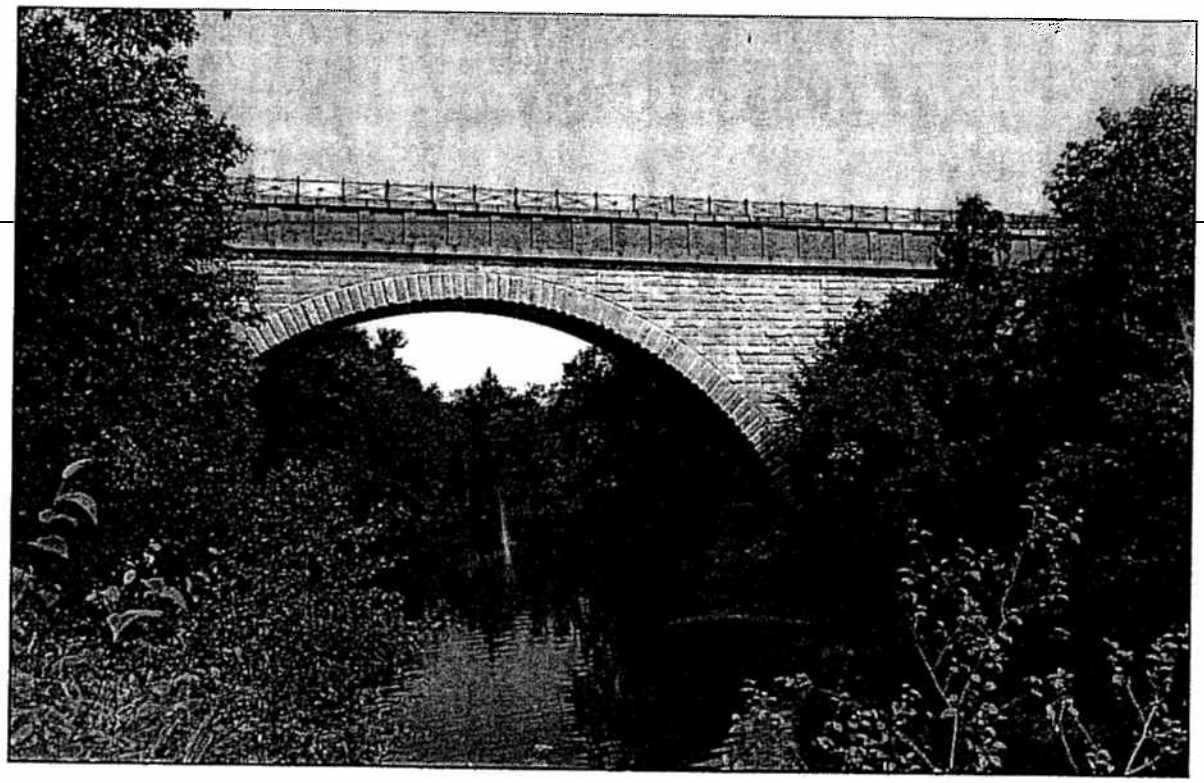
ECHO BRIDGE SAFETY IMPROVEMENT PROGRAM

MWRA CONTRACT No. 6988
TASK ORDER No. (18)

Historic Cast Iron and Steel Railings Report

Newton Upper Falls – Needham, Massachusetts

Prepared for the Massachusetts Water Resources Authority



Green International Affiliates, Inc.
Consulting Engineers
407R Mystic Avenue, Unit 25
Medford, MA 02155

McGinley Kalsow & Associates LLP
Architects & Preservation Planners
324 Broadway, PO Box 45248
Somerville, MA 02145

September 2007

Echo Bridge Safety Improvement Program

MWRA CONTRACT NO. 6988
TASK ORDER NO. (18)

Historic Cast Iron and Steel Railings Report

Newton Upper Falls - Needham, Massachusetts

September 2007

Prepared for the
Massachusetts Water Resources Authority

McGinley Kalsow & Associates LLP
ARCHITECTS & PRESERVATION PLANNERS

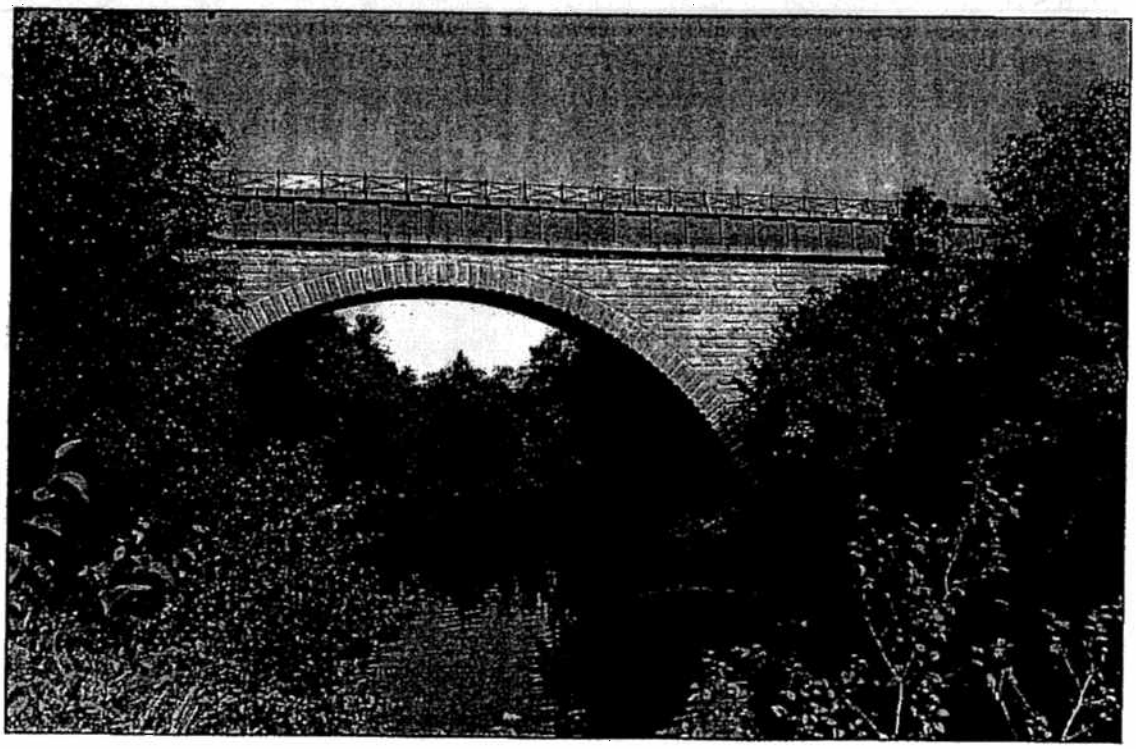
TABLE OF CONTENTS

Page Number

Introduction

The Massachusetts Water Resources Authority (MWRA) and Green International Affiliates, Inc. engaged McGinley Kalsow & Associates LLP (MKA), Architects and Preservation Planners, to evaluate the condition of the historic railings at Echo Bridge, make recommendations for repairing the railings and meet the current Massachusetts State Building Code. McGinley Kalsow & Associates LLP has 30-years of experience in the evaluation and repair or restoration of historic structures and particularly historic bridges throughout New England.

A state appropriation of $250,000 directed at MWRA has been received but additional funding will be necessary for the work that needs to be completed for the railings at Echo Bridge. At present, additional funding for the railing repairs is currently unavailable from the MWRA due to continued budget cuts, existing priorities focused on "active" facilities rather than "back-up" facilities, and the need for further Board of Directors approval. MWRA's chief concern is public safety, which is why the Bridge was fenced off from the public over a year ago. Since that time, temporary snow fencing was installed to improve safety conditions to keep the Bridge accessible, but a more permanent solution is needed. Given that the Bridge is on the National Register of Historic Places, MWRA cannot simply replace the railings without review by the Massachusetts Historical Commission and the local Historical Commissions. The intent of this report is to provide an existing conditions assessment of the railings, a listing of alternative ways to address the safety conditions and historical preservation issues (materials, design, etc.) with pros and cons, and provide a cost estimate for each scenario.



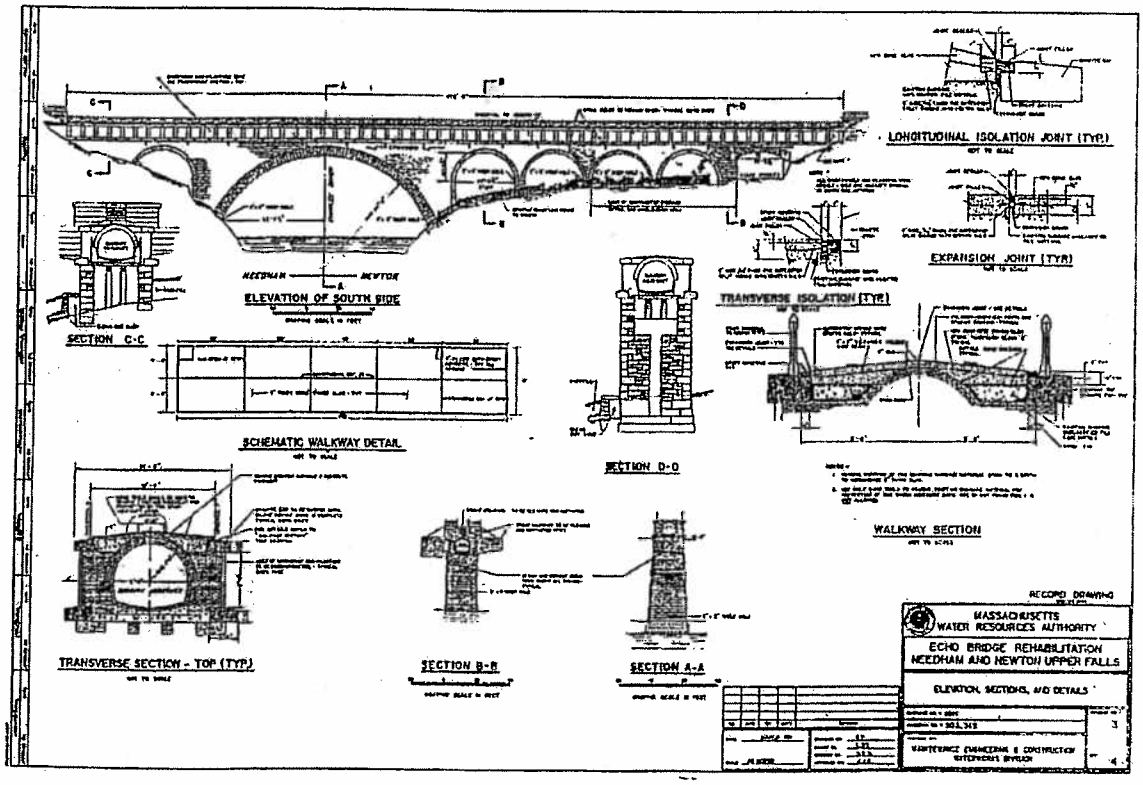
Echo Bridge – View from Charles River, 2007

Background

Echo Bridge is officially known as the Charles River Bridge and spans over the Charles River and Ellis Street, connecting the City of Newton and the Town of Needham. Echo Bridge is primarily an aqueduct that was built to carry water from the Sudbury River to Boston and has also served as a pedestrian bridge. The bridge was constructed in 1876 and 1877 at a cost of $200,000. The stone and brick bridge is 475 feet in length, 19 feet wide with seven stone arches. The arches vary in span from 127 feet to 28 feet with five arches at 36 feet 8 inches. The 127-foot arch was recognized in 1877 as the second longest span in North America and one of the largest stone arches in the world. Echo Bridge is located in Hemlock Gorge and connects two Department of Conservation and Recreation (DCR) parks on either side of the Charles River. In this capacity, it serves as a well-used pedestrian bridge. The bridge is listed individually on both the State and National Registers of Historic Places. It is also a contributing member of the Newton Upper Falls Historic District, which is also on both state and national registers.

