EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
2022 UNDERGRADUATE SEISMIC DESIGN COMPETITION

Architectural Engineering Undergraduate Senior Project
Guidelines for The EERI Seismic Design Competition

BY
KATE ROBINSON

California Polytechnic State University
San Luis Obispo, CA

Senior Project Advisor
Anahid Behrouzi, PhD

2022

Acknowledgements

A very gracious thank you to the 2022 EERI Student Chapter for their hard work in preparation for the competition, and for a great turnout in Salt Lake City.

Thank you to Garrett Barker (EERI team captain) for taking on this tremendous project to keep the tradition alive, and for using your previous experience to help everyone along the way. Thank you to third-year student Olek Piechaczek (EERI member), who used his job experience in Cal Poly's Digital Fabrication Lab to help train students on laser cutters and prepare testing specimens. A special thank you to alumni Ryan Millward and Ryan Thornton for providing guidance to our analysis team in their use of ETABS.

Finally, special thanks to our advisor Anahid Behrouzi, PhD and Architectural Engineering Professors Cole McDaniel, PE, PhD and Peter Laursen, PE, PhD for their guidance and expertise.

As a final thank you to our 2022 EERI sponsors, they are listed below.
CSI Structural Resiliency Fund
Cal Poly Instructionally Related Activities (IRA) Fund
Taylor & Syfan Consulting Engineers
Filippin Engineering

Abstract

The Earthquake Engineering Research Institute (EERI) has been dedicated to exposing undergraduate students to the wide range of interdisciplinary subjects related to earthquake engineering through the Seismic Design Competition. In 2022, California Polytechnic State University, San Luis Obispo (Cal Poly) sent 14 students to Salt Lake City, Utah for the competition – to compete with 31 other teams who all tackled the competition problem statement uniquely. The 2022 team was tasked with the research, design, analysis, and construction of a new structure to be built in downtown Salt Lake City, with the goal of replicating the design sequence of real-world engineering. The following report outlines the preparation, organization, and timeline taken by the Cal Poly team in advance of the seismic design competition, with the intent of guiding future EERI teams. It should be noted that this report is not only intended to serve as a guide for future students, but also will explain the demand of interdisciplinary subjects in the competition in hopes of attracting undergraduate students who are interested in broadening their vision of engineering to participate in the competition. For public access, this document, including additional supplementary materials, will be available in the Cal Poly Digital Commons.

Table Of Contents

Nomenclature

Refer to Supplementary Document A5 for the Seismic Design Competition Glossary.

Throughout the report, the reader may find these common abbreviations:
12NCEE – 12^{th} Annual National Conference of Earthquake Engineering
ARCE – Architectural Engineering (Major, Department at Cal Poly)
CAED – College of Architecture and Environmental Design (College at Cal Poly)
CSI – Computers and Structures, Inc.
D-Fab – Digital Fabrications Laboratory (Laboratory at Cal Poly)
EERI – Earthquake Engineering Research Institute
ETABS – Extended 3D Analysis of Building Systems (Analysis Software by Computers and Structures, Inc.)
SDC – Seismic Design Competition (organized by EERI SLC)
SLC – Student Leadership Council (council within EERI)

List of Figures

List of Tables

Supplementary Materials

The supplementary materials listed below include competition criteria documents, design guides, competition deliverables, logistics documents, and referenced design codes. These documents, referenced where necessary, provide the reader with more context into design considerations. All files listed below (except design codes) can be found in a zip folder titled 'Supplemental Project Files', submitted with this final report to Cal Poly Digital Commons.

A. EERI Competition Documents

[1] 2022 Official Rules
[2] 2022 Design Guide
[3] 2022 Proposal Requirements
[4] 2022 Geotechnical References
[5] 2022 Glossary
[6] 2022 Architecture Rubric
[7] 2022 Poster Rubric
[8] 2022 Presentation Rubric
[9] 2022 Summary of Competition Results
[10] 2022 Seismic Design Competition Mailer

B. Student Design Guides

[1] AutoCAD Cutsheet Setup
[2] Operation of Laser Cutters
[3] Operation of Tinius-Olsen Machine

C. Competition Deliverables

[1] Submitted Proposal
[2] Submitted Poster
[3] Submitted Presentation

D. Competition & Travel Logistics

[1] Spring Quarter Schedule (by Team)
[2] Fundraising Tips & Sample Letter
[3] Competition Packing List
[4] Seismic Design Competition – Student Schedule

E. Referenced Design Codes

[1] ASCE 7-16 Provisions, Minimum Loads and Associated Criteria for Buildings and Other Structures
[2] ASCE 41-17, Seismic Evaluations and Retrofit of Existing Buildings
[3] NDS Supplement 2018, National Design Specification, Design Values for Wood Construction

1.0 Introduction to EERI

The Earthquake Engineering Research Institute (herein referred to as EERI) – holds an undergraduate seismic design competition (SDC) each year to help students research and explore seismic-governed structural design. The seismic design competition helps “promote the study of earthquake engineering among undergraduate students” [9] and give students a hands-on opportunity to design, analyze, and test a mid-rise, multiple-occupancy building located in a seismic region, which in 2022 was Salt Lake City, Utah.

1.1. Seismic Design Competition Scope

The SDC committee releases a design guide and official rule book each year to teams of undergraduate students located at universities worldwide. See supplementary document A1 for rules and A2 for design guide. Once a team has been formed, they must submit a proposal to be considered for the competition, as there is limited space to compete in-person. The proposal (which covers basic categories such as geology, architecture, and structure, among others) is the first opportunity to gain points in the competition. To be awarded as many points as possible throughout the competition, students must be conscious of design decisions, seismic implications, and non-structural factors. Not only should the proposed building be designed to survive the provided earthquake ground motions, but students should also be learning and exploring the importance of architecture, aesthetic, economy, environment, and public need. The competition requires all teams that participate to produce several deliverables that capture the broad scope, challenging students to expand their understanding of seismic engineering. See Section 2.1 for competition deliverables.

1.2. Seismic Design Competition Culture

Aside from the “learn by doing” approach that the competition takes, it also provides students the opportunity to attend the EERI Annual Meeting or, every four years, the National Conference on Earthquake Engineering (NCEE). Students in EERI’s 2022 chapter attended the 12NCEE in Salt Lake City, Utah. Concurrently with the competition, industry professionals discuss important policy updates, give lectures on their research, and collaborate with other professionals. The competition, while encouraging students to be ambitious, also promotes sportsmanship and the importance of collaboration in the field of engineering.

1.3. Cal Poly SLO’s EERI Chapter

California Polytechnic State University, San Luis Obispo has participated in the SDC since 2007. In the past several years, it has been important for younger students who participate in the competition to be exposed to each aspect of design, analysis, and construction to ensure continuity of knowledge. Most recently, the EERI chapter has been organizing a team of motivated and interested students in late fall quarter. Younger students are generally assigned to materials testing team or construction team, since design and analysis teams require knowledge from higher level ARCE design labs and analysis courses. However, as mentioned above, the EERI team benefits (and thrives) most when students collaborate in a positive and diverse environment.

2.0 Problem Statement

To mimic the need for a structural engineer in reality, the competition releases a problem statement in conjunction with the design guide and official rulebook. The problem statement provides each team with the "who-what-where" of the project: specifically, the proposed occupancy, architectural design (including elevations and floor plans), and location. Below is an excerpt from the 2022 problem statement:

> "Given the challenges posed by the seismicity of the area, your company has been tasked with responding to a Request for Proposal (RFP) to construct a new building in downtown Salt Lake City. … First, on the first (bottom) 7 floors, the central section of the building will be hollow to allow for a tall atrium. Then, between the 11th floor and the 15th floor, the inverse will occur. Those floors will only have the central sections, creating a high-ceiling terrace. All other floors (i.e. floors 8-10 and 16-19) of the building will have the full square-shaped floor area." (Supplementary Materials A1)

2.1. Seismic Design Competition Deliverables

Along with the physical model structure to be tested, there are several deliverables throughout the competition that students will complete by their respective deadlines. Outlined below is the complete list of competition-required deliverables, with a due date and general scope.

Proposal – January 17, 2022
See supplementary document A3 for proposal requirements, and C1 for the final submitted proposal.

Damping System – March 2022
See Supplementary Document A1 for damping requirements.
The 2022 EERI Cal Poly SDC team decided against proposing a damping system, which would greatly impact the design of the structure itself.

Physical Model – June 24, 2022
The physical model must conform to the official rules and design guide, provided as supplementary documents A1 and A2, respectively.

Design Poster – June 24, 2022
See supplementary document A7 for poster requirements, and C2 for the final submitted poster.

Verbal Presentation – June 24, 2022
See supplementary document A8 for presentation requirements, and C3 for the final submitted presentation slides.

Floor Area Calculations & Performance Predictions – June 24, 2022

In addition to the competition-required deliverables, the Cal Poly SDC team also produces a physical study model, which is used for preliminary physical testing ahead of the competition.

The final physical model that is required for the competition was constructed, but not tested, by students. At the competition, the physical model will be subjected to two lateral ground motions to collect displacement and acceleration data. This real-time data is then compared to each team’s performance predictions. If a team’s structure collapses, a “total collapse”, they are ineligible from scoring further. However, a “floor collapse”, where a small number of members fail, resulting in the collapse of a singular floor of the structure, is allowable. As a general statement, the competition deliverables only portray a portion of the work that is put into preparations for the competition.

2.2. Spring Quarter Scheduling

See Supplementary Document D1 for the full spreadsheet schedule describing the necessary tasks to prepare for the competition for the design, analysis, construction, and materials testing sub-teams. In the case of the 2022 SDC, held in late June, the Cal Poly SDC team used Spring Quarter to prepare for the competition. Due to the shifting timeframe of the competition, often sometime in early March to mid-April, this spreadsheet can be used to map out the 12-14 weeks leading up to the competition.

The 2022 Cal Poly SDC team used Microsoft Teams as a means of scheduling work time, sharing documents, and keeping track of important deadlines. In the past, teams have used a shared Google drive folder, OneDrive folder, or other means of collaborative platforms. The 2022 SDC team recommends Microsoft teams for the ease of use, file organization, and virtual meeting capabilities.

3.0 Seismology Determinations

One of the first, and most important, steps in the design process is an analysis of the soil conditions for the proposed project site. For the proposal, students were asked to summarize site conditions and expected seismic activity – including soil types, historic earthquakes, major faults, expected magnitude and shaking of future earthquakes, and seismic site class (A-F) in accordance with ASCE 7-16 [15]. To further explain design choices, students were asked to discuss the possibility of liquefaction or lateral spreading at the site.

3.1 Provided Information

The Student Leadership Council releases a geotechnical reference guide each year to provide students with the information they need to make seismology determinations. Students are provided with project location, fault map of Salt Lake City, earthquake intensity map, surficial geology map, major surficial geologic units (name, description, age), subsurface stratigraphic unit fence diagram, boring log, cone penetration testing (CPT), and idealized soil profile model. See Figure 3.1 for an excerpt of the provided idealized soil model. There is plenty of useful information provided in this geotechnical reference guide, but this document will break down the most important information for students and how to analyze it.

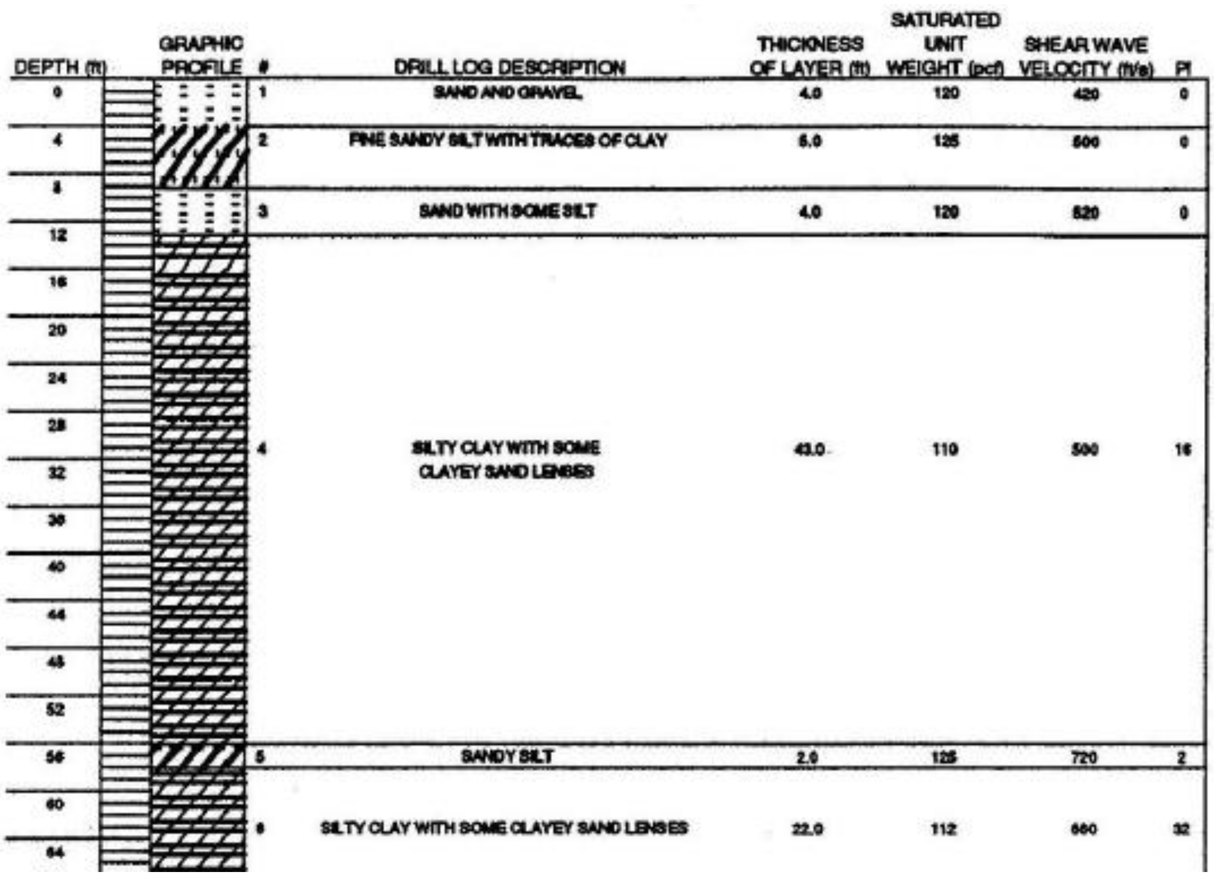

Figure 3.1. Idealized Soil Profile

3.2 Analyzing Geotechnical Information

Using surficial mapping, students identified units of stream alluvium deposited as far back as 120,000 years ago. According to the boring log, students also noted the presence of dominantly lean and fat clay with thin lenses of poorly graded sand. Lean clay deposits, found at 12 ft and 97 ft, in addition to a wet medium dense unit of poorly graded sand with silt from 36-40 ft, were determined to be susceptible to liquefaction. Groundwater level was found to be at 13 ft, with liquefaction criteria of $PI < 12$ and $w_C/LL > 0.85$ for fine soils (Supplementary Materials C1).

3.2.1 Site Class Determination

According to ASCE 7-16 Chapter 20, “the site soil shall be classified in accordance with Table 20.3-1 and Section 20.3 based on the upper 100 ft of the site profile”. Based on the idealized soil profile model, students averaged the shear velocity of the top 100 feet of soil profile, returning 575 ft/s velocity. In accordance with Table 20.3-1, site class E was selected. This indicates soft clay soil, potentially subject to liquefaction.

To avoid damage to foundations due to liquefaction, students proposed deep caisson footings 65 ft deep below surface level to reach the competent older alluvium in the soil, which has an average CPT tip resistance of 30,000 kPa according to the fence diagram.

3.2.2 Major Faults & Seismic Hazard

Using the fault map, students noted the presence of two major fault lines, which intersect under downtown Salt Lake City. The Wasatch fault zone (WFZ) and West Valley fault zone (WVFZ) both experience normal slip. See Figure 3.2 for fault map.

