EERI STUDENT DESIGN COMPETITION TOWER
Project ID: CEEn_CPST_012

by

BYU Earthquake Engineering Design Team
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A Capstone Project Report

Submitted to

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BYU EERI Student Chapter

Department of Civil and Construction Engineering
Brigham Young University

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Executive Summary

PROJECT TITLE: EERI STUDENT DESIGN COMPETITION TOWER
PROJECT ID: CEEn_CPST_012
PROJECT SPONSOR: BYU EERI Student Chapter
TEAM NAME: BYU Earthquake Engineering Design Team

As described in the official rule statement for the EERI Undergraduate Student Design Competition, teams are to deliver the design for a structure that fulfills unique criteria including successful performance in an earthquake such as those experienced in the Seattle, Washington region. Design criteria included a tower with a narrow base about 2/3 the total width that then expands periodically up the height of the tower. The eccentric loading pattern of this structure presents various challenges such as torsion and imbalances load paths. We designed a truss tube type structure to meet these demands adequately.

Competition requirements have specified that the competing team submit a proposal detailing the identified approach to the structural solution as well as related details for planning purposes. The proposal was submitted in December and received a score of 90%.

Teams are expected to construct a model version of the tower design using balsa wood as described in the official design guide document. The model tower is required to adhere to established standards and then tested in a simulated seismic event for both a design level earthquake and a maximum considered earthquake for the site. One of the construction requirements is for the tower to weigh less than 5 pounds. Our tower weighed 4.995 pounds. Excluding the base plate and roof plate, our tower weighed 1.39 pounds.

Additionally, teams must prepare a PowerPoint presentation describing how we chose ground motions to assist in our design, addressed geotechnical considerations, described our structural system and the corresponding architectural response, as well as how we analyzed our tower. This presentation received a score of 83%. A poster is also required to summarize the towers design. This received a score of 64%.

Ultimately, our tower had a building period of 0.27 seconds, and 0.5 seconds in the East-West direction and North-South direction, respectively. This lead us to predict the tower would experience 0.5 inches of peak roof drift and 1.2 g’s of peak roof acceleration in the North-South direction and 0.25 inches of peak roof drift and 1.3 g’s of peak roof acceleration in the East-West direction. The tower shook in the East-West direction at the competition. The peak roof acceleration was 1.96 g’s and the peak roof drift was 0.66 inches for the design level earthquake. The peak roof acceleration was 3.11 g’s and the peak roof drift was 1.23 inches for the maximum considered earthquake. We had 95% error in our predictions, but we avoided a catastrophic collapse.

All of this resulted in a final annual building income of $111,280.

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Introduction

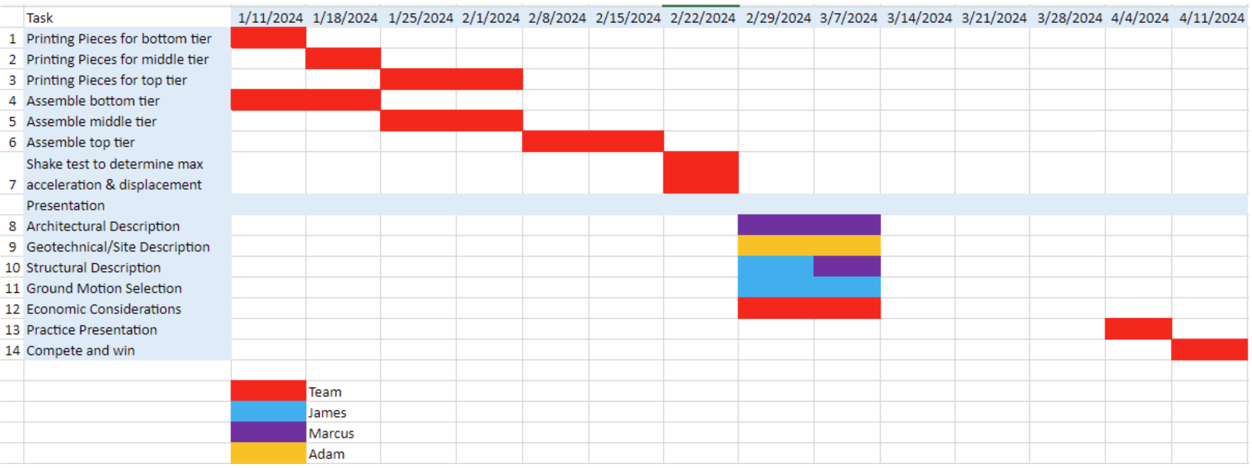
The objective of the EERI sponsored student design competition is to provide students with practice and increase confidence in applied seismic and structural design. The BYU student chapter developed a structural model that demonstrates design principles coherent with seismic research and design. Our objective was to obtain performance estimates through seismic analysis and structural calculations and then to produce a tower whose performance coincides with the identified estimations.

Preparations for the project began with examining the design guide and official rules as posted by the EERI student council. Design constraints and requirements were identified, and possible structural iterations were developed. Team members drafted a project proposal indicating proposed structure design and preliminary estimates for seismic performance. This required attention to structure frame design including vertical and lateral bearing components, architectural planning and layout of spaces, floors, and exterior, preliminary analysis of soil conditions at site, and seismic estimates for potential activity. After the proposal was completed, one design iteration was selected for construction and the tasks outlined previously were further pursued until a final design was created and final performance estimations are calculated. Results were then combined into the following products before travel for competition: scale model tower of structure made of balsa wood, presentable poster, and presentation. At the competition from April 8th to April 12th, products and performance were rigorously evaluated and a team score was produced.

Schedule

The following schedule shown in Figure 1 was created to ensure the tower was constructed in a timely manner to compete in Seattle. We were able to stick to this schedule decently well. A lot of focus was placed on construction in the early months and the three weeks of buffer time in March was used to make a second tower. Our first tower was a prototype tower which was tested on a shake table in the soil's lab. The purpose of these tests was to determine the buildings fundamental natural period in both the North-South and East-West directions to help us determine the performance of the building in the mock seismic events it would endure in Seattle's competition.

Many of the final calculations were left to the end. This was because we couldn't finalize any predictions or calculations until the building period was known. The purpose of building the second tower was not to change our design in any way, but to have a fresh building that was void of cracks or flaws that resulted from the shake tests run on the prototype tower. The prototype tower took about 5 weeks to construct and with the experience and foresight from building one tower, we were able to construct the second tower in 2 weeks of working time. This was a significant improvement.



	Task	1/11/2024	1/18/2024	1/25/2024	2/1/2024	2/8/2024	2/15/2024	2/22/2024	2/29/2024	3/7/2024	3/14/2024	3/21/2024	3/28/2024	4/4/2024	4/11/2024
1	Printing Pieces for bottom tier	🟥													
2	Printing Pieces for middle tier		🟥												
3	Printing Pieces for top tier			🟥	🟥										
4	Assemble bottom tier	🟥	🟥												
5	Assemble middle tier			🟥	🟥										
6	Assemble top tier					🟥	🟥								
7	Shake test to determine max acceleration & displacement							🟥							
	Presentation														
8	Architectural Description								🟪	🟪					
9	Geotechnical/Site Description								🟨	🟨					
10	Structural Description								🟦	🟪					
11	Ground Motion Selection								🟦	🟦					
12	Economic Considerations								🟥	🟥					
13	Practice Presentation													🟥	
14	Compete and win														🟥

🟥 Team
🟦 James
🟪 Marcus
🟨 Adam

Figure 1: Schedule

Assumptions & Limitations

General Assumptions

We assumed that the presentation would be based on an actual building. This includes using practical building materials, such as concrete and steel, for our proposed solution. The model tower is used to demonstrate the feasibility of the structural system we designed which is made entirely of balsa wood.

Assumptions for Analytic Analysis

Classical damping, lumped masses, and uniform story stiffness were all assumed in our analytic model. We did a multiple degree of freedom (MDOF) modal analysis to determine the behavior of the tower analytically. Classical damping is a relevant assumption because we didn’t include any damping devices, and all of the floors had almost the same exact stiffness. This would suggest that the damping would remain constant in the building, which is the definition of classical damping. Lumped masses seemed much more appropriate than consistent masses because the masses used at the competition are all concentrated at one point on the floors specified. Uniform story stiffness seemed more accurate than any other assumption because our lateral force resisting system remained consistent moving up the tower. Our columns and shear walls were all the same size so the stiffness would not change.

The modulus of elasticity is a major part of calculating the stiffness and this turned out to be a major challenge. Balsa wood is not a normal construction material so there is not standard information to be used in design. We did our own material tests to determine the axial tension and compression strengths to calculate the modulus of elasticity using the elongation of the specimen. These tests are shown in Figure 2. The data from these tests are shown in Figure 3. The calculated modulus of elasticity from these tests can only be used in the axial direction: in tension and compression, not in shear. This is due to the anisotropic nature of wood. The stiffness of the shear walls would require the use of the shear modulus of elasticity. This value was back calculated using the building period we found from the experimental tests from our prototype tower.

Figure 2: Tensile and Compression Test to Determine Modulus of Elasticity

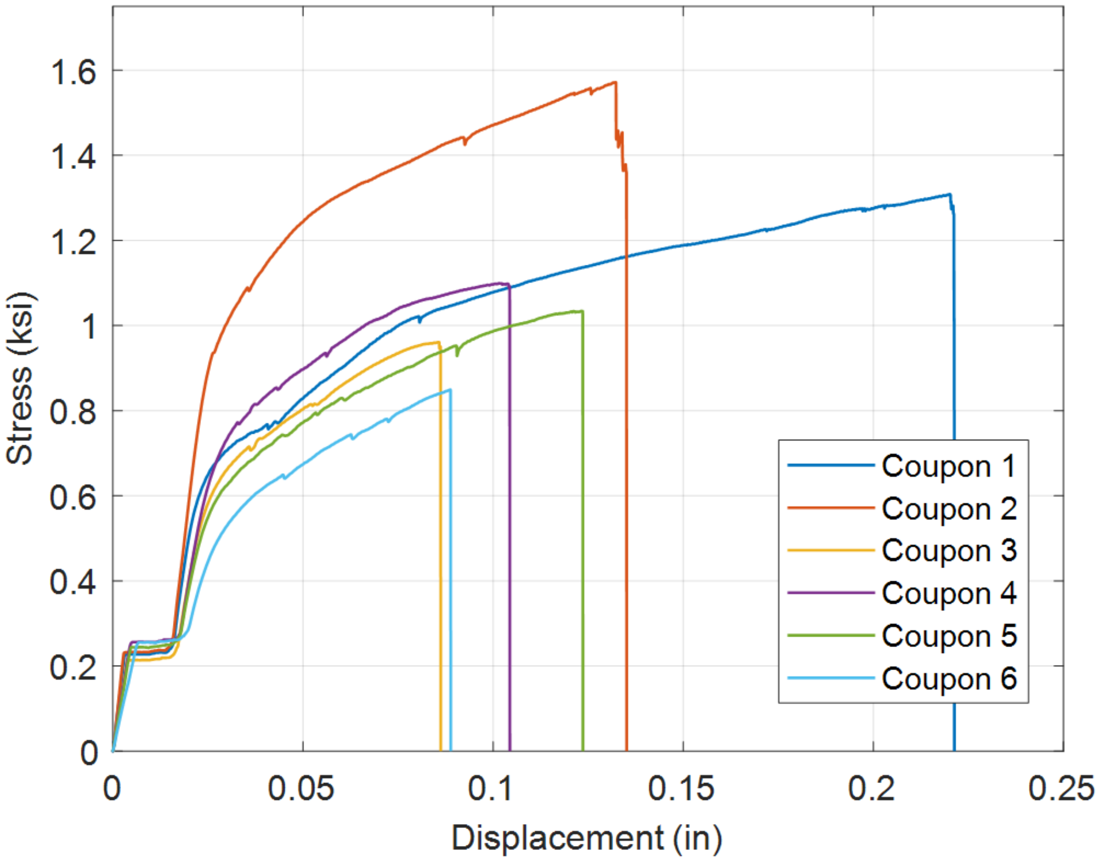


Figure 3: Tensile Test Data (Used to find the axial modulus of elasticity)

Design, Analysis & Results

Ground Motion Selection

Our site in Seattle resides in an active seismic zone. Figure 4 shows these fault lines. There are both strike slip faults in the East-West direction and subduction faults from the Cascade subduction zone in the North-South Direction. Additionally, multiple earthquakes in recent history including a 6.7 magnitude earthquake in 1965, with its epicenter in the Puget Sound, set a high precedence for including these considerations in our design.

