Historic Dam Guardrail and Vehicle Barrier Retrofit for Public Safety

Abstract

A local utility company issued a request for proposal to our university's capstone program for the retrofit design of guardrails and vehicle barriers on the walkways of a historic dam. Existing safety features pose an immediate life-safety hazard. The walkways are regularly accessed by the utility to perform maintenance and provide tours for the public, particularly school-age children. Retrofit recommendations were to consider: historical aesthetics, environmental concerns because the water is a drinking source, and constructability.

The walkways consist of three distinct sections with varying safety features: a handrail (Section 1), a vehicle barrier (Section 2), and a concrete parapet (Section 3). The three sections do not meet current geometric and loading criteria to serve as a guardrail and vehicle barrier. All three sections lack the minimum required height of 42"; the existing spacing of horizontal members of the handrail and vehicle barrier exceeds the minimum required spacing of 4". Structural analysis indicates that the handrail cannot withstand vertical loading demand and the anchor plate in the vehicle barrier is insufficient to prevent concrete blowout.

The structural capacity of the concrete parapet was verified by load testing because as-builts were unavailable and the condition of the concrete was not known. Concrete cores were obtained to determine compressive strength, and the load-deflection behavior of the parapet was measured using a field-test procedure developed by the design team which involved pulling the two walls on either side of the walkway inward with a hydraulic jack. The results indicate that the parapet has adequate structural capacity.

For the handrail portion, a retrofit option of concrete parapet with 1" panel indents was proposed. The vehicle barrier retrofit included a horizontal rail attachment, post-tensioned cable, and reinforcement plate for the concrete curb. Retrofit for the concrete parapet provided an additional horizontal railing to meet the minimum required height with specialized attachments for the existing base plates.

The designs were completed by a four-member senior student team during an academic year. Students met weekly with their faculty advisor and two utility company liaisons, one of whom is a licensed structural engineer and the other a project manager. The team's design calculations were reviewed by the faculty advisor, company liaisons, and two external licensed structural engineers (SEs). Project highlights include site visits; the development and implementation of on-site load testing; an opportunity to work with maintenance crews; professional presentations to their peers, the utility company, and local professional chapters (American Society of Civil Engineers and Structural Engineers Association); a visit to the utility's fabrication shop to discuss connection design; and a peer-reviewed conference publication. The project culminated in a final report to the utility company and a poster. Throughout the year, students developed important technical, communication, and project management skills to help prepare them for their future careers as practicing engineers.

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I. Project Description

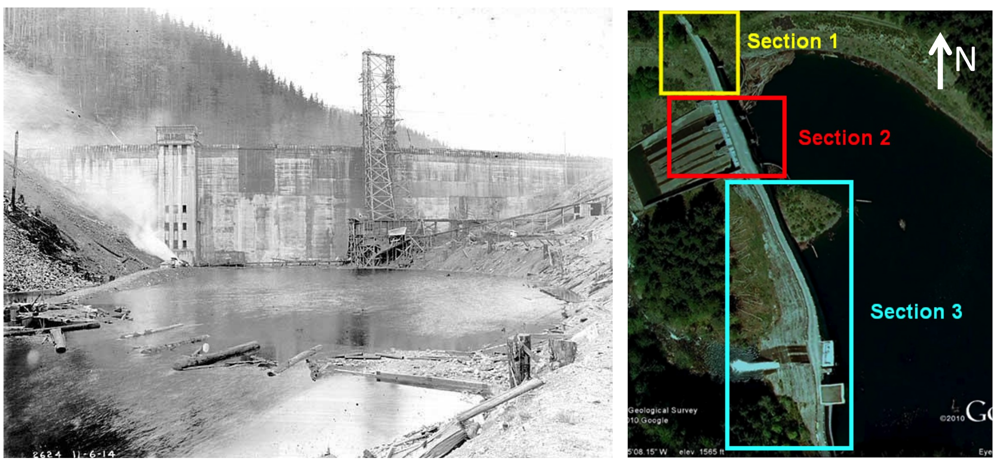
Introduction

A local utility company issued a request for proposal to our university's capstone program for the retrofit design of safety features on a historic dam that pose a life-safety concern. The design was to consider current loading and geometric standards, the historic aesthetics of the original dam, and to minimize the environmental impact from any proposed construction. The final product was a design basis memorandum including analyses of the existing structures, design and retrofit options, cost analysis, and recommendations.

