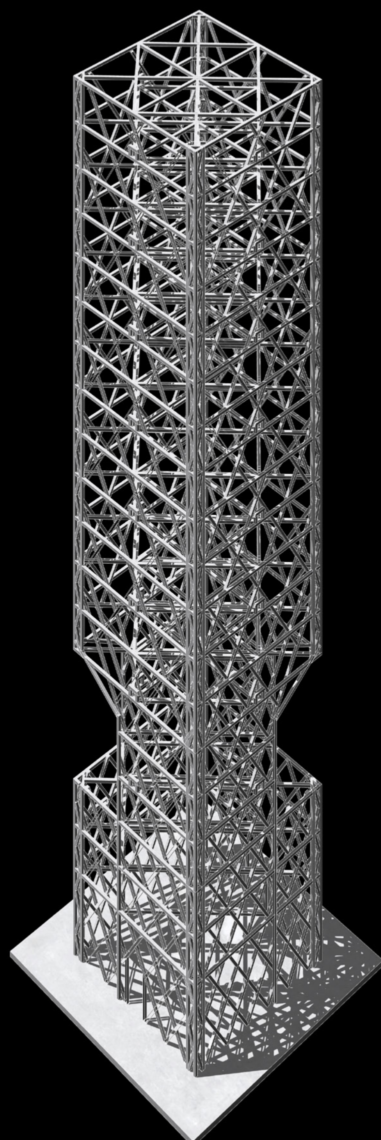
CORNELL UNIVERSITY

2025 DESIGN PROPOSAL



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I. Project Description

Cornell University will design and construct a scaled balsa wood model of a 20-story high-rise to be built in Kobe, Japan. The tower will contribute to the city's revitalization by incorporating public library spaces, residential units, and an adaptable facade that integrates sustainability and aesthetic elements. The structure must be able to withstand the risk posed by multiple nearby active fault zones, the Nankai Trough Subduction Zone, and uncompressed soil susceptible to liquefaction. Our design will provide a structurally sound and economically advantageous solution that maintains Japan's sustainability goals while paying homage to the built environment and culture of the city.

II. Architectural Description

In 1995, the Great Hanshin Earthquake devastated Kobe, causing massive damage and loss of life. Since then, the city has made reconstruction efforts like the Luminari, a series of illuminated gates marking the earthquake anniversary. Our proposed tower will complement the Kobe Port Tower, using light to symbolize the harbor's revitalization and a welcoming beacon to the city.

Aligning with Kobe's focus on creating livable spaces, the first four floors of our building will house a public library to provide a community space at the harbor. The remainder of the tower will be residential, encouraging a vibrant, lived-in atmosphere.

The building's facade draws from traditional Japanese tatami mat flooring and the Metabolism movement, emphasizing modular construction [1]. The enclosure features a single unit, functioning as solid cladding and green facade. This module repeats along the building's silhouette, revealing programmatic organization within the structure while existing as one system. These repeatable units promote flexibility and efficiency for both construction and aesthetics. The outer walls serve multiple functions, such as book storage, balconies, and public gardens. The facades modules also allow for adaptability to the climate by incorporating photovoltaic cladding, metal mesh for thermal performance, or vertical farming aligning with Kobe's Green Growth Strategy.

The visual expression also reflects the Japanese art form Kintsugi, which repairs broken pottery with gold-mended edges [3]. The technique introduces irregularity and is both functional and artistic. The facade highlights material breaks with golden edges, symbolizing the disparate programs and materials coming together to form our tower.

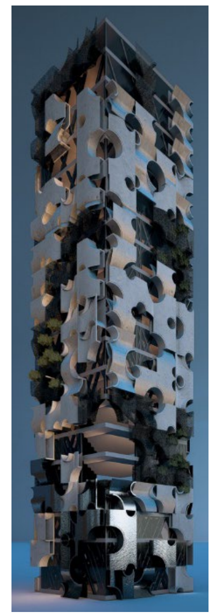

Figure 1: Architectural Rendering

III. Economic Considerations

Our structural design will maximize floor area while maintaining diagonal symmetry. With a total rentable floor area of 2388.5 in^2, the revenue generated will be $1,161,346 per year. The annual building cost, derived from the estimated structural weight of 1.5 lbs (based on previous Cornell towers), reduces the annual revenue of the project to $1,005,946.

