# Learning Challenges and Opportunities from Seismic Retrofit Capstone Projects

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## Abstract

Civil and Environmental Engineering students at Seattle University are required to complete a three-quarter capstone project that is team-based and industrially-sponsored under the supervision of a liaison engineer from industry and a faculty member. These projects offer students opportunities to apply concepts from analysis and design classes to solve real-world problems. In the last two years, student teams have completed three seismic retrofit projects of different complexity levels. Benefits to the students that are particularly unique to these projects include direct application of design principles, exposure to specialized structural software and seismic assessment/retrofit standards and codes, and the use of visualization tools to convey solution schemes to clients. During the execution of the entire project, students are challenged to learn fundamental concepts of earthquake engineering without having formal training on the subject. In addition, students have to adhere to a standard seismic assessment code and produce reasonable solutions that could be constructible in practice. Because these issues go beyond the knowledge and experience that a typical undergraduate education can offer, close collaboration and mentoring by faculty and industry liaisons are critical to the project success. This paper presents an overview of three seismic retrofit capstone projects and describes the students' experience of experiential learning. Results from a student learning survey are also presented.


## Introduction

Over the years, seismic events cause severe damage to infrastructure around the world and remind us of the importance of sound engineering design to mitigate the losses. Unfortunately, structural dynamics and earthquake engineering are subjects often not included in an undergraduate curriculum. To address this deficiency, some structural engineering faculty have tried to include hands-on, shake table experiments into their undergraduates courses to provide exposure to basic seismic concepts[1,2]. In the Civil Engineering program at Seattle University, we are able to introduce some of our students to earthquake engineering topics through senior design projects. In addition to exposing them to the fundamental principles of structural dynamics, they are also exposed to the industry standard, ASCE/SEI 31-03[3], for conducting seismic assessment.

Problem-based learning (PBL) is defined as an active learning approach in which problem solving becomes the environment for students to apply prior knowledge and acquire new knowledge. This pedagogical approach was developed in the sixties and first applied to medical school[4]. Over the years PBL has been used in a wide variety of other disciplines such as management, law, and engineering[5]. Based on the results from a survey on the effectiveness of active learning methods, Prince[6] suggests that PBL better prepares engineering students for life-long learning than traditional teaching methods because the students are involved in self-directed learning. Quinn[7] presented PBL as a strategy for expanding the civil engineering curriculum to include a directed study and problem-solving experience in structural engineering. Qualitative assessment of the experience suggested that PBL was productive for students as they appreciated the freedom to explore a problem of their choice and apply the knowledge gained in previous classes.

We believe that seismic retrofit capstone projects can provide an ideal scenario for the implementation of PBL. Through guidance and mentoring from faculty advisers and industry liaisons, students can have the opportunity to apply their previously acquired knowledge in structural mechanics and develop creative solutions that build upon this knowledge during the seismic assessment of buildings and components. This paper illustrates the PBL process through three seismic retrofit capstone projects for a local utility company that were carried out at Seattle University during the last two years. We also provide alumni assessment data about how they perceived their experience in these projects.

## Overview of senior design program

All seniors in the engineering programs at Seattle University are required to complete a team-based, year-long, externally sponsored capstone project. The student teams work under the supervision of a liaison engineer from the sponsoring company, a faculty adviser and a design coordinator (i.e., a course instructor). Team size typically ranges from three to five students, with an optimum team size of four.

Student teams visit the site, learn the details of the project and prepare a written proposal for the client in fall quarter. The proposal describes the scope of work, plan of implementation for the rest of the academic year with detailed tasks, deliverables and milestones.  Teams work on the project in winter and spring quarters. The project culminates with a final report summarizing the team's work, calculations, engineering drawings, recommendations and conclusions.

Since the inception of the project center in 1988, the civil and environmental engineering program has completed close to 150 projects of which a third have had structural engineering focus.  The structural engineering projects have covered a wide range of projects, e.g. design of new bridges, replacement, rating and seismic retrofit of existing bridges, design of buildings and extension to existing buildings, structures supporting ferry traffic, highway ramps, and new structural product development.

A local utility company has sponsored 17 civil and environmental projects since 1992.  Of these, 11 have been structural in nature ranging from the design of bridge and storage facilities, to assessment and retrofit of structural features in a dam. Over the past few years the utility company has been looking into retrofitting several of its substation buildings.  These are excellent PBL projects for the students to learn about seismic engineering.

