Experiential Learning Through Structural Retrofit Capstone Projects

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At Seattle University, Civil and Environmental Engineering students are required to complete a year-long, industrially-sponsored, capstone project. These projects serve as an authentic experiential learning opportunity where students learn design principles through practice. Recently, the department has worked on several structural retrofit designs of existing structures. This type of project is often more difficult than the design of new structures because it requires students to not only analyze the structures and identify deficient elements but also to develop mitigation measures that are feasible and constructible. Though challenging, retrofit design projects expose students to topics that are not covered in a standard undergraduate curriculum such as specialized software and visualization tools that can convey the design to the client clearly. To add to this, students start working on these projects before taking structural design courses and, as a result, spend much of their time learning as they go. Due to the complex nature of these projects, having a good relationship between the department and the project sponsor is important. This paper presents the students' experiential learning experience in three structural retrofit projects sponsored by the same company as well as summarizes the best practices for these projects to be successful.

Keywords: Structural retrofit, constructability, visualization

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Introduction

Capstone projects provide the framework for students to be engaged in experiential learning, where they learn by doing. The important connection between education and personal experience was first identified by Dewey[1]. Kolb[2] later defined a model for effective experiential learning that involves a four-stage cycle: concrete experience, reflective observation, abstract conceptualization, and active participation. Students actively participate in an experience, reflect on the experience and then apply their newly gained knowledge in other areas. Experiential learning activities can be classified as either simulations or authentic involvment[3]. Simulations involve scenarios created by faculty, while authentic involvement uses real-world problems.

Background

At Seattle University (SU), Civil Engineering seniors participate in a year-long, capstone project that is sponsored by industry through authentic involvement. Students work in teams of three to four under the guidance of a project coordinator, faculty advisor, and a liaison from the company sponsor. As part of the capstone course, students complete: (1) a written proposal during the fall quarter, (2) most of the analysis and design work during the winter, and (3) a final report and presentation in the spring quarter. In addition, they give two presentations to the sponsor – one in the fall detailing the proposal and one in the spring explaining the final design. The student teams meet weekly with their faculty advisor and sponsor liaisons.

The structural capstone projects provide an opportunity to learn the elements of the design process (analysis, use of codes/specifications/standards, and the iterative process of design) before they have had structural design courses. In our curriculum, Reinforced Concrete Design and Steel Design are offered in the winter and spring quarters of senior year. Thus, students carry out calculations for their design projects that they have not yet seen formally in the classroom. Furthermore, these projects expose students to topics outside the curriculum including aluminum, timber, and reinforced masonry design, lateral loads (wind and seismic), and computer software programs (Hilti Profis™, SAP2000™, Solid Works™, Trimble SketchUp™, etc.)

Structural Retrofit Projects

Recently, the SU Civil Engineering department has worked on several structural retrofit projects for existing structures. Retrofits are often more challenging than the design of new structures. Students must learn to analyze structures, identify deficient structural elements, and then propose mitigation measures that are constructible and compatible with the existing structure.

Following are three examples of structural retrofit projects we have completed, highlighting the skills learned. All three projects were sponsored by the same local utility company, Seattle City Light (SCL). We have worked with SCL for the past 23 years. This long-term relationship has resulted in project liaisons who understand our program and curriculum, know the skill sets of the students, and can scope out work that is feasible within a school year. Project scopes have evolved significantly over the years to become complete, stand-alone analysis and designs, with final deliverables that include calculations, drawings, cost estimates, construction specifications, and recommendations. Often these designs are implemented by SCL, which is an exciting outcome for our students. Because SCL is also located in downtown Seattle (approximately a ten minute walk from our campus) it is easy for teams to meet weekly with their client and also to give presentations to the end users of their designs. Teams consisted of four to five students.

Retrofit of a Relocated Steel Warehouse

A capstone team performed a structural evaluation and retrofit designs of a warehouse that was not up to current codes and thus posed a life-safety threat to its employees. The warehouse has a footprint of 350 by 80 feet and functions as an office, gymnasium, and storage facility of key replacement parts for SCL's powerhouses and dams. Originally constructed in Boundary, WA, the building was later moved over 300 miles and reconstructed at its current location in Newhalem, WA in the late 1980's. During reconstruction, multiple modifications (Figure 1) were made without formal structural analysis.

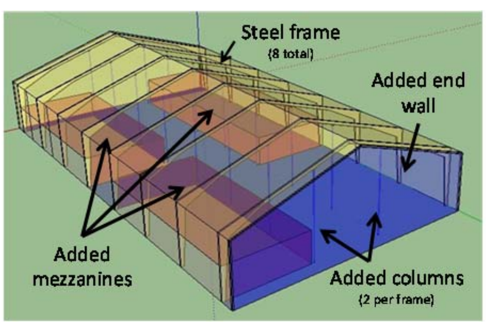


Figure 1. Schematic of steel warehouse: original portion, elements added during reassembly (blue), and the subsequent modifications (orange)

The capstone project began with a site visit and creation of as-built drawings. Next, the design loads were determined according to current building codes. Finally, a structural analysis was performed and retrofits were designed for any deficient members. Due to the operational importance of the structure, mitigations had to be able to be completed while the building was in use.

