2021 SDC - Structural Deliverable

Background and Problem Statement

Seattle, Washington is one of the largest metropolitan regions in the Western United States, which is exposed to large magnitude earthquakes. The Cascadia subduction zone is a significant source of seismicity in the area and research has shown that various earthquake scenarios could have a significant impact on the region. Seattle has been one of the fastest growing cities in the United States. Its population has increased from 1150 people in 1870 to around 750,000 people in 2018. Seattle has also gone through an industrial boom in recent years, and major companies such as Amazon, Microsoft, Stabucks and Expedia have established their headquarters in the Seattle area. Therefore, there has been a significant increase in new building construction, especially tall buildings. Furthermore, The city of Seattle is located on top of deep sedimentary basins. Deep basins have the potential to amplify the earthquake ground motions and make them more damaging to the built environment.

The COVID-19 pandemic has increased risk from natural disasters due to the reduced healthcare capacity. A major earthquake during the pandemic could have more severe consequences than an earthquake during non-pandemic times. As a result, emergency preparedness must be improved throughout the region, requiring effort from all sectors including planners, engineers, and policy-makers. To this end, the Mayor of Seattle made a plea to acquire urgent funds for increasing hospital space to catch up with the hospitalization demand arising from COVID-19. FEMA has pledged funding for hospital construction so that stress can be reduced on the Greater Seattle Area Hospital System. The Center for Disease Control and Prevention (CDC) issued a dire warning to the hospitals throughout the country to prepare for the next wave of COVID-19. New hospitals are being constructed around the city, but additional hospital space is needed in various highly populated areas. It is decided in an emergency meeting, overseen by the mayor of Seattle, that an on top addition/extension to an existing hospital be constructed. Plans were already in place that the existing hospital should be extended, but the timeline is moved forward because of the pandemic. Since your firm expressed interest by submitting the (pseudo) expression of interest form issued by SDC, the (pseudo) client, you are selected as the consulting firm for the engineering design of this addition.

Before designing the addition, you decide that a thorough analysis of the existing structure should be conducted. Within this deliverable, you are expected to carry out a linear response history analysis (time-history analysis) of a balsa wood model of the original structure and explore design ideas for the addition. All structural analyses should be conducted for a scaled balsa wood tower. A finalized design of the addition with a thorough analysis of the entire structure will be required in the final deliverable. Please supplement your submission for this deliverable with any drawings and figures that you believe are appropriate and informative. Your ETABS or SAP2000 model should not be submitted with this deliverable, but will be required as a part of the final (retrofit) deliverable.

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Part 1: Existing Building Modeling and Performance Assessment

Because of your company's familiarity and skill with shake table testing of scaled balsa wood models to analyze structural behavior, you decide to construct a scaled balsa wood tower for your numerical modeling of the hospital. To assess the feasibility of building an addition onto the existing structure, your company has decided to first analyze the existing building to determine how well the structure will perform in an earthquake given the seismicity and geotechnical conditions of the area.

1. The construction documents for the original structure have been found and replicated as a scaled balsa wood approximation. Your first task is to build a numerical model of the existing structure in SAP2000 or ETABS using these Existing Construction Documents and the applicable material properties provided in Table 1. Use the following modeling requirements and assumptions and state any other assumptions that you make.
    a. Column base connections should be fixed and all member connections should be continuous (moment-carrying). State whether you believe this assumption is valid for a balsa wood model and whether it is valid for a real structure.
    b. There should be a continuous connection at any intersection of two members. For example, where two braces cross each other, there should be a continuous connection at the intersection rather than free movement of the braces independent of each other.
    c. Assume a Poisson's ratio of 0.3 and constant modal damping of 0.025 for all modes.
    d. Diaphragms should be completely flexible and have zero stiffness. Any stiffness in the floors will be accounted for by modeling of the beams themselves.
    e. A superimposed dead load of 1.44 psf must be applied to each floor and roof level. This dead load and the self-weight of the balsa wood members should be included in the mass of the structure. Any other loads (live, wind, etc.) do not need to be considered for the balsa wood model.

Table 1. Design Properties for Low- to Medium-Density Balsa Wood

Fb	Ft	Fv	Fc	E	Emin	Density
2000 psi (13.8 MPa)	1200 psi (8.27 MPa)	200 psi (1.38 MPa)	900 psi (6.21 MPa)	600,000 psi (4137 MPa)	350,000 psi (2413 MPa)	8 lb/ft^3 (128 kg/m^3)

2. Run a modal (eigenvalue) analysis of your numerical model. Observe and comment on the characteristics of the dominant mode shapes and discuss relative displacements of floors for each mode. Report the period of the first 3 modes of the balsa wood model and

determine the number of modes that should be included in analysis for 90% mass participation of the structure in both translational directions. Provide justification for this conclusion with mass participation ratios.

3. Ground motions have been selected and scaled for the existing building based on the fundamental period of the structure and response spectra for the site. Run these Scaled Time Histories (TH1, TH2, TH3, and TH4) on your model of the existing structure in both the N/S and E/W directions to determine its response to ground motions that can be generated in the area. Report the maximum inter-story drift ratio for each time history analysis and the two floors between which the maximum drift occurs. Determine the average inter-story drift ratio between all time histories for each floor. Also, report the maximum axial, bending, and shear forces that are undergone by individual members during each ground motion after applying Allowable Stress Design (ASD) load combinations. Identify which members undergo these peak forces by reporting the gridlines and floor on which the members are located (preferably in table format). Also report which load combination (which time history) results in the largest forces and drifts. Consider the following notes.
   a. A total of eight time histories will be run during the analysis. There are four ground motions; each of these should be applied separately in the N/S and E/W directions. The unscaled motions do not need to be run on the structure.
   b. Allowable Stress Design (ASD) load combinations should be used when determining member forces. Refer to ASCE 7 for the appropriate load combinations. Service level (unfactored) loading should be used when determining inter-story drift ratios.
   c. Do not consider ASCE 7 response modification (R) factors or importance (I) factors in your analysis.