## Seismic retrofit capstone projects

Over the last two years the Civil and Environmental Engineering department at Seattle University has completed seismic evaluations of three power station buildings. Schematic views and a general description of the buildings, hereafter referred as to Buildings 1 through 3, are shown in Figure 1.

All three facilities are considered essential to emergency response efforts of the city and thus expected to be operational following an earthquake. The structures were also built before formal seismic design provisions existed thus making them potentially vulnerable to earthquake damage.

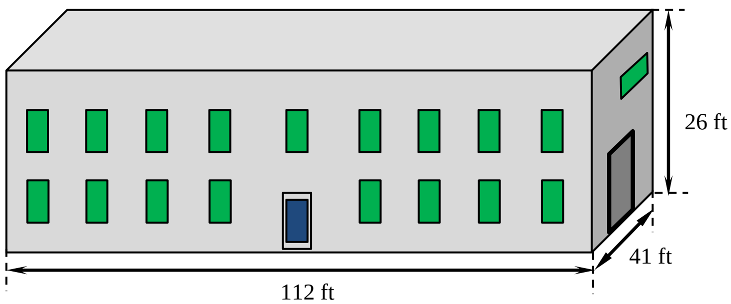
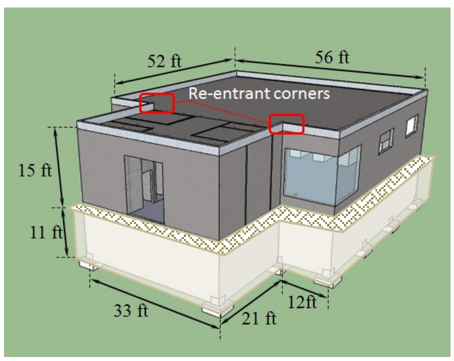
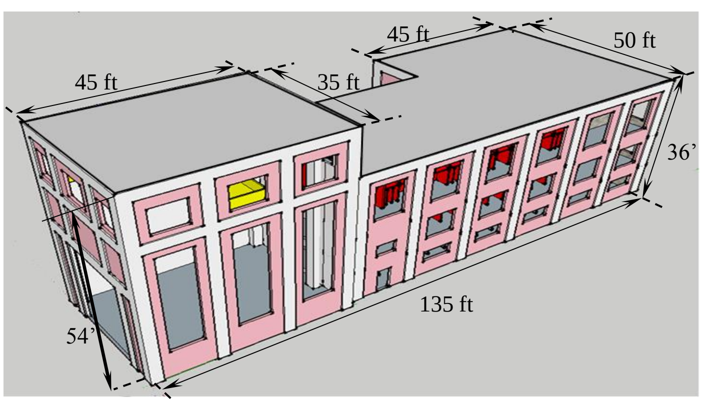
| | Description | Year Built |
|---|---|---|
| <br>(a) Building 1 | Two-story reinforced concrete structure with full basement | 1937 |
| <br>(b) Building 2 | One-story reinforced concrete building with a basement | 1950 |
| <br>(b) Building 3 | Connected 54-ft tall single-story and a 36-tall three-story reinforced concrete structures | 1937 |

Figure 1. Power Stations Control Buildings for Seismic Retrofit Capstone Projects.

The capstone project teams were tasked to conduct a two-tier seismic assessment following the provisions of the industry standard ASCE/SEI 31-03[4]. Although it is beyond the scope of this standard, students were also asked to develop preliminary mitigation solutions for non-compliant components of the buildings. The liaisons from the utility company recognize the limited expertise of the students. Therefore, the capstone teams’ findings and recommendations will serve the utility company mostly to prioritize resources for retrofitting their substation buildings.

In the near future, the utility company will contract with seismic engineering consultants to formally assess the buildings and develop retrofit solutions that are in compliance with current seismic codes.

A summarized version of the seismic assessment and retrofit process that student teams followed in their capstone projects is as shown in Figure 2. The Tier 1 screening is a process that allows identifying potential deficiencies in an expedited manner using a checklist provided by ASCE/SEI 31-03. Alternative checklists are available depending on the extent of damage that the building owner is willing to tolerate following a major earthquake. This is referred as "performance level" in the standard. Less risk of damage requires more rigorous retrofitting solutions which in turn would have a higher initial cost. For all three seismic capstone projects, liaisons from the utility company decided that their buildings were to remain operational under a rare seismic event and not collapse under a very rare seismic event. These seismic criteria are rather stringent but common for essential facilities like substation control buildings. Tier 1 screening requires investigating the original structural drawings of the building and conducting an on-site investigation for condition assessment of building components. Calculations are also performed at this stage to identify portions of the buildings that do not meet requirements associated to the design performance (damage) level.