Echo Bridge Location Map (Google Maps)

Historic Rendering of Echo Bridge



1991 Drawing of Echo Bridge Walkway Improvements

Previous MWRA Maintenance to Echo Bridge

The MWRA completed limited improvements to the Bridge in 1991 under the Echo Bridge Phase I Rehabilitation Contract. That contract included:

- Cleaning, repointing and resetting of brick masonry on both spandrels.
- Removal of the existing asphalt-paved walkway atop the bridge, and replacement with a concrete walkway.
- Cleaning and minor repointing of granite ashlar masonry on nearly all exterior bridge surfaces, and graffiti removal.

The rehabilitation of the bridge railings was not included in the project because the focus was on masonry repairs to protect the public from unstable brickwork and deterioration, and minor cosmetic improvements such as cleaning, graffiti and dirt removal. The railing rehabilitation and/or replacement was to be addressed in a subsequent phase when MWRA would consider the costs, public safety and continued public access to the bridge deck.

Previous Engineering Reports and Documentation of Echo Bridge

Several reports on the proposed Phase II work were completed and are listed below:

1. 1990 Existing Conditions Report - The Society for the Preservation of New England Antiquities documented the railing conditions as generally deteriorated by moisture entrapment due to various factors. The main recommendation of the report was to remove a test portion of railing and try various repair methods on it.

2. 1992 Preliminary Report - MWRA outlined a Phase II scope of work that included repairs to existing railings.

3. 1994 Preliminary Design Report - MWRA outlined alternative methods of railing renovations with estimated costs. Please note that these alternatives focused on in-kind replacement using original materials and/or aluminum instead of cast iron, but would look exactly like the original design.

    - Remove, clean, repair, and reinstall existing historic railings.
      1994 estimate: $350,000. 2004 estimate: $448,000.

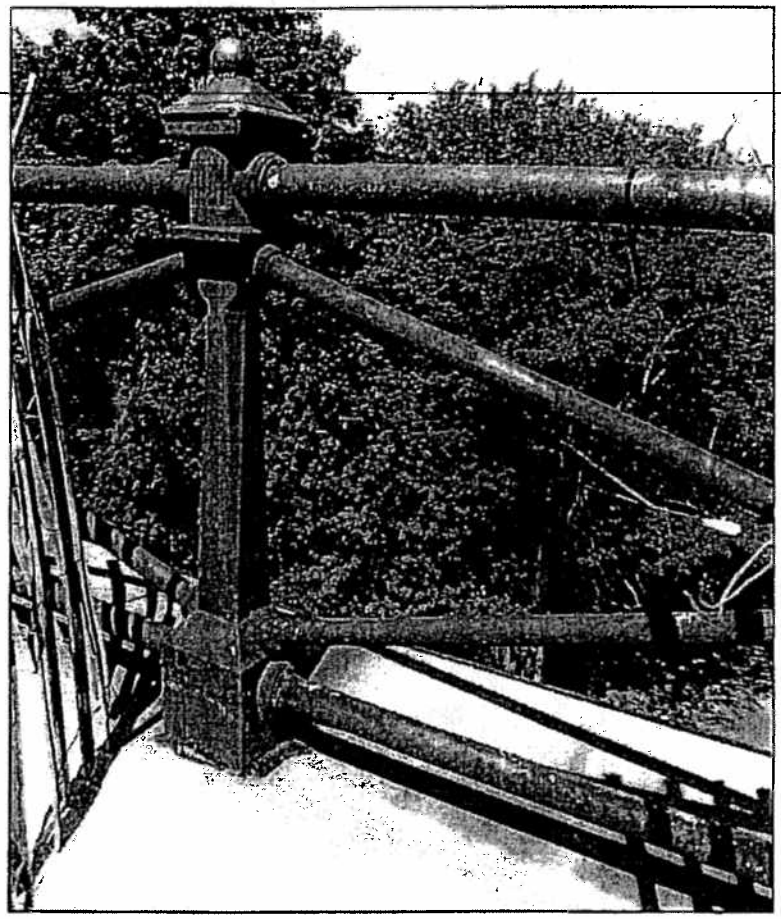
    - Remove all railings and install new cast aluminum railings that look like the originals.
      1994 estimate: $440,000 2004 estimate: $565,000.

    - Remove all railings and install in-kind cast iron railings.
      1994 estimate: 485,000 2004 estimate: $620,000.[1]

[1] Previous Maintenance and Previous Engineering Reports and Documentation excerpted from Attachment A, which was prepared as part of a January 29, 2007 submission to the Massachusetts Historical Commission.

Summary of Existing Conditions

All of the highly decorative posts on the bridge and abutments are constructed of cast iron and a variety of cast iron and steel railings connect these posts. On the bridge, cast iron rosettes containing the initials of the Boston Water Works (BWW) are at the intersection of the intermediate rails. The cast iron posts were secured to the granite copingstones with a threaded steel rod that extends from the granite to a cast iron ball cap at the top of the post. Where visible, virtually all of these threaded rods have corroded and detached from the ball cap that clamps the post to the bridge. In 1990 it was estimated that 20% of the cast iron posts needed to be replaced. In the past, efforts were undertaken to stabilize the posts by partially filling the posts with a cementitious grout and then welding the cast iron ball tops to the post. This cementitious grout not only trapped moisture but also gave a surface for ice-jacking to take place.

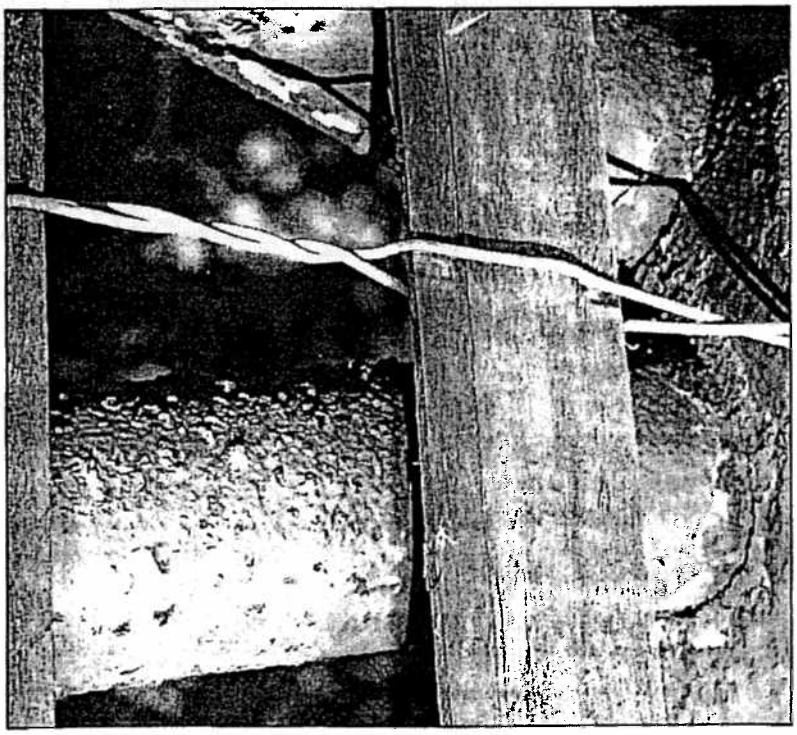


Typical Bridge Post and Rail

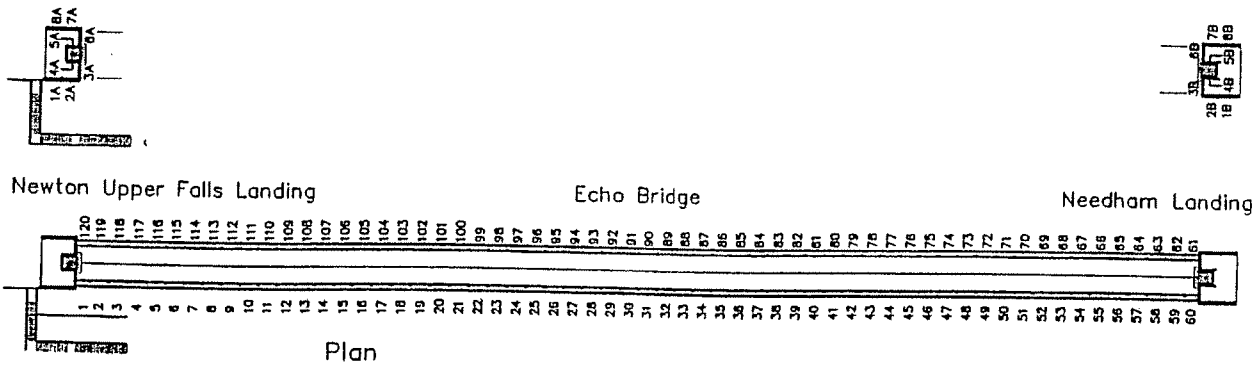
At this time more than 50% of the posts are severely damaged. Because of the grout that was added and the severe rusting of railings, half of the visually sound posts are likely to be damaged during the dismantling process, leading to replacement of approximately 75% of all decorative cast iron posts. Extensive corrosion inside the cast iron posts is taking place as evidenced by the rusting pattern on the granite coping. A much lower percentage (21%) of the BWW rosettes have spalled at the bottom or rusted at the rail pipe joints beyond repair. This number will also significantly increase during the disassembly process. Five to twenty-three percent of the railings have rust corrosion, reducing the mechanical strength of the rail and its connections. However, the most severe corrosion is on the inside of the pipe where it is not visible in-situ. Because of extensive corrosion where the railing is connected to the cast iron post, freeing this joint without damage to one part may be impossible in many cases. With an estimated 25% of the posts being repairable, the clear priority should be given to refurbishing them and replacing the railings.

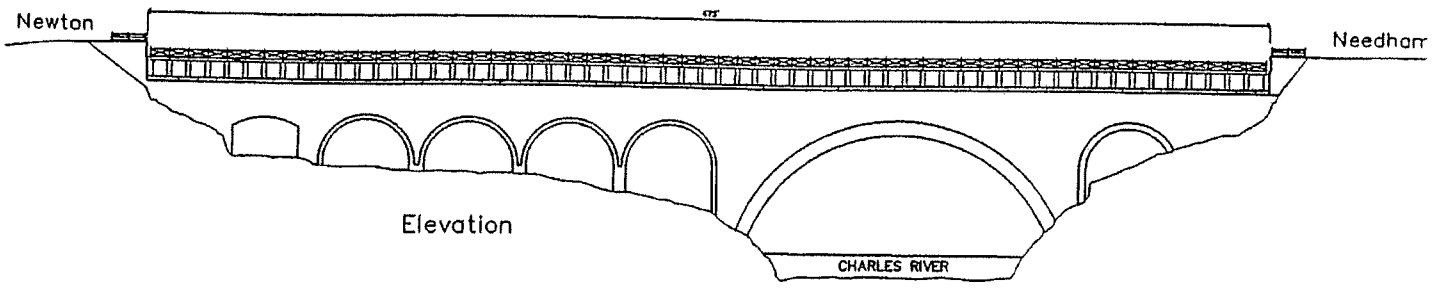
Spalling Cast Iron at Post Base

Inappropriate Repairs and Eroded Paint



Paint Blistering and Rail Joint Failure at Rosette





EXISTING CONDITIONS SURVEY

RAILING SECTION NUMBERING SYSTEM

Echo Bridge - Bridge Railings
Existing Conditions Summary Table

Section Number	Railing Components														
	Post									Observable Rail Damage					
			Post Type		Finial (Ball)			Concrete	Paint		"X"	"X"		
	Replace	Breakage	Middle	End	3"	2"	Missing	Filled	Failure	Top	Left *	Right *	Rosette	Bottom
1	1	1		1			1	1	1		0.5			
2			1				1		1	1				1
3			1		1				1					1
4	1	1	1		1				1	1			1	
5	1	1	1			1			1					
6			1			1			1					
7			1		1				1				1	
8			1			1			1			1		
9	1	1	1			1			1					
10			1			1			1					
11	1	1	1		1				1					
12	1	1	1			1			1					1
13			1		1				1				1	
14			1		1				1					
15	1	1	1			1		1	1		0.5			
16	1	1	1				1	1	1					
17	1	1	1		1				1					
18	1	1	1			1		1	1					
19			1			1			1		0.5	0.5		1
20	1	1	1			1		1	1					1
21			1				1		1					1
22	1	1	1			1		1	1					
23			1				1		1					
24	1	1	1				1	1	1					
25	1	1	1			1		1	1				1	
26	1	1	1			1		1	1					1
27		1	1			1			1		0.5			
28	1	1	1			1			1		1		1	
29	1	1	1		1			1	1					
30	1	1	1			1			1					
31	1	1	1			1		1	1					
32	1		1			1		1	1					1
33	1	1	1		1				1		1			
34	1	1	1		1				1				1	
35	1	1	1		1				1					
36			1		1			1	1					
37	1	1	1			1			1					
38	1	1	1			1		1	1					
39			1				1		1		0.5			
40			1		1				1					
41			1				1		1		0.5			
42			1			1			1					1
43			1		1				1					
44	1	1	1			1		1	1		1			
45	1		1				1	1	1					1
46	1		1			1		1	1			0.5		1
47	1		1			1		1	1					1
48			1			1			1				1	
49			1		1				1				1	
50	1	1	1			1		1	1					1
51			1		1				1					
52	1	1	1		1				1	1				
53			1		1				1	1				
54			1		1				1					1
55	1	1	1		1				1		0.5	0.5		
56	1	1	1			1		1	1					
57	1	1	1			1		1	1					1
58	1	1	1			1		1	1		0.5			1
59			1			1			1					
60				1					1					1
61	1	1		1		1		1	1	1	1	1	1	
62			1		1				1					
63			1		1				1					
64		1	1		1				1					
65			1		1				1					