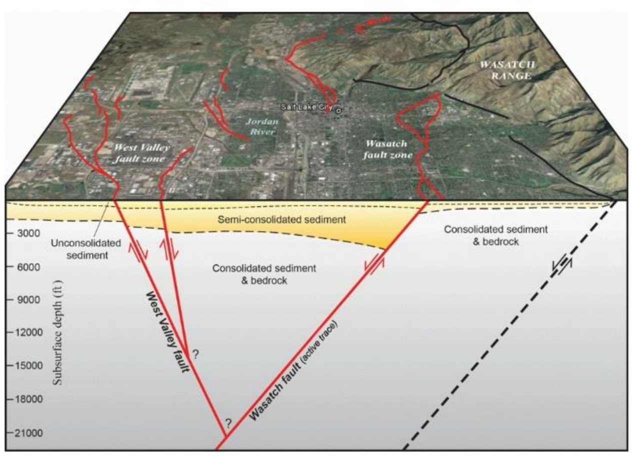

Figure 3.2. Fault Map of Salt Lake City [12]

One of the most useful tools for students is the USGS Unified Hazard Tool available online at: https://earthquake.usgs.gov/hazards/interactive/. Using this tool, students were able to determine the seismic hazard deaggregation of the peak ground acceleration for a 2475-year return period. Using websites run by local (Salt Lake City) government, students also found records of the WFZ rupturing in 1949, 1962, and 2020, with a peak magnitude of 5.7. It was determined that there is a 33% chance of the WFZ rupturing and causing a M6.75+ earthquake in the next century. Because the fault lines intersect, students also noted the possibility of a combined rupture of faults – further increasing seismic hazard for downtown Salt Lake City. See Figure 3.3 below for the hazard deaggregation map produced by USGS Unified Hazard Tool.

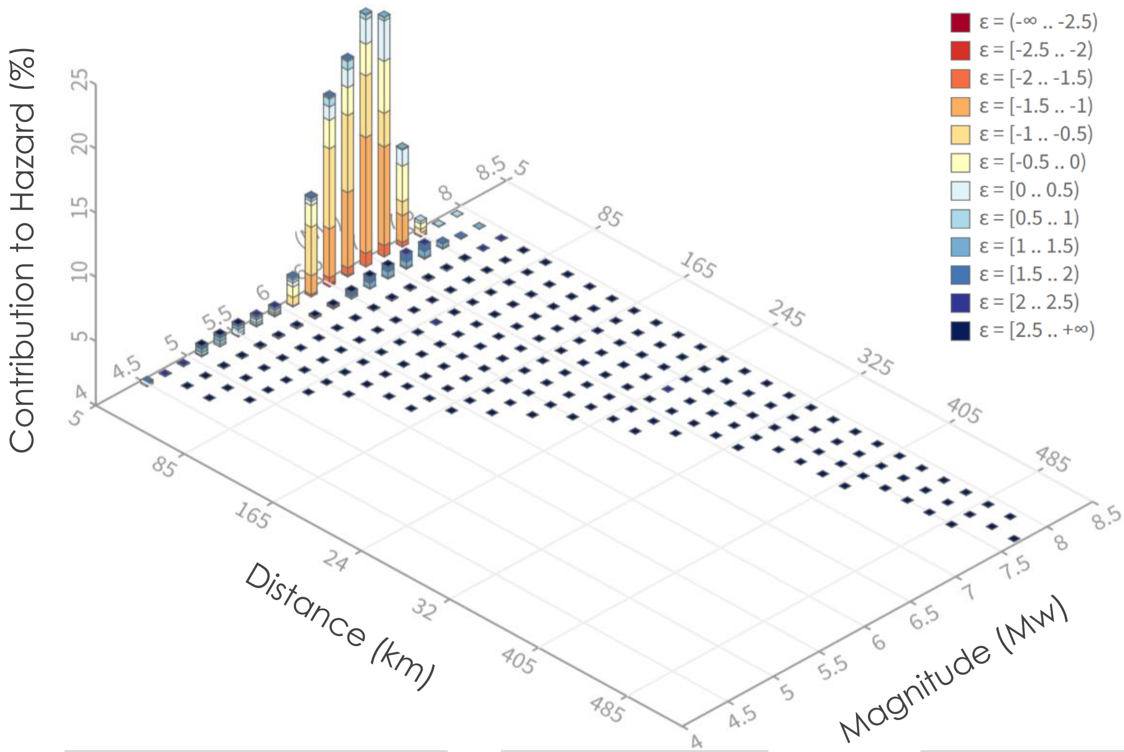

Figure 3.3. Hazard Deaggregation [10]

By analyzing the plot above, students found that the Wasatch fault zone contributes most to seismic hazard, with the greatest hazard being within about 10km from site with an expected magnitude of 6.7M.

3.3 Resources for Geotechnical Information

For these determinations, in addition to the geotechnical reference guide and USGS website, students used:

- J. D. Bray and R. B. Sancio's "Assessment of the Liquefaction Susceptibility of Fine-Grained Soils" [13]
- N. Nilay, P. Chakrabortty, and R. Popescu's "Liquefaction Hazard Mapping Using Various Types of Field Test Data" Published September 16, 2021. [14]
- Working Group on Utah Earthquake Probabilities, Earthquake Probabilities for the Wasatch Front Region in Utah, Idaho, and Wyoming, vol. 16–3 [16]

- M. D. Hylland, C. B. DuRoss, and G. N. McDonald's "Evaluating the Seismic Relation between the West Valley Fault Zone and Salt Lake City Segment of the Wasatch Fault Zone." [17]

It should be noted that the competition proposal requires this information to be gathered so that students may propose a general foundation system for the building based on their understanding of soil mechanics. However, this information is not relevant following the proposal. In a real-life scenario, this information would inform the selection of ground motions to be implemented in computer analysis and foundation calculations. In the case of the competition, ground motions are provided to students and the foundation system is not explicitly designed.

After the research for the proposal has been concluded, all other steps taken by students are directly in preparation for the competition and competition deliverables. In Sections 4.0 – 10.0, this report will detail the unique design, analysis, testing, and construction of a physical balsa wood model of a mid-rise building located in Salt Lake City.

4.0 Materials Testing

The first step in design and analysis of the physical balsa-wood model of the mid-rise competition building is to determine accurate and replicable material properties of the required building material. Using balsa wood samples taken from the sheets used for the structural model, students perform uniaxial tests on multiple specimens until failure. Tracking the tensile load applied to the specimens, as well as measuring the strain with an Epsilon strain gauge, allows students to compute the modulus of elasticity, E, of the material.

$$E = \frac{\sigma}{\varepsilon} \qquad \text{(Eqn. 4-1)}$$

Where: σ is the stress of the material (psi)
ε is the strain of the material (in/in)

4.1. Tinius-Olsen Machine Training

To perform uniaxial tension tests on balsa wood specimens, students met with Professor Peter Laursen to train on the Tinius-Olsen machine located in the Materials Testing Lab. After students have been properly trained on the machine by a member of faculty, they may use the machine on their own with permission. The student-written supplementary document (B3) is intended to be a refresher on operating the Tinius-Olsen machine. Prior to testing, scheduling time in the lab for use of the machine must be arranged. See Figure 4.1(a,b) for basic machine set-up and strain gauge attachment.

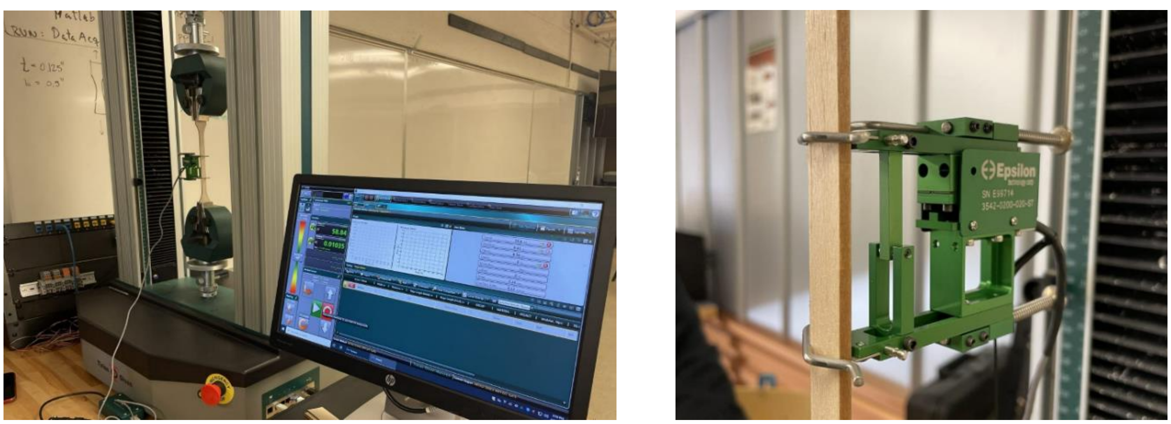

Figure 4.1. (a) Tinius-Olsen Machine & Program, (b) Strain Gauge Attachment

4.2. Preliminary Testing

Students performed preliminary testing on materials several months ahead of the competition, a minimum of about 14 weeks prior to the competition start date. Using leftover balsa wood from the previous year students practiced using the machine to become familiar with the failure mechanisms of balsa wood and idealize the shape of the tested specimen for the most accurate results. In this testing, students also practiced calculating the modulus of elasticity, but ultimately ended up discarding results due to inconsistencies between past and the new batch of material, conducting follow up testing with new balsa wood specimens.

Three dogbone test specimens were drawn using AutoCAD and laser cut. During preliminary testing, students realized a flaw in the design and reinforced the ends of Specimens 2 and 3 by sandwiching two additional layers of balsa wood at the end locations where the machine would grip the specimens. By doing this, students forced failure into the reduced central cross section, or 'web'. Figure 4.2 below shows each failed preliminary test.

Figure 4.2. Preliminary Dogbone Tensile Failures

After testing preliminary specimens, students found that the results were inconsistent – which was expected due to material properties of balsa wood. Because the wood is so soft, many of the tested specimens ruptured at different maximum forces. It should also be noted that balsa wood can be purchased in a variety of hardnesses – and preliminary tests were done on leftover balsa wood with no information provided. Taking the average of all the preliminary tests, students reported a modulus of elasticity estimated to be between 500-700 psi. Comparing this to previous year's results, students were confident with their findings, but thought it was necessary to continue testing with new balsa wood specimens of known quality, cut with the modified template, to force all the failures into the web. For these future testing sessions, the modified dogbone template used a wider curve radius between the end flanges and central web to produce more consistent results in failure mechanism. See Figure 4.3 for the modified dogbone.

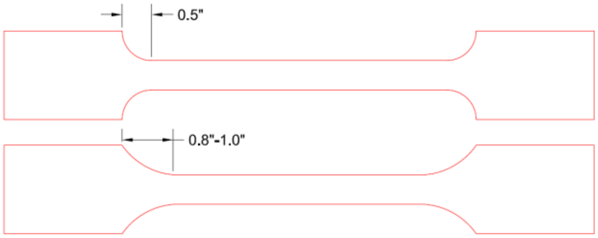

Figure 4.3. Original versus Modified Dogbone Specimen

4.3. Finalized Testing

During spring quarter, and the start of the construction process about 12 weeks out from competition, students performed testing on 4 softwood and 4 hardwood balsa specimens, to compare the effectiveness of each type of wood in terms of stress and strain capacities. Each specimen in finalized testing was cut to the modified dogbone shape. When the new balsa wood for the prototype model, Model A, arrived, students tested a total of 4 more specimens to compare the average modulus of elasticity values to the calculated value resulting from the leftover wood samples. Figure 4.4 below shows an example of a failed balsa wood specimen.

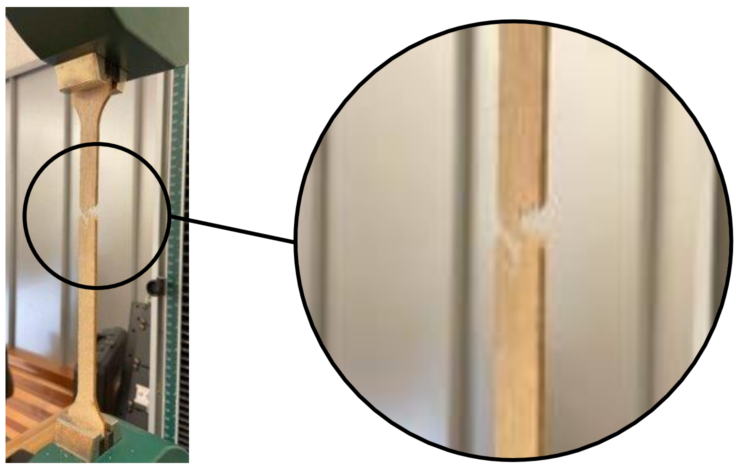

Figure 4.4. Example Dogbone Tensile Failure

Students found a greater level of consistency with the new balsa wood cut to the modified dog bone shape. By averaging the results of the finalized material testing, students found a modulus of elasticity of 320 ksi. Figure 4.5 shows the stress versus strain graph of the three most consistent tests – ultimately used to inform the material properties input into the ETABS model (discussed in Section 8.0).

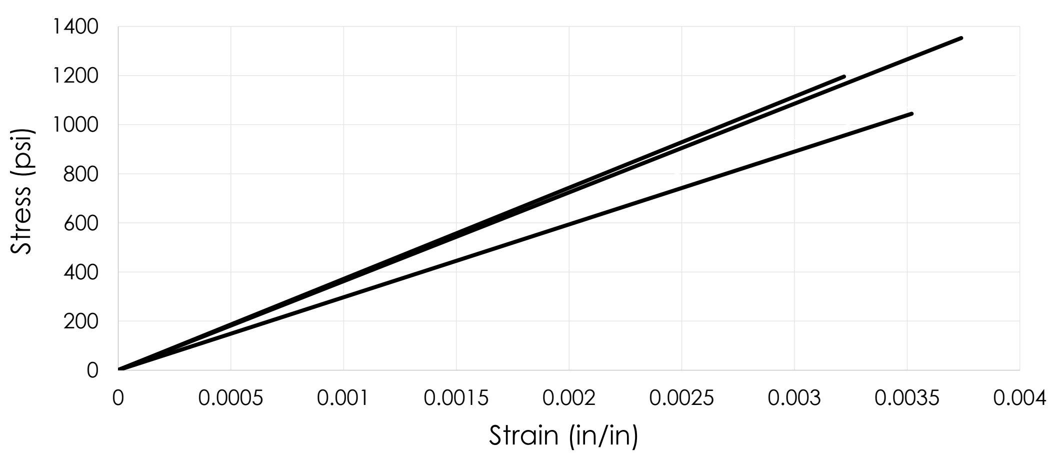

Figure 4.5. Stress vs. Strain of Finalized Dogbone Testing

While the materials testing team conducted tests to determine the modulus of elasticity, the design team worked towards developing an appropriate structural configuration for the required elevations and floor plans.

5.0 Structural Design

The EERI Design team is responsible for designing the main structural system used to transfer both vertical and lateral loads through the mid-rise balsa wood building model. Vertical loads include the dead weight of the structure and point loads applied via rods located at every other diaphragm, while competition-designated ground motions activate the seismic mass to result in lateral loading (see Section 8.1.2). See Figure 5.1. for competition-required geometry of both the building elevation and floorplan.