4. Hospitals usually house expensive equipment, which are sensitive to floor accelerations. Sometimes, the cost of these equipment can even exceed the cost of the structure. Determine which is the most suitable floor level for housing this equipment, primarily considering the acceleration of each floor. Assuming comfort level for occupants of the hospital is a function of floor acceleration, qualitatively state how the relative comfort level varies with different floor numbers. Justify your responses with reasoning.

5. Identify critical members and check their design using the American Wood Council's National Design Specification for Wood Construction and the NDS Supplement. The NDS and NDS Supplement can likely be found from a professor or colleague or using online resources, but please contact sdc@eeri.org if the NDS cannot be quickly acquired so that an alternative may be provided. Both 2015 and 2018 editions are acceptable. Report the most critical demand/capacity ratios after completing axial, bending, and shear

checks using Section 3 of the NDS. Determine the most critical D/C ratios both by selecting D/C ratios for the worst-case time history and by taking the average D/C ratios across all time histories. Identify which members are most critically stressed and undergo these peak D/C ratios by reporting the gridlines and floor on which the members are located. If a design check is omitted, please provide reasoning for doing so. Use the following specifications and state any other assumptions that you make, providing justification for these assumptions.

a. Use the initial, unfactored material properties provided in Table 1 of this deliverable document for capacity calculations. All relevant ASD adjustment factors found in the sawn lumber section of the NDS should be applied to the values in Table 1 of this document when determining member capacities.
b. For the size factor (C_F), assume that values for a 2” wide by 2” thick dimension lumber member are equivalent to the size factor that should be used for all members in the balsa wood model.
c. If you need an effective length factor in your calculations, use a value of $K_e = 1.0$. In your report, provide reasoning/comments for or against this effective length factor but do not change the factor in your calculations.

6. Summarize your analysis of the existing building. Did the structure perform well over some or all of the ground motions? To perform well, all individual members should pass the demand/capacity checks and all inter-story drift ratios should be less than 5%. If the existing structure did not perform well, what type(s) of failure occurred? If a failure occurred, do you believe the failure that occurred would result in complete collapse of the structure? If not, would there be damage and how severe would it be? Regardless of whether the building performed well or not, which selected ground motions were the most critical for the structure? What was the peak inter-story drift and most critical demand/capacity ratio experienced by the structure for the worst case time history analysis? What were the peak values when averaged across all time histories? Was the initial design of the structure effective? What could have been done differently to make the original structural design safer and more efficient?

7. Attach any supplementary calculations in an appendix at the end of your deliverable submission.

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Part 2: Extension (Addition)

The hospital that you're working on is located immediately to the east of an existing high-rise building. The adjacent high-rise has a flexible lateral system and is expected to experience large displacements during an earthquake. A gap separating the two structures is deemed too narrow to continue the existing west face of the hospital vertically to the desired height because doing so would result in pounding of the two structures as they oscillate at different frequencies. You express this concern to the design team and the proposed solution involves tapering the hospital addition away from the existing high-rise. The architect decides the taper should be dramatic so that the building stands out on the Seattle skyline. Your company has been tasked with designing a structural system that will accommodate this tapered geometry without altering the existing hospital structure.

1. As you begin to design the addition, you recognize that the existing structure's lateral system is located primarily on the west side of the building while the addition extends on the east side of the building and tapers away from the existing lateral system. The building geometry, member sizes, spacing, and other requirements are provided in the Design Guide and should be followed while designing the addition. Experiment with design iterations for the addition that you anticipate will perform the best given the constraints. Provide documentation via schematic diagrams and drawings of several structural designs and describe your reasoning for these design ideas.

2. You decide to use a numerical model in ETABS or SAP2000 to construct the addition on top of your existing model so that the irregular lateral systems can be analyzed. Try different design ideas then select the one that you believe is most effective. Are you able to create a structure that performs well across all ground motions? Describe the performance of your structure qualitatively and with any analysis results that you would like to include. A thorough analysis of the structure with the addition is not required in this deliverable. Rather, this preliminary analysis should inform your design when determining the structural configuration for the addition in the final (retrofit) deliverable.

3. After conducting a preliminary analysis, select one of your design ideas and provide a more detailed set of construction documents. Use drawings to describe how connections will be designed between the addition and the existing structure and how connections will be implemented within the addition itself. Please provide reasoning for how you decide to model your connections in ETABS/SAP2000 and how your connections would correspond to a physical balsa wood structure.

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4. Determine the total rentable floor area for this addition design and the total volume of structural members in the addition (not including the existing structure). Provide the total weight of structural members in the addition not including the 1.44 psf applied dead load. In the final (retrofit) deliverable, higher scores will be awarded for maximizing floor area and minimizing structure weight while meeting the design criteria.

5. Using the addition design that you selected, describe how the addition would be constructed. The existing structure has already been built and you are tasked with managing construction of the addition. Provide a construction schedule and sequence that you would use if you were to build a real building without disturbing the operation of the existing hospital structure. Include diagrams to convey your ideas.