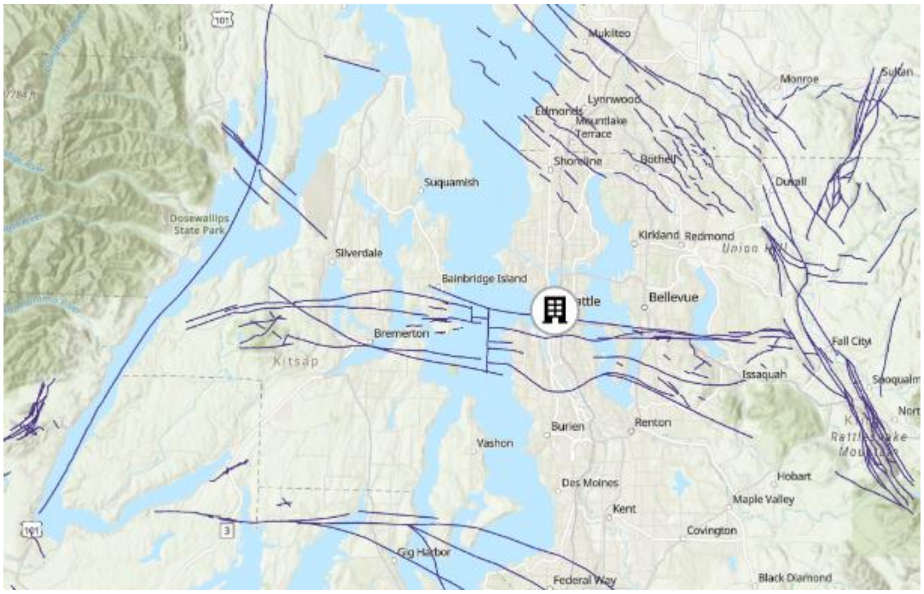
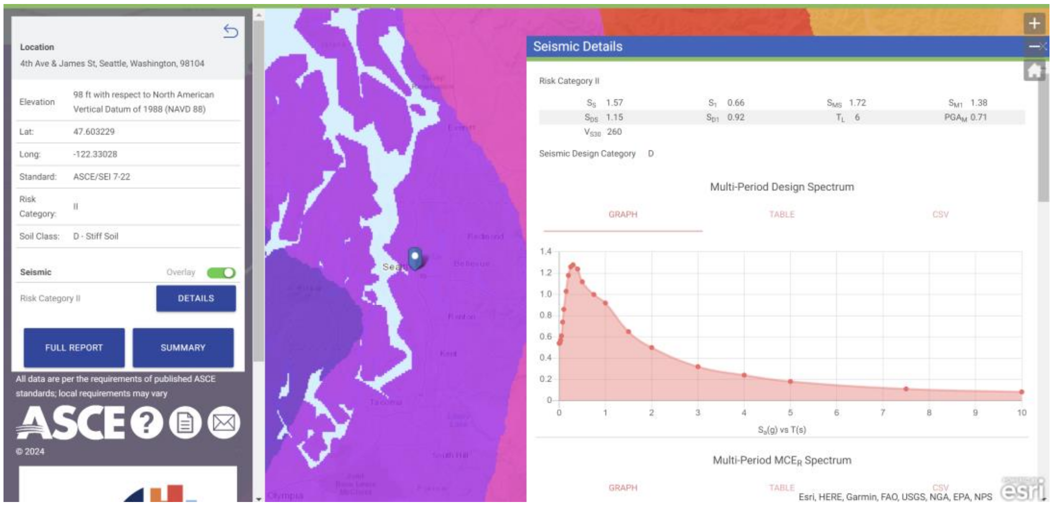


Figure 4: Fault Lines around our building site

We began by using the ASCE 7 Hazard tool to find the seismic criteria for our site, shown in Figure 5.



Location
4th Ave & James St, Seattle, Washington, 98104

Elevation	98 ft with respect to North American Vertical Datum of 1988 (NAVD 88)
Lat:	47.603229
Long:	-122.33028
Standard:	ASCE/SEI 7-22
Risk Category:	II
Soil Class:	D - Stiff Soil

Risk Category II

All data are per the requirements of published ASCE standards; local requirements may vary

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Risk Category II

S_S 1.57	S_1 0.66	S_{MS} 1.72	S_{M1} 1.38
S_{DS} 1.15	S_{D1} 0.92	T_L 6	PGA_M 0.71
V_{S30} 260			

Seismic Design Category D

Figure 5: Seismic Criteria

With this information we used the USGS Disaggregation tool to find the probable earthquake magnitude that would hit this site, and the distance from epicenter. Figure 6 shows these results. These details were used to find a set of ground motions using two different databases: the PEER NGA-West2 database, and the NHR3 NGA-Subduction Web Portal. The former was used for finding strike slip ground motions, and the latter was used for finding subduction ground motions. We did visual spectral matching to find 12 ground motions that reasonably matched our target response spectrum. Figure 7 shows these results lined up against one another. The blue lines are from the subduction ground motions, green lines are from the strike slip ground motions, and the red line is our target response spectrum. The specific ground motion records we used are listed in Table 1.

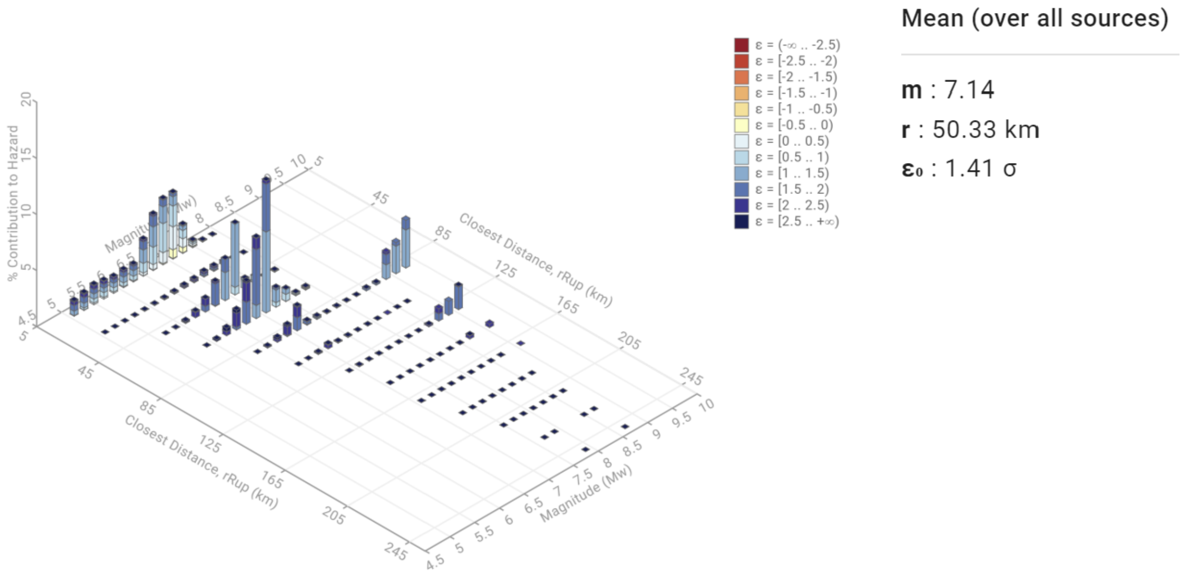


Figure 6: Results from USGS Disaggregation Tool

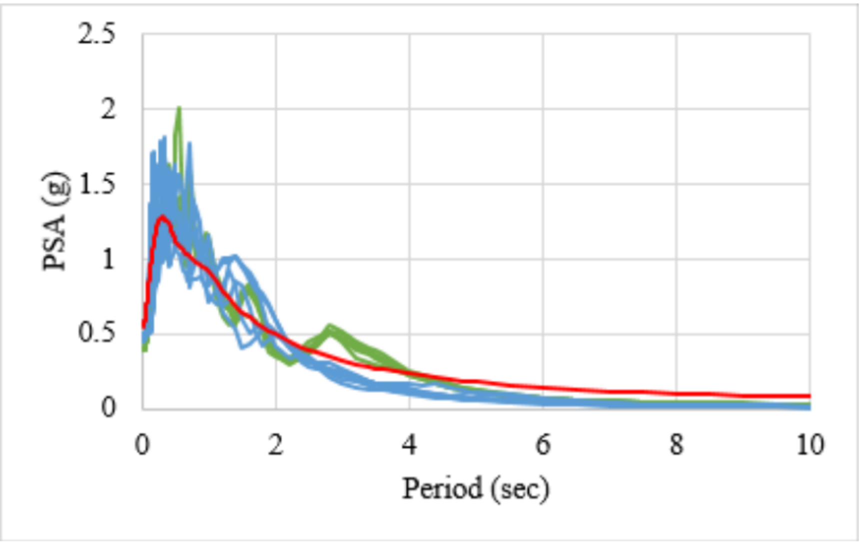
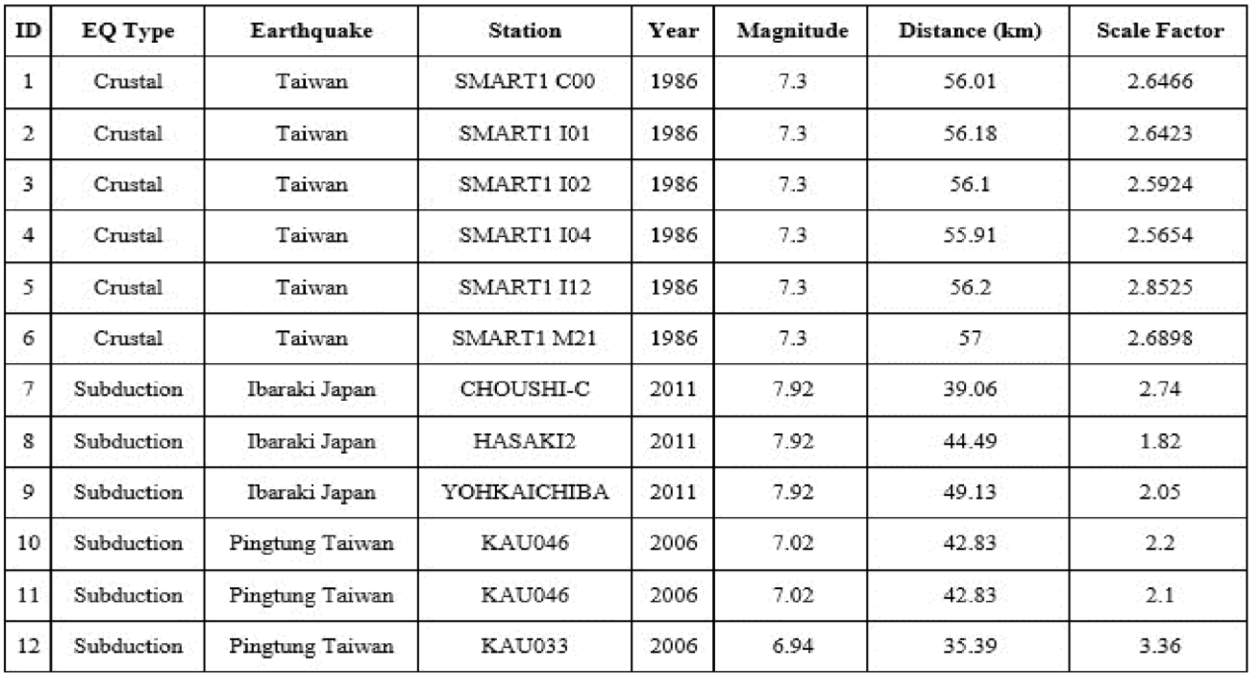


Figure 7: Response Spectrums

Table 1: Ground Motion Records



ID	EQ Type	Earthquake	Station	Year	Magnitude	Distance (km)	Scale Factor
1	Crustal	Taiwan	SMART1 C00	1986	7.3	56.01	2.6466
2	Crustal	Taiwan	SMART1 I01	1986	7.3	56.18	2.6423
3	Crustal	Taiwan	SMART1 I02	1986	7.3	56.1	2.5924
4	Crustal	Taiwan	SMART1 I04	1986	7.3	55.91	2.5654
5	Crustal	Taiwan	SMART1 I12	1986	7.3	56.2	2.8525
6	Crustal	Taiwan	SMART1 M21	1986	7.3	57	2.6898
7	Subduction	Ibaraki Japan	CHOUSHI-C	2011	7.92	39.06	2.74
8	Subduction	Ibaraki Japan	HASAKI2	2011	7.92	44.49	1.82
9	Subduction	Ibaraki Japan	YOHKAICHIBA	2011	7.92	49.13	2.05
10	Subduction	Pingtung Taiwan	KAU046	2006	7.02	42.83	2.2
11	Subduction	Pingtung Taiwan	KAU046	2006	7.02	42.83	2.1
12	Subduction	Pingtung Taiwan	KAU033	2006	6.94	35.39	3.36