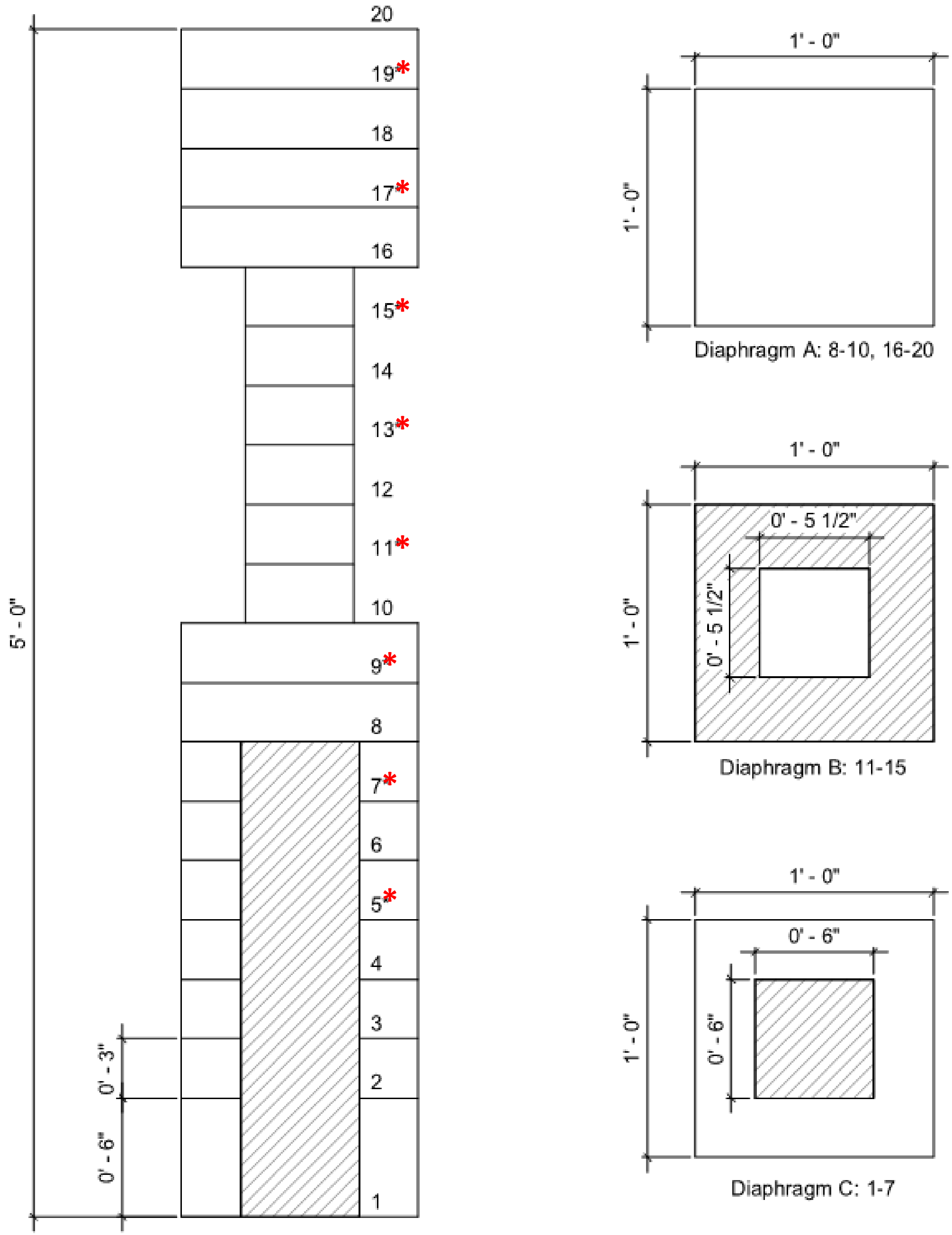

Figure 5.1. Structure Elevation and Floor Plans per Level

Floors marked with an asterisk are to be loaded at the competition. Diaphragm A applies to floors 8-10 and 16-20. Diaphragm B applies to floors 11-15, at the mid-height reduced floor plan. Diaphragm C applies to floors 1-7, which includes a large opening for the inner atrium. The hatched regions shown in Figure 5.1. indicate the void space through each cross-section cut. In the elevation view, the double-height first floor is shown, along with the inner atrium spanning 7 floors in height. Due to these structural irregularities imposed by competition rules, students were required to address each structural challenge for success.

In Figure 5.2, students model the required geometry to clearly determine each structural irregularity that must be addressed.

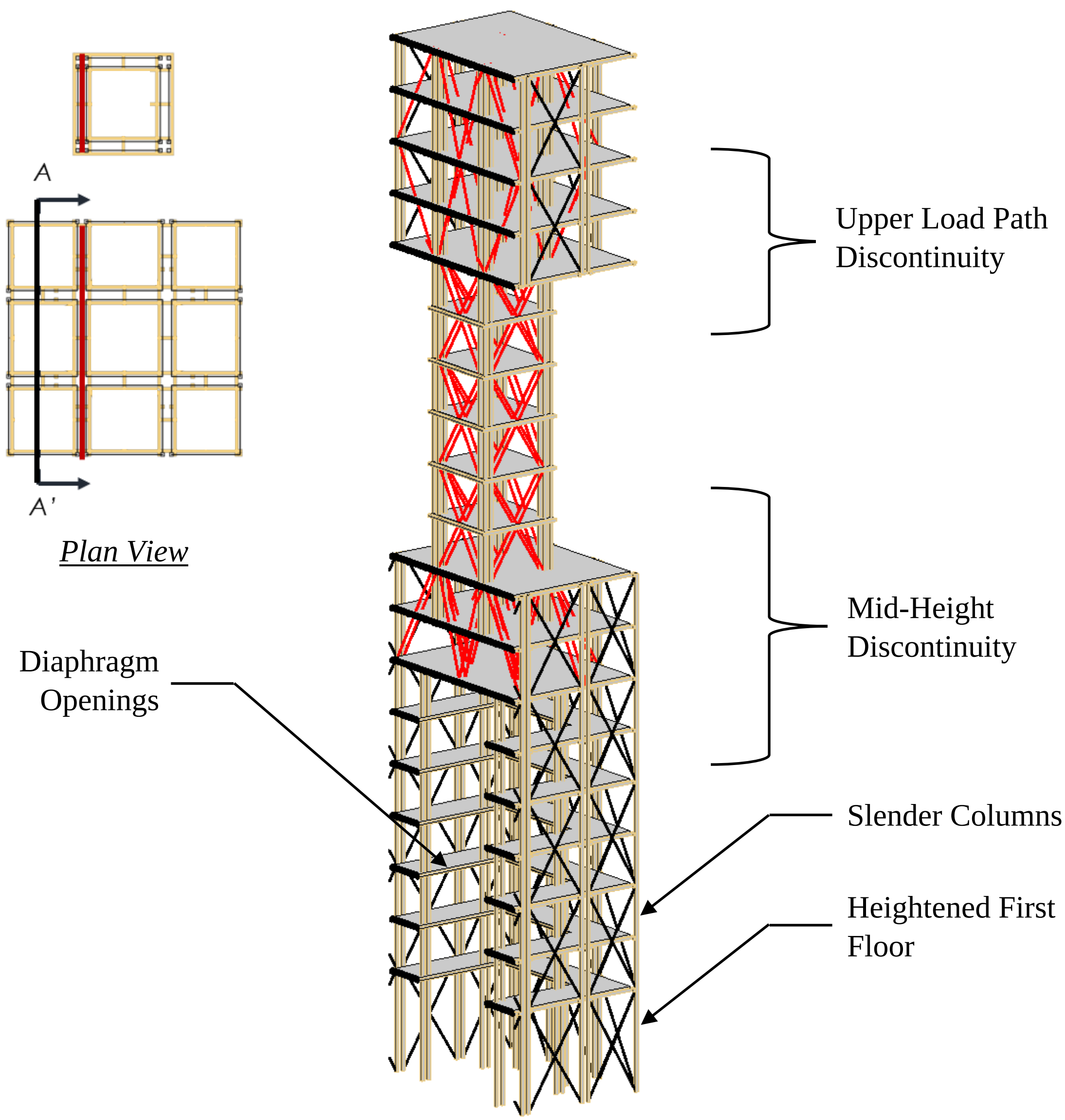

Figure 5.2. Structure Section Cut with Load Path Discontinuities

5.1. Precedent Study

To tackle the puzzling design problems presented in this year's competition requirements for the structure, students looked at precedent studies. Starting from the first design meeting, students researched the Ministry of Taxation (MOT) Tower in Baku, Azerbaijan, for its unique cantilevered corners and changing floor plan (see Figure 5.3). Designed by Architects at FXCollaborative and engineered by Thornton Tomasetti, MOT Tower employs two-way cantilevers, giving the structure its characteristic stacked cube appearance, and "promoting access to the outdoors all the way up the tower" [11]. At the "neck" of the structure, students decided on using a system of transfer trusses, or chord members designed to create a tension/compression balance between the two bottom cantilevered floor levels.

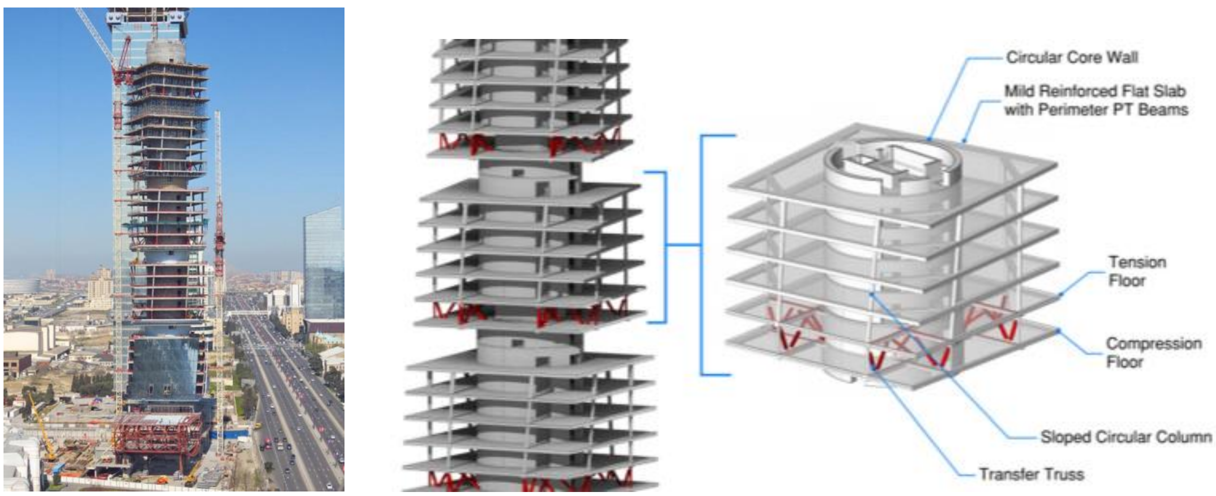

Figure 5.3. (a) MOT Tower – Baku, Azerbaijan, (b) MOT Tower Lateral System [2]

Shown in red in Figure 5.3, these transfer trusses inspired a similar system of tension and compression chords to combat lateral loads in the SDC physical shaking portion of the competition. The most important part of this design, however, was stiffening the central interior core, to provide the resistance needed to transfer cantilevered exterior loads to.

5.2. Proposal – Initial Design

For the proposal, students followed this precedent study, along with previous year's bracing patterns, to develop a structural system to use as a base design. During this time, students continued to improve the structural system, meeting with professors to discuss potential load transfer ideas. Using a 3D modelling software, such as Revit, allowed students to theorize the out-of-plane bracing techniques that would eventually drive the design. Shown in Figure 5.4, red transfer trusses extend through the top four floors, intending to help transfer lateral loads from the bulbed head back to the slender neck of the structure. Also circled in Figure 5.4, discontinuous columns at the base of the "neck" were assumed to be the greatest threat to the top of the structure's integrity. Lateral blocking was placed around the column interface to help transfer lateral loads. Again, competition-loaded floors are marked with a red asterisk.

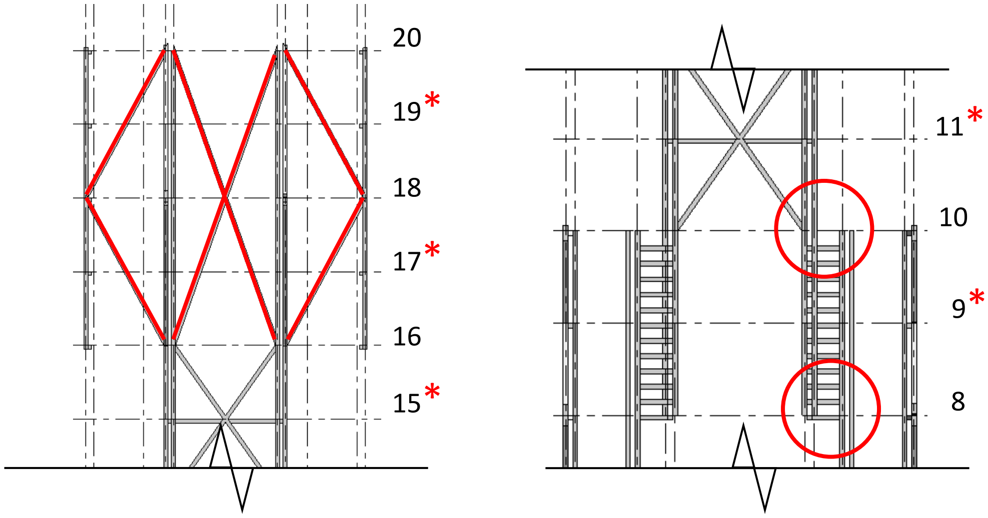

Figure 5.4. Proposal Structural Design: Interior 'Central Core' Elevation

5.3. Test 'Model A' Design

After the proposal, students felt that the proposed structural design presented in Section 5.2 would not be sufficient for the prototype model. Considering the challenging load path and cantilevered corners, students modified the design to create a more cohesive and rigid structure, specifically by focusing on stiffening the central core. Additionally, students decided on the best diaphragm configuration to account for weighted floors (see Figure 5.1) and lateral stiffness required for sufficient load transfer. Model A, constructed by students during spring quarter, was used as a physical replica of the expected structural system using for the final competition model. During construction, it was expected that there would be minor design changes made between the prototype model (Model A) and the final model (Model B) based on seismic performance and preliminary analysis.

5.3.1. Brace Design

The first thing to be modified for Model A was the bracing layout. Students discussed many possible layouts, shapes, and angles – keeping in mind the rules for opening height to allow a door into useable space. This became one of the biggest challenges to work around. Braces are concentrated in areas that need to be reinforced laterally and thicken as they transition to the smaller floor plan spanning between floors 10 and 16. At these locations, to provide rigidity, the single bay of bracing must be significantly stiffer in comparison to the braces at widened floor plans, which can employ three bays of bracing. See Figure 5.2 for a section cut of the full height of the structure.

5.3.2. Diaphragm Design

The main design considerations for diaphragms are relative stiffness and elastic deflection response. At the full floors (Diaphragm A), all diaphragm members were full-length rigid members to distribute stiffness. At locations where the transfer trusses connect to Diaphragm B, continuous members span the whole width and length of the reduced-size diaphragm to improve stiffness and continuity. At loaded atrium floors (Diaphragm C), diagonal braces at the midspan of each diaphragm edge direct load into the center of the diaphragm to stiffened column areas. At unloaded atrium floors, (Diaphragm D), the small central members are simply placed to account for member spacing requirements.

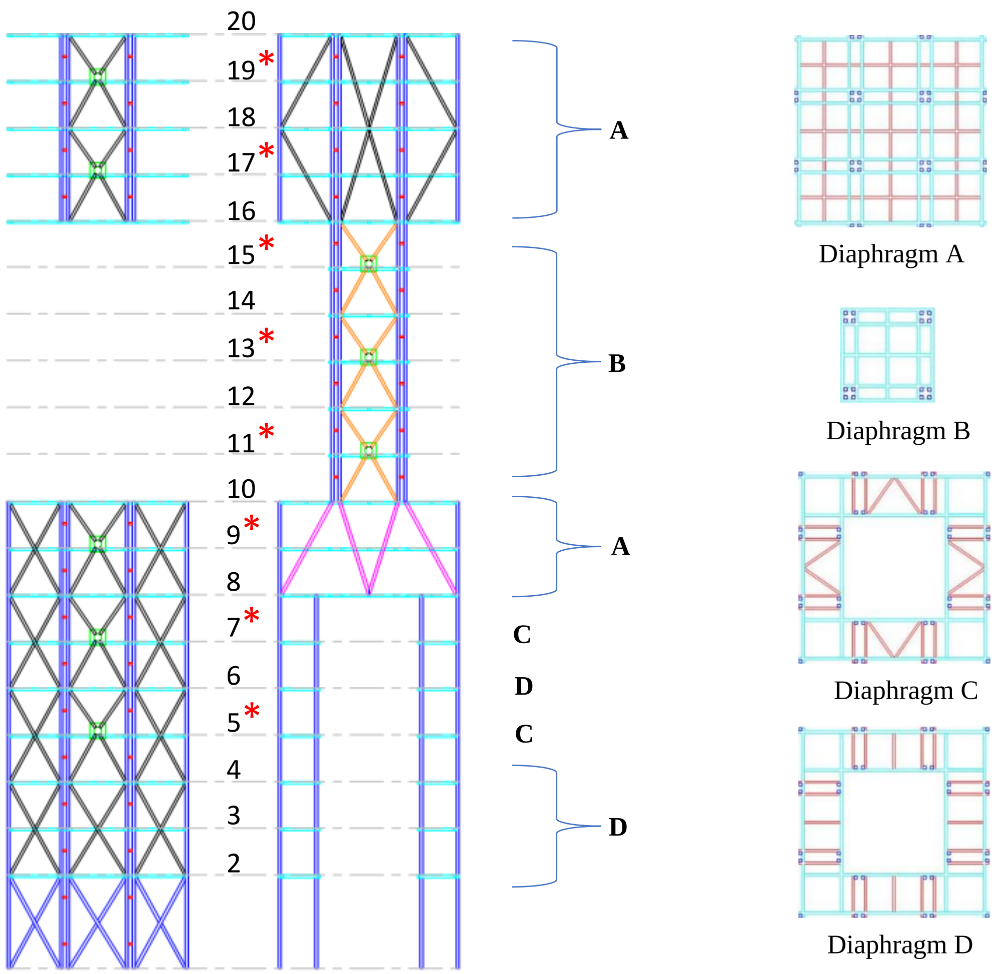

Figure 5.5. Model A Elevations: (a) Exterior (b) Interior (c) Diaphragm Layout

5.4. Competition 'Model B' Design

After construction, testing, and analyzing Model A, several design changes were made to help with ease of construction, improve load path, and calibrate the ETABS model. The following adjustments were made to the design:

I. Transfer trusses were redrawn and edited in a 3D format to help better understand the angle, connection to columns/diaphragms, and help with ease of construction.