Background

The dam is a cyclopean-masonry structure built in 1914 (Figure 1a) that provides power and water to a large city. In 2000, it was added to the National Register of Historic Places. The dam walkway is regularly accessed by the utility. Staff perform maintenance, sometimes requiring vehicles to be driven across the dam. Educational tours are also provided to the public, often for local-area grade schools.

Figure 1b shows an aerial view of the dam and distinguishes three sections based on the walkway safety features: Section 1 (handrail), Section 2 (vehicle barrier), and Section 3 (concrete parapet). Since the walkway is used for dam maintenance as well as public tours, safety features need to serve as both a guardrail and a vehicle barrier. The existing safety features do not protect people from accidentally falling into the water, posing an immediate life-safety concern.



(a) (b)

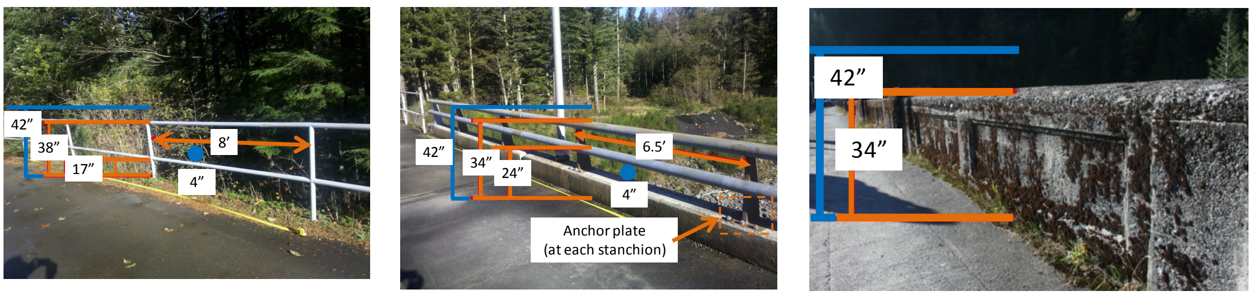
Figure 1. Dam: (a) original construction in 1914 and (b) aerial view identifying: Section 1 (handrail), Section 2 (vehicle barrier), and Section 3 (original concrete parapet)

Analysis of Existing Conditions

The first phase of the project was an analysis of the existing conditions of the safety features and included determination of design criteria, team site visits, experimental testing of the concrete parapet, and an evaluation of the structural demand/capacity of existing elements.

Geometry

Figure 2 shows the geometry of the existing features as measured by the design team during a site visit. To serve as a guardrail, a minimum height of 42 inches is required, and openings cannot allow the passage of a 4 inch diameter sphere (2009 *International Building Code*). All three sections are too short to serve as guardrails, and Sections 1 and 2 exceed the opening limitations.



(a) (b) (c)

Figure 2. Existing (in orange) and required (in blue) geometry of safety features in: (a) Section 1 (guardrail), (b) Section 2 (vehicle barrier) and (c) Section 3 (concrete parapet)

Structural Capacity

Using information obtained from the site visit and as-builts, the team analyzed the existing structural capacity of the safety features. Loading requirements were determined according to the *American Society of Civil Engineers* (ASCE*) 7-10 Minimum Design Loads for Structures and Other Buildings*. To serve as a guardrail, the safety features must be able to withstand a 200 lb concentrated load and a 50 lb/ft distributed load along the top lateral element. Furthermore, a vehicle barrier must be able to withstand a 6 kip concentrated load applied horizontally at 18 or 27 inches, whichever is most severe.

Both Sections 1 and 2 were determined to be unable to sustain a vehicle load. In Section 1, the vertical elements could not withstand the 50 lb/ft distributed load with a demand/capacity of 1.6. For Section 2, the anchor plate connection was found to be inadequate because it did not meet current geometrical requirements pertaining to anchor plate size, edge distance, and axial spacing, indicating the likelihood of concrete blowout.

