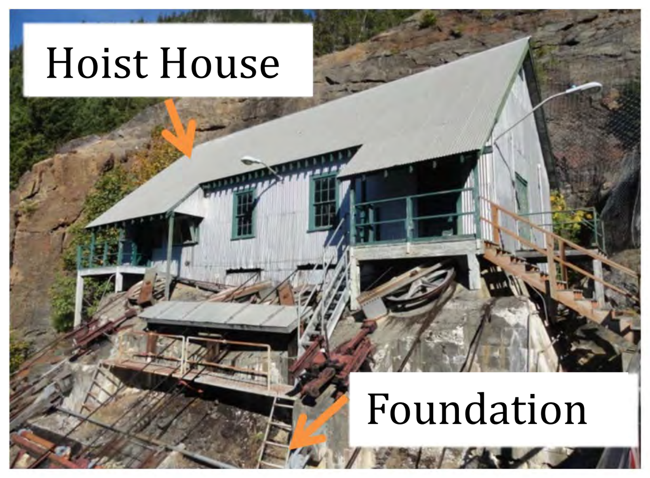
Historic Landmark Incline Lift Structural Evaluation and Retrofit

Background



- Provides alternate access to dam in event of landslides
- Incline lift travels 340 feet at 34° slope
- Concrete in foundation deteriorated - compressive strength 30% lower than original

Evaluate foundation; design retrofits and increase longevity

Special Considerations

Historical Significance

- Incline lift built in 1928 to hoist train cars, workers, and materials to build dam that *supplies power to major city*
- On Registry of Historical Places

→Historical aesthetics must be preserved

Environmental Concerns

- Located in national park

→Any construction must minimize noise, limit project footprint, leaching of toxic material, sediment transport to groundwater, and impact on migratory birds

Student Collaboration with Faculty, Licensed Engineers and Allied Professionals

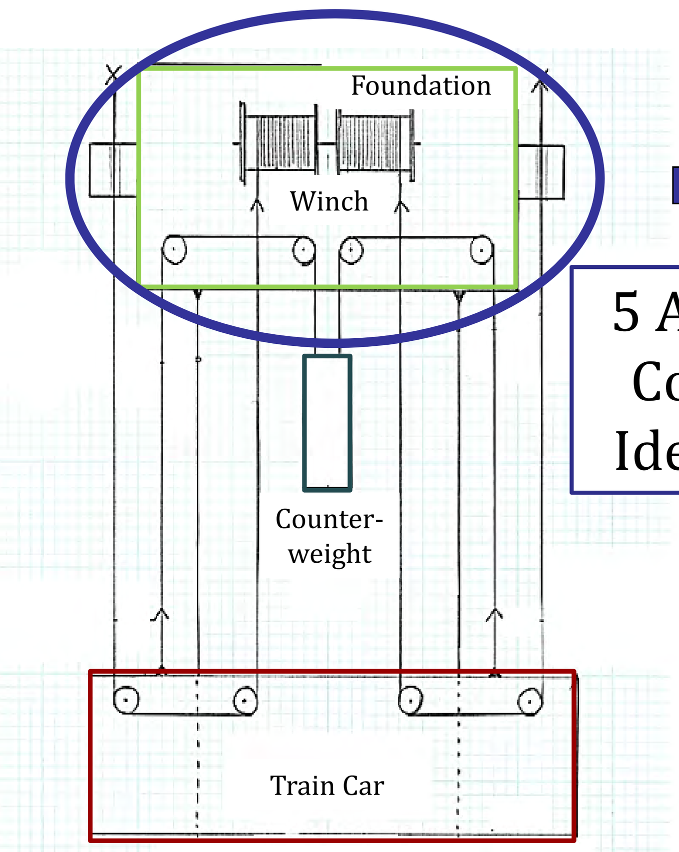
- Four-student team worked with faculty advisor and two company liaisons (a ***licensed Professional Engineer (PE)*** and a project manager)

Fall	Winter	Spring
Site Visit Written Proposal	Analysis and Design	Final Report, Presentation

- Proposal/Report reviewed by five civil engineering faculty (multiple sub-disciplines and of whom four licensed PEs) and two ***licensed PEs*** (external to the project)
- Team presented to civil engineering capstone class (multiple sub-disciplines), power company (attended by individuals from multiple disciplines) and professional societies
- Interacted with allied professionals:

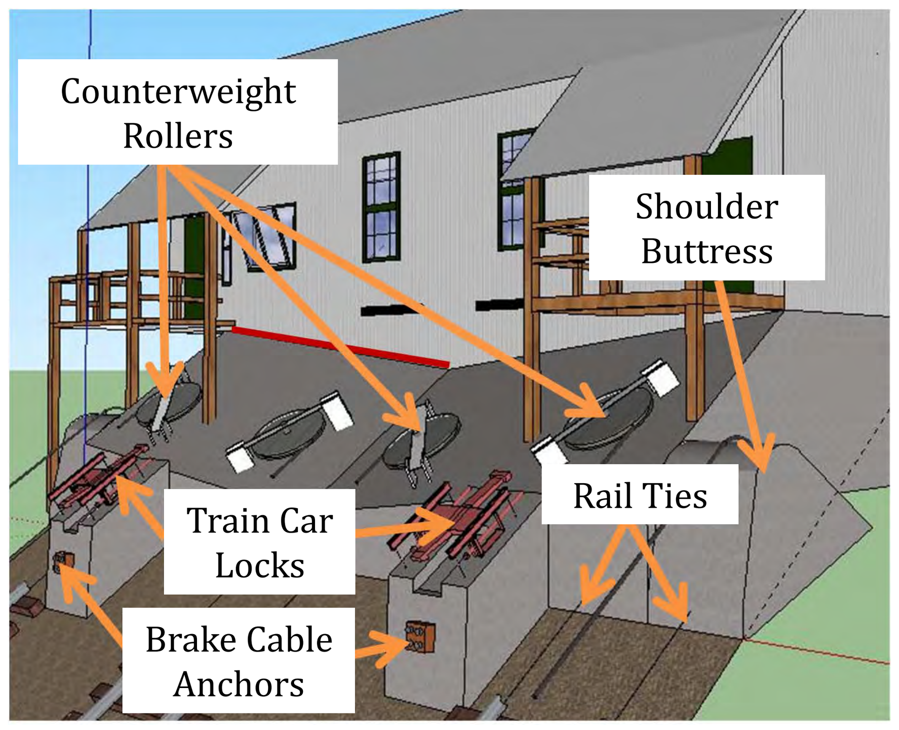
Student Team ↔
- Power Company Workers (operations)
- Cement Materials Experts (concrete)
- Historical Expert (preservation)
- Ecologist (environmental)
- Power Company Fabricators (connections)
- ASCE and Structural Eng. Assoc. (presentation)

Project Scope and Analysis

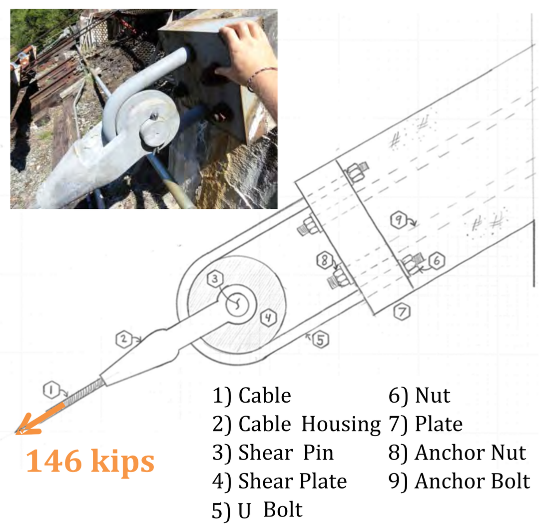


Lift Plan View

5 Areas of Concern Identified



Individual Analyses
(brake cable shown)



Component	Area (in²)	Force (kip)	Demand (ksi)	Capacity (ksi)	Demand/Capacity
Cable Housing	13.1	146	11	60	0.19
Shear Pin	10.3	146	7	35	0.20
U Bolt	4.0	146	18	60	0.31
Take Up Nuts	3.1	37	12	60	0.19
Anchor Nuts	3.1	37	12	60	0.19
Anchor Bolt	1.0	37	37	60	0.61

Analysis Process

Areas of Concern

- From site visit, team understood lift operation – winch and counterweight system
- Team identified 5 areas of concern for further foundation and anchor analysis