II. Columns from floors 10-20 were extended down to floor 9 to improve stiffness at the change from diaphragm A to B. Doubled braces at the neck have been reconfigured to reduce the amount of gusset plates necessary to create a positive connection.

III. Slender columns spanning throughout the atrium opening have been lapped to increase the acting moment of inertia and cross-sectional area of the members.

Figures 5.6, 5.8, and 5.9 were prepared by Elizabeth Claypool (design team lead) in advance of the competition presentation. Each of the final design decisions discussed plays a major role in load path and structural detailing around discontinuities, noted in Figure 5.2. Sections 5.4.1 – 5.4.3 below detail how each of those discontinuities was addressed, following gravity load path top to bottom.

5.4.1. Transfer Trusses

A series of transfer trusses addresses the upper-level load path discontinuity. Rather than pursuing a more material-heavy bracing pattern, students used out-of-plane bracing as discussed in Section 5.1 to transfer lateral loads throughout the top of the structure. Not only does the transfer truss system help transfer loads from the cantilevered floors to the interior columns at the reduced floor section, but they also maximize rentable floor area, minimize weight as compared to more typical bracing patterns, and enable unique architecture. See Figure 5.6 for a breakdown of the transfer truss system.

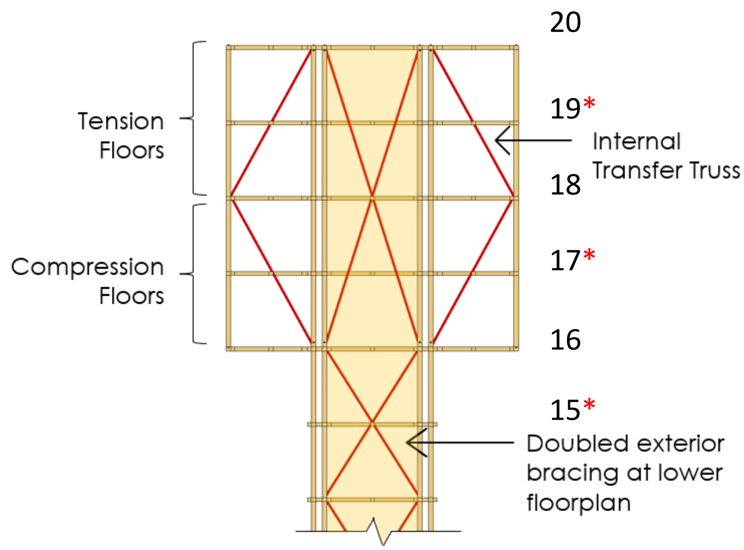

Figure 5.6. Upper-Level Discontinuity: Transfer Trusses

5.4.2. Column Design

In past EERI competitions, the method to "bulk up" long-spanning load-bearing columns was to bundle them together, creating a greater total cross-sectional area. With bundled columns written as against the spacing rules this year, students grouped columns together in central load bearing locations, but spaced them sufficiently apart with horizontal blocking to reduce midspan deflection resulting from flexure in the columns. To aide in the construction of the very slender columns that span throughout the structure, a lapping diagram was created to ensure that member spacing requirements (see Supplementary Document A1) were satisfied while columns remained grouped to act compositely. See Figure 5.7 for column lapping pattern.

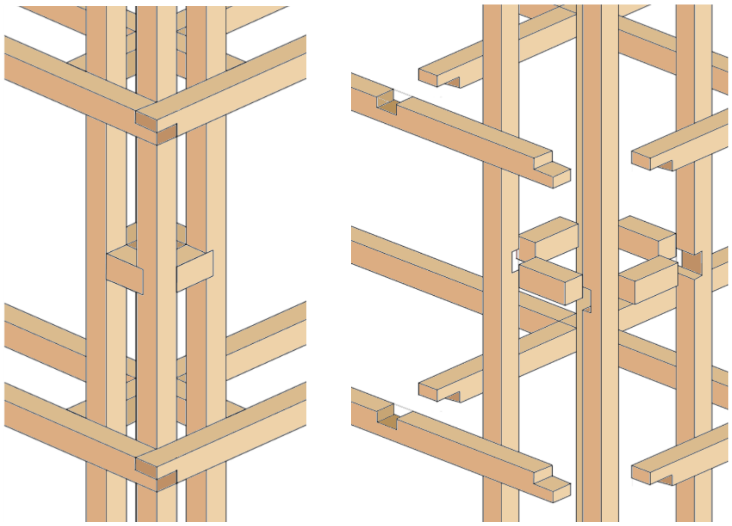

Figure 5.7. Column Lapping Diagram (a) Constructed (b) Exploded

To alleviate stress build-up at the mid-height discontinuity, where the ‘neck’ of the structure frames into the lower 10 floors, columns from the central core were extended down to floor 9 to assist in keeping the upper floors square, rather than terminating on top of diaphragm 10, where the only positive connection would occur at the bottom of the columns. To help these interior columns distribute load back out to the widened exterior of the building, transfer trusses were used again at the full-floor levels 8-10. Figure 5.8 shows a cross-section of the structure through the mid-height discontinuity.

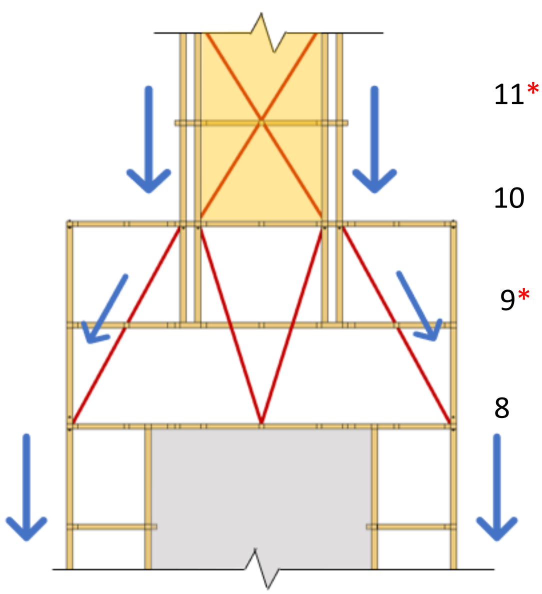

Figure 5.8. Mid Height Discontinuity: Extended Columns

5.4.3. Column Design at Atrium

The last column load transfer discontinuity to be addressed was the increased floor level height at the bottom floor. To maintain an open and inviting architectural style, many modern structures will have a taller bottom floor, sometimes creating a soft-story condition, where the opening's height and width can put extra stress into bottom floor's support members as shown in Figure 5.9. This vertical stiffness discontinuity was resolved through increasing the thickness of the bottom floor's braces – helping to balance the stiffness distribution throughout the lower-level floors.

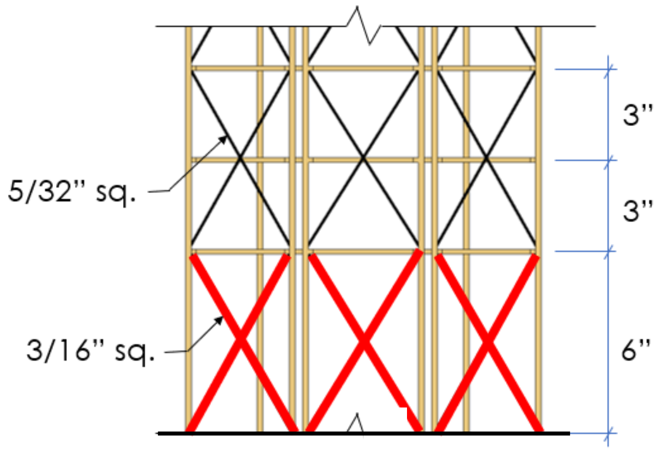

Figure 5.9. Bottom Floor Elevation: Bracing Size Comparison

The main goal of the design team was to identify structural discontinuities that would result in stress concentrations at weak points in the structure and address them individually to transfer both vertical and lateral loads through the structure to the supporting base plate connections. However, as the design team worked mainly on the structural design of the balsa wood model, students also had to keep in mind other design considerations that would affect the structure. Specifically, design team also considered architectural design – governed by innovative approaches to occupancy and location-specific features – and economical and sustainable material use. Section 6.0 elaborates on the additional design considerations taken for the structure.

6.0 Additional Design Considerations

To promote well-rounded learning, and an understanding of real-world collaboration between disciplines, the competition also requires that students address non-structural considerations for their respective project. The 2022 EERI team discussed methods of integrating these design considerations into the final product and associated deliverables. Listed below are the main interdisciplinary design considerations required of the student teams.

6.1. Architectural Design

While the proposed structure must perform well seismically, it should also be an aesthetically pleasing and architecturally intriguing building. Students will generally design architectural components around the proposed building occupancy – designing thoughtful apartment layouts for residential structures, beautiful garden terraces for office or commercial structures, or a purposeful mix of community open space.

It is beneficial to research the architecture of the local area to find precedents. Using the natural landscape and man-made infrastructure of Salt Lake City as a basis of design, students ultimately chose the images in Figure 6.1. to drive architectural design. Architectural design, like structural design, must include thoughtful reasoning behind design choices. The 2022 Cal Poly SDC team used a sustainably sourced façade and creative spaces for mixed-use office and retail occupancy to combine site-relevant aesthetic through architectural design.

Figure 6.1. (a) Hoodoo Formation, Bryce Canyon National Park (b) Salt Lake City Skyline

The textured façade not only mimics the surrounding landscape in its rippling effect (see Figures 6.1a and 6.2b), but also reduces solar heat gain on the hot southern face of the structure. Students liked the idea of using recycled perforated metal to create a lightweight “sunshade” around the exterior of the structure. The sustainable material intends to provide thermal insulation, reducing the heat transfer from the exterior sunlight to interior rooms.

Mixed-use office and retail space, with community-driven areas such as the rock-climbing attraction and terrace restaurant, cultivate an approachable and welcoming environment. The multi-story hoodoo rock climbing wall, situated in the inner atrium, is intended to bring the adventurous outdoor spirit of Utah into the core of the structure. See Figures 6.2a-b below for architectural renderings used for the competition poster and presentation.

Figure 6.2. (a) Terrace View: Restaurant (b) Atrium View: Rock-Climbing Attraction

6.2. Economy

The proposed structural design should be conscious of cost-saving techniques and its effect on local economy. This can be expressed in a wide variety of ways: through expected building income, creation of local jobs for construction and contracting teams, conscious use of material, and more. Each project will have its own specific economic impact.

At the competition, points are awarded to teams that maximize the rentable floor area of their structure, which in turn increases the expected annual income of the structure. This can be accomplished by using all the designated build areas throughout the structure and designing internal bracing elements which would allow user circulation throughout the building. If an area of the structure is blocked by a brace, that area is deemed “non-rentable area”.

Aside from maximizing rentable floor area, students also consciously sized structural elements for maximum material efficiency. For example, non-load bearing diaphragms (at unloaded floors) had fewer interior members than load-supporting diaphragms. As the building height progressed upwards, students reduced the overall size and repetition of structural members – concentrating them at critical load path points such as the interior transfer trusses and reinforced column and diaphragm connections. Braces at the exterior were used as the main lateral-load resisting system, with vertical elements strengthened to withstand load transfer. With this proposed structural system, the building cost reflects the built-in value of seismic resilience. Students expected the structure to withstand both ground motions, estimating the building lifespan to be 100 years, speaking to the concept of performance-based design in building resilience.

In contrast to building revenue, the annual seismic cost is reflective of the building’s seismic performance, equipment cost, return period, and construction cost. In each primary direction, the measured peak roof drift and peak roof acceleration will be different due to physical model building inconsistencies that a computer model cannot account for, like material deficiency and human error. This measured data is used to estimate the economic loss of the structure. As a note, the calculation for economic loss varies depending on the performance of the structure – collapsed after GM1, collapsed after GM2, or not collapsed. See Supplementary Document A1 for calculations associated with building income and seismic cost. Table 6.1 shows the estimated building income and seismic cost for the 2022 SDC – a table which was included in the competition presentation post-end slide as a resource if judges asked about building income.

Table 6.1. Building Income and Seismic Cost

	N/S	E/W
Annual Building Revenue	$ 512,499.22	$ 512,499.22
Land Cost	$ 4,729,921.88	$ 4,729,921.88
Construction Cost	$ 8,000,000.00	$ 8,000,000.00
Damping Device Cost	$ -	$ -
Building Lifespan	100 yr.	100 yr.
Annual Building Cost	$ 127,299.22	$ 127,299.22
Annual Seismic Cost	$ 81,806.56	$ 92,454.35
Annual Net Revenue	$ 303,393.44	$ 292,745.65
Final Annual Building Income (with predicted bonuses)	**$ 484,187.70**	**$ 474,391.73**

Aside from annual revenue and annual seismic cost, students should be aware of other variables that can affect the Final Annual Building Income (FABI). Listed below are the most critical of these variables, discussed in the Scoring section of the Official Rules [A1].

- Bonuses from noteworthy submittals (Proposal, Presentation, Poster, Architecture)
- Annual Building Cost (a function of construction cost – directly related to structural model weight, and violations added as a penalty as additional construction cost)

6.3. Sustainability

In recent years, it should come as no surprise that sustainable design choices have been at the forefront of all design proposals. As much as structure (material use) or architecture (building efficiency) is considered, the environmental impact of the construction industry must be as well. By choosing locally available and sustainable materials, the impact of transportation decreases, as well as placing less strain on the local environment. Each project will have a unique approach when it comes to sustainability, but it is crucial that the discussion surrounding sustainable practice is ongoing and evolving throughout the design process [3]. For more specific sustainability information, students looked to the local government, geological, and environmental agencies in Salt Lake City, Utah. Though it is outside the scope of this paper, listed below is AIA’s sustainability site that may aid in sustainable design.

Architectural Practices (published by the American Institute of Architects, AIA): https://www.aia.org/landing-pages/6423877-sustainability

6.4. Example Questions Related to Non-Structural Design Considerations

During the presentation portion of the competition, judges will often ask non-structural design related questions to gauge the team's understanding of interdisciplinary effects on structure. Listed in Table 6.2 below are non-structural questions asked at the 2022 SDC.

Table 6.2. Judge's Non-Structural Questions

1	How did the historic architecture of the area influence your design?
2	Discuss your sustainable design considerations.
3	What was the choice behind the aesthetic of the building?
4	How did you choose the architectural precedents that ultimately inspired you?
5	How does the structure integrate with the site and the larger cityscape?
6	Did any of your architectural choices impact your structure?

During the competition, students are challenged to consider architectural design, economy, and sustainability through their structures, while finding innovative ways to present and communicate those ideas. While not directly related to the construction of the scale balsa wood structural model, these design considerations directly impact the main structural design.

7.0 Construction

The EERI Construction team handles the preparation of structural members and the fabrication of a prototype model (Model A) and a competition model (Model B). While all students are expected to help fabricate the models, the construction team should be well-versed in directing other students, forming efficient assembly lines, and precisely erecting the structure. The role of construction lead is best fit by a student who is detail-oriented and able to organize a long-term project deadline.

As for construction materials, a material take-off for balsa wood is required based on the number of cutsheets needed, discussed in Section 7.2. As a note, the construction team decided to purchase the mid-grade "Medium" density balsa wood from Specialized Balsa Wood, LLC. Table 7.1. below outlines the materials required for building each balsa wood model, with the approximated cost, location to be purchased, and timeframe-specific order details. The balsa wood sheets for Model A were ordered on 4/6/2022 and delivered on 4/11/2022, while additional sheets for Model B were ordered on 4/19/2022 and delivered on 5/2/2022 – each with a $32 shipping fee.