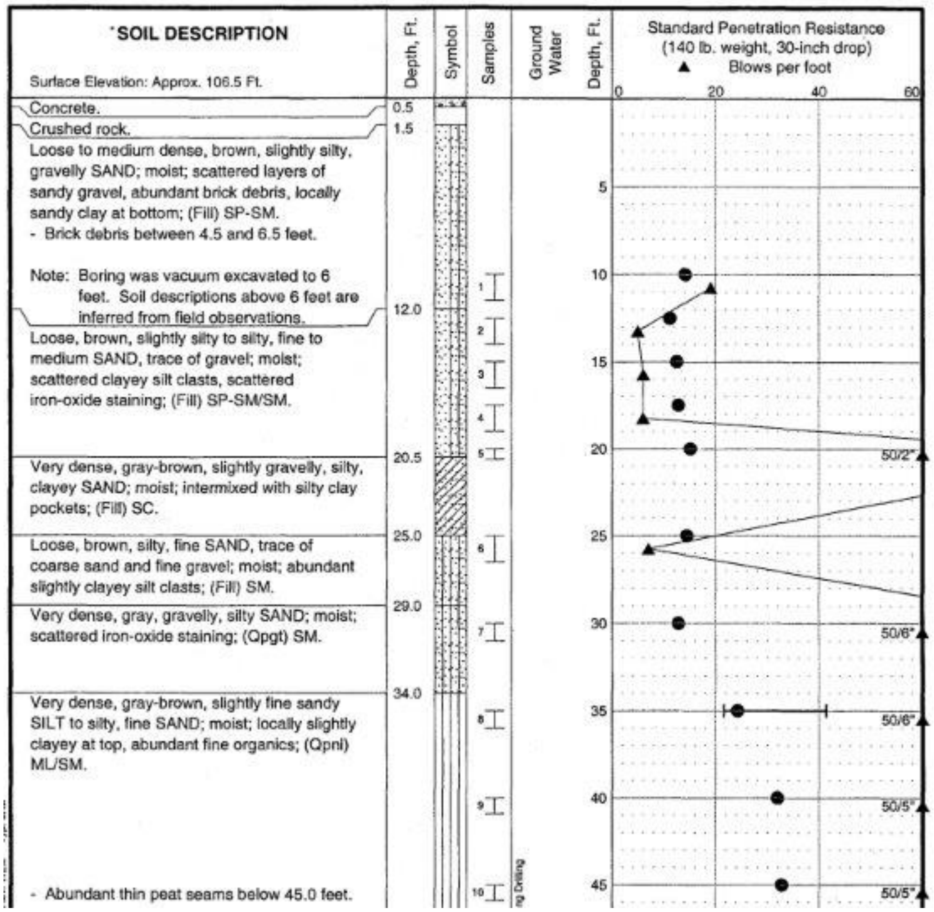
Geotechnical Considerations

Offering a possible foundation design was critical to the overall design of our building. Most of Seattle, including the site of our building, rests on glacial till. A massive glacier covered the northwest corner of Washington during the last ice age, carving out the Puget Sound, nearby Lake Washington, and depositing glacial till. Glacial till is the result of a glacier depositing the remains of all the soil that was picked up as it moved slowly south across the continent. Therefore, the soil profile is full of a random mix of soils, some of which can behave extremely unpredictably. While some soils, such as the clays, were overconsolidated by the weight of the glacier, weaker soils, such as organics and peat, did not overconsolidate due to not having enough cohesive strength.

The use of a deep foundation will be required to meet the demands placed on this foundation. We began by analyzing the soil profile of the site shown in Figure 8. This boring log was given to us by the client. Some important things to note include the construction debris in the top 12 feet of soil. This prohibits the use of driven pile foundations. Driven piles are unreliable when large obstructions are present in the soil. It can cause the piles to deviate in direction as they go in the ground creating unsafe conditions for neighboring buildings and subway lines or cause damage to the piles themselves. We needed a design that was sure to go exactly where we needed.

The client’s site gave us no concern of liquefaction. The loose sands in the top 30 feet of the soil, the abundant fine organics and abundant peat seams below 30 feet, and the sand at 35 feet showing signs of behaving plastically led us to give that a site classification of F. We used the table shown in Figure 9 to make this conclusion. This led us to choosing a drilled shaft deep foundation for our building (See Figure 10).

Additionally, we chose to anchor our shafts to bedrock if feasible. Furthermore, drilled shafts are the only deep foundation type that would allow anchors to bedrock. In Seattle, the depth of bedrock is highly variable, ranging from under 100 feet to over 1000 feet below the ground surface. So, we recommended an additional geotechnical investigation regarding bedrock depth. If we could reasonably attach our drilled shaft to bedrock, the design would provide us with the necessary strength capacity to survive a seismic event. The drilled shaft would have a high end-bearing strength since it is anchored to bedrock, balancing out the low side-friction strength, which results mostly from the loose soil, fine organics, and the peat seams. Thus, the design would allow for a sturdy foundation, even when faced with a dangerous earthquake.

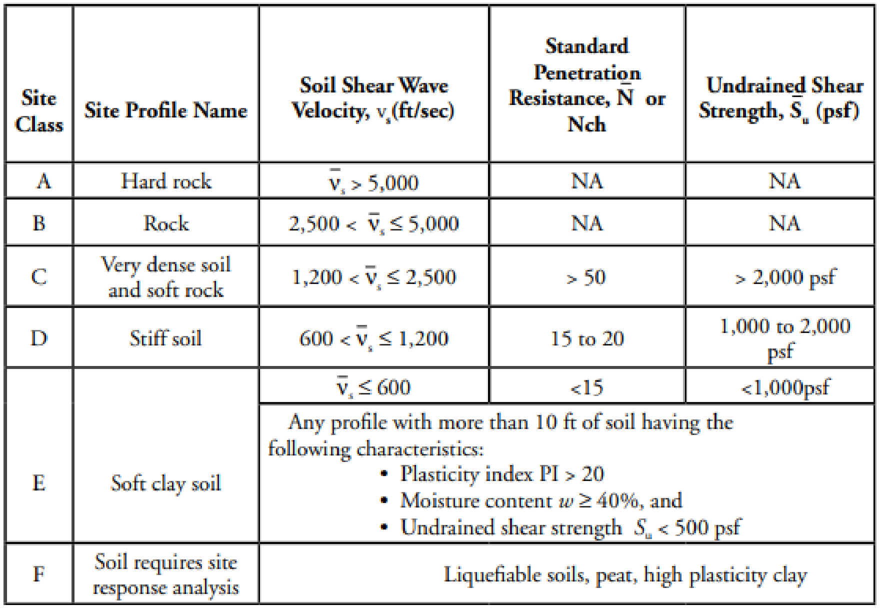


SOIL DESCRIPTION

Surface Elevation: Approx. 106.5 Ft.

Soil Description	Depth, Ft.
Concrete.	0.5
Crushed rock.	1.5
Loose to medium dense, brown, slightly silty, gravelly SAND; moist; scattered layers of sandy gravel, abundant brick debris, locally sandy clay at bottom; (Fill) SP-SM. - Brick debris between 4.5 and 6.5 feet. Note: Boring was vacuum excavated to 6 feet. Soil descriptions above 6 feet are inferred from field observations.	12.0
Loose, brown, slightly silty to silty, fine to medium SAND, trace of gravel; moist; scattered clayey silt clasts, scattered iron-oxide staining; (Fill) SP-SM/SM.	20.5
Very dense, gray-brown, slightly gravelly, silty, clayey SAND; moist; intermixed with silty clay pockets; (Fill) SC.	25.0
Loose, brown, silty, fine SAND, trace of coarse sand and fine gravel; moist; abundant slightly clayey silt clasts; (Fill) SM.	29.0
Very dense, gray, gravelly, silty SAND; moist; scattered iron-oxide staining; (Qpgt) SM.	34.0
Very dense, gray-brown, slightly fine sandy SILT to silty, fine SAND; moist; locally slightly clayey at top, abundant fine organics; (Qpnl) ML/SM. - Abundant thin peat seams below 45.0 feet.	

Figure 8: Boring Log of Neighboring Site



Site Class	Site Profile Name	Soil Shear Wave Velocity, v_s(ft/sec)	Standard Penetration Resistance, $\bar{N}$ or Nch	Undrained Shear Strength, $\bar{S}_u$ (psf)
A	Hard rock	$\bar{v}_s > 5{,}000$	NA	NA
B	Rock	$2{,}500 < \bar{v}_s \leq 5{,}000$	NA	NA
C	Very dense soil and soft rock	$1{,}200 < \bar{v}_s \leq 2{,}500$	> 50	> 2,000 psf
D	Stiff soil	$600 < \bar{v}_s \leq 1{,}200$	15 to 20	1,000 to 2,000 psf
E	Soft clay soil	$\bar{v}_s \leq 600$	<15	<1,000psf
		Any profile with more than 10 ft of soil having the following characteristics: • Plasticity index PI > 20 • Moisture content $w \geq 40\%$, and • Undrained shear strength $S_u < 500$ psf		
F	Soil requires site response analysis	Liquefiable soils, peat, high plasticity clay		

Figure 9: Site Classification Table

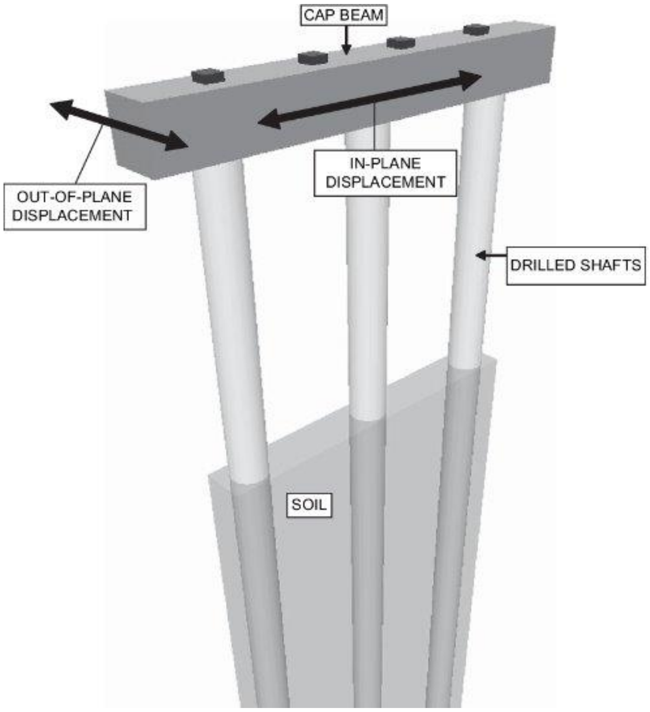


Figure 10: Drilled Shaft Foundation

Structural System

The lateral force-resisting system (LFRS) is comprised of shear walls at each corner connected by cross bracing on the exterior. (See Figure 11) Designing the LFRS at the furthest extents of the area maximizes the area moment of inertia and global stiffness. This design provided greater strength using less material than previous designs where were aimed to use a shear wall core to support the building. (See Figure 12)

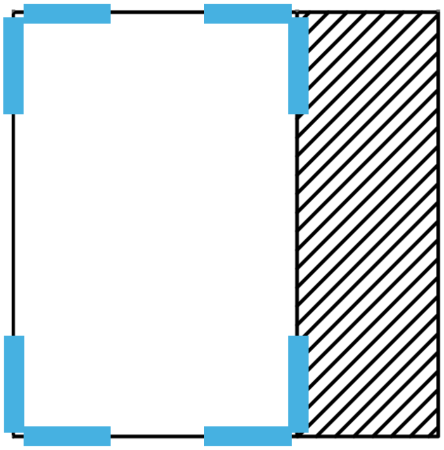


Figure 11: Design with LFRS on the outside

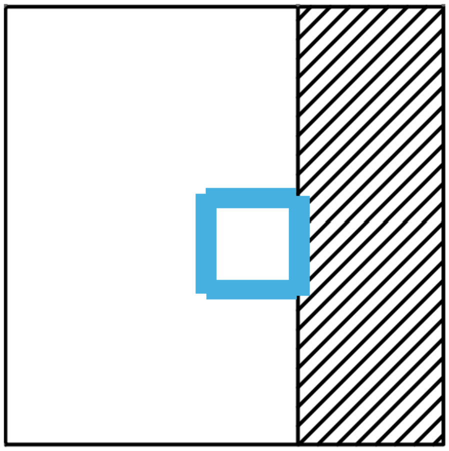


Figure 12: Preliminary Design of Shear Wall Core

We call this design a truss tube type structure. The shear walls and braces are shown on the building in Figure 13. Inherent torsion was a major concern in our design because the center of mass is offset from the centroid. The effect of torsion in our building would result in twisting during a seismic event which is extremely undesirable, as it can lead to more damage. The solution to this problem lies in our ability to adjust our center of stiffness to match the center of mass. By summing the moments, we found that the East side of the building would experience three times the force of the West side. These calculations are shown in Appendix B.1. Our conclusion from these calculations was to make the East shear walls stiffer by adjusting the brace sizes. We used RISA 3D to iterate through different brace sizes and configurations until we found a set up that matched the drift on each side. These results are shown in Figure 14 and Figure 15.