The Tier 2 evaluation involves detailed analyses of individual components of the building that were identified as non-compliant in the Tier 1 evaluation. This evaluation typically requires the use of structural analysis software for the estimation of demands and capacity.

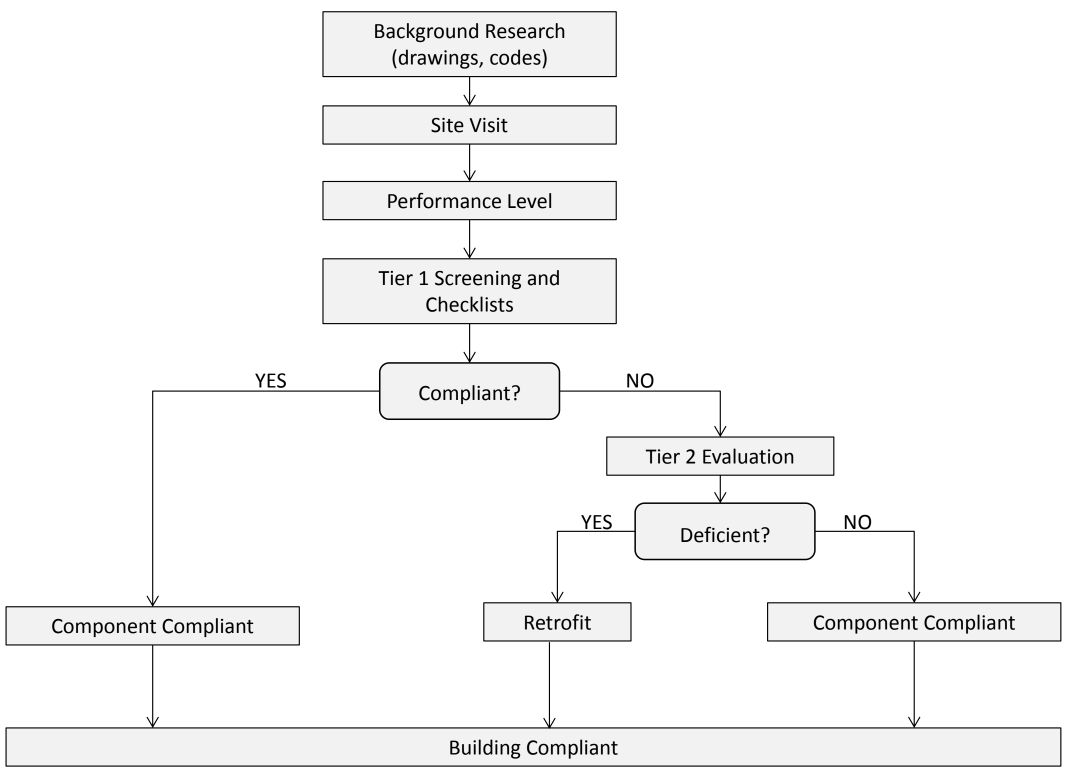



Figure 2. Process for Tier1/2 Seismic Assessment and Preliminary Retrofit

**Execution of seismic retrofit capstone projects**

Typical structural projects in our senior design program involve weekly meetings of the student team with their faculty adviser and company liaison. Faculty and liaisons provide technical assistance and continuous feedback to students on their proposal, presentations to the class and professional organizations, and reports. Because the majority of the design work takes place during the fall and winter quarters while structural design courses (steel and concrete design) are offered in winter and spring quarters, interactions of the students and faculty adviser – in the form of informal meetings and tutorial sessions - are provided to the teams on an as-needed basis. Seismic retrofit capstone projects are even more challenging as they heavily depend on courses that are not covered in undergraduate curriculum. To offset this challenge, the faculty adviser scheduled additional weekly meetings throughout the academic year that served to direct the students in their independent learning of earthquake engineering analysis and design. In the near future, senior students at Seattle University would also be eligible to register for earthquake engineering class that will be offered as part of the master's program in structural engineering. This class which could serve to alleviate the difficulties that current students go through in the seismic retrofit projects.