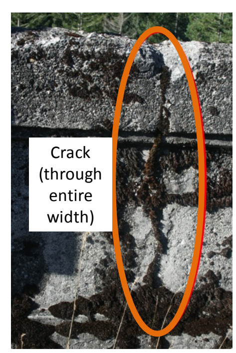
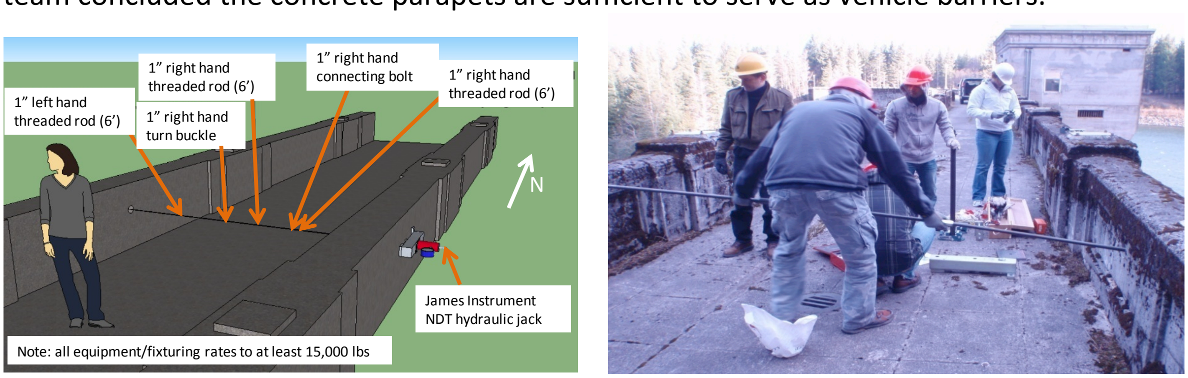


Figure 3. Existing concrete parapet

The team observed the condition of the parapet and the location of the rebar (using a pacometer) during a site visit. Figure 3 shows the existing concrete with large cracks and extensive moss growth, suggesting severe weathering. The team decided to evaluate the parapet by concrete core compressive testing and on-site load testing.

Concrete Core Testing: Six cores were taken from the parapet. Drilling was performed by the utility agency staff. The students consulted with a local cement company manager about the testing procedure and data analysis. The final concrete strength was determined to be 4,000 psi using the appropriate American Society for Testing and Materials (ASTM) standards and the *American Concrete Institute (ACI) 318 Building Code.*

Parapet Field Testing: Figure 4a presents a schematic of the testing procedure developed by the team to measure the load-deflection behavior of the wall. A hydraulic jack was mounted on the outside of one of the parapets and a threaded rod was extended across the walkway to pull the walls inward to simulate a vehicle impact. Loading occurred at the location of the concrete coring holes, minimizing additional damage to the existing structure. Deflection gauges were used to measure movement at the top of each parapet as a 9 kip load was applied (1.5 times the design load of 6 kips as specified by *ACI 318*). Figure 4b shows the team conducting the test. Since the deflections observed were negligible (maximum deflection was 0.00035 inches), the team concluded the concrete parapets are sufficient to serve as vehicle barriers.



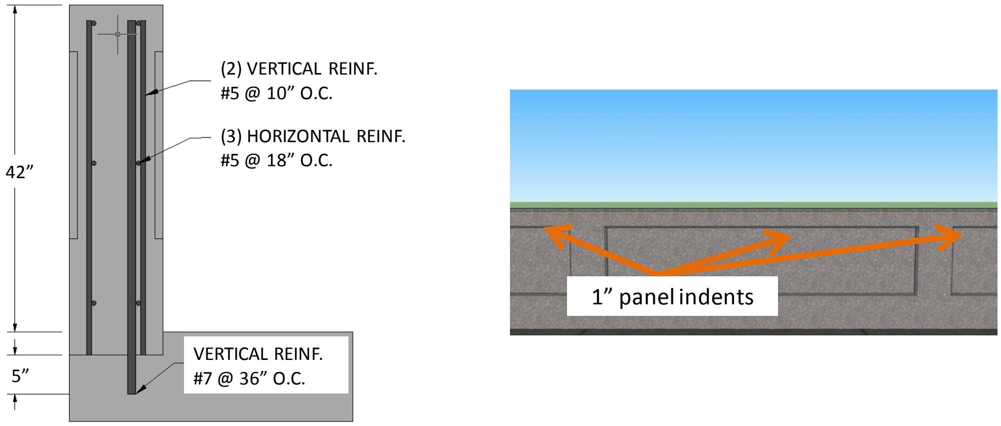
(a) (b)