Echo Bridge - Bridge Railings
Existing Conditions Summary Table

Section Number	Railing Components													
	Post									Observable Rail Damage				
			Post Type		Finial (Ball)									
	Replace	Breakage	Middle	End	3"	2"	Missing	Concrete Filled	Paint Failure	Top	"X" Left *	"X" Right *	Rosette	Bottom
66			1		1				1					
67			1		1				1			0.5		
68			1		1				1			0.5		
69			1		1				1		0.5			
70			1			1			1					
71	1	1	1				1	1	1					1
72	1	1	1			1		1	1				1	
73			1		1				1					
74			1		1				1					
75	1	1	1			1		1	1				1	
76	1	1	1		1				1					
77			1		1				1			0.5		1
78			1		1				1			0.5	1	
79			1		1				1					
80	1	1	1			1		1	1			0.5	1	
81	1	1	1				1		1				1	
82			1		1				1			0.5		
83		1	1				1		1					
84			1				1		1	1				
85	1	1	1		1			1	1					
86			1		1				1				1	
87	1	1	1			1		1	1				1	
88	1	1	1			1		1	1			0.5	1	
89			1				1		1			0.5		
90	1	1	1				1	1	1			0.5	1	
91	1		1				1	1	1				1	1
92	1		1				1	1	1				1	
93			1				1		1				1	
94	1	1	1			1		1	1		0.5	0.5		
95	1	1	1			1		1	1					
96			1		1				1		0.5			1
97			1				1		1					
98			1				1		1				1	
99	1		1			1		1	1		0.5			
100	1	1	1			1		1	1				1	
101			1			1			1			0.5		
102	1	1	1		1			1	1					1
103	1	1	1		1			1	1				1	
104	1	1	1		1			1	1					1
105	1	1	1		1			1	1			0.5		
106			1		1				1		0.5	0.5	1	
107	1	1	1			1			1					
108			1		1				1				1	
109			1		1				1		0.5			
110			1			1			1			0.5		
111			1		1				1					1
112	1	1	1			1		1	1			0.5		
113			1		1				1					
114			1				1		1		0.5			
115	1	1	1			1		1	1					1
116	1	1	1		1				1					
117	1		1			1		1	1		0.5			
118	1	1	1		1			1	1					1
119	1	1	1			1		1	1					
120				1					1			0.5		1
Totals	63	58	116	4	49	48	21	46	120	6	12	11	25	27
Percentages	52%	48%	95%	3%	42%	41%	18%	38%	100%	5%	10%	9%	21%	23%

* The survey identifies the cross railings by their locations left or right of the rosette. There are two cross rails on each side of the rosette. ".5" would mean that one of the rails on a side is damaged.

Echo Bridge - Landing Railings
Existing Conditions Summary Table

Newton Upper Falls Landing

Section Number	Railing Components																	
	Post												Observable Rail Damage					
			Post Type					Finial (Ball)			Concrete	Paint						
	Replace	Breakage	End	Middle	Corner	Cast Iron	Galv. Stl	3"	2"	Missing	Filled	Failure	Top	Middle	Bottom	Cast Iron	Steel/ Galv. Stl	
1 A	1	1		1		1						1			1		3	
2 A	1	1		1		1						1		1			3	
3 A	1				1		1					1					3	
4 A	2		1		1		2					2	1				3	
5 A	2	2	1		1	2		1		1	1	2	1	1	1	3		
6 A	1	1			1	1				1	1	1	1		1	3		
7 A	1	1		1		1			1		1	1			1	2	1	
8 A			1			1		1				1		1	1	3		
Totals	9	6	3	3	4	7	3	2	1	2	3	10	3	3	5	11	13	
Percentages	90%	60%	30%	30%	40%	70%	30%	20%	10%	20%	30%	100%	38%	38%	63%	46%	54%	

Needham Landing

Section Number	Railing Components																
	Post												Observable Rail Damage				
		Base	Post Type					Finial (Ball)			Concrete	Paint					
	Replace	Rust Fail	End	Middle	Corner	Cast Iron	Galv. Stl	3"	2"	Missing	Filled	Failure	Top	Middle	Bottom	Cast Iron	Galv. Stl
1 B	1	1	1				1					1				3	
2 B	1	1		1			1					1				2	1
3 B	1	1			1		1					1				2	1
4 B	2	2	1		1		2					2	1		1	2	1
5 B	2	2	1		1		2					2				1	2
6 B	1	1			1		1					1				1	2
7 B	1	1		1			1					1				1	2
8 B	1	1	1				1					1			1	2	1
Totals	10	10	4	2	4	0	10	0	0	0	0	10	1	0	2	14	10
Percentages	100%	100%	40%	20%	40%	0%	100%	0%	0%	0%	0%	100%	13%	0%	25%	58%	42%

Lead Paint

The railings and posts have been repainted numerous times since they were first installed in the late 1870's. Most painted metals at that time were primed with red lead or lead based paints.

Lead testing of the posts and rail components was performed by an independent testing lab. (Please reference Appendix E for lead paint evaluation.) At least ten separate tests were performed on each type of rail component. As expected for a railing of this age, most surfaces showed regulated levels of lead with results above the Massachusetts residential standard of 1.0mg/cm2.

The presence of regulated levels of lead containing paint on the posts and rails will require compliance with both federal and state regulations. The health and safety of the workers and the public will need to be protected during dismantling, removal of paint and disposal of lead-containing materials.

Historical and Safety Considerations

A solution to the Echo Bridge guardrails must be developed and implemented which adequately addresses the historic significance of the railings and provides safety to the public, and is in general conformance to the State Building Code for guardrails. The ornate railing system is a significant historic and character defining element of Echo Bridge. Deterioration of the existing railing system is so severe and rapidly advancing due to previously inadequate repair attempts, that the railing cannot be left in place as a "relic" because of the danger of cast iron or steel components falling off the bridge. The existing railing assembly, if left in place will present potential risks to pedestrians and vehicles below. The deterioration of the railing system has been publicly recognized since 1990. It is now imperative that a long term solution be developed and implemented that addresses both historic and public safety concerns.

Immediate Safety Considerations

During the week of August 6th, the MWRA installed areas of snow fencing to infill gaps in the railing system. In addition to these repairs, we recommend that a structural assessment of the existing cast iron posts and snow fence assembly take place to determine if they are structurally adequate.

Massachusetts Historical Commission Regulatory Review

Since Echo Bridge is listed on the State and National Registers of Historic Places, historic review and consultation are required with the Massachusetts Historical Commission (MHC) in compliance with Chapter 254 of the Acts of 1988. No federal actions are anticipated in this project.

Echo Bridge is a property under the management of the Massachusetts Water Resources Authority (MWRA), the project proponent. Limited funding ($250,000.) is being provided through an appropriation in the State Budget. A Project Notification Form (PNF) was submitted to the MHC on January 29, 2007. MWRA conducted two public meetings held on March 7, 2007 with the Newton Upper Falls Historic District Commission and with local stakeholders, MHC, and legislators from Newton and Needham on March 21, 2007.

An architectural and preliminary design evaluation of the existing railings was initiated in May 2007 and determined that the existing deteriorated and non-compliant railings could not be simply rehabilitated and made code compliant. An initial meeting was held with local community interests and stakeholders to review evaluation findings and to solicit their input. The community input to date has been carefully considered in the development of the alternative design proposals and recommendations contained herein. Another community meeting will be held shortly to present the alternative design proposals and recommendations and to elicit public input from all stakeholders. MWRA will consult with MHC and decide on a final design approach in compliance with Chapter 254 of the Acts of 1988 before proceeding with final design of the project.

Massachusetts Architectural Access Board Rules and Regulations

It is important that the MWRA address the issue of accessibility with the Massachusetts Architectural Access Board.

Summary of Alternatives

After evaluating the conditions of the existing railing system, we have explored various alternative solutions and listed their positive and negative salient characteristics. The common element to both of these recommended approaches is the careful refurbishment and testing of existing sound structural cast iron posts, and cast iron BWW rosettes with the addition of new replica structural cast ductile iron posts, rosettes and new galvanized steel pipe iron railings. (See Summary Chart on Page 13)

The following is a summary of various alternatives with the opinion of MKA given under the comments heading:

Recommended Alternatives

Description	Comments
1. Refurbish and Retrofit Existing Railing to Meet Code Refurbish sound existing structural cast iron architectural elements. Replicate deteriorated structural elements with new cast ductile iron and use painted galvanized steel railings. Attach stainless steel wire mesh guard panels to railing system.	• Retains or replicates historic railing • Adds opening reducing panel system to make original railings code conforming • Probable Cost: $ 1,045,000
2. Refurbish Existing Railing and Install Additional Code Compliant Railing Refurbish sound existing structural cast iron architectural elements. Replicate deteriorated structural elements with new cast ductile iron and use painted galvanized steel railings. Construct an independent guardrail attached to the concrete bridge deck.	• Retains or replicates historic railings • Adds code conforming independent guardrail system. Refurbished original rails become decorative. • Probable Cost: $ 1,077,000

Other Alternatives Considered

3. New Steel Guardrail Remove the existing railing system and replace with modern steel guardrails.	• Loss of significant historic fabric • Historically unacceptable • Probable Cost: $ 471,000
4. New Cast Iron and Galvanized Steel with New Guardrail System Replicate original design with all new cast ductile iron and galvanized steel. Add attached or independent guardrail system.	• Loss of significant historic fabric • Probable Cost: $ 893,000
5. Aluminum Simulated Historic Guardrail Replicate original design with all new cast aluminum and extruded aluminum tubing. Add attached or independent guardrail system.	• Loss of significant historic fabric • Probable Cost: $ 978,000
6. Decorative Fiberglass Simulated Historic Guardrail with Steel Supports Replicate decorative cast iron and rail elements with fiberglass. Add attached or independent guardrail system.	• Loss of significant historic fabric • Decorative fiberglass is not recommended as a structural element • Poor substitution for cast iron • Poor long term durability • Probable Cost: $ 928,000, if used with concealed steel structural system.

