

University of Toronto Seismic Design Team

2020 Design Overview

Outline

- The Competition
- Structural Concepts
- Auto-Builder
- Testing and Calibrating
- 2020 Competition Tower
- Other Projects



The Competition

What we do: Design and build a 1.5m balsa wood tower that is loaded with 8kg of weights and is tested under 2 ground motions

Objectives

- Promote the study of earthquake engineering to undergraduates
- Build relationships between EERI student and professionals
- Provide undergraduate students with practical design and project experience

2020 Rule Changes: Buildable Area

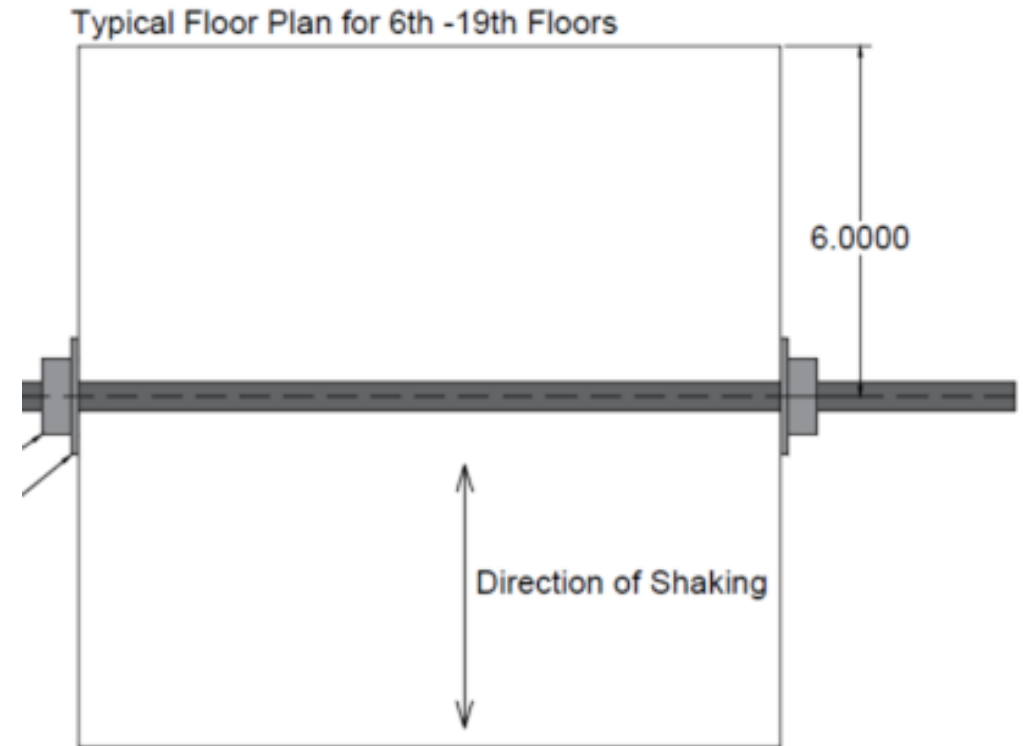
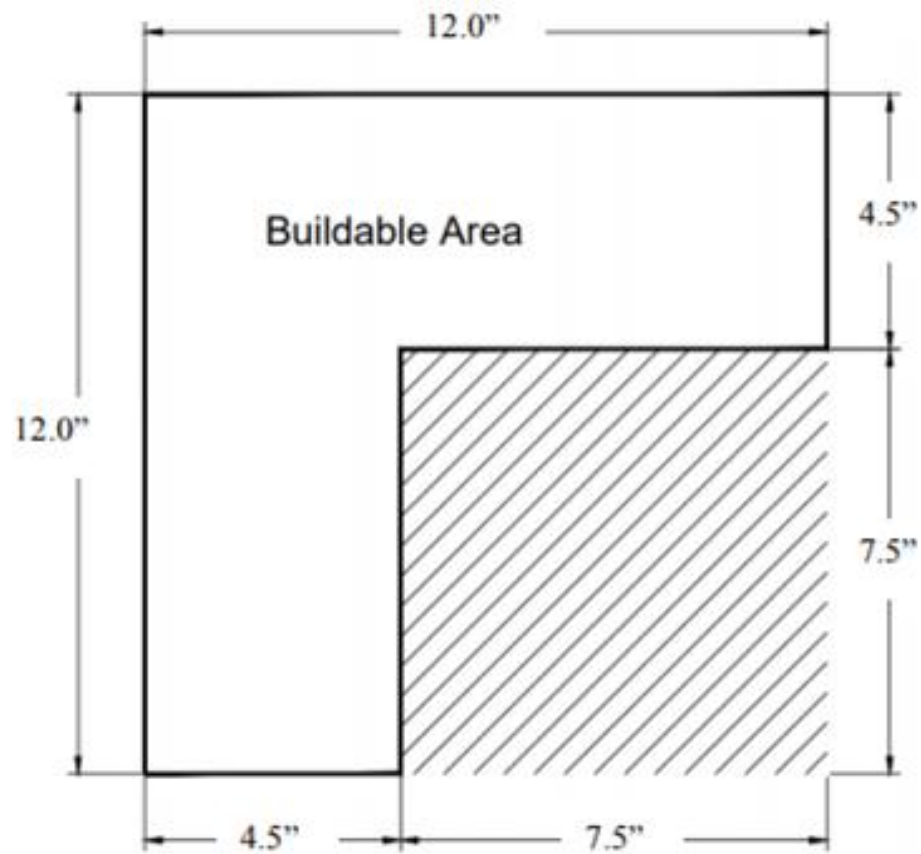
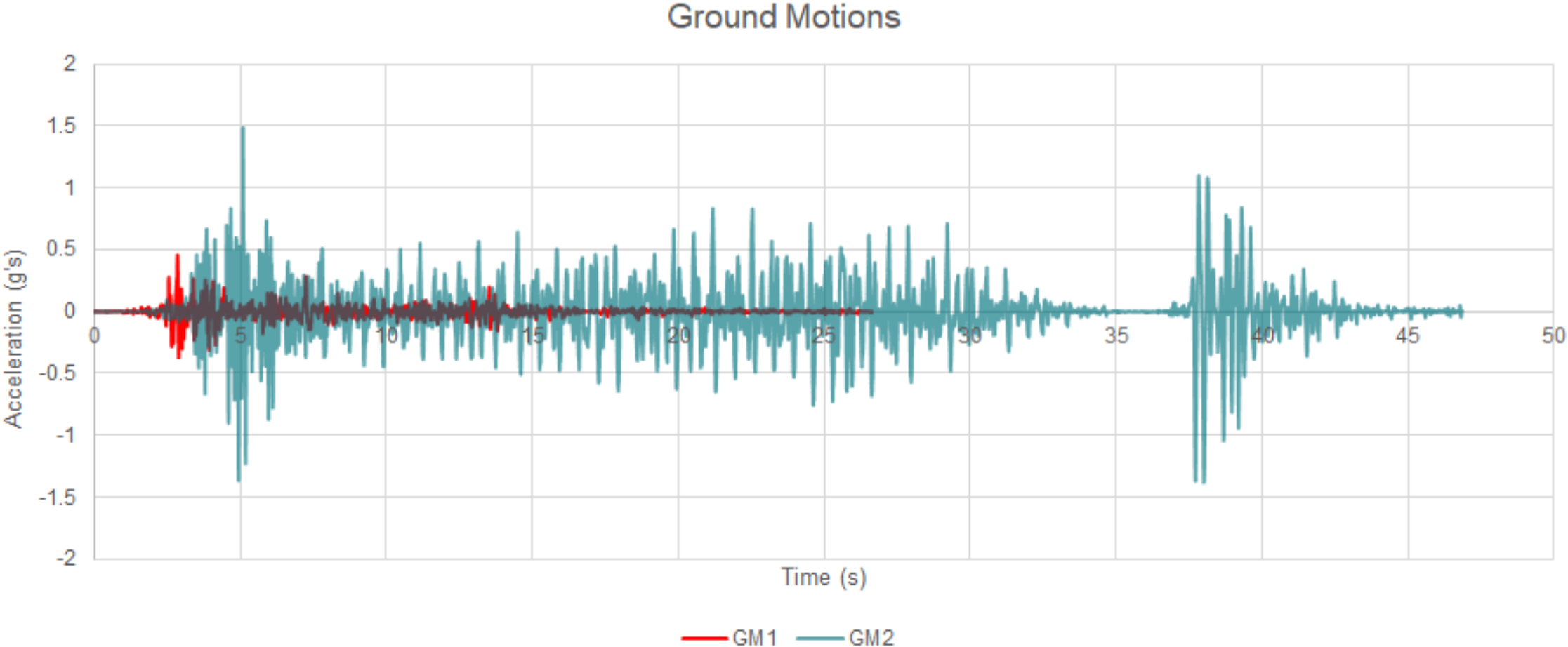