Table 7.1. Construction Materials Spreadsheet

Material	Cost	Company	Model A ($477)			Model B ($344)		
			Date Req'd	Amt. (#)	Total Cost	Date Req'd	Amt. (#)	Total Cost
3/32"x12"x36" Balsa Sheet	$15	Specialized Balsa Wood, LLC	4/11/22	3	$45	5/2/22	2	$30
1/8"x12"x36" Balsa Sheet	$16	Specialized Balsa Wood, LLC	4/11/22	3	$48	5/2/22	2	$32
5/32"x12"x36" Balsa Sheet	$17	Specialized Balsa Wood, LLC	4/11/22	6	$102	5/2/22	4	$68
3/16"x12"x36" Balsa Sheet	$18	Specialized Balsa Wood, LLC	4/11/22	5	$90	5/2/22	3	$54
Quik-Cure Epoxy	$10	Cal Poly Bookstore	4/18/22	2	$20	5/9/22	2	$20
Maxi-Cure	$10	Cal Poly Bookstore	4/18/22	5	$50	5/9/22	5	$50
Insta-Cure +	$10	Cal Poly Bookstore	4/18/22	5	$50	5/9/22	5	$50
Zip Kicker	$8	Cal Poly Bookstore	4/18/22	5	$40	5/9/22	5	$40

7.1. Laser Cutter Machine Training

To create structural members and specimens for training, students must make an appointment in Cal Poly CAED's Digital Fabrication Laboratory to laser cut balsa wood sheets. For the 2022 SDC, students laser cut each piece used for the model. As a note, the laser cutting machines (particularly the 24-inch by 36-inch red laser cutter) are generally busy towards the end of the quarter. While construction team students practice on the laser cutters, design team students should prepare cutsheets. All EERI members should be attempting to make appointments for the laser cutter once construction begins to ensure a timely schedule. Students on the 2022 Cal Poly SDC team used a shared excel spreadsheet to notify the team of secured laser cutting appointments. See the laser cutter guide Supplementary Document B2.

7.2. Cutsheet Development

To develop cutsheets, students draft each member 2-dimensionally, as the width will be the thickness of the balsa wood sheet. Each member will be cut to include notches for lapped connections. Generally, cutsheets are drafted in AutoCAD as a .dwg file, which is imported to Rhino and converted to a .3dm file for the laser cutter - see some examples of the 2022 SDC team's cutsheets in Supplementary Document B1. Based on the required number of cutsheets, balsa wood should be ordered about 1-2 weeks in advance of the first laser cutting appointment.

7.3. Model A Construction

Students on the 2022 Cal Poly SDC team got permission to use both the Berridge Lab and Seismic Lab on Cal Poly's campus to construct the model. Most of the construction was done in the Seismic Lab, with time allocations scheduled around ARCE classes. Students organized the materials into storage containers in that facility, out of the way from other classes and models. Once the laser cut members were sorted into their respective use piles, students started construction on Model A. The first section of the model to be completed was diaphragms, which are mainly continuous members cut to lap, squared at each corner using a T-square then glued into place at laps. Next, students constructed the spliced columns, with column blocking.

Figure 7.1. (a) Completed Diaphragms (b) Students Splicing Continuous Column Members

One design consideration that did not make it to the cutsheets was an extra 0.5-in at the end of each column to be inserted into to the base plate, set into a drilled hole to provide a secure connection. Because the columns were cut too short, students cut extender pieces for the bottom of these columns, to ensure that the study model remained the correct height for analysis purposes. These pieces were epoxy-fixed to the bottom of each column, and then placed into the base plate and sealed at the connection with more epoxy. Figures 7.2(a-b) below show the pre-epoxy column fitting process.

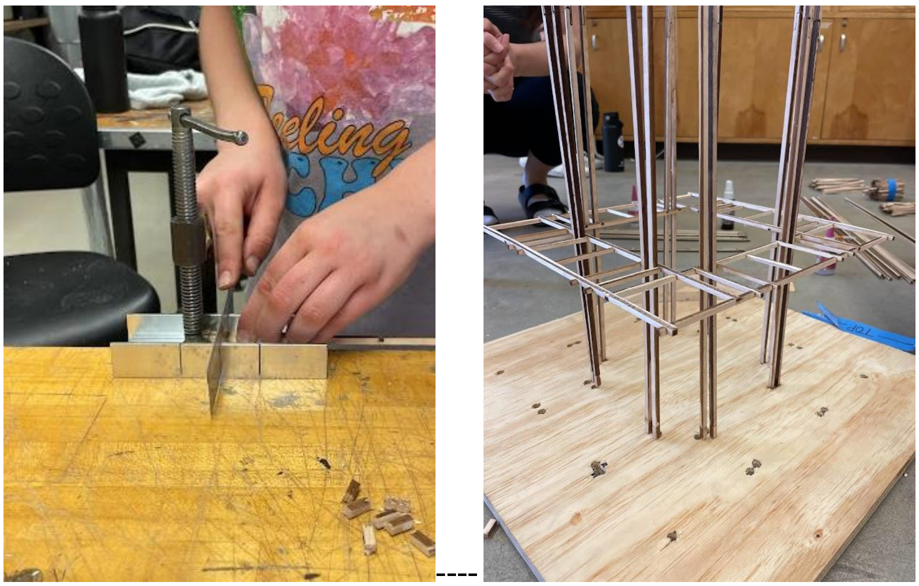

Figure 7.2. (a) Column Extender Pieces (b) Checking Column Location/Angle Pre-Epoxy

When applying the liquid epoxy to the connection, there should be no overflow or spill, as it may lead to point reductions at the competition. Students used duct tape to cover the holes on the underside of the base plate. Due to the interaction between the epoxy and plywood, slight warping is expected. Students discovered that taping the top of the base plate around each hole helped prevent both epoxy overflow and messiness on the visible face. It should be noted that the epoxy connection needs about 1 hour to dry once columns are inset into the pre-cut base plate, and the base plate should be firmly clamped to a flat surface during drying.

Once all columns had been placed into the base plate and the epoxy had dried, students started sliding the diaphragm into place over the columns. Students confirmed that the correct diaphragm was being used per Figure 5.4, set it at the right elevation, level on all sides, and then glued the diaphragm at the column connections. By placing columns at an inner corner of the diaphragm, students had two surfaces to apply glue to, creating the most rigid connection possible. Multiple students assisted in the process, to help support the diaphragm as the glue dries. Figure 7.3(a-b) below shows the analog caliper used to measure floor-to-floor placements heights and the gluing process.

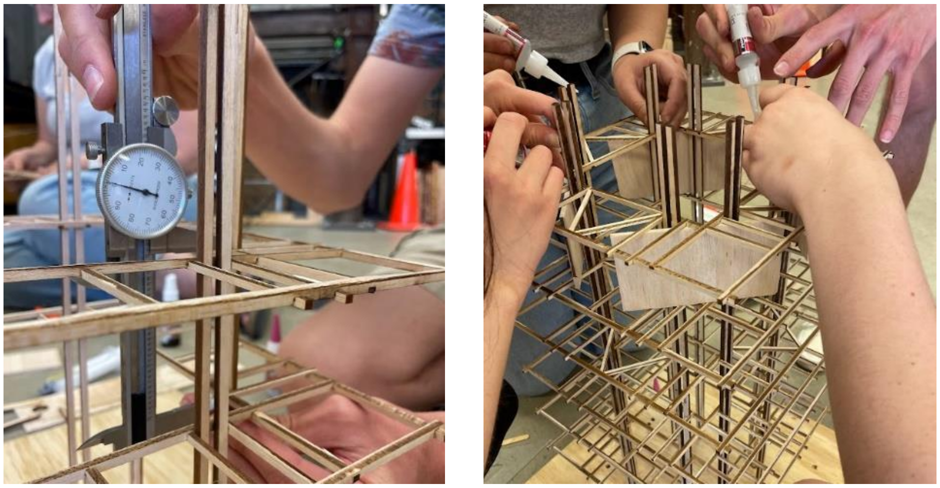

Figure 7.3. (a) Floor to Floor Height (b) Gluing Diaphragm to Column Bundles

At the ‘neck’ of the structure, students placed the smallest diaphragms. The transition from the bottom floors to the reduced floor plan is stiffened by transfer trusses, which span for two floors. Because of the three-dimensional aspect to the transfer trusses, students did not realize that they needed to prepare detailing for the intersection of the truss chord at the diaphragms. The diaphragms had to be modified (via taking out a section of continuous bracing) to allow the transfer truss to pass through the levels. As a note, this design issue was considered in the final model and addressed before cutsheets were printed. By building a prototype model, simple constructability issues such as this can be addressed while still achieving the desired load path that has been designed, rendered, and input into the corresponding ETABS model.

After placing all diaphragms and internal bracing, students placed the final members: exterior braces, gusset plates, and exterior columns on the structure. See Figure 7.4(a-b) below.

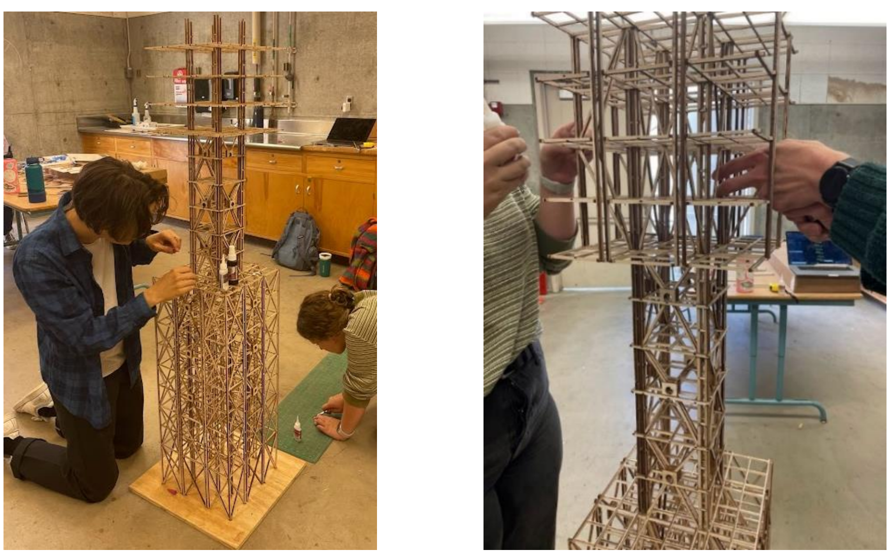

Figure 7.4. (a) Lower-Level Exterior Bracing (b) Upper-Level Transfer Trusses

7.3.1. ‘Model A’ Construction Schedule

Students spent about two weeks completing the construction for Model A, with a total of about 34 hours per person spent on the prototype. See Table 7.2 for the construction schedule and associated breakdown of person-hours put into the model over the course of construction. Laser cutting hours are shown in orange, construction hours in blue, and testing hours in yellow.

Table 7.2. Construction Schedule of Model A

Date	Task	Hours Worked	# Of Workers	Person * Hours
4/18/22	Laser Cutting: Diaphragms, Columns	5	2	10
4/19/22	Laser Cutting: Columns, Braces	3	1	3
4/20/22	Construction: Organize Laser Cut members	2	3	6
4/21/22	Construction: Organize Laser Cut members, Spliced Columns, Diaphragms	4	3	12
4/24/22	Construction: Diaphragms	3	2	6
4/25/22	Laser Cutting: Columns, Base Plate, Gussets	1	2	2
4/30/22	Construction: Epoxy Columns to Base Plate, Place all Diaphragms in Place	8	4	32
5/1/22	Construction: Interior Bracing, Transfer Trusses	4	3	12
5/2/22	Construction: Exterior Bracing, Exterior Columns, Gusset Plates	4	5	20
		Total Hours:		103

Based on the variable (but expected) construction team member turnout during the quarter, the total number of hours spent on construction in a single setting is not necessarily reflective of the productivity of work. The construction team saw an average of about 3 workers for each session – which translates to approximately 34 hours per worker over the course of two weeks. The construction team should be aiming to have 4-5 members present at each building session for maximum efficiency. With a greater number of student workers, a two-week build is extremely manageable.

7.3.2. Lessons Learned

The construction of Model A provided students with many new ideas about design, construction sequence, and ultimately – the performance of the structure. See Section 5.4 for the main design changes addressed by the construction team between Model A and the competition model. There were two notable edits to the design in terms of ease of construction:

I. Redesign of diaphragms on levels 9, 17, and 19 to allow the angled transfer truss to pass through without intercepting a horizontal member.

II. The brace-to-gusset connection was challenging to construct in the prototype due to the number of pieces used to fill in gaps between bracing members. The construction team redrew the bracing configuration and redesigned the gussets to minimize the number of members required for gusset plate construction.

7.4. Competition Model Construction

Due to the similarity between the construction processes for Model A and the competition model, this section will detail the most notable design and construction considerations. Once the design team finished the redesigned cutsheets (see Section 5.4 Model B design), the construction team laser cut the members necessary to complete the diaphragms and lower-level floors. See Figure 7.5 below for diaphragm placement and finalized lower section.

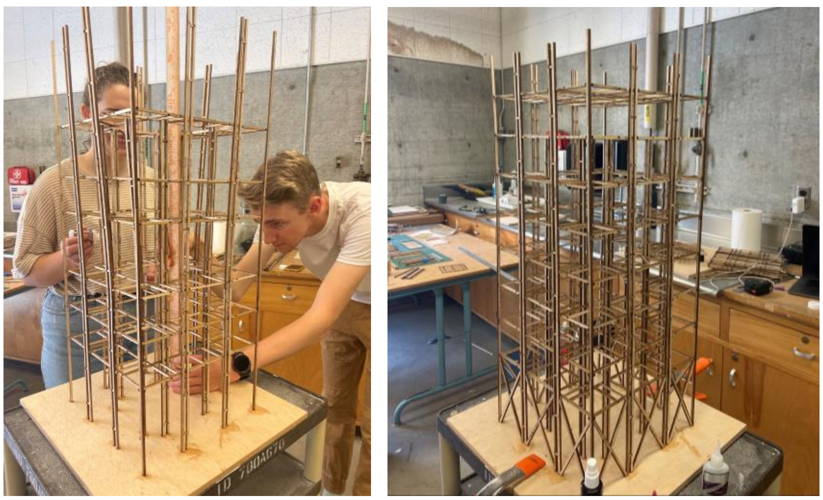

Figure 7.5. (a) Diaphragm Placement (b) Completed Levels 1-8

Figure 7.6 is annotated to show some crucial connection points unique to Model B – and overall, its effect on the construction process and results.

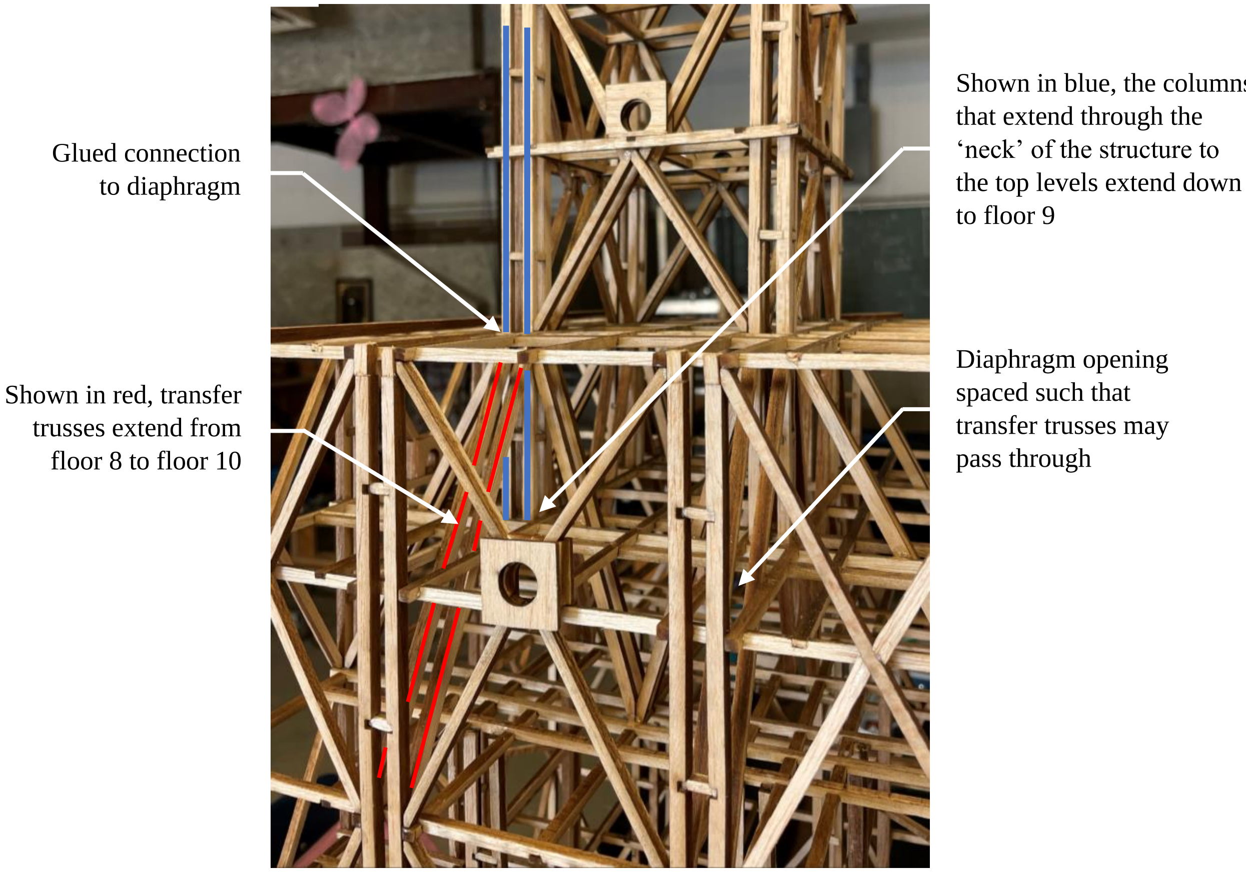

Figure 7.6. Neck to Base Connection Details

By extending the central neck columns down to the ninth floor, the construction team was able to glue the columns at multiple locations into place at the tenth-floor diaphragm. Originally, these columns were epoxy-fixed to the top of the tenth floor, which allowed quite a bit of deflection. This new connection, though more secure, failed during the competition when the weight of the upper floors induced a tension load onto the glued connection and ruptured.