In addition to weekly project meetings with the liaison engineer, a SCL structural engineer offered weekly steel design tutorials to the students, since they had not yet taken a steel design course. The content of these tutorials was driven by the structural elements the team currently needed to analyze. The team also had to analyze the roof sheathing, which was composed of cold-formed steel, requiring a different type of analysis than what traditional steel design courses cover.

The team used Trimble SketchUp™ to create a three-dimensional model of the structure, which helped to visualize and communicate the retrofit options to the client. They also went on a second site visit in the spring quarter to verify that their designs were constructible.

Figure 2 and Figure 3 show examples of the retrofits for the deficient frame and interior columns, respectively. The frame mitigation included a slip critical bolt connection that allows a channel to be inserted inside the frame, held in place by the connection, and then field welded. The column retrofit (Figure 3) strengthened existing columns by adding an encasing steel pipe.

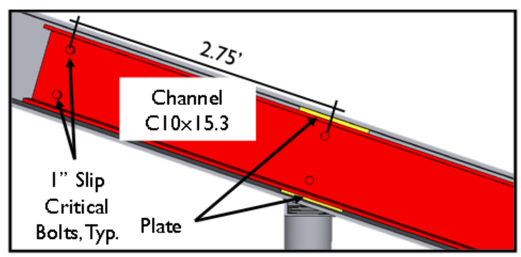


Figure 2. Frame mitigation design to prevent bending failure with existing frame (gray) and retrofit channel (red)

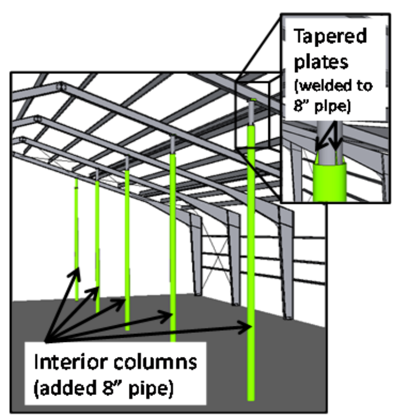


Figure 3. Column mitigation to improve stability and prevent frame shear failure with existing members (gray) and retrofit columns and plates (green)

Retrofit or Replacement of Dam Walkway Slabs

Seattle City Light requested a capstone team to develop repair or replacement designs for damaged reinforced concrete walkway slabs that were located at each of Boundary Dam's (Boundary, WA) seven sluice gates. Figure 4 and Figure 5 show a plan view and cross section through one of the sluice gates, respectively. The walkways are routinely used by staff for dam maintenance, posing a life-safety issue.

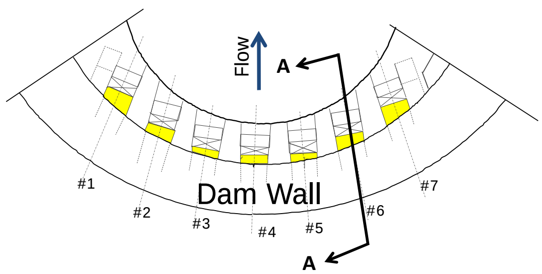


Figure 4. Plan view of seven maintenance walkways (yellow) with varying geometries

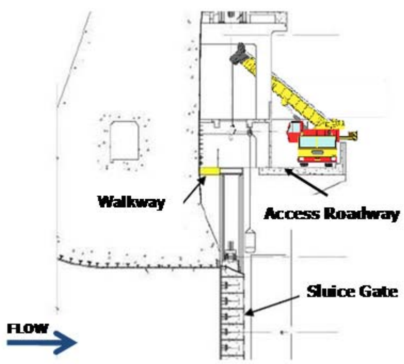


Figure 5. Typical cross section (A-A) through sluice gate showing access issues from roadway

The capstone project began with a site visit. During the visit the team observed a number of site-specific challenges: remote location, variable slab geometry, limited walkway access, and an aggressive environment. The team prepared two separate design concepts: (1) steel retrofit and (2) reinforced concrete slab demolition and replacement plan.

Figure 6 presents the steel retrofit plan. A similar plan was created for the replacement of the reinforced concrete slabs. While the analysis and designs required the students to learn reinforced concrete and steel design, they also needed to visualize the construction sequencing and connections. The team used Trimble SketchUp to build a three-dimensional model of the two plans. They also visited the SCL's fabrication shop to observe one of their wall bracket connections being made. This experience was helpful because it showed the team what the fabrication process was like and also allowed them to watch someone interpret their drawing.

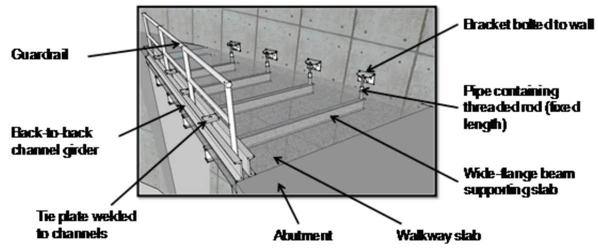


Figure 6. Steel retrofit design

Construction of either option was challenging due to worker safety and environmental issues. There is no access below the slab without the use of complex scaffolding. Worker safety was considered by not requiring any person to go below the slabs, protecting workers from being struck by falling debris. Because construction work would occur directly over the river, all designs included methods to prevent debris from falling into the water and causing contamination.