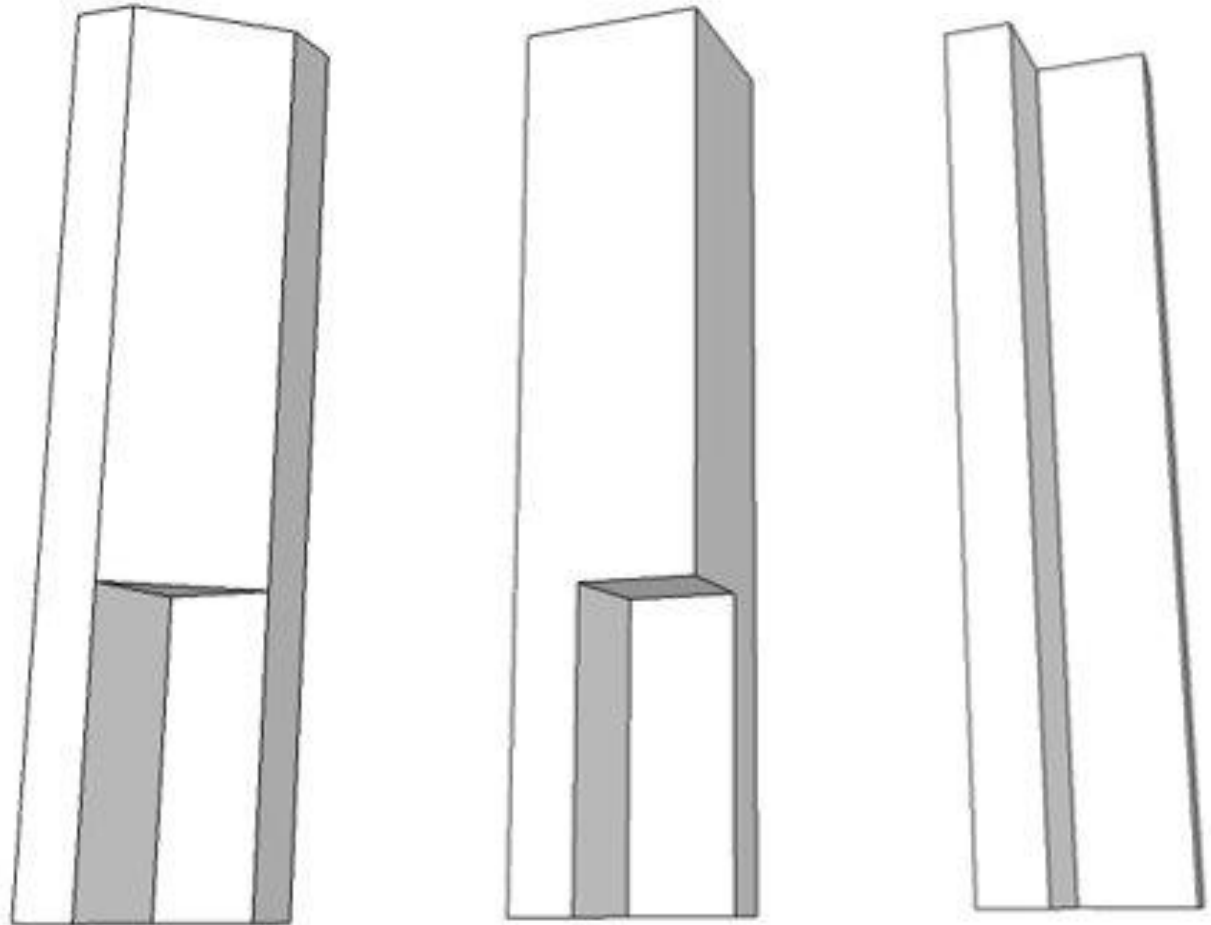
Figure 5-1: Maximum Floor Plan Dimensions Floors 1-5