7.5. Conclusions and Recommendations

Overall, the construction process for each model takes an average of 34 hours per person (with 3 workers) depending on the complexity of the design and number of members needed to adequately transfer loads. It is at the recommendation of previous construction team leaders that all students on the Cal Poly EERI SDC team help to construct the model and help to make appointments in the Cal Poly Digital Fabrication Lab.

8.0 Analysis and Testing

The EERI Analysis team works largely in part with the design team, with the goal of creating a structure that displays predictable behavior and can undergo the required loading. For this, the analysis team developed an ETABS model to predict the structure's behavior based on finalized design, applied loading, and material properties. With these inputs, the analysis team made informed predictions about deflection, acceleration, and local damage/failure through prototype testing and computer analysis. Analysis team lead(s) are also responsible for arranging an appointment with ARCE faculty to be trained on the large shake table in the CAED Seismic Laboratory. Once trained and with permission, analysis team students can then use the large shake table for testing the prototype structure.

8.1. Design Considerations

The Analysis team started building an ETABS model immediately after the test model's (Model A) construction began. In previous years, an ETABS model was developed prior to construction, for the purpose of tracing load flow through the structure and identifying structural challenges. In 2022, the Cal Poly SDC team felt that the design and construction teams could meet the physical requirements of the structure – including surviving both ground motions – through means of addressing structural irregularities through iterative design and visible load path. However, the analysis team was still required to develop structural predictions. To ensure that the ETABS model accurately reflected the physical model, the program design considerations are presented in Sections 8.1.1. – 8.1.3.

As a note, students generally used the Computers and Structures, Inc. (CSI) sponsored computer laboratory within the ARCE department, to access ETABS. Many faculty and alumni were available to review the ETABS model and mentor the 2022 team in design and analysis. In the future, the team recommends contacting professors Peter Laursen, Cole McDaniel, or alumni Ryan Thornton and Paulina Robles with ETABS-related questions.

8.1.1. Diaphragm Rigidity

Generally, in this competition, the vertical gravity-loaded members provide most of the stiffness required to transfer loads to each lower floor. In this case, most diaphragms see very little load flow through them. After doing some research into previous model designs, it was clear that in past competitions, the diaphragms were merely a means of connecting the vertical system together. For most previous years, diaphragms were modeled as flexible in ETABS. In this model, however, the full diaphragms at each end of the "neck" of the structure are used to help transfer lateral loads from the central core (continuous through neck) to the exterior columns, by means of the transfer truss system. For this reason, diaphragms were considered rigid structural members in ETABS.

8.1.2. Self-Weight & Application of External Loads

Due to the lightness of the balsa wood, the self-weight of each member was not considered a large factor in the behavior of the structure. Below are the questions that students discussed when considering self-weight.

- Are we going to weigh the model and apply a uniform load based on self-weight?
- Are we going to ignore self-weight?
- Is the self-weight included in each modelled member of the ETABS model in section/material properties?

Neglecting self-weight, the only other gravity loads applied at the competition are point loads, applied via rods with washers fixing small weights at each end of every other floor. See Figure 8.1 for the loading configuration. These loads were applied as gravity loads in the ETABS model, which act as seismic mass to help initiate the lateral load response of the structure during ground motions. The lateral loads introduced are a result of the structure's mass participation. See Figure 8.2 for the ground motion inputs acting on the structure.

Figure 8.1. Threaded Rods with Dead-Load Weights

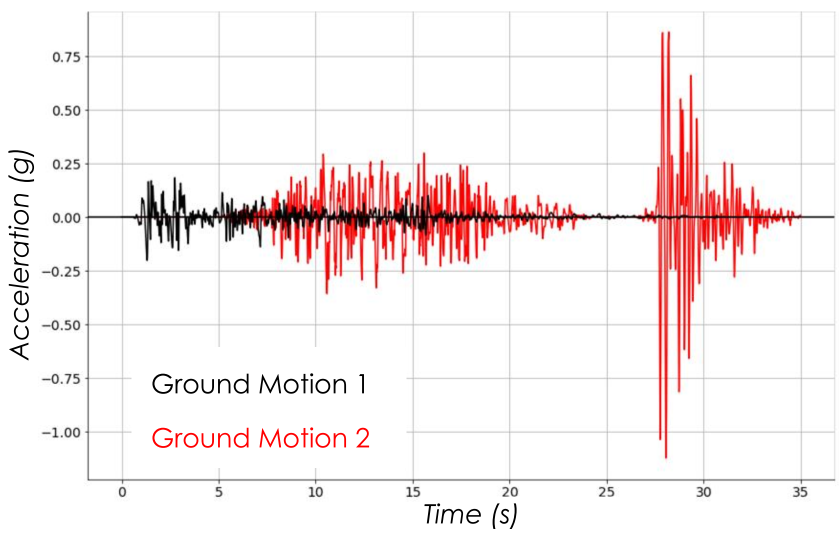

Figure 8.2. Ground Motion Accelerations (1) and (2)

8.1.3. Connection Fixity

All inter-story connections were modelled as fixed, except for the (generally flexible) diagonal brace members. The bottoms of the columns, attached and embedded with epoxy into the base plate, were modelled as pinned to account for expected rotation. Although the epoxy base feels like a “fixed” connection on the physical model, the data output and physical response shows students that the columns still undergo rotation at their base, suggesting that a pinned connection is a more accurate representation of the actual structure’s response.

8.2. Model A Shake Table Testing

To calibrate the ETABS model, students loaded Model A with weights and attached an accelerometer to the top of the structure, then ran a frequency sweep and a free vibration test on the large, uni-directional shake table located in the CAED Seismic Laboratory. By analyzing the structure’s response to each frequency, students estimated the resonant frequency to be 6.2 Hz, or a fundamental period of 0.156 seconds (Equation 8-1). To estimate damping, students performed a free vibration test by shaking the structure at its resonant frequency, stopping the shake table, and allowing the structural model to come to a rest while measuring acceleration data from the top of the structure. In previous years, students opted to do a pullback test, in which the top of the structure was displaced a known deflection, then released to dampen as students measure the structure’s response. Using the Logarithmic Decrement Method, students used Equation 8-2 to estimate fundamental period. See Figure 8.3 for the Free Vibration Acceleration vs. Time test output.

$$T = \frac{1}{f} \qquad \text{(Eqn 8-1)}$$

Where: T = Fundamental Period (s)
f = Resonant Frequency (Hz)

$$\zeta = \frac{1}{2\pi j} \ln \frac{\ddot{u}_i}{\ddot{u}_{i+j}} \qquad \text{(Eqn 8-2)}$$

Where: ζ = Damping Value
j = # cycles between data points
$\ddot{u}_i$ = acceleration at 1st data point
$\ddot{u}_{i+j}$ = acceleration at 2nd data point

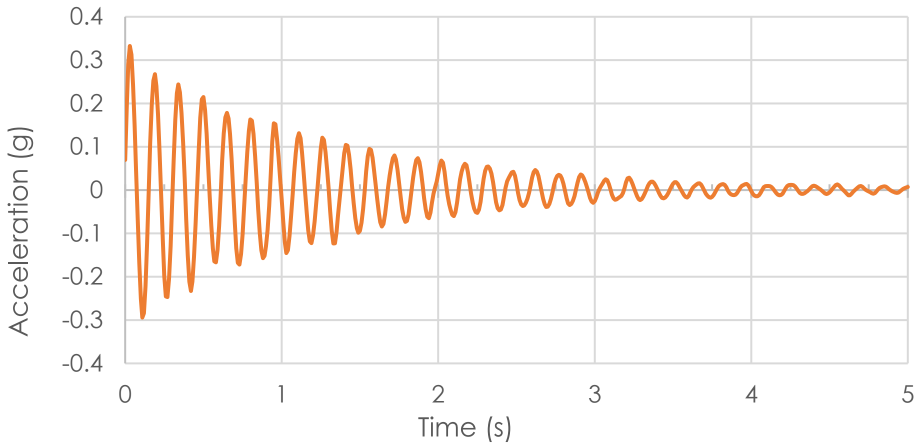

Figure 8.3. Free Vibration Test: Acceleration vs. Time Output

Using the data output from the free vibration graph above and Equation 8-2, students picked two data points and calculated the estimated damping value to be 0.02, or 2%. Then, the averaged fundamental period was compared to the ETABS output before running the real ground motions through the physical prototype structure on the uni-directional shake table.

8.2.1. Ground Motion Testing

After completing a frequency sweep and free vibration test, students ran ground motions 1 and 2 on the shake table with only an accelerometer (no physical model). The purpose of this was to record the shake table's acceleration and displacement output to compare to the given competition ground motions and verify the shake table was performing as expected so structural testing would be accurate. Analysis team leads confirmed that the shake table output was within a suitable range of error compared to the competition motions. Students then attached Model A to the shake table to run tests. See Figure 8.4 below for the shake testing setup.

Figure 8.4. (a) Loading Structure with Threaded Rods (b) Accelerometer Locations

Shown in Figure 8.4(b), students placed accelerometers at three critical locations on the model: one at the baseplate (red), one at the Level 10 ‘terrace’ (blue), and one at the top of the structure (white). This allowed students to calculate the relative accelerations experienced by the model during both shake tests.

After finishing testing, students remove all weights from the model and are responsible for cleaning up any equipment used in the seismic lab. Section 8.3 details the results of the shake table testing, and comparison to the ETABS model.

8.3. Model A Shake Table Results/Comparison

Model A performed very well when subjected to each ground motion. The results of testing validated initial design choices, as students saw very little damage to the structure. Shown in Figure 8.5. in red, the only visible damage to the structure was a deflected column and a diaphragm member that cracked due to the reaction of the transfer truss. Due to the success of Model A, students chose to make only necessary adjustments to the design, as discussed in Sections 5.4.1. – 5.4.3. and 7.4.

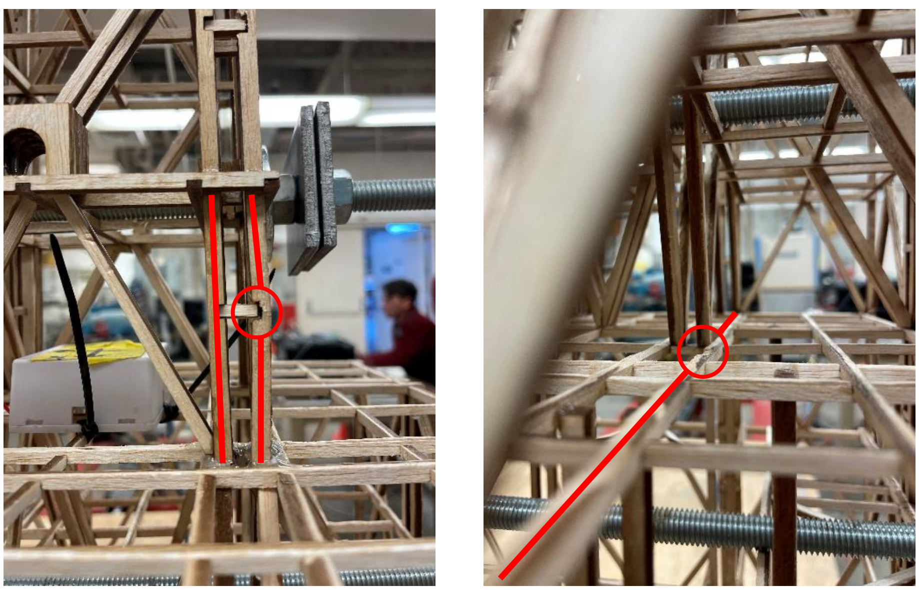

Figure 8.5. (a) Damaged Column (b) Damaged Diaphragm Member

8.3.1 ETABS Calibration (Based on Model A Testing)

In comparison to the ETABS model, Model A also performed very well. The expected maximum acceleration for ground motion 2 was estimated to be 3.390 g in ETABS, as compared to the actual output of 3.205 g – a 5.7% difference deemed acceptable by the 2022 Cal Poly EERI team. The data from the bottom of the structure was subtracted from the data at the top of the structure to calculate the net accelerations used to produce the acceleration-time history graphs in Figure 8.7. Figures 8.6 and 8.7 represent the expected (ETABS) and actual net accelerations experienced by the structure during the entirety of each ground motion.

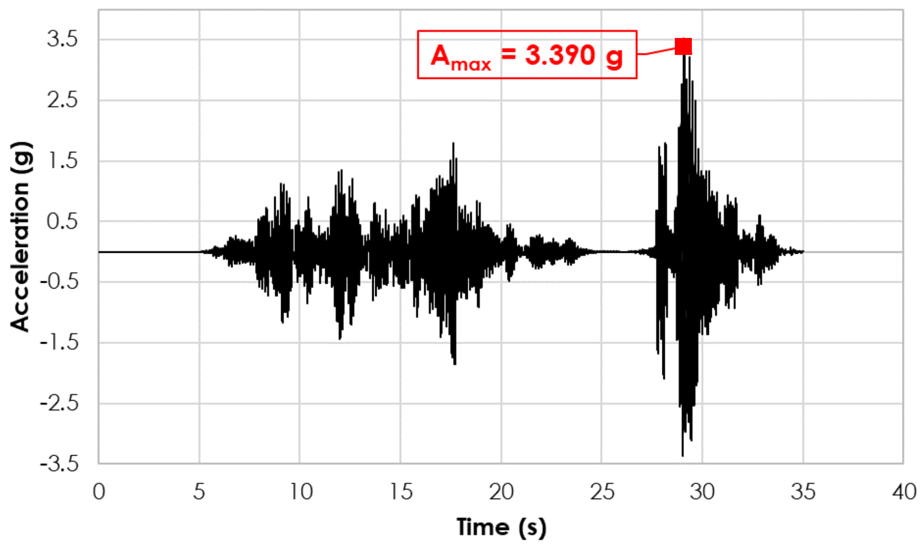

Figure 8.6. ETABS Acceleration Time History Analysis (Ground Motion 2)

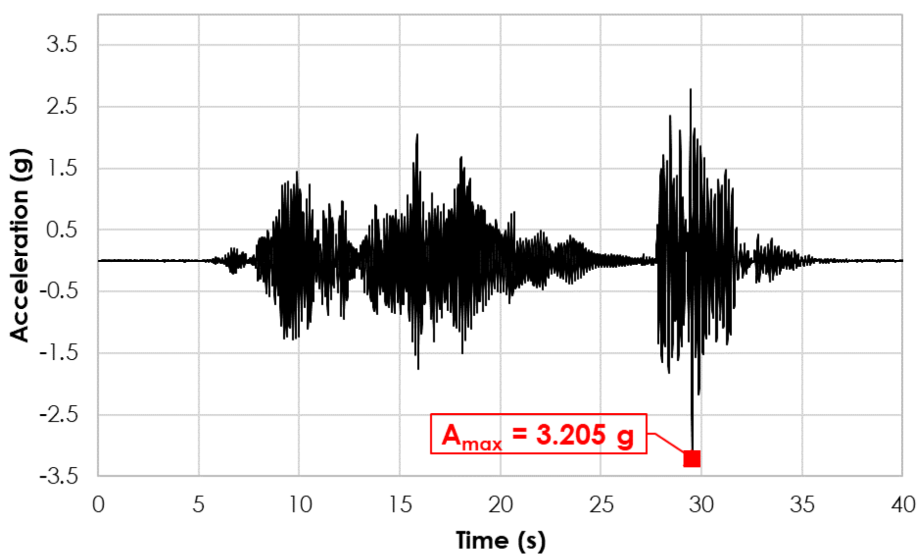

Figure 8.7. Actual Acceleration Time History Analysis (Ground Motion 2)

By comparing Figures 8.6 and 8.7 above, the analysis team continued to calibrate the ETABS model. The design considerations implemented at the start of the model largely stayed the same, with only minor adjustments made to the modulus of elasticity because students found that the actual model was experiencing slightly smaller accelerations than the ETABS model. The final ETABS model was then used to analyze mode shapes and produce a final linear time history analysis. Students also produced a response spectrum analysis using Newmark's average method.