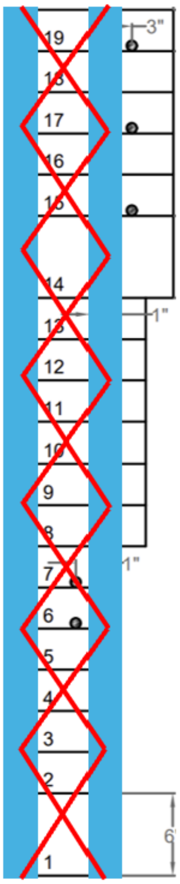


Figure 13: Truss Tube Type Structure

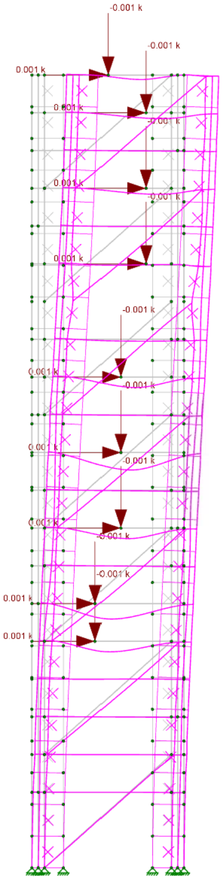


Figure 14: RISA 3D Analysis, West Wall

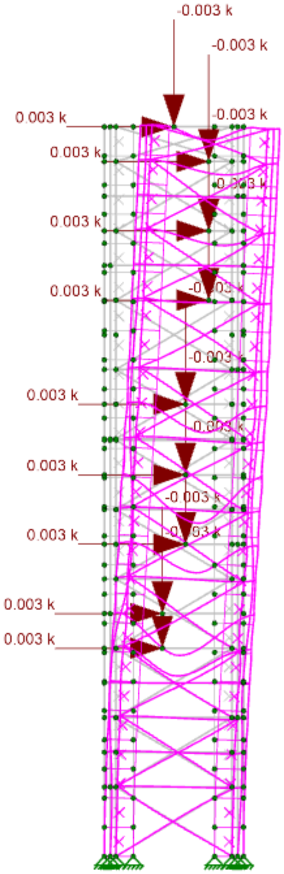


Figure 15: RISA 3D Analysis, East Wall

Architectural Response

Our approach to architectural design was dictated strongly by the requirements laid out by the client in their design program. Figure 16 shows the final rendering of our structure. The facade and solar shading elements were selected to comply with high performance design criteria as specified by the client and discussed further in the related issues section of this report.

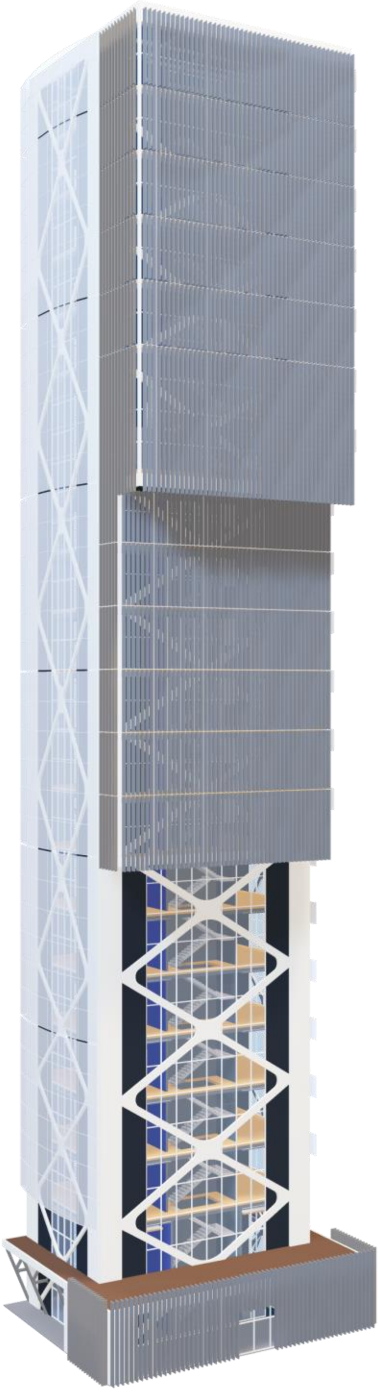


Figure 16: Architectural Rendering

The building's unique form with two zones of cantilevered floor areas was a required criterion which the structure was fitted to. The structure is pushed to the widest extents of the first zone area space to accomplish our structural design approach of stiffening the tower with the greatest moment area of inertia. The structural elements then continue upward through the expanded floor zones, partially interrupting the adjoining cantilevered spaces. This was accommodated in the design to still maintain comfortable accessibility between the primary floor area and the adjoining cantilevered floor area. The circulation corridor was placed at the east side of the first zone area to accommodate accessibility across the widening floor area as the tower rises. The circulation corridor features a code-compliant staircase and two ADA-compliant elevators accessible to each floor. Additionally, all stories are ADA-compliant allowing wide enough gaps between spaces to not restrict any occupant's accessibility. See Figures 17, 18 and 19 for typical floor plans of each zone.

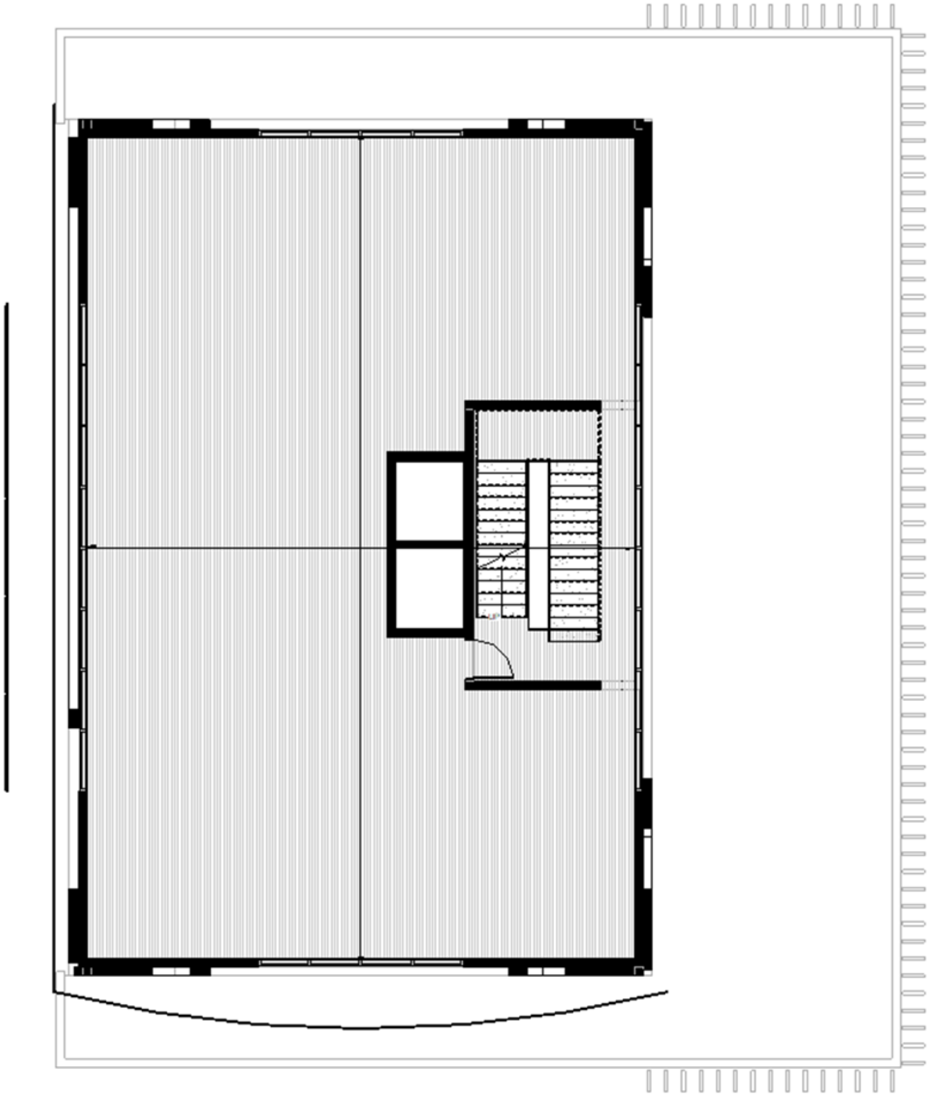


Figure 17: Architectural Floor Plan Zone 1

Figure 18: Architectural Floor Plan Zone 2

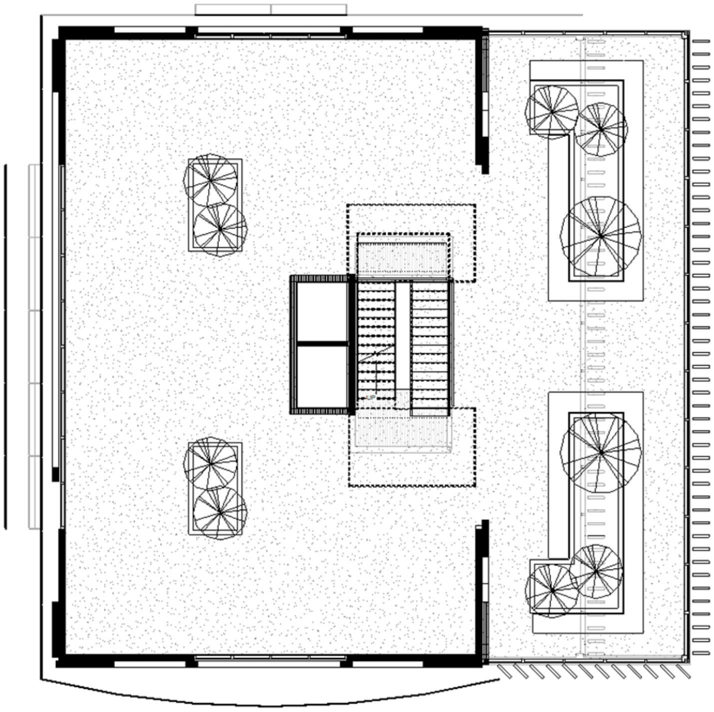


Figure 19: Architectural Floor Plan Zone 3

Analysis

In order to prove the validity of our design, we analyzed our structure both experimentally and analytically.

Analytic Analysis

We did a MDOF modal analysis to find our building period analytically. The assumptions for this analysis were explained previously. We used MATLAB to do all these calculations. The live script including our mass matrix, and stiffness matrix are shown in Appendix C. The ground motion used in this analysis was the first ground motion that would be used in the competition. There would be two ground motions used at competition, but only the first ground motion was released before the competition. The results are shown for both the North-South and East-West directions. From our MDOF modal analysis, we found that our fundamental building periods would be 0.48s and 0.29s in the North-South direction and the East-West direction, respectively.

Experimental Analysis

With the prototype tower that we built, we were able to conduct shake tests to find the fundamental building period and other tests that would offer us insight into how our building would perform against the seismic events it would endure at competition. The shake table at competition was supposedly capable of delivering a 2.5g acceleration while our shake table at BYU was only capable of delivering a 1g acceleration. These differences were taken into account during our analysis. Figure 20 and Figure 21 show the towers on the shake table in East-West direction and North-South direction, respectively.