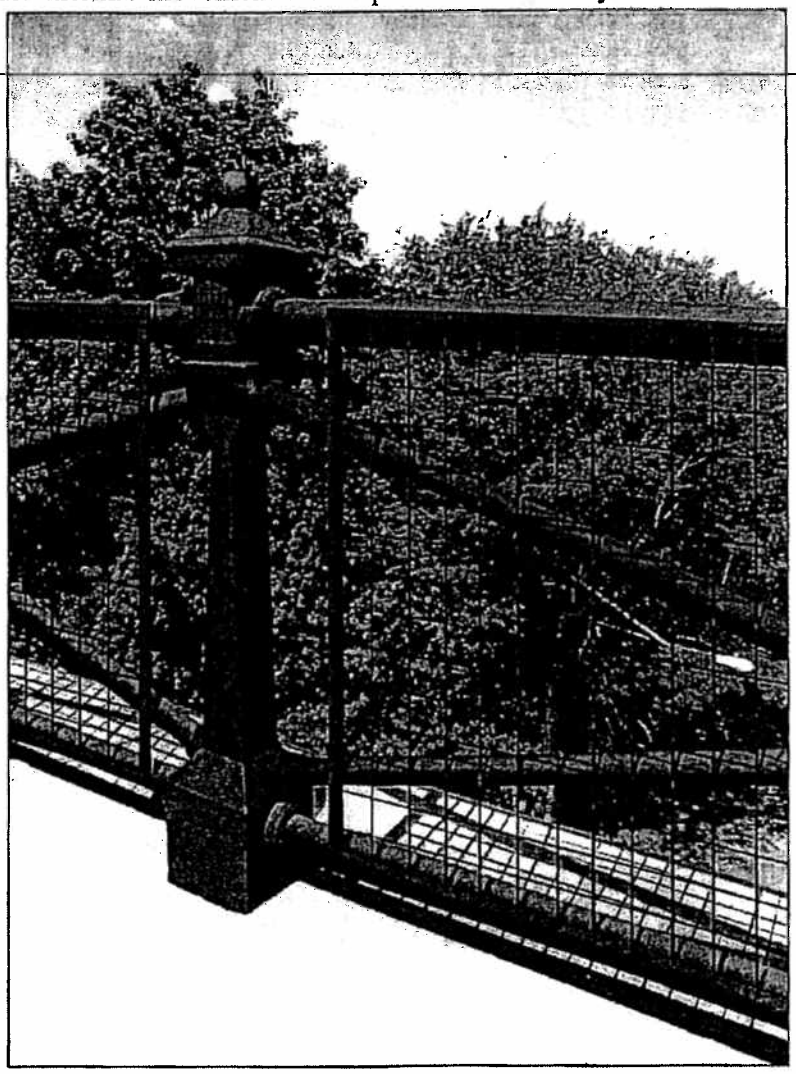
Proposed Alternatives

Common elements to both recommended alternatives are the careful dismantling of all components with the intent of salvaging the greatest possible number of sound decorative cast iron elements for shop refurbishment. The interior and exterior of each element will need to be sandblasted. Minor cracks can be repaired with nickel alloy welding electrodes (Ni-Rods). Each existing cast iron element will need to be examined by an architectural conservator and undergo load testing acceptable to the structural engineer. New cast iron posts and rosettes should be cast with ductile cast iron rather than "grey" cast iron with a wall thickness that is more substantial (3/8" minimum) and more uniform than the existing. This will increase the ability of the new post to resist corrosion and its structural capacity. Small detail changes to the connections, such as slightly increasing the opening size where pipe rails penetrate the post and substituting color galvanized steel rails for cast iron, will allow the rail system to better handle thermal movement and improve its durability All surfaces including the inside of cast iron elements should be painted with a durable industrial paint system.

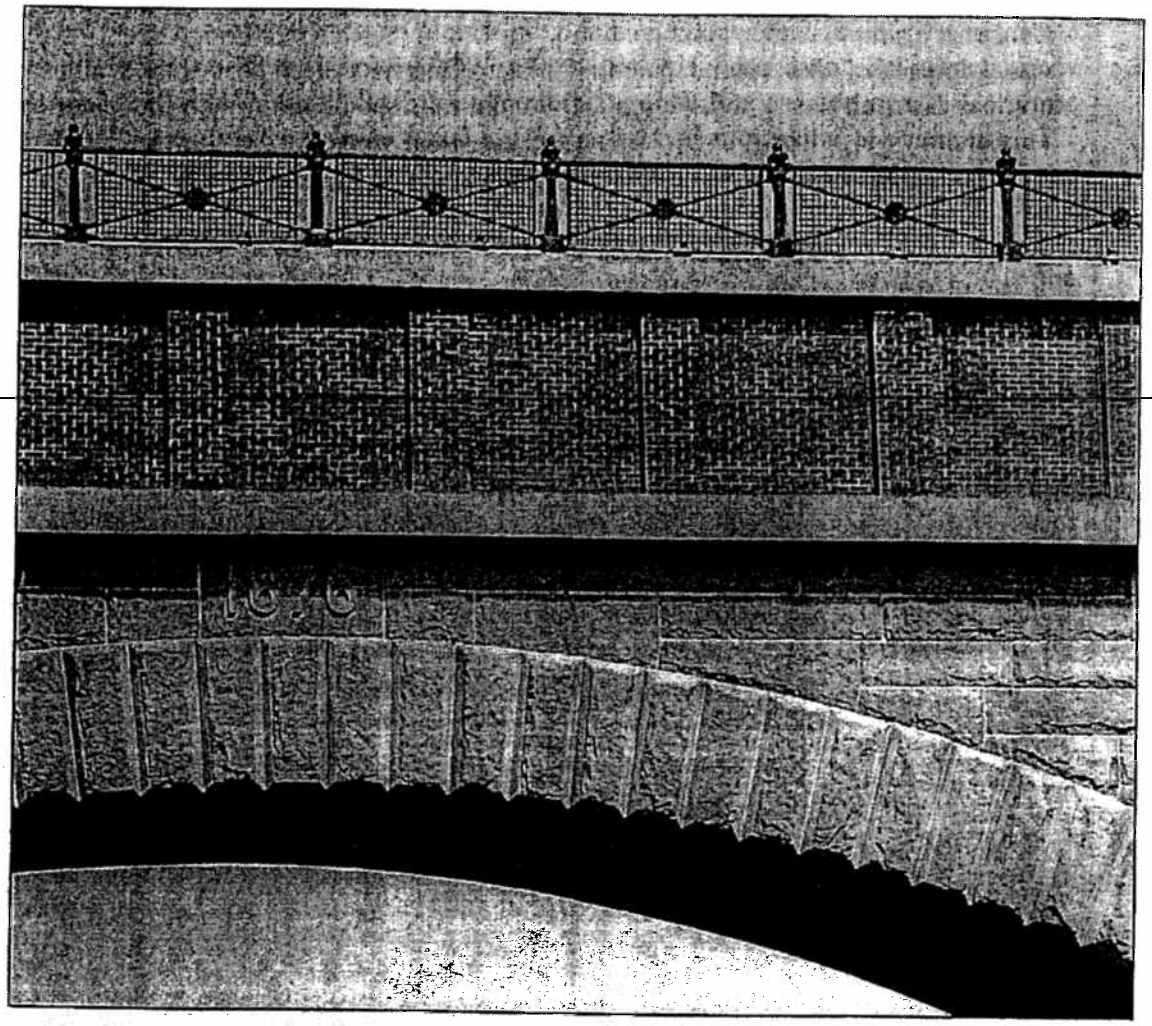
Alternative Number One:
Refurbish and Retrofit Existing Railing to Meet Code

Directly attach a 7 feet by 3 feet framed panel of painted 2-inch stainless steel wire mesh to the historic railing system. To visually separate this panel from the historic cast iron posts, it would be kept approximately 3 inches away from each post. Painted stainless steel is recommended for these panels since pre-galvanized mesh will rust where welded to the framing and the panel is too light to galvanize after assembly.

Probable Cost: $ 1,045,000



Alternative Number One: View from Bridge.
(See additional Photo on Page 15)

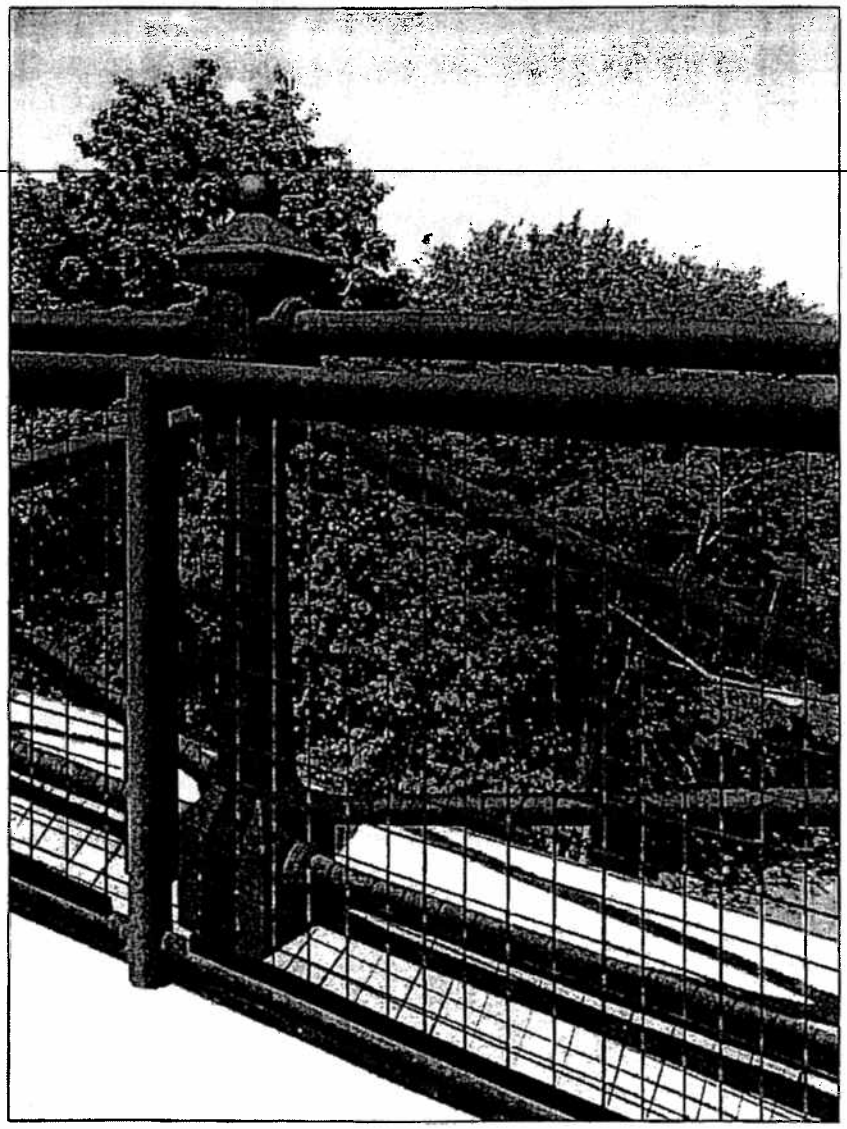


Alternative Number One: View from Charles River

Alternative Number Two:

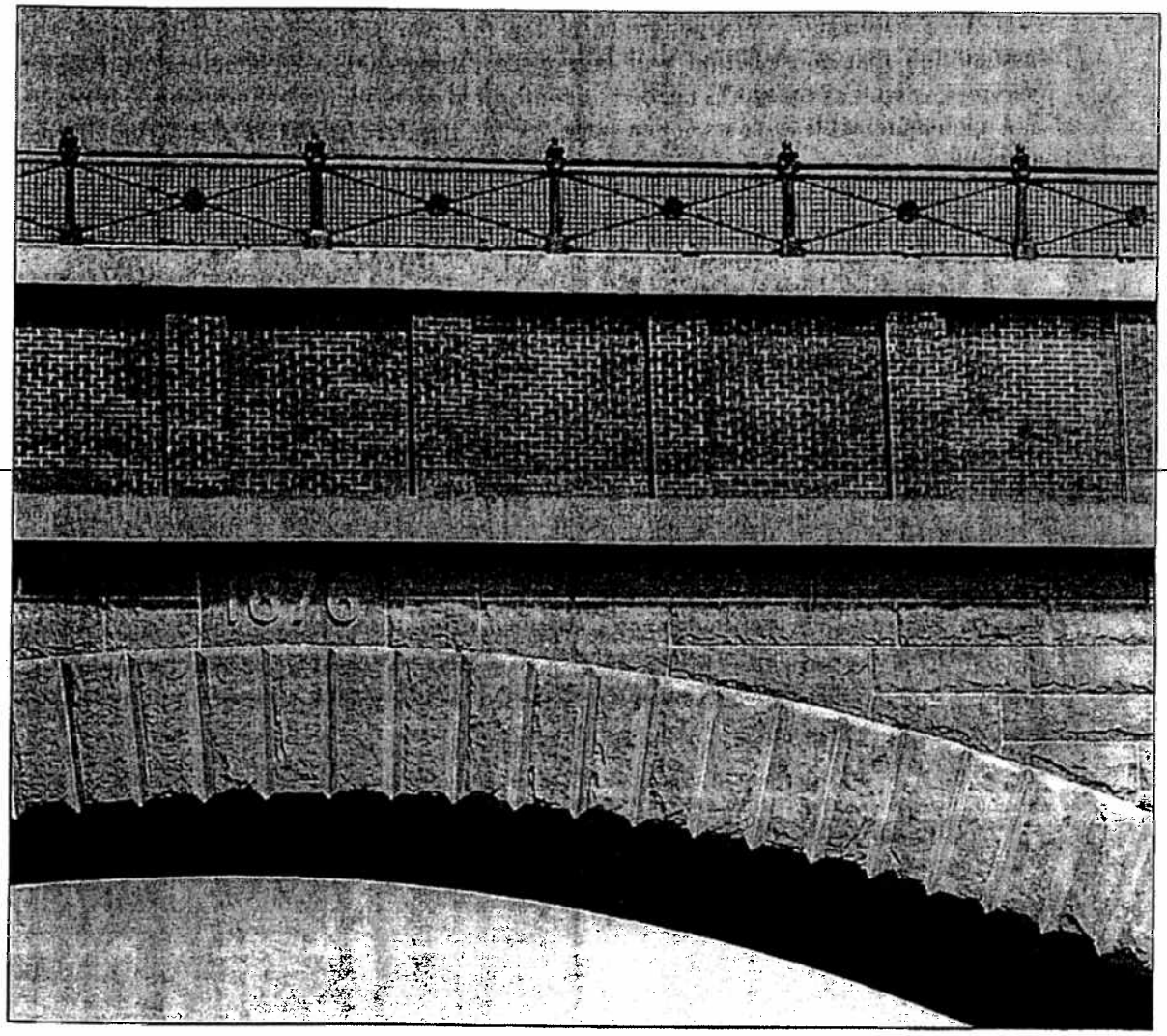
Refurbish Existing Railing and Install Additional Code Compliant Railing

Construct a simple independent guardrail attached to the concrete bridge deck. To reduce the visual impact of this second guardrail system, the new steel post should align with the original cast iron posts, and the top and bottom rails should align with the historic railings. This alternative is likely to be less noticeable when viewed from the two DCR parks but more noticeable when viewed from the high deck.



Probable Cost:
$1,077,000

Alternative Number Two: View from Bridge.
See additional Photo on page 17



Alternative Number Two: View from Charles River

Estimated Construction Costs

We have estimated construction costs for the two recommended alternatives with the assumption that construction will take place during 2008. Architectural and Engineering services as well as measures needed to conform to accessibility requirements, if required, are not included in these costs. See page 29 for itemized probable costs for alternatives 1 through 6.

Alternative Number One (Directly attached wire mesh panel to restored railing assembly)	**$ 1,045,000**
Alternative Number Two (Independent guardrail separate from restored railing assembly)	**$ 1,077,000**

Green International Affiliates, Inc. has estimated the cost to completely replace the existing Ellis Street stairs to Echo Bridge with a new steel stair and railing system.[2] Architectural and Engineering services as well as measures needed to conform to accessibility requirements are not included in these costs.

Ellis Street Stairs	**$ 100,000**

Construction Methodology and Schedule

Both recommended alternatives will have the same basic construction methodology and schedule. The total construction time for both alternatives is estimated to be between 10 and 13 months during which Echo Bridge will need to be closed to the public. Since the bulk of the work that is weather-sensitive will be performed off site, we do not believe there is a strong preference for the start date. If begun in the fall, work could be completed a year and three months later in the spring.

[2] Although not part of this report, the repairs to the Ellis street stairs may be incorporated into the Echo Bridge railing refurbishing and rehabilitating plan.

Technical Assessment & Considerations

Schedule

We estimate the following schedule for the construction phase for this project (excluding any accessibility improvements):

Phases	Time Period
1. Secure site with construction fencing and install OSHA fall protection.	2 weeks
2. Paint stripping at railing locations that will be cut during disassembly because of lead-based paint.	2 weeks
3. Disassemble railing system and preliminary separation of potentially salvageable cast iron elements. Conduct TCLP (Toxic Characteristic Leaching Procedure) sampling to separate hazardous waste material from non-hazardous waste material. Cleaning of rust-stained granite.	6-8 weeks
4. Sandblast potentially salvageable cast iron in an off-site facility licensed to abate lead-based paint.	4 weeks
5. Shop drawings, creation of mold patterns, casting of samples and installation of mock-up for review and approval	10-12 weeks
6. Casting of ductile iron posts and rosettes. Fabrication of new railings. Repair, inspection and testing of original cast iron elements. Fabrication of framed panels or independent guardrail assemblies.	10-16 weeks
7. Painting of cast iron elements and color galvanizing of steel elements.	3-4 weeks
8. Installation of refurbished and replica historic railing and new guardrail assembly.	5-8 weeks
9. Paint touch-up and inspection.	1-2 weeks
10. Remove construction fencing and repair site.	1-2 weeks
Total	**44-60 weeks**

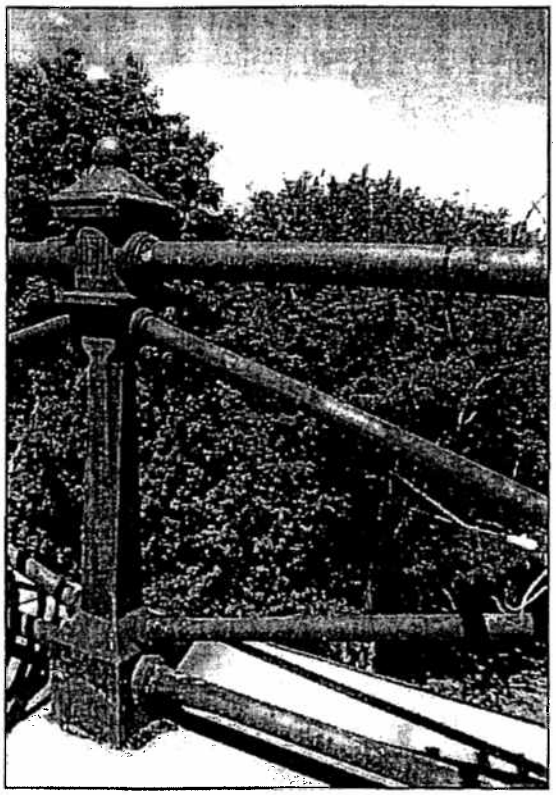
Technical Assessment and Considerations

The following section includes a more detailed explanation of the existing conditions survey, regulatory review, evaluation of alternative materials, material comparison table, line item cost estimate and other railing designs considered during this study.

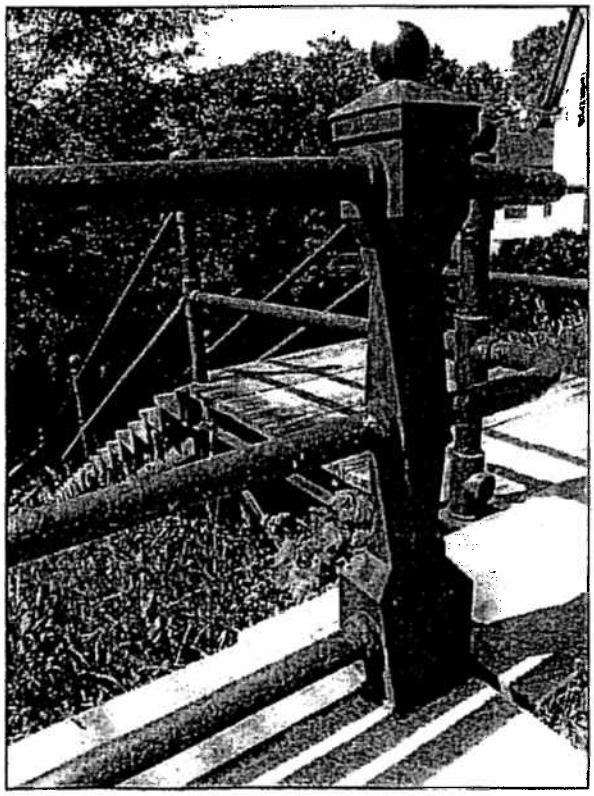
Existing Conditions Survey

Posts and Railings

There are two distinct styles of historic cast iron posts and steel railings present at Echo Bridge. Flanking both sides of the 475 feet long bridge, there is the larger and more ornate cast iron post with a double rail and intermediate diagonal railing forming an "X". At each end of the bridge there are raised granite landings. The landing railing system is similar to the bridge's railing system but with smaller and less ornate cast iron posts and a simple three-rail system. Present on the raised granite landings are later galvanized steel pipe posts and rails. These have replaced over 85% of the cast iron railings that originally flanked the granite landings. The paint on all these railings is thin from severe exposure to weather and a lack of regular maintenance. The paint system has eroded, blistered and peeled, exposing cast iron and steel to the environment resulting in extensive rusting. The finish paint color appears to have always been black.

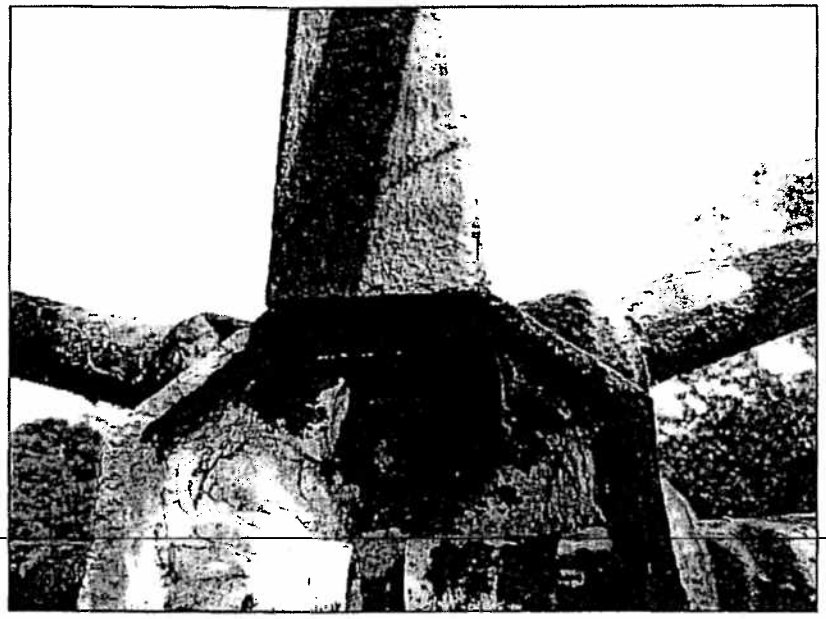


Historic Bridge Post and Railing



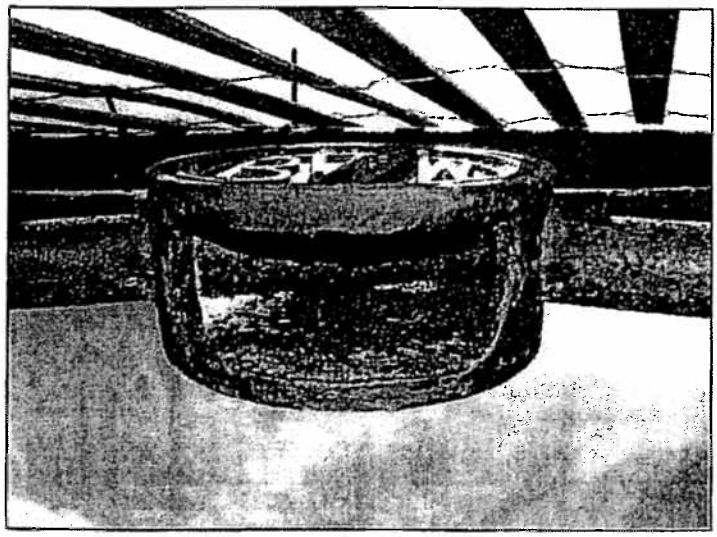
Historic Landing Post and Railing

Both the bridge and landing posts are a one piece iron casting. Traditional "gray" cast iron is very strong in compression but much weaker in tension because of the carbon it absorbs during production. The wall thickness of the cast iron post varies from ¼ inch to ½ inch. This lack of quality control during casting and the resulting thinned walls have made the posts less durable to corrosion and weaker in strength than they would be able to if all walls were of a uniform ½ inch thickness. In general, when the wall thicknesses in cast iron posts are less than 3/8 inches there is a marked reduction in their ability to adequately resist the forces of corrosion and ice jacking. The historic cast iron posts were originally secured to the deck with a threaded rod embedded in the granite deck that ran to the top of the post and was secured by a threaded spherical cap. Originally these caps would have been securely tightened to hold the post to the deck. The threaded steel rod was much more susceptible to corrosion than the surrounding cast iron posts. In general, where the cast iron post is broken, this rod is missing or rusted through. Rather than replacing these threaded rods, an attempt was made to stabilize the post by adding a cementitious grout. The grout in the post cavity ranged from a few inches to filling of the entire post. This repair attempt has greatly accelerated the deterioration of the posts by trapping moisture and providing a surface for ice jacking. Typically, the ball caps are now welded to the posts.