During the fall quarter, in addition to the preparation of the project proposal, students characterized the structural system of their buildings (based on predefined standard types) with the purpose of selecting the appropriate Tier 1 evaluation checklist included in the ASCE31-03. Seismic demand was quantified through the construction of design acceleration spectrum (a graph that allows one to estimate how much a building will accelerate during an earthquake) that is particular to each project site. Students accomplished this by using seismic hazard maps available from the United States Geologic Survey (USGS). The checklist also required the calculation of the overall seismic forces acting on the building. A detailed study of design drawings was necessary to estimate the mass of the building and the stiffness of columns and walls that resist the inertial forces generated by the design earthquake. Students learn to use code provisions and conventional procedures from earthquake engineering to calculate seismic forces on different structural members including columns, walls, and floors.

ASCE31-03 Tier 1 was completed during fall quarter and part of winter quarter. Some of the checklist items are qualitative and strictly require the judgment of experienced engineers. The company liaison, having expertise with the seismic evaluation of buildings, facilitated the discussion during regular weekly meetings to help students arrive at their own conclusions about the compliance or non-compliance of all the building components. Students, with the guidance of the faculty adviser, evaluated quantitative items of the checklist and submitted the results of their calculations for review and discussion at the regular weekly meetings with the liaison. For the components of the building that were found to be non-compliant, the students reported the reason for such classification. An example of portion of the Tier 1 checklist, as evaluated by the student team working with one of the buildings, is shown in Table 1.

Table 1. Portion of Tier1 Checklist as Evaluated by Student Team

| BUILDING SYSTEM | | | | |
|---|---|---|---|---|
| Decision[1] | Section ASCE31-03 | Item | Description | Comments |
| C | | Load path | | |
| N/A | | Mezzanines | | |
| C | Tier 2: 4.3.2.1 | Weak story | The strength of the lateral-force resisting system shall not be less than 80% of the strength in an adjacent story, above or below for life safety and immediate occupancy. | 79% x direction (N-S), only 1% less than limit, say OK. |
| NC | Tier 2: 4.3.2.1 | Soft story | The stiffness of the lateral-load resisting system in any story shall not be less than 70% of the lateral force resisting system in any adjacent story above or below, or less than 80% of the average lateral load resisting system stiffness of the three stories above or below. | |
| C | | Vertical discontinue-ties | All vertical elements in the lateral-force resisting system shall be continuous to the foundation. | Exterior walls discontinuous in the long direction but with sufficient reinforcement at their slab interface. |
| C | | Deterioration of concrete | | |
| N/A | | Post-tensioning anchors | N/A | N/A |
| C | | Concrete wall cracks | | |

[1]C: Compliant, NC: Non-compliant,
N/A: Not applicable

While the Tier 1 checklist and preliminary seismic evaluation can be challenging to students, because it is in this phase that they are introduced to earthquake engineering concepts for the first time, we believe it also had the most educational value because the students:

- Examine design drawings and extract specific information that is relevant to a structural evaluation.
- Identify the interdependency of structural members with nonstructural components such as electrical, heat and ventilation, plumbing, etc.
- Recognize standard practices of how to present design drawings for building projects.
- Experiment with their previous knowledge of courses, e.g. on the calculation of member stiffness, in a real-life context and with a specific purpose.
- Recognize idealized conditions that are introduced in basic mechanics courses and realize the need to exercise judgment to fit their real-world problem into those theoretical boundaries.
- Discover that often times the idealized conditions previously learned in coursework do not apply to their real-world project. Rather, they evaluate extreme cases that provide boundaries to their design solutions.

The Tier 2 evaluation was conducted primarily during the first half of the winter quarter and involved hand calculations to estimate the distribution of inertial forces among the different lateral load resisting members (columns and walls). This more detailed level of analysis often required modeling individual building components using structural software to estimate both demand and capacity. Although the Tier 2 evaluation required a deeper understanding of seismic design, the process of execution for students seemed to be easier as the fundamental concepts of earthquake engineering had already been covered with the Tier 1 evaluation. In winter quarter, students were enrolled in their first structural engineering design course (reinforced concrete design or steel design) and consequently they were also eager to apply concepts learned in class. This also facilitates the execution of this phase of the project. Benefits from the Tier 2 evaluation process include that students:

- Evaluate different modes of failure for structural components and recognize the importance of ductility in seismic design.
- Calculate the lateral load distribution and to think about load path as a fundamental principle of structural design.
- Apply structural idealizations commonly used in consulting practice.
- Use specialized software to calculate capacity and demand of structural members of the building.
- Recognize the importance of structural detailing in seismic design.