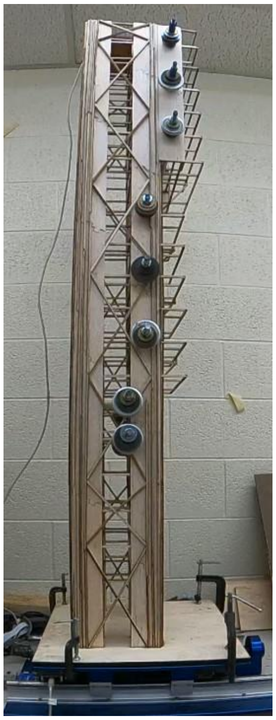


Figure 20: Shake Test in EW Direction

Figure 21: Shake Test in NS Direction

The masses on the structure were measured to the specified weight that would be used in competition: 2.76 lbs on the top floor and 2.36 lbs on the other floors. Using a sine sweep, we found when our building resonated, and used this frequency to calculate the fundamental building period. In the East-West direction our building period was 0.27s. And in the North-South direction our building period was 0.5s. This was a satisfactory comparison to our analytic results. Figure 22 shows where these periods fall on our response spectrum for a design level earthquake. Our predictions were based on the design level earthquake, but our building was built to withstand a maximum considered earthquake for this site.

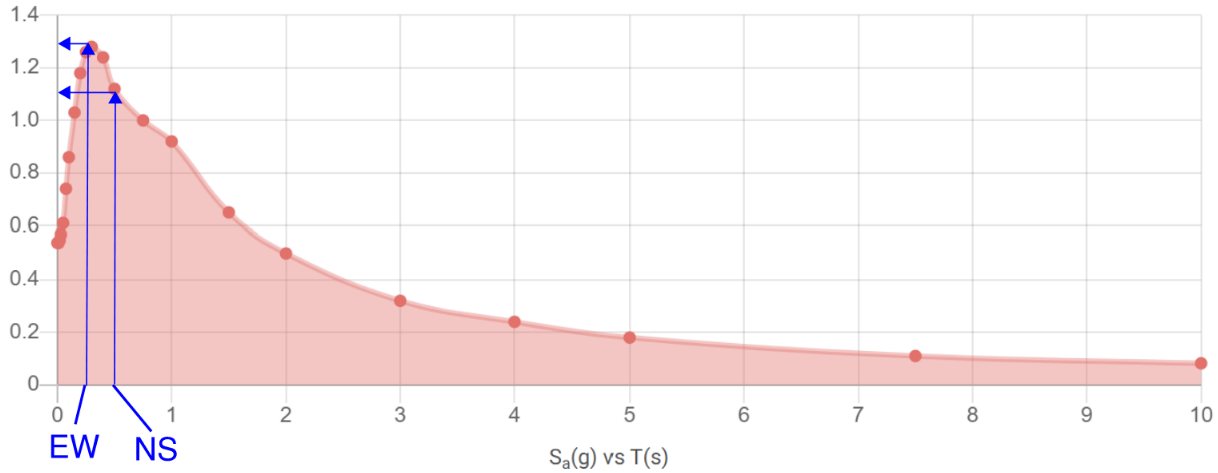


Figure 22: Building Periods on the Response Spectrum

Predictions

A result of making our building so stiff is having higher seismic demands, as shown in Figure 22, the spectral accelerations are about as high as they can get in both directions. We had to compensate for this by ensuring that our tower was strong enough to withstand these high forces. By comparing the MDOF drift results and comparing them with the results from our shake tests, we made the following predictions shown in Table 2. These predictions are only for a design level earthquake.

Table 2: Design Level Earthquake Performance Predictions

	East-West	**North-South**
Peak Roof Acceleration	1.3 g	1.2 g
Peak Roof Drift	0.25 in	0.5 in

Based on our floor space and revenue we would generate from renting those spaces, we predicted an annual revenue of $741,234.

Competition Performance

In the competition, they only shake the tower in one direction. This is determined by a coin flip. The chosen shake direction was the East-West direction. Table 3 shows the results of our towers' performance when subject to a design level earthquake and a maximum considered earthquake (MCE).

Table 3: Competition Performance Results

	Design Earthquake	**MCE**
Peak Roof Acceleration	1.96 g	3.11 g
Peak Roof Drift	0.66 in	1.23 in

Our final profit calculations are shown in Table 4.

Table 4: Economic Value of Tower

Final Annual Building Cost	$235,921
Final Annual Revenue	$610,225
Final Annual Seismic Cost	$263,025
Final Annual Building Income	$111,280

Related Issues

One of the prominent related issues to the structure design that extended more broadly to building planning and design were the architectural considerations for high performance design. As part of the client program, they specified requirements for water and energy high performance design that would qualify the structure for consideration in the Seattle 2030 district. The Seattle 2030 district is comprised of a collection of high-rise structures in the Seattle downtown area meeting an array of environmental impact criteria such. The identified high-performance criteria that the client specified for the pioneer square tower included a 50% reduction in both water and energy consumption in the building as well as mitigation of environmental impacts during building construction and operation.

Our approach to the high performance demands of the client is addressed in the building facade design. Solar exposure on the building is the highest thermal load contributor when considering the energy costs of the internal environment control. Thermal loads on the building from solar exposure can be largely mitigated through site specific solar shading elements integrated into the building's construction. We conducted a site study of the solar exposure patterns using Sketchup’s Pre-design platform to determine the best approach to shading on each façade, as shown in Figure 23. Taking the best advantage of the natural light available at the site can significantly reduce the energy demands for the buildings from illumination and internal environment control.

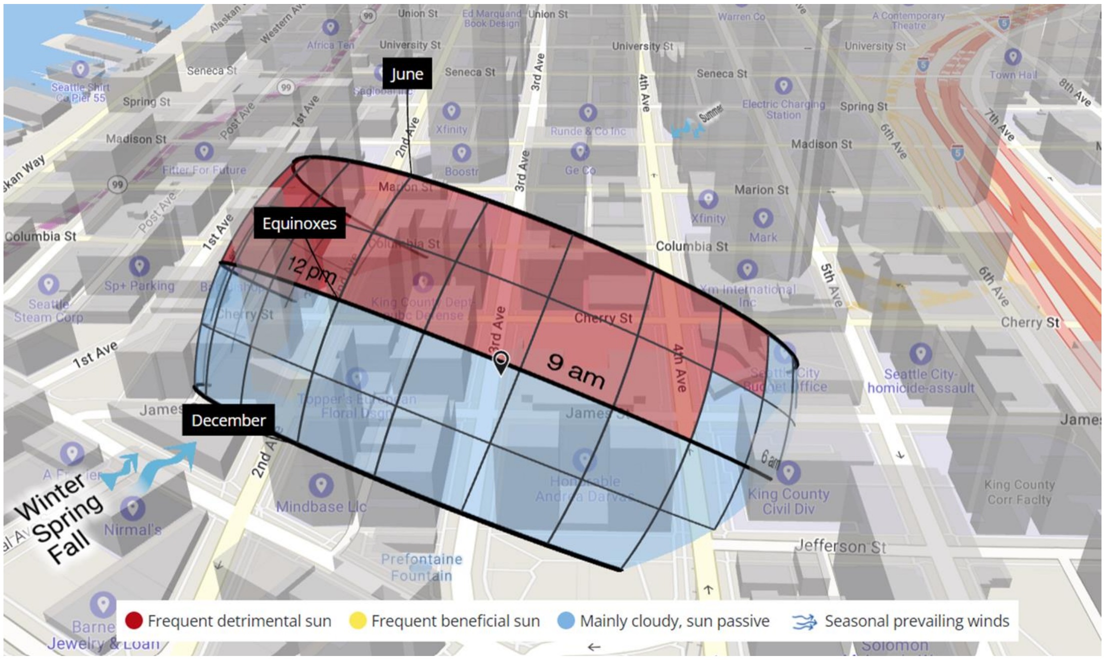


Figure 23: Pre-design Solar Exposure Study Chart

From the study we determined that there was most detrimental heat gain on the south and west facades during the summer warmer months. All other facades during warmer months and all facades during colder months had the potential for beneficial heat gain, so the solar shading approach would need to consider the varying solar angles. Solar exposure during the morning hours specifically would be most crucial as morning sunlight can provide free heating energy to the building as it begins operations. Vertical solar shade fins were selected as they allow light to pass into windows at a direct angle then provide shade from the light as the sun shifts towards later day angles. Fins along the east facade are positioned perpendicularly to allow light directly from the east direction to pass, and fins places along the southeast corner are angled at a 45-degree angle to catch sunlight at a late morning angle but provide shade during warmer periods from direct south exposure. (See Figure 24) For facades with more direct and frequently detrimental sunlight, a more robust shade element would need to cover the facade. Wire mesh solar shade screens were selected to cover most of the south facade, the entire west facade, and a partial amount of the north facade. The wire mesh solar shade screens provide constant shade from harsh solar exposure significantly reducing thermal bridging effects from the exterior to the interior environment.

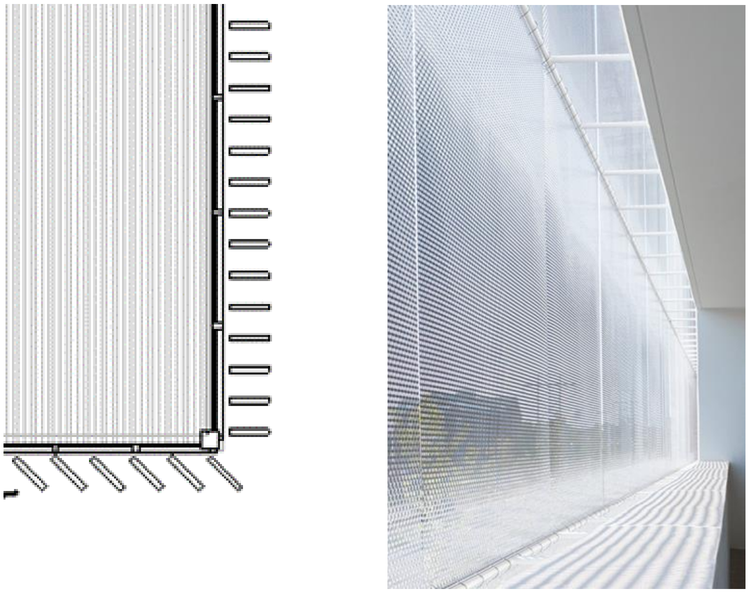


Figure 24: Plan View of Vertical Solar Fin Orientations & Wire Solar Shade Screen

The unique use of the wire mesh solar shade screens is the dual function they provide to reduce the water demands of the building as well. Given the ample rainfall Seattle receives annually, rainwater harvesting was a very viable approach to supplementing the building’s water supply and reducing the city water demands. Water from rainfall can be captured in the wire mesh, collected in troughs and stored in a reservoir at the building's base. This harvested water is not potable but can be used to offset water demands from grey water systems such as toilet plumbing and air conditioning units, and water for vegetation. Both energy reducing measures and water supplementing measures are sustainable across the building's operation lifecycle and provide investors and occupants with greater returns and comfort in the tower.

Lessons Learned

In developing the foundation design, we realized that we did not have much experience with the properties of peat and organic soils under seismic conditions. We realized that we would not be able to design the foundation on our own. So, we consulted Dr. Rollins, who pointed us to the limited research on peat and helped us to develop a reasonable foundation design.

Last year, we cut balsa wood by hand. As a result, we had multiple violations from uneven floors and variable lengths. Last year's tower did not survive the competition's mock earthquake. This year, we decided to use the laser cutter in the basement of the engineering building to create our beams more precisely. Not only did we not have variability in our structure, but construction was able to be finished weeks ahead of last year's tower. This year, our tower received zero violations, which was a substantial improvement for us.

We were able to spend a significant amount of time in preparing for our presentation this year. The week before the presentation, we gave it to a group of professors (Dr. Sorensen, Dr. Richards, and Dr. Mitchell). They gave excellent feedback about organizing our presentation and asked great technical questions on our structural design. We changed our presentation significantly due to that meeting. When in Seattle, the entire morning before the presentation was spent ironing out the details. We faced the challenge of presenting all of our technical information in under ten minutes, according to competition rules. This meant we had to spend approximately seventeen seconds on each slide. So, we kept practicing our parts until we could do the presentation in approximately eight minutes. This gave us enough time to spare for when we would have to pause or add details. Our final presentation at the competition went very well. We were able to calmly finish our presentation with about fifteen seconds to spare. Additionally, we were prepared to answer the questions from the judges afterward. Overall, the extensive preparation for the presentation enabled us to be successful in that phase of the competition.