Overly Thinned Post Section

The main bridge rail posts are 48 inches high and located 8 feet on center. Where the bridge rails terminate at the granite landings, the railings are connected to flat 1-inch thick cast iron pilasters that are slightly recessed into the vertical face of the granite walls. Typically the cast iron posts are set on a ¼ inch leveling bed of lead and set in a square recess in the granite bridge coping stones. They were originally secured with a single ¾ inch diameter threaded rod embedded in the granite coping stones and tightened at the top of the post with a screw-on cast iron spherical cap. Both 3-inch and 2-inch diameter caps are found on the posts. The majority of these caps are 3 inches in diameter and aesthetically this proportion relates better to the posts below. The 3-inch spheres are most likely original and the 2-inch spheres are replacement pieces. About 20% of these finials are missing and all except one has been tack-welded to the top of the post to prevent removal.



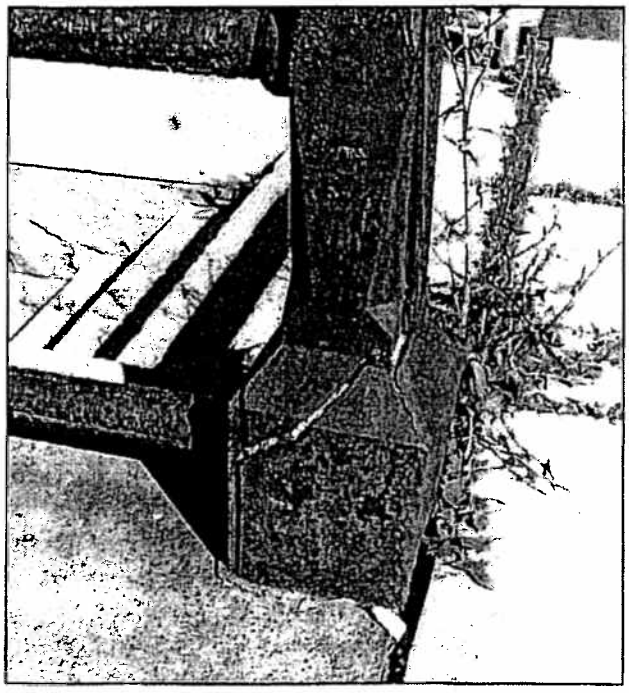
Cast Iron Spalling at Rosette

The 3-inch top, 2-¼ inch bottom and 2-inch diagonal pipe rails are all 1/8-inch thick cast iron with some steel replacements. The high point of the top rail is 42 ½ inches above the sloped bridge deck. The space between the bottom rail and the bridge deck is less than 4 inches.

The "rosette" at the center of the diagonal rails is a one piece cast iron casting. This 9 inch diameter "rosette" is cast with the letters "BWW". The letters "BWW" stand for *Boston Water Works*, which was the original governing authority when the aqueduct was constructed.

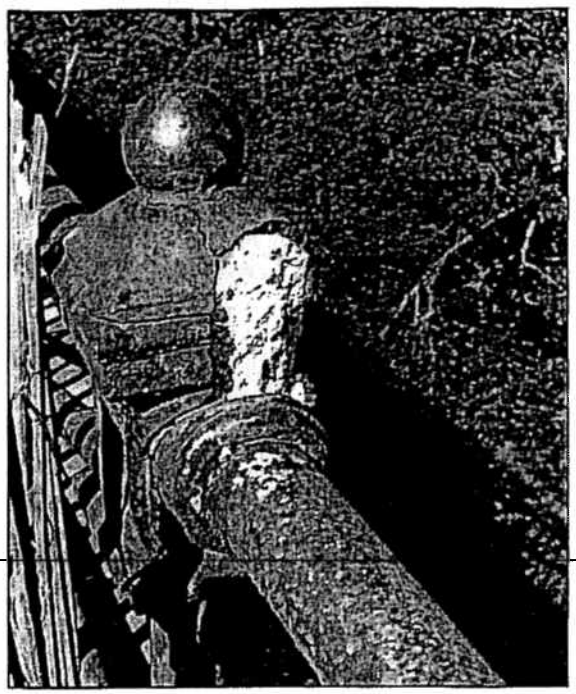
The historic cast iron posts on the granite stair landing at each end of the bridge are 44 ½ inches high and located 6 to 7 feet on center. Only 35% of the historic posts on both stair landings remain. Thirty percent of these historic posts have been replaced with a "modern" galvanized pipe railing system at the Newton Upper Falls landing and 100% replaced at the Needham landing. The historic rail system has three 2¼-inch diameter horizontal rails. The top rail is 38 inches above the granite deck. The space between the bottom rail and the bridge deck is less than 4 inches.

The most serious issue with both of these railing systems is the deteriorated condition of the posts due to widespread cracking, rusting and spalling. More than 48% of the bridge and 60 % of the landing posts have severe cast iron breakage. These damaged posts are beyond repair and will need to be recast. Eighteen percent of the bridge and 20% of the remaining landing finials on top of these posts are missing and half of the remaining ones are different sizes.



Fractured Post

In examining the cast iron posts with broken sections, 38% of the bridge and 57% of the landing posts have been filled with a cementitious grout composed of a sand and cement mixture. All these posts show severe vertical cracking from the top rail to the base as well as spalling. The grout shrinks after it has filled the cavity and acts as a water collector. When water penetrates the inside of the post it fills the voids and freeze-thaw cycles take place, resulting in ice jacking. Cast iron is weak in tension. Ice expansion and wedging (ice jacking) create stress-relieving cracks and breaks in the cast iron.



Spalling at Post Cap Due to Grouting of Post and Ice Jacking

Many of the intermediate diagonal and bottom rails have rusted through and some are missing or have been replaced with galvanized pipe. Most of the rail damage is due to failure at the joints where the rails meet the posts or the rosettes. Water penetrating into the joints is trapped causing rapid oxidation of the iron from the interior. Where water was trapped during winter seasons, ice jacking has occurred. The entire system will need to be disassembled for inspection, refurbishing and replacement. The detailing of the patterns needs to be revised to allow greater expansion and contraction to take place and to prevent future failures to the new cast iron rosettes.

Paint

Historic cast iron and steel needs to be protected from air and moisture in order to prevent oxidation. This protection is typically done with paint. Paint is a sacrificial coating that needs to be inspected on a regular basis and renewed every several years to maintain coating thickness and prevent rust.

The paint on over 25% of the post and railing systems has blistered, eroded and peeled. On some individual elements the paint failure is over 50%. This erosion and blistering is most severe on horizontal surfaces, edges and raised details exposed to the weather. Weathering has worn the paint thin or exposed bare metal. Where the iron and steel have been exposed, oxidation has taken place and the rust as it develops and expands has caused additional paint to peel and separate from the metal surface.

Shop-applied industrial paint systems for cast iron railing components and the color-galvanized finish for steel railing components should both have a service life of about 15 years. After this time period, the field applied coatings typically last 5-7 years before they should be recoated.

Graffiti

The deteriorating condition of the rails coupled with the temporary snow fence welcomes graffiti. With each subsequent visit to the bridge, there has been an increase in the amount and size of the graffiti. The graffiti is appearing not only on the railings and posts but also on the sloped concrete bridge surface. In addition, some individuals have carved initials in and removed the sealant/expansion joint at the centerline of the bridge.

Findings

Bridge

- 75% of the decorative cast iron posts will need to be totally replaced.
- 55 to 95 % of the railing systems (i.e. posts, railings, finials) have failed (loss of strength, break down or stop working)or are suspected to have failed due to joint failure.
- 5 to 25% of the railings have rust corrosion, reducing the mechanical strength of the rail and its connections.
- More than 48 % of the bridge posts have severe cast iron breakage (beyond repair and will need to be recast).
- 18% of the finials are missing on bridge.
- At least 38% of the cast iron posts on bridge have been filled with cementitious grout accelerating deterioration (and more could have actually been filled but not observed because there is no obvious exterior evidence of such work.) Once posts are disassembled, more posts might suffer from the grout damage.

Recommendation: The entire system will need to be disassembled and some detailing revised to allow greater expansion and contraction to take place and to prevent failure to the new cast iron posts. A post-by-post interior inspection did not take place as part of this work, which may reveal further deterioration on additional posts when construction work begins.

Bridge Landings

- Over 85% of the railings on top of granite landings have been replaced.
- 71% of the landing posts have severe cast iron breakage.
- 30% of the historic posts have been replaced on Newton side.
- 100% of the historic posts have been replaced on Needham side.
- 29% of the finials are missing (and remaining finials are tack-welded to the top of the post).
- 57% of the cast iron posts on landings have been filled with cementitious grout.

Recommendation: Since there has been so much deterioration and replacement of the elements of the railing system at the landings on the Newton and Needham side, total replacement for both sides of the landing is the recommended course of action.

Regulatory Review

Massachusetts State Building Code

The bridge posts and railings in their present state will need to be brought up to current Massachusetts Safety Codes. The posts and railings will need to be repaired, restored, modified and replaced, depending on their condition, to have them meet the structural load requirements of 780 CMR 1615 *Special Loads* for guardrails. The guardrails must be able to resist a 200 pound concentrated load in any direction and uniformly distributed loads of 100 lb/ft vertically and simultaneously 50 lb/ft horizontally. This load condition must be met without exceeding the allowable design working stresses of the materials, anchorage and connection devices.

The rails must also meet the provisions of 780 CMR 1021.0 *Guards* for height and opening limitations. The guards must be at least 42 inches high measured vertically above the adjacent walking surface. Open guards shall have balusters or other solid material such that a sphere with a diameter of 4 inches cannot pass through any opening. Further, guards shall not have an ornamental pattern that would provide a ladder effect.

Presently the bridge's 42½" high railings exceed the minimum 42-inch height requirement for safety. The bottom rail meets the maximum 4-inch opening requirement between it and the bridge deck. The railing fails in the opening sizes between the diagonal "X" rails and the top and bottom rails as well as at the post. The present size of the openings varies from 1 inch to 2 feet.

The granite landing railings are 38 inch high and fall 4 inches short of the required 42-inch height requirement. The distance between bottom rail and the granite deck meets the maximum 4-inch opening size requirement. The open space between the top, bottom and intermediate rails is 13 inches, exceeding the maximum 4-inch requirement.

Lead Paint and Lead

The railings and posts have been repainted numerous times since they were first installed in the late 1870's. Most painted metals at that time were primed with red lead or lead based paints. In 1978 due to increased knowledge and health concerns about lead containing paint, it was banned from residential use in the United States. Prior to this date, all paint is suspect of containing lead.