Retrofit of Historic Dam Safety Features

SCL asked SU's capstone program for the retrofit design of safety features - the vehicle barrier (Figure 7a), hand rails and parapet (Figure **7**b) - on the historic Cedar Falls Dam (Cedar Falls, WA) 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.

Cedar Falls Dam was built in 1914 and provides power and water to Seattle. The dam walkway is used for maintenance as well as public tours. The existing safety features pose an immediate life-safety concern because: (1) all features are too short (less than 42" as required by building code), (2) the vertical spacing between the horizontal bars of the handrail and vehicle barrier and is too large (> 4" as required by building code), and (3) the concrete parapet is severely degraded. Figure 7a shows the dangerous situation that can result from these deficiencies - a child leaning over the vehicle barrier to see the water.

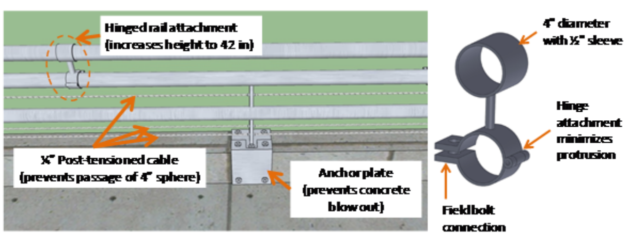
To evaluate the condition of the existing safety features, the team used historic drawings, site visit data, and experimental data. Concrete cores were taken from the parapet and tested at the SU lab according to American Society for Testing and Materials (ASTM) Standards. The lateral capacity of the parapet was determined from a field test developed and conducted by the team and found to be adequate.

The team prepared replacement and retrofit options to address the geometrical and strength deficiencies for each of the safety features. Much of this work required an understanding of reinforced concrete behavior before they had any related coursework. They also needed to understand aluminum specifications, a topic not covered in our curriculum. To analyze and design anchorage connections, they used commercially-available software, Hilti Profis, with assistance from the project liaison and faculty advisor, as needed.

(a) (b)

Figure 7. Existing safety features: (a) vehicle barrier and (b) degraded historic concrete parapet

Figure 8a shows the retrofit design of the vehicle barrier, which includes a horizontal rail attachment, post-tensioned cable, and reinforcement plate for the concrete curb. The rail attachment (Figure 8b) consists of a horizontal steel pipe with a hinge design to minimize protrusion into the walkway.



(a) (b)

Figure 8. Recommended retrofit design for rail attachment on vehicle barrier: (a) schematic representation with added safety features and (b) hinged rail attachment connection

Designs for each section were presented to the client using Trimble SketchUp™ and SolidWorks™. The team also met with SCL specialists to discuss the historical and environmental concerns of the project. Because the dam is part of a watershed, construction is regulated to reduce contamination of the water. The team minimized on-site work that could pollute the water. For example, the hinge connection proposed for Section 2 (Figure 8b) does not require any field drilling. Due to the historic nature of the dam, all designs sought to mimic existing conditions.

Best Practices

Capstone projects at Seattle University have provided our students the opportunity to learn design principles through practice. Three recent structural retrofit projects are discussed, highlighting key aspects. Following are some best practices we have from these, and similar, projects:

- ***Sponsor Relationship:*** Developing a close, continuous working relationship with the sponsor strengthens the project. This relationship allows the sponsor to understand the curriculum and the students' skill level. As a result, project scopes can be defined such that students are challenged and develop new skills within the nine month capstone course timeframe. Additionally, sponsors are committed to the projects and there is an open line of communication between the sponsor and faculty.
- ***Regular Project Meetings***: Weekly meetings including a liaison engineer and faculty advisor are important for providing timely feedback and keeping the project on schedule. If specific technical needs arise, additional tutorial sessions must be led by the liaison or faculty advisor.
- ***Site Visits:*** If possible, multiple site visits should be made. Initial site visits help the students understand the problem, while later visits allow them to assess the feasibility of their designs.
- ***Visualization Tools***: Visualization tools help students improve their designs. Three-dimensional models (such as Trimble SketchUp™) are particularly useful to convey design concepts and the construction sequence to non-technical and technical clients.
- ***Observing Fabrication Details:*** Designs can be improved if students observe what the fabrication process entails. This observation gives them an appreciation for the work involved in creating the individual pieces and provides them some insight into constructability.
- ***Industry Experts:*** Meeting with experts from the sponsoring company or elsewhere, such as an environmental scientist, can help students understand the global aspects of their project.
- ***Deliverables:*** When possible, final project deliverables should include a calculation package, construction drawings, design specifications, and cost estimates to help provide a real-world context for the designs and empower the students to make recommendations to their client.

References

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