During the second half of the winter quarter and part of the spring quarter students developed retrofitting schemes for the structural and non-structural components of the buildings that were found to be non-compliant using the ASCE31-03 Tier1/Tier 2 evaluation process. The proposed solutions were conceptual and did not strictly meet the requirements of specific code provisions or standards. As such, students enjoyed the freedom to exercise their creativity while practicing fundamental principles of structural analysis and design. Weekly meetings with the faculty adviser and industry liaison were used to discuss the constructability of alternative solutions schemes. The team reflected on the impact of each retrofit option on the normal operations of the building. Because Buildings 1 and 3 were part of the National Register of Historic Places, the solutions were intended to minimize impacts on the architectural features of the buildings. The teams also performed cost estimates using unit costs provided by the liaison. Benefits from this phase of the project are that the students:

- Design solutions based on fundamental principles of structural analysis that they have learned in the classroom.
- Recognize practical aspects of the design such as constructability, functionality/operational requirements, architectural/historical features, and costs.
- Use (and become proficient with) visualization tools, such as Trimble Sketchup®, to better explain their solutions to technical as well as non-technical audiences.
- Identify standard cost estimate documents.

Throughout the academic year, students from the seismic retrofit capstone projects also had plenty of opportunities to improve their communication skills, including:

- During the fall quarter, the teams prepared a written project proposal in which they expressed their understanding and scope of the project, defined the basis of design (project specifications), and identified major tasks and deliverables. Teams received independent feedback from the company liaisons, faculty adviser, two external structural engineering consultants, and a technical writer.
- Twice every quarter, the teams were required to make oral progress presentations to the senior design class and faculty advisers.
- At the end of the fall quarter, the teams presented their project proposal to professionals from the sponsoring company including engineers and building operators.
- Early in the winter quarter, the students presented their proposals to department's advisory board.
- Teams presented their project at a local Structural Engineering Association meeting in the middle of the winter quarter, in which students received more technical feedback.
- During the spring quarter, students participated in a local ASCE competition that is judged by a panel of four or more licensed civil engineers.
- For Building 3, which was found to have significant structural deficiencies, the company sponsor liaison facilitated a meeting at the end of the spring quarter in which students gave a presentation to the control building personnel and management about their findings and proposed solutions.
- At the end of the year, the teams presented their work to the university community, current and prospective sponsors of capstone projects, friends, family and alumni and held a poster session in a conference-style event.
- The liaison arranged a final meeting of the team with engineers from the sponsoring company in which students presented their findings and proposed solutions.
- The teams prepared final reports after receiving feedback from the liaison, faculty adviser, and two external structural engineering consultants.

## Sample retrofitting schemes developed by students

The capstone teams were asked to develop conceptual-level retrofitting schemes for the structural and non-structural components of the buildings that were found to be non-compliant through the Tier1/2 evaluation process. Some of the deficiencies and proposed retrofit solutions proposed by the team for each of the three buildings are presented below.

**Short Columns:** Concrete partition walls could restrain the lateral movement of columns in the second floor of Building 1 (Fig. 3). When an earthquake occurs, the portion of the column above the partition wall behaves a short member that could fail in a brittle mode thus posing a life safety concern. The team demonstrated this condition by hand calculations and proposed to simply eliminate the partition walls as illustrated in Figure 3. As part of this solution, the team specified the use of tenting for dust control during demolition.

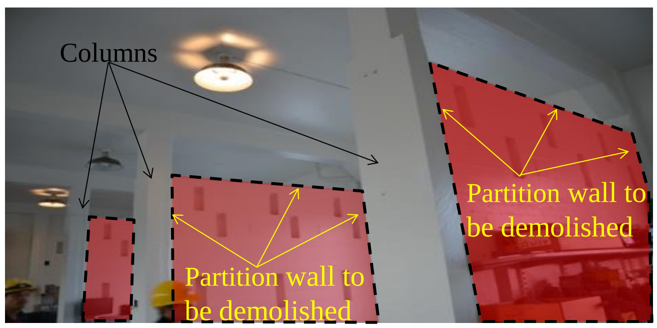
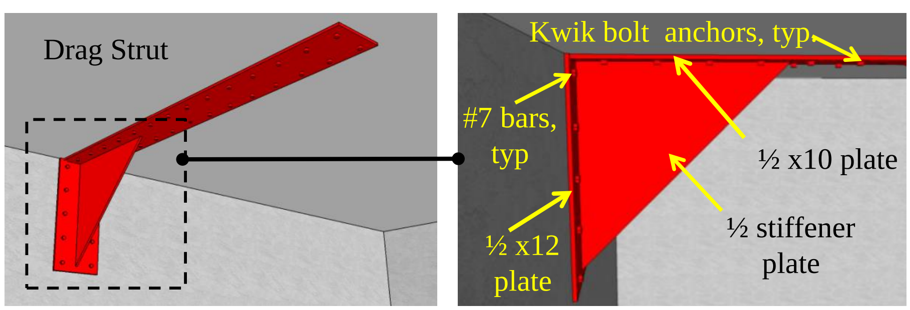