Figure 4. Concrete parapet wall evaluation: (a) testing schematic developed by team and (b) on-site load testing

Design Options

The team prepared replacement and retrofit options to address the geometrical and strength deficiencies. All designs considered: (1) historical aesthetics, (2) environmental concerns since the water is a drinking source, and (3) constructability.

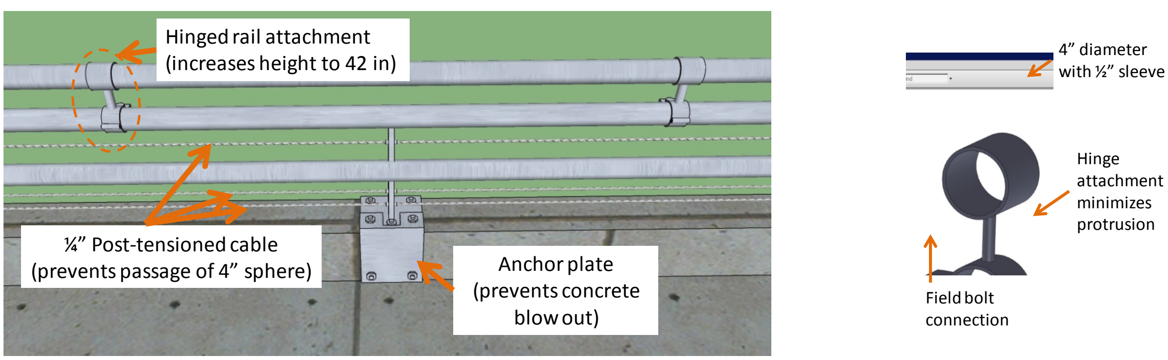
The team developed three options for Section 1 (handrail): (1) full steel design that mimics the aesthetics of Section 2 (vehicle barrier), (2) combination concrete and steel design that mimics the proposed design for the concrete parapet, and (3) full concrete parapet design. An economic analysis indicated the option 3 was preferred and, therefore, recommended by the team. Figure 5 presents this design, showing (a) the reinforcement and (b) a final schematic representation. The concrete parapet is 12 inches thick at the top and bottom with 1 inch panel indents in between to mimic the historic parapet (Section 3). Reinforcement extends into the existing concrete curb. The team used epoxy to reduce the development length of the flexural rebar, decreasing the construction cost of drilling.



(a) (b)

Figure 5. Recommended design option for Section 1 (handrail): (a) elevation view of concrete wall and reinforcement and (b) panel indents mimicking historic concrete parapet

The proposed design of Section 2 (vehicle barrier) is a retrofit of the existing vehicle barrier and includes a horizontal rail attachment, post-tensioned cable, and reinforcement plate for the concrete curb. Figure 6 shows a schematic of the complete design (Figure 6a) as well as a rendering of the custom hinge connection developed (Figure 6b). The rail attachment consists of a horizontal steel pipe with a hinge design to minimize protrusion into the walkway. There is one post-tensioned cable centered between the two existing horizontal pipes, and two cables between the existing horizontal rail and concrete curb. The new anchor plate considers the curb reinforcement and existing bolt embedment and increases the capacity of the connection (preventing concrete blow out).



(a) (b)

Figure 6. Recommended design option for rail attachment on Section 2 (vehicle barrier): (a) schematic representation with added safety features and (b) hinged rail attachment connection

The recommendation for Section 3 (concrete parapet) is shown in Figure 7a. This retrofit design uses the existing concrete parapet and adds a horizontal 4 inch pipe to increase the height. The design varies depending on whether or not light fixtures are present. Figure 7b and c show the custom-connection designs for the base plates with and without light fixtures, respectively. The difference in the outer diameter of the rail and the inner diameter of the sleeve is to account for the radius of curvature of the dam.

