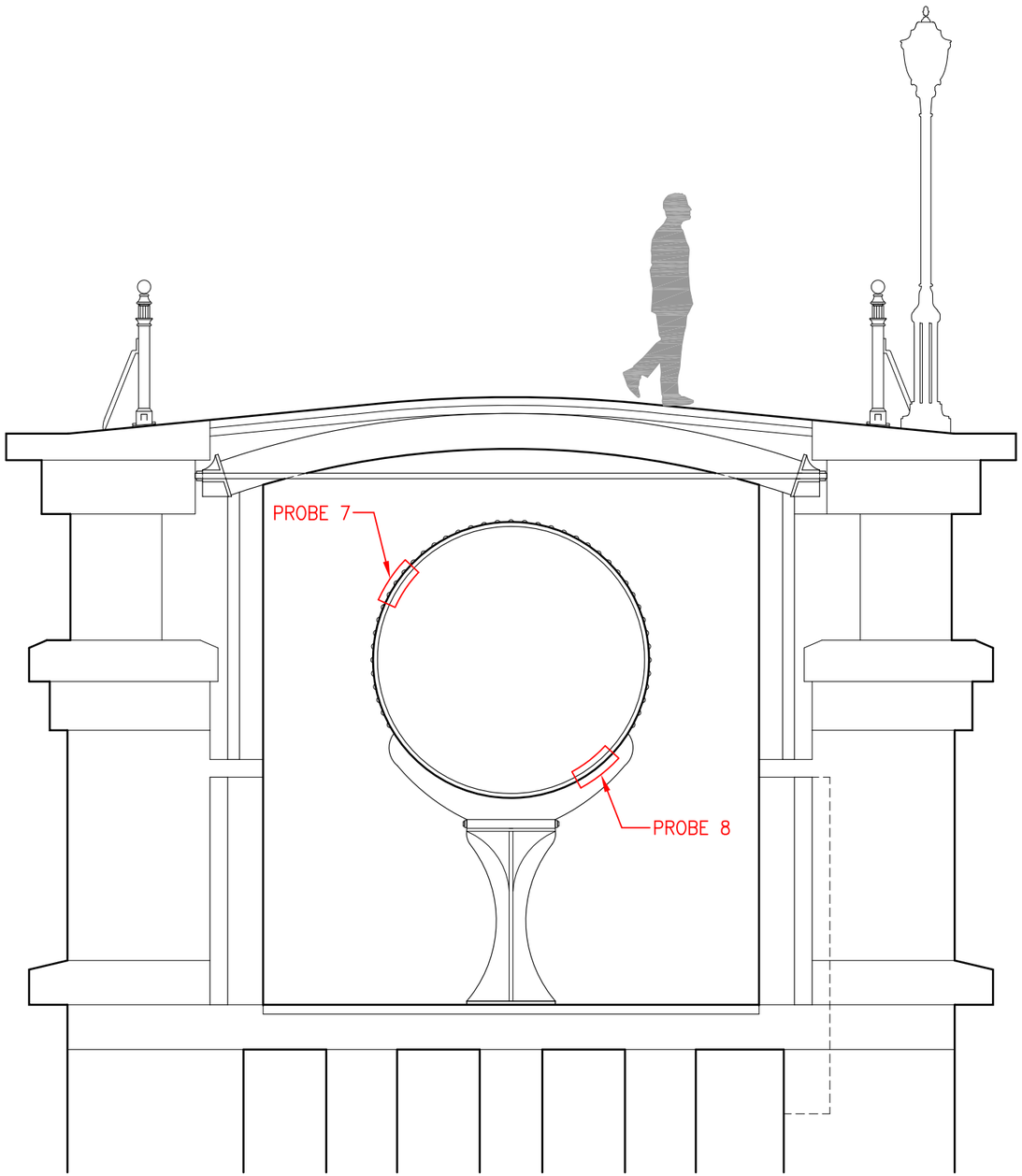
No.	Date	Issue

SEAL:

DRAWING TITLE:
PROBES & TESTING LOCATIONS
ATTIC LEVEL PLAN

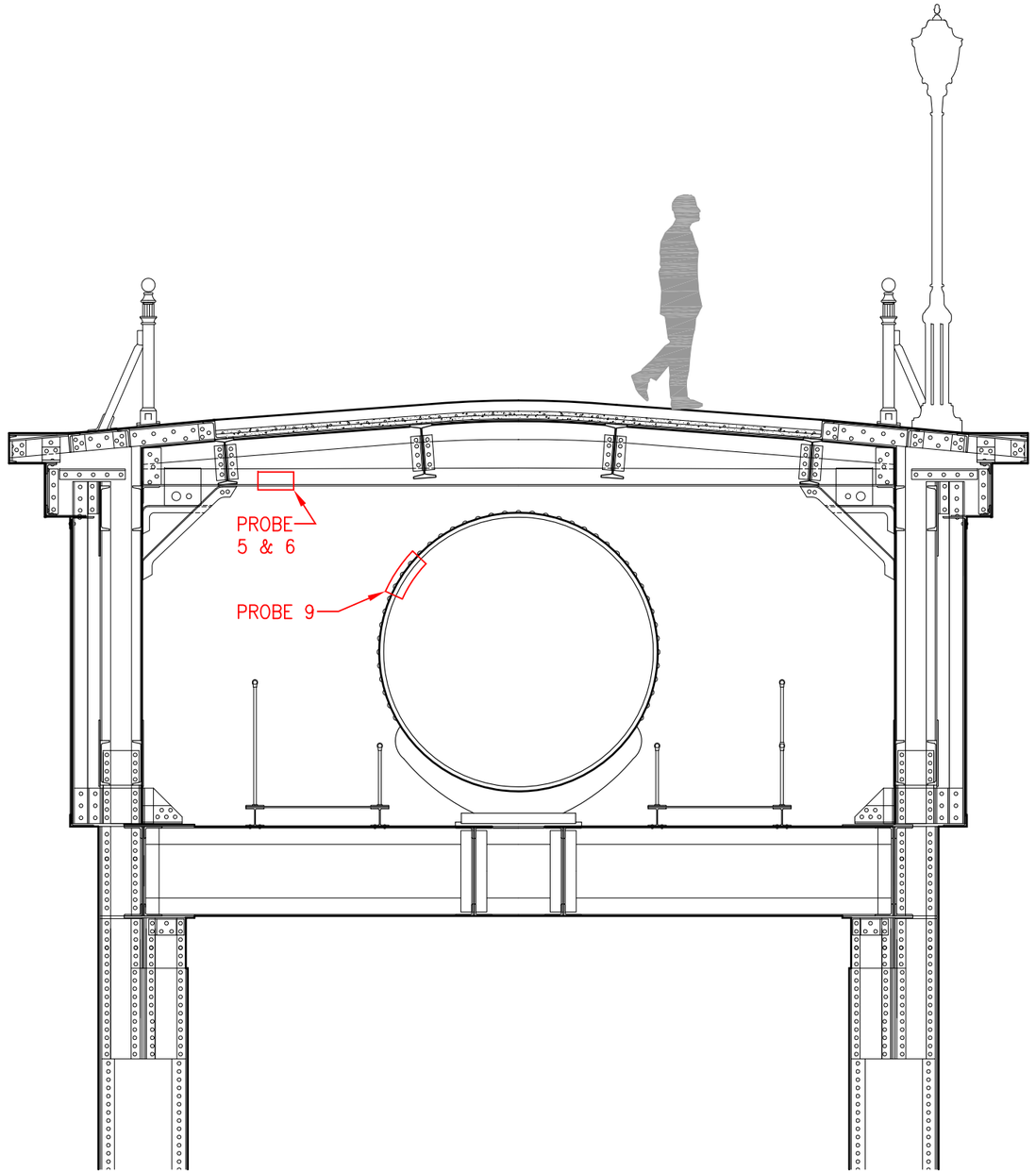
SCALE: 1"=60'
DATE: 01/10/2011

DRAWING NO:
HB-02



1 CROSS SECTION AT MASONRY ARCH

SCALE: 1/4"=1'-0"



2 CROSS SECTION AT STEEL ARCH

SCALE: 1/4"=1'-0"

0 1' 2' 4'

HIGH BRIDGE RESTORATION

The Bronx, NY
New York, NY

NYC DEPARTMENT OF PARKS & RECREATION

NEW YORK CITY DEPARTMENT OF DESIGN + CONSTRUCTION

PROJECT ID: P-3PNYC01

LI • SALTZMAN ARCHITECTS, P.C.
ARCHITECTURE AND PRESERVATION
62 WHITE STREET NY, NY 10013.3598
TEL : 212.941.1838 FAX : 212.941.1834

ENGINEERS
STRUCTURAL ENGINEER
LICHTENSTEIN CONSULTING

LANDSCAPE ARCHITECT
MKW + ASSOCIATES, LLC

INTERPRETIVE CONSULTANT
ALTA PLANNING + DESIGN

No.	Date	Issue

SEAL:

DRAWING TITLE:
PROBES & TESTING LOCATIONS CROSS SECTIONS

SCALE: 1/4"=1'-0"
DATE: 01/10/2011

DRAWING NO:
HB-03

MATERIALS ANALYSIS REPORT

High Bridge

The Bronx and Manhattan, NY



Prepared for:
Lichtenstein Consulting Engineers
350 5th Ave Suite 924
New York, NY 10118

Li/Saltzman Architects, PC
62 White Street
New York, NY 10013-3593

Prepared by:
Jablonski Building Conservation, Inc.
40 West 27th Street, Suite 1201
New York, NY 10001

April 5, 2011

TABLE OF CONTENTS

Mortar Analysis and Replication Recommendations 2

Paving Brick Coating Analysis and Recommendations 9

Selective Finish Color Investigation 10

Appendix A: Chromochronologies

MORTAR ANALYSIS AND REPLICATION RECOMMENDATIONS

INTRODUCTION

At the request of Lichtenstein Consulting Engineers and Li/Saltzman Architects, Jablonski Building Conservation, analyzed five samples of mortar removed from the High Bridge located in The Bronx and Manhattan, NY. One mortar sample was taken from the original 1860 brick pavers on the bridge. One sample was taken from the brick in Niche 4 of the bridge interior and one sample from the stone in Niche 4. Two mortar samples were taken from the north wall on the Manhattan exterior of the bridge: one from the granite and one from the masonry.

The analysis, which conformed to standard wet-chemical techniques, was requested to provide the primary characteristics of the historic mortar used on the various elements of the structure. This analysis is critical in the formulation of an appropriate replication mix.

Data was compared to the results of analysis by Testwell Laboratories found in "Appendix B – Material Sampling Reports" of the "Bridge Condition and Assessment Report for the High Bridge, BIN: 2-24658-0, PIN: 84101MBBR181, Boroughs of Manhattan and the Bronx, New York (August 2006) completed for Baker Engineering.

METHOD OF ANALYSIS

Portions of the samples were examined under magnification. Using natural daylight, the binder in the sample was matched to a color standard of the Munsell Color Chart (as per ASTM 1535, "Specifying Color by the Munsell System"). The examination also included separating the sample into three components: the acid-soluble fraction, the "fines" (i.e. pigment, clay or cement residue), and the aggregate or sand fraction. Separation was accomplished via wet-chemical techniques. The acid-soluble fraction was removed by digestion with 3M hydrochloric acid. Levigation and filtration were then used to separate the fines from the aggregate (sand). Percent weights were calculated for further assessment. The color of the fines was matched to the Munsell Soil Color Chart. Predominating colors and shapes of sand grains were noted during examination of the aggregate fractions.

RESULTS OF ANALYSIS:

HBM-01 - 1860s Brick Pavers Mortar

The sample was grayish brown (Munsell 10YR 5/2) in color. The mortar was moderately difficult to crush. Small quantities of calcium carbonate were visible in the pores of the freshly broken sample, but under microscopic examination, these particles do not appear to be lime blebs.

Components of Paver Mortar:

Acid soluble fraction –32.90% of the total sample weight. A 3M solution of hydrochloric acid was added to the crushed portion of the sample, which produced a vigorous and sustained reaction.

"**Fines**" – 13.96% of the total sample weight. The "fines" were pale brown in color (Munsell 10YR 6/3).

Aggregate – 53.13% of the total sample weight. Colors of individual grains are red, brown, black, pink, white, gray and clear. Aggregate was well sorted with grains ranging from fine to very coarse sand with some larger granules.

HBM-02 - Exterior Stone

The sample was light gray (Munsell 10YR 7/2) in color, though heavily weathered. The mortar was soft and easily crushed.

Components of Exterior Stone Mortar:

Acid soluble fraction –62.56% of the total sample weight. A 3M solution of hydrochloric acid was added to the crushed portion of the sample, which produced a vigorous and sustained reaction.

"**Fines**" – 13.70% of the total sample weight. The "fines" were light brownish gray in color (Munsell 2.5Y 6/2).

Aggregate – 23.74% of the total sample weight. Colors of individual grains are white, clear, cream, gray, black, and brown. Aggregate was well sorted with grains ranging from fine to coarse sand.

HBM-03 - Exterior Stone

The sample was light brownish gray (Munsell 10YR 6/2) in color. The mortar was moderately difficult to crush. Small quantities of calcium carbonate were visible in the pores of the freshly broken sample, but under microscopic examination, these particles do not appear to be lime blebs.

Components of Exterior Stone Mortar:

Acid soluble fraction – 18.01% of the total sample weight. A 3M solution of hydrochloric acid was added to the crushed portion of the sample, which produced a vigorous and sustained reaction.

"**Fines**" – 11.01% of the total sample weight. The "fines" were light brownish gray in color (Munsell 10YR 6/2).

Aggregate – 70.98% of the total sample weight. Colors of individual grains are red, brown, black, pink, white, gray and clear. Aggregate was well sorted with grains ranging from fine to coarse pebbles. The larger aggregate pieces were concentrated close to the surface.

HBM-04 - Interior Stone – Niche 4

The sample was very pale brown (Munsell 10YR 7/3) in color. The mortar was moderately difficult to crush.

Components of Interior Stone Mortar:

Acid soluble fraction –22.43% of the total sample weight. A 3M solution of hydrochloric acid was added to the crushed portion of the sample, which produced a vigorous and sustained reaction.

"**Fines**" – 6.45% of the total sample weight. The "fines" were pale brown in color (Munsell 10YR 6/3).

Aggregate – 71.12% of the total sample weight. Colors of individual grains are red, brown, black, pink, white, gray and clear. Aggregate was well sorted with grains ranging from fine to coarse pebbles. The larger aggregate pieces were concentrated close to the surface.

HBM-05 - Interior Brick – Niche 4

The sample was very pale brown (Munsell 10YR 7/3) in color. The mortar was moderately difficult to crush.

Components of Interior Brick Mortar:

Acid soluble fraction –12.72% of the total sample weight. A 3M solution of hydrochloric acid was added to the crushed portion of the sample, which produced a vigorous and sustained reaction.

"**Fines**" – 10.57% of the total sample weight. The "fines" were light yellowish brown in color (Munsell 10YR 6/4).

Aggregate – 76.71% of the total sample weight. Colors of individual grains are red, brown, black, pink, white, gray and clear. Aggregate was well sorted with grains ranging from fine to coarse pebbles. The larger aggregate pieces were concentrated close to the surface.

CONCLUSIONS

Despite some slight variations between the samples, there appears to have been one mortar used for the entirety of the High Bridge. There is some variation in the color of the mortars which may be attributed to workmanship, prolonged exposure and natural weathering, as well as the visible residue of calcium carbonate and calcium hydroxide in the freshly broken samples. These residues are consistent with the findings of the Testwell Laboratories report of 2006. The original mortars are consistent with the characteristics of natural cement mortars. Based on historic evidence that Rosendale natural cement was used in the construction of the High Bridge, a Rosendale cement mortar is recommended rather than a Portland cement-lime mortar.

DESCRIPTION AND HISTORY OF NATURAL CEMENT

Natural cements are produced from limestone that contains a high content of clay minerals. The limestone is broken into pieces and calcined below the sintering point, and the burnt cement is then ground into powder and packaged for sale.[1] Natural cement was first commercially available in the United States in 1818. It was originally produced in Chittenango, New York (near Syracuse) and was one of the materials used to construct the Erie Canal. A large, high quality deposit of natural cement was found around Rosendale, New York in 1825 during excavation for the Delaware and Hudson Canal. This cement was praised for its high strength and its proximity to transportation to New York City.

By 1905, natural cement was available from fifty-eight lime works in sixteen states. New York State was the largest supplier of natural cement in the United States.[2] As early as 1900, however, production of natural cements had decreased due in large part to increased production of Portland cement.

Natural cement was used on masonry buildings and engineering works which required great strength, were exposed to moisture, and where the mortar was required to set under water. According to Harley J. McKee, natural cement "was rarely used except for buildings of the finest construction."[3] Natural cement shrinks in the presence of moisture. Over the years, researchers and masons discovered that the optimal proportion of natural cement mortar was 1 part binder to two parts aggregate.[4] Compared to Portland cement, Rosendale cement "weighs about two thirds as much…, sets in one tenth of the time, and attains to about half the ultimate strength of the Portland."[5] Rosendale cement contains one third magnesium silicate,[6] which is typically higher than other natural cements.

[1] ASTM Standard C219-07a, "Standard Terminology Relating to Hydraulic Cement," (West Conshohocken, PA: ASTM International, 2007), 2.
[2] Harley J. McKee, *Introduction to Early American Masonry: Stone, Brick, Mortar and Plaster* (Washington, D.C.: National Trust for Historic Preservation, 1973), 68.
[3] McKee, 68.
[4] Paul J. Krumnacher, "Lime and Cement Technology: Transition from Traditional to Standardized Treatment Methods" (MS Thesis, Virginia Polytechnic Institute, 2001), 50-51.
[5] Ira O. Baker, *A Treatise on Masonry Construction* (New York: John Wiley & Sons, 1896), 52.
[6] Frances Marion Platt, *A History of Binnewater in the Cement Mining Times* (Rosendale, NY: Women's Studio Workshop, 2003), 8.

REPLICATION RECOMMENDATIONS

The recommendations below represent an effort to approximate the properties of the mortars using modern materials. The historic mortars were prepared without standards and, as such, cannot be easily categorized using modern ASTM standard mixes. Conversations with Michael Edison of Edison Coatings, a supplier of Rosendale Natural Cement, indicated that standard mixes using Rosendale Cement typically fall between a 1:1 and 1:3 ratio of Natural Cement to aggregate. Based on the aggregate content of the samples, a 1:3 ratio was selected for the replication of the High Bridge mortars as it most closely approximates the historic mortar composition. Aggregate was sieved in order to achieve an aggregate size that matches the aggregate found in the historic mortar. Consideration was given to matching the color, texture, and strength of the sample.

All mortar joints should be fully raked to a depth of ¾ inches to 1 inch, and the units should be pointed to the same depth.

Mortar Mix

1 part Natural Cement (ASTM C10) to be composed of:
1 part Rosendale Natural Cement, 10C upper

3 parts aggregate **passing through a #16 sieve** to be composed of:
2 parts Schofield “125”
1 parts Schofield “219”

NOTE: All parts should be measured by volume (not by weight). Dry ingredients should be well blended before the addition of water. The enclosed samples are made from the above-recommended mixes. Note that the enclosed samples have been etched to simulate the effect that natural weathering (erosion of binder, exposure of aggregate) will have on the appearance of the pointing over the next few years.

RECOMMENDED MATERIALS AND SUPPLIERS

As accurate replication mixes are difficult to formulate, the type and quantity of materials used are essential to ensure on-site reproduction. Materials recommended in this report or their equal may be used. If materials are substituted, resulting appearance of mortar may vary.

Sands Used by JBC to Replicate Original Aggregate:

As the selection of an appropriate aggregate is critical to the formulation of any replication mortar, the sand fraction isolated during analysis was compared to a library of sands commercially available in the greater New York area. Aggregate samples have been enclosed to facilitate substitutions with locally available sands.

Schofield
"125" - described as a variably sized tan sand, with a moderate amount of dark grains.
"219" – described as a variably sized, sub-angular to sub-rounded red-brown sand with lighter colored pebbles.
Available from George Schofield Co., Inc., P.O. Box 110, Bound Brook, NJ 08805 (732) 356-0858

Recommended Cement:

Rosendale Natural Cement, 10C upper
Available from Edison Coatings, 3 Northwest Drive, Plainville, CT 06062 (800) 341-6621, or substitute equal

PROMENADE PAVING BRICK COATING ANALYSIS

The promenade of the High Bridge is covered with paving brick. While a great deal of this brick is new, there is a significant portion that is old and assumed to be original to the promenade dating to the 1860's. The older brick has a black surface appearance. As it was not uncommon to coat brick in the mid 1800's, it was decided to try and test the brick to see if the black material was a coating.

The brick was examined under a stereomicroscope as well as chemically analyzed using Fourier Transform Infrared Spectroscopy (FTIR). The magnified stereomicroscope examination was inconclusive. While there is a black layer in the surface of the brick, there was no layering of coating materials visible. Orion Analytical performed the FTIR analysis. This technique uses a materials transmittance and reflectance of the infrared rays at different frequencies to plot a spectral pattern that is analyzed and matched to known signatures of materials in an FTIR library.

The comparison of the FTIR spectrum of the brick with reference spectra for a variety of asphaltic and bituminous materials did not point to a match. This means that the material on the brick is not an asphaltic or bituminous material. The spectra did indicate that the black layer on the brick is a complex mixture of materials. As this brick was used as a horizontal exterior surface, it is to be expected that a great deal of material has been deposited on the brick over time. Also, the surface has undergone 150 years of weathering as well as soiling.

Further testing would have to be undertaken to try to more completely identify the coating. This analysis would include additional chemical and elemental analysis using scanning electron microscopy (SEM). SEM produces imaging using an electron microscope which provides information about the surface topography of the sample and the electrical conductivity of the surface materials. However, this further testing may not provide conclusive information.

Should there be a desire to remove the black material from the brick, it will be extremely difficult. JBC tested 12 products in the laboratory to find a class of product that would remove the black material. The strippers tested included highly alkaline products, neutral pH products and acid based strippers. None of the products were successful.

FINISH COLOR INVESTIGATION

INTRODUCTION

A selective paint color investigation of historic interior and exterior elements at the High Bridge located in The Bronx and Manhattan, NY was performed by Jablonski Building Conservation. Conservator Jennifer Kearney took 17 samples from elements on the bridge and within the aqueduct.

FINISH COLOR INVESTIGATION METHODOLOGY

Samples measuring approximately three to six millimeters in length were removed from the identified areas using a scalpel for further examination. A minimum of three paint chip samples were taken from each element. In most cases, *in situ* cratering and close-up examination of the surfaces was performed to quickly determine the status (degree of surviving original paints) and complexity of the finishes before sample collection.

The samples were mounted in clear resin, cut and polished to reveal fresh cross-sections. Each sample was examined in normal reflected light, under illumination conditions that simulate daylight (fiber optic illuminator) for the purpose of color-corrected stratigraphy identification. The samples were examined microscopically during the investigation using a Nikon Stereo Zoom microscope with 10X-63X power.

All layers have been recorded using a descriptive color name rather than a standardized color notation system. This was done to document the seriation of the samples for comparative purposes prior to the identification of early layers using both a standardized universal color system (Munsell) and commercial paint color systems (Sherwin-Williams).

Each paint layer was identified as a primer or a finish coat. While primers did not usually affect the color of the finish coat, they were important for the opacity and richness of the finish.

The sheen of each layer was identified during microscopic analysis. The sheen match was based on a four-point scale ranging from the lowest amount of sheen (flat) to the highest surface sheen (glossy). Flat paint has no surface sheen when examined under the microscope. Semi-flat paint has some surface sheen and could be compared to modern eggshell or satin finishes. Semi-glossy paint has moderate surface sheen. Glossy paints are heavily oiled and glossy glazes are typically translucent.

Under illumination conditions that simulate natural daylight, the original finish layers were matched to a commercially available paint system. A chromochronology and photomicrograph of each sample is included in Appendix A of this report.

PAINT SAMPLE LOCATIONS
High Bridge

Sample #	Description
HBP-01	1850s wrought-iron railing outside Manhattan entrance
HBP-02	Cast-iron railing scrollwork near Bronx entrance (North elevation)
HBP-03	Cast-iron railing post – at missing arch ornament (North elevation)
HBP-04	Lamp post at Manhattan entrance (South elevation)
HBP-05	Cast-iron railing scrollwork near Manhattan entrance (South elevation)
HBP-06	Cast-iron railing near center of bridge – top rail (North elevation)
HBP-07	Lamp post at Bronx entrance (North elevation)
HBP-08	Cast-iron railing post – near missing brace (South elevation)
HBP-09	Cast-iron pipe – West end (in attic on Manhattan side)
HBP-10	Saddle for wrought-iron pipe – West end (in attic on Manhattan side)
HBP-11	Saddle for wrought-iron pipe – at pipe support 18
HBP-12	Wrought-iron Pipe – at pipe support 18
HBP-13	Pedestal for wrought-iron pipe – at pipe support 18
HBP-14	Saddle for wrought-iron pipe near spandrel beam (East side of arch)
HBP-15	Steel span beam below pipe (East side of arch)
HBP-16	Steel span bottom flange of spandrel beam (East side of arch)
HBP-17	Brick coating – Attic North wall at #53

FINDINGS

Paint finishes in the mid- to late-nineteenth century were generally prepared by on site and used hand-ground pigments. This method of preparation led to a wide variation in the consistency of the paints, especially with differences in pigment concentration and size. The finishes found on exterior elements of the High Bridge are far more consistent in appearance than paints from this period in general and visible pigment particles were not found for these layers. This information coupled with the relatively few finish layers found for these elements indicates that the majority of elements do not have finishes which predate the 1970 renovation. The finishes with the least variation were finishes on the walls and the pipes in the attic space, which are more likely to be original based on the lack of alteration to these elements.

Iron oxide pigments were cited in construction documents for use in the original finish paint colors. In an effort to identify these pigments, microchemical spot tests were used. The tests confirmed the presence of iron in the dark brown paint of the pipe elements, however this result is not conclusive because of the presence of ferrous dust from the attic space found throughout the samples. Polarized light microscopy was used to more specifically identify the pigment in the paint and confirmed the presence of the iron oxide pigments burnt umber, raw umber and yellow ochre. As a point of comparison, samples from the later exterior metal elements of the bridge were also tested for pigment identification and it was determined that the same iron oxide pigments were also found in the brown finish layers used on these elements. Iron oxide pigments are widely available and have been in constant use for hundreds of years and continue to be widely used in a variety of modern paints.

Exterior Finishes

Samples were taken from a range of elements on the exterior and interior of the High Bridge, including railings, lampposts, pipe supports and structural steel. The metal elements are known to date from different periods of alterations and therefore the original finishes for individual elements are not contemporaneous. In addition, many of the samples showed evidence of severe discoloration and weathering of the early finishes, as well as absence of initial primer layers. The reputed earliest extant element, the ca. 1850s railing on the Manhattan side of the bridge, shows far fewer layers than would be expected for an element of this age. The lack of both early primer and finish layers indicates that much of the metal work was stripped of finishes.

Despite the lack of early finishes, it appears that for most elements on the exterior, three principal colors were used as finishes throughout the history of the extant finishes: dark brown, black, and dark green. The majority of elements have a dark grayish reddish brown (between Munsell 10R 2/2 and 2.5YR 2/2) identified as the earliest finish. This finish was found on the scrollwork adjacent to the entrances on both the Manhattan and Bronx sides of the pedestrian walkway, on the railing, and the lamp posts. This finish had a semi-gloss sheen and was matched by Benjamin Moore 2838. It was nearly always followed by a black finish (Munsell N1) which was matched by Benjamin Moore 6989.



Finish
Exterior metalwork on pedestrian walkway
(railings, lampposts, scrollwork)

Sherwin-Williams
6989

Semi-gloss sheen

The steel arch span of the bridge was constructed in 1925 to make the river navigable by larger boats. Construction specifications indicate that the steel was primed with a minimum of two shop coats of red lead paint, the first of which was tinted with lampblack. A second layer of red lead primer would then be applied on site over any damaged surfaces prior to finishing. The finish coat is described as using white lead, burnt umber and Chinese blue pigment in linseed oil.[7] This appears to correspond with the first finish layer identified on the steel elements of the span, pale blue gray (Munsell 10BG 7/1) which was preceded by two primer layers of orange paint that may correspond with red lead primer described in the specifications, though no black pigment particles were visible in the layer. This finish had a semi-gloss sheen and was matched by Sherwin-Williams 2832. It should be noted that the finishes found as the initial layers on the other elements would not have been the visible finishes during the period that this pale blue gray was used on the span.



Finish
Steel Span Arch

Sherwin-Williams
2832

Semi-gloss sheen

Interior Finishes

Elements on the interior of the aqueduct were also finished with dark grayish reddish brown (between Munsell 10R 2/2 and 2.5YR 2/2). This finish was found on all the elements of the pipe and supports. The dark brown finish had a semi-gloss sheen and was matched by Sherwin-Williams 2838.



Finish
Interior metalwork

Sherwin-Williams
2838

Semi-gloss sheen

[7] New York City Dept of Plants and Structures, "For the Reconstruction of High Bridge" (New York, NY: 1925) 47.