Figure 3. Short Column Remediation Scheme for Building 1

**Reentrant Corners:** Building 2 was found to have a reentrant corner (identified in Figure 1.b) that was not properly reinforced to be able to resist the seismic (inertial) forces and relative movement from portions of the roof on either side. The team recommended the installation of drag struts which would be connected to the roof by mean of epoxy anchor bolts as illustrated in Figure 4.




(a) Isometric View (b) Close up Details

Figure 4. Reentrant Corner Retrofitting Scheme for Building 2

**Weak Direction:** Building 3 did not have sufficient walls oriented in the short direction of the building thus making the structure particularly vulnerable to earthquake damage under excitation in that direction. The capstone team proposed to install new 30 inch, 12 inch and 8 inch- thick reinforced concrete (R/C) walls in the first, second and third story of the building as shown in Figure 5. The different wall thicknesses account for the fact that seismic forces at lower levels are higher than those at upper levels. Students conducted hand calculations to determine the optimum location and thickness for the proposed new walls.

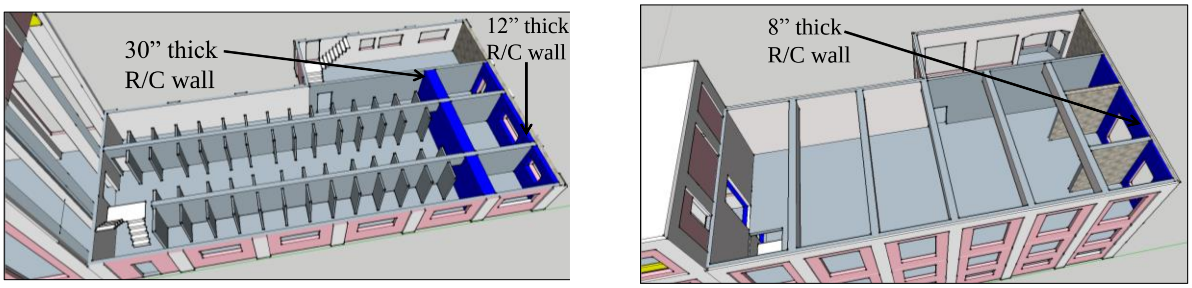



Figure 5. Structural Retrofitting Scheme for the Short Direction of Building 3

**Connecting Building:** As described before, Building 3 has a tall one story portion and a shorter three story portion. The tall one story building accommodates a crane that is used to hoist transformers. To prevent the potential earthquake-induced brittle failure of the walls that project beyond the roof of the three-story portion, the team proposed to connect the two structures with a steel truss as shown in Figure 6.

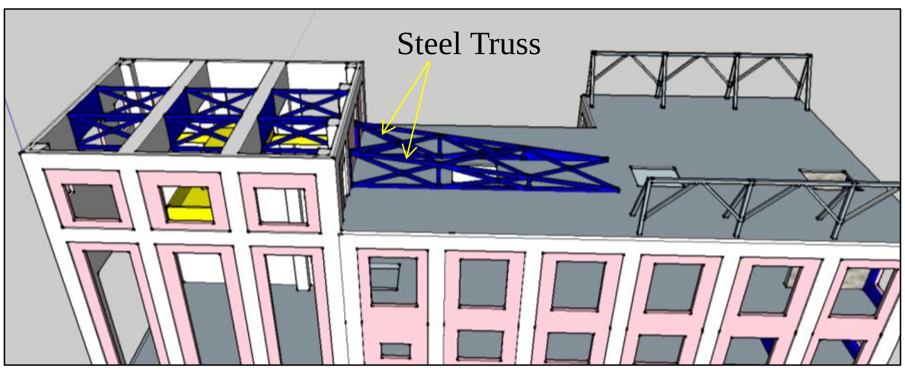
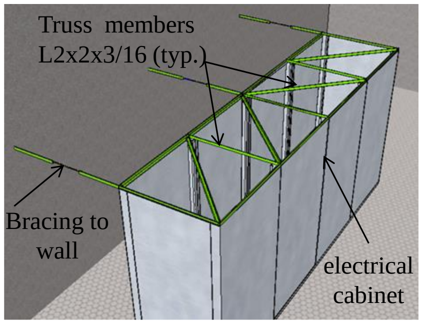
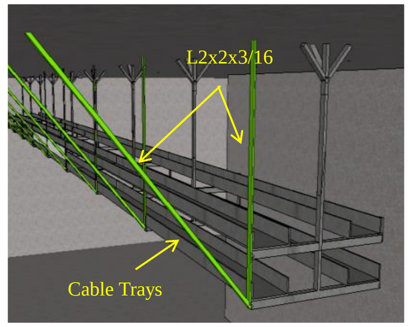