8.3.2. ETABS Analysis

Following testing, students decided to compare several predictions - using the physical model acceleration time history, the calibrated ETABS model acceleration time history, modal analysis, and a response spectrum analysis. Refer to Section 8.3.1 for the direct comparison and calibration between the ETABS acceleration time history and the physical acceleration time history. Reflected below, the 2022 Cal Poly EERI team felt that the use of a modal analysis was not particularly informative due to the symmetry of the model. In addition, the results of Newmark's Average Method for approximating acceleration and displacement were generally discarded due to period sensitivity. Sections 8.3.2.1 – 8.3.2.2 below briefly describe the investigation into each analysis method and results.

8.3.2.1. Modal Analysis

Students found 90% mass participation in the first five modes, suggesting that the structure's symmetry creates semi-regular mode shapes. As expected with the symmetrical structure, the first three modes were translation in the N-S direction, translation in the E-W direction, and rotation about the central axis. Modes four and five are a result of bending in the neck of the structure. Figure 8.8 below shows the first three mode shapes experienced by the structure.

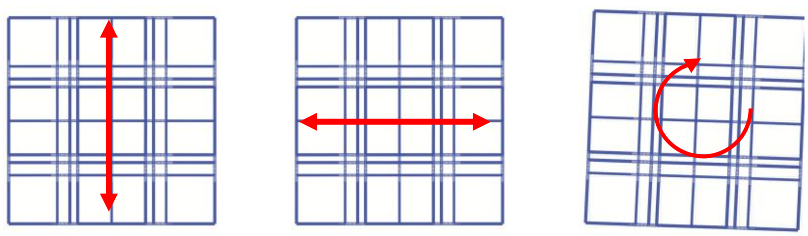

Figure 8.8. Mode Shapes 1-3

8.3.2.2. Response Spectrum Analysis (Newmark's Average Method)

Students produced both acceleration and displacement response spectrums for both ground motions. By implementing Newmark's average method, in conjunction with ground motions and calculated damping ratio, the analysis team created Figures 8.9 and 8.10. As a note, the use of 5% damping of the response spectrum provided by the SLC to competition teams was discarded due to the preliminary testing results of a 2% damping response, and this refined spectra was utilized instead.

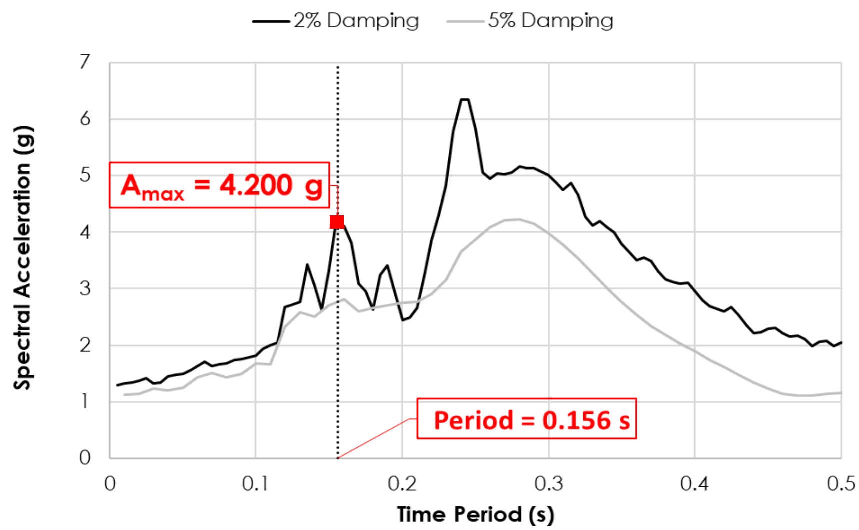

Figure 8.9. Spectral-Acceleration (Ground Motion 2)

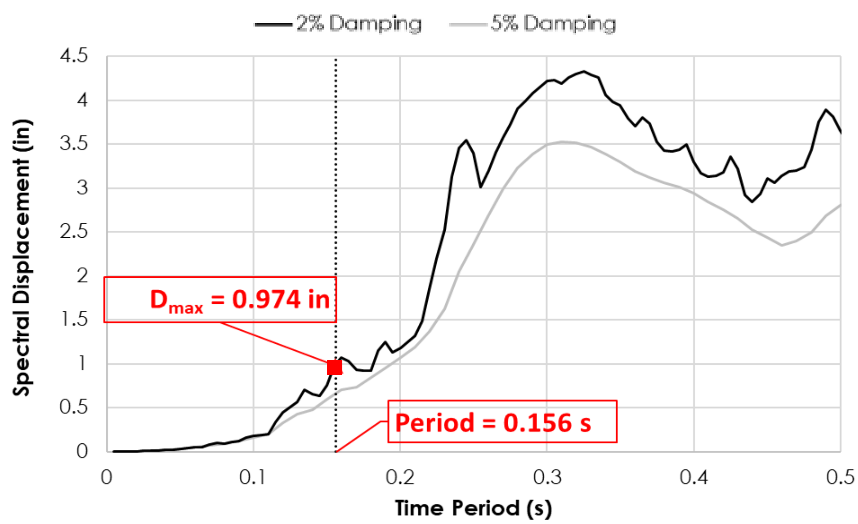

Figure 8.10. Spectral-Displacement (Ground Motion 2)

Students used the following assumptions to implement Newmark's Average Method:

- Experimental period (from resonant frequency) of 0.156 seconds
- Experimental damping value (from free vibration) of 0.02
- First mode analysis – aimed at a quick and brief comparison due to the high mass participation experienced during the first mode. As a note, students felt that including other modes would be unnecessary for the purpose of this competition, but encourage future teams to continue using multiple analysis methods for comparison.

This output shows a maximum acceleration value of 4.2 g, large compared to the 3.39 g (ETABS acceleration time history analysis) and 3.205 g (actual acceleration time history). The analysis team discussed that this output must represent in terms of accuracy. Because the acceleration time history analysis produced consistent results, the plots shown in Figures 8.9 and 8.10 were used as verification for results. In addition, analysis team students noted that the shake table in Seismic Lab does not always produce consistent results, as it may not reach the same acceleration peaks and displacement amplitudes that are guaranteed at the competition. The shake table testing is a great verification of expected values but cannot be taken as the final value. Listed below in Table 8.1 are the final predicted values, with selected values in orange.

Table 8.1. Final Predictions

North-South Shaking			**East-West Shaking**		
GM1	**Acc (g)**	**Disp (in)**	**GM1**	**Acc (g)**	**Disp (in)**
Physical Test	0.551	0.102	Physical Test	0.684	0.159
ETABS	0.770	0.142	ETABS	0.871	0.160
Response Spectrum	0.710	0.168	Response Spectrum	0.710	0.168
GM2	**Acc (g)**	**Disp (in)**	**GM2**	**Acc (g)**	**Disp (in)**
Physical Test	3.205	1.111	Physical Test	3.306	1.512
ETABS	3.390	0.714	ETABS	3.500	0.813
Response Spectrum	4.200	0.974	Response Spectrum	4.200	0.974

9.0 EERI Competition Logistics

Cal Poly's 2022 Earthquake Engineering Research Institute team attended the 2022 Seismic Design Competition in Salt Lake City, Utah from June 27 – June 30, 2022. To attend the competition, several preparation steps were taken to ensure the team arrived on time and safely – while also being prepared for the week ahead.

At the actual competition, students took note of the schedule, competition activities, and recorded advice, questions, and feedback for future reference. Post-competition activities, including 2022 EERI SDC Results, are included in Section 10.0. For the SDC Mailer that was sent to students in advance of the competition week, see supplementary document A10.

9.1. Competition Preparation

In preparation for travel, EERI team leaders initiated fundraising, collected information needed from each student, planned travel logistics, and developed an anticipated schedule for the competition week.

9.1.1. Fundraising

A bulk of the EERI budget comes from the existing Instructionally Related Activities (IRA) fund from the University – with renewal applications for this grant due in March. Additional funds are secured through CAED grants, with applications due in April of each year. This bulk of the budget has historically been supported by the faculty advisor (as it was renewed by 2022 Advisor Anahid Behrouzi). However, gaining funds to help pay for the competition is a crucial part of the process for students and should be discussed well in advance of the trip. Students are responsible for aiding in the fundraising process and should take it upon themselves to reach out to companies, friends, and family for donations. The most successful means of gaining funds is generally by connecting with local structural engineering firms who are looking to advertise their services. Local firms, and firms who EERI students have interned/worked at in the past, are generally happy to support students, especially when given simple recommended fundraising amounts, such as the estimate of sending one student to the competition. After breaking down model costs, competition registration, hotels, food, and transportation for 14 students and one advisor, the estimated travel and competition cost $16,500 in total. In 2022, the estimated cost per student for attendance to the SDC was about $900, about $1800 for one advisor, and a $1,750 team registration fee. See Supplementary Document D2 for more information on fundraising and a sample letter to send to potential donors.

9.1.2. Travel Logistics

For the competition, students were asked to provide several important pieces of information necessary for trip logistics. Because the competition was held a few weeks after school finished, many students would be flying into Salt Lake City from different areas of the Unites States, while some students would be driving the model. Students decided that driving the model would save a significant amount of time and money required for safe and reliable shipping. Table 9.1 outlines the information required from each student attending the competition.

Table 9.1. Required Information from SDC Attendees

Personal Information	Travel Information	Cal-Poly Required Forms
Emergency Contact Info Preferred hotel roommates Preferred snacks Dietary Restrictions	Planned method of travel Flight info or driving schedule Arrival & Departure time	Driver Authorization Form (for drivers only) Travel Preauthorization Form Reimbursement Form (post-competition if applies)

A few weeks before the competition is held, EERI team leaders hold a meeting to ensure that all students are prepared. Some important points to cover in the preparation meeting:

- Room assignments
    - Rooms are fully male or female by university requirements, so choosing an equal amount of male and female students (that can share a four person – two-bed room) to attend the competition is a conscious economic decision.
- Personal Packing Requirements
    - All students attending the competition should be notified of packing requirements, including clothing options to meet formal business wear, business casual, and locally appropriate casual attire.
    - For example, students travelling to Salt Lake City were asked to bring at least one business formal outfit for professional events and ceremonies, one to two business casual outfits for general competition attire, team t-shirt with jeans or khakis for both Day 01 (setup) and Day 03 (Shake Day), and casual clothes appropriate for the warm summer weather in Utah.
- Competition Packing Requirements
    - To alleviate stress at the competition, students come prepared with modelling supplies, backup construction materials, posterboards for the team display, and note-taking items.
    - See Supplementary Document D3 for the full list of tools and materials that were packed in advance of the competition and transported with the model.

Finally, students discussed the general schedule for the competition and discussed suggestions for team meals, dedicated practice times, and mandatory events.

9.1.3. Competition Schedule

A finalized formal schedule was made in advance of travel to help students with final preparations. The schedule includes a full timeline of events at the conference (both required and optional – and marked as such), provided in advance by the EERI Student Leadership Council

(SLC). Each event should be marked with the attire required, and time between events should be allocated to dedicated practice time, team meals, or free time. In Salt Lake City, students chose to place a large group order for pickup for several team lunches, which were planned and booked in advance. Any meals provided by the competition were built into the schedule as anticipated. As a note, the 2022 EERI team did not find the SDC meal schedule to be consistent. When meals were provided, students generally ate at the conference, however – the team was prepared with a backup option should food be lacking.

See Appendix A6 for the full schedule developed in advance of the Salt Lake City trip. As a note, this schedule was modified slightly after the competition to reflect the actual schedule of events that took place.

9.2. The 2022 Seismic Design Competition

The following section outlines the week of the seismic design preparation from student arrival to departure. This schedule is specific to the 2022 SDC and is expected to vary depending on the competition year.

9.2.1. Day 01: Set-Up

On day 1, all teams arrived at the conference center to spend a few hours finishing their structure, placing their posters, or walking around to visit with other teams. At the 2022 competition, Cal Poly's structure was fully finished upon arrival, and students took the extra time to ensure that there were no rule violations. Additionally, this time was a great opportunity to meet with students from other schools, discuss unique designs, and settle into the competition week. In past years, students have spent an hour or two walking the display room with the faculty advisor to discuss other approaches to the competition problem statement. This year, Cal Poly was able to assist a team who needed help finishing their structure. Packed with extra materials and tools, the Cal Poly team provided sanding blocks and extra glue to another team. The welcome ceremony took place around 5:00 pm, followed by a mandatory captain's meeting at 8:00 pm. At this meeting, the team captain, Garrett Barker, represented the team while a council member from the Student Leadership Council (SLC) checks the structure for rule violations. After this meeting, students return to the hotel to practice for presentation day.

9.2.2. Day 02: Presentations

Presenters from each team must go to a presentation slide review meeting at 8:30 am. Then, each team will deliver their presentation at their scheduled time slot. In general, presentations last all day, and students are expected to view a few other presentations than their own. For the 2022 competition, three to four members of Cal Poly's team watched each session. This allows students to take notes on other team's design choices, successes and failures, and questions posed by the judge's panel.

9.2.3. Day 03: Shake Day

The team captain must attend the shake day rules meeting at 8:00 am. After that, each team loads their structure onto the shake table during their respective time slot. This process takes all day – but students are free to come and go. Like presentation day, most Cal Poly students will attend an entire session apart from their own, to cheer on and support other teams. At the end of shake day, the Student Leadership Council puts on a social event for the teams to participate in. Table 9.2 shows Cal Poly's shake test data.

Table 9.2. Competition Shake Test Data - Results

Predictions	Recorded
Peak Roof Acceleration	Peak Roof Acceleration
GM1 = 0.77 g	GM1 = 1.02 g
GM2 = 3.39 g	GM2 = 2.57 g
Peak Roof Displacement	Peak Roof Displacement
GM1 = 0.14 in	GM1 = 0.17 in
GM2 = 0.71 in	GM2 = 2.22 in

These results represent a range of 18% to 68% difference in predictions to recorded. Due to the minor structural failure that occurred on the mid-rise balsa wood model during ground motion 2, students felt that the recorded results were not reflective of the intended structural response of the structure, and therefore could not be used as an argument for or against any specific analysis method or guidance for modification of the ETABS model for subsequent Cal Poly SDC teams.

9.2.4. Day 04: 12NCEE Conference

The last day of the competition is generally when students will attend presentations at the larger 12NCEE conference. Because the conference hosts many professionals across the scope of earthquake engineering, this is a perfect opportunity for students to network and broaden their knowledge of seismic design. Students attend the PERW (Post-Earthquake Reconnaissance Workshop) from 9:00 am – noon. Following the workshop, the Cal Poly SDC team attended presentations by Cal Poly graduate students Claudia Zapata-Kraft and Sarah Navias, in addition to other speakers over a wide variety of topics. Many EERI sponsors and professionals are at the event, so students are encouraged to dress professionally for the afternoon and take a look around the exhibit hall. Finally, the top three teams are announced at the closing and awards ceremony at 5:00 pm.

10.0 EERI SDC Results

At the closing ceremony of the seismic design competition, the top three teams (and special awards) were presented. In the following weeks, the remaining teams are scored and placed into their respective rankings. Listed below are the results from the Student Leadership Council:

1st Place: Technical University of Cluj-Napoca
*2nd Place: Cornell University
3rd Place: Technical University of Civil Engineering Bucharest
5th Place: California Polytechnic State University, San Luis Obispo
*Based on the competition scores, University of British Columbia would have placed second overall in the competition, but their structure collapsed during ground motion 2 on shake day, making them ineligible for top rankings due to the inflated seismic cost of their structure.