The interior brick walls of the aqueduct were finished with whitewash. Three layers of this semi-flat white paint were identified (Munsell 10Y 9/1). Whitewash is a preparation of lime and water, occasionally with alum, salt, or other additives used for greater adhesion to wall surfaces. Calcimine paints are similar to whitewashes, though they contain a glue binder. Whitewash adhered well to masonry substrates, but was often too brittle for use on materials like wood which had a tendency to expand or contract with fluctuations in humidity. Whitewash was verified using microchemical spot tests which confirmed the reactivity of the paint to hydrochloric acid (which reacts with both whitewash and calcimine paints), but not water (which reacts with calcimine). The finish was most closely matched in color by Sherwin Williams 7009.[8]

Finish
Interior Brick walls

Sherwin-Williams
7009

Semi-flat sheen

[8] JBC was asked to comment on the possibility of a preparation of Castile Soap and water being applied to the walls of the attic prior to the application of an alum and water dilution as this treatment was cited in an 1870 report by the resident engineer of the Croton Aqueduct Board as being used for the gatehouse structures of the Croton Reservoir in Central Park. Castile Soap is an oil-based soap derived from olive oil. Soaps were occasionally used as a size for painting with calcimine and could be combined with alum which served as a hardener (Kelly, A. Ashmun. *The Expert Calciminer.* (Malvern, PA: Master Painter P, 1912) 17; 39. Additional testing with gas chromatography-mass spectrometry (GG-MS) which can identify the Castile Soap if present in large quantities, would be required to determine whether this treatment was used.

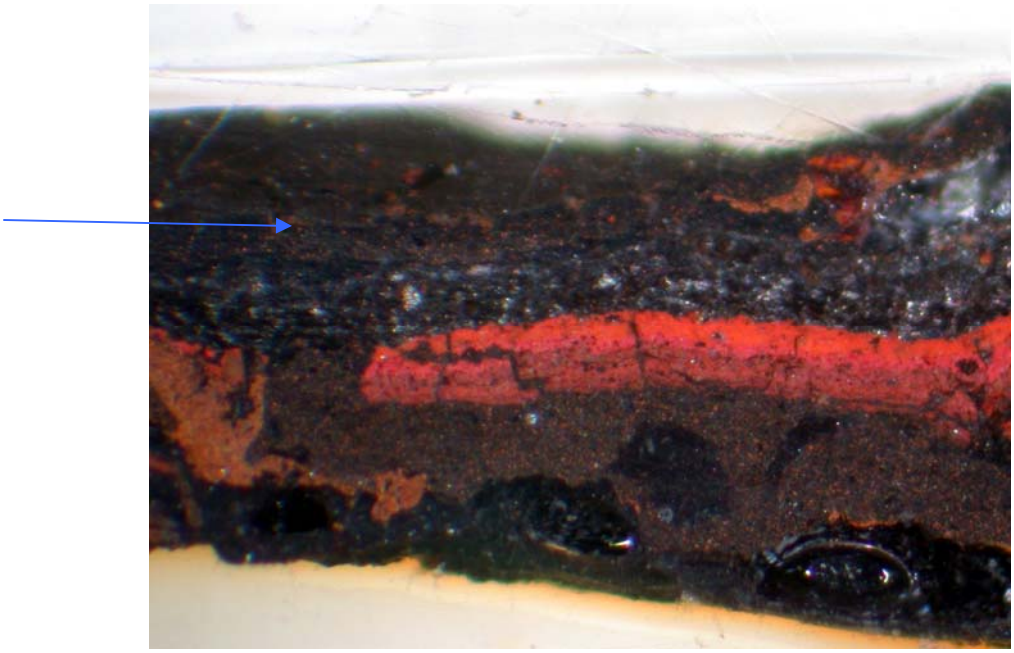
APPENDIX A

CHROMOCHRONOLOGIES

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-001
LOCATION: 1850s wrought-iron railing outside Manhattan entrance
SUBSTRATE: Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss		10R 2/2	SW 2838
2. black	Finish	Semi-gloss		N1	SW 6989
3. black	Finish	Semi-gloss			
4. black	Finish	Glossy			
5. red	Primer	Semi-gloss			
6. black	Finish	Semi-gloss			
7. brown	Finish	Semi-gloss			
8. black	Finish	Semi-gloss			
9. black	Finish	Semi-gloss			



Sample HB-01: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-002
LOCATION: Cast-iron railing scrollwork near Bronx entrance (North elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. red	Primer	Semi-gloss			
2. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigment	10R 2/2	SW 2838
3. orange	Primer	Semi-gloss			
4. black	Finish	Semi-gloss			
5. black	Finish	Glossy			
6. dark brown	Finish	Semi-gloss			
7. graphite paint	Primer	Semi-gloss			
8. reddish brown	Finish	Semi-gloss			
9. white	Primer	Semi-gloss			
10. orange	Primer	Semi-gloss			
11. black	Finish	Semi-gloss			
12. black	Finish	Semi-gloss			

Note: Mounted sample cleaved in half between layers 4 and 5.



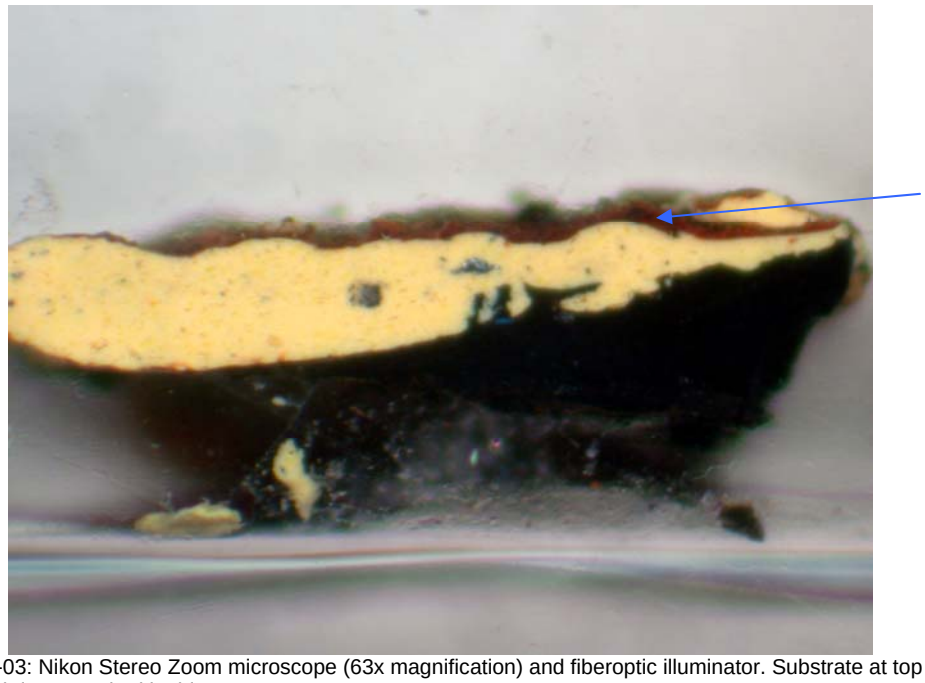
Sample HB-02: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow. Primer layer marked by green arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-003
LOCATION: Cast-iron railing post – at missing arch ornament (North elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark brown	Finish	Semi-gloss			
2. yellow	Primer	Semi-gloss			
3. black	Finish	Semi-gloss			
4. black	Finish	Semi-gloss			

Note: Earliest finish does not correspond to earliest finishes from similar elements. Dark brown layer is significantly later than other finishes.



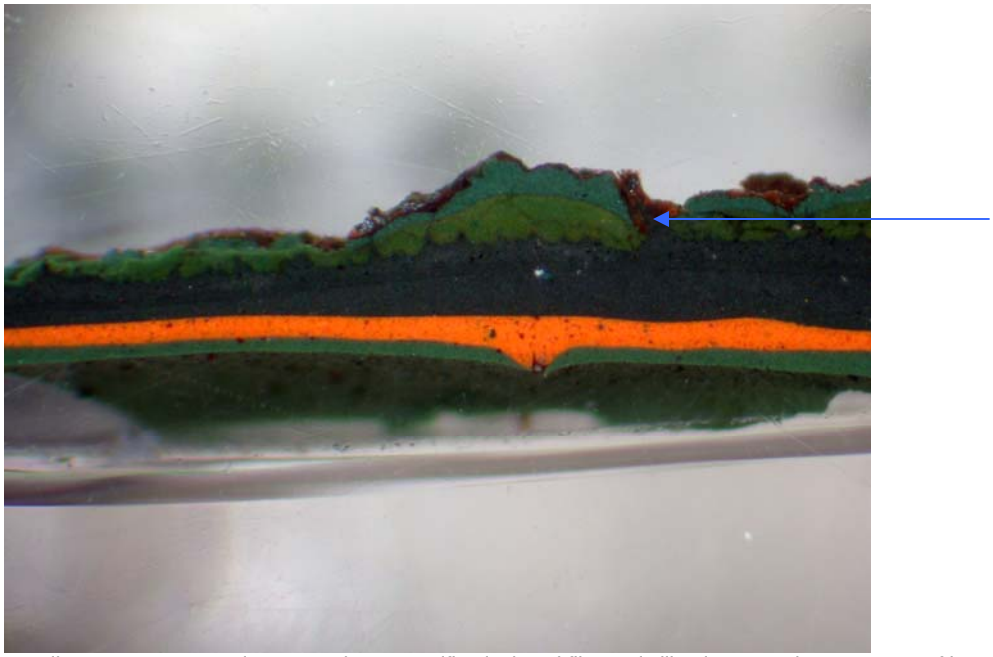
Sample HB-03: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-004
LOCATION: Lamp post at Manhattan entrance (South elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigment	10R 2/2	SW 2838
2. grayish brown	Finish	Semi-gloss			
3. grayish white	Finish	Semi-gloss			
4. grayish brown	Finish	Semi-gloss			
5. dark green	Finish	Semi-gloss			
6. dark green	Finish	Semi-gloss			
7. green	Finish	Semi-gloss			
8. blackish green	Finish	Semi-gloss			
9. blackish green	Finish	Semi-gloss			
10. orange	Primer	Semi-gloss			
11. dark green	Finish	Semi-gloss			

Note: No initial primers found.



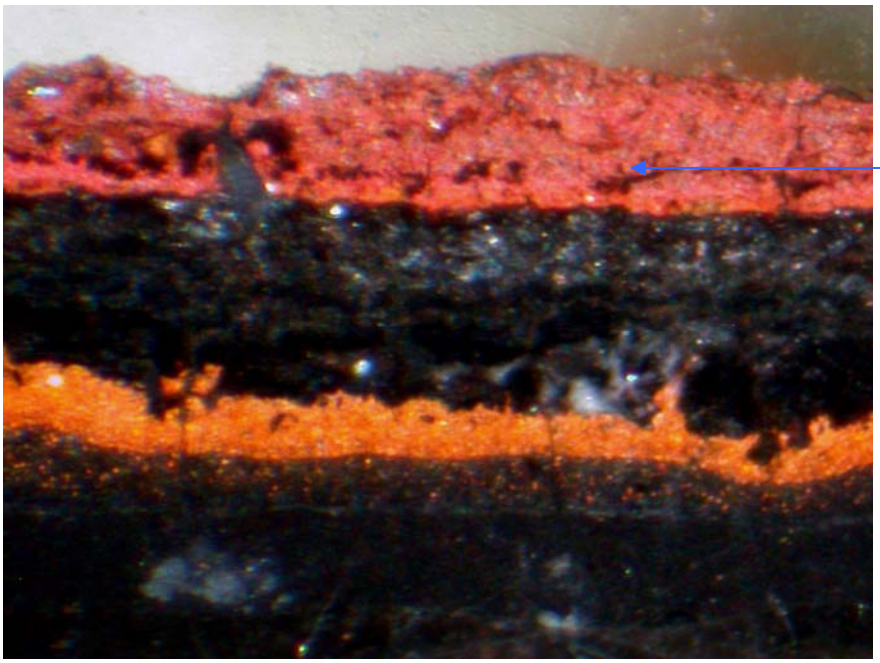
Sample HB-04: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-005
LOCATION: Cast-iron railing scrollwork near Manhattan entrance (South elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigment	2.5YR 2/2	SW 2838
2. black	Finish	Semi-gloss			
3. black	Primer	Glossy			
4. red brown	Finish	Semi-gloss			
5. red	Finish	Semi-gloss			
6. graphite paint	Primer	Semi-gloss			
7. black	Finish	Semi-gloss			
8. brown	Finish	Semi-gloss			
9. black	Finish	Semi-gloss			
10. black	Finish	Semi-gloss			
11. black	Finish	Semi-gloss			

Note: No initial primers found.



Sample HB-05: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-006
LOCATION: Cast-iron railing near center of bridge – top rail (North elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigment	2.5YR 2/2	SW 2838
2. dark brown	Finish	Glossy			
3. reddish orange	Primer	Semi-gloss			
4. black	Finish	Semi-gloss			
5. black	Finish	Semi-gloss			
6. brown	Finish	Semi-gloss			
7. black	Finish	Semi-gloss			
8. orange	Primer	Semi-gloss			
9. black	Finish	Semi-gloss			

Note: No initial primers found.



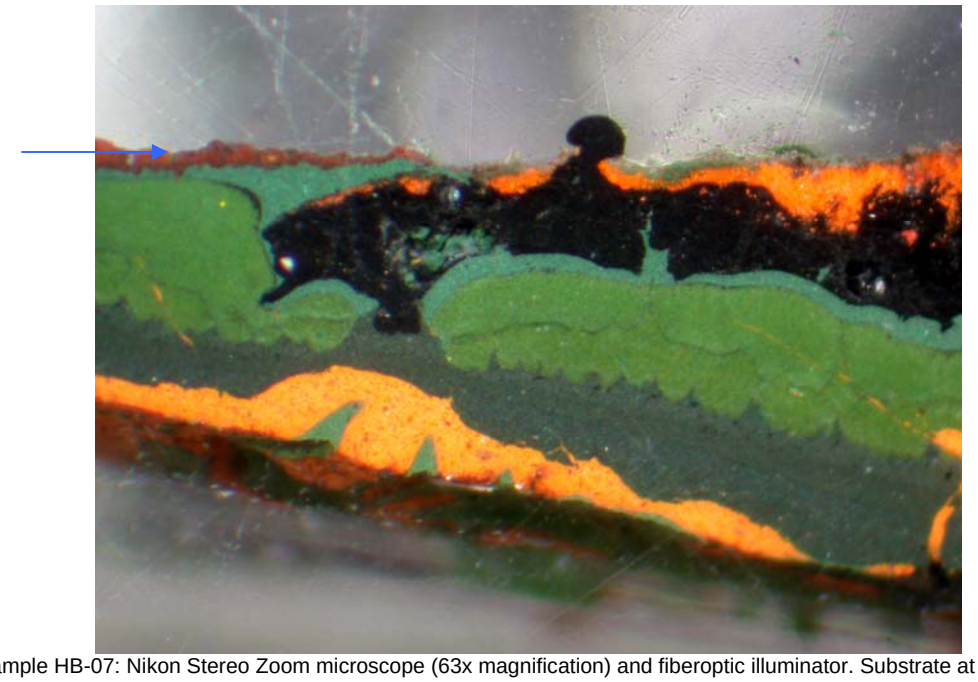
Sample HB-06: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-007
LOCATION: Lamp post at Bronx entrance (North elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. white	Finish	Semi-gloss			
2. grayish brown	Finish	Semi-gloss			
3. dark green	Finish	Semi-gloss			
4. orange	Primer	Semi-gloss			
5. dark green	Finish	Semi-gloss			
6. dark green	Finish	Semi-gloss			
7. green	Finish	Semi-gloss			
8. green	Finish	Semi-gloss			
9. blackish green	Finish	Semi-gloss			
10. blackish green	Finish	Semi-gloss			
11. blackish green	Finish	Semi-gloss			
12. blackish green	Finish	Semi-gloss			
13. orange	Primer	Semi-gloss			
14. dark green	Finish	Semi-gloss			

Note: No initial primers found; lower layers severely deteriorated. White is not original finish.



Sample HB-07: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-008
LOCATION: Cast-iron railing post – near missing brace (South elevation)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. black	Finish	Semi-gloss			
2. black	Finish	Semi-gloss			
3. black	Finish	Semi-gloss			

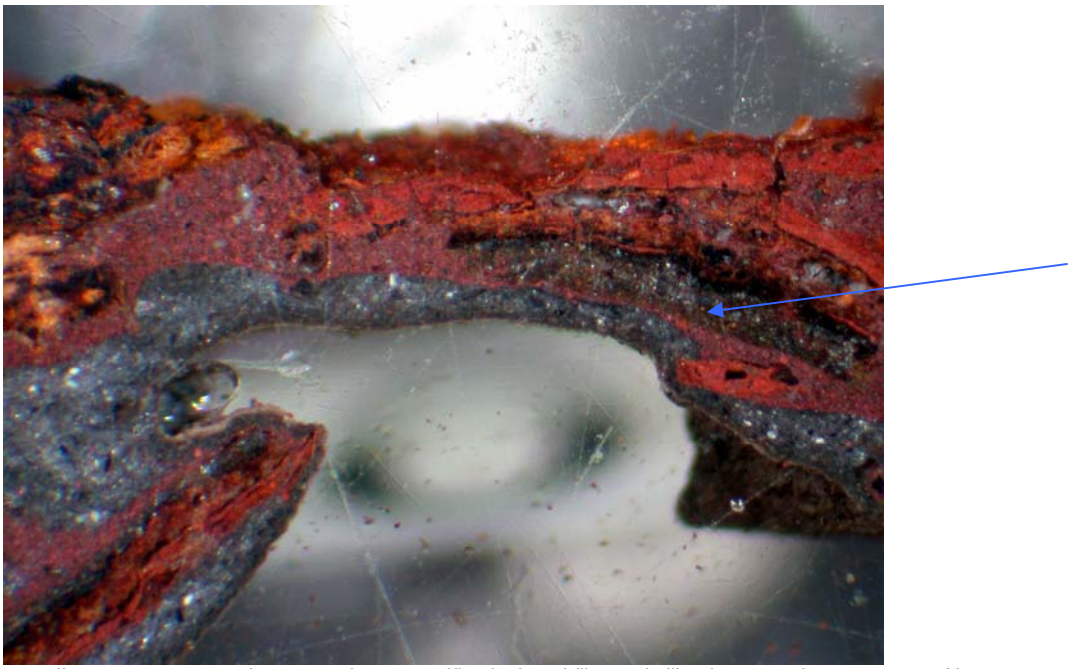
Note: Chronology is a composite of mounted and unmounted samples. Sample heavily deteriorated.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-009
LOCATION: Cast-iron pipe – West end (in attic on Manhattan side)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	10R 2/2	SW 2838
2. black	Finish	Semi-gloss			
3. orange	Primer	Semi-gloss			
4. dark brown	Finish	Semi-gloss			
5. black	Finish	Semi-gloss			
6. black	Finish	Semi-gloss			
7. black	Finish	Semi-gloss			
8. white	Finish	Semi-gloss			

Note: Sample substrate highly deteriorated. Finish layers are amorphous with corrosion product visible throughout. Chronology is a composite of mounted and unmounted samples. Upper layers only visible in unmounted sample.



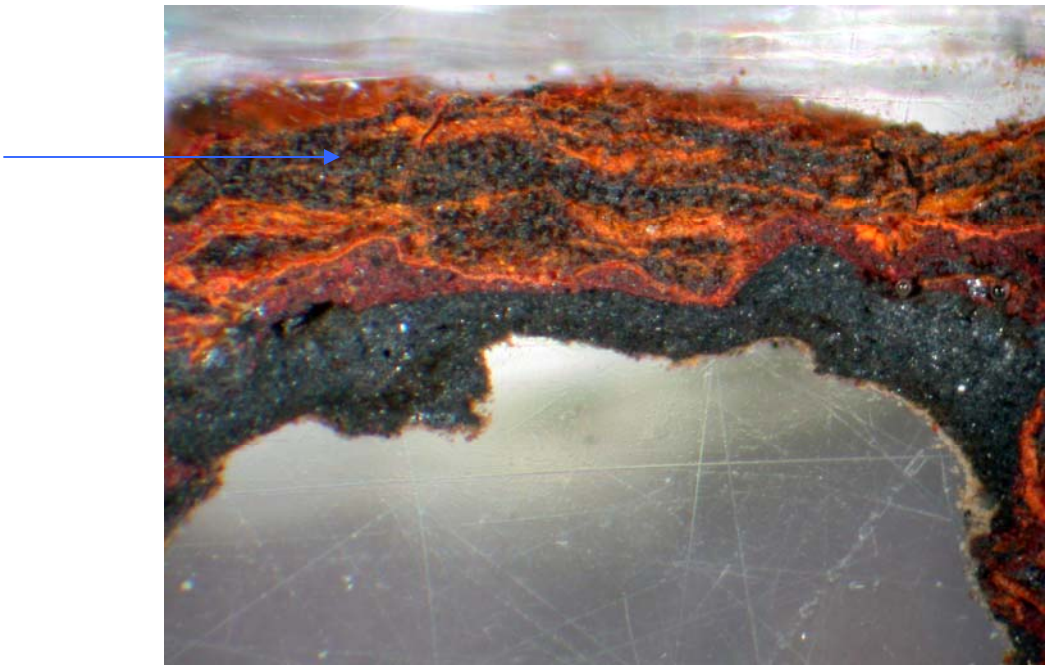
Sample HB-09: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image (iron has expanded due to corrosion). Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-010
LOCATION: Saddle for wrought-iron pipe – West end (in attic on Manhattan side)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
2. dark brown	Finish	Semi-gloss			
3. black	Finish	Glossy			
4. black	Finish	Semi-gloss			
5. dark brown	Finish	Semi-gloss			
6. dark brown	Finish	Semi-gloss			
7. orange	Finish	Semi-gloss			
8. black	Finish	Semi-gloss			
9. black	Finish	Semi-gloss			
10. black	Finish	Semi-gloss			

Note: Sample highly deteriorated; layers amorphous with corrosion product visible throughout.



Sample HB-10: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-011
LOCATION: Saddle for wrought-iron pipe – at pipe support 18
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. reddish brown	Primer	Semi-gloss	Iron oxide pigments		
2. reddish brown	Primer	Semi-gloss	Iron oxide pigments		
3. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
4. dark grayish reddish brown	Finish	Semi-gloss			
5. black	Finish	Semi-gloss			
6. reddish brown	Finish	Semi-gloss			
7. black	Finish	Semi-gloss			
8. dark brown	Finish	Semi-gloss			
9. dark brown	Finish	Semi-gloss			
10. black	Finish	Semi-gloss			
11. black	Finish	Semi-gloss			
12. black	Finish	Semi-gloss			



Sample HB-11: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow. Primer layers marked by green arrows. Note: Bleed-through of upper black layer between first two primer layers.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-012
LOCATION: Wrought-iron Pipe – at pipe support 18
SUBSTRATE: Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. yellow orange	Primer	Semi-gloss	Possible corrosion product		
2. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
3. black	Finish	Semi-gloss			
4. dark brown	Finish	Semi-gloss			
5. dark brown	Finish	Semi-gloss			
6. black	Finish	Semi-gloss			
7. black	Finish	Semi-gloss			

Note: Sample highly deteriorated; layers amorphous with corrosion product visible throughout.



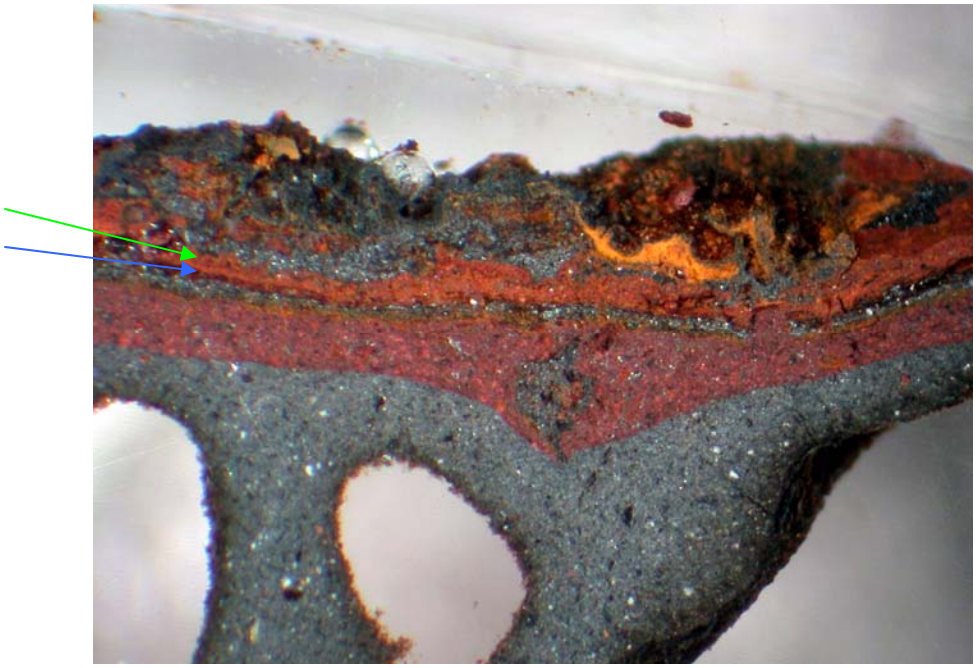
Sample HB-12: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow. Primer marked by green arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-013
LOCATION: Pedestal for wrought-iron pipe – at pipe support 18
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Primer	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
2. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
3. black	Finish	Semi-gloss			
4. dark reddish brown	Finish	Semi-gloss			
5. black	Finish	Semi-gloss			
6. dark brown	Finish	Semi-gloss			
7. dark brown	Finish	Semi-gloss			
8. black	Finish	Semi-gloss			
9. black	Finish	Semi-gloss			

Note: Sample highly deteriorated; layers amorphous with corrosion product visible throughout.



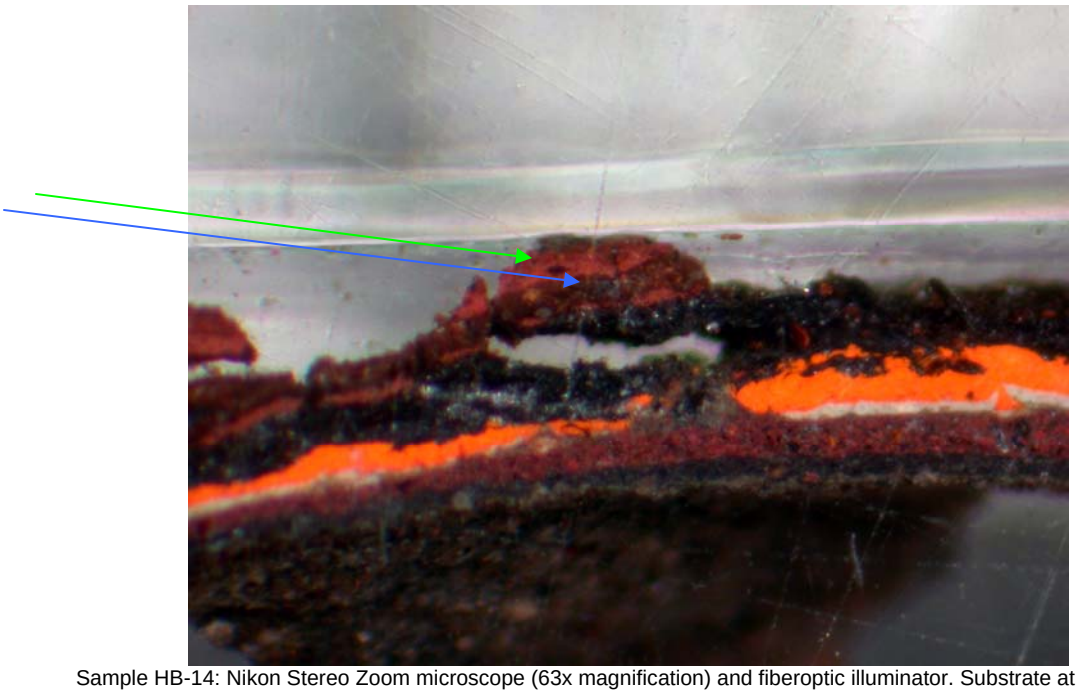
Sample HB-13: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-014
LOCATION: Saddle for wrought-iron pipe near spandrel beam (East side of arch)
SUBSTRATE: Cast Iron

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. dark grayish reddish brown	Primer	Semi-gloss	Iron oxide pigments		
2. dark grayish reddish brown	Finish	Semi-gloss	Iron oxide pigments	2.5YR 2/2	SW 2838
3. black	Finish	Semi-gloss			
4. dark brown	Finish	Semi-gloss			
5. black	Finish	Glossy			
6. orange	Primer	Semi-gloss			
7. grayish white	Finish	Semi-gloss			
8. dark brown	Finish	Semi-gloss			
9. dark brown	Finish	Semi-gloss			
10. black	Finish	Semi-gloss			
11. black	Finish	Semi-gloss			

Note: Isolated areas have two layers of white paint between layers 5 and 6.