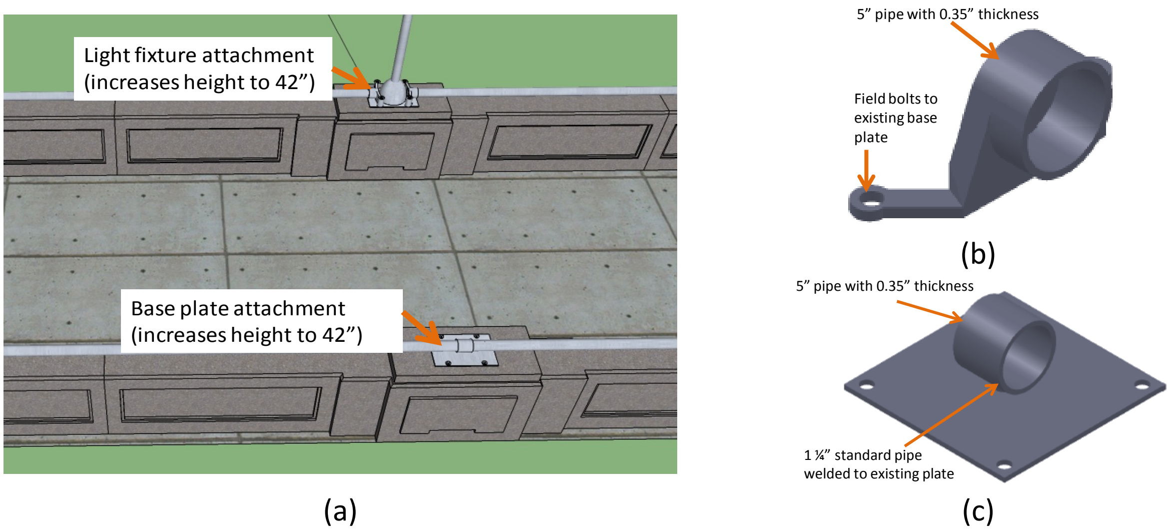


Figure 7. Recommended design option for Section 3 (concrete parapet): (a) schematic representation (b) light fixture attachment and (c) base plate attachment

II. Collaboration of Faculty, Students, and Licensed Professional Engineers

At our institution, senior civil and environmental engineering students are required to complete a year-long, real-world, capstone design project. A team of four students (one female, three male) was assigned to the project described previously, working under the guidance of a faculty advisor and two company sponsor liaisons, one of whom is a licensed structural engineer (S.E.) and the other a project manager.

As part of the capstone course, students completed: (1) a project proposal during the fall quarter, (2) the major analysis and design work during the winter, and (3) a final report and presentation in the spring quarter. To accomplish these tasks, the student team held weekly meeting with their faculty advisor and company liaisons. They gave two presentations for the sponsor—one in the fall detailing the proposal and one in the spring explaining the final design. These presentations were attended by other licensed professional engineers (P.E.s) and project managers from the company sponsor.

The team also interacted with licensed professional engineers outside of the sponsor company. They gave presentations at the local chapter of the Structural Engineers Association (SEA) in the fall and to the ASCE in the spring. A licensed professional engineer who is the technical manager at a local cement company provided guidance for their concrete testing. Finally, the team’s final project report was reviewed by two external structural engineers.

III. Benefit to Public Health, Safety and Welfare

Public Health – Because the dam is part of a watershed, construction is regulated to reduce contamination of the water. As possible, the team minimized on-site work that could pollute the water. For example, the hinge connection proposed for Section 2 (Figure 6a) does not require any field drilling. However, in some cases, on-site drilling or concrete pouring are necessary. The team included these considerations in their report, noting a hydraulic work permit would be required, and made recommendations for minimizing water contamination.