Additional Awards:
Charles Richter Award for Spirit of the Competition: University of British Columbia
Egor Popov Award for Structural Innovation: Oregon State University
Best Seismic Performance: Pontificia Universidad Católica Madre y Maestra
Best Communication Skills Award: Technical University of Cluj-Napoca
Best Architecture Award: University of Toronto

10.1. Discussion

Based on the results of the competition, the California Polytechnic San Luis Obispo team was pleased with the team's performance. The competition was a great opportunity to dive deeper into the scope of seismic engineering and allowed students to practice many conceptual ideas in a real-life setting.

Moving forward, the Cal Poly team has the goal of once again ranking in the top three teams. To make this goal possible, the team discussed several steps that may be taken to improve competition results in the future. Listed below are several topics for consideration when preparing for the competition:

- Emphasis on the proposal – which awards extra points to the top nine entries
- Additional testing of construction materials: tension capacity of glued connections, bending stress analysis of critical diaphragm members, and additional tensile testing
- ETABS specifications and design considerations – how to model a short (five foot) rigid structure with a short period, experiencing lateral force
- Repetitive testing with averaged results
- Precedent of test shake table versus competition shake table and how they may vary

Many other teams took the opportunity to excel in non-structural considerations. In particular, the presenter for Technical University of Cluj-Napoca executed a flawless demonstration of competition considerations and structural design, emphasizing the innovative approaches taken in architecture and sustainability – giving them the highest communication score in the competition. Cal Poly’s presentation fell just 11.3 points behind. Several teams chose to explore damping systems or architectural-driven structure, catching the eye of many judges. While architecture was not a specific area of focus for any member of the team this year, this is an area that could be supplemented in the future by an architecture student outside of ARCE. The University of Toronto received a perfect architecture score, while the Cal Poly team received 77.3/100 points. By staying consistent in structural performance, analysis, and structural design, the Cal Poly team felt that the results of the competition reflect the hard work, dedication, and time that was put into the project overall.

11.0 Conclusion

The EERI Seismic Design Competition has been a staple activity in the Architectural Engineering department for many years – allowing students to apply the advanced theories and methods discussed in lectures into a physical project. Seismic engineering influences countless other disciplines, which makes it a prime example of a structural engineer's impact. While the competition is a great example of multi-disciplinary work, it can also shed a light on seismic engineering's impact on local communities, culture, environment, economy, and socio-political sectors.

11.1. Discussion of Impact

In earthquake engineering, the word 'resilient' is used frequently. Designing a structure that is well equipped to handle a major seismic event, and remain functional through the aftermath, helps to cultivate a resilient community.

11.1.2. Community Impact

The most important consideration when pursuing a structural engineering project is life safety, or the safety of the structure's occupants in the event of a seismic hazard. Through code enforcement, all structures must be designed to preserve life safety. However, this simply means that in the event of a major hazard, all occupants can safely leave the structure. It does not imply that the structure itself will remain unharmed. The focus of innovative seismic engineering is to design a structure that remains fully operational after a natural disaster.

In March of 2020, Salt Lake City experienced a M5.7 earthquake – ruptured along the Wasatch fault line. While there were no casualties associated with the disaster, several people experienced injuries and many structures suffered minor damaged in the earthquake. The community was mainly affected through extensive power outages, cancelled flights out of Salt Lake City international airport, and decreased public health response to the Covid-19 pandemic [4].

Designing a structure that is earthquake-resilient provides the local community with a safe space in the event of an emergency. Though the structure in this competition was designed for residential and commercial occupancy, it is meant to be a space that the community feels welcome in. The strength of a community is measured by its ability to function in the face of disaster – and functional, safe, structures are the first step.

11.1.3. Cultural Impact

Salt Lake City, Utah is the home to a wide variety of people – including artists, small business owners, outdoor enthusiasts, and worshippers of the Mormon religion. Since being pioneered and planned by the first Mormon migration, subsequently built into the transcontinental railroad, Salt Lake City has experienced massive cultural and economic growth. To support its growing population, the city's infrastructure grew tremendously as well. Though it is nestled in the intermountain seismic belt (between the Great Basin and Rocky Mountains), much of the city's historic infrastructure is preserved to maintain cultural and architectural significance. When new structures are considered, it is critical to remain conscious of the local historic architecture and culture, as to enhance it rather than diminishing it.

11.1.4. Environmental Impact

The construction industry creates an environmental impact that cannot be overlooked. Each year, the built environment generates 40% of annual CO_2 emissions [5]. From architecture2030, "Of those total emissions, building operations are responsible for 27% annually, while building and infrastructure materials and construction (typically referred to as embodied carbon) are responsible for an additional 13% annually."

Designing a structure that is environmentally-conscious is critical to have a positive impact. Even newer buildings, built to a much higher energy-use standard, are still contributing to the carbon emissions into our atmosphere. An advanced and innovative approach to green energy and resilient structures allows structural engineers to minimize our negative impact on the environment. New structures, aside from implementing renewable energy and sustainable features, should be engineered to remain functional post-hazard. A structure that fails during a seismic event generally must be deconstructed, repaired, or rebuilt – which places a large economic and environmental burden on the local community.

11.1.5. Economic Impact

Designing, engineering, and constructing a new structure has a significant cost. While this money must come from somewhere, the initial cost can, in many ways, justify the economic growth that a new building may bring to a community. In a local sense, engineers, construction managers, and contractors will be hired to carry out the project. Hundreds of people may gain employment due to a large structure being constructed.

Seismic engineering also prepares the structure for natural disaster. Putting in the upfront cost to take damage-preventative measures is generally less expensive than repairing, replacing, or retrofitting a poorly performing structure. The most economical route for infrastructure is generally to take preventative measures to protect old historic buildings (reducing future repair costs) or to construct new buildings to a much higher standard of care.

11.1.6. Socio-Political Impact

There is no measure of the toll that a large seismic hazard can cause on a community. When structures, both personal and public, experience damage in an earthquake, many people are forced to be displaced for their own safety. Especially in urban areas, such as Salt Lake City, the impact of a seismic event can be devastating. In 1994, a M6.7 earthquake struck the Los Angeles area – centered in Northridge. The communities surrounding the area were hit by losses adding up to an estimated 20 billion dollars. The event caused 57 casualties, injuring more than 9,000 people, and displacing 20,000 people from their homes [6]. USGS was quick to respond to the disaster, which provided critical data that would eventually lead to policy change and necessary seismic improvements to the building code.

In the long-term, four NEHRP (National Earthquake Hazards Reduction Program) agencies organized four main objectives:

(1) Apply efforts to assist local, state, and federal jurisdictions with carrying out recovery, reconstruction, and mitigation
(2) Investigation into the earthquake and the series of events before and after
(3) Communicate the lessons learned from this investigation to society
(4) Apply these lessons to southern California and necessary regions of the United States

EERI is dedicated to pushing for policies that create earthquake-resilient communities. It is the responsibility of local politicians, policymakers, and engineers to plan and carry out community-driven strategies for resiliency. When a disaster occurs, communities that are prepared to respond immediately have less negative impact to their economy, environment, culture, and existing infrastructure. In their article “Creating Earthquake-Resilient Communities”, EERI states, “All earthquake-prone communities should develop and implement resilience plans to ensure rapid and robust recovery from earthquakes… Planning efforts of any type should engage a diverse group of community stakeholders, define community risk by linking critical social functions to the built environment, and set appropriate functional recovery goals for the community.” [7].

11.2. Personal Reflection

It was an honor and a privilege to work within a niche of engineering that has so much passion. Not only does this competition cultivate a strong sense of community, but it elevates the level that undergraduate students perform at.

The 2022 SDC was my first year participating in EERI activities, but I knew that I wanted to do something more for the Student Chapter than simply participate. Through my involvement with this organization, I have learned more about earthquake engineering, and critical preventative measures, than I thought possible. Not only did this add to the theoretical portion of my coursework, but it gave me a chance to see these practices in action.

In helping to lead a team of 14 active members, among others who could not join for the competition, I learned how to effectively communicate a long-term goal to my peers, organize and carry out time-sensitive deadlines, and manage several different aspects of one larger goal. From February 2022 through the competition in June 2022, my focus (aside from the already demanding ARCE coursework) was preparation for the competition. While the EERI competition tasks are distributed among multiple teams, it was necessary that I helped organize and carry out tasks relating to each team to complete this report.

Staring with team organization, I helped to delegate required tasks for each team while providing necessary scheduling and deadlines. The materials testing team, generally comprised of underclassmen, can apply their knowledge of mechanics of materials to the competition. In this sense, I helped to schedule their time getting trained on the Tinius-Olsen machine, attending each material testing session to best provide guidance and support, and verified data output values. The design team, generally third- or fourth-year students who have completed at least one material design lab, must have highly technical discussions about load path and load transfer throughout the challenging model configuration. For the design team, it was critical that I heard and participated in these conversations to accurately convey design decisions. The construction team, led by motivated upperclassmen (who generally have less coursework responsibilities in spring quarter) required my help in the organization of construction timeline and with the physical construction of the models. Lastly, the analysis team, led by EERI team captain Garrett Barker, oversaw the highly technical data collection and analysis of the structure, in comparison to the creation and analysis of an ETABS model. Similar to the design team, I felt that recording the testing and analysis processes, helping to organize meetings with alumni and professors, and accurately representing analysis design considerations was the most critical aspect to this report.

Aside from acquiring new knowledge about team leadership and time management, I gained several other new skills as well. By producing this report, I was able to look deeper into the design and analysis portions of the competition, and further clarify design challenges (such as load path discontinuities) and analysis methods (such as time history analysis, free vibration testing, and frequency sweep analysis). As for more technical aspects of the competition, I greatly increased my understanding of ETABS with help from faculty, alumni, and fellow students. Due to the wide range of topics that are covered in this competition, I researched code provisions in ASCE 7-16, read technical papers and web articles about geotechnical soil profile analysis, sustainable material use, and the connection between architecture and structure.

Overall, this competition, coupled with this project, forced me to broaden my scope of seismic engineering, and taught me critical lessons. Keeping up with the various simultaneous tasks and deadlines associated with this competition was a challenge that I am happy I embarked on. The overall process gave me more insight into geotechnical engineering, architecture, structural design, construction, seismic analysis, and structural engineering. I feel that this competition prepared me to become a well-rounded engineer, and a community member who is dedicated to producing structures that are well-prepared to experience a seismic event. As I have graduated and started working locally in central California, I look forward to applying what I have learned to my career.

11.3. Conclusion

The 2022 EERI SDC asked students to design, analyze, and construct a new proposed building to be erected in downtown Salt Lake City, Utah. This structure, displaying unique architectural geometry, is designed to withstand expected seismic activity in the region. This report summarized the entire preparation process for participation in the competition, with an emphasis on the steps that each student-led team took to complete their required tasks. The required competition deliverables included a design proposal, a physical model of the structure, performance predictions, an oral-visual presentation, and a poster to display at the competition.

Once the problem statement was reviewed and understood, students started assessing subsurface geotechnical conditions for the proposed site, followed by a basic structural design. With architectural design in mind, a structural system was then chosen to transfer both vertical and lateral loads throughout the structure. A physical model was then completed by the construction team based on elevation and plan views, drafted by the design team. As the analysis team started creating their ETABS model, the materials testing team sampled balsa woods specimens to better understand the material mechanics. Finally, the physical model was tested and compared to the results of the ETABS model, which was then calibrated to output resulting data that would eventually inform final performance predictions.

Following the conclusion of preliminary competition preparations, students constructed a final competition model, and prepared both poster and presentation deliverables. The 2022 Cal Poly SDC team then travelled to Salt Lake City to attend the competition and present the work that they had completed.

Overall, students who participated in the SDC had the opportunity to apply theoretical concepts, taught in the Cal Poly classroom, to a physical project. This competition combines the requirements of multiple disciplines – allowing students to explore the research, design, and analysis that goes into designing a new structure.

The 2022 Student Chapter is happy to provide advice and guidance to Cal Poly's SDC team. Listed below is the contact information for several alumni in case any assistance is needed.

Garret Barker (Team Captain & Analysis lead): garrettbarker1430@gmail.com
Cameron Grant (Construction lead): cammie.w.grant@gmail.com
Gabrielle Favro (Design & Construction lead): gabriellefavro@gmail.com
Elizabeth Claypool (Design lead): elizclay@stanford.edu
Paulina Robles (ETABS Analysis lead): paulinar248@gmail.com
Alex Poirier (Testing Analysis lead): alexpoirier805@gmail.com
Michelle Dennin (Testing Analysis lead): michelledennin@gmail.com
Kate Robinson (General Team lead): kate.robinson1072@gmail.com

References

[1] Ihtiyar, O., P.E., H. S. C., Sundholm, N., & In. (n.d.). *Mot Tower*. STRUCTURE magazine. Retrieved April 23, 2022, from https://www.structuremag.org/?p=14743

[2] Choi, H. S. I. (n.d.). *Ministry of Taxation Tower in Baku, Azerbaijan: Turning away from prescriptive limitations*. International Journal of High-Rise Buildings. Retrieved May 5, 2022, from http://koreascience.or.kr/article/JAKO202006960486033.page

[3] Pons-Valladares, O., & Nikolic, J. (2020, November 22). *Sustainable Design, construction, refurbishment and restoration of architecture: A Review*. MDPI. Retrieved November 9, 2022, from https://www.mdpi.com/2071-1050/12/22/9741

[4] Wikimedia Foundation. (2022, August 1). *2020 Salt Lake City earthquake*. Wikipedia. Retrieved November 5, 2022, from https://en.wikipedia.org/wiki/2020_Salt_Lake_City_earthquake

[5] *Why the built environment?* Architecture 2030. (n.d.). Retrieved October 6, 2022, from https://architecture2030.org/why-the-building-sector/

[6] Powersp. (n.d.). USGS Response to an Urban Earthquake -- Northridge '94. Retrieved October 6, 2022, from https://pubs.usgs.gov/of/1996/ofr-96-0263/introduc.htm

[7] Mortimer. (n.d.). *Creating earthquake-resilient communities*. EERI.org. Retrieved October 7, 2022, from https://eeri.org/advocacy-and-public-policy/creating-earthquake-resilient-communities

[8] *National earthquake hazards reduction program*. NEHRP. (n.d.). Retrieved November 25, 2022, from https://www.nehrp.gov/

[9] *2022 Seismic Design Competition*. EERI. (n.d.). Retrieved September 6, 2022, from https://slc.eeri.org/2022-sdc/

[10] *Unified hazard tool*. U.S. Geological Survey. (n.d.). Retrieved October 4, 2022, from https://earthquake.usgs.gov/hazards/interactive/

[11] *Ministry of Taxes*. FXCollaborative. (n.d.). Retrieved October 7, 2022, from https://www.fxcollaborative.com/projects/144/ministry-of-taxes/

[12] *Utah faults*. Utah Geological Survey. (2021, January 26). Retrieved October 10, 2022, from https://geology.utah.gov/hazards/earthquakes/utah-faults/

[13] J. D. Bray and R. B. Sancio, "Assessment of the Liquefaction Susceptibility of Fine-Grained Soils," Journal of Geotechnical and Geoenvironmental Engineering, vol. 132, no. 9, pp. 1165–1177, Sep. 2006, doi: 10.1061/(asce)1090-0241(2006)132:9(1165).

[14] N. Nilay, P. Chakrabortty, and R. Popescu, “Liquefaction Hazard Mapping Using Various Types of Field Test Data,” Indian Geotechnical Journal, pp. 2–3, Sep. 2021, doi: 10.1007/s40098-021-00570-3.

[15] American Society Of Civil Engineers and Structural Engineering Institute, Minimum Design Loads and Associated Criteria for Buildings and Other Structures: ASCE/SEI 7-16. Reston, Virginia American Society of Civil Engineers, 2017.

[16] Working Group on Utah Earthquake Probabilities, Earthquake Probabilities for the Wasatch Front Region in Utah, Idaho, and Wyoming, vol. 16–3. Salt Lake City, Utah: Utah Geological Survey Miscellaneous Publication, 2016, p. 137.

[17] M. D. Hylland, C. B. DuRoss, and G. N. McDonald, “Evaluating the Seismic Relation between the West Valley Fault Zone and Salt Lake City Segment of the Wasatch Fault Zone,” Utah Geological Survey, May 2012. https://geology.utah.gov/map-pub/survey-notes/evaluating-the-seismic-relation-between-the-west-valley-fault-zone-and-salt-lake-city-segment-of-the-wasatch-fault-zone/ (accessed Jan. 12, 2022).