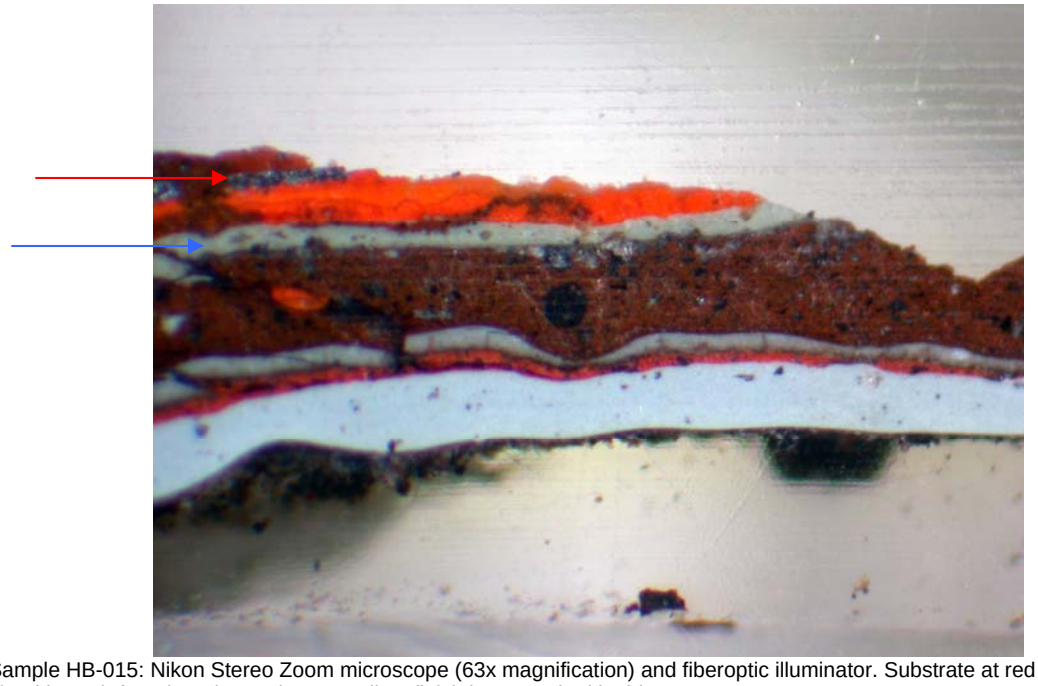


Sample HB-14: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at top of image. Earliest finish layer marked by blue arrow. Primer layer marked by green arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-015
HBP-016
LOCATION: Steel span beam below pipe (East side of arch)
Steel span bottom flange of spandrel beam (East side of arch)
SUBSTRATE: Steel

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. orange	Primer	Semi-gloss			
2. orange	Primer	Semi-gloss			
3. pale blue gray	Finish	Semi-gloss		10BG 7/1	SW2832
4. dark brown	Finish	Semi-gloss			
5. pale blue gray	Finish	Semi-gloss			
6. orange	Primer	Semi-gloss			
7. pale blue gray	Finish	Semi-gloss			

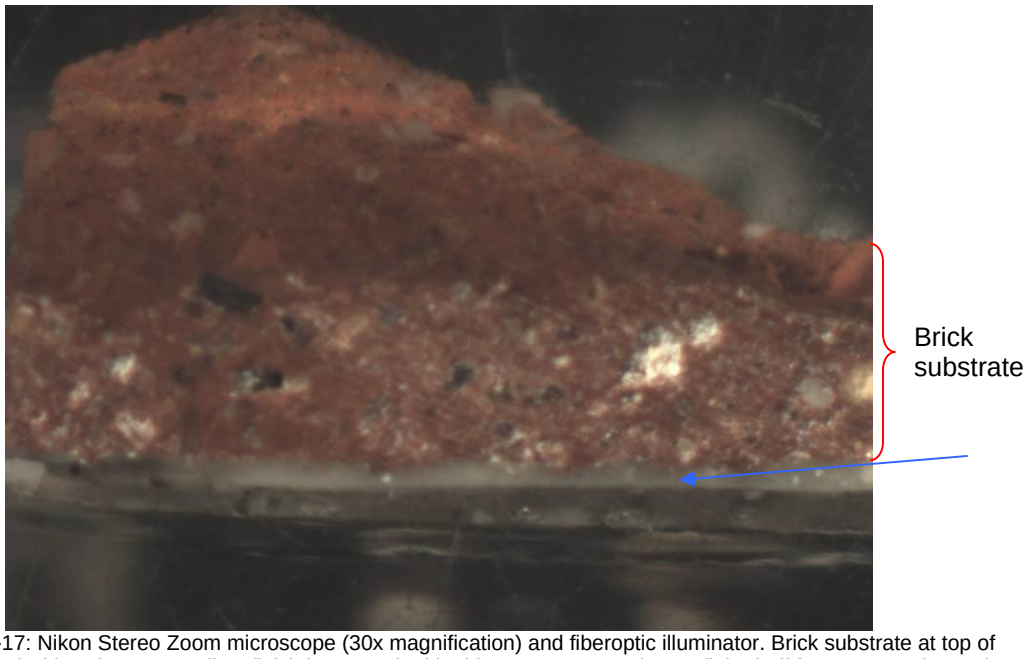


Sample HB-015: Nikon Stereo Zoom microscope (63x magnification) and fiberoptic illuminator. Substrate at red arrow, due to bleedthrough from later brown layer. Earliest finish layer marked by blue arrow.

PAINT CHROMOCHRONOLOGY AND COLOR MATCH

SAMPLE NUMBER: HBP-017
LOCATION: Brick coating – Attic North wall at #53
SUBSTRATE: Brick

Color	Coat	Sheen	Characterization	Munsell Match	Commercial Match
1. white	Finish	Semi-flat		10Y 9/1	SW 7009
2. white	Finish	Semi-flat			
3. white	Finish	Semi-flat			



Sample HB-17: Nikon Stereo Zoom microscope (30x magnification) and fiberoptic illuminator. Brick substrate at top of image marked with red arrow. Earliest finish layer marked by blue arrow. Upper layers flaked off from mounted sample.

JABLONSKI BUILDING CONSERVATION INC
ARCHITECTURAL CONSERVATORS

MEMORANDUM

To: Judith Saltzman
Li-Saltzman Architects

From: Jennifer Kearney
Jablonski Building Conservation, Inc.

Date: January 7, 2011

Re: High Bridge – Brick Paver Coating Removal

On December 10, 2010, a cleaning test program was performed on one paver brick. The goal of the testing was to determine if any cleaning product could be found that would remove the surface soiling or coating from the brick.

In an effort to remove the coating from the paving bricks of the High Bridge, a range of paint and mastic removers were tested on the brick surface. These products included solvent-based, alkaline and acidic paint removers from a variety of manufacturers. The sample brick was divided into test sections using blue painter's tape. Each test section was numbered and the brick was photographed (Image 1)

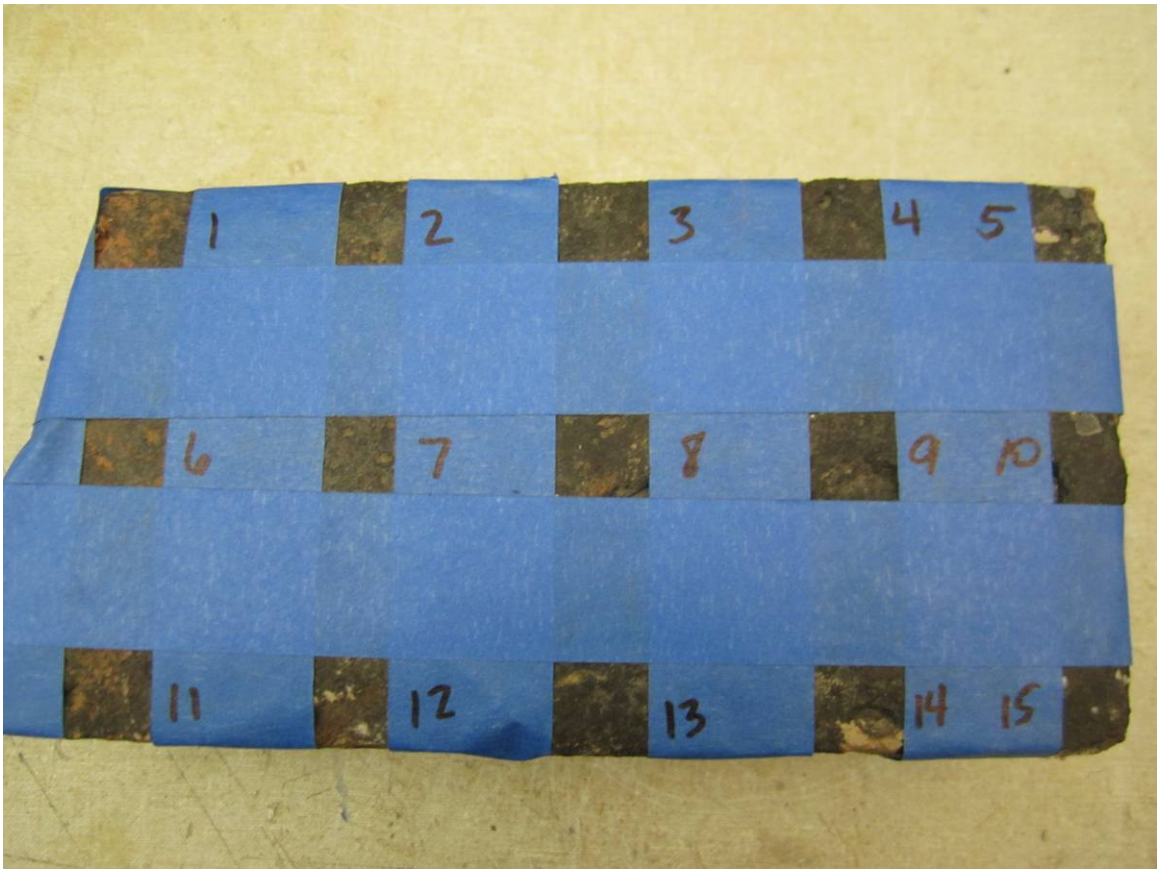


Image 1: Sample brick before cleaning

40 WEST 27 TH STREET SUITE 1201 NYC 10001 TEL 212.532.7775 FAX 212.532.2188

The following chemicals were applied and allowed to dwell according to the manufacturers' recommendations:

1. Prosoco HD Paint Stripper
2. Prosoco EK SafStrip
3. Prosoco SafStrip 8
4. Franmar Chemicals Beanedoo
5. Franmar Chemicals Soy Gel
6. Cathedral Stone S-303
7. Shorebest 2220 Safe Strip
8. Prosoco Fast Acting Stripper
9. Zip Strip Professional
10. Zip Strip Industrial
11. Dumond Peel Away 1
12. Dumond Peel Away 7

The dwell times ranged from 15 minutes to 24 hours. The brick was then rinsed with clean water and scrubbed with stiff nylon bristle brushes to remove all residue. The brick was rinsed to a neutral pH and, if necessary according to the manufacturer's recommendations, a neutralizer was applied. The brick was allowed to dry and then photographed (Image 2).

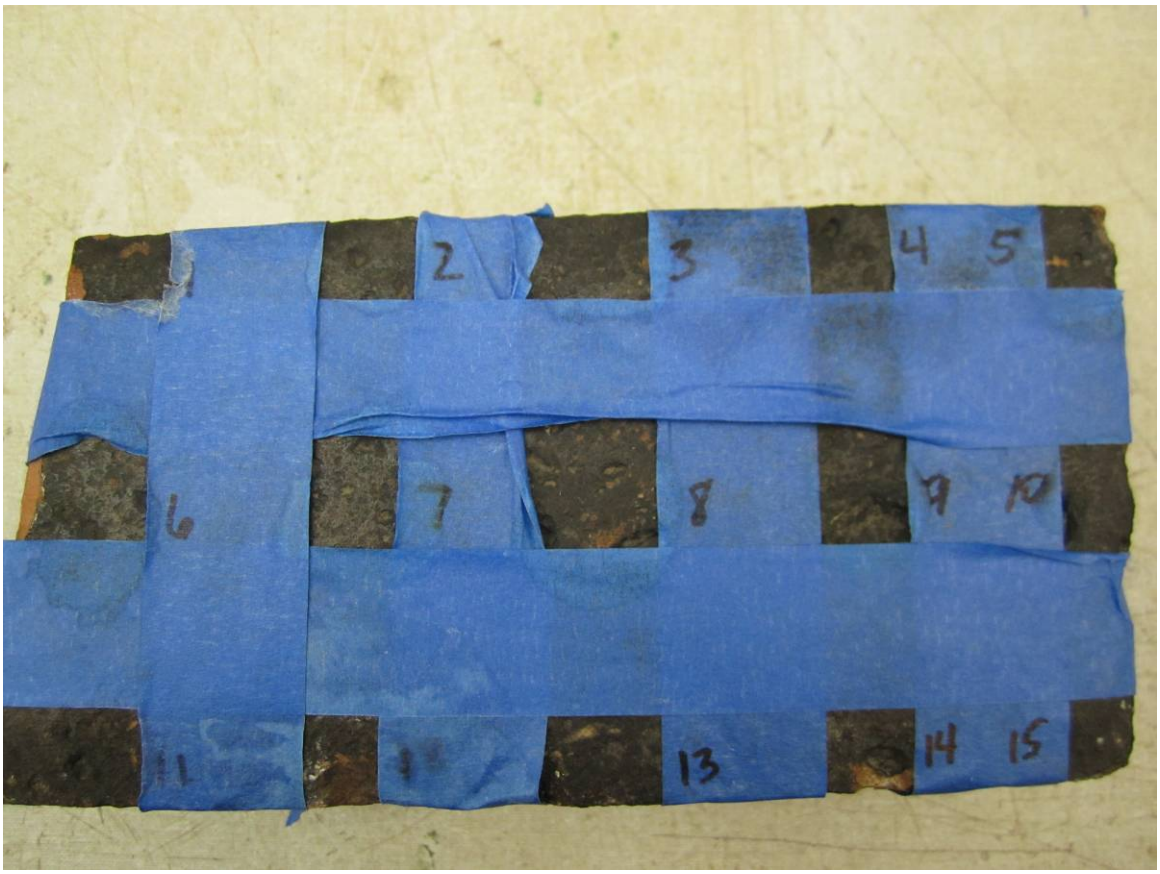


Image 2: Sample brick following cleaning

Findings

The test cleaned areas on the brick showed no improvement in terms of coating removal or disintegration of the surface material for any of the applied products.

CONSERVATION SOLUTIONS INCORPORATED TM

CONSERVATION ASSESSMENT
of
SELECTED HISTORIC IRON ELEMENTS
of the
HIGH BRIDGE, NEW YORK, NY



Prepared for:

LI-SALTZMAN ARCHITECTS, PC
62 White Street
4th floor
New York, New York 10013
212 941 1838 x215
212 941 1834 fax
917.698.1314

Prepared by:

Justine Posluszny Bello, Conservator/Project Manager
Conservation Solutions, Inc.
(301) 758-9688 cell
justine.bello@conservationsolution.com

November 2010

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

INTRODUCTION

On Thursday, August 26, 2010, CSI Conservator/Project Manager Justine Posluszny Bello performed a brief site visit and condition assessment of selected elements of the circa 1860 wrought iron pipe and cast iron elements within the attic of the High Bridge, over the Harlem River between Manhattan and the Bronx. The goals of this general assessment were to determine the best means of studying the materials of its construction, present conditions, the likely causes of any observed deterioration and likely means of remediating or reversing that deterioration. More specifically, CSI was looking primarily at indications of material failure rather than structural failure, which will be documented by the engineer. This report follows and expands upon our preliminary memo, submitted on August 30. This report also incorporates information gleaned from the report, *Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report* prepared by Robert Gordon and Colin Thomas, October 2010. The weather was clear, moderately sunny, and warm over the course of the site visit, with air temperatures ranging from approximately 75-82 °F.

OBSERVATIONS

Siting and Environment

Observations concerning the structure and environment include the following:

- The attic spaces around the pipe are generally warm and humid spaces. On the day of the site visit, the Conservator measured temperature and relatively humidity at fixed intervals of one every five supports along the length of the attic, from support #65 to the Bronx end of the attic. Air temperature and relative humidity of the space were measured using a portable thermo-hygrometer. Surface temperature of the pipe was measured using a laser thermometer, consistently aimed first at the "6:00" location on the pipe, then the "9:00" location. Moving towards the end of the attic, readings demonstrated the following:
    - Air temperature began at 84.6°F at support #65, rose and peaked at 88°F at #45, and then decreased steadily to 81.9°F at the end of the attic.
    - Relatively humidity rose fairly steadily from 54% to 75%, from support #65 to the end of the attic
    - Surface temperature of the 6:00 position tended to be approximately 0.5 to 1.0 degrees higher than that at the 9:00 position. The temperature began at 73.5°F and 72.5°F (respectively) at support #65, rose and peaked at 77°F and 76.5°F (respectively) at support #25, and returned back to 75°F and 74.5°F (respectively) at the end of the attic (See Appendix A, Sample and Testing Locations)
- We suspect that the farthest ends remain damp and never fully dry. Obvious sources of moisture include both active overhead leaks (which allow the penetration of rainwater that is probably acidic due to contaminated city air); moisture absorbed through the brick masonry; and moisture contributed by moist air, introduced through the open-air, 1928 steel span segment. The inconsistent and continually variable nature of this semi-contained, semi-exposed micro-climate creates a fundamentally unstable environment. Rather than ever achieving any sort of stasis or equilibrium, the elements are subjected to cyclical pe-

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

riods of wetting, drying, warming, and cooling. Tangent to this, we concur with the metallographer's finding that episodic exposure would inhibit the formation of protective layers of corrosion product.

- Furthermore, the tie rods, which span the space at intervals of 5 feet on-center, appear to be primary points of overhead condensation, which in turn generate directed dripping onto the pipe. This repeated and concentrated exposure appears to be correlated with areas of accelerated deterioration and loss on the upper surfaces of the pipe.
- The portion of the pipe that is partially exposed through the 1928 steel span exhibits deterioration which differs from that seen within the attic spaces. This includes greater incidence of surface pitting rather than flaking, and the accumulation of significant calcite runs attributable to leaks in the masonry surface overhead, as well as the collection of bird guano, which should be considered a health hazard in and of itself.

Wrought Iron Pipe

Observations on the condition of the pipe include the following:

- Deterioration of both interior and exterior pipe surfaces is most obviously visible as widespread delamination of thin fragments and/or layers of iron, which become detached in flakes of varying sizes, suggesting a layered orientation and structure of the iron in this element. The metallographer observed in one sample of wrought plate that the pattern of deterioration seen also suggests that the rolling direction of the iron plate is perpendicular to the cylinder axis of the pipe; however, the orientation may vary in different location. The surfaces also exhibit pervasive blistering and dimpling.
- The interior and exterior surfaces of the pipe shed a significant amount of material through such flaking. This is most obviously illustrated by the thick accumulation of iron oxide flakes and particles, which has developed into piles 2-3 inches deep in areas, as well as the delaminated sheets of pipe that remain on the upper exterior surface.
- Material loss appears to be greatest on the upper half of the pipe—primarily on the exterior, but also on the interior surfaces—where there has been a significant reduction in pipe thickness, resulting in full voids and through–wall losses in numerous areas. The metallographic report suggests that residual tensile stress arising from bending the plate to the radius of the pipe could also contribute to rapid corrosion on the outer surfaces. The metal on the lower half of the pipe appears to be much more sound by comparison.
- Limited remnants of a paint coating were observed on the upper exterior surface of the pipe. It is our understanding that paint analysis undertaken by Jablonski Building Conservation, Inc., demonstrated that the wrought iron pipe had been coated with an iron oxide pigment paint, consistent with a product known as "Prince's Metallic Paint." Historic documentation circa 1860-61 reports that this protective pipe would have been applied to both interior and exterior surface of the pipe, although evidence of this paint on interior surfaces was not observed in the course of performing this scope.

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774



Significant accumulation of iron flakes on the lower surface within the pipe.



Typical exterior pipe surface exhibiting pervasive blistering and delamination.



Material loss on the upper half of the pipe is significant enough to have resulted in through-wall losses.



The upper half of the cylinder (seen above dashed line) was consistently damp along the length of the pipe.



Detail of obvious condensation on the exterior surface, found to be common along the length of the pipe.



Detail of exterior wrought iron surface within the 1928 span exhibiting less flaking and more surface pitting.

Conservation Solutions, Inc.
www.conservationsolution.com
Washington, DC Metro Office • Santa Fe, NM Office
Mail: 833 East Palace Ave, Santa Fe, NM 87501 **Email:** info@conservationsolution.com
Voice: (505) 983-1950 **Fax:** (866)843-1774

Cast Iron Elements

In addition to the wrought iron pipe, there are numerous cast iron elements within the High Bridge as well, namely the 116 pipe supports for the wrought iron pipe, as well as the remainders of the two original 36-inch cast iron pipes in the Manhattan end of the attic, circa 1840.



Typical condition of cast iron support, exhibiting partial loss of coatings and overall oxidation, but little loss of material.

Cast Iron Pipes

The majority of these pipes, made of ferritic grey cast iron, has been lost, and what little survives remains mostly in fragments. According to metallographic testing, a sample of this pipe demonstrated it contains type C graphite flakes that range up to about 0.4 mm long, and form a nearly continuous network through the microstructure. The iron has a high phosphorous content and a small amount of unconnected porosity. Corrosion has attacked the inside surface of the pipe to a depth of 0.6 to 0.7 mm. Although visual observations did not suggest aggressive corrosion, the sample tested demonstrated that the corrosive attack started as pits and developed inward along the path of the graphite flakes, resulting in deeper penetration than visual observations might belie.

Cast Iron Support Saddles

The supports and saddles were determined to be made of pearlitic grey cast iron with a moderate phosphorus content, a material that is typically less susceptible to destructive corrosion than wrought iron, and the conditions at this site are consistent with this. The surface is oxidized overall, but exhibits less visible corrosion-related loss of material. Damage to cast iron is much more likely to be found in the form of breaking or fracturing—again, consistent with the conditions seen here. The cast iron supports show evidence of prior paint coatings, the remnants of which are poorly bonded and are most likely lead-bearing. It is our understanding that paint analysis undertaken by Jablonski Building Conservation, Inc., demonstrated that the cast iron saddles and supports were similarly coated with an iron oxide pigment paint, consistent with a product known as "Prince's Metallic Paint."



Detail of white haze on iron fragment sample NY-HIGHB-01. The haze substance has yet to be identified.

SAMPLING AND MATERIAL CHARACTERIZATION

Several samples were collected from the site and

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

taken back to our lab for preliminary characterization (See Appendix A, Sample and Testing Locations). All photomicrographs were taken using a Meiji stereo-zoom microscope at 30X magnification unless otherwise noted.

Salt Testing

Three samples were collected from both exterior and interior surfaces of the wrought iron pipe to test for the presence of soluble salts (chlorides, sulfates, nitrates). Samples were collected from a total of three representative locations using a Chlor*Rid CSN kit, a non-destructive method designed to collect surface samples from vertical metal surfaces. The tests are designed to be run in a specific order (chlorides, nitrates, sulfates) to further the useful life of a limited sample. Although this test has been designed for use on metal surfaces, common modifications to the recommended technique were employed to test on a brick substrate. The following general procedures were employed:

10 mL of Chlor*Rid extract solution is placed into the flexible membrane sock.

- The adhesive ring at the end of the membrane is affixed to the surface to be tested, ensuring as much air has been evacuated from the membrane as possible. Loose particles should be dusted from the surface to promote good adhesion, while taking care not to dislodge surface salts within the testing area.

- The membrane is inverted so that the collection solution comes in contact with the surface. However, brick presents a challenge in that unlike metal, it is porous, and may absorb some or all of the testing solution if it is in contact with the surface for the full 2 minutes recommended. To ensure that sufficient fluid is collected for testing, the membrane is massaged in such a way to provide repeated but intermittent contact between the solution and the surface over the specified time period.

After two minutes, the membrane is removed, the extract solution filtered and recaptured in the original vial. Ion readings were taken using three different instruments.

The levels of sulfates identified are negligible. The presence of sulfates is likely tied to air-

Sample Number	Location	Chlorides	Nitrates	Sulfates
CSN-01	Exterior wrought iron pipe surface, near support #59	None detected	None detected	1 ppm
CSN-02	Exterior wrought iron pipe surface, near support #71	None detected	None detected	15 ppm
CSN-03	Interior wrought iron pipe surface, near support #64	None detected	None detected	11 ppm

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

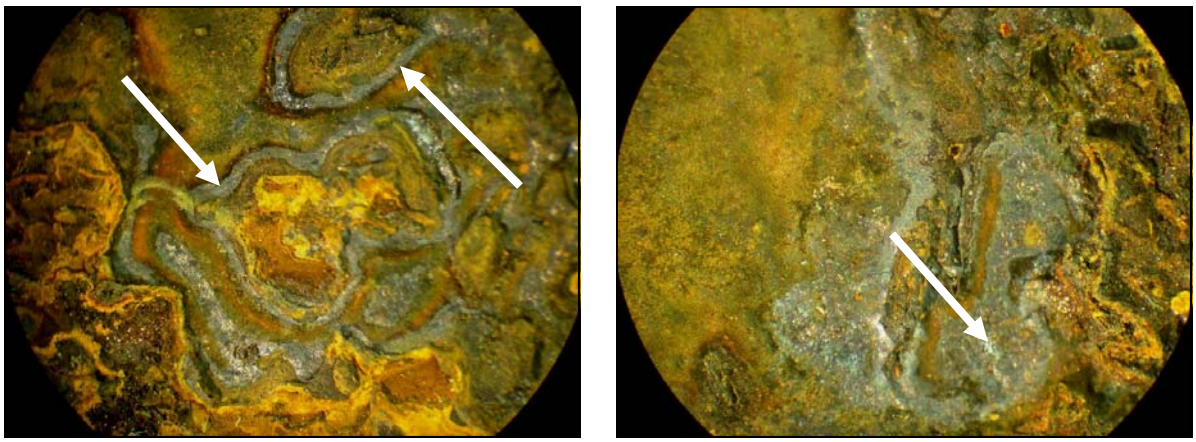
borne pollution, and at this low level, probably does not pose a danger to the artifact.

The wrought iron surface tested by CSN-01 exhibited a white surface haze, the appearance of which suggested a salt bloom. Because of this apparent condition, we collected an iron flake sample that included this haze. Microscopic examination of the sample showed that the white haze did not appear to be crystalline, as salts typically are; this was consistent with the testing, which indicated negligible salt presence. The area from which this sample was taken was extremely damp, and could reasonably be hospitable to mold growth. However, this was the only incidence of this surface condition observed during the survey, and there is no indication to explain why this condition would occur here and not elsewhere. At this time, the white haze remains unidentified.

Iron Sample Characterization

Several samples of iron flakes were collected from both exterior and interior surfaces of the wrought iron pipe for limited off-site observation regarding condition, material characterization, etc. Flakes were easily removed by hand, aided by a stainless steel scalpel from surfaces which were already delaminating; no mechanical or power tools were needed. Samples were typical of deteriorated iron surfaces observed at this site, and combined obvious red/orange iron oxide with a shiny, granulate black component as well. This suggests a high-carbon content steel, wherein the deterioration has led to the obvious differentiation between the iron component (red/orange iron oxide) and the carbon component (black, graphitic). The black seam described above was found to be magnetic, indicating that the material is magnetite, one of the possible corrosion products of wrought iron.

These observations were augmented by the metallographer, who added that large seams of slag or iron oxide probably resulted from the piling process used in fabrication of the metal during rolling. Both the presence of such inclusions, combined with foliate structure of the iron are



Photomicrographs of samples NYHIGHB-05 (left) and NYHIGHB-06 (right), illustrating red/orange iron oxide versus dark carbon content (arrows).

Conservation Solutions, Inc.
www.conservationsolution.com
Washington, DC Metro Office • Santa Fe, NM Office
Mail: 833 East Palace Ave, Santa Fe, NM 87501 **Email:** info@conservationsolution.com
Voice: (505) 983-1950 **Fax:** (866)843-1774

characteristics which would reduce the corrosion resistance of the metal. Specifically, where pitting of the iron surface has allowed moisture to access slag fibers contained in the iron, these fibers provide a direct pathway for moisture intrusion—and by extension, corrosion—throughout the matrix of the iron. The course of corrosion along these interconnected pathways results in the isolation of metal fragments, ultimately leading to entire encapsulation of the metal by the corrosion product, leading to the fragment flaking off.

Zinc Sample Characterization

A zinc-based bar (NYHIGHB_04) was also collected from the interior of the pipe. The bar was easily removed by hand; no mechanical or power tools were needed. The bar was one of a series located at a consistent height along the inner surface of the pipe, for approximately the first 40' length beginning at the far Manhattan end. The bar was covered in a layer or layers of whitish corrosion (salts). The bar was likely cast to fit the curvature of the pipe; microscopic examination of a fresh cross-section of the sample illustrates a highly consistent distribution of crystals, and lacks inclusions sometimes associated with the casting process (sand, etc).

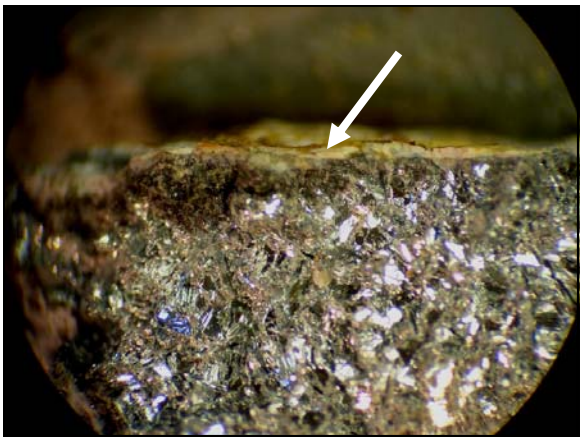
Historic documentation provided by LSA suggested that the zinc was installed circa 1866 as an attempt at galvanic protection, providing a sacrificial anode to deteriorate preferentially before the iron. Although this may have been the intent, we find no evidence that the quantity of zinc present was sufficient to offer any such protection to the iron. The metallographer suggested that the whitish corrosion observed was probably zinc salts formed by reaction of the water that flowed within the wrought iron pipe, the presence of which show that the zinc was not providing galvanic protection to the wrought iron pipe, and that a nearly continuous layer of zinc would have been needed to suppress corrosion of the pipe.