Individual Analyses of Each Area of Concern

- Team identified individual load path with demand train car load = 160,000 lbs
- Calculated **Demand/Capacity** ratios for each component within the area:
  - **Demand** according to governing loads (local building code, ASCE 7-10)
  - **Capacity** based on steel and concrete specifications (AISC 14th ed and ACI 318-11)
- ***If Demand/Capacity (D/C) > 1 → member is deficient***

Overall Analyses – Team checked D/C ratios for all components for five areas of concern

Overall Results

Area of Concern	Number of Components Analyzed	Governing Demand/Capacity
Brake Cable Anchors	6	0.61
Counterweight Rollers	10	0.83
Rail Ties	3	0.85
Train Car Locks	10	0.49
Winch Cable and Buttress	14	0.62

All D/C < 1 → members adequate, but concrete deteriorated and needs retrofitting for longevity

Benefit to Public Health, Safety and Welfare

Lift operation ensures that power company workers can access the dam in the event of a landslide closing the road. Thus, the dam will **continue to supply power to large city.**

Public Health: Designs prevent sediment and contaminants from reaching ground water.

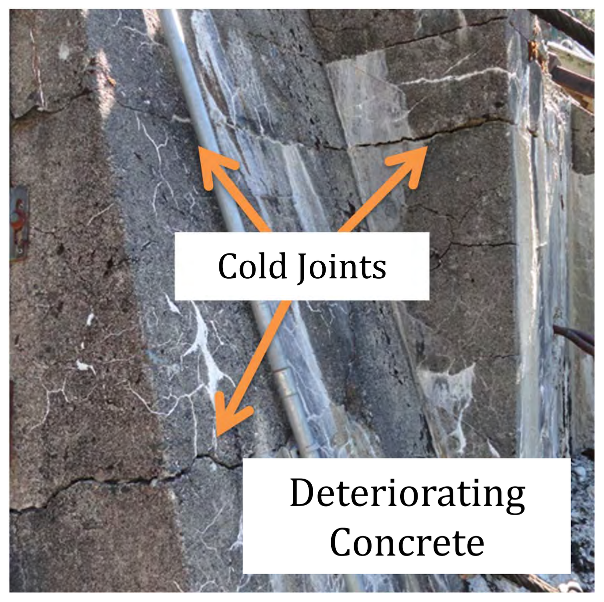
Public Welfare: Historic lift is landmark that tourists used to be able to ride; restoring it revitalizes area.

Retrofit Designs

Option 1: Aesthetic Repair

- Patch and repair cracked and spalled concrete
- Mix concrete to match existing

→ $10,000

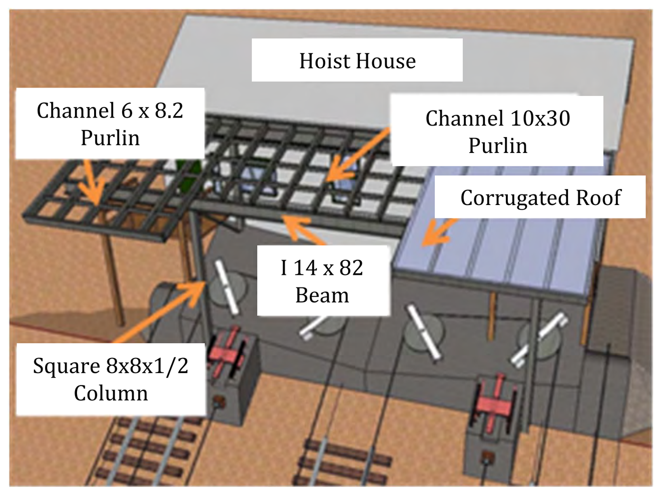


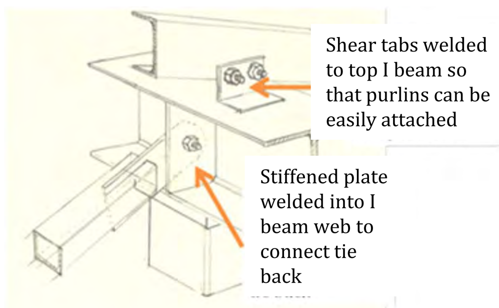
Option 2: Remove and Replace Foundation

- Remove and replace exposed concrete with modern, durable concrete
- Design new reinforced concrete foundation
- New foundation maintains shape and concrete mixed to match existing