IV. Geotechnical/Site Description

Japan, located on the eastern edge of the Eurasian tectonic plate, has a long history of seismic activity driven by the subduction of the Philippine Sea and Pacific plates [4]. A megathrust earthquake from the Nankai Trough subduction zone poses the greatest seismic threat to Kobe. The most recent major events from this zone were two magnitude Mw 8.1 earthquakes in 1944 and 1946. With a return period of 100–200 years, another large earthquake from the subduction zone is a significant concern [5]. Additionally, Japan has many onshore and offshore faults, including the Nojima Fault, which caused the 1995 Great Hanshin Earthquake (Mw 6.9) [6]. This strike-slip earthquake inflicted severe damage on Kobe's infrastructure, with liquefaction and lateral spreading devastating some buildings [4].

Using data from J-SHIS focusing on the Rokko-Awajishima fault zone and the Nankai Trough subduction zone, the analysis projects that Kobe will experience average magnitudes of Mw 6.6 and Mw

8.65 from each zone, respectively [7]. Maps from OpenQuake estimate that peak ground acceleration at the building site could reach 0.35 g, with a 10% probability of exceedance over the next 50 years [8].

The coastal area of Kobe is primarily composed of reclaimed land, developed between 1953 and 1992 to extend Kobe's coastline and create Port Island [4]. The fill material, consisting of sand and weathered granite sourced from the Rokko Mountains, was deposited over layers of silty clay and gravelly sand. Due to inadequate compaction, Standard Penetration Test (SPT) blow counts averaged 5-10 prior to the 1995 earthquake [9], raising concerns about liquefaction. These concerns were realized during the 1995 earthquake; however, post-earthquake maps indicate that the area near the Port Tower—where our tower will be located—remained unaffected by liquefaction. Without additional site-specific geotechnical tests, such as Cone Penetration Testing (CPT), or supporting historical evidence, we cannot classify the site as Site Class F [10]. According to the Shear Wave Velocity Map, velocities in the area range from 500 ft/s to 650 ft/s. Offshore, the floor of Osaka Bay comprises a thick layer of soft clay with water content between 70% and 100% and a shear wave velocity of approximately 590 ft/s [11]. Based on the soil composition, onshore and offshore shear wave velocities, and SPT N-values, we classify the site as Site Class E in accordance with Table 20.3-1 of ASCE 7-16.

The soil of coastal Kobe poses several challenges. The loose, uncompacted fill amplifies shaking, increasing peak amplitudes and prolonging shaking [11]. Liquefaction threat should still be addressed due to the low blow count of the soil and its impact during the 1995 earthquake. Lateral spreading is also a threat, particularly at the edges of man-made fill. During the 1995 earthquake, lateral spreading caused quay wall failures, with displacements reaching up to 2 meters [11].

To address these concerns, we plan to use a piled-raft foundation. Reinforced bored piles, 125 ft deep, will socket into the gravelly layer starting at 120 ft. The raft will consist of a uniformly thick concrete slab covering the building's entire footprint. This foundation design incorporates redundancy by utilizing deep piles that bypass the unstable silt layer, ensuring the building remains stable during liquefaction and minimizing reliance on the silt for support [12]. Additionally, a cable damping system will be integrated into the tower's design. Tensioned cables, anchored within the raft, will absorb and dissipate seismic energy, mitigating the higher peak accelerations caused by amplification [13].

V. Ground Motion Selection

The ground motion selection process utilized the NHR3 NGA-Subduction database, selected for its inclusion of records from the Nankai Trough Subduction Zone. We followed the parameters recommended in the Ground Motion Selection Guide, with a modified upper shear wave velocity limit of 1,100 ft/s to better reflect the Site Class E classification. A weighting function was applied to prioritize periods between 0 and 2 seconds, aligning with the characteristic response of the MCER spectrum.

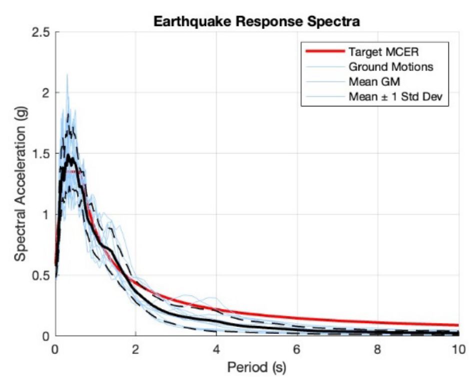

Figure 2: Selection of 11 Ground Motion Matching MCEr

From 30 ground motions yielded, 9 were removed due to visual discrepancies with the target MCER spectrum or peak intensities that were either too high or too low. An additional 7 were excluded for having scaling factors exceeding 3.5, as such large adjustments could produce unrealistic shaking intensities. Finally, the remaining records were ranked by their Mean Squared Error (MSE) relative to the target spectrum, allowing us to select 11 representative ground motions displayed in Figure 2 and listed in Table 1.