2020 Rule Changes: Ground Motions



Structural Concept Development

- Three Main Design Concepts:
 - L shape transitioning to pentagon
 - L shape transitioning to square
 - L shape for full height



Final Structural Concept

Structural Performance

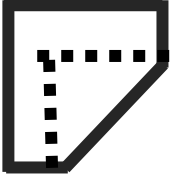

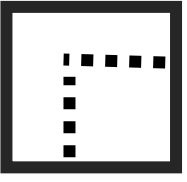









- Peak Roof Drift
- Peak Roof Acceleration

Centre of Rigidity

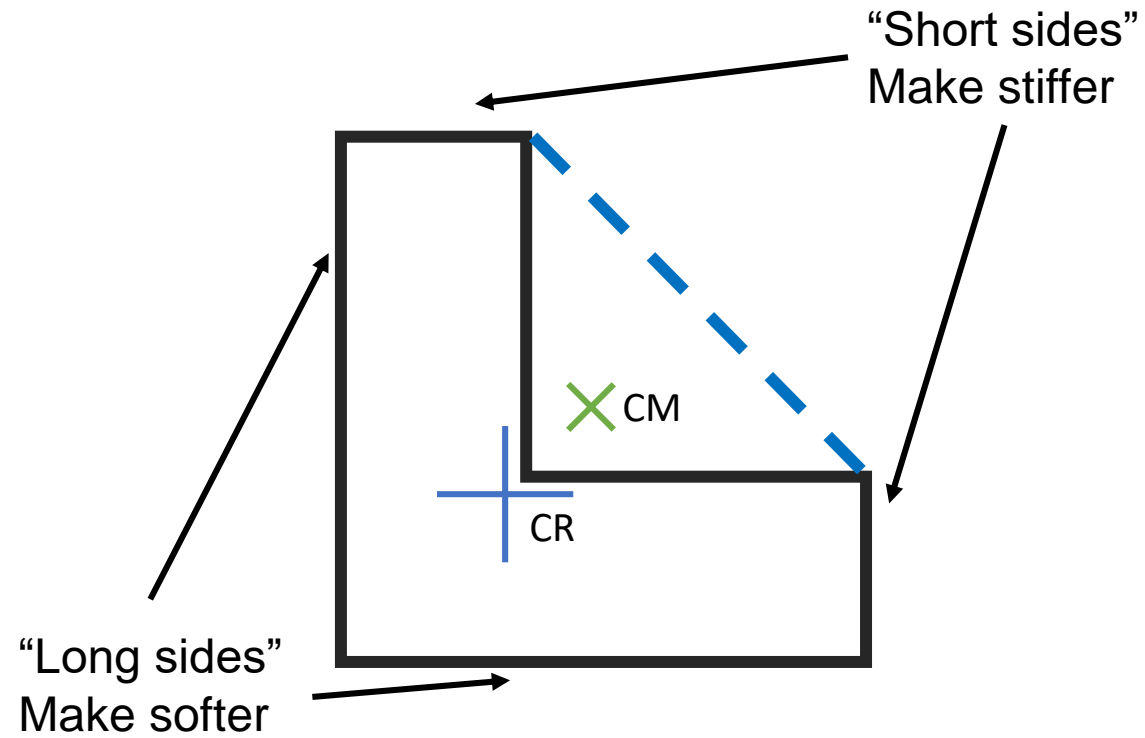
- Close to centre of mass

Constructability & Weight

- Fewest faces
- Easier connections

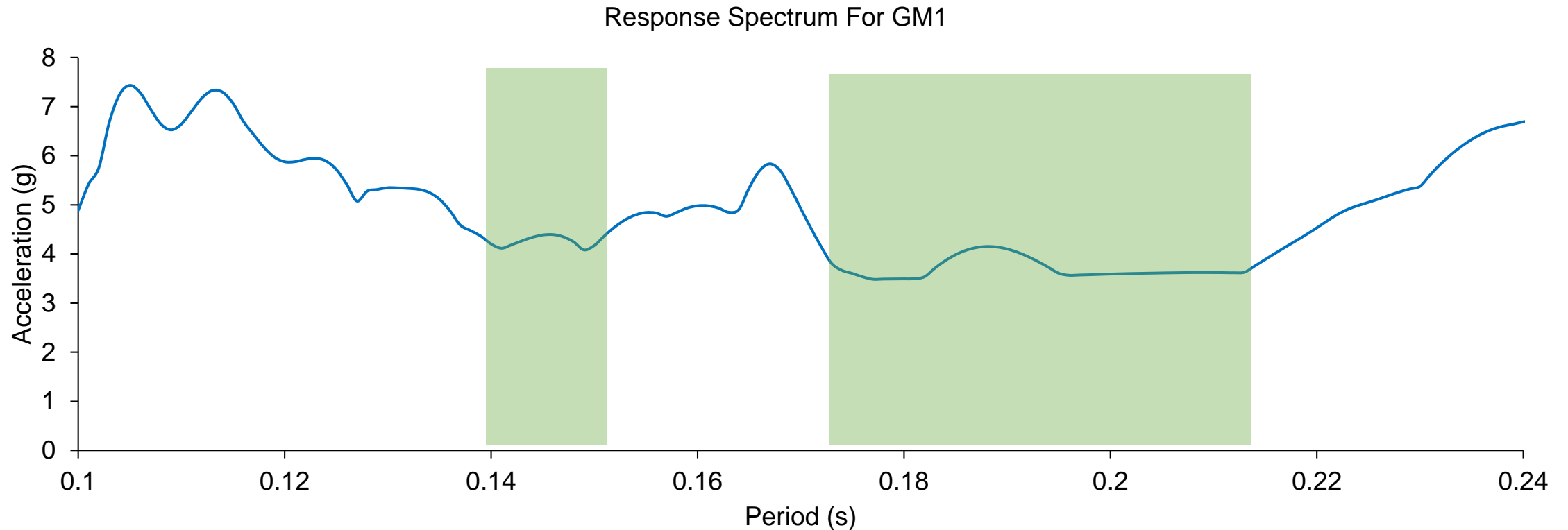
			
			
			
			

Reducing Torsion



Optimizing Period

- Response spectrum used to determine optimal periods



Auto-Builder

- Developed an "Auto-Builder" program to help design iteration