→ $132,000

Option 3: Steel Cover Structure





Constructible beam-column connection design

- Structure mimics hoist house and concrete mixed to match existing

→ $134,000

➡ Recommend Option 2 to ensure longevity of structure

Skills Gained

Technical

- Learned to analyze and make recommendations for existing structure
- Worked with building codes, design specifications, structural analysis software, and presentation aids
- Accounted for historical and environmental restraints in their designs
- Unique exposure to constructability, connection design and cement-material behavior

Communication

- Written – proposal, presenting calculations, final report, sending professional emails
- Oral – Effective presentations to senior design class, sponsor, local chapter of engineering societies, use of Trimble-SketchUp® to effectively communicate mitigation concepts to the client and non-engineers

Project Management and Leadership

- Weekly meetings organized by team
- Rotating project manager responsibilities
- Working as a team and conflict resolution
- Time management skills

Cost Estimating - Prepared detailed cost estimate of design options

Historic Landmark Incline Lift Structural Evaluation and Retrofit

Abstract

A local power company requested our university's capstone program to perform a structural evaluation and retrofit of their historic incline lift. A design team was tasked with assessing the structural integrity of the lift's concrete foundation and anchorages to propose retrofit designs to mitigate deficiencies and increase the longevity of the structure.

The incline lift was built in 1928 to access the mountainous construction site at a dam critical to the power supply of a large city. The lift was designed to hoist train cars, materials, and workers up the slope. After completion of the dam, the lift remained an integral part of power company operations until it was decommissioned in 2001 due to security concerns. The power company wants to bring the lift back into service to provide redundant access to the dam for when the highway is closed due to landslides. The lift is on the National Registry of Historic Places and is located in a national park, thus both historic and environmental factors had to be considered.

The team visited the project site to learn how the incline lift is intended to function. They also observed the deteriorated state of the exposed concrete foundation. A materials laboratory report done on the lift confirmed that concrete in exposed areas was deteriorating and the compressive strength severely compromised. From the site visit, the team identified five areas of concern within the lift system. Each of these areas of concern was analyzed by tracing the individual load path through the components to the concrete foundation. The governing demand to capacity ratios of the five systems showed that all components are adequate.

Although the foundation and anchors have sufficient capacity, the aesthetics of the existing foundation are a concern as is the longevity of the foundation as it is exposed to continued weathering. Therefore, the design team presented three retrofit options to the power company: (1) aesthetic patching of the concrete, (2) removal of the existing weathered concrete and replacement with new modern, durable concrete, and (3) construction of a steel roof cover structure to protect the exposed foundation. The total estimated costs of the three options were $10,000, $132,000 and $134,300, respectively. The team recommended that design option 2 be implemented.

Students met weekly with their faculty advisor and the sponsoring company liaisons, two of whom are licensed professional engineers (PEs). The team's design calculations were reviewed by the faculty advisor, company liaisons, and two other PEs. Project highlights include site visits, professional presentations to their class, the project sponsor and outside professional chapters, working with a historical specialist and ecologist, and a visit to the sponsor's fabrication shop to discuss connection design. The team also learned to use Google SketchUp® to effectively communicate their mitigation concepts to the client and non-engineers. The project culminated in a final report to the utility company and a poster presentation to the local university and engineering community. Throughout the year, students developed important technical, communication, project management and cost estimating skills to help prepare them for their future careers as practicing engineers.

Historic Landmark Incline Lift Structural Evaluation and Retrofit

I. Project Description

Introduction

A local power provider issued a Request for Proposal to our university's capstone program for the structural evaluation and retrofit of their historic incline lift. A design team was tasked with assessing the structural integrity of the lift's concrete foundation and anchorages to propose retrofit designs to mitigate deficiencies and increase the longevity of the structure. The final design was to consider current loading standards, the aggressive freeze-thaw climate to which the structure is exposed, the historic aesthetics of the original lift, and to minimize the environmental impact from any proposed construction.

Background

Figure 1 shows the incline lift, which was designed to hoist train cars, materials, and workers up 340 feet at a 34 degree slope. The lift was built in 1928 to access the mountainous construction site at a dam critical to the power supply of a large city. It served as the only access to the dam until a highway was constructed in the vicinity in 1964. After completion of the dam, the lift remained an integral part of power company operations until it was decommissioned in 2001 due to security concerns. The power company wants to bring the lift back into service to provide redundant access to the dam for when the highway is closed due to landslides during the area's aggressive winter climate. The lift is on the National Registry of Historic Places and is located in a national park, thus both historic and environmental factors must be considered when retrofitting the structure.