Figure 6. Retrofitting of Connection Between Portions of Building 3

**Non-structural components:** Seismic assessment of buildings per ASCE 31-03 requires evaluation of both structural and non-structural components. The evaluation of non-structural components proved to be a great learning experience for students as they realized the broader scope of a standard seismic evaluation. The teams found through analysis that Buildings 1 and 2 had non-structural components that were non-compliant because they were not securely attached to the structure. Figure 7 shows some examples of the retrofitting schemes proposed by the students to anchor electrical cabinet and cable trays to walls and floor of the building.




(a) Electrical cabinet (b) Cable trays

Figure 7. Retrofitting Schemes for Non-Structural Elements in Building 1

**Overall benefits of seismic retrofit capstone projects**

Seismic retrofit projects, although challenging, help the students to develop a wide range of skills. Some of these holistic benefits are summarized below:

- The students gained new knowledge:
  - Fundamentals of seismic analysis/assessment of buildings.
  - Structural idealization/modeling of buildings and members.
  - Evaluate different structural failure modes.
  - Learn to distribution of lateral loads and identify load paths.
  - Recognize practical aspects of design such as constructability, architectural constraints, and cost.
  - Realize the importance of structural detailing in seismic design.
  - Recognize the interdependency of structural members with other features of the buildings such as nonstructural components.
  - Read technical drawings and learn the professional drafting practices
- Students were exposed to use the following design tools:
  - Codes and Standards: ASCE Seismic Evaluation of Existing Buildings (ASCE 31-03); ASCE – Minimum Design Loads for Buildings and Other Structures (ASCE 7-10); American Concrete Institute Building Code Requirement for Structural Concrete and Commentary (ACI 318-11), American Institute of Steel Construction Manual.
  - <u>Design Software:</u> Structural Analysis Program SAP 2000® was used to model the dynamic response of the buildings under the design ground motion; Hilti Profis® was used to design the anchor systems used in some of the retrofit schemes.
  - <u>Product Catalog:</u> UniStrut metal framing catalog was used to size the bracing systems for non-structural components.
  - <u>RS Means</u> was used for unit costs along with the efficiency rates provided by the Company to estimate the cost of mitigations.
  - <u>Trimble Sketchup®</u> was used to visually communicate the design concepts to the Company and to a lay audience.
- In addition to developing technical skills, students improved their communication, project management, leadership s and teamwork skills

**Student learning assessment**

Alumni who worked in these seismic retrofit projects were recently (January 2015) asked to share their learning experience during the capstone projects. A survey was sent to all of the eleven students (two groups of four and a group of three) and seven (64%) of them responded. The capstone survey data for the three seismic retrofit projects is shown in Table 2. Most students either agreed or strongly agreed that the projects were challenging without having formal training in earthquake engineering. They also believed that through the projects they became more aware of earthquake design as it applies to practice and that the capstone projects were beneficial towards their professional goals. Overall, the students did not feel that seismic projects were less beneficial towards achieving their educational goals when compared to structural projects without a significant earthquake engineering focus. The students also felt that the design work they did in the projects strengthened their learning in subsequent design courses, suggesting the problem-based learning approach of these projects is beneficial.