DISCUSSION

The testing performed by the metallographer confirms empirically much of what was observed qualitatively by the Conservator on-site. The most compelling findings, with the greatest rami-



Zinc "anodes" found in sequence along a portion of the pipe interior, near the Manhattan end.



Zinc fragment in cross section, which includes a layer(s) of corrosion (arrow).

Conservation Solutions, Inc.
www.conservationsolution.com
Washington, DC Metro Office • Santa Fe, NM Office
Mail: 833 East Palace Ave, Santa Fe, NM 87501 **Email:** info@conservationsolution.com
Voice: (505) 983-1950 **Fax:** (866)843-1774

fications of possible courses of action, are summarized below.

The testing found that the nature of the wrought iron is such that a variety of inclusions (slag or surface scale) have provided, and will continue to provide, an ample pathway for moisture and corrosion to enter and travel through the metal. The sample indicated that rather than being confined locally to an outer margin, the network is substantially interconnected and continuous through the iron matrix. This also suggests that the corrosion would be nearly impossible to arrest. The full extent of the progression cannot be known with certainty, and the depth to which corrosion has penetrated likely varies. However, despite visible corrosion, observations made on-site supplemented by testing performed by others supports the conclusion that a significant portion of sound metal remains, particularly on the lower half of the pipe.

The metallographer also underscored the relationship between the condition of the wrought iron pipe and the environment. Although the structure of the iron matrix certainly makes it a candidate for corrosion, the metallographer echoed our observations that the variable nature of the microclimates surrounding—as well as within—the pipe have generated varying conditions on the pipe. For example, there are distinct differences in the nature and extent of corrosion observed on the inside of the pipe as compared to the outside, as well as the upper half of the pipe as compared to the lower, which can in turn be traced to variations in environmental factors. We concur with the metallographer that cyclical, intermittent wetting and drying from leaks and condensation over the course of decades—as opposed to even constant submersion—has been one of the more detrimental forces acting upon the pipe.

PRELIMINARY TREATMENT RECOMMENDATIONS

General Considerations

We recommend that any planned treatment of the element itself be considered only after a thoughtful and realistic determination of the intended programming of the space (for example, the intended level of accessibility for purposes of maintenance, tourism, lifetime goals and expectations for this artifact, etc) as well as structural and architectural improvements to the space.

We also recommend that the debris which has accumulated within and atop the pipe should be cleaned up and removed, regardless of whatever avenue of treatment is pursued. We observed qualitatively that these piles of corrosion trap moisture, promoting high humidity levels and corrosion within the pipe. We also consider these piles to be an environmental and occupational concern due to the likely quantity of particulate lead paint dust and possibly other as-yet unidentified heavy metals mixed in with the corrosion, prompting the need for removal.

Treatment Considerations

The High Bridge wrought iron pipe has been subjected to deterioration over the past 150 years,

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

much of which appears to be largely related to the actions of an inhospitable and variable environment upon an iron matrix that is highly receptive to attack.

Consequently, we recommend that repairs and improvements to the surrounding structure be performed, as a means of fundamentally improving the environment in which the pipe is being housed. Repairs should focus on eliminating water infiltration through leaks or faults in the masonry construction, both in the attic spaces and the walkway over the span, as well as ensuring existing weeps and drains are sufficiently cleared and allowed to perform properly so that there are ample avenues for water to weep out of these spaces if it does find its way in. Efforts should also include reducing condensation and wetting time by the introduction of air movement from both ends of the attic. Overall, lowering relative humidity and dew point should be a goal. We believe architectural improvements of this sort are the most practical, both to design and implement, and are consistent with responsible custodianship of this structure as a whole.

Conservation treatment of the pipe itself would be significantly more challenging. Conventional treatments of an industrial ferrous element might typically call for the application of a high-performance coating, or the implementation of a cathodic protection system. However, treatments such as this would be more appropriate for an element with a different intended use, service life, or environment than that of this pipe.

We do not believe that traditional paint coatings are a viable treatment for the High Bridge pipe. Such coatings would necessitate a level of surface preparation that we think is not only infeasible, but would be largely destructive to this artifact. Paint coatings would also require a level of maintenance that we do not think is realistic for this artifact. Alternatively, vapor phase corrosion inhibitors (VpCI) could have some usefulness in these circumstances. Simply put, VpCI are volatile, corrosion inhibiting chemical compounds with inherent vapor pressures that allow them to vaporize, and subsequently be deposited on metallic surfaces. When an appropriate VpCI is used in conjunction with a compatible substrate, the VpCI form a relatively stable bond at the metal interface, producing a protective layer that limits penetration of corrosion to the underlying metal[1].

The advantage of VpCI is that they will find their way into difficult-to-reach areas that a traditional, dimensional paint coating could not enter, making them ideal for artifacts with complicated internal systems of tubes, pipes, large tank interiors, or other generally inaccessible areas. These products are often clear, and certain products require less surface preparation than traditional coatings. However, even protective films of this nature would require some level of cleaning and surface preparation which might not be feasible on this artifact. They also do require some cycle of renewal, which may not be practical given the restricted access to the artifact. A treatment of this nature represents a moderate to high level of on-going conservation intervention.

Please note, VpCI are an evolving and highly sophisticated technology, currently employed in a wide variety of fields ranging from metalworking and high performance coatings to electronics

Conservation Solutions, Inc.
www.conservationsolution.com
Washington, DC Metro Office • Santa Fe, NM Office
Mail: 833 East Palace Ave, Santa Fe, NM 87501 **Email:** info@conservationsolution.com
Voice: (505) 983-1950 **Fax:** (866)843-1774

manufacturing, packaging, and oil and gas industries. A major producer of VpCI is the Cortec Corporation, with US headquarters based in St. Paul, Minnesota. To serve such varied industries, they produce quite literally hundreds of products, found in forms such as powders, water-based solutions, gels, greases, wiping cloths, and countless others, to address the widely varying needs of different industries, circumstances, and substrates. If further interest in this avenue is pursued, we recommend consultation with a corrosion specialist associated with the production of VpCI to ensure the most current and appropriate products are specified for use in this location, the anticipated life-span, renewal/maintenance recommendations, etc.

Cathodic protection systems are sometimes employed to provide protection against corrosion of large metal elements, in which the element is encouraged to act as a cathode (protected against corrosion), either through the use of a sacrificial-anode cathodic protection system (SACP) or impressed current cathodic protection (ICCP) system. Unfortunately, these methods of electrochemical protection are not viable options for treatment of this artifact. In addition to being materially continuous, which the pipe is, a candidate for cathodic protection must also either be fully embedded (concrete, soil, other) or submerged (underwater). This is because material must be present around the artifact to act as an electrolyte, providing a pathway for the protective current to be transmitted to the element [2].

An alternative option may be a metallic coating, one which is higher on the galvanic series (more electronegative) than iron, and therefore more reactive. A traditional paint or clear coating primarily provides barrier protection by physically interrupting the ability of moisture to come in contact with the underlying iron. A metallic coating provides the additional benefit of offering galvanic protection in addition to barrier protection, whereby the more reactive metallic coating would be "sacrificial," deteriorating preferentially to iron, and thereby cathodically protecting the underlying metal.

Please note, however, that even a metallic coating would still necessitate a stringent level of surface preparation, a process which could end up eliminating a significant percentage of material. A treatment of this nature also represents a fairly high level of conservation intervention. If further interest in this avenue is pursued, we recommend consultation with a qualified electrochemical specialist with demonstrated experience in the treatment of significant historic elements. Such expertise is needed to accurately determine the practical feasibility of implementing this type of treatment in this location, the anticipated life-span, renewal/maintenance recommendations, cost implications, etc.

Treatment Recommendations

Ultimately, because of the extent to which the element has been corroded already, the significant quantity of material which stands to be lost in the requisite surface preparation, as well as the logistical challenges associated with implementing and maintaining these treatment, we recommend that efforts be focused on identifying and preserving a representative section of the pipe, rather than treating the entire element. This approach can be thought of as a way to highlight a "window" on to this unique heritage artifact. The presentation of a less aggressive con-

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

servation treatment as such offers continued opportunities for education and research, while promoting the preservation of this portion of the pipe. Indeed, being able to compare and contrast treated versus untreated pipe may present opportunities for promoting this intervention as a case study in preservation ethics, in and of itself.

Furthermore, treatment should focus on retaining and preserving the material present "as is", while not seeking to "restore" the pipe or attempting to reverse the corrosion sustained thus far. This would constitute a lower level of conservation intervention. We believe a reasonable approach to treatment would include the following:

- Cleaning and containment: the surface should be cleaned of loose rust, scale, dirt, oils, etc through the most effective means, which should be determined through cleaning tests. This may include the use of water-jetting. Through careful operation by highly trained technicians at appropriate pressures determined through initial cleaning tests, water-jetting results in highly controlled cleaning using remarkably little water. The authors and other conservators have extensively researched and demonstrated water-jetting as a viable method for removal of both existing coatings, loose corrosion and soluble salts without damage to the underlying metal. Effluent should be contained and removed from the site [3].
- The application of a rust converter: tannic acid-based product, such as Fertan, may be applied to the metal to remove and convert corrosion to provide a surface suitable for overcoating. Firmly bonded rust may be allowed to remain, and will be "converted" by the tannic acid. Additionally, the development of the rust conversion is actually aided by the surface being damp at the time of application as well as being followed by intermittent misting during the initial reaction process. Visually, this treatment would result in a blackening of the surface.
- Clear Coating: Following corrosion conversion, the element should be coated with a clear coating such as a wax and/or lacquer with added corrosion inhibitors. Visually, either coating may "saturate" the underlying material, causing it to appear slightly darker and richer in color. A coating may impart up to 10 years of added protection. Please note, however, that waxes and/or lacquers would require removal with a solvent before retreatment. The use of a water-soluble VpCI-based coating may also be explored, which is likely to be more easily renewed.
- Consolidation: A dilute solution of a modified acrylic such as Paraloid B-48 may be used in conjunction with the above treatment to consolidate loose fragments of material. Additional investigation would be needed at the specific site identified for treatment to determine if this is a viable option, based on the nature and extent of the fragmentation of the metal at that specific location. Visually, an acrylic may "saturate" the underlying material, causing it to appear slightly darker and richer in color. It may also impart a certain level of sheen, although this may be adjusted somewhat with the use of certain matting agents. An acrylic consolidant may impart up to 10 years of added stabilization of fragments.
- Coating cast iron elements: The specific cast iron elements (supports and saddles) directly associated with the specified segment of wrought iron pipe should also be cleaned, and, if the client desires, may be coated with a high-performance paint system in a color determined to be historically appropriate. However, as the deterioration of the cast iron is less

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

advanced than that of the wrought iron pipe, this may be considered a lower treatment priority.

The cost of performing a treatment of this type to a section of wrought iron pipe up to a maximum of approximately 20 feet in length is anticipated to be approximately $100,000 to $125,000. This is highly contingent upon a number of specific curatorial decisions regarding the treatment, as well as yet unknown logistical challenges associated with performing a treatment in this semi-remote and challenging location. This also assumes that full removal of hazardous debris would be performed by others prior to the conservation treatment, and no cost for such is included in this budgetary estimate.

Future Considerations

It is extremely difficult to predict how long the pipe might survive if left untreated. Certainly, it has substantially withstood 150 years of varying levels of exposure and/or use thus far, a significant milestone. It is also difficult to assess how much additional time a treatment might add to the lifespan of the pipe. However, we do believe that if no intervention is made—particularly in regards to improving the surrounding environment—the pipe will continue to deteriorate steadily. Furthermore, we believe the treatment of a "window" of the pipe and subsequent observation over the course of several years as compared to a comparable section of untreated pipe would help to provide a general indication of the extent to which the deterioration has been slowed.

Please note that the cast iron saddles and supports associated with the wrought iron pipe offer a slightly different set of variables in that the condition of the material is more stable at present, more likely to survive better in the current environment, and a better candidate for cleaning and coating. However, as the wrought iron pipe is the primary artifact at hand, we recommend that the circumstances associated with this element drive the majority of the treatment decisions from both exterior and interior surfaces of the wrought iron pipe

Additional Considerations

The development of a site specific treatment plan will be heavily dependent on the results of a variety of these curatorial decisions, and should be informed and accompanied by additional materials testing and treatment mock-ups. Although treatment options can be recommended generally based upon prior experience with similar materials and conditions, each site and artifact presents conditions which are entirely unique. Mock-ups are an important step in refining the exact means and methods to be employed to implement a treatment at a given site. It would also provide an avenue for establishing consensus on variables such as the desired extent of treatment, final appearance, etc.

ENDNOTES

[1] K.L. Vasnath, "Vapor Phase Corrosion Inhibitors for Navy Applications," (paper presented at the annual meeting of the National Association of Corrosion Engineers [NACE], New Orleans, LA, 1997).

[2] David M. Farrell and Kevin Davies, "Cathodic Protection of Iron and Steel in Heritage Buildings in the United

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

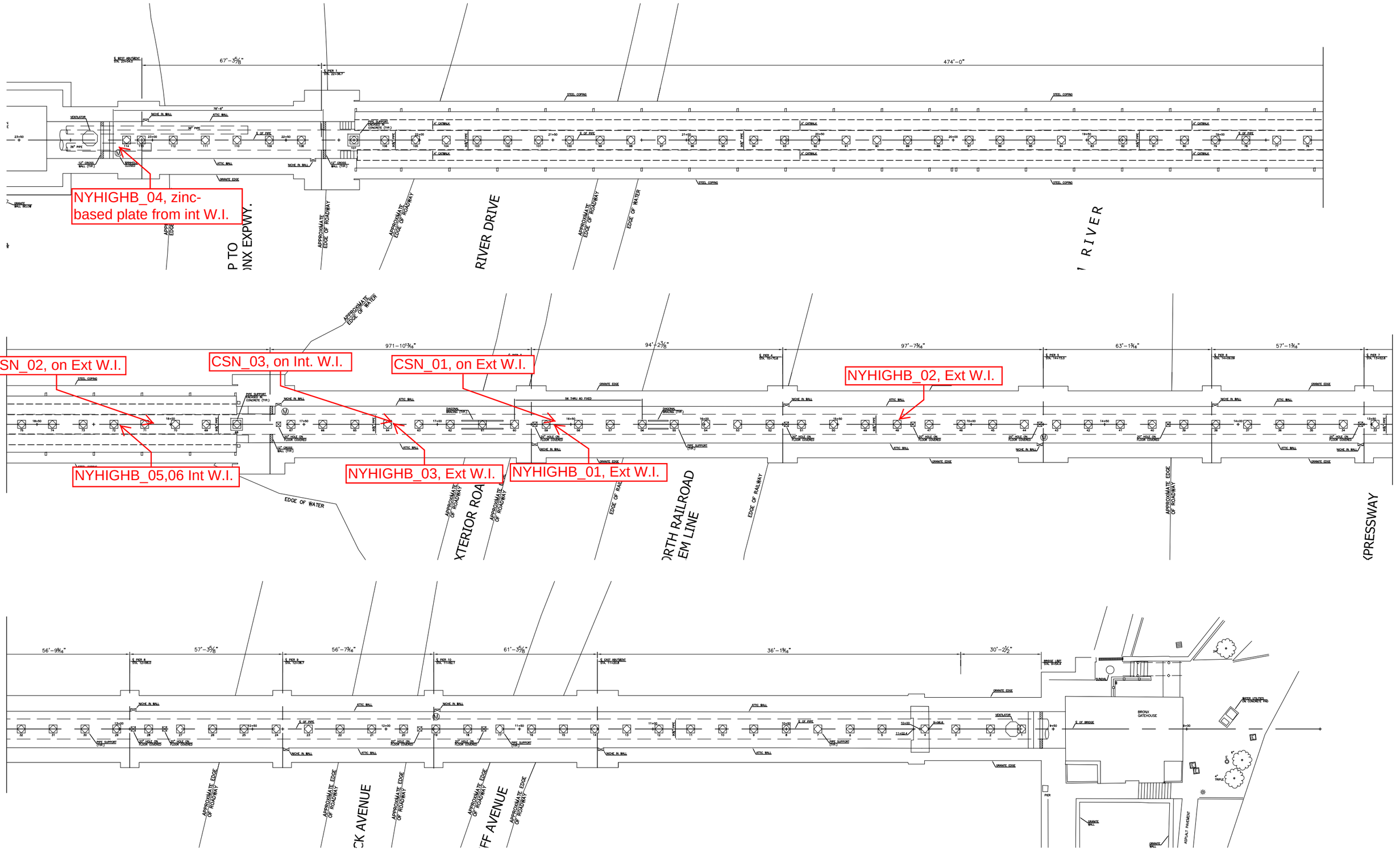
Kingdom," *APT Bulletin* Vol 36, No. 1 (2005): 19-24.

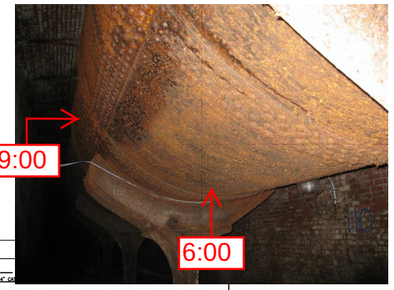
[3] J. Sembrat, P. Miller, J. Skavdahl and L. Frenzel, "Conservation of Historic Metals by Waterjetting Techniques," *Cleaning Techniques in conservation Practice – Journal of Architectural Conservation* v. 11, n. 3, ed. K. Normandin and D. Slaton, Donhead Publishing Ltd (November 2005): 121-146.

CONSERVATION SOLUTIONS, INC.
WWW.CONSERVATIONSOLUTION.COM
WASHINGTON, DC METRO OFFICE • SANTA FE, NM OFFICE
MAIL: 833 EAST PALACE AVE, SANTA FE, NM 87501 EMAIL: INFO@CONSERVATIONSOLUTION.COM
VOICE: (505) 983-1950 FAX: (866)843-1774

APPENDIX A: *Sample and Testing Locations*

Conservation Solutions, Inc.
www.conservationsolution.com
Washington, DC Metro Office • Santa Fe, NM Office
Mail: 833 East Palace Ave, Santa Fe, NM 87501 **Email:** info@conservationsolution.com
Voice: (505) 983-1950 **Fax:** (866)843-1774


NYHIGHB_04, zinc-based plate from int W.I.
CSN_02, on Ext W.I.
CSN_03, on Int. W.I.
CSN_01, on Ext W.I.
NYHIGHB_02, Ext W.I.
NYHIGHB_05,06 Int W.I.
NYHIGHB_03, Ext W.I.
NYHIGHB_01, Ext W.I.
67'-5⅝"
474'-0"
971-10 13/16"
94'-2⅞"
97'-7 3/16"
63'-1 3/16"
57'-1 3/16"
56'-9 1/16"
57'-3⅝"
56'-7 3/16"
61'-3⅝"
36'-1 9/16"
30'-2½"
RIVER DRIVE
EDGE OF WATER
APPROXIMATE EDGE OF ROADWAY
EDGE OF RAILWAY
BRONX GATEHOUSE
GRANITE EDGE
ATTIC WALL
NICHE IN WALL
STEEL COPING
PIER SUPPORT (TYP.)
ASPHALT PAVEMENT



Typical view of wrought iron pipe, identifying "6:00" and "9:00" positions

Starting air temp: 84.6°
Starting rh: 54%

Peak air temp: 88°

Starting surface temp (6:00/9:00 position): 73.5°/72.5°

Ending air temp: 81.9°
Ending rh: 75%

Peak surface temp (6:00/9:00 position): 77°/76.5°

Ending surface temp (6:00/9:00 position): 75°/74.5°

Metallurgy of the Croton Aqueduct, High Bridge Iron, First Report

Robert Gordon and Colin Thomas
Yale University Archaeometallurgy Laboratory
51 Hillhouse Avenue, New Haven, Connecticut

Samples of the iron aqueduct components and structural members of the High Bridge - Croton Aqueduct were submitted for evaluation. This report deals with the results of the metallographic study of these artifacts.

Artifacts Examined

Section of the 36-inch diameter cast iron pipe. This is one of the two original 1842 or 1848 pipes that carried Croton water across the bridge. Designated HBF-01

Part of the cast iron stanchion saddle. The stanchions supported the 7.5-foot diameter wrought iron pipe that was installed in 1860-61 to increase the aqueduct capacity. Designated HBF-02

End of wrought iron tie rod with attached nut. The tie rod spanned the roof arch of the brick vault built in 1860-61 to enclose the aqueduct pipes. This specimen is the remaining part of the tie rod and nut pulled to failure in a tensile test at Lehigh University in 2006. Designated HBF-03

Section of cast iron skewback. The outer ends of the tie rod crossing the top of the aqueduct vault attach to the skewbacks. Designated HBF-04

Length of a wrought iron tie rod. The tie rod spanned the roof arch of the brick vault built in 1860-61 to enclose the aqueduct pipes. Designated HBF-08.

Zinc plate. Zinc plates were attached to the interior of the wrought iron pipe in 1865 to reduce corrosion.

Piece of the wrought iron pipe. Part of the 7 ½ foot diameter wrought iron pipe installed in 1860– 61 to increase the capacity of the aqueduct. This specimen is described as "in masonry at the west end of support No. 62." It was taken near the top of the pipe. Designated No. 1.

Part of wrought iron pipe with riveted joint. This piece is from the bottom of the pipe. Designated No. 2.

Piece of the wrought iron pipe. It is described as "Wrought iron pipe over steel span west of support No. 70." It is from the top of the pipe. Designated No. 3.

Methods

After visual examination sections were cut from the specimens for metallographic study. Sections of the cast iron parts were cut large enough to sample each of the corroded surfaces. Parallel faces were milled on each specimen. Then one of the milled surfaces was

polished and etched. Oriented sections of the wrought iron pipe joint (No. 2) were cut a mounted in resin for examination.

Longitudinal and transverse sections of the wrought iron rod HBF-08 were cut and milled flat. The milled surfaces were macroetched. Smaller longitudinal and transverse sections of the rod were cut and mounted in resin for microscopic examination. The nut with its attached tie rod stub HBF-03 was cut in half to reveal the condition of the threaded joint. One of the sections was polished and macroetched.

All sections were prepared for microscopic examination by the standard metallographic technique of grinding on successively finer grit papers followed by polishing with 6, 3, and 1 μm diamond suspensions. All etching was done with nital, 5% nitric acid in ethyl alcohol.

Results – Cast Iron Components

Cast Iron 36-inch Pipe 001. The 25 x 30 mm polished surface of specimen includes the inside and outside surfaces of the pipe and one relatively modern fracture surface that was made when the pipe was broken after it was taken out of service. The wall thickness of the pipe here is 25 mm.

The pipe is made of ferritic gray cast iron. It has type C graphite flakes that range up to about 0.4 mm long, and form a nearly continuous network through the microstructure Fig. 1-1. The presence of a large amount of steadite in the microstructure, Fig. 1-2, indicates that the iron has a high phosphorous content. A small amount of unconnected porosity present. One casting defect, an included iron splash formed during filling the mold in which the pipe was cast, is present in the sample examined, Fig. 1-3. It would not have a significant effect on the performance of the pipe.

Corrosion has attacked the inside surface of the pipe to a depth of 0.6 to 0.7 mm. The corrosive attack started as pits and propagated inward along the graphite flakes, Fig. 1-4. Since the graphite makes a continuous path into the metal's interior, the penetration is relatively deep. The porous layer could make it difficult to arrest the ongoing rusting should this be undertaken.

The iron at the outside surface of the pipe has a chill margin of pearlitic gray iron that is now 0.6 mm thick, Fig. 1-5. Corrosion on this surface proceeds primarily by solution of the ferrite constituent of the pearlite, Fig. 1-6, and would have advanced more slowly than on the inside surface since the pearlite does not afford easy channels to the interior metal.

Cast Iron Stanchion Saddle 002. The stanchion sample is "T" shaped, and a specimen with a 28 x 30 mm face was taken from the stem of the "T." Three of the four specimen edges were outside, corroded surfaces.

The stanchion is made of slightly mottled pearlitic gray cast iron, Fig. 2-1. The eutectic graphite flakes do not form a continuous network through the structure. The amount of steadite present in the microstructure, Fig. 2-2, indicates a moderate phosphorous content.

There is a chill margin of pearlitic gray iron 0.65 mm at the surface of the casting. It contains large graphite flakes, Fig. 2-3. The chill margin is not continuous as in some areas of the surface where it has been removed by corrosion. Ferritic gray iron with a small

amount of pearlite and graphite in the form of isolated rosettes is found immediately beneath the chill margin. Here steadite was concentrated in interdendritic spaces during solidification of the iron, Fig. 2-4. There is a large concentration of steadite at the interface with the chill margin, Fig. 2-5.

Corrosion has penetrated the chill margin by advancing along the large graphite flakes, Fig. 2-6. Where flakes were oriented more-or-less parallel to the surface this has resulted in undercutting of the metal, as shown in Fig. 2-6.

Cast Iron Skewback 004. A specimen 25 x 15 mm was cut so as to form a cross section through the external, rusted surfaces of the skewback specimen.

The skewback is made of ferritic gray cast iron, Fig. 4-1. The graphite is present as small flakes in rosettes (Type B graphite) in a matrix of ferrite. The flakes do not make a continuous path through the structure. There is a chill margin of pearlite 0.2 mm thick at the surface of the casting. Steadite is present in small, isolated amounts Fig. 4-2. This indicates that the phosphorous content of the iron is relatively small. Gray inclusions, probably manganese sulfide, are abundant in the structure. Some slag was incorporated in the iron near the side surfaces during casting, Fig. 4-3.

Pitting corrosion penetrates to a depth of about 0.2 mm on the exposed surfaces, Fig. 4-1. The penetration of the corrosion is small because the graphite flakes do not make a continuous path into the metal interior.

Results, Wrought Iron Components

Wrought Iron Pipe Joint Section, 2. The configuration of the rivets identifies the inside and outside of the sample as well as the specimen orientation relative to the cylinder axis of the pipe. Two sides of the specimen were smoothed sufficiently by filing to show the joint, the thickness of the metal parts, and the rivet section. This exposed a large and several smaller seams of non-metallic material in the pipe plate.

The top surface of the pipe within the joint has lost little metal to corrosion. The pipe thickness here is 10.5 mm. Since the nominal thickness of the plate used to make the pipe was ½ inch (12.7 mm), the loss of metal on the inside of the pipe due to corrosion at this location is about 2 mm. The exposed end of the pipe is on average 7.5 mm thick with the additional reduction in thickness only on the outside surface. The loss to corrosion on the outside surface of the pipe at this location is therefore about 3 mm.

A specimen for metallographic examination oriented transverse to the cylinder axis of the pipe was taken from the part of the metal that extends beyond the joint. Figure WIP-1 shows that the metal here has a concentration of slag inclusions far in excess of that in even the most ordinary grades of wrought iron. The orientation of the slag fibers indicates that the plate used to make the pipe was oriented with its rolling direction perpendicular to the cylinder axis of the pipe. The metal structure has a uniform, medium ferrite grain size except for one band relatively free of slag that has a large ferrite grain size (it is visible even on a filed surface). All of the slag inclusions are fully shattered by fractures, Fig. WIP-2. A test with Stead's reagent shows that the metal does not have an excessive phosphorous content.

The structure of the corrosion attack and its products differ on the inside and outside surfaces of the pipe. On the outside 90% of the surface in this section has no adherent corrosion product. The metal surface is more heavily pitted than on the inside surface. Where pits have penetrated to slag fibers the attack has followed the fibers into the metal interior, Fig. WIP-3. Since the slag fibers are approximately parallel to the surface this results in undercutting of the metal, Fig. WIP-4. The metal so isolated would eventually corrode completely and flake off.

On the inside surface of the pipe dense, black corrosion product is present on 57% of the section. In some places corrosion has penetrated beneath the surface, Fig. WIP-5. More commonly it enlarges pits that had originally formed on the surface, Fig. WIP-6.

Since the metal structure is the same at both the outside and inside surfaces of the pipe, the difference in corrosion attack originates in the different corroding environments on the inside and outside.

Wrought Iron Pipe Plate Sections, 1 and 3. Not enough curvature is retained in these specimens to indicate their orientations relative to the cylinder axis of the pipe. The inside surfaces of both plates are covered with black corrosion product. On the outside surfaces of both specimens red rust covers a layer of black corrosion product, fragments of which are weakly magnetic. The outside surfaces have roughness with a length scale of about 10 mm. The topography of the inside surface consists of depressions with a length scale of about 20 mm and a finer texture with a 3 to 5 mm length scale. Both plates have holes that emerge on the outside surface of the pipe at the bottom of conical depressions. The conical slope surrounding each hole is about 15 mm wide.