Lead was also used extensively in cast iron railing systems to seal the joints between the rails and the posts and in sheet form to level and plumb the posts. While no lead caulking was observed, lead was observed at the base of posts as a means to level them.

Lead testing of the posts and rail components was performed by an independent testing lab. (Please reference Appendix E for lead paint information.) It was performed using an RMD x-ray fluorescence analyzer on site. At least ten separate tests were performed on each type of rail component. As expected for a railing of this age, most surfaces showed regulated levels of lead with results above the Massachusetts residential standard of 1.0mg/cm2.

The presence of regulated levels of lead raises issues about protecting public health and safety during disassembly. A small amount of chemical paint stripping on-site will likely be required prior to disassembly of the railing system. The majority of paint removal must be done under controlled and licensed shop conditions.

Material Evaluation

The following is an evaluation of cast iron, carbon steel, aluminum and reinforced polyester as alternative materials to restore, repair and/or replace the damaged components of the two railing systems.

Cast and Ductile Iron

The existing historic posts and "BWW" rosettes are made of cast iron. As the name implies, it is easily poured when molded for both structural and decorative purposes. It is an iron-carbon alloy with high carbon content. This makes cast iron able to resist great compressive forces but poor in elastic behavior (tension). It has generally good resistance to corrosion but requires a coating of paint in order to adequately protect the surface. Since it is used as a hot, pourable material, it is subject to imperfections during casting. These could be airholes, cold shuts (imperfections caused by cooling of the molten surface during casting or interruption of pouring), cracks and cinders. These can weaken the final product. The mold pattern is just as critical in the process to ensure these defects do not occur and that proper wall thickness meets the specifications and is maintained during repetitive castings.

Today, ductile iron is often used to recast historic pieces. Ductile cast iron is superior to historic "gray" cast iron in that it has high ductility as well as high strength. This is due to the presence of carbon in the form of spheres rather than flakes. Using ductile iron instead of historic "gray" cast iron will add about 20% to the cost of the material. This is well worth the cost since the quality of the casting and the longevity of the material are greatly enhanced.

Steel

Steel is an alloy of iron and carbon. It typically has a lower carbon content than cast iron. It generally possesses great strength and ductility. Steel generally has poor resistance to corrosion. Steel can be galvanized to increase resistance to corrosion. Galvanization places a sacrificial coating of zinc on the metal's surface. The type and thickness of this zinc coating determines how well it is able to resist corrosion in any particular environment. However, there is no need to galvanize cast iron. The cost of steel by weight is slightly higher than cast iron.

Since steel cannot be cast, it would not be a good substitute for making replicas of the existing posts. The diameters of the existing pipe railings are standard manufactured steel pipe sizes, making it a cost effective substitute for cast iron. Color galvanized steel would be appropriate as a replacement material for the pipe rails for strength, durability and cost. Color galvanization is a two set process that can be provided by three independent facilities in the Boston area. This process has successfully addressed the paint failure problems typically associated with painting galvanized surfaces. Galvanized metal accepts paint well for the first 48 hours after galvanization and after six months of exposure to the atmosphere. Color galvanization takes advantage of the first 48-hour time period and comes with a 20 year paint warranty.

Aluminum

Aluminum is a durable metal derived from bauxite ore. It is about one half the weight of cast iron and highly resistant to corrosion. However, it is very soft and has about the same ductility as lead. Aluminum can be cast and easily worked by most metal fabrication methods.

Aluminum is predominantly more valuable as a substitute for decorative elements than for structural tubes and beams. For this application, the cast iron posts could be easily recast in aluminum. The structural connection of the aluminum post to the granite deck will need to be reinforced with a stainless steel anchoring system. The collars where the pipe rails connect with the post will also have to be reinforced. To use aluminum as a pipe railing component would require tubing for the 8-foot spans. This would be costly compared to standard steel pipe. One cannot use standard steel pipe rails in place of aluminum rails, since this would introduce different metals and the occurrence of galvanic corrosion. Galvanic corrosion is the electrochemical reaction that occurs when two different metals come into contact and moisture is present. If dissimilar metals are used then the contacts must be isolated by a nonporous gasket or caulking in order to avoid galvanic corrosion. These neoprene gaskets, butyl rubber and other isolation materials typically have a limited lifespan of a maximum of ten years. It is critical that these isolation materials be periodically examined and maintained. They must be removed and replaced before the end of their life span.

The cost of aluminum by weight is 2-3 times that of cast iron. However this figure is deceptive. Typically if an aluminum casting is made of the same cast iron object, the weight (amount of material) is greatly reduced and the overall increase in material cost would only be 15-20% higher.

Reinforced Polyester

Reinforced polyester (fiberglass) is a lightweight and cost effective method for recreating decorative non-structural elements. It is usually lighter than aluminum and shrinks less during casting than cast iron. Because it is not metallic, it does corrode like iron, steel or aluminum and does not have the associated problem of galvanic corrosion when combined with metal components.

Decorative fiberglass is weak structurally as a single element and in its ability to form structural connections. The main fabricator of architectural fiberglass in New England does not recommend its use as part of a guardrail system. If it were to be used to replicate the posts, it would require a hidden structural stainless steel post to be installed with the appropriate pipe rail connections. The fiberglass post would have to be cast in two halves and fastened together to hide this structural post. While fiberglass pipe of the appropriate rail diameter is a standard manufactured item, it is not an appropriate structural element for 8-foot spans. If reinforced, fiberglass rails might be used. However the fiberglass needs to be protected from ultra violet (UV) light by painting, otherwise it deteriorates. UV light breaks the chemical bonds in fiberglass and this first appears as a chalky surface. The rails would be particularly vulnerable if the protective paint coating is not maintained. Fiberglass pipe, as a result of UV damage, time and stress, tends to produce glass shard splinters. This is a serious safety hazard for its use as a guardrail.

The associated fabrication and material costs for fiberglass are much lower than cast iron or cast aluminum. However, there are additional costs associated with providing a hidden metal structural post system for the decorative fiberglass. Fiberglass is also regarded as a poor substitute material for cast iron.

Material Comparison Table

(Comparisons are to original cast iron material.)

Comparison Criteria	Cast & Ductile Iron	Carbon Steel	Aluminum	Reinforced Polyester (Fiberglass)
Historical	• Replicates original historic material + aesthetics. • Ductile iron is modern form of cast iron with improved ductility.	• Similar material to cast iron.	• Visually very similar to cast iron when painted (sharper corners and smoother surface).	• Not a good substitute for decorative cast iron.
Aesthetic	• Matches original material in weight, strength, texture and appearance. • Capable of being cast into highly complex geometries and details.	• Higher melting point makes it more difficult to cast intricate details. Not practical for detailed casting of historic posts. • Indistinguishable from original railings when painted.	• Castable - visually replicates molded architectural ornamental work.	• Castable - visually replicates molded architectura ornamental work. • Molds directly from historic features.
Structural + Physical Properties	• Good strength to weigh ratio. Good for posts and structurally meets codes. • Not good in tension. Rails tend to have hidden internal corrosion due to water infiltration at joints. For these reasons, not appropriate for handrails.	• Structurally good in tension. Appropriate for handrails + guardrails. • As post, good structurally. • Similar thermal expansion as cast iron. • Decreases in volume during solidification.	• Lower structural strength than cast iron, but structurally adequate for posts • Less brittle than cast iron • Not economical as structural rails • Difficult to prevent galvanic corrosion with other metals • Twice the thermal expansion of steel	• Non load bearing use.. Best suited as a façade ornament in non-structural applications. • Requires separate hidden structural post system. with stand static forces as a rail system. • Cracks when impacted • Twice the thermal expansion of steel, Similar to aluminum
Design + Installation	• Posts anchorage location will match historical. • Patterns/molds need to consider shrinkage as iron cools during fabrication.	• 10% heavier than ductile iron. • Galvanizing gives complete coverage, coating steel internally, externally and at intricate details. • Factory applied zinc coating (galvanizing) provides greater quality control than field painting.	• Light weight material makes handling easier. than cast iron and lowers transportation costs • Easily assembled and good delivery time. • Greater expansion and contraction requires careful detailing and gaskets and/or caulked joints. • Patterns/molds need to consider shrinkage as iron cools during fabrication.	• Light weight material makes handling easier than cast iron and lowers transportation costs. • Internal structural support system requires longer installation time and greater complexity than cast iron. • Greater expansion and contraction requires carefu detailing and gaskets and/or caulked joints. • Little shrinkage during fabrication.
Maintenance	• Relatively limited natural corrosion resistance. Regular preparation + painting required. • Difficult to weld due to high carbon content and may lead to brittleness.	• Zinc (Galvanizing) weathers at a very slow rate. Galvanizing produces a coating bonded metallurgically to steel. • Lower Maintenance when color galvanized	• Difficult to keep paint on aluminum • Regular preparation + painting required • Should not be used with cast iron rails due to galvanic action • Replacement of caulking and galvanic action barriers	• Ultraviolet sensitive unless surface is coated or pigments are in gel coat. • Regular Painting + Prep Required. • Lower Material Maintenance. • Good resistance to chemicals.
Useful Life Expectancy	• 100-150 years	• 20-50 (Not Galvanized) • 40-60 (Galvanized)	• Long life, durable Cast Alum: 100-125 years Tubing: 50-100 years	• 10-30 years • Vapor impermeable, will require ventilation detail prevent rusting and short life expectancy of intern structural steel system.
Cost	• Similar in material cost to carbon steel. • Least expensive of materials for posts. • Due to necessity of creating molds and slow production rates, expensive for rails.	• Very cost effective for handrails. Pipe railing is manufactured in standard sizes.	• For similar size casting, aluminum is about 15-20% higher in material cost than cast iron	• Approximately 1/3 the cost to cast a fiberglass pos vs. a ductile iron post. Cost of internal structural steel support posts not included. • Small cost saving compared to cast iron when use with concealed structural steel supports.

Summary of Rail Alternatives

Alternative One
Restore salvageable historic posts and rosettes. Replace unsound posts and rosettes with new ductile iron castings that replicate the historic components. Replace all existing rails with new color galvanized steel rails. Infill the rail openings with new 2"x2" stainless steel mesh panels mounted on the internal side.

Alternative One

Alternative Two
Restore salvageable historic posts and rosettes. Replace unsound posts and rosettes with new ductile iron castings that replicate the historic components. Replace all existing rails with color galvanized steel rails. Add an entirely new and independent guardrail system to the inside of the existing rail system.

Alternative Three
Totally remove the existing historic rail system. Install an entirely new and "off the shelf" steel guardrail system built from the manufacturer's standard rail components.

Alternative Four
Totally remove the existing historic rail system. Install an entirely new ductile cast iron post and rosette rail system with color galvanized steel pipe rails. The posts and rosettes would be cast from molds replicating the existing cast historic components. Infill the rail openings with new 2"x2" stainless steel mesh panels. This alternate, when painted, would look similar to Alternative One above.

Alternative Two

Alternative Five
Totally remove the existing historic rail system. Install an entirely new cast aluminum post and rosette rail system with color galvanized steel pipe rails, The posts and rosettes would be cast from molds replicating the existing cast historic components. Infill the rail openings with new 2"x2" stainless steel mesh panels. This alternate, when painted, would look similar to Alternative One above.

Alternative Six
Totally remove the existing historic rail system. Install an entirely new decorative fiberglass post and rosette rail system with color galvanized steel pipe rails. An internal structural steel post is required. Posts and rosettes would be cast from molds replicating the existing cast historic components. Infill the rail openings with new 2"x2" stainless steel mesh panels. This alternate, when painted, would look similar to Alternative One above, but would not have the look or feel like cast iron. The major difference between them would be the size of the posts. The fiberglass post would be noticeably larger (About 2-4" larger at the base) in order to cover the steel structural railing system. The post and rosettes would need to be cast into two separate pieces in order to install them over the hidden steel structural system. This joint between the post and rosette halves would be clearly visible.

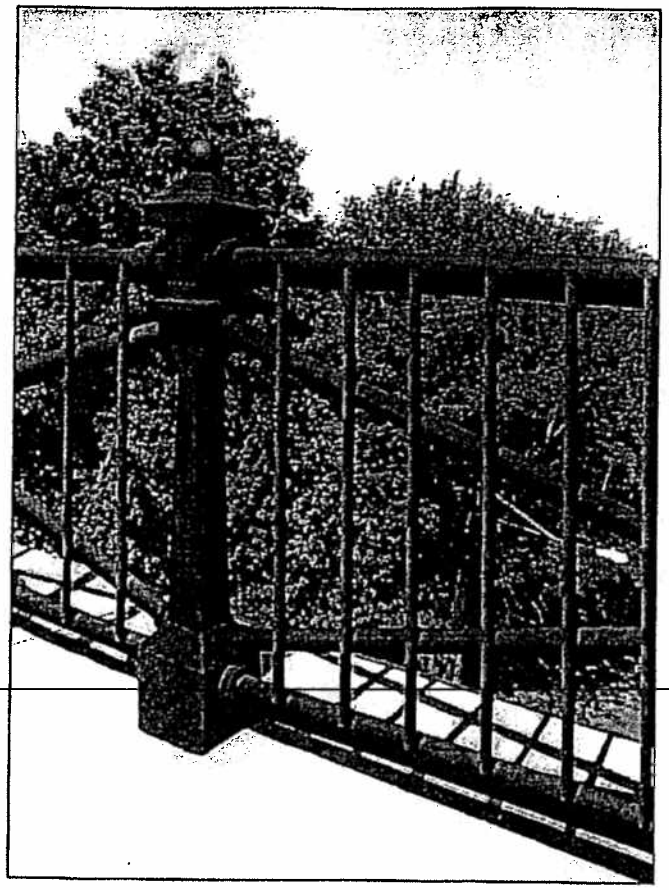
Alternative Three

Other Railing Designs Considered

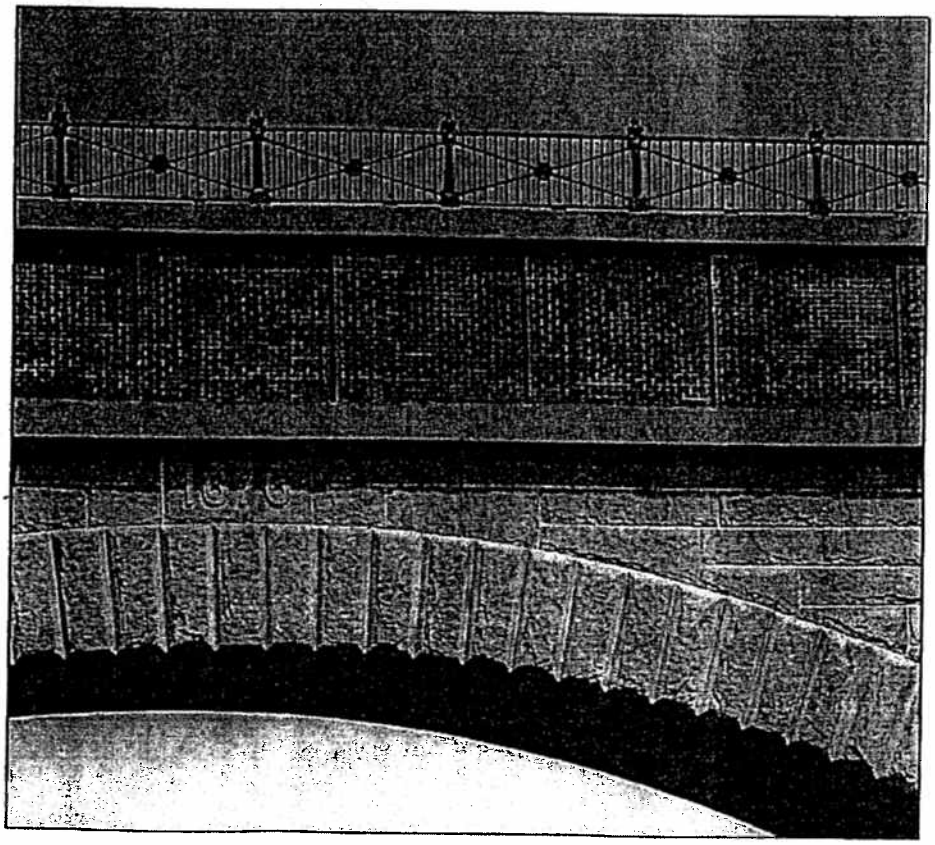
Two other guardrail systems were explored during the design process. These systems were developed in order to illustrate the range of designs considered. PhotoShop renderings are included so that they can be considered by all stakeholders.

Both designs are variations on Alternative One. The difference between Alternative 1 and these designs is the style and method used to resolve the safety issues created by the large openings at the existing rails.

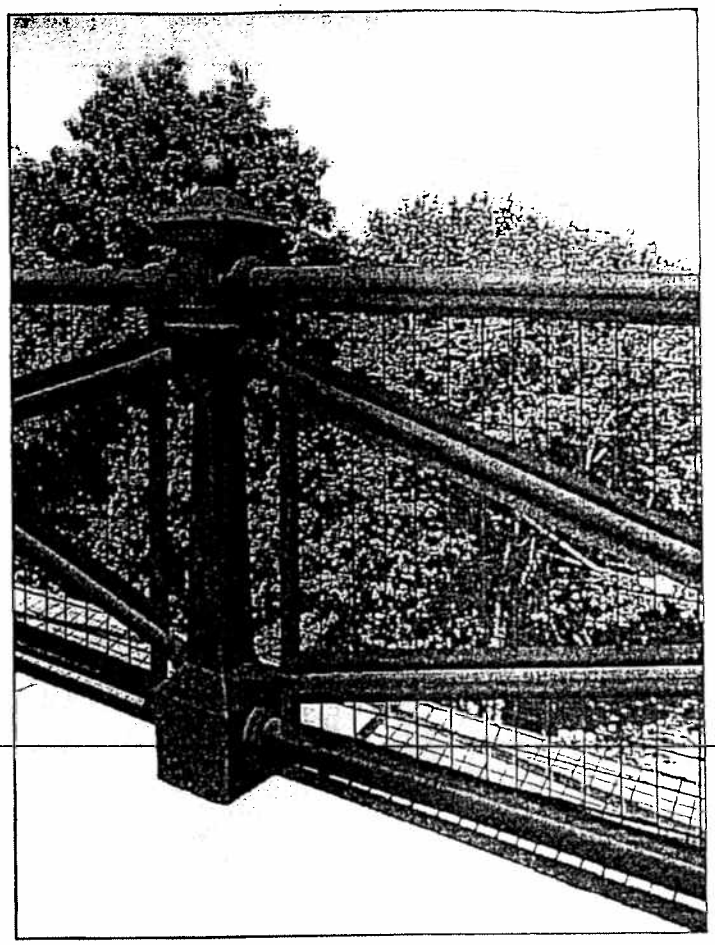
Design "1a" resolves the safety issues by installing 1/2" diameter vertical galvanized steel bars at 4" on center between the upper and lower rails. This design introduces a vertical element that contrast with the existing horizontal railing system. Alternative One, Vertical Bar Design, would be comparable in cost to Alternative One or $1,045,000.



Design "1a": Vertical Bar Design, View From Bridge

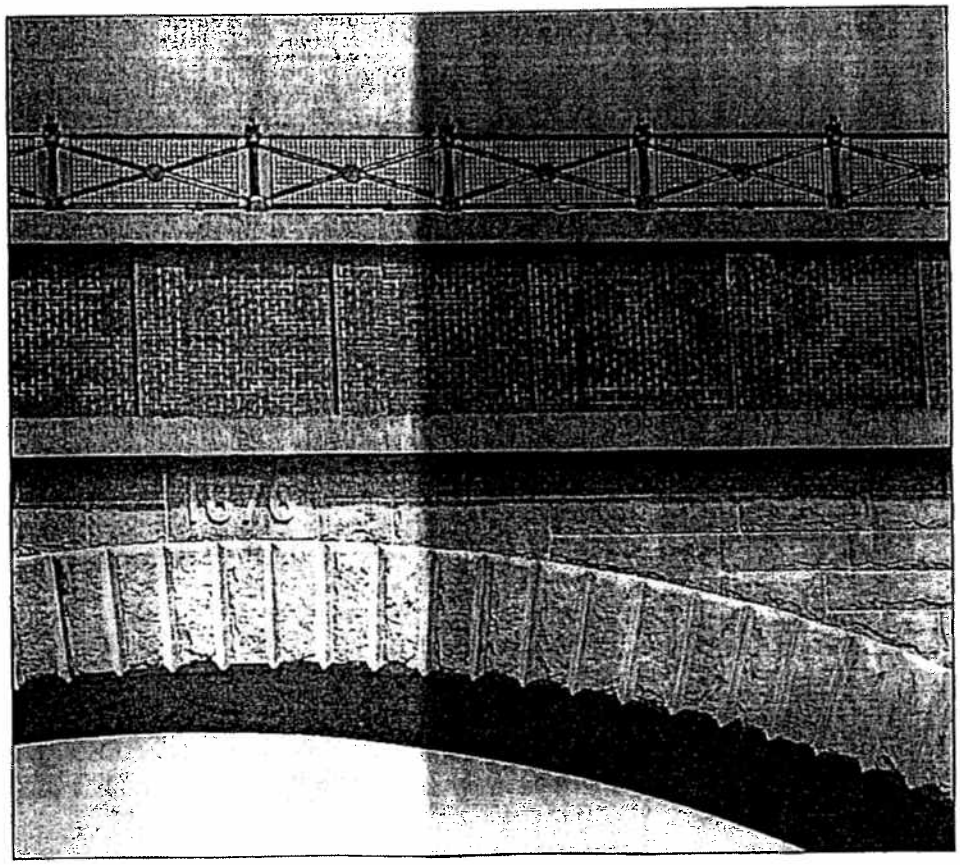


Design "1a": Vertical Bar Design, View From Charles River



Design "1b" resolves the safety issue by installing 2"x2" stainless steel mesh panels between the triangular shaped openings formed by the railings. This design clearly delineates the geometry of the original historic structure. Design "1b", Recessed Mesh Panels, would be approximately five percent more expensive than alternative One or $1,098,000.

Design "1b":
Recessed Mesh Panels,
View From Bridge



Design "1b":
Recessed Mesh Panels,
View From Charles River

Probable Construction Costs of Alternatives

Echo Bridge

Item #	Description	Alternative Five Entirely New Alum. Simulated Hist. Guardrail [3]	Alternative Six Entirely New Decorative Fiberglass Sim. Hist. Guardrail[3]
1	**General Conditions**		
	Install site fencing + fall protection	25,000	25,000
	Field stripping of lead based paint at cut	10,000	10,000
	Remove rust stains from granite	10,000	10,000
	Disassemble + remove offsite historic ra	63,000	63,000
	Shop blast + removal of lead paint off si	0	0
	TLCP Testing, lead paint removal off sit	25,000	25,000
	Refurbish existing posts + rosettes with	0	0
	Conservator inspection and structural te	0	0
	Pattern cast of bridge post	20,000	7,000
	Pattern cast of "BWW" rosette	2,500	2,500
	Pattern cast of landing post	12,000	5,000
	Replacement posts	186,300	100,000
	Replacement rosettes	46,800	30,000
	Supply + fabricate pipe railings	71,500	55,000
	Color galvanize steel pipe railings	0	27,500
	Sand blast + paint new cast iron	0	0
	Install railing assembly	165,000	178,750
	Site repair	3,000	3,000
2	**Safety and Code Compliance**		
	Galvanized steel structural post system	0	78,000
	Steel pipe rail of meshed panels	0	0
	Color galvanize railing system	0	0
	Core drill post holes	0	0
	Install guardrail	0	0
	Stainless steel wire mesh panels	66,000	55,000
	Paint wire mesh panels	13,200	11,000
	Install wire mesh panels	33,000	27,500
	Accessibility compliance	N.I.C.	N.I.C.
		752,300	713,250
	General Requirements		
	Contingency	188,075	178,313
	Bond	37,615	35,663
		977,990	927,225

[3] For safety reasons, the bridge railings are defi g the possibility of an accidental fall.