Table 2. Student perception of seismic retrofit capstone projects[1]

| Question | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree | Mean |
|---|---|---|---|---|---|---|
| It was challenging to work on a seismic project without having any formal training on the subject | 0 | 1 | 1 | 4 | 1 | 3.7 |
| Through this project, I became more aware of the fundamental principles of earthquake engineering design and practice | 0 | 0 | 0 | 2 | 5 | 4.7 |
| It was beneficial toward achieving my professional goal to have worked on a seismic project | 0 | 0 | 1 | 1 | 5 | 4.6 |
| Compared to a structural project that did not focus solely on earthquake engineering working on this project was more beneficial towards achieving my educational goals | 0 | 0 | 2 | 4 | 1 | 3.9 |
| It was challenging to carry out structural analysis and design before taking Reinforced Concrete or Steel Design courses | 0 | 0 | 4 | 3 | 0 | 3.4 |
| The design work I did in my project prior to taking structural design courses (Concrete or Steel Design) strengthened my learning experience when I took those. | 0 | 0 | 1 | 3 | 3 | 4.3 |

[1]survey data based on a Likert scale (1: strongly disagree and 5: strongly agree) (number of responses = 7)

Table 3 presents student responses when asked to rank the main project activities based on the amount of time and effort spent using a scale from 1 to 5 (1 being the least and 5 being the most). Performing the structural analysis was ranked as the activity that required most effort, while developing mitigation concepts required the least. The latter must be because students did not conduct a detailed and thorough design following standard code provisions but only developed concept-level solutions. Responses as to the difficulty of completing the Tier 1 screening and checklist were divided. The difference in opinion could be due to diverse projects types. For those projects in which the structure was found to have fewer deficiencies, completing the checklist might have been more straightforward. Interestingly, the students ranked understanding the design standard or learning fundamental engineering concepts as requiring a moderate level of effort only.

Table 3 Student ranking of activities based on the level of effort and amount of time spent

| Level of effort[1] | 1 | 2 | 3 | 4 | 5 | Mean |
|---|---|---|---|---|---|---|
| Completing tier 1 screening and checklist | 1 | 2 | 0 | 3 | 1 | 3.1 |
| Understanding the intent and philosophy of the design standard ASCE 31-03 | 0 | 1 | 4 | 2 | 0 | 3.1 |
| Performing structural analysis (hand calculations and software modeling) | 1 | 0 | 0 | 2 | 4 | 4.1 |
| Learning fundamental concepts of earthquake engineering | 0 | 2 | 3 | 2 | 0 | 3 |
| Developing mitigation concepts | 4 | 1 | 0 | 1 | 1 | 2.1 |

[1] in a scale of 1 to 5 (1 being the least and 5 being the most)

In addition to the quantitative assessment, we also asked alumni what the most and least valuable aspects of their seismic retrofit senior project experience. Of the most valuable responses, the common themes are the real-world nature of the projects and professional skills development. Some of the alumni feedback is presented below:

- "Learning about seismic design at an undergraduate level."
- "Getting to collaborate on a team to learn new information and complete a project."
- "The most valuable aspect of the senior design experience was being exposed to an actual project from beginning to end. Being exposed to the code was also very helpful. A huge chunk of the analysis was all new material and ideas (for me), which was awesome! Learning to work with a team that you didn't choose is always a learning experience, including the positives and negatives (all learning experiences are good). I also enjoyed working with a professor and a liaison, connections and contacts that I will keep and cherish forever!"
- "Working with a PE/SE on the project to both help my understanding of the project and seismic engineering. Reviewing the as-built drawings prior to a site visit was helpful. Working with a team and managing a team was especially helpful for gaining an awareness of time management and division of work load to complete a task/project."

Overall, the assessment data show that the students valued a seismic assessment capstone project. They felt that the project was beneficial to their professional objectives and that they learned fundamental principles of earthquake engineering design.

## Summary and conclusions

Capstone seismic retrofit projects challenge students to learn fundamental concepts of earthquake engineering without having formal training on the subject. This can become a tremendous learning opportunity for the students but requires more mentoring efforts from sponsoring company liaison and faculty advisers. Parallel to the execution of this type of project, the capstone experience takes the form of an independent/directed study in which the faculty adviser plays an important role. Through this process, students experience a problem-based learning (PBL) approach because they apply their knowledge in structural mechanics to gain new knowledge on earthquake engineering design.

This paper shows examples of seismic retrofit capstone projects for three power station buildings managed by a local public utility company. The student teams performed a two-tier seismic assessment following the provisions of the industry standard ASCE/SEI 31-03 and developed preliminary retrofitting schemes for structural and non-structural components of the buildings. Results from learning assessment survey suggest that although the projects were challenging for the students they learned the fundamental principles of earthquake engineering design. Furthermore, the problem-based learning approach and professional skills they develop through the process were beneficial.

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