Table 1: Metadata of 11 Ground Motions Selected from NHR3 NGA-Subduction Database

NGAsub RSN	Earthquake Name	Date	Magnitude	Epicenter Distance (mi)	Station Name	Station Database Region	Scale Factor
2000092	Nisqually	2/28/2001	6.8	52.29	7032	Cascadia	3.49
2000891	Ferndale	1/10/2010	6.55	48.77	89509	Cascadia	2.86
4000427	Tohoku	3/11/2011	9.12	314.99	HASAKI2	Japan	2.7
4003182	IbarakiOff	3/11/2011	7.92	55.54	HASAKI2	Japan	2.1
4017059	Miyagi_Pre.Off	4/07/2011	7.15	62.72	ISHINOMAKI	Japan	1.56
4027321	Geiyo	3/24/2001	6.83	34.55	MATSUYAMA	Japan	2.07
4027329	Geiyo	3/24/2001	6.83	40.48	IYO	Japan	2.23
4028565	Tokachi-oki	9/25/2003	8.29	131.04	SHIRANUKA	Japan	1.59
4040629	IbarakiOff	3/11/2011	7.92	75.38	YOHKAICHIBA	Japan	2.31
5004242	2016-11-13T11:02:56.346Z	11/13/2016	7.85	39.76	WAKC	New Zealand	3.35
5004244	2016-11-13T11:02:56.346Z	11/13/2016	7.85	28.78	SCAC	New Zealand	2.39

VI. Structural Description

Our structure, shown in Figure 3, experiences several challenges including high shear and torsion around the central walkway in Zone 2 and significant moments at the base. These are resolved through a symmetrical diagrid system on all four faces of the building. The diagrid bracing system extends up the height of the building and acts to distribute load from dead load connections to the base of the tower. Vertical trusses spanning all zones increase strength at the corners, bringing loads to the ground as quickly as possible.

The high bracing density from Zone 1 continues into Zone 2 to mitigate shear and torsion and address the building's inherent weakness in Zone 2 due to the walkway. The bracing concentration decreases in Zone 3 to reduce stiffness and acceleration at the top of the building. The diagrid system is positioned out of plane with the columns and exterior floor members to minimize connections and floor member joints.

The floor plans start with X bracings and move to triangle-based systems in Zone 2 to accommodate the walkway. The floor members tie each diagrid face together to create a rigid system, and the floors' symmetry reduces torsion.

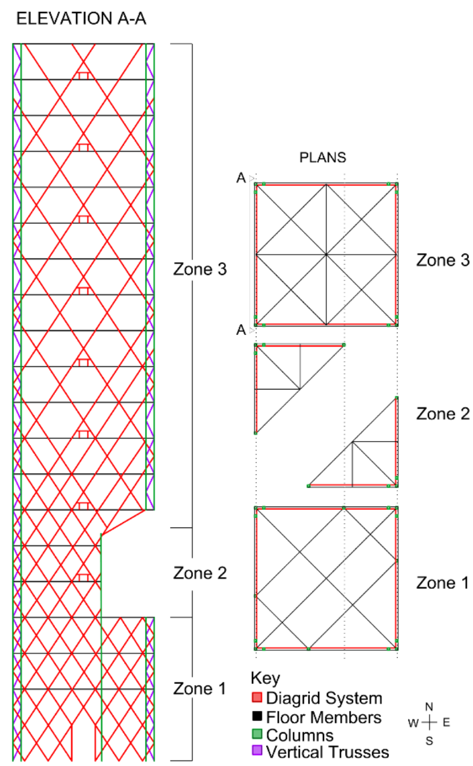

Figure 3: Structural Diagrams

VII. Predicted Structural Behavior

To predict our building's performance, we will model our structure in SAP2000 to estimate its response to each ground motion. We will then physically test the balsa-wood model using impulse and ground motion tests. Accelerometers attached to the base and roof of the model tower will record acceleration data. The impulse test will provide frequency response through Fourier transforms, while ground motion tests will yield peak roof acceleration and maximum relative displacement data. These physical tests will be compared with the SAP2000 results to offer a more accurate overall performance estimate.

References

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