Large non-metallic inclusions are visible on the edges of plate 1. To better reveal these one edge of the plate was milled to a smooth surface. The largest inclusion is 40 mm long with the part 1 mm thick 23 mm long. Fragments extracted from the inclusion are magnetic, indicating the presence of magnetite. This is characteristic of the scale that forms on the surface of iron heated in air to welding temperature. The inclusion is interpreted as scale that was incorporated in the metal during piling and rolling. Small inclusions in the metal are visible with a hand lens on the other faces of both specimens 1 and 3.

Wrought Iron Tie Rod with Nut 003. The nut and its remaining stub of rod (Figs. R3-1 and R3-2) are covered with rust but they appear to have lost little metal to corrosion. The exposed stub of the rod is 1 7/8 inch in diameter, which is the reported original diameter of the rod.

The nut with its contained rod end was sawn in half to reveal the threaded joint. The diameter of the rod within the nut is 1 7/8 inch, and it is threaded with 5 threads per inch. The cross section of the nut and rod stub shows that little corrosion has penetrated the threaded joint, and that it would therefore have retained is full original strength, as was confirmed by the tensile test that broke the rod without pulling it out of the nut. Four of the threads were stretched by the force that broke the rod but did not fail in the test, confirming the rule of thumb that a joint with four threads develops the full possible strength in a threaded joint.

Wrought Iron Tie Rod 008. The longitudinal section, Fig. 8-1, shows the range of slag fiber sizes and densities commonly found in wrought iron, and ferrite in bands with differing grain sizes. Tests with Stead's reagent indicate there are no unusual concentrations of phosphorous.

Corrosion attack at the surface of the rod has formed pits and detached layers of metal, Fig. 8-2. The picture shows that the advancing corrosion bypassed a slag fiber as it advanced into the metal. As corrosion proceeded it undercut the surface, Fig. 8-3. Continuation of this process results in the eventual loss of the undercut metal, and the formation of a groove in the surface. The fibrous texture of the corroded surface is formed by this process.

Measurement of the cross section of the rod shows that the diameter has been reduced from it original 47 mm to as little as 40 mm in some places. The contrast with the rod 003, which has retained its original diameter, indicates that the section of rod 008 was exposed to a more severe corrosive environment than the rod 003.

Zinc Plate. The plate, assumed to be the remains of one of those installed in 1866 in an attempt to arrest rusting of the interior of the wrought iron pipe, is 70 mm wide and 5 mm thick compared to the original width of 89 mm and 6.6 mm thickness. The remaining zinc metal within the plate is surrounded by layers of corrosion products. One surface of the plate is stained with rust, Fig. Zn-1, and is probably the surface in contact with the interior surface of the iron pipe. The reverse surface is white, Fig. Zn-2. Although part of the specimen was lost during collection it appears that the reduction in width and thickness is probably the actual change that occurred within the pipe.

Two layers of corrosion products surround the remaining zinc metal, a black layer adjacent to the metal with a white layer outside. These would be zinc salts formed by reaction of the water that flowed within the wrought iron pipe. X-ray diffraction analysis would be needed for positive identification of these salts.

Discussion; Cast Iron

The principal constituents of the cast iron microstructures, graphite, pearlite, ferrite, and steadite, can be identified by their structures as seen with an optical microscope. Inclusions such as manganese sulfide are seen in the microstructure but require microprobe analysis for positive identification. Corrosion products can be distinguished visually as red, porous, poorly consolidated material consisting of hydrated iron oxide minerals; and dense, darker material that probably contains some magnetite. X-ray diffraction tests would be needed to identify the mineral species in the corrosion products.

The ferritic gray iron with large flake graphite used for the pipe 001, the mottled gray iron in the stanchion 002, and ferritic gray iron with rosette graphite in the skewback are common types of cast iron that are appropriate choices for these products. The high phosphorous content of the pipe iron would have increased the fluidity of the molten metal and facilitated the casting of the long, thin wall tube that might otherwise have been difficult. The porosity in all the samples was small and the casting defects observed would not degrade the strength properties since they are small in relation to the section thicknesses of the castings. These

defects are the included splash metal in 001 and the included slag in 004. (The relatively small samples examined do not constitute a survey of possible defects in the castings.)

All of the castings have chill zones consisting of pearlitic iron at the surfaces that were in contact with mold walls during casting. Such chill zones, often present at the surfaces of large iron castings, arise from the relatively rapid cooling of the metal in contact with the mold. The chill effect in the stanchion 002 was enhanced by segregation of phosphorous toward the surface during solidification of the casting. Phosphorous increases graphitization (by enhancing the effect of silicon) and in this case resulted in formation of large graphite flakes in the surface layer. Slow cooling coupled with the large section thickness of this casting appears to be responsible for the phosphorous enrichment of the surface.

Because iron is anodic relative to graphite and cementite, cast iron is susceptible to corrosion controlled by the distribution of these constituents in the microstructure. Corrosion has penetrated relatively slowly on the outside surface of the iron pipe 001 because the pearlitic chill layer does nor offer a continuous path to the interior. This layer is absent from the interior surface of the pipe, and the large, nearly connected graphite flakes in the pipe allow moisture to penetrate deep into the structure. The resulting corrosion forms a porous layer nearly one millimeter thick. We lack evidence on whether or not a chill layer on the inside surface was formed when the pipe was cast or, if formed, was subsequently removed by corrosion. Nevertheless, loss of sound metal due to corrosion never impaired the serviceability of the pipe.

In the skewback 004 the corrosion rate is small because graphite is present as isolated rosettes that doe not offer a continuous path to the interior of the metal. Corrosion has undercut metal on the surface of the stanchion 002 due to the structure of the chill margin. Where this has been removed by the rusting corrosion has reverted to relatively slow pitting attack as in the skewback. The metal in the skewback is mechanically sound and the rate of corrosion sufficiently slow as not to degrade the strength of the casting for the foreseeable future.

Because all of these cast iron parts have large section thicknesses they will last for a prolonged time without attention. Were conservation to be attempted the penetrated surface layers would probably have to be removed to arrest further corrosion.

Discussion, Wrought Iron

Wrought iron made by the puddling process in use by 1860 consists of a matrix of polycrystalline ferrite containing fibers of retained slag. The fabrication of the iron by hammering followed by welding piles of hammered plates in a rolling mill gives the iron a fibrous texture. The ferrite matrix in pipe sample 2 is free of defects or unusual features. However, the quality of the iron in pipe samples 1 and 2 is poor due to the large concentration of non-metallic inclusions present. In sample 2 they appear as a large inclusion and as a high density of slag fibers, Fig. WIP-1. The included slag that is present in the puddle ball as it emerges from the puddling furnace should have been expelled in the subsequent shingling with the steam hammer used at the Canton Rolling Mill in Baltimore, the maker of the iron plates. This was not done adequately for the metal in plate sample 2. The massive inclusions found in plate sample 1 are probably scale that was included when the shingled iron was piled and rolled. Two of three plates in the pipe that were sampled

have significant defects. Although this is not an adequate sampling of the entire pipe it indicates that the quality of the iron used to make the pipe plates was deficient.

The iron plates supplied by the Canton works were bent to the required curvature at the Continental Iron Works in Brooklyn. Bending the plates cold shattered the included slag fibers in plate sample 2, Fig. WIP-2. It also left residual tensile stress on the outer half of the plate. The high density of inclusions and their fractured condition enhanced the susceptibility of the iron to corrosive attack.

The character of the corrosion differs between the inside and outside surfaces of all three pipe plate samples. Additionally, the corrosion on the inside surface of specimen 2, which would have been almost continuously submerged while the aqueduct was in service, differs from that on the inside surfaces of samples 1 and 3, which are from locations near the top of the pipe, where they would be intermittently wetted. On the submerged surface the length scale and depth of pitting are smaller, and the red oxide is absent in contrast to the inside surfaces of the samples from the upper part of the pipe.

The long-held popular notion that wrought iron has better corrosion resistance than mild steel led to comparative trials in the late nineteenth and early twentieth centuries that were generally inconclusive because corrosion resistance is sensitive to environmental factors as well as metal properties. Chilton and Evans [1955] searched for evidence that would settle this question. They found that the corrosion response of wrought iron is influenced by the presence of sulfur, phosphorous and nickel in the ferrite, and that the only advantage of wrought iron over steel is that the rough surface caused by the slag inclusions in wrought iron could make protective coating adhere better. Wranglén [1969] demonstrated that iron sulfide particles in ferrite form local corrosion cells that grow into pits. The principal modern research on the corrosion resistance of wrought iron is the detailed studies of the Delhi pillar, which has remained rust free for over a thousand years. Balasubramaniam [2000] showed that the high phosphorous content of the iron in the pillar results in the formation of adherent phsophide corrosion product that is resistant to penetration in the atmosphere at Delhi. Other corrosion products formed on iron lack the adherence and impermeability needed to arrest the progress of corrosion.

Wrought iron is not a homogeneous material. Nickel or phosphorous, when present, are typically found in layers formed during hammering and rolling of the metal. Metallography suggests that the High Bridge iron lacks sufficient phosphorous to affect its corrosion resistance. Microprobe analysis would be needed to test for the presence of nickel or other elements that might enhance corrosion resistance. Based on what we know of the source of the iron used, their presence is probably unlikely. Sulfides that could act as pit nuclei are too small to be reliably detected by standard optical metallography; probe analyses are needed to investigate them. The microstructures examined show that once initiated the progress of corrosion is next controlled by the distribution of non-metallic inclusions in the iron. The distribution of inclusions is primarily responsible for the texture of the surface of the tie rod 008.

Chilton and Evans [1955] and others have shown that the corrosion process on wrought iron is sensitive to the environment in which the metal is placed. The differences in the corrosion attack between the inside and outside surfaces of the iron pipe, and between the bottom and upper part of the inside surface are due environment rather than properties of the iron. The outside surface is exposed to condensation and possibly rain water that is

acidic. The inside has been primarily exposed to potable water. Since the pipe was not kept continuously filled to the top, the upper inside surface has been subject to intermittent wetting. It would have been exposed to larger temperature changes than the bottom surface. Corrosion product on this surface may have suffered mechanical damage from gravity waves formed on the water surface whenever flow through the pipe was altered. Water flow over the bottom of the pipe would have been turbulent, and the scale of the turbulence may be the factor responsible for the length scale of the surface pitting. Thus the corrosion features of the pipe are more strongly dominated by environmental factors than by inherent characteristics of the wrought iron.

These considerations help explain why the zinc plates failed to protect the pipe from corrosion. The small reduction in thickness and the presence of the corrosion layers surrounding the zinc metal in the sample examined show that the zinc was not providing galvanic protection to the wrought iron pipe. Corrosion of the pipe is due to galvanic action initiated between microscale constituents of the iron, such as sulfide inclusions. A nearly continuous layer of zinc would have been needed to suppress this.

Unlike the iron in the pipe plates the metal in the tie rods is free of gross defects. The strength data and chemical analysis of the tie rod 003 fall within the usually range for wrought iron used in structures [Gordon 1988, Fig.8]. Corrosion is expected to continue on the exposed sections of the rods unless the scale is removed and the surface protected.

References.

Balasubramaniam, R., "On the Corrosion Resistance of the Delhi Iron Pillar," *Corrosion Science* 42 (2000): 2103-2129.

Chilton, J. P., and U. R. Evans, "The Corrosion Resistance of Wrought Iron," *Journal of the Iron and Steel Institute* 181 (1955): 113-122.

Gordon, R. B., "Strength and Structure of Wrought Iron," *Archeomaterials* 2 (1988): 109-137.

Wranglén, Gösta, "Influence of Sulphide Inclusions on the Corrodability of Iron and Steel," *Corrosion Science* 9 (1969): 585-602.

Microstructure of Cast Iron Pipe 001

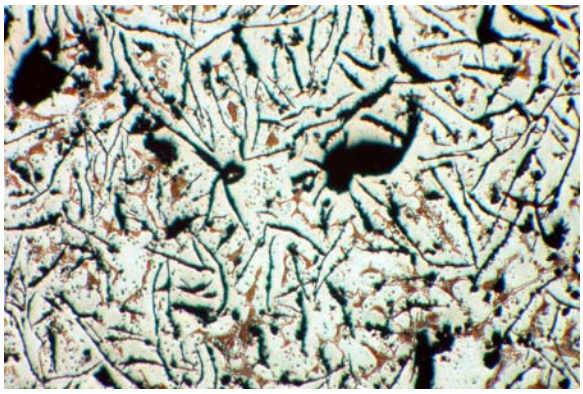


Fig. 1-1. Interior structure of the cast iron pipe. 50x
The pipe is ferritic gray iron. Eutectic graphite flakes are in a matrix of ferrite, and form a nearly continuous network. Read areas are steadite.

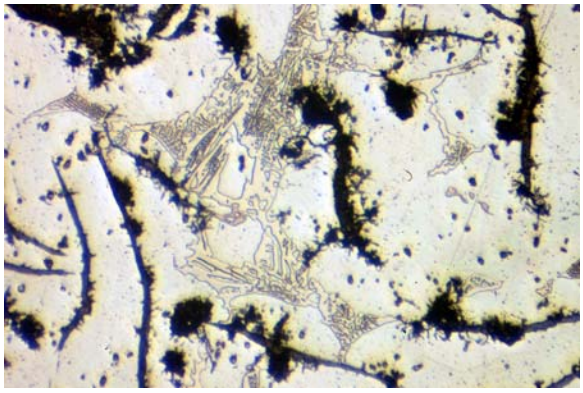


Fig. 1-2. Interior structure of the cast iron pipe. 200x

At high magnification the structure of the steadite is visible.

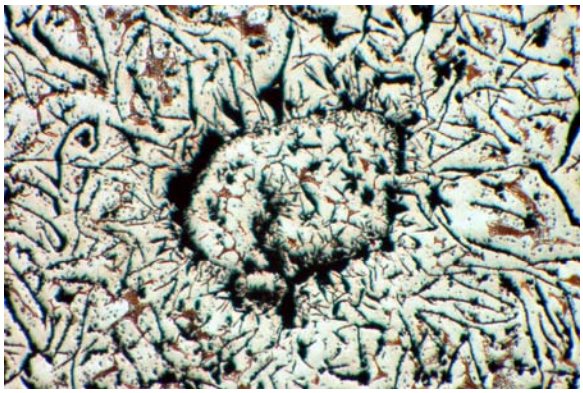


Fig. 1-3. Interior structure of the cast iron pipe. 50x

When the liquid iron was poured into the mold some of it splashed upon hitting the mold wall and was later incorporated in the metal that filled the mold.

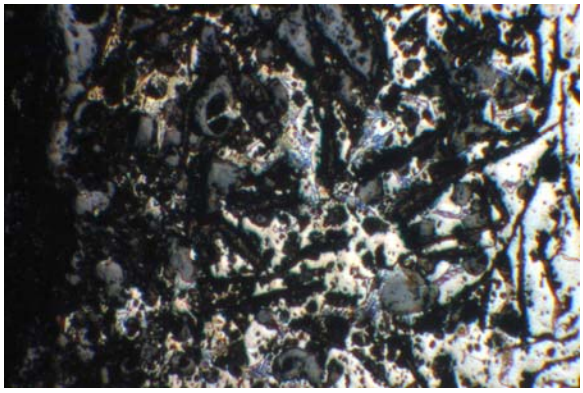


Fig. 1-4. Inside surface of cast iron pipe. 50x

Some corrosion product adheres at the left. Corrosion has penetrated along the graphite flakes to a depth of up to 0.7 mm.

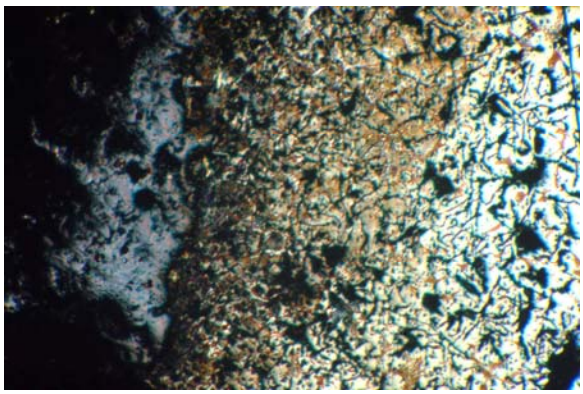


Fig. 1-5. Outside of cast iron pipe. 50x
A layer of pearlite gray iron formed as a chill margin (dark red) on the outside of the pipe when it was cast. Some corrosion product (dark blue) remains attached to the surface. 50x

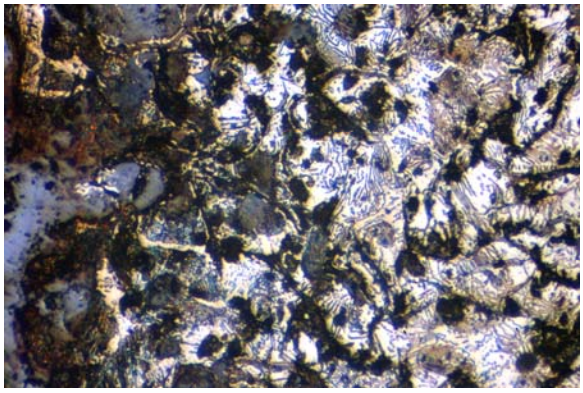


Fig. 1-6. Outside of cast iron pipe. 200x

Corrosion proceeds more slowly through the chill margin than on the inside of the pipe. Ferrite is preferentially removed from the pearlite structure. The cementite survives within the corrosion product in some areas.

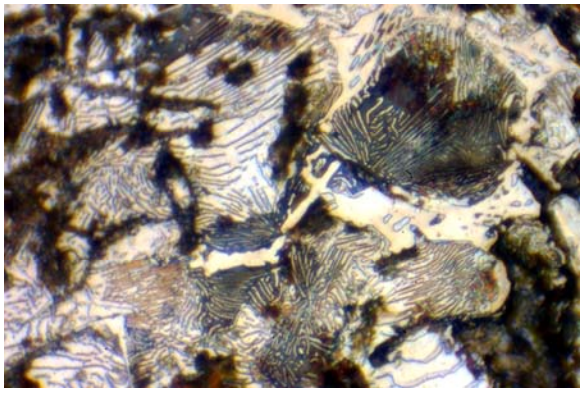


Fig. 1-7. Chill margin, outside of cast iron pipe. 460x

Corrosion proceeds more slowly through the chill margin than on the inside surface of the pipe. Ferrite is preferentially removed from the pearlite structure. The Cementite in survives within the corrosion product in some areas.

Microstructure of Cast Iron Stanchion Saddle 002

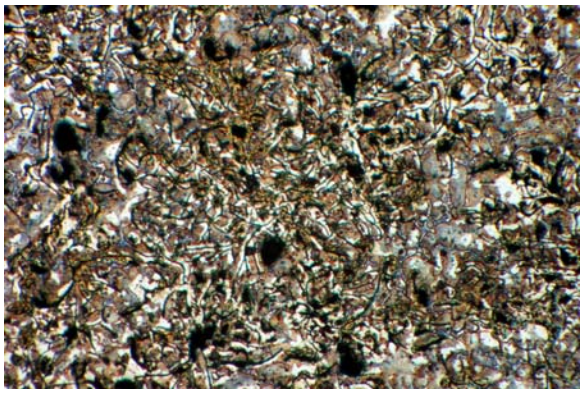


Fig. 2-1. Microstructure of the cast iron stanchion. 50x

The interior of the casting is slightly mottled pearlitic gray cast iron. Pearlite appears dark red in the micrograph, and ferrite bright.

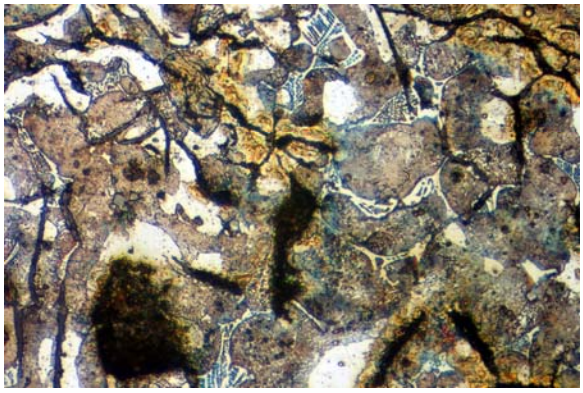


Fig. 2-2. Microstructure of the cast iron stanchion. 418x

The structural constituents in the interior of the casting are graphite flakes, pearlite (dark, colored areas) and small areas of steadite.

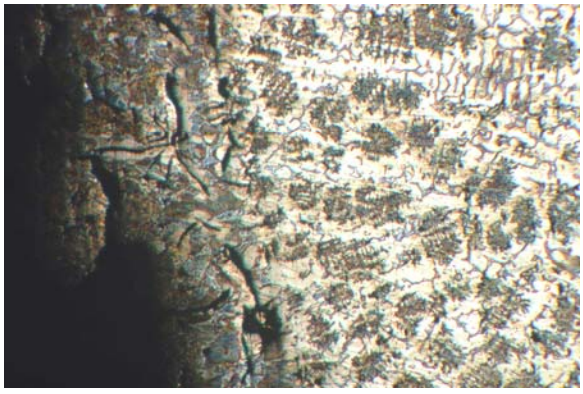


Fig. 2-3 Microstructure at the top edge of the stanchion. 96x

There is a chill margin of pearlitic gray iron with large graphite flakes at the surface of the casting. Immediately beneath is ferritic gray iron with a small amount of pearlite present.

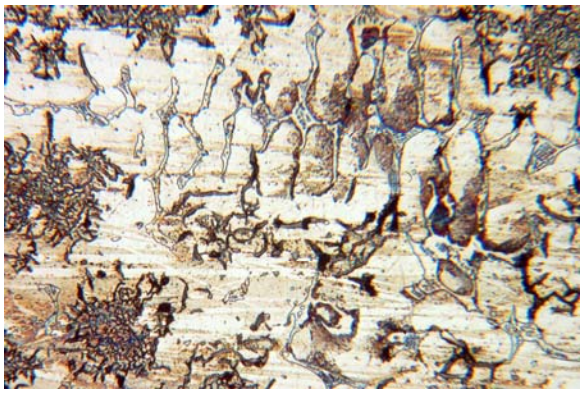


Fig. 2-4 Cast iron stanchion, structure below the chill margin. 337x

The matrix is ferrite with dendritic structure. Steadite has concentrated in the interdendritic spaces during solidification. Graphite is present in isolated clusters.

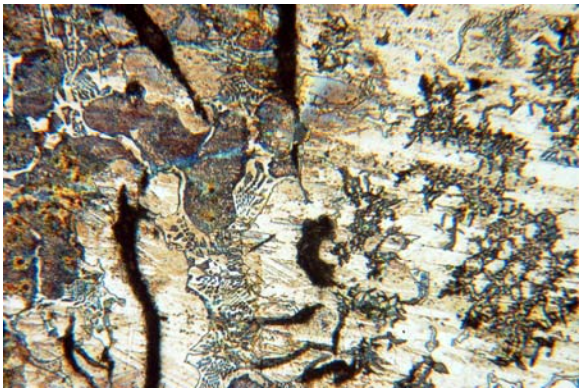


Fig. 2-5. Cast iron stanchion, inner edge of the chill margin. 337x

A large concentration of steadite is present in the chill margin.

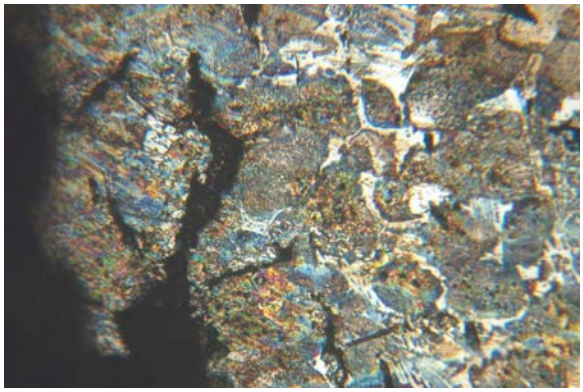


Fig. 2-5. Cast iron stanchion, outer edge of the chill margin. 337x

The dark constituent is pearlite. Corrosion has followed a graphite flake into the interior of the structure.

Microstructure of Cast Iron Skewback 004



Fig. 4-1. Edge and interior of cast iron skewback. 50x

The structure consists of rosettes of graphite in a pearlite matrix. There is a chill zone of pearlite (red) at the surface of the specimen. The surface is marked by corrosion pits. Magnification 50x.



Fig. 4-2. Interior structure of cast iron skewback. 170x

Small areas of steadite and gray inclusions, probably manganese sulfide, are present in the microstructure. .

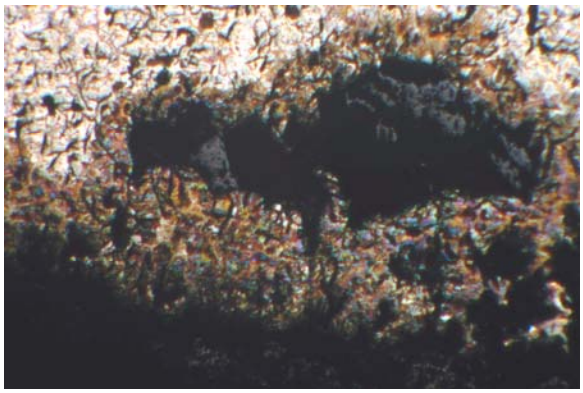


Fig. 4-3. Side of cast iron skewback. 50x

Particles of slag appear to have been incorporated in the iron as it was poured into its mold. The slag would have been splashed on the mold wall as the pour began, and then incorporated as the metal rose in filling the mold.

Microstructure of Wrought Iron Pipe

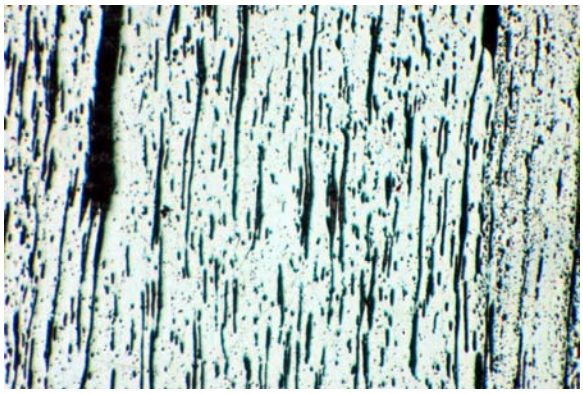


Fig. WIP-1. Interior of wrought iron pipe specimen 2. 50x, un-etched

The concentration of slag fibers is unusually high. The band with small particles at the right is one of the welds made when the iron was piled.

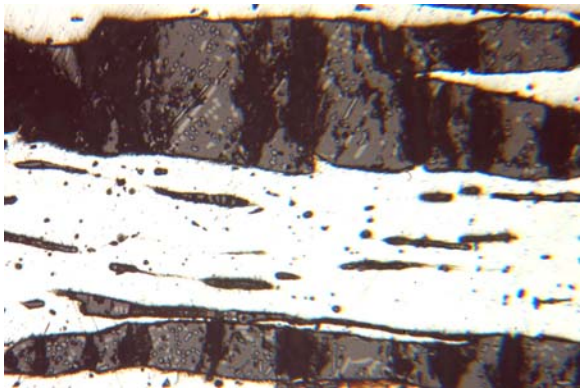


Fig. WIP-2. Interior of wrought iron pipe specimen 2. 170x, un-etched

All the slag fibers in this iron are broken by abundant fractures.

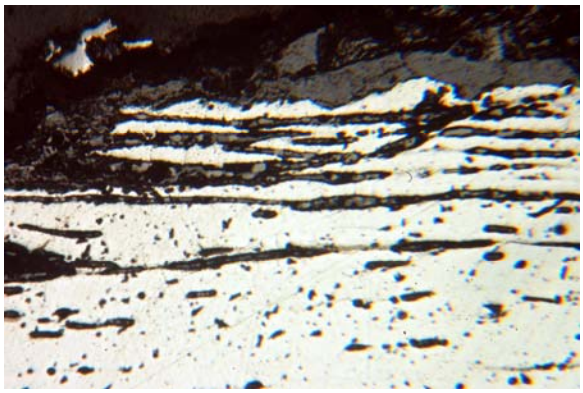


Fig. WIP-3. Section at outside surface of wrought iron pipe specimen 2. 170x, un-etched

The adherent layer of corrosion product on the surface of the iron is cracked and disintegrating. Corrosion has penetrated along the small slag fibers that intersect the pit on the right.

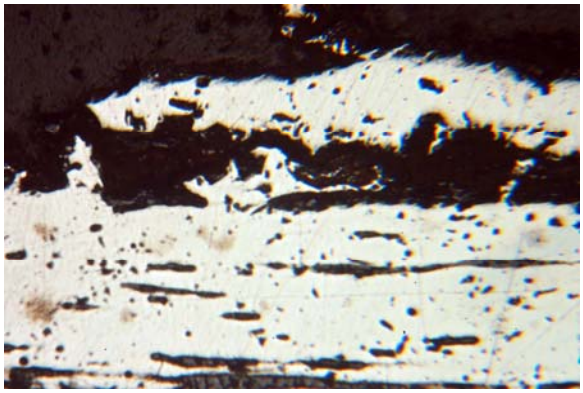


Fig. WIP-4 Section at outside surface of wrought iron pipe specimen 2. 170x, un-etched

Corrosion has penetrated beneath the outside surface leaving a layer of metal over the corroded cavity.