Conclusions

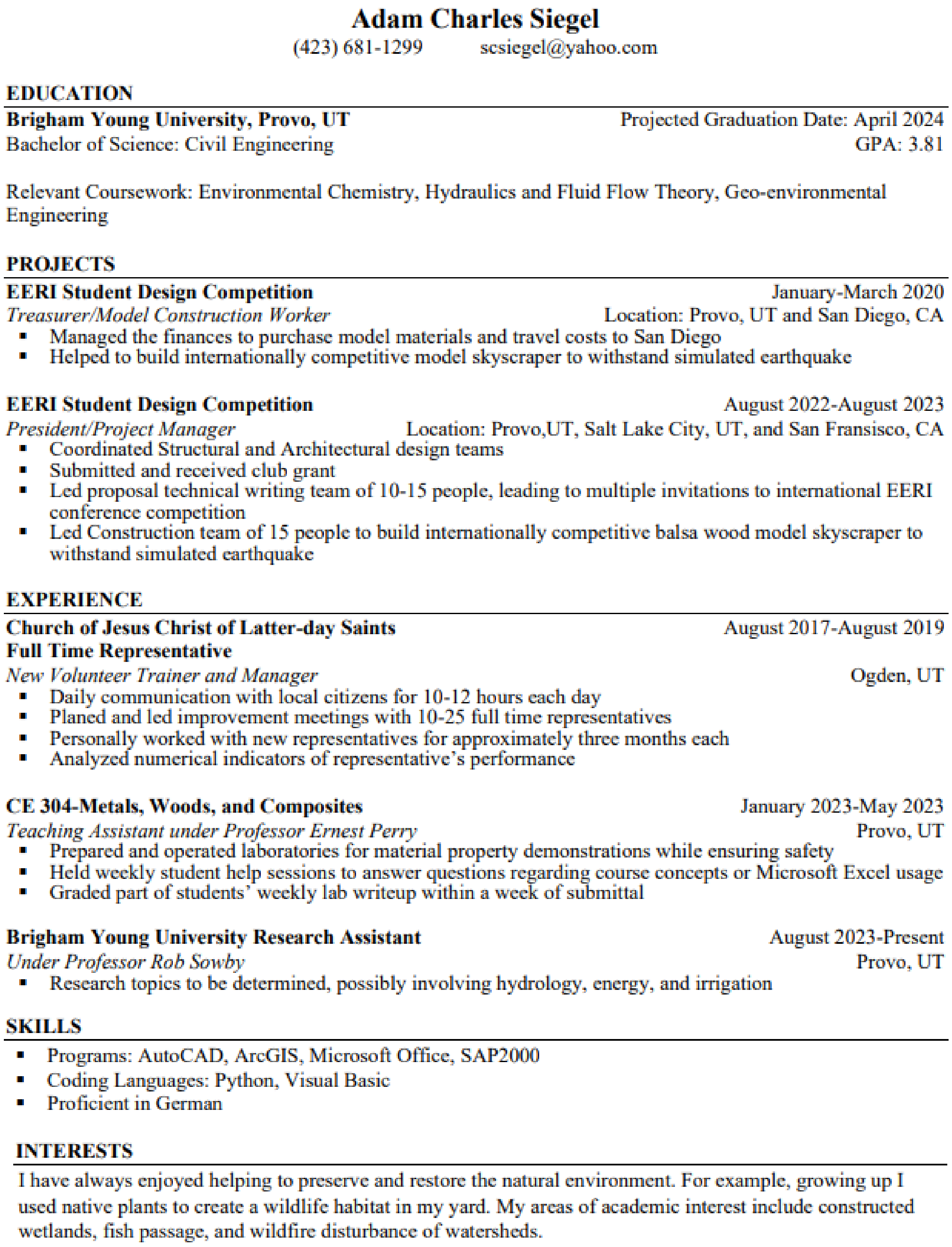
Our predictions for the design earthquake had 95% error when compared with the actual results. This could be a result of the unpredictable behavior of balsa and the variable behavior of the superglued connections. We also don't know exactly how the students running the competition calibrated the shake table and executed the ground motions. The shake table could have been calibrated incorrectly which would widen the gap between our predictions and the performance of the tower, but we have no way of knowing that. Ultimately, 80% of the teams at the competition were unable to produce predictions that had less than 100% error. We feel proud of both our performance and how BYU was represented in the outcome of this event.

Our performance between last year and this year improved a hundredfold. We effectively moved from second to last place to the top third of the competition. The thing that made the biggest difference was seeing the other schools compete and know first hand how high the bar was. We were able to learn things and take classes that would give us an extra advantage in competing. Classes that were particularly helpful were foundation design, structural vibrations, and advanced steel design. Having a better understanding of architecture would help us have a higher score in that category and thereby rank higher overall. Building a prototype tower and using the laser cutter were the most influential factors that led to our success in predicting our towers behavior in the long run.

Recommendations

- Perform further borings at the site to learn more about the soil profile, especially the friction strength of the peat seams. This will help determine the needed size and depth of the foundation.
- Calibrate the accelerometers in the soils lab on the shake table. Some of the results we got from the shake tests were extremely questionable. Some of the equipment is very old and could most likely use some calibration.
- Consider inviting an expert to consult for graphic design assistance when preparing the proposal, presentation, and technical poster to ensure that content is presented in the most efficient and professional manner.

Appendix A: Resumes of Team Members



Adam Charles Siegel

(423) 681-1299 scsiegel@yahoo.com

EDUCATION

Brigham Young University, Provo, UT Projected Graduation Date: April 2024
Bachelor of Science: Civil Engineering GPA: 3.81

Relevant Coursework: Environmental Chemistry, Hydraulics and Fluid Flow Theory, Geo-environmental Engineering

PROJECTS

EERI Student Design Competition January-March 2020
Treasurer/Model Construction Worker Location: Provo, UT and San Diego, CA

- Managed the finances to purchase model materials and travel costs to San Diego
- Helped to build internationally competitive model skyscraper to withstand simulated earthquake

EERI Student Design Competition August 2022-August 2023
President/Project Manager Location: Provo,UT, Salt Lake City, UT, and San Fransisco, CA

- Coordinated Structural and Architectural design teams
- Submitted and received club grant
- Led proposal technical writing team of 10-15 people, leading to multiple invitations to international EERI conference competition
- Led Construction team of 15 people to build internationally competitive balsa wood model skyscraper to withstand simulated earthquake

EXPERIENCE

Church of Jesus Christ of Latter-day Saints August 2017-August 2019
Full Time Representative
New Volunteer Trainer and Manager Ogden, UT

- Daily communication with local citizens for 10-12 hours each day
- Planed and led improvement meetings with 10-25 full time representatives
- Personally worked with new representatives for approximately three months each
- Analyzed numerical indicators of representative's performance

CE 304-Metals, Woods, and Composites January 2023-May 2023
Teaching Assistant under Professor Ernest Perry Provo, UT

- Prepared and operated laboratories for material property demonstrations while ensuring safety
- Held weekly student help sessions to answer questions regarding course concepts or Microsoft Excel usage
- Graded part of students' weekly lab writeup within a week of submittal

Brigham Young University Research Assistant August 2023-Present
Under Professor Rob Sowby Provo, UT

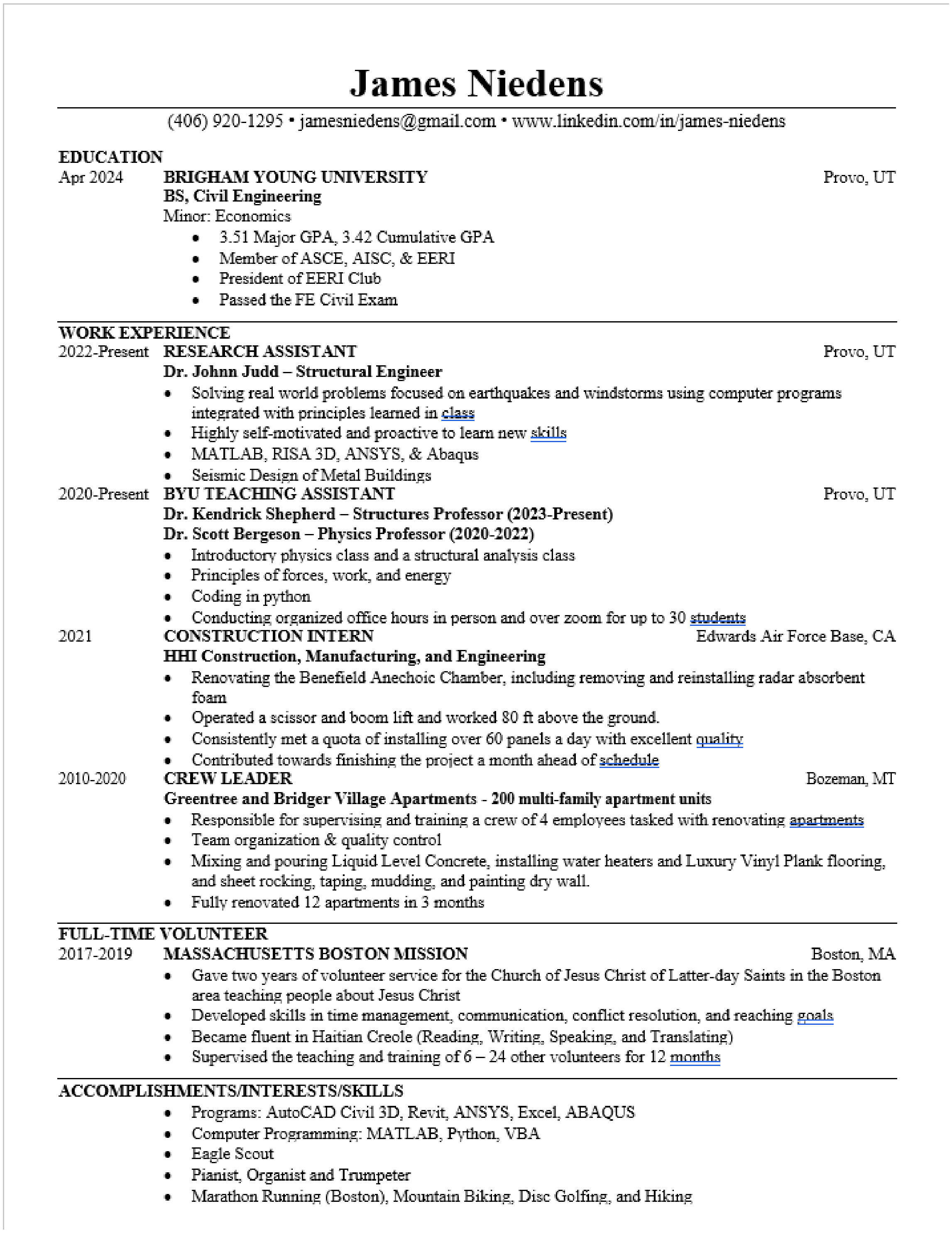
- Research topics to be determined, possibly involving hydrology, energy, and irrigation

SKILLS

- Programs: AutoCAD, ArcGIS, Microsoft Office, SAP2000
- Coding Languages: Python, Visual Basic
- Proficient in German

INTERESTS

I have always enjoyed helping to preserve and restore the natural environment. For example, growing up I used native plants to create a wildlife habitat in my yard. My areas of academic interest include constructed wetlands, fish passage, and wildfire disturbance of watersheds.



James Niedens

(406) 920-1295 • jamesniedens@gmail.com • www.linkedin.com/in/james-niedens

EDUCATION

Apr 2024 **BRIGHAM YOUNG UNIVERSITY** Provo, UT
BS, Civil Engineering
Minor: Economics

- 3.51 Major GPA, 3.42 Cumulative GPA
- Member of ASCE, AISC, & EERI
- President of EERI Club
- Passed the FE Civil Exam

WORK EXPERIENCE

2022-Present **RESEARCH ASSISTANT** Provo, UT
Dr. Johnn Judd – Structural Engineer

- Solving real world problems focused on earthquakes and windstorms using computer programs integrated with principles learned in class
- Highly self-motivated and proactive to learn new skills
- MATLAB, RISA 3D, ANSYS, & Abaqus
- Seismic Design of Metal Buildings

2020-Present **BYU TEACHING ASSISTANT** Provo, UT
Dr. Kendrick Shepherd – Structures Professor (2023-Present)
Dr. Scott Bergeson – Physics Professor (2020-2022)

- Introductory physics class and a structural analysis class
- Principles of forces, work, and energy
- Coding in python
- Conducting organized office hours in person and over zoom for up to 30 students

2021 **CONSTRUCTION INTERN** Edwards Air Force Base, CA
HHI Construction, Manufacturing, and Engineering

- Renovating the Benefield Anechoic Chamber, including removing and reinstalling radar absorbent foam
- Operated a scissor and boom lift and worked 80 ft above the ground.
- Consistently met a quota of installing over 60 panels a day with excellent quality
- Contributed towards finishing the project a month ahead of schedule

2010-2020 **CREW LEADER** Bozeman, MT
Greentree and Bridger Village Apartments - 200 multi-family apartment units

- Responsible for supervising and training a crew of 4 employees tasked with renovating apartments
- Team organization & quality control
- Mixing and pouring Liquid Level Concrete, installing water heaters and Luxury Vinyl Plank flooring, and sheet rocking, taping, mudding, and painting dry wall.
- Fully renovated 12 apartments in 3 months

FULL-TIME VOLUNTEER

2017-2019 **MASSACHUSETTS BOSTON MISSION** Boston, MA

- Gave two years of volunteer service for the Church of Jesus Christ of Latter-day Saints in the Boston area teaching people about Jesus Christ
- Developed skills in time management, communication, conflict resolution, and reaching goals
- Became fluent in Haitian Creole (Reading, Writing, Speaking, and Translating)
- Supervised the teaching and training of 6 – 24 other volunteers for 12 months

ACCOMPLISHMENTS/INTERESTS/SKILLS

- Programs: AutoCAD Civil 3D, Revit, ANSYS, Excel, ABAQUS
- Computer Programming: MATLAB, Python, VBA
- Eagle Scout
- Pianist, Organist and Trumpeter
- Marathon Running (Boston), Mountain Biking, Disc Golfing, and Hiking

Marcus Allan

(435) 828-6068 · mrayallan@outlook.com · linkedin.com/in/marcus-allan-7b14671a0/

EDUCATION

Brigham Young University April 2024
Bachelor of Civil Engineering, Emphasis in Structural Provo, UT

- President of BYU Architecture Association and Member of local ASCE chapter
- Completed courses covering Engineering Computer Programs
- Will Receive Certificate of Spanish Language
- GPA 3.55

ENGINEER / FACILITY DRAFTING EXPERIENCE

Acute Engineering Inc. Jan 2022 - Present
Production Engineer Orem, UT

- Draft structural engineering marks on architectural drawings on AutoCAD
- Interpret architectural drawings and assess projects in construction terms for builders
- Assess structural components and perform calculations for professional engineers

Becton Dickinson Medical Jun 2021 - Aug 2021
Facility Drafting Intern Sandy, UT

- Drafted new facility additions on AutoCAD and revised drawings of Sandy manufacturing plant
- Surveyed facility and worked with facility management to draft current plans
- Participated with a team of engineers in a professional environment

LEADERSHIP EXPERIENCE

BYU Architecture Association Jan 2022 - Present
President of Association Provo, Utah

- Coordinate regular meetings for students interested in the architecture industry
- Lead instructional activities and promote portfolio building opportunities
- Network with professionals and organize events for students

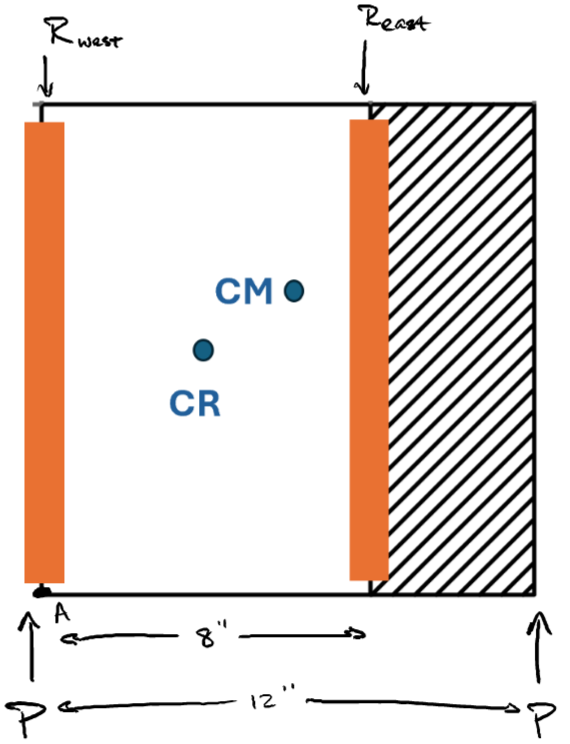
Argentina Rosario Mission Jul 2017 - Jul 2019
Executive Secretary to Mission President Rosario, Argentina

- Managed legal documentation for over 200 individuals over a 10-month period
- Organized local and foreign travel itineraries for missionary volunteers
- Coordinated weekly meetings to discuss individual and collective team goals

DESIGN SKILLS / ACHIEVEMENTS

- Proficient in design using AutoCAD and Civil 3D
- Frequently practice drafting design skills using REVIT program
- Participated in BYU Hosted Design Competition drafting residential structures
- Architecture enthusiast and currently building portfolio for graduate studies
- Seeking opportunities to split work environments between office space and project sites
- Proficient in Spanish speaking and translation

Appendix B: Calculations



$$\Sigma M_A = P(12") - R_{east}(8") = 0$$

$$R_{east} = 1.5P$$

$$\Sigma F_y = 2P - R_{east} - R_{west} = 0$$

$$2P + 1.5P = R_{west}$$

$$R_{west} = 0.5P$$

$$R_{east} = 3R_{west}$$

Figure B.1: Shear Wall Reaction Calcs For NS Shaking

Appendix C: MATLAB Scripts

MDOF Modal Analysis North-South Direction

```
clear

% Input parameters
g = 9.80665*39.3700787; % Accel. due to gravity (in./s²)
m = 1.5; % Story mass (k-s2/in.)
k = 75; % Column stiffness (k/in.)
h = 12*12*[1 1 1 1]; % Story height (in.)
zeta = 0.05; % Modal damping ratio

% Import ground motion record
accel = importdata("GM1_Acc(g).txt")'; % Horizontal ground acceleration (g)
dt = 0.001; % Time (sampling) step (s)
nPoints = size(accel,2); % Number of data points
t = (0:dt:(nPoints - 1)*dt); % Time array
```

Part A. Determine the periods of vibration and the corresponding mode shapes.

Mass Matrix

```
g = 386.088;
M = 1/g * [2.36 0 0 0 0 0 0 0 0;
    0 2.36 0 0 0 0 0 0 0;
    0 0 2.36 0 0 0 0 0 0;
    0 0 0 2.36 0 0 0 0 0;
    0 0 0 0 2.36 0 0 0 0;
    0 0 0 0 0 2.36 0 0 0;
    0 0 0 0 0 0 2.36 0 0;
    0 0 0 0 0 0 0 2.76 0;
    0 0 0 0 0 0 0 0 0.85]
```

```
M = 9×9
    0.0061         0         0         0         0         0         0 ⋯
         0    0.0061         0         0         0         0         0
         0         0    0.0061         0         0         0         0
         0         0         0    0.0061         0         0         0
         0         0         0         0    0.0061         0         0
         0         0         0         0         0    0.0061         0
         0         0         0         0         0         0    0.0061
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
```

Stiffness matrix

```
 h = 3; %in
 E = 500; %psi
 %E = 264463;
 %I = 8*12^3/12-(8-6/32)*(12-6/32)^3/12-2*(3*(3/32)^3/12+3*3/32*6^2)-
2*(3/32*7^3/12+3/32*7*4^2); %EW
 I = 12*8^3/12-(12-6/32)*(8-6/32)^3/12-2*(3/32*(3)^3/12+3*3/32*6^2)-
2*(7*(3/32)^3/12+3/32*7*4^2); %NS
 A = 3/32 * 2.5 *8; %in^2
 v = 0.38; %poissons ratio
 G = E/(2*(1+v)); %psi
 %G = 100;
 k = 1/ (h^3/(3*E*I) + 1.2*h/(A*G));
 K = [2*k -k 0 0 0 0 0 0 0;
     -k 2*k -k 0 0 0 0 0 0;
     0 -k 2*k -k 0 0 0 0 0;
     0 0 -k 2*k -k 0 0 0 0;
     0 0 0 -k 2*k -k 0 0 0;
     0 0 0 0 -k 2*k -k 0 0;
     0 0 0 0 0 -k 2*k -k 0;
     0 0 0 0 0 0 -k 2*k -k
     0 0 0 0 0 0 0 -k k]
```

```
K = 9×9
   67.2599  -33.6299         0         0         0         0         0 ⋯
  -33.6299   67.2599  -33.6299         0         0         0         0
         0  -33.6299   67.2599  -33.6299         0         0         0
         0         0  -33.6299   67.2599  -33.6299         0         0
         0         0         0  -33.6299   67.2599  -33.6299         0
         0         0         0         0  -33.6299   67.2599  -33.6299
         0         0         0         0         0  -33.6299   67.2599
         0         0         0         0         0         0  -33.6299
         0         0         0         0         0         0         0
```

Solve the Eigenvalue Problem

```
 [mode, omegasq] = eig(K,M);
 omega = sqrt(omegasq);
 T_period = 2*pi() ./ omega
```

```
T_period = 9×9
    0.4873       Inf       Inf       Inf       Inf       Inf       Inf ⋯
       Inf    0.1635       Inf       Inf       Inf       Inf       Inf
       Inf       Inf    0.0996       Inf       Inf       Inf       Inf
       Inf       Inf       Inf    0.0730       Inf       Inf       Inf
       Inf       Inf       Inf       Inf    0.0591       Inf       Inf
       Inf       Inf       Inf       Inf       Inf    0.0509       Inf
       Inf       Inf       Inf       Inf       Inf       Inf    0.0461
       Inf       Inf       Inf       Inf       Inf       Inf       Inf
```

```
       Inf         Inf         Inf         Inf         Inf         Inf         Inf
```

Part B. Determine the number of modes required to capture 90% of the base shear.

```
Mn = mode.' * M * mode;
i = ones(size(mode,1),1);
P = M*i;
Gamma = zeros(size(mode,1),1);
Peff = zeros(size(mode));
for i = 1:size(mode,1)
    Gamma(i) = mode(:,i).'*P./Mn(i,i);
    Peff(:,i) = Gamma(i) * M * mode(:,i);
end
```

Shear Per Mode

```
SumPeff = zeros(size(mode,1),1);
for j = 1:size(Peff,1)
    for i = 1:size(Peff,2)
        SumPeff(i) = SumPeff(i) + Peff(j,i);
    end
end
SumPeff;
```

Base Shear

```
Vb = 0;
for i = 1:size(SumPeff,1)
    Vb = Vb + SumPeff(i);
end
Vb
```

```
Vb = 0.0521
```

Modal Participation

```
SumPeff/Vb
```

```
ans = 9×1
    0.8542
    0.0913
    0.0302
    0.0133
    0.0064
    0.0030
    0.0013
    0.0004
    0.0000
```

Including the first 2 modes will include 96.9% of the base shear.

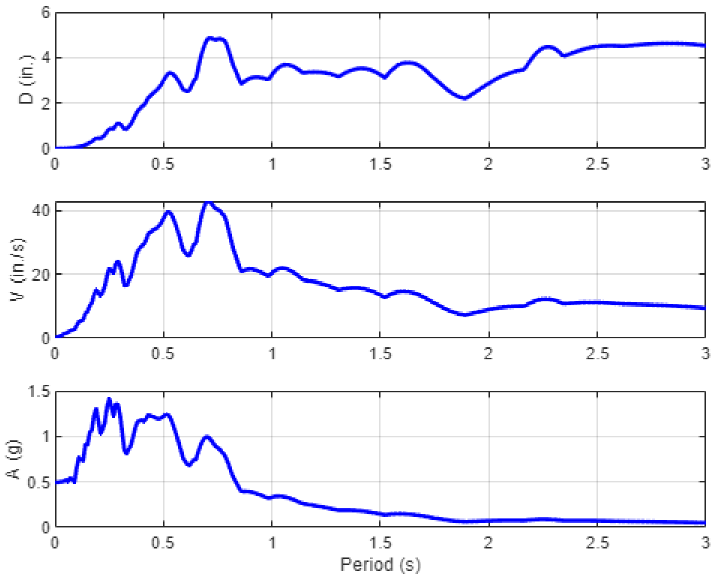
Part C. Plot the response spectra (D,V, and A) of the ground motion and determine the spectral values for each mode.

```
Tmax = 3;
nPeriods = 300;
p = -accel*g;
[D,V,A] = responseSpectra(p,dt,zeta,Tmax,nPeriods);
```

Plot the response spectra.

```
% Displacement (deformation) spectrum
T = (0:Tmax/nPeriods:Tmax);
subplot(3,1,1);
plot(T,D,'Color','b','LineWidth',2);
ylabel('D (in.)');
grid on;
% Pseudo-velocity spectrum
subplot(3,1,2);
plot(T,V,'Color','b','LineWidth',2);
ylabel('V (in./s)');
grid on;

% Pseudo-acceleration spectrum
subplot(3,1,3);
plot(T,A/g,'Color','b','LineWidth',2);
ylabel('A (g)');
grid on;
xlabel('Period (s)');
```



Part D. Determine peak roof displacement (in.) and peak base shear (k) using modal response spectrum analysis (RSA) and the SRSS combination rule.

Peak Roof Disp. for each mode

```
 u_mode = zeros(size(mode,1));
 for i = 1:size(u_mode,1)
     u_mode(:,i) = Gamma(i)*D(round(T_period(i,i)*100))*mode(:,i);
 %     u_mode(:,i) =
Gamma(i)*A(round(T_period(i,i)*100))*g/omegasq(i,i)*mode(:,i);
 end
 u_mode;
```

Base Shear

```
 F_n = zeros(size(u_mode));
 for i = 1:size(F_n,1)
     F_n(:,i) = K * u_mode(:,i);
 end
 F_n;
 Vbn = zeros(size(F_n,1),1);
 for j = 1:size(Vbn,1)
     for i = 1:size(F_n,2)
         Vbn(i) = Vbn(i) + F_n(j,i);
     end
 end
 Vbn
```

```
Vbn = 9×1
   19.9049
    1.4101
    0.2477
    0.0907
    0.0481
    0.0191
    0.0097
    0.0017
    0.0000
```

Combine Modes

```
%Peak Roof Drift
u_sq = zeros(size(u_mode,1),1);
for j = 1:size(u_mode,1)
    for i = 1:size(u_mode,1)
        u_sq(i) = u_sq(i) + u_mode(i,j)^2;
    end
end
u = sqrt(u_sq)
```

```
u = 9×1
    0.5934
    1.1682
    1.7067
    2.1931
    2.6133
    2.9550
    3.2081
    3.3645
    3.4017
```

```
%Base Shear
Vbsq = 0;
for i = 1:size(Vbn,1)
    Vbsq = Vbsq + Vbn(i)^2;
end
Vb = sqrt(Vbsq)
```

```
Vb = 19.9566
```

MDOF Modal Analysis East-West Direction

```
clear

% Input parameters
g = 9.80665*39.3700787; % Accel. due to gravity (in./s²)
m = 1.5; % Story mass (k-s2/in.)
k = 75; % Column stiffness (k/in.)
h = 12*12*[1 1 1 1]; % Story height (in.)
zeta = 0.05; % Modal damping ratio

% Import ground motion record
accel = importdata("GM1_Acc(g).txt")'; % Horizontal ground acceleration (g)
dt = 0.001; % Time (sampling) step (s)
nPoints = size(accel,2); % Number of data points
t = (0:dt:(nPoints - 1)*dt); % Time array
```

Part A. Determine the periods of vibration and the corresponding mode shapes.

Mass Matrix

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g = 386.088;
M = 1/g * [2.36 0 0 0 0 0 0 0 0;
    0 2.36 0 0 0 0 0 0 0;
    0 0 2.36 0 0 0 0 0 0;
    0 0 0 2.36 0 0 0 0 0;
    0 0 0 0 2.36 0 0 0 0;
    0 0 0 0 0 2.36 0 0 0;
    0 0 0 0 0 0 2.36 0 0;
    0 0 0 0 0 0 0 2.76 0;
    0 0 0 0 0 0 0 0 0.85]
```

```
M = 9×9
    0.0061         0         0         0         0         0         0 ⋯
         0    0.0061         0         0         0         0         0
         0         0    0.0061         0         0         0         0
         0         0         0    0.0061         0         0         0
         0         0         0         0    0.0061         0         0
         0         0         0         0         0    0.0061         0
         0         0         0         0         0         0    0.0061
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
```

Stiffness matrix

```
h = 3; %in
E = 500; %psi
```

```
 %E = 264463;
 I = 8*12^3/12-(8-6/32)*(12-6/32)^3/12-2*(3*(3/32)^3/12+3*3/32*6^2)-
2*(3/32*7^3/12+3/32*7*4^2); %EW
 %I = 12*8^3/12-(12-6/32)*(8-6/32)^3/12-2*(3/32*(3)^3/12+3*3/32*6^2)-
2*(7*(3/32)^3/12+3/32*7*4^2); %NS
 A = 3/32 * 2.5 *8; %in^2
 v = 0.38; %poissons ratio
 G = E/(2*(1+v)); %psi
 %G = 100;
 k = 1/ (h^3/(3*E*I) + 1.2*h/(A*G));
 K = [2*k -k 0 0 0 0 0 0 0;
     -k 2*k -k 0 0 0 0 0 0;
     0 -k 2*k -k 0 0 0 0 0;
     0 0 -k 2*k -k 0 0 0 0;
     0 0 0 -k 2*k -k 0 0 0;
     0 0 0 0 -k 2*k -k 0 0;
     0 0 0 0 0 -k 2*k -k 0;
     0 0 0 0 0 0 -k 2*k -k
     0 0 0 0 0 0 0 -k k]
```

```
K = 9×9
  179.2823  -89.6412         0         0         0         0         0 ···
  -89.6412  179.2823  -89.6412         0         0         0         0
         0  -89.6412  179.2823  -89.6412         0         0         0
         0         0  -89.6412  179.2823  -89.6412         0         0
         0         0         0  -89.6412  179.2823  -89.6412         0
         0         0         0         0  -89.6412  179.2823  -89.6412
         0         0         0         0         0  -89.6412  179.2823
         0         0         0         0         0         0  -89.6412
         0         0         0         0         0         0         0
```

Solve the Eigenvalue Problem

```
 [mode, omegasq] = eig(K,M);
 omega = sqrt(omegasq);
 T_period = 2*pi() ./ omega
```

```
T_period = 9×9
    0.2985       Inf       Inf       Inf       Inf       Inf       Inf ···
       Inf    0.1002       Inf       Inf       Inf       Inf       Inf
       Inf       Inf    0.0610       Inf       Inf       Inf       Inf
       Inf       Inf       Inf    0.0447       Inf       Inf       Inf
       Inf       Inf       Inf       Inf    0.0362       Inf       Inf
       Inf       Inf       Inf       Inf       Inf    0.0312       Inf
       Inf       Inf       Inf       Inf       Inf       Inf    0.0282
       Inf       Inf       Inf       Inf       Inf       Inf       Inf
       Inf       Inf       Inf       Inf       Inf       Inf       Inf
```

Part B. Determine the number of modes required to capture 90% of the base shear.

```
Mn = mode.' * M * mode;
i = ones(size(mode,1),1);
P = M*i;
Gamma = zeros(size(mode,1),1);
Peff = zeros(size(mode));
for i = 1:size(mode,1)
    Gamma(i) = mode(:,i).'*P./Mn(i,i);
    Peff(:,i) = Gamma(i) * M * mode(:,i);
end
```

Shear Per Mode

```
SumPeff = zeros(size(mode,1),1);
for j = 1:size(Peff,1)
    for i = 1:size(Peff,2)
        SumPeff(i) = SumPeff(i) + Peff(j,i);
    end
end
SumPeff;
```

Base Shear

```
Vb = 0;
for i = 1:size(SumPeff,1)
    Vb = Vb + SumPeff(i);
end
Vb
```

```
Vb = 0.0521
```

Modal Participation

```
SumPeff/Vb
```

```
ans = 9×1
    0.8542
    0.0913
    0.0302
    0.0133
    0.0064
    0.0030
    0.0013
    0.0004
    0.0000
```

Including the first 2 modes will include 96.9% of the base shear.

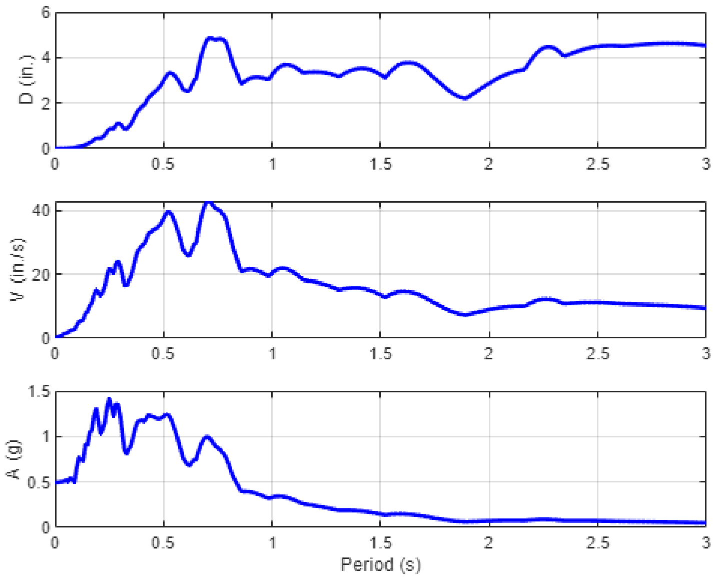
Part C. Plot the response spectra (D,V, and A) of the ground motion and determine the spectral values for each mode.

```
Tmax = 3;
nPeriods = 300;
p = -accel*g;
[D,V,A] = responseSpectra(p,dt,zeta,Tmax,nPeriods);
```

Plot the response spectra.

```
% Displacement (deformation) spectrum
T = (0:Tmax/nPeriods:Tmax);
subplot(3,1,1);
plot(T,D,'Color','b','LineWidth',2);
ylabel('D (in.)');
grid on;
% Pseudo-velocity spectrum
subplot(3,1,2);
plot(T,V,'Color','b','LineWidth',2);
ylabel('V (in./s)');
grid on;

% Pseudo-acceleration spectrum
subplot(3,1,3);
plot(T,A/g,'Color','b','LineWidth',2);
ylabel('A (g)');
grid on;
xlabel('Period (s)');
```



Part D. Determine peak roof displacement (in.) and peak base shear (k) using modal response spectrum analysis (RSA) and the SRSS combination rule.

Peak Roof Disp. for each mode

```
u_mode = zeros(size(mode,1));
for i = 1:size(u_mode,1)
    u_mode(:,i) = Gamma(i)*D(round(T_period(i,i)*100))*mode(:,i);
%     u_mode(:,i) =
Gamma(i)*A(round(T_period(i,i)*100))*g/omegasq(i,i)*mode(:,i);
end
u_mode;
```

Base Shear

```
F_n = zeros(size(u_mode));
for i = 1:size(F_n,1)
    F_n(:,i) = K * u_mode(:,i);
end
F_n;
Vbn = zeros(size(F_n,1),1);
for j = 1:size(Vbn,1)
    for i = 1:size(F_n,2)
        Vbn(i) = Vbn(i) + F_n(j,i);
    end
end
Vbn
```

```
Vbn = 9×1
   21.9720
    0.7416
    0.2122
    0.0604
    0.0445
    0.0125
    0.0064
    0.0020
    0.0000
```

Combine Modes

```
%Peak Roof Drift
u_sq = zeros(size(u_mode,1),1);
for j = 1:size(u_mode,1)
    for i = 1:size(u_mode,1)
        u_sq(i) = u_sq(i) + u_mode(i,j)^2;
    end
end
u = sqrt(u_sq)
```

```
u = 9×1
    0.2453
    0.4830
    0.7061
    0.9078
    1.0821
    1.2237
    1.3285
    1.3931
    1.4084
```

```
%Base Shear
Vbsq = 0;
for i = 1:size(Vbn,1)
    Vbsq = Vbsq + Vbn(i)^2;
end
Vb = sqrt(Vbsq)
```

```
Vb = 21.9856
```

Appendix D: Work Cited

ASCE 7 Hazard Tool. 2024. Accessed April 17, 2024. https://ascehazardtool.org/

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