(a) (b) (c)

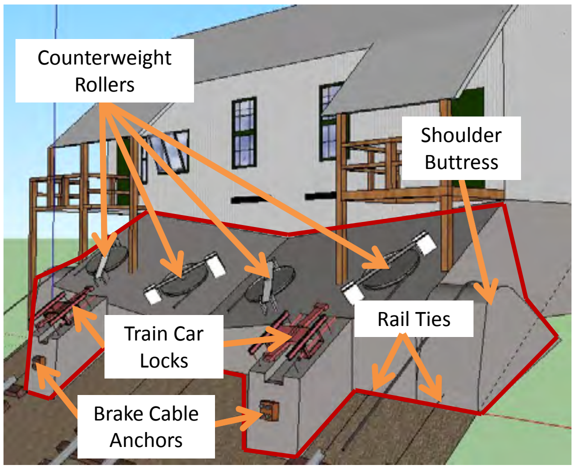
Figure 1. Incline Lift: (a) Present Day System, (b) Historic Picture of Train Car Carrying Workers, and (c) Present Day Hoist House

Analysis of Existing Conditions

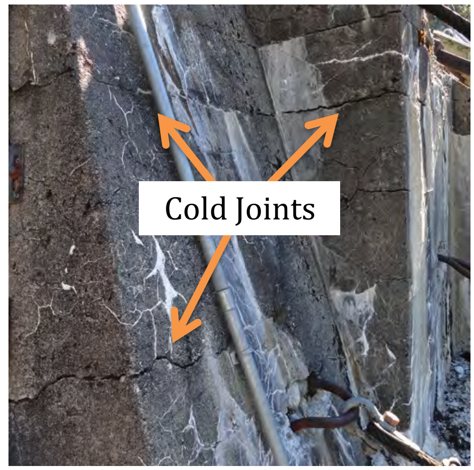
Site Visit

The capstone project began with a site visit so that the team could understand how the lift is intended to function and observe present conditions. The lift is designed to operate similar to a conventional elevator, with a winch and counterweight system. It hoists a 20 foot by 60 foot level platform that rides on two sets of tracks up the incline (Figure **1**b). The concrete foundation securing the winch, counterweight rollers, and emergency break cables is approximately 40 feet x 20 feet x 6 feet.

Figure 2 shows a schematic of the hoist house and also the exposed deteriorated concrete foundation that the team observed on their site visit. This deterioration is evidenced by extensive cracking, including cracks at the cold joints from construction (Figure 2b). The power company provided the team a report from a materials lab confirming that concrete in exposed areas was deteriorating, with a compressive strength that had decreased from an original 5,000 psi to 3,500 psi.



(a)



(b)

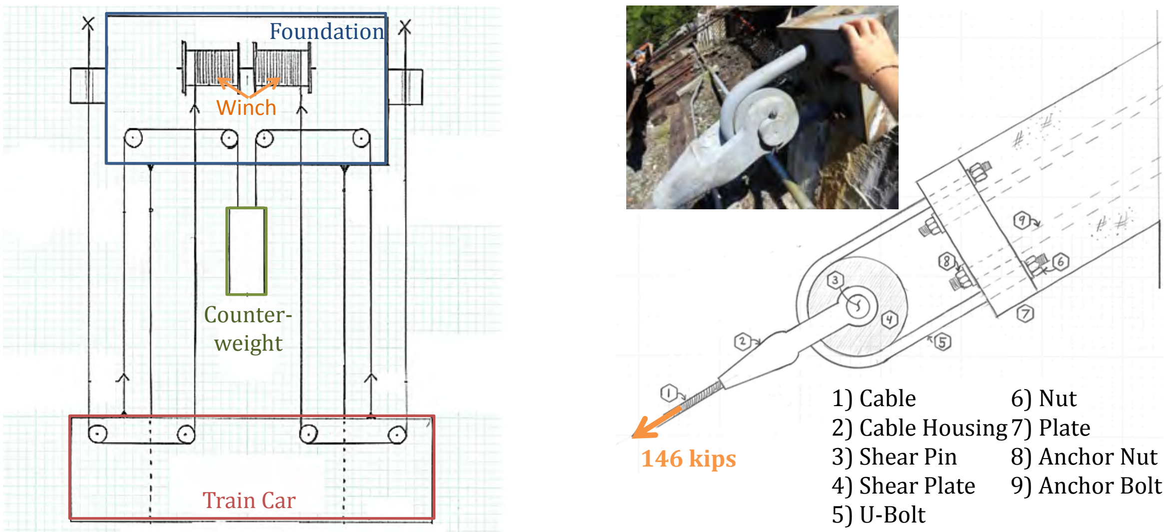
Figure 2. Hoist House (a) Schematic showing the Five Areas of Concern and Concrete Foundation (Outlined in Red) and (b) Exposed Deteriorated Concrete