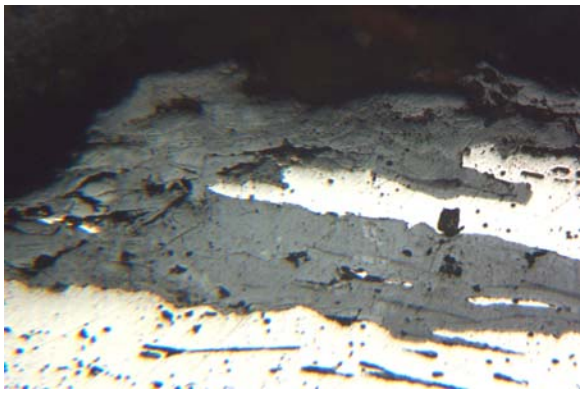


Fig. WIP-5 Section at inside surface of wrought iron pipe specimen 2. 170x, un-etched

Large mass of corrosion product on the surface and penetrating the interior

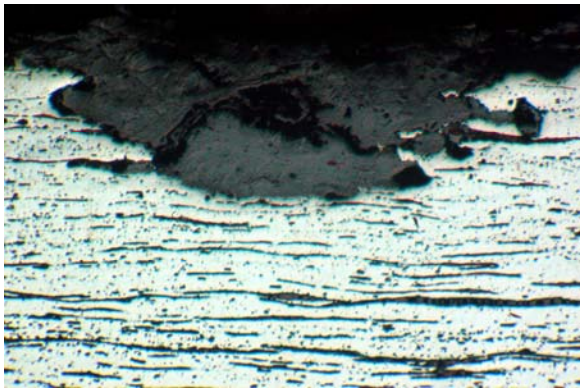


Fig. WIP-6. Section of inside surface of wrought iron pipe specimen 2. 50x

Cavity that originated as a pit is now filled with corrosion product.

Tie Rod and Nut 003



Fig. R3-1 Outer end of tie rod with attached nut.

The rod diameter is 1 7/8 inch and the width across the flat of the nut is 3 inches. The threaded rod extends ½ inch beyond the nut.



Fig. R3-2 Ductile fracture of tie rod resulting from pull test to failure.

Microstructure of Wrought iron Rod 008



Fig. 8-1. Longitudinal section of wrought iron tie rod 008 50x

The iron has bands of larger and smaller ferrite grains and typical slag fiber content

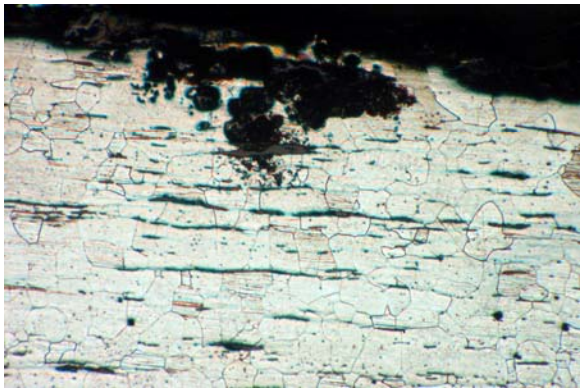


Fig. 8-2. Edge of longitudinal section of wrought iron tie rod 008 50x

A corrosion pit has developed under the surface, bypassing a slag fiber. Lateral extension is forming a detached layer of metal that will later be corroded.

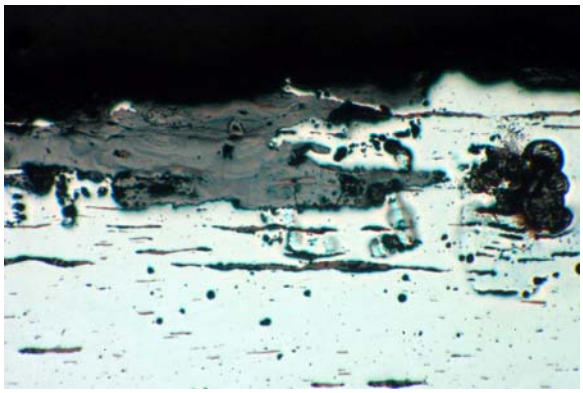


Fig. 8-3. Edge of longitudinal section of wrought iron tie rod 008 50x

Zinc Specimen



Fig. Zn-1 Surface of zinc plate probably exposed to water in the wrought iron pipe



Fig. Zn-2 Surface of zinc plate that was probably in contact with the wall of the wrought iron pipe.

MSi Testing & Engineering, Inc.
Your Source for Metallurgical Testing and Failure Analysis
1390 N. 25th Avenue
Melrose Park, IL 60160
708·343·3444
F A X·3033

ACCREDITED
TESTING CERT #0510-01

Jablonski Building Conservation
40 West 27th Street – Suite 1201
New York, NY 10001

Report No.: 163080
Date: 8-11-10
Order No.: XF08092010
Page: 1 of 1

Attn: Ms. Xsusha Flandro

SAMPLE IDENTIFICATION

Quantity	Description
2	Samples Received 8-5-10

TEST RESULTS *

Chemical Testing

Element	Highbridge East: HB. F009	Highbridge West : HB. F010
Carbon	.08 %	.08 %
Manganese	.42	.44
Phosphorus	<.005	<.005
Sulfur	.015	.014
Silicon	<.01	<.01
Nickel	.04	.04
Chromium	.02	.03
Molybdenum	<.01	<.01
Copper	.22	.25
Aluminum	<.01	<.01
AISI Steel Grade	**1006 / 1008 / 1010**	**1006 / 1008 / 1010**
Carbon Equivalent (CE)	**.17**	**.18**

Tensile Testing

Tensile Strength, psi	51,500	54,500

* Testing performed in accordance with ASTM E415, A370 and E8. Carbon equivalent for weldability was calculated using the formula: CE = %C + %Mn/6 + (%Cr + %Mo + %V)/5 + (%Si + %Ni + %Cu)/15.

COMMENTS

The preceding test results indicate the submitted samples would exhibit good weldability.

Respectfully Submitted,
MSi ***Testing & Engineering, Inc.***

Allan W. Scheive

Allan W. Scheive
Senior Metallurgical Engineer

AWS/dk/E-Document

The Above Test Report Relates Only To The Items Tested And Shall Not Be Reproduced Except In Full, Without The Written Consent Of MSi Testing & Engineering, Inc.
All Specimen Remnants Pertaining To The Above Tested Items Are Retained For a Maximum Of 30 Days, Unless Notified In Writing.

10. Treatment Philosophy

11. Use and Interpretation of the Resource

11.1 PROPOSED AND RECOMMENDED USE

11.2 INTERPRETIVE PROGRAM

12. Feature Treatment Recommendations

12.1 RECOMMENDED TREATEMENT FOR EACH AREA, MATERIAL, OR FEATURE

ATTACHMENTS

Summary of Treatment Recommendation Graphic Presentations, August 31, 2010

10. Treatment Philosophy

The treatment recommended for the High Bridge is "Rehabilitation" defined in *The Secretary of the Interior's Standards for the Treatment of Historic Properties* (1995) as:

> The act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, and architectural values.

The historic features, form, and integrity of the High Bridge are largely intact; the intent of the proposed scope of work is to maximize retention of historic character, minimize the loss of historic fabric, and meet *The Secretary of the Interior's Standards for the Treatment of Historic Properties* while addressing the required program for the High Bridge, e.g., safety, security, and barrier-free access. Rehabilitation is an appropriate treatment for the High Bridge as it allows the historic character and most of the architectural and engineering features of the bridge to be retained and preserved, yet accommodates modern programmatic requirements.

Within the primary treatment of rehabilitation of the High Bridge, preservation of the form, integrity, and features of the bridge should be the preferred approach wherever possible. "Preservation" is defined in *The Secretary of the Interior's Standards* as:

> The act or process of applying measures to sustain the existing form, integrity, and materials of a historic property.

Most of the features of the High Bridge can be preserved *in situ* with selective repair:

- The existing form and materials of the granite arches, piers, spandrels, and flanking abutments, dating from 1848, should be fully preserved. To ensure the continued longevity of the bridge, some repair work will be required, including selective repointing, pinning, and Dutchman stone repairs.
- The existing form and materials of the granite and brick parapet and "attic," dating from 1864, should be preserved. Where required, selective repointing, pinning, rebuilding and repair should be performed.
- The brick arches which form the structure for the 1864 walkway should be preserved, including the existing tie rods, and reinforced as required through the use of additional tie rods in the bridge's "attic." Selective repointing and crack repair of the brick arch should also be performed.
- The steel arch, dating from 1928, should be preserved, repaired as required, and repainted to match the historic color.
- The enlarged granite piers (original piers modified in 1928) flanking the steel arch should be preserved. Where required, selective repointing, removal and replacement of cracked granite, repair of deteriorated concrete and rusting rebar, and reinstallation of granite with repairs to cracks should be performed.
- The aqueduct pipes and pedestals in the attic should be preserved in situ. The work should include removal of loose rust and debris, selective painting of the pipe at the steel section to increase longevity, repositioning the pedestals to their original locations, and making provisions for ventilation in the attic. In addition, as the pipes and attic/gallery were not documented as part of the previous Historic American Engineering Survey of the High Bridge in 1978, it would be useful to photographically document them prior to the commencement of the work.

Selective features will require repair and modifications to meet functional and code requirements, necessitating historic materials to be removed and subsequently reinstalled:

- The iron railings on the bridge, dating primarily from 1864 over the masonry arches, and 1928 over the steel arch, with some later repairs, should be carefully documented and inventoried , removed from the site, stripped of paint, repaired, reinforced as required, and reinstalled in the original locations to the full extent possible. Accommodations for expansion and contraction, structural stability, code requirements, and coordination with the installation of lighting should be provided with the minimal modification possible.
- The existing granite steps connecting the gatehouse plazas and the bridge walkway should be salvaged and re-installed over appropriate substrate on site. The addition of handrails will be required to meet code requirements.

There are areas of the High Bridge where functional requirements will necessitate the replacement of some historic materials:

- Based on probes, the original extant asphaltic waterproofing (dating from 1864) over the brick arches has reached the end of its useful life and should be replaced to address the leaks within the attic space.
- Removal of the waterproofing will entail removal of the brick pavers. As many of the brick pavers are part of the 1864 installation of the walkway, they should be very carefully removed, those in good condition salvaged, and reinstalled over the new waterproofing. The brick herringbone pattern, installation techniques and materials should match the original to the full extent possible.
- While the intent is to salvage as much brick as possible, sample removals of the 1864 brick by a restoration contractor indicate that a substantial number of the brick pavers may be damaged in the course of the work despite careful removal techniques. The damaged brick pavers should be replaced with new custom brick pavers to match the original. In addition, where the original 1864 brick pavers had previously been replaced with non-matching brick pavers (including the Bronx plaza and various repairs on the bridge) the non-matching pavers should be replaced with new brick pavers to match the original.
- Similarly, the brick pavers from 1928 over the steel arch will need to be removed and salvaged for reinstallation to accommodate the insertion of waterproofing over concrete underlayment. The damaged brick pavers should be replaced with new brick to match the original. The brick running bond pattern, installation techniques and materials should match the original to the full extent possible.
- The bluestone pavers around at the Manhattan gatehouse are typically in poor condition, or in some cases, missing. The paving around the Bronx gatehouse is concrete and in good conditions. The stone pavers will typically require replacement with new stone to match the existing; pavers in good condition should be salvaged and re-installed.
- The existing lampposts, dating from 1935, should be carefully documented and inventoried, and removed from the site. To meet functional, code, safety, and maintenance requirements, new taller lampposts, accommodating energy-efficient LED lamping should be installed. The lampposts should be appropriate to the historic bridge, and located in alignment with the masonry piers as the extant posts are. Additional intermediate lampposts, needed to meet illumination criteria, should be added symmetrically. Placement should be coordinated with the safety fences. Existing lampposts should be reused at a limited number of locations where fixture height is not critical to achieve lighting levels.

There is one feature of the 1864 High Bridge, i.e., the thirteen round cast-iron and glass vault lights which have been lost, severely damaged, changed to manholes, or covered over. At the original locations, the geometric form can be restored and used for vault lights, interpretive panels, or manhole covers required for access and egress.

Given the requirements for barrier-free access and safety standards for pedestrians and wheeled users, there will be the need for new features on the High Bridge. Where new features or materials are being added to meet modern programmatic requirements, they should be clearly distinguished from the historic in form

and/or material. This approach will allow the additions to the High Bridge to be recognized as a physical record of their time and use.

- Safety Fences: Eight foot high safety fences will be required over the waterways, roadways, and railways which run below the High Bridge. The location, form, materials, and detailing of the fences should ensure that they provide the requisite safety while minimizing negative visual and physical impact on the historic features of the bridge.
- Ramps: To accommodate wheelchairs, bicycles, strollers and maintenance vehicles, new ramps will be required at both the Manhattan and Bronx ends of the bridge. This is due to the substantial change in elevation from the entry plaza level to the bridge level (5.2 feet on the Manhattan side and 4.8 feet on the Bronx side.) The new ramps should be carefully placed and designed to have the least visual impact on the historic bridge and minimize any loss of historic fabric, yet provide universal access. Contemporary form and materials should be utilized to allow the ramps to be seen as a modern intervention.
- Gates: While access control is required, the existing security gates are inappropriate to the historic character of the bridge, and should be replaced with gates located off the bridge itself. The gates should be designed to minimize the loss of historic fabric and, to the full extent possible, take advantage of areas where access is already restricted, e.g., adjacent to the Bronx and Manhattan gatehouses. To accommodate ventilation within the attic space, gates should also be added in the former masonry openings at grade on the Bronx side. The design of the new gates should be carefully integrated with the design vocabulary of the existing park elements.
- As part of the proposed rehabilitation, there are additional work items that would allow the public to more fully appreciate the beauty, civic-mindedness and technical achievement of the High Bridge. These include cleaning the bridge, installing architectural lighting of the granite and steel arches, installing wayfinding signage, and providing interpretive materials. While this work is not critical to the preservation and function of the High Bridge, each would enhance the bridge and provide greater public appreciation and understanding of the historic resource.
- The proposed modifications to the High Bridge are intended to respect the architectural and engineering integrity of the bridge, and to provide necessary structural stabilization, watertightness, and code compliance. The intent of the proposed rehabilitation is to avoid or minimize any adverse effects on the High Bridge, to minimize the loss of significant historic fabric, to perform the work in accordance with quality preservation standards, to clearly distinguish new elements from the historic features, to make the proposed alterations reversible where possible, and to broaden the public understanding and appreciation of the High Bridge.

11. Use and Interpretation of the Resource

As the High Bridge is an individually designated NYC landmark; listed on the National Register of Historic Places; listed as a National Historic Civil Engineering Landmark; and designated a National Historic Landmark as part of the Old Croton Aqueduct, its use and interpretation are of great significance to the public. While the project will have its most immediate benefit on the communities at either end of the bridge – High Bridge in the Bronx and Washington Heights in Manhattan, the High Bridge has the potential of attracting substantial numbers of users from the larger metropolitan area, if not beyond. The rehabilitation of the High Bridge should be performed in accordance with the highest quality preservation standards, with the goal of universal accessibility, and with careful consideration for the safety of all of its users.

11.1 PROPOSED AND RECOMMENDED USE

The proposed use as stated in the NYC Department of Parks and Recreation's Request for Proposal, and the consultants' recommended use, is the creation of a linear park linking the Bronx and Manhattan sides of Highbridge Park, and forming a critical component of the Old Croton Aqueduct Greenway. The bridge will accommodate commuting travel, recreational or social travel (park and neighborhood access), passive and active use, tourism, and special events (festivals); the bridge should also provide enjoyment to its users and passers-by.

The proposed rehabilitation of the High Bridge over the Harlem River creates a wonderful opportunity to return a monumental artifact of New York City's history to public service. The High Bridge was enjoyed by pedestrians for over 100 years, linking two boroughs, providing open space and views of the majestic river and the Highbridge Water Tower; and for many decades, providing water for New York City's inhabitants as part of the Croton Aqueduct system. Its history represents a value placed on municipal infrastructure, a concern for the well-being of the city's residents, and a respect for good design and construction. While the High Bridge's purpose-built use, supplying the City of New York with water, came to an end in 1958 and the bridge was subsequently closed to pedestrians, the proposed and recommended use aims to rehabilitate the bridge as a public amenity. The bridge will serve as a linear park accommodating pedestrians, wheelchair users, and cyclists. To do so the bridge must be made safe for public access and meet modern programmatic requirements, e.g., safety fences and ramps for barrier-free accessibility. As these new features will have impact on the historic resource, the Owner and the Design Team met with the New York City Landmarks Preservation Commission and the State Historic Preservation Office early in the design process to review philosophical approaches to the design of the ramps and safety fences. With the understanding that the design intent is to meet *The Secretary of the Interiors Standards for the Treatment of Historic Properties,* numerous options were studied and the impact on the historic bridge and site analyzed both from the view of the pedestrians crossing the bridge and the view from the roadways, railway and waterway below. The American Disabilities Act Accessibility guidelines for Buildings and Facilities (ADAAG), New York State Department of Transportation Highway Design Manual (NYSDOT) and the American Association of State Highway and Transportation Officials (AASHTO) Guide for the Development of Bicycle Facilities served as references to guide the design process in addressing programmatic requirements.

To effectively meet the goals of historic preservation and universal access, an equilibrium must be established that both respects the integrity of the historic bridge and provides reasonable access for all potential users of the linear park.

Barrier-free Access

To ensure barrier-free accessibility at both the Bronx and Manhattan ends of the bridge, the addition of three ADA compliant ramps is planned. On the Manhattan side, both an exterior ramp to the north side of the bridge, and a shorter ramp over the granite steps from the ventilator plaza to the main deck, will be required to effectively provide access. (A single exterior ramp proved infeasible due to the location of the Harlem River

Drive below.) On the Bronx side, a ramp on the north side of the bridge is required. Options for ramp locations were studied to determine the most visually appropriate and functional relationships on both the Manhattan and Bronx sides of the bridge. With the addition of the ramps, wheelchair users will have access to the High Bridge deck.

The proposed access ramps for the High Bridge are designed in accordance with ADA requirements; however, they do not fully meet the specifications in the AASHTO Guide for the Development of Bicycle Facilities due to their potential adverse impact on the character-defining features of the bridge. As the High Bridge is a unique and significant historic resource, the accommodation of bicycles, the safety of cyclists and pedestrians, and the impact on the landmark were carefully reviewed with the State Historic Preservation Office, the NYC Landmarks Preservation Commission, the Department of Parks and Recreation, the Department of Design and Construction, and access specialists to determine the most appropriate and safe solution. The shared design goal was to respect both the bridge and its users. Appropriate signage is included in the design to warn cyclists to dismount as required for safety.

Traversing the Bridge

The brick walkway's crown, which reflects the brick arch of the attic/pipe gallery beneath and the presence of the aqueduct pipe within, results in a cross slope from approximately 2% at the center of the bridge up to 7% at certain locations on the masonry span, and 5% on the steel span.

Consideration to reduce the existing cross slope requires a balance between the historic significance of the brick walkway and radial crown that reflects the aqueduct shape below and the minimum guidelines for universal access and user safety. It was desirable to maintain the existing deck surface to the fullest extent possible while meeting the intent of universal access. Introduction of a curb was most undesirable from a preservation perspective. Lowering or reducing the deck grade profile was not feasible due to the shallow depth superstructure.

In order to strike a balance between historic preservation and universal access, the proposed walkway will provide a 60-inch wide pedestrian accessible route (PAR) centered at the walkway crown that will have maximum 2% cross slope for the full length of the bridge. During the relaying of the brick walkway, attempts will be made to "flatten out" the top of the bridge crown with minimal alterations the appearance. The shallow depth of the bridge superstructure precludes a more significant change to the High Bridge's crown. The center portion of the walkway becomes the designated Pedestrian Accessible Route; one viewing platform facing north and two facing south that accommodate universal access will also be provided. The remaining portions of the walkway will have a variable cross slope that exceeds 2%. Railings and safety fence will both be provided to each side.

Viewing Platforms

Since the steeper slope at the edges of the bridge does not comfortably accommodate a person in a wheelchair wishing to remain at the edge of the bridge looking out, the creation of viewing platforms, in compliance with the ADA recommended sidewalk cross slope of 2%, is proposed. The proposed viewing platforms on the steel span overlooking the Harlem River, one facing north and one facing south, and a third platform at the abutment on the Bronx side, will mitigate the cross slope and provide an accessible grade for wheelchair users wishing to experience the views out to the river. The viewing platforms should be designed to provide seating areas for both wheeled and non-wheeled users. The platforms should be designed to have minimal impact on the historic fabric.

11.2 INTERPRETIVE PROGRAM

In addition to making this resource available to the public as a historic and cultural artifact, an interpretive program highlighting the High Bridge's role in supplying water to the City of New York should be incorporated into the program. As the aqueduct pipes are fundamental to the High Bridge's history, they

must be retained as part of the historic record. The narrative history of the supply of water to New York City via the Croton Aqueduct is key to the public's understanding of the High Bridge. The interpretive program should explore provisions for visual access to the pipes through the use of viewing portals, as well as historic narrative/informational panels leading to and on the bridge. The use of the former openings for the glass and cast-iron vault lights will be used to form the basis of a linear narrative with new cast interpretive panels. The interpretation will focus on the High Bridge, within the context of the Croton Aqueduct. The use of viewing portals through the bridge deck was explored but was determined not to be feasible without extensive alterations to the historic fabric to achieve the needed site lines, in addition to maintenance and vandalism issues associated with the glass enclosures. The possibility of using periscopes or electronic video equipment that users could interact with was also investigated and may be implemented at a later date. In addition, the NYC Parks Department may offer occasional guided tours, which could potentially include access to the attic space and pipe gallery to see the extant aqueduct pipes.

The gatehouses at the Bronx and Manhattan plazas were integrally designed and constructed with the High Bridge and would serve well as interpretive areas. While they are not part of the contract or this HSR, the gatehouses are within the proposed linear park. They, remain under the ownership of the Department of Environmental Protection (DEP) rather than DPR. As the gatehouses provide a critical understanding as to the function of the High Bridge within the Croton Aqueduct, interpretive panels describing their function are planned for use at each gatehouse for an interpretive function.

12. Feature Treatment Recommendations

12.1 RECOMMENDED TREATMENT FOR EACH AREA, MATERIAL ELEMENT, OR FEATURE

12.1.1 Masonry Span

Stone Arches, Piers, and Abutments

The High Bridge piers are constructed of granite blocks. While the first three to five base courses are solid, each pier contains three hollow shafts that extend up to the spring line of the arches. The piers were filled with concrete up to the high water line, and weep holes was constructed to accommodate drainage of water, due to leaks or precipitation. The abutments are similar to the piers. Ten of the original 15 semi-circular arches remain in place. Seven of the ten arches measure 50 feet wide at the spring line, and each of the other three, measure 80 feet wide. The outer surfaces of the bridge (piers, arches, spandrels and parapets) are granite, while the interior stonework is primarily gneiss. Above each arch, parallel to the outer walls, are three gneiss haunch walls, approximately 2 feet thick, resulting in four longitudinal hollow chambers in each arch.

The proposed work for the stonework includes removal of all vegetation and cleaning of the granite. The required work includes repointing with mortar to match the original natural cement mortar in visual and physical characteristics, and pinning of cracked stones using appropriate stainless steel pins. To reduce the failure of the topmost horizontal joints of the stringcourses and impost blocks, which are subject to extreme weathering, new lead weathercaps are being considered in these specific areas, in addition to the original pointing.

Brick Arch

The brick arch that supports the walkway and forms the Attic roof dates to 1864. The arch exhibits several transverse cracks, moisture penetration, and plant growth. The Baker report, dated August 2006, notes that bricks were sampled from four locations and tested for strength. While the results of the compressive strength testing yielded lower than expected results, they are more than adequate for the applied compressive loads. An analysis by John Ochsendorf, a structural engineer specializing in historic masonry arches demonstrates

the stability of the original brick arch for the deck of the High Bridge (See Appendix). It indicates that the brick arch has reserve capacity for the design loading which will be applied to it. Therefore, the proposed treatment for the historic brick radial arch is crack repair and repointing of deteriorated mortar joints, in conjunction with the addition of supplemental tie rods (See LCE inspection report.)

Wrought Iron Tie Rods

The existing tie rods for the structural brick arch are wrought iron, spaced 5 feet on center within the attic. All of the tie rods exhibit section loss from corrosion, due principally to condensation, but also to leaks, and are structurally compromised. A finite element analysis demonstrates that the deteriorated wrought iron tie rods do not possess sufficient strength and therefore require supplemental supports. In accordance with *The Secretary of the Interiors' Standards* to retain as much historic fabric as possible, the recommended treatment is to keep the existing tie rods in situ and supplement them with new galvanized steel tie rods as required. The new tie rods should be placed evenly in relation to the historic tie rods, e.g., ten feet on center. Insertion of the new tie rods will require drilling into the cast-iron skewbacks, brick, and stone; the work should be carefully executed to ensure no damage to the historic material. The existing tie rods should be cleaned and painted with an appropriate rust-inhibitive paint to extend their longevity.

Cast Iron Skewbacks

The existing cast iron skewbacks are not visible from the walkway or the attic. Based on a probe and supported by archival drawings, they are set about two inches from the back of the granite coping, and about ten inches below the top of the coping. Each skewback is ten feet long, with the web and ribs measuring one inch thick. Based on the probe, the skewbacks are in good condition, and no work is anticipated. However, the insertion of new tie rods will impact the skewbacks, and should be carefully coordinated.

Waterproofing

The extant waterproofing is original to the 1864 construction, and is comprised of hot coal tar and Trinidad Lake asphalt. The top of the structural brick arch was coated with 1/2 inch of waterproofing, and the next brick underlayment course was dipped in the hot asphalt, laid flat, and then the joints were filled with hot asphalt, providing a cohesive waterproofing assembly. Based on probes, the existing waterproofing, which is almost 150 years old, shows significant loss of integrity, and should be removed and replaced. Given the extreme success of the original waterproofing, a similar asphaltic waterproofing assembly should be considered as the preferred option. Re-establishing the integrity of the waterproofing at the High Bridge will increase the longevity of the masonry and metal features below.

Underlayment

The paving bricks are set on a second course of bricks laid flat in a running bond pattern set in the waterproofing, as described above, and serve as the underlayment for the paving.

The existing brick underlayment should be replaced with a new underlayment to match the physical characteristics and performance of the original materials and assembly. Therefore a brick underlayment is the preferred option, set in either asphalt or a weak natural cement – lime mortar.

Brick Paving

The original brick paving of the masonry span is a hard burned red pressed paving brick set in herringbone pattern with natural cement mortar. The brick pavers exhibit the patina of age caused by natural soiling over time. Deficiencies include holes, cracks, chips, and replacement areas with non-matching brick.

The original brick pavers are almost 150 years old, and are a character-defining feature of the High Bridge. To the full extent possible, the original brick should be salvaged and re-used, with the understanding that the removal of the well bonded mortar from the brick requires extreme care and skill. The historic bricks which are determined to be in good and serviceable condition (estimated at 7,800 square feet) should be re-laid in selected areas such as the vault plazas, the masonry arch at the Manhattan side and several masonry arches at

the Bronx side. New brick paving should be custom fabricated to match the original pavers in composition, dimension, color range, texture, and physical properties. The brick should be laid in a herringbone pattern to match the existing. Consideration should be given to adding an expansion joint at the perimeter of the brick paving to accommodate expansion and contraction.

Given the dark appearance on the surface of many of the historic bricks, testing was performed to determine if a asphaltic or bituminous coating had been applied; it had not. (See Section 9: Materials Evaluation.) The patina of the bricks, consisting of close to a century and a half of dirt and grime, is a character-defining feature. New pavers should be custom fabricated to match the color range of the historic brick. If additional visual blending between the old and new pavers is desired, the new pavers may be treated with a reversible coating or "soiling" process so they appear closer in color to the soiled historic pavers.

Mortar

All mortar used on the High Bridge should be a natural cement mortar, e.g., Rosendale cement to match the original natural cement mortar in color, texture, tooling, and physical properties.

Vault lights

Historically there were round cast iron vault lights with glass lenses in iron frames in the brick walkway of the High Bridge, aligning with alternate piers and one pair at the top of the steps at the Manhattan end of the walkway. The glass vault lights allowed daylight to filter into the attic space below the walkway. While thirteen frames still exist, the vault lights no longer function; three openings now serve as manholes, and the other vault lights were simply covered over or removed. Only one vault light is visible from inside the attic; if others exist, they are concealed by sheetmetal or plywood coverings. The vault light openings were carefully integrated into the 1860s attic construction; the brick debris that lies below is from the circa 1979 campaign to patch selective areas of the brick.

The openings in the brick walkway which accommodated the vault lights should be used to provide access to the attic space below, i.e., manholes; for new cast interpretive plaques; and at least in one location for a restored or re-created vault light.

Attic

The attic exhibits brick walls from the construction periods of both 1848 and 1864. The attic is subject to localized water infiltration from various areas on the bridge deck including the penetrations at the security gates, manhole covers, expansion joints, stairs, and poor repairs. The proposed scope of rehabilitation work should stop the sources of water penetration into the attic. In addition, there is condensation clinging to the attic surfaces, and in the winter a thin sheet of ice coats the inner walls and brick arch areas. While the attic walls and ceilings are generally in good condition, there are localized areas of mortar loss, evidence of water penetration, efflorescence, broken bricks, cracks, and hollow and delaminated areas. There are niches in the walls at every other pier and haunch access in the concrete floor.