- Over 15,000 models were created



Variables

- Bracing schemes
- Column sections

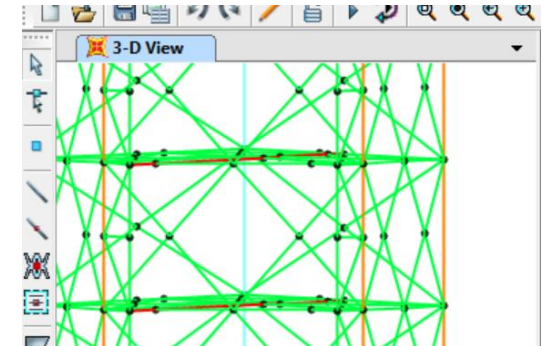
Input →

```
print('\nInitializing SAP2000 model...')  
# create SAP2000 object  
SapObject = win32com.client.Dispatch('SAP2000')  
# start SAP2000  
SapObject.ApplicationStart()  
# create SapModel Object  
SapModel = SapObject.SapModel  
# initialize model  
SapModel.InitializeNewModel()
```

Python + VBA

Creates all possible permutations of variables

Combinations →



SAP2000

Models and analyzes all combinations

↓ Output

Spreadsheet of Results

Test Tower Design

Diverge: Brainstorm structural concepts while accounting for centre of rigidity, load paths, and relative stiffness of storeys and faces