Public Safety – The dam is a historic structure that is routinely accessed by utility staff and the public. The existing safety features pose an immediate life-safety issue. During a site visit, the team observed the dangerous situation of children leaning over the vehicle barrier. The design recommendations presented consider the historic nature of the dam while providing safety for staff and visitors.

IV. Multidiscipline and Allied Profession Participation

The project included a number of opportunities for the students to interact with other disciplines and licensed professional engineers, which are described below in Figure 8.

Conducted multiple site visits – During site visits the team interacted with utility workers to learn about the site. Students also observed public attitude and behavior during tours.

Developed an experimental testing procedure – While developing the testing procedure for the concrete parapet, the team interacted with the university machinist to discuss fixturing. Additionally, to determine the compressive strength of the concrete, the team consulted with a laboratory manager (licensed professional engineer) from a local cement company about the relevant ASTM standards and ACI provisions.

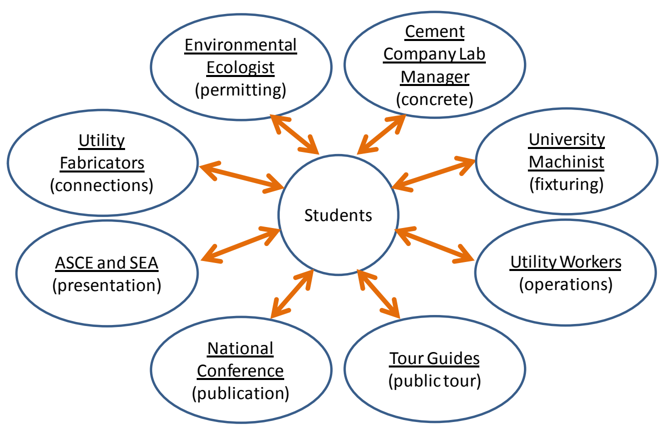


Figure 8. Student interaction with outside resources

Considered historical preservation/environmental considerations – In winter quarter, the students met with utility company representatives to discuss the design challenges presented by the historic nature of the dam and the location over drinking water. They learned about the company's Historic Management Plan and that designs should avoid any intense modification to the original concrete parapet. As possible, the historical aesthetics should be preserved and any additional structure must be identifiable from the original construction. An environmental ecologist discussed the permitting issues and instructed, as possible, they should limit any construction work that could contaminate the drinking water.

Learned about connection design – The students visited the sponsor's fabrication shop to discuss connection detailing. The sponsor prepared mock-up of their handrail attachment (Figure 7a) for the team's final presentation. They also received feedback from the fabricators about how to improve their design and drawings.

Authored a peer-reviewed publication – The team submitted a paper to a national conference. The paper was peer-reviewed by experts in the field and accepted for publication.

V. Knowledge and Skills Gained

The senior design experience is unique in that it helps students to develop a variety of important skills needed for practicing engineers.

Technical – The students learned how to assess and analyze an existing structure and then prepare design recommendations to remedy structural deficiencies. This process included using:

- **Building codes** – 2009 *International Building Code*, ASCE 7-10 *Minimum Design Loads for Structures and Other Buildings*
- **Design specifications** – *American Institute of Steel Construction (AISC) Steel Construction Manual 13th Ed., ACI: 318-08 Building Code Requirements for Structural Concrete and Commentary*, 2010 Aluminum Association *Aluminum Design Manual*
- **Computer aided drafting** – AutoCAD 2007, SolidWorks
- **Design aid** – Hilti PROFIS Anchor 2

Additionally, the students learned about constructability and detailed connection design, topics not covered in traditional courses. Their final designs addressed site-specific issues of historic preservation and environmental considerations.

Communication – During the year, students developed both writing and speaking skills. The students submitted a written proposal and a final report for the capstone course. Students provided detailed engineering calculations to the liaison throughout the year and received feedback. The students were also responsible for sending professional emails to the project liaisons. The team prepared oral presentations for their senior design course, the project sponsor, and professional engineering societies (Structural Engineers Association and ASCE).

Project Management and Leadership – The team organized weekly meetings with the faculty advisor and sponsor liaisons. Throughout the year, students took turns serving as the project manager. The project manager was responsible for preparing the agenda, leading meetings, assigning tasks, and tracking overall progress.