The attic space should be carefully cleaned of debris; the work should be monitored by an industrial archaeologist, documenting and salvaging historic material. The brick of the attic should be repointed where the mortar joints have deteriorated, using a natural cement mortar to match the original mortar in visual and physical properties. Areas of brick that are cracked should be repaired, providing structural stability, yet retaining historic material to full extent possible. Niches and haunch access should be retained. Areas in the floor where a person could fall through should have operable access panels installed to accommodate inspections. For safety during maintenance in inspections, the attic should have lighting installed.

Ventilation of the attic is critical for the longevity of the metal features contained within. At present there is significant condensation occurring in the space, resulting in deterioration of the wrought iron tie rods and the historic aqueduct water pipes. Therefore, if the conservation of the aqueduct pipes is considered a significant project objective, the introduction of ventilation into the attic space should be carefully considered. Options

include installing open grilles in the sealed masonry openings of the Bronx abutment, utilizing former openings the gatehouses and ventilators.

12.1.2 Steel Span

The steel span, dating from 1928, is of built-up construction using rivets. The replacement span required the removal of five stone arches and four piers, as well as the modification of two piers to support the new steel arch. It is a three hinged open spandrel deck arch, with one hinge at each abutment and one at the center span, allowing the bridge to expand and contract with temperature changes. Plate girders with crossbeams carry the aqueduct pipe. The walkway deck is comprised of steel floorbeams which curve to form the transverse profile of the walkway, with stringers placed normal to the profile, rather than vertical. The steel span is painted with lead paint. There are localized areas exhibit pitting, section loss, paint deterioration, surface rust, impacted rust build-up, crevice corrosion, rivet head and section loss, and debris accumulation. The hinges located at each abutment and at the center of the span are functioning as designed. There is heavy debris and corrosion surrounding all deck level bearings; the expansion bearings appear to be frozen. Rivets connecting the bottoms of the spandrel columns to the arch do not have sufficient strength for the imposed loadings.

The proposed treatment is to retain and repair the existing components of the steel span, with limited new elements to meet waterproofing and structural requirements. The intent is to abate the lead paint, provide waterproofing where none previously existed, and provide localized repair to elements including gusset plates, lateral bracing, deck floor beams, outside stringers, knee braces, deck plates, steel copings, and the inspection walkway, as required. In addition, deck level bearings will be replaced and rivets will be replaced with high strength bolts as required. The steel will be prepared, primed and painted per the historic paint analysis.

Brick Paving

The original brick paving of the steel span, dating to 1928, is a red pressed paving brick set in a running bond pattern with a white Portland cement mortar over a cementitious underlayment. The steel deck never had waterproofing and leaks in multiple locations. There are three steel expansion joints in the deck, corresponding to the location of the three hinges of the steel arch. Typical deficiencies include cracked, broken, bulging and depressed bricks, loss of mortar, and growth of moss, and vegetation. There are crushed bricks at the crown hinge joint from excessive expansion.

The running bond brick is a character defining feature of the 1920s section of the bridge walkway. Salvaged or new brick to match the match the original pavers in composition, dimension, color, texture, and physical properties should be re-laid over a new waterproof substrate. The brick should be laid in a running bond pattern to match the existing.

Mortar

Although the original mortar for the brick paving on the steel section of the bridge was a white Portland cement, it has weathered poorly, and the recommendation is to use a natural cement as was used throughout the rest of the bridge. The new mortar should match the original mortar in color, texture, and tooling. The original natural cement on the High Bridge has proven to be remarkably long-lasting, and for the longevity of the rehabilitation work, natural cement is proposed throughout.

Concrete Transition Between Masonry And Steel Sections

There are concrete transitional sections between the Attic and the Water Main Gallery, which isolate the masonry spans from the steel arch. The deck slabs above are also concrete and isolate the brick and steel decks. The walls are in poor condition and exhibit widespread efflorescence, cracking, spalling and hollow areas with evidence of alkali-silica reaction within the concrete. The proposed treatment is one of repair: remove spalled concrete, clean and paint exposed rebar, and patch concrete. As the repairs will most likely

damage the historic graffiti on the concrete, photographic documentation of the graffiti should be performed prior to performance of the work.

12.1.3 Aqueduct Pipes

36" Cast Iron Pipes

The two short segments of original 36" diameter ca. 1848 cast iron water pipes located in the Manhattan end of the attic should remain *in situ,* as should all the broken fragments of pipe in both ends of the attic. Based on reports by metal conservators and metallographer (see Section 9 of the HSR) the cast iron pipes are stable, and due to their one inch thickness, preservation of the pipes is best achieved by no intervention.

90 ½" Wrought Iron Pipe

The 1864 water main inside the attic exhibits areas of significant rust and section loss, with some holes in the pipe under the tie rods and vault light openings. Treatment of the pipe and supports should focus on retaining and preserving the material present "as is," without seeking to "restore" the pipe or attempting to reverse the corrosion. The proposed work is intended to improve environmental conditions for the pipe by removing sources of water infiltration and lessening condensation so as to stabilize the pipe from future deterioration.

The wrought iron water pipe should remain *in situ*. The first work required in the attic is to provide a safe work environment by removing dangerous conditions, which includes removal of delaminated sheets of wrought iron and loose scale from the top of the pipe by hand, and removal of accumulated loose iron flakes and paint from the interior of the pipe and the attic floor by hand and vacuuming.

To eliminate sources of water infiltration from above, the walkway and waterproofing should be restored, and manholes and former vault lights openings should be provided with waterproof seals. Ventilation of the attic is required to improve the drying time of the ironwork due to condensation. At the Bronx end of the attic to the two existing closed doorways in the abutment should be reopened and provided with new vandal-proof grille doors installed. Because there are no historic or original openings at the Manhattan end of the attic improved ventilation will require making opening into either the gatehouse or the wrought iron pipe to provide ventilation. Neither method of ventilating the Manhattan end of the attic is proposed for this rehabilitation project. To provide ventilation inside the wrought iron pipe the existing stone ventilators at both the Manhattan and Bronx gatehouse plazas should be re-opened, with new vandal-proof grilles installed.

In the masonry span no surface coating is recommended for the wrought iron pipe. At the steel span the wrought iron pipe should be painted in order to ensure its longevity and prevent it s deterioration which could result in material loss over the Harlem River or on the Harlem River Drive. Painting work for the wrought iron pipe at the steel span includes surface preparation by careful removal of loose rust, scale, dirt, guano, and efflorescence using water-jetting at a pressure capable of removing the rust without stripping the iron of its patina. Effluent from the water-jetting should be contained and removed from the site and disposed of as required by environmental regulations. The wrought iron pipe should be primed and painted with a high performance industrial coating system. Based on the paint analysis (see "Materials Analysis Report" in Section 9 of the HSR) the final coating color to be dark grayish reddish brown to match the original Prince's Metallic Paint.

Cast Iron Pedestals

The 1864 cast iron pedestals support the wrought iron water pipe on rollers to accommodate movement from expansion and contraction. The pedestals should remain *in situ,* unless they have been displaced. Where displaced, the pedestals should be reset in their original locations, ensuring no damage to the pipe in course of work. The pedestals should be properly seated, with new mortar below where missing. At the steel span only, the pedestals shall be prepared and painted as described above for the wrought iron pipe.

12" Pipes

The small segment of 1913 pipe should remain *in situ*. Based on reports by the metal conservator (see Section 9 of the HSR) the 12" pipes are stable, and preservation of the pipes is best achieved by no intervention.

12.1.4 Railings

The Gatehouse plazas and walkway at the masonry arch and steel arch spans feature cast iron and wrought iron railings that date from 1848, 1864, and 1928, each reflecting a significant period of the bridge's development. In addition, there has been some modern day repair work performed including replacement of selected areas of deteriorated bottom rails with non-matching elements, addition of non-historic post finials, non-historic braces, and one small section (approx. 10') of new rail (ca. 1979) at the Bronx Gatehouse plaza. Although each rail type has variations, such as the size and spacing of newel posts and pickets, and the type and extent of bracing, the ironwork generally reads as one continuous railing system. There are areas with significant replacement sections, areas in poor repair or missing elements, areas with undulations, and areas where the typical arch dimensions have been altered. Testing found detectable levels of lead in black over yellow over orange primer on the railings throughout the bridge.

The preferred treatment is the restoration of the historic railings, maintaining the existing locations and configurations, with modifications to ensure structural stability, safety and code compliance. These modifications include: making the top rail height consistent at 3'-6" (it currently varies from 3'-4" to 3'-6") by the installation of a base plates at newel posts and bottom rail supports; removing non-original post finials and bottom rails and replacing them with new to match the historic, removing non-original inboard rails braces that pose a tripping hazard to users; structural modifications such as new sleeves and angles at existing posts and braces to ensure compliance with structural load requirements; accommodations for expansion and contraction; and, to prohibit the possibility of small children walking between pickets, the installation of new oxidized stainless steel cable mesh at railings in the limited locations where there is an 8" clearance between pickets without the safety fence behind it. Finally, all historic elements to remain will be stripped of lead-containing paint, cleaned, primed and repainted black to match the historic finish.

In order to accommodate modern programmatic requirements for illumination and the safety fence, the proposed design calls for the discontinuity of the historic railing in limited locations. (See Section 12.1.5 Lighting.) The interruptions in the railing to accommodate the light fixtures should be carefully detailed to ensure minimal loss of historic fabric.

12.1.5 Lighting

Lampposts: The existing lampposts date from 1935. They are non-functional and exhibit peeling paint and light rust. The 18 lampposts are placed on alternate piers of the masonry span, and are symmetrically placed on the steel span. They measure approximately 9 feet in height to the line of the missing luminaires. The electrical conduit and junction boxes are surface mounted on the copings of the bridge deck.

To achieve the programmatic requirements for illumination and maintenance, the existing light poles would have to be raised to approximately 11 feet in height, thereby compromising their visual and historic integrity. Therefore, the proposed design calls for new 11 foot high lampposts appropriate to the historic character of the bridge.

Lamppost Location and Quantity: The original location of the light fixtures cannot be re-used due to the requirement for the safety fence. Locating the fixtures outboard of the fence would require an access panel in the fence adjacent to each fixture; access would be difficult and potentially dangerous. Locating the fixture in-board of the fence allows for safe maintenance access and focuses on the pedestrian experience of the historic railing and light poles, with the safety fence being in the background. As there is not sufficient room for the lamppost between the safety fence and the historic railing, the proposed location is in line with the historic railing; this will entail making the historic railing discontinuous to accommodate the light fixtures.

To achieve the required illumination using energy-efficient LED lamping in accordance with City's sustainability goals, the number of lampposts will be need to be increased from 18 to 24. The proposed design follows the historic alignment using the center-line of alternate piers and symmetrically supplements the number of lightpoles.

Conduit and Junction Box Locations: The intent is to limit the visual and physical impact on the historic fabric, including the potential for leaks. The proposed treatment is to surface-mount the conduit in the least visually intrusive manner while meeting code requirements. The conduit will be mounted close to the historic rail, on the outboard side, with small feet to allow drainage and to align with the bottom rail. The option for locating the conduit in the attic and core-drilling the granite up the deck was explored, but determined to be a potential source of leaks and damage to historic fabric. The junction boxes will be concealed within light fixtures bases.

Navigational Lights: The existing navigational lights are non-functional and will be replaced with new navigational lights.

Attic Lights: The existing lighting within the Attic is temporary and also not operational. New contemporary industrial attic lighting should be provided.

12.1.6 Gatehouses and Ventilators

The Bronx and Manhattan Gatehouses and Ventilators are not in the contract (NIC) or part of the HSR scope and are therefore no treatments are included except for reopening blocked openings to allow for ventilation of the attic and wrought iron pipe. They will remain in place and should be carefully protected during all phases of mobilization, demolition, and construction.

Granite Steps

The existing granite steps at both the Manhattan and Bronx gatehouses plazas are part of the 1864 construction. They should be removed, salvaged, and rebuilt ensuring an adequate pitch to drain. In addition, appropriate railings need to be added to the steps which historically did not have railings; the addition of railings is a safety feature and code requirement.

Coping Stones

Where displaced, the existing granite coping stones should be removed, salvaged, and reset in mortar to match the original in visual and physical characteristics, i.e., natural cement.

Bluestone Paving

The existing bluestone paving around the Manhattan gatehouse is typically in damaged condition. While the stone cannot effectively be salvaged for re-use, it should be documented and the new bluestone fabricated and installed to match the historic fabric in dimension, tooling, pattern, finish, and color. Mortar should match the historic in visual and physical characteristics as well.

Brick Paving

The existing pressed brick pavers at the Bronx gatehouse plaza and isolated areas of patching on the bridge should be removed, salvaged, and reinstalled over stable and waterproof substrates. The non-original wire-cut brick at both the Manhattan and Bronx gatehouse plazas should be discarded and replaced with new pressed brick to match the original pavers.

12.1.7 Safety Fence

The High Bridge traverses parkland, roadways, railways, and a waterway. Programmatically, the NYC Department of Parks and Recreation (DPR) requested safety fencing for several reasons: to deter people from dropping or throwing things off of the bridge, to deter people from jumping off of the bridge, to deter people from walking along the coping stones at the edge of the bridge, and to meet appropriate regulatory requirements. As the addition of the safety fence along the length of the bridge on both sides alters the

historic resource, careful consideration was given to the extent, location, design, and detailing of the proposed fencing.

Extent: Per the NYSDOT Bridge Manual, the determination was made that a safety fence would be required over all roadways, railways, plus an additional 10 feet extending beyond the shoulder of the under roadway and a minimum of 20-feet past the centerline of a single track or from the centerline of the two most external tracks over railroads. As there has been a documented history of vandalism in terms of objects thrown from the High Bridge onto boats in the Harlem River below, it is only prudent that the safety fence continue over this navigable waterway. To meet the programmatic issues outlined above, the safety fence would run from the west end of the access ramp on the Manhattan side to the east end of the access ramp on the Bronx side of the bridge, approximately 1300 feet, traversing parkland, roadways, railways, and a waterway.

Location: The masonry section of the High Bridge is approximately 25 feet wide including the coping stones; the historic iron railings are approximately 20'-6" feet apart; and the brick walkway is approximately 17 feet wide. The steel section of the High Bridge is approximately 28'-6" wide, aligning with the piers of the masonry section; the width at the piers of the steel section is approximately 36'-6" wide. The iron railings and brick walkway of both sections generally align. Numerous options were explored for the location of the safety fences, starting with attachments outboard of the bridge's piers and coping stones, thereby placing the safety fence as far as possible from the historic railing. The outboard option was determined to require the addition of brackets attached to the fascia of the bridge for structural stability, thereby altering the existing architectural rhythm. The second option was to locate the safety fence approximately one foot outboard of the historic railings, in alignment with the historic diagonal braces. This option would accommodate structural support of the fence without the addition of brackets, and would provide easier access for maintenance. However, it will require new anchorage into the historic granite and steel copings. This preferred location allows the historic rails to maintain their integrity – both visually and functionally; they stand clear of the safety fence, and can be used by pedestrians. Options for either attaching the fence directly to the historic rail or inboard of the rail would render the historic rail inutile, undermining the historic railing's integrity; therefore, these they are not recommended.

Form: The initial studies for the safety fence followed a linear form paralleling that of the historic railing. In an effort to relieve the potential monotony of two parallel lengths of 1200 linear feet of safety fence, options were explored for curved and undulating forms. While some of the undulating forms added interest to the safety fence, there were concerns regarding the appropriateness to the historic structure, cost, and maintenance. Therefore, the recommendation is for simplicity of form, i.e., a straight safety fence.

Post Spacing: The vertical supports establish the rhythm of the safety fence in relation to the historic bridge. It is therefore critical that the posts be located in a rhythm responsive to that of the bridge, e.g., centered on the stone piers of the granite arches and evenly spaced between the piers.

Material: The Owner of the High Bridge, DPR, as well as community stakeholders strongly voiced their objection to a safety fence that would result in an overwhelming sense of enclosure and loss of visibility from the bridge, as the High Bridge is intended for use as a park. Numerous options were explored for the material of the fence, including safety glazing, "lace fence" utilizing chain link in custom patterns, welded wire mesh, perforated metals, and metal cable net materials. The safety glazing was determined to be difficult to maintain, as it requires constant cleaning and is subject to etching. To achieve the greatest sense of openness, and provide a secure fence with aesthetic quality, the preferred material is the stainless steel cable net with a 2mm diameter thickness. To reduce reflectivity of the stainless steel cable net, it could be oxidized, resulting in a charcoal black appearance; the vertical supports could have a powder-coat paint or matte stainless steel finish. Selection of finishes should be carefully coordinated with the overall palette of the elements of the bridge, including the historic railings, light posts, and steel span.

Height of Fencing: The New York State Department of Transportation requires that pedestrian bridge fencing have a minimum height of 8 feet and in some applications have a 90 degree or 45 degree return inboard (NYSDOT Bridge Manual Section 6.5-Pedestrian Fencing). To reduce the sense of enclosure, the recommendation is to omit the return, and simply have a vertical fence.

Aperture in Fencing: NYSDOT standards would require the openings in the mesh of the fence to be no more than 1 inch square (NYSDOT Bridge Detail Drawing BD-FD2E). As this would create a sense of enclosure inappropriate to a historic pedestrian bridge, compliance with AASHTO LRFD Bridge Design Specification 13.8.1 would allow that mesh size in chain link or metal fabric fence have openings no larger than 2.0 inches: therefore a 60 mm aperture of the cable net is recommended.

12.1.8 Access

In order to accommodate wheeled users including wheelchairs, bicycles, strollers, and small maintenance vehicles, two new ramps at the Manhattan end and one new ramp at the Bronx end of the High Bridge are proposed. The location, design, materials, and details of each ramp are critical to its compatibility with the historic structure. In accordance with *The Secretary of the Interiors Standards for the Treatment of Historic Properties*, modifications should provide a reasonable balance between universal accessibility and the preservation of the historic character and features of the High Bridge. The focus should be on meeting the requirements of the American Disabilities Act (ADA), coordinated with addressing safety for bicyclists and minimizing visual and physical impact on the historic bridge.

- Manhattan: On the Manhattan side of the High Bridge, the 86'-8" foot long straight ramp is located along north side of gatehouse, parallel to the historic granite wall with 90 degree entry points at the upper plaza and vent plaza. The historic railing along the northern edge of the upper plaza would be removed and replaced with a seven foot high picket fence. Double gates, 7 foot in height, would be located at the ramp entrance to provide security when the park is closed. At the vent plaza, a 13 foot section of historic railing would be removed to accommodate the ramp. The granite coping stone would also need to be cut down to allow the ramp to meet the plaza at a smooth gradient. An additional 26 foot long ramp would be placed over the historic granite steps onto bridge at the north side of the walkway. This would require the addition of a landing on the bridge to compensate for the 7% cross slope at the edge of the walkway and the transition to the herringbone patterned brick walkway, as well as a tapered curb on top of the historic granite coping. As the ramp rises, the height of the safety fence would have to be raised to maintain the required 8'-0" height.

  An option was considered for locating the ramp on the north side of the bridge providing access directly from the gatehouse plaza to the walkway but was determined to be infeasible due to structural considerations of extending the ramp over the highway. Options for locating the ramp on the south side of the bridge were also considered, but were eliminated due to visual impact and the distance between the ramp entry and stair entry for the bridge. Finally, options for locating ramps either next to or inside of the gatehouse were considered, but eliminated due to feasibility, restricted clearances, impact on the historic fabric and security issues.

- The Manhattan ramp location may be potentially sensitive due to its proximity to the footprint of a former Pump House associated with the Croton water distribution system. The Pump House once stood northwest of the High Bridge Manhattan Gate House, and there is an extant retaining wall immediately north of the Gate House. Archaeological monitoring should be provided as required.

- Bronx: On the Bronx side of the High Bridge, the 73'-9" foot long straight ramp is located along north face of bridge, parallel to structure, with a 90 degree approach onto the bridge. At the entry to the ramp, a 7 foot high security gate will be placed between the gatehouse and the historic railing. A 10'-6" foot section of non-historic railing would be removed at the entry point adjacent to the gatehouse. To maximize the width of the ramp approach, approximately 13 feet of historic railing would also removed,

and replaced with a new ramp rail. At the ramp's juncture with the bridge, approximately 12 feet of historic railing would be removed to accommodate entry.

Options for utilizing existing access from the gatehouse plaza to the vent plaza and locating the ramp on the bridge surface was considered but eliminated due to its encroachment on the bridge. An option was considered for one ramp on the north side of the bride from the gatehouse plaza to the vent plaza combined with a ramp on the bridge from the vent plaza to the walkway. This option was determined to have too much impact on the bridge. Finally, an option was considered for one ramp providing access from the gatehouse plaza directly to the walkway, but was again determined to have too much impact on the bridge and the distance between the ramp entry and the stair entry for the bridge.

- Form and User Accommodation: The ramps were designed to accommodate pedestrians, wheelchair users, bicyclists, an NYPD scooter, and the GEM E2 maintenance vehicle. The maintenance vehicle is 99" long by 55" wide. To minimize the visual impact to the historic fabric, the ramp was designed as narrow as possible to accommodate the GEM E2, the larger of the two vehicles. The short ramp onto the bridge deck is 8-foot wide with an inside rail to rail clearance of 7'-1"; the longer ramps adjacent to the bridge are slightly wider to accommodate the vehicle turning movement.
- Material: To achieve the greatest sense of openness, and provide safety and aesthetic quality, the preferred material is the oxidized stainless steel cable net. Horizontal railings and vertical supports should be in a design vocabulary similar to the safety fences. The ramps should utilize a contemporary design vocabulary, responding to a modern programmatic requirement, and be clearly distinguished from the historic fabric.

12.1.9 Signage and Markings

The approach to the High Bridge from the Manhattan and the Bronx sides will include both lozenge-shaped greenway wayfinding signs and thermoplastic stencils on the paths that lead to the bridge. In most cases, both will include directional arrows and a text description to indicate a destination. Examples include: "To High Bridge and the Bronx", "To Highbridge Park Pool/Amsterdam Avenue", etc. There will be two new wayfinding signs on the Manhattan side and two on the Bronx side; three thermoplastic stencils will be located on each side of the bridge as well, indicating bicyclist and pedestrian graphic icons to clarify shared use of the path and gatehouse plaza areas.

SUMMARY OF TREATMENT RECOMMENDATION GRAPHIC PRESENTATIONS

AUGUST 31, 2010

Historic Rail Treatment Recommendations - Advantages and Disadvantages

Treatment Recommendation Option	Advantages	Disadvantages
▪ Restore rail with no alterations (other than structural)	▪ Historic rail will be preserved ▪ Historic rail can be seen in its original appearance	▪ Only works with safety fence options inside of historic rail or immediately adjacent to it due to the fact that the existing rail does not meet code requirements for rail height and pedestrian structural loads.
▪ Remove rail and replace with code compliant rail	▪ New rail will be code compliant with similar appearance to the original one ▪ Can be used with all safety fence options	▪ Significant historic fabric (historic rail) is removed from the bridge
▪ Restore rail with alterations for code compliance, including: ▪ Adding netting at balusters at any locations where railing has baluster spacing is larger than 6” and there is no safety fence behind it (for code compliance) ▪ Raising top rail height to 3’-6” with base plate ▪ Structural improvements (sleeves and angles)	▪ Historic rail will be preserved ▪ Alterations to the historic rail are reversible	▪ Alterations to historic rail will change its appearance slightly

Safety Fence Treatment Recommendations Advantages and Disadvantages

Treatment Recommendation Option	Advantages	Disadvantages
Location of Safety Fence		
▪ Safety Fence Inside of Historic Rail	▪ One continuous fence adjacent to bridge users	▪ Historic rail is obscured and non-functional ▪ Width of pavement slightly reduced ▪ Increased sense of enclosure ▪ New support holes required at deck
▪ Safety Fence Adjacent to and Outboard of Historic Rail	▪ Historic rail is visible & functional ▪ Width of pavement is not reduced ▪ No additional mesh required at historic rail	▪ Increased sense of enclosure ▪ Lessens sense of the historic rail ▪ New support holes required at deck
▪ Safety Fence Outboard of Historic Rail at Edge of Pier or Coping (Non-Pier)	▪ Historic rail is visible & functional ▪ Width of pavement is not reduced ▪ Safety fence is remote from bridge users; less sense of enclosure	▪ Some sense of enclosure, but not extreme ▪ Historic rail requires netting due to baluster spacing ▪ Large gap between fence and rail ▪ Structural attachment may require bracket extensions & new holes ▪ New support holes required at deck
▪ Safety Fence Set Back 1‘-0” Outboard of Historic Rail	▪ Historic rail is visible & functional ▪ Width of pavement is not reduced ▪ Potential to reuse existing holes at vertical supports	▪ Historic rail requires netting due to baluster spacing ▪ Large gap between fence and rail ▪ Some sense of enclosure, but not extreme ▪ New support holes required at deck
▪ Safety Fence Above Historic Rail in Same Plane	▪ Creates one barrier composed of rail & fence combined ▪ Width of pavement is not reduced	▪ Historic rail is altered or incorporated into a new assembly ▪ Historic rail must be retrofitted for current pedestrian load requirements ▪ New support holes required at deck

Treatment Option	Advantages	Disadvantages
Shape of Safety Fence		
▪ Straight Fence	▪ Uniform panel sizes	▪ Utilitarian appearance
▪ Curved Fence (Top to Bottom)	▪ Curves relate to bridge arches ▪ Curved form softens sense of enclosure	▪ Curved section at top of fence could potentially limit headroom at edges of the bridge
▪ Undulating Top (In/Out or Up/Down or Both)	▪ Fence reflects bridge piers ▪ Changes in height softens sense of enclosure	▪ Undulations create non-uniform panels
▪ Bear Claw Top	▪ Meets NYS DOT standard	▪ Extreme sense of enclosure ▪ Utilitarian appearance
▪ 45º or 90º Angled Top	▪ Meets NYS DOT standard ▪ Uniform panel sizes	▪ Extreme sense of enclosure ▪ Utilitarian appearance
Selection of In-Fill Material		
▪ Stainless Steel Cable Mesh (Various Sizes)	▪ Greatest sense of transparency of all the metal fence options ▪ Aesthetically appealing ▪ Difficult to climb if smaller apertures are used ▪ Flexibility makes it difficult to climb	▪ Slightly more difficult to create panels ▪ Easy to climb if larger apertures are used ▪ Moderately susceptible to being vandalized
▪ Woven Wire Mesh (1”x1” or 1”x3”)	▪ Meets NYS DOT requirements ▪ Easy to create panels ▪ Difficult to climb ▪ Difficult to vandalize	▪ Aesthetically unappealing
▪ Glass	▪ Most sense of transparency ▪ Difficult to climb	▪ Easy to vandalize ▪ Requires constant maintenance to keep clean
▪ Chain Link Fence	▪ Easy to create panels ▪ Difficult to climb if smaller apertures are used ▪	▪ Aesthetically unappealing ▪ Easy to climb if larger apertures are used
▪ Cambridge Metal Mesh	▪ Aesthetically appealing ▪ Difficult to climb if smaller apertures are used	▪ Slightly more difficult to create panels ▪ Easy to climb if larger apertures are used ▪ Moderately susceptible to being vandalized

See the following matrix for a complete list of all the schemes developed for the safety fence with selected graphic images to represent each type of treatment option.

13. Bibliography

13. Bibliography

PRIMARY SOURCE DOCUMENTS

Manuscript Collections

John B. Jervis Papers, 1827-1878. Microfilm edition.

New York City Department of Environmental Protection Archives.

New York City Municipal Archives. Bureau of Plant and Structures Collection.

Books

Bone, Kevin. *Water-Works: The Architecture and Engineering of New York Water Supply.* New York: Monacelli Press, 2006.

Bronx Society of Arts and Sciences. *In Memoriam: Edgar Allan Poe.* New York: Bronx Society of Arts and Sciences, 1909.

Craven, Alfred Wingate. *Answer of A. W. Craven, Chief Engineer Croton Aqueduct*. New York: Baker & Godwin, 1860.

DWSGE. *Minutes of the Croton Aqueduct Board of the City of New York, July 18, 1849 to April 9, 1870*. New York: Mail and Express Company, 1903.

Hone, Philip. *The Diary of Philip Hone: 1828-1851.* Volume II. New York: Dodd, Mead and Company, 1889.

Jervis, John B. *Description of the Croton Aqueduct*. New-York: Slamm and Guion, 1842.

King, Charles. *A Memoir of the Construction, Cost, and Capacity of the Croton Aqueduct*, *Compiled from Official Documents Together with an Account of the Civic Celebration of the Fourteenth October 1842, on Occasion of the Completion of the Great Work*: *Preceded by a Preliminary Essay on Ancient and Modern Aqueducts*. New York: Printed by C. King, 1843.

Schodek, Daniel L. *Landmarks in American Civil Engineering*. Boston: MIT Press, 1987.

Schramke, Theopholus. *Description of the New-York Croton Aqueduct, in English, German and French*. New York and Berlin: T. Schramke, 1846.

_____. *Description of the New-York Croton Aqueduct, in English, German and French*. New York and Berlin: T. Schramke, 1855.

Sutherland, Cara A. *Portraits of America: Bridges of New York.* New York: Barnes & Noble Books, 2003.

Tower, F. B. *Illustrations of the Croton Aqueduct*. New York, London: Wiley and Putnam, 1843.