Foundation and Anchor Analysis

The analysis of the exposed foundation was divided into five areas of concern: the brake cable anchors, counterweight rollers, rail ties, train car locks, and shoulder buttress. These areas are identified in Figure 2a. A schematic plan view of the entire incline lift system is shown in Figure 3a. The winch and counterweight are both connected to the train car and work in tandem to hoist the car up the slope. Cables connect the major elements in the system and pass around the rollers.

The individual load path for each area of concern (Figure **3Error! Reference source not found.**b) was determined by tracing the demand load through the components to the concrete foundation. If the governing demand/capacity ratio is less than 1, the member is adequate. For example, Figure 3b shows a picture and schematic of the brake cable anchor assembly. For a train car demand of 160,000 lbs, the cable must be able to carry 146,000 lbs. This load is then transferred to the other components. Table 1 presents the analysis for the brake cable anchor. The governing demand/capacity ratio is 0.61, which is less than 1. Therefore, the brake cable anchor is sufficient.

Table 2 summarizes the results of the structural analysis conducted, including the number of components analyzed and the governing demand/capacity. For each area of concern, a load path analysis and individual demand/capacity checks for each component was performed (similar to what was shown for the brake cable anchors). All of the demand/capacity ratios are less than one, indicating all components are adequate.



(a) (b)

Figure 3. Incline Lift Load Path Analysis: (a) Plan View Schematic of Entire System and (b) Brake Cable Anchor Picture and Schematic with Structural Components Identified

Table 1. Demand/Capacity Analysis for Brake Cable Anchor

Component	Area (in^2)	Force (kip)	Demand (ksi)	Capacity (ksi)	Demand/Capacity
Cable Housing	13.1	146	11	60	0.19
Shear Pin	10.3	146	7	35	0.20
U Bolt	4.0	146	18	60	0.31
Take Up Nuts	3.1	37	12	60	0.19
Anchor Nuts	3.1	37	12	60	0.19
Anchor Bolt	1.0	37	37	60	0.61 ← Governing D/C

Table 2. Structural Component Analysis for the Five Areas of Concern

Area of Concern	Number of Components Analyzed	Governing Demand/Capacity
Brake Cable Anchors	6	0.61
Counterweight Rollers	10	0.83
Rail Ties	3	0.85
Train Car Locks	10	0.49
Winch Cable and Buttress	14	0.62

Retrofit Design Options

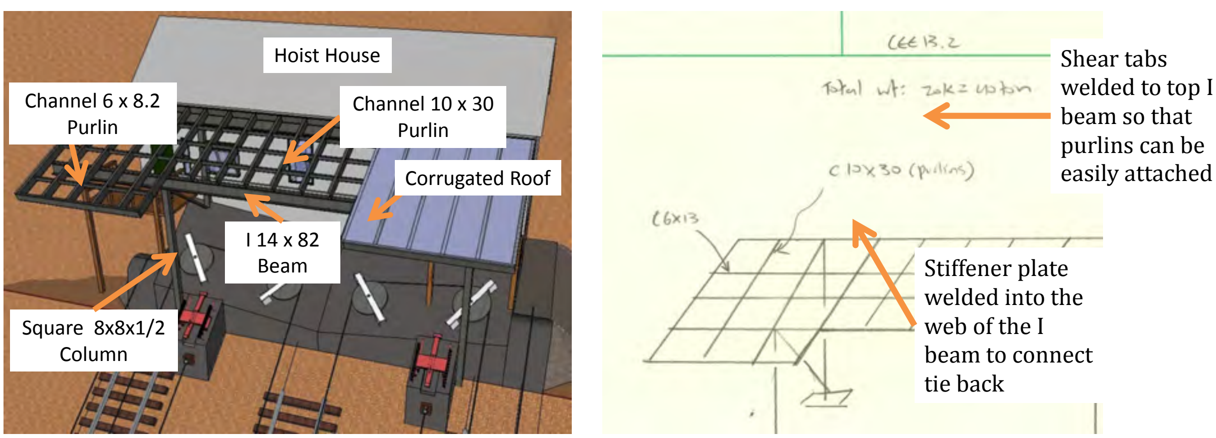
Analyses revealed that the foundation and anchors had sufficient capacity. However, the aesthetics of the existing foundation are a concern as is the longevity of the foundation as it is exposed to continued weathering. Therefore, the design team presented three retrofit options to the power company: (1) aesthetic repair only, (2) removal and replacement of the existing foundation, and (3) construction of a roof over the exposed foundation.

Option 1: Aesthetic repair only
Though the concrete foundation has sufficient capacity, it shows significant signs of weathering and does not give the overall appearance that it is structurally sound. In this option, the effervescence is removed from the foundation surface and spalled concrete patched, leaving a cleaner and more homogenous surface. To preserve the historical appearance of the lift, the concrete patchwork needs to match the color and texture of the existing concrete to achieve a consistent appearance.

Option 2: Removal and Replacement of Existing Foundation
While the foundation is currently adequate, the existing cracks suggest that it could continue to deteriorate. To overcome this continued deterioration, the exposed portion of the concrete (outlined in red, Figure **2Error! Reference source not found.**a) is removed and replaced with modern, durable concrete. The new foundation would be much better suited to endure the aggressive winter climate to which it will be exposed, increasing the longevity of the incline lift.

For this option, the team developed a construction plan for the existing concrete foundation to be removed and designed a new reinforced concrete foundation according to applicable codes and specifications. The historical aesthetics are preserved because the dimensions and overall appearance of all proposed concrete features match those of the existing ones. New concrete is mixed to match the color of the existing foundation.

Option 3: Construction of a Roof over the Exposed Foundation
An alternative option to replacing the exposed concrete is to protect it from weathering with a cover structure. This structure limits the amount of moisture that can penetrate existing cracks by minimizing the accumulation of rain and snow. The team proposed an open-walled, free-standing steel structure, as shown in Figure 4a**.**



(a) (b)

Figure 4. Option 3: (a) Steel Roof Design to Cover Exposed Concrete (Corrugated Roof Only Shown on Right so that Structural Components Below Visible) and (b) Schematic of Beam-Column Connection Design

A corrugated steel roof sits flush under the bottom edge of the corrugated roof of the hoist house. From the hoist house, it extends to the front edge of the concrete foundation, spanning the entire width of the hoist house, supported by columns anchored into individual concrete footings. The load and demands were determined according to applicable codes and specifications. A structural analysis software (SAP) was used to determine the demands.

Constructability was taken into account in the design. The cover structure consists of a limited amount of members, decreasing construction time and overall cost. Bolted connections are fabricated at the power company's machine shop and completed on site. An example connection designed by the team is shown in Figure 4b.

Final Recommendation

The design team presented these options to the power company, along with corresponding cost estimates. The costs for options 1, 2, and 3 are $10,000, $132,000 and $134,300, respectively. Because the long-term durability of the existing concrete is not known, the team recommended that design option 2 be implemented.

II. Collaboration of Faculty, Students and Licensed Professional Engineers

At our institution, senior Civil Engineering students are required to complete a year-long, real-world, capstone design project. Four students were assigned to this project and worked under the guidance of a faculty advisor, a licensed professional and structural engineer (PE and SE), and two company sponsor liaisons, one of whom is a licensed professional engineer (PE) 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 (PEs) and project managers from the company sponsor. The team also interacted with licensed professional engineers outside of the sponsor company by giving a presentation at the local chapter of the Structural Engineers Association (SEA) in fall.

III. Benefit to Public Health, Safety, and Welfare

The design team considered public health, safety, and welfare in the project. The operation of the lift ensures that power company workers can access the dam in the event of a landslide closing the road. Thus, the dam will continue to supply power to a large city. Additionally, the project addressed issues related to:

<u>Public Health</u> – All designs included measures to prevent sediment and toxic materials from reaching the ground and surface water during construction.

<u>Public Welfare</u> – The historic lift is a landmark that tourists used to be able to ride as part of a tour of the dam and surrounding areas. Restoring the lift will revitalize the area.

IV. Multidiscipline and Allied Profession Participation

The project included a number of opportunities for the students to interact with other disciplines and licensed PEs, as shown in Figure 5.

Power Company Interactions – During the site visit, the design team interacted with power company workers and PEs to learn about the site. They also presented their proposal (fall) and final recommendations (spring) at the power company to an audience that included staff working regularly at the dam, project managers, and engineers (all PEs).

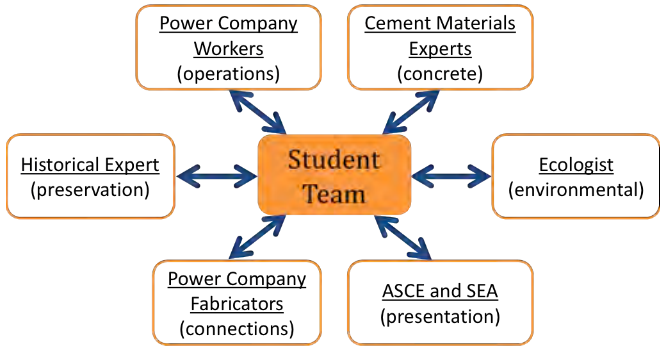


Figure 5. Multidiscipline and Allied Profession Participation

Materials Lab Report – The team was provided a comprehensive materials laboratory report about the condition of the concrete foundation. They discussed this report with a materials lab engineer and also a faculty member specializing in cement-based materials, both of whom are PEs. Understanding the report required knowledge of American Society for Testing and Materials (ASTM) and American Concrete Institute (ACI) testing methods as well as cement-based material behavior.

Historical Preservation – As mentioned earlier, because this site is a historical landmark, the aesthetic appearance had to be taken into account when designing the retrofit options. In winter quarter, the students met with power company's historical specialist to discuss the design challenges presented by the historic nature of the lift. They learned about the company's Historic Management Plan and that the historical aesthetics are to be preserved and any additional structure must be identifiable from the original construction.

Environmental Considerations – The team met with an Environmental Ecologist from the power company. The incline lift is within a national park and requires authorization for the implementation of the design options. Environmental considerations in the designs included noise impact, project footprint, potential leaching of toxic material, and sediment transport caused by construction processes. Additionally, toxic materials or sediment could not be allowed to reach water sources because of its adverse impact to the aquatic life. Construction also could not impact migratory birds which inhabit the area.

Connection Design – The students visited the sponsor's fabrication shop to discuss connection detailing. The sponsor prepared a mock-up of their beam-column connection (Figure 4b) for the team's final presentation. The students also received feedback from the fabricators about how to improve their design and drawings.

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 to assess and analyze an existing structure and prepare design recommendations to remedy structural deficiencies. This process included using:

- Building codes - *2012 International Building Code*, *American Society of Civil Engineers 7-10,* local county code
- Computer-aided drafting - AutoCAD
- Cost estimate catalogs – RS Means
- Design specifications – *American Institute Steel Construction Manual 14th ed.*, *ACI: 318-11*, ASTM
- Structural analysis software - SAP2000
- Presentation aid – Trimble® SketchUp

Additionally, the students had to take into account **constructability** issues in their design and perform **detailed connection design**, topics not covered in traditional course work. Their retrofit designs addressed **site-specific constructability issues** (such as severe winter weather, issues related to construction in a remote location, and bird migration patterns). Finally, they learned about **cement-based material behavior and testing methods**, topics not covered in our undergraduate curriculum.

Communication - During the year students developed both writing and speaking skills. The students submitted a written proposal and a final report. 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 a professional engineering society. For their final presentation, the team developed a detailed Trimble® SketchUp model of the incline lift, including an animated ride up the lift and around the proposed steel cover structure. This model was a powerful way to present their final retrofit options, particularly to a more general audience.

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.

VI. Summary

A local power company requested that a capstone design team from our civil engineering department perform a structural evaluation and retrofit of their historic incline lift. The team worked closely with a licensed professional engineer from the power company, as well as a faculty advisor who is also licensed, to perform a structural analysis of the lift's foundation and anchorages. Their analysis showed that the system was adequate; however, due to the degradation of the exposed concrete, the longevity of the structure was still uncertain. The team came up with three proposed retrofit designs, all of which considered the unique historical and environmental considerations of the project. The students developed valuable technical, communication, project management, and cost estimating skills for their future careers as practicing engineers.