Trautwine, John C. *The Civil Engineer's Pocket-Book*. 16th ed. New York: John Wiley & Sons, 1893.

Wegmann, Edward. *The Water-Supply of the City of New York, 1658-1895*. New York: John Wiley & Sons, 1896.

Periodicals

"The Great Croton Pipe." *The American Gas-Light Journal* 2, no. 18 (1860): 90.

"New Croton Water Works." *Mining & Petroleum Standards and American Gas-Light Journal* 8, no. 2 (1866): 20.

"Croton Water of New York." *Science* 3, no. 82 (1882): 31-36.

"John Bloomfield Jervis." *Science* 5, no. 112 (1885): 250-251.

"The Fate of High Bridge, New York City: Do the Facts in the Case Warrant Its Reconstruction or Demolition?" The *American Architect* 119 (1920): 45-49.

"Current News: Happenings and Comments in the Field of Architecture and the Allied Arts High Bridge Has Been Saved." *The American Architect* 119, no. 2355 (1921): 4.

"Our Point of View: Municipal Vandalism." *Scientific American*, May (1923): 300.

"Reconstructing Croton Aqueduct High Bridge." *Engineering News-Record* 99, no. 22 (1927): 864-866.

"Old Masonry Arches Give Way to New Steel Span at High Bridge." *Construction Methods Abbreviated* 10, no. 5 (1928): 16-19.

"Engineering and Construction: The Reconstruction of High Bridge, New York." *American Architect* 135, no. 2560 (January 5, 1929): 55-61.

Brush, W. W. "A 90-Inch Wrought Iron Main in Service 60 Years." *Fire and Water Engineering* 77, no. 16 (1925): 787-788 and 868.

Burnell, R. George. "Waterworks in the United States." *The Civil Engineer and Architect's Journal*, (August 1850): 259-261.

Church, Benjamin S. "Notes and Suggestions on the Croton Water Works and Supply, for the Future." Paper read before the ASCE, February 2, 1876 in *Transactions of the American Society of Civil Engineers* 5, 1876.

Church, B. S., and Robert A. Welcke. "The New Croton Aqueduct. Engineering Drawings and Data." (1885).

Dana, James D. "Geological Relations of the Limestone Belts of Westchester County, New York," *American Journal of Science [Third Series]* XXI, no. 126 (1881): 425-443.

Dearborn, William L. "Experiments for Making Brick Masonry Impervious to Water Tried on the Walls of the Back Bays of the Gate Houses of the New Croton Reservoir in New York, and on the Brick Arch of High Bridge in 1863." Paper read before the ASCE, May 4, 1870 in *Transactions of the American Society of Civil Engineers* (1870): 203-208.

Gregory, Charles E., and Eugene W. Stern. "Proposed Reconstruction of the High Bridge: An Informal Discussion." *The Municipal Engineers Journal* 3, no. 1 (1917): 96-102.

Jervis, John B. "Croton Water: A Correction." *Scribner's Monthly* XIV, no. 5 (1877): 723.

Rideing, William H. "Croton Water." *Scribner's Monthly* 14, no. 2 (1877): 161-175.

Rowell, Hugh Grant. "The Philipse Castle Restoration and Its Lessons." *The Journal of the American Society of Architectural Historians* 3, no. 4 (1943): 7-15.

Vrooman, John J. "Preservationism in New York State." *The Journal of the American Society of Architectural Historians* 4, no. 2 (1944): 37-41.

West, W. B. "Revising High Bridge." *Scientific American* 124, no. 18 (1920): 448.

Newspapers

Schwaner-Albright, Oliver. “Design Challenge: Fend off Disaster. *The New York Sun*, July 22, 2008.

"Croton Aqueduct-Notice." *New York Evening Post*, June 17, 1837.

"Board of Aldermen, July 16, Petitions Referred." *New York Spectator*, July 19, 1838.

"Croton Aqueduct, "the Great Bridge'." *New York Spectator*, August 2, 1838.

"Meeting of the Citizens of the County of Westchester in Relation to Crossing the Harlaem River with the Croton Aqueduct." *Hudson River Chronicle*, March 27, 1838.

"The Croton Water Work." *Morning Herald*, July 18, 1839.

"High Bridge Is Low Bridge." *New York Spectator*, January 28, 1839.

"The Water Commissioners and the Croton Aqueduct." *Morning Herald*, September 26, 1840.

"Fresh Water and New Potatoes." *Weekly Herald*, October 16, 1841.

"The Croton Aqueduct." *The New York Herald*, October 14, 1842, 1.

"The Croton Aqueduct." *New York Spectator*, June 29, 1842.

"The Great Croton Celebration Yesterday." *New York Herald*, Saturday, October 15, 1842.

"Drainage and Sewerage." *The New York Tribune*, December 31, 1844.

"Money Market Sunday March 9." *New York Herald*, March 3, 1845.

"Our Weekly Gossip: High Bridge Fountain." *The Harbinger*, June 24, 1848, 62.

"View of the High Bridge by Which the Croton Water Is Conducted across the Harlem River." *New York Herald*, April 17, 1848, 1.

"The Croton Aqueduct Investigation." *New York Herald*, September 12, 1860, 4.

"Croton Department: Opening of Bids for Important Jobs." *The New York Times*, July 3, 1860.

"Great Croton Pipe." *The Railways Times*, September 15, 1860.

"Great Croton Pipe." *New York Tribune*, September 8, 1860, 10.

"The High Bridge Croton Pipes: Reply of the Croton Board to the Mayor's Letter." *The New York Times*, September 27, 1860.

"The High Bridge: The Mayor Consents to the Completion of the Work." *The New York Times*, September 25, 1860.

"Improvements at the High Bridge." *The New York Times*, June 20, 1860.

"The Laying of the New Croton Mains over High Bridge." *New York Herald*, November 3, 1860.

"Navigation of Harlem River." *New York Tribune*, March 13, 1860.

"Completion of New Croton Main over the High Bridge." *Boston Daily Advertiser*, December 17, 1861.

"The Croton Aqueduct Is Guarded by the Police." *The Scioto Gazette*, May 7, 1861.

"The High Bridge-Croton Main." *New York Daily Tribune*, January 10, 1861.

"Improving Harlem River." *New York Daily Tribune*, April 4, 1861.

"Increase in the Supply of Croton." *New York Daily Tribune*, July 19, 1861.

"The New Croton Pipe over High Bridge." *New York Herald*, November 24, 1861.

"The New Reservoir." *New York Daily Tribune*, August 20, 1862.

"Our Water Supply." *The New York Times*, August 23, 1865.

"Croton Department: New High-Service Reservoir and Water-Works at Washington Heights." *The New York Tribune*, January 14, 1868.

"High Bridge: The Scenery and Surroundings - the New Reservoir - Progress of the Work." *The New York*

Times, August 22, 1869.

"Letter from Andrew H. Green." *The New York Times*, February 15, 1869.

"New York of the Future." *The New York Times*, February 15, 1869.

“The Sinking Fund.” *New York Times*, October 31, 1871.

"Obituary: Edward H. Tracy." *The New York Times*, August 29, 1875.

"The High Bridge over Harlem River." *Frank Leslie's Illustrated Newspaper*, September 6, 1879.

"Death of John B. Jervis." *The New York Evangelist*, January 22, 1885.

"John B. Jervis." *The New York Tribune*, January 14, 1885.

"Bicyclers Get Impatient: They Urge the Passage of the Aqueduct Path Bill." *The New York Tribune*, April 24, 1895.

"The Croton Cycle Path." *The New York Tribune*, April 21, 1895.

"The Croton Cycle Path." *The New York Tribune*, Sunday, April 21, 1895.

"The Croton Cycle Path: A Wheelam's Paradise, Thirty-Three Miles of Rural and Sylvan Pathway." *The New York Tribune*, April 21, 1895.

"On the New Speedway: Progress of the Work Along the Bank of the Harlem River." *New York Tribune*, July 18, 1897.

"Thomas F. Rowland Dead." *The New York Times*, December 14, 1907.

"High Bridge in Danger." *The New York Times*, November 13, 1916.

"Plans to Improve Harlem River: Picturesque High Bridge May Be Destroyed in Interest of Better and Safer Navigation." *The New York Times*, June 29, 1919.

“Mayor Makes Plain that His Namesake is a Seagoing Tug,” *New York Tribune,* May 8, 1920.

"Plan to Save High Bridge Demolition." *The New York Times*, April 18, 1920, Real Estate.

"Plans Presented for Reconstruction of High Bridge." *New York Tribune*, May 8, 1920.

"Pleas for High Bridge Changes Made to Us: Bronx Business Men Want the Structure Removed or Two Alternate Piers Demolished." *New York Tribune*, March 31, 1920.

"City to Save High Bridge." *New York Tribune*, January 22, 1921.

"Remove Two Piers of High Bridge: Borings Soon to Begin Will Mark First Effort in Harlem River Improvement." *The New York Times*, January 22, 1922.

"High Bridge May Go, New Defect Found: Structure Has Sagged Badly and the Cost of Remodeling Is Prohibitive." *The New York Times*, January 26, 1923.

"High Bridge Razing Officially Voted: Board of Estimate Approves Demolition of Structure Called Menace to Navigation." *The New York Times*, March 13, 1923.

"Open Fight to Save Historic High Bridge: Engineers, Architects and Historical Societies Unite to Prevent Demolition." *The New York Times*, March 14, 1923.

"‘Save High Bridge’ Campaign Grows: Parks and Playgrounds Association Join Architects, Engineers and Artists." *The New York Times*, March 15, 1923.

"Will Appeal Today to Save High Bridge: Engineers, Architects and Others to Appear before the Board of Estimate." *The New York Times*, March 16, 1923.

"Won't Tear Down High Bridge at Once: Board of Estimate Postpones Decision to Study Practicability of Remodeling Plan." *The New York Times*, March 17, 1923.

"High Bridge Saved: To Be Remodeled: Committee of Engineers and Architects Convince City Their Plan Is the Cheaper." *The New York Times*, June 30, 1923.

"Huge Steel Arch in High Bridge Plan." *The New York Times*, April 20, 1924.

"High Bridge Remodeled." *The New York Times*, July 16, 1925.

"Plans to Rebuild High Bridge Ready: Mills Submits Specifications for Reconstruction of Aqueduct to Bidders." *The New York Times*, December 27, 1925.

"$291,000 Is Saved on High Bridge Bids: Offer of $1,190,300 Received by the City on Simplified Reconstruction Plans." *The New York Times*, September 17, 1926.

"High Bridge to Be Rebuilt: War Department Approves Plans for Harlem River Span." *The New York Times*, August 20, 1926.

"To Rebuild High Bridge." *The New York Times*, June 8, 1926.

"High Bridge Opens as a Single Span: Modernized Structure Permits Navigation of the Entire Width of the Harlem." *The New York Times*, October 28, 1928, 24.

"High Bridge Transformed." *The New York Times*, October 30, 1928.

"Viaduct Being Razed for Bridge Approach." *New York Times*, August 10, 1950.

"High Bridge Water Tower Saved as City Landmark." *New York Times*, November 24, 1951.

"Letters to the Times: New York's Historic Site, Recent Moves to Preserve Monuments of Past Commended." *New York Times*, July 9, 1952.

"Tunnels and Ramps to Speed Traffic: West 179th Street Tube and Highbridge Interchange Due to End Snarls in April." *New York Times*, January 18, 1952.

O'Kane, Lawrence. "Span Is 'Swapped' on City Boat Ride; Top Officials, Viewing Harlem river Drive from Tug, Get Into Deal for High Bridge, Moses Agrees to Take It, Water Supply Head Seems Eager to Be Rid of It, but there May Be Difficulties," *New York Times*, July 8, 1954.

"Four Main Reservoirs Are Pouring over Spillways as a Result of Storm Rainfall: City Cuts Off Use of Croton Water." *New York Times*, October 18, 1955.

"River Landmarks to Be Park Units." *New York Times*, January 20, 1955.

"Carillon Offered to City for Park: Altman Fund Would Donate Electronic Equipment for Highbridge Area Tower." *New York Times*, December 19, 1957.

Lissner, Will. "Trail to Run Along Croton Aqueduct." *New York Times*, September 25, 1966.

Bird, David. "A 32-Mile Long Swath of Green From the Country to the City." *New York Times*, October 27, 1968, Resorts and Travel Section.

Government Documents

Croton Aqueduct Commission. *The Report of the Aqueduct Commission*. New York, 1883-1887.

Croton Aqueduct Commission. *Aqueduct Commission: Report of the Chief Engineer*. New York, 1887, 1895, and 1907.

Board of Commissioners of Central Park. *Twelfth Annual Report of the Board of Commissioners of the Central Park*. New York, 1868.

New York DWSGE. Bureau of Water Supply. *Annual Report of the Chief Engineer*. 1955-60.

Office of the Mayor, New York. *Report from the Mayor to the Board of Aldermen*. Clark, Aron. New York, 1838.

Croton Water Board. *Quarterly Report of the President of the Croton Water Board*. Coffin, James A. New York, 1845 and 1846.

Committee on Fire and Water. *Document No. 45, Board of Aldermen*. New York, 1835.

Committee on Roads and Canals. *Report of the Committee on Roads and Canals on the Petition of the Harlem River Canal Company Together with Affidavits Relating to the Same*. New York, 1839.

Committee on the Croton Aqueduct. *Report of the Committee on the Croton Aqueduct, in Favor of Discontinuing the Salaries of the Water Commissioners*. New York, 1841.

Committee on Finance. *Report of the Finance Committee*. New York, 1838.

Corporation of the City of New York. *Annual Report of the Comptroller, Exhibiting The Receipts and Expenditures of the City Government, Including the Operations of the Several Trust and Sinking Funds, for the Year 1862*. New York, 1863.

_____. *Communication from the Comptroller Transmitting a List of Contracts of the Corporation Filed and Registered in the Department of Finance During the Year 1864*. New York, 1864.

Croton Aqueduct Board. *Report of the Croton Aqueduct Board in Relation to the Ways and Means of Paying the Croton Water Debt*. New York, 1842.

_____. *Annual Report of the Croton Aqueduct Board*. New York, 1845.

_____. *Annual Report*. New York, 1851.

Croton Aqueduct Commission. *Expenditures and Receipts for the Years 1895 to 1907 [Statements Nos 1 and 2, Accompanying the Secretary's Report*. 1895-1907.

Croton Aqueduct Department. *Annual Report of the Croton Aqueduct Department Made to the Common Council of the City of New York*. New York, 1849-69.

Croton Aqueduct Department. *Fourteenth Annual Report of the Croton Aqueduct Department Made to the Common Council of the City of New York, January 5, 1863.* New York, 1862.

Croton Aqueduct Department. *Quarterly Report of the President of the Croton Aqueduct Board with the Draft of Two Acts in Relation to Said Department*. New York, 1848.

Board of Aldermen. *Report to the Board of Aldermen*. Davies, Henry E. Esq. New York, 1840.

Department of Plant and Structures, DWSGE. *Form of Proposals for Bids, Bid, Contract, Bond and Specifications for the Reconstruction of High Bridge over the Harlem River between the Boroughs of Manhattan and the Bronx*. New York, 1925.

_____. *Annual Report*. 1926-27.

Department of Public Parks. *Annual Report of the Board of Commissioners of the Department of Public Parks*. New York, 1872 and 1873.

Department of Public Works. *Annual Report of the Department of Public Works of the City of New York*. New York, 1870 and 1873.

DWSGE. *Annual Report*. New York, 1920-30.

Laws of the State of New York, 22nd sess., ch. 134, 816.

National Park Service. History Division. *Croton Aqueduct: National Register Nomination. Langie, Robie S., 1991, 12-13.*

New York Water Works. *Report of the Chief Engineer in Relation to the Plan for Crossing Harlem River*. Jervis, John B. New York, 1837.

_____. *Report of the Chief Engineer on Plans for Crossing Harlem River*. Jervis, John B. New York, 1839.

_____. *Report of J.B. Jervis, Chief Engineer with a Letter from Sing Sing, Containing an Account of the Late Flood*. Jervis, John B. New York, 1840.

_____. *Report on the General State of the Work on the Croton Aqueduct*. New York, 1842-48.

Water Commissioners. *Communication of the Water Commissioners under the Act of 2nd May, 1834 Which Was Referred to the Committee on Fire and Water*. New York, 1834.

_____. *Report of the Commissioners under an Act of the Legislature of This State Passed May 2, 1834 Relative to Supplying the City of New York with Pure and Wholesome Water.* New York, 1835.

_____. *Communication from the Water Commissioners*. New York, 1836.

_____. *Semi-Annual Report of the Water Commissioners*. New York, 1837-1848.

_____. *Communication from the Water Commissioners to the Board of Aldermen*. New York, 1838.

_____. *Supplemental Report of the Late Water Commissioners*. New York, 1840.

_____. *Communication from the Water Commissioners in Relation to the Aqueduct Bridge across the Harlem River,* June 5, 1848.

_____. *Supplemental Report of the Late Water Commissioners*. New York, 1848.

Water Commissioners, and John B. Jervis. *Communication from the Water Commissioners, in Reply to a Preamble and Resolution Adopted by the Board of Aldermen*. New York, 1841.

Department of Water Supply, Gas and Electricity, Bureau of Water Supply. *High Bridge Reconstruction: Progress Report for the Quarter Ended March 21, 1922*. Yates, W. H. Assistant Engineer, High Bridge Reconstruction. New York, 1922.

SECONDARY SOURCE DOCUMENTS

Books

Little Visits to Historical Points in Westchester County. Mamaroneck, New York: The Richbell Press, 1902.

The Old Croton Aqueduct: Rural Resources Meet Urban Needs. Edited by The Hudson River Museum of Westchester. Yonkers, New York: 1992.

Cowan, John F., Harry W. Walker, and Walter H. Sears. *Report to the Aqueduct Commissioners*. Aqueduct Commissioners New York: Press of W.P. Mitchell & Sons, 1907.

Committee on History and Heritage of American Civil Engineering. *A Biographical Dictionary of American Civil Engineers*, vol. 2. New York: ASCE Historical Publication, 1972.

Fitzsimons, Neal. *The Reminiscences of John B. Jervis: Engineer of the Old Croton.* Syracuse, New York: Syracuse University Press, 1971.

Galusha, Diana. *Liquid Assets: A History of New York City's Water System*. Purple Mountain Press, 2002.

Koeppel, Gerard T. *Water for Gotham: A History*. Princeton, New Jersey: Princeton University Press, 2000.

Lankton, Larry D. *The "Practicable" Engineer: John B. Jervis and the Old Croton Aqueduct: Essays in Public Works History Essay No. 5*. Chicago: Public Works Historical Society, 1977.

Larkin, F. Daniel. *John B. Jervis: An American Engineering Pioneer*. Edited by Iowa State University Press. Ames, Iowa: Iowa State University Press, 1990.

Lockwood, Charles. *Manhattan Moves Uptown: An Illustrated History.* Boston: Houghton Mifflin, 1976.

Miller, James. *Miller's New York as It Is, or Stranger's Guide-Book to the Cities of New York, Brooklyn and Adjacent Places*. New York: J. Miller, 1867.

Parsons Brinckerhoff and Engineering and Industrial Heritage. *A Context for Common Historic Bridge Types: NCHRP Project 25-25, Task 15, Prepared for the National Cooperative Highway Research Program, Transportation Research Council, National Council.* 2005.

Puzzo, Dante Anthony. *Walks Along the Croton Aqueduct: An Esstory*. Dobbs Ferry, New York: Randatamp Press, 1979.

Ruddock, Ted. *Masonry Bridges, Viaducts, and Aqueducts.* Studies in the History of Civil Engineering, vol. 2. Aldershot, Hants ; Burlington, Vermont: Ashgate/Variorum, 2000.

Dissertations

Larkin, F. Daniel. "The New York Years of John B. Jervis, a Builder of Nineteenth Century America." PhD Diss., State University of New York at Albany, 1976.

Theses

Hunter, Meisha. “Stewardship and Sustainability of Historic Waterworks Infrastructure: Rome and New York.” Post-Graduate Thesis, Columbia University, 2008.

Periodicals

"An Exhibition Illustrating the History of the Water Supply of the City of New York from 1639 to 1917." *Bulletin of the New York Public Library* 21, no.(**?**) (June 1917): 407-412.

"Rehabilitation of Historic Bridges." *Journal of Professional Issues in Engineering Education and Practice* 131, no. 3 (2005): 178-186.

Finch, J. K. "John Bloomfield Jervis, Civil Engineer." *Transactions of the Newcomen Society* 11 (1931): 109-20.

Kessler, William Conrad. "Letters of John B. Jervis." *Railway & Locomotive Historical Society Bulletin* 53 (1940): 11-18.

_____. "The Private Library of John Bloomfield Jervis." *Railway & Locomotive Historical Society Bulletin* 52 (1940): 41-47.

Kramer, Ellen W. "Contemporary Descriptions of New York City and Its Public Architecture Ca. 1850." *Journal of the Society of Architectural Historians* 27, no. 4 (1968): 264-280.

Lankton, Larry D. "Valley Crossings on the Old Croton Aqueduct." *IA* 4, no. 1 (1978): 27-42.

Molloy, Peter M. "Nineteenth-Century Hydropower: Design and Construction of Lawrence Dam, 1845-1848." *Winterthur Portfolio* 15, no. 4 (1980): 315-343.

Rappole, George H. "The Old Croton Aqueduct." *IA* 4, no. 1 (1978): 15-25.

Rosenberg, Elissa. "Public Works and Public Space: Rethinking the Urban Park." *Journal of Architectural Education* 50, no. 2 (1996): 89-103.

Stone, May N. "The Plumbing Paradox: American Attitudes toward Late Nineteenth-Century Domestic Sanitary Arrangements." *Winterthur Portfolio* 14, no. 3 (1979): 283-309.

Reports

Church, David. A Short History of Water Supply and Waste Disposal in New York City with Reference to Wall Street: Cultural Resources Survey Testing and Mitigation Phases, 60 Wall Street Site, New York City. Section X: Appendices A-F, Binder 1, B14.

Baker Engineering NY, Inc. "Bridge Condition and Assessment Report: High Bridge." BIN 2-24658-0, PIN: 84101MBBR181. 4 vols. August, 2006.

Lankton, Larry D. "Old Croton Aqueduct." Historic American Engineering Record, HAER NY-120, 1976.

Mead and Hunt. *Contextual Study of New York State's Pre-1961 Bridges, Prepared for New York State Department of Transportation*. November, 1999.

Websites

American Society of Civil Engineers, Met Section, "The Croton Water Supply System, "American Society of Civil Engineers, http://www.ascemetsection.org/content/view/341/875/"

14. Glossary

14. Glossary

AICE: American Institute of Consulting Engineers

BEA: New York City Board of Estimate and Apportionment

DPR: New York City Department of Parks & Recreation

DPS: New York City Department of Plant and Structures

DWSGE: New York City Department of Water Supply, Gas & Electricity

FWAWP: Federal Works Agency Works Project Administration

LPC: New York City Landmarks Preservation Commission

NYC-AIA: New York Chapter, American Institute of Architects

WPA: Works Progress Administration

Abutment: a masonry mass (or the like) which receives the thrust of an arch, vault, or strut**.**

Attic: the upper story of a structure, usually built above the cornice line, which may have windows or a blank wall. At the High Bridge the space above the haunches and below the walkway of the masonry span.

Battle deck: a type of deck configuration that originated in the construction of naval ships of war in the early part of the 20th century. It consisted of transverse steel frames and longitudinal I-beams, with steel plates riveted on top. At the High Bridge this is the structural steel deck below the brick paving of the steel span.

Cast iron: an iron alloy, usually including carbon and silicon; a large range of building products are made of this material by pouring molten metal into sand molds and then machining. Has high compressive strength, but low tensile strength.

Charcoal pig iron: a high purity pig iron obtained through the reduction of high grade ores in a blast furnace.

Cofferdam: a temporary watertight enclosure around an area of water or water-bearing soil, in which construction is to take place, bearing on a stable stratum at or above the foundation level of new construction. The water is pumped from within to permit free access to the area.

Coping: a protective cap, top or cover of wall, parapet, pilaster or chimney; often of stone, terra cotta, concrete, metal or wood. May be flat, but commonly sloping, double-beveled, or curved to shed water so as to protect masonry below from penetration of water from above. Most effective is extended beyond wall face and cut with a drip.

Efflorescence: generally whitish, powdery or whisker-like crystals on the surface of stone, brick, concrete, or other masonry materials. Efflorescence is commonly the result of evaporation of saline water present in the porous structure of the stone which are drawn to the surface where they then crystallize. Efflorescence is generally poorly cohesive and can be brushed off when dry.

Extrados: the external or upper surface of an arch or vault.

Gatehouses: gatehouses were situated at reservoirs, siphons, and other junction points. Subsurface waterworks at gatehouses included large valves and chambers for regulating and directing the water. Commonly, the works were sheltered by an ornamental superstructure. At the High Bridge, one-story granite gatehouses were situated at strategic points along the Croton Aqueduct channel, coinciding with the locations of reservoirs, siphons and other junction points nearby. Each gatehouse's at-grade superstructure was integrally linked with a sub-grade substructure of valves, sluice-gates, and chambers necessary for regulating water flow. Gatehouses provided access for maintenance crews responsible for performing repairs to the aqueduct channel. The performance of cyclical or emergency maintenance necessitated the temporary isolation and drainage of a segment of the Croton aqueduct. The cast-iron sluice-gates controlled by stopcocks in two gatehouses provided physical barriers for the water from entering or exiting the isolated segment. To drain the conduit segment, water was diverted to the Hudson River via the sewer line.

Gravity Supply: a water system in which the source of water is at a higher elevation than the place where the water is to be used.

Hance: see Haunch.

Haunch: the part of an arch midway between the springline and the crown.

Herringbone bond: in masonry, a type of raking bond in which the rows of headers are laid at right angles to each other so as to form, in plan a series of zigzags.

Hydraulic Cement: a cement that sets and hardens by chemical reaction with water and is capable of doing so under water.

Impost: a masonry unit or course, often projecting or distinctly profiled, from which an arch or vault springs, and which receives and distributes the thrust.

Intrados: the inner face of an arch or vault, generally forming the concave underside or soffit.

Inverted siphon: a pipe for conducting water at a depressed place, as from one hill to another across an intervening valley; water follows the path of a "U" where the inverted siphon allows a water to flow uphill without a pump, and then discharge at a level lower than the surface of the original reservoir. Siphons operate because gravity causes the hydrostatic pressure at the entrance to the pipe to exceed that at the top of the pipe by a sufficient amount to force water into the pipe and uphill. Gravity causes the hydrostatic pressure at the downstream end of the pipe to be significantly higher than the surrounding pressure so fluid flows out of the pipe into the atmosphere or into a second reservoir lower than the first.

Masonry conduit: A pipe or tube constructed of masonry used to convey a fluid, e.g. a masonry aqueduct.

Natural Cement: An hydraulic cement produced by calcining a naturally occurring argillaceous limestone at a temperature below the sintering point and then grinding to a fine powder. Commercial production of natural cement in North America began in 1819 following the discovery near Chittenango, central New York, by engineer Canvass White while working on the Erie Canal of an appropriate limestone for making hydraulic cement. Similar limestone was soon discovered in several states and production quickly expanded.

Pipe Gallery: unenclosed segment of the High Bridge corresponding to the steel arch (Section 3B in 1926 Construction Drawings) which contains the aqueduct pipe.

Portland Cement: hydraulic cement produced by pulverizing clinker, consisting essentially of crystalline hydraulic calcium silicates, and usually containing one or more of the following: water, calcium sulfate, up to 5 % limestone, and processing additions.

Rosendale Cement: natural cement from the region near the town of Rosendale in New York's central Hudson Valley, and used extensively in construction of the Croton Aqueduct and for all masonry on the High Bridge.

Running bond pattern (or stretcher bond): in masonry, a bond in which bricks or stones are laid lengthwise; all courses are laid as stretchers with the vertical joints of one course falling midway between those of adjacent courses.

Sluice gates: a sliding gate for controlling a flow of water in an artificial channel; a sluice is a water channel that is controlled at its head by a gate. A sluice gate is traditionally a wooden or metal plate which slides in grooves in the sides of the channel.

Skewback: a course of masonry, stone, or an iron plate having an inclined face against which the voussoirs of an arch abut

Spandrel: an area, roughly triangular in shape, between the extrados of an arch or two adjacent arches, and a horizontal bounding line above the crown of the arch or arches, such as a floor, coping, or road deck, in the case of bridges.

Standard: a structure built for or serving as a base or support.

Three Hinged Arch: a curved structure with hinges usually at each abutment and at the crown.

Tie Rod: a slender structural unit used as a tie and (in most applications) capable of carrying tensile loads only; a rod (as of steel) used as a connecting member or brace.

Waterproofing: a material, usually a membrane or applied compound, placed to make a structure impervious to water.

West Point Foundry: an early ironworks in Cold Spring, New York that operated from 1817 to 1911, founded by Gouvernour Kemble. Organized to remedy deficiencies in national armaments production after the War of 1812, it became most famous for its production of Parrott rifles and other munitions during the Civil War, although it also manufactured a variety of iron products for civilian use. The foundry also produced miles of cast-iron piping for the New York City water system.

Wrought iron: an easily welded and forged iron that is a mechanical mixture of refined metallic iron with 1 to 3 percent siliceous slag; a pure form of iron having a low carbon content and a fibrous microstructure; made by various processes and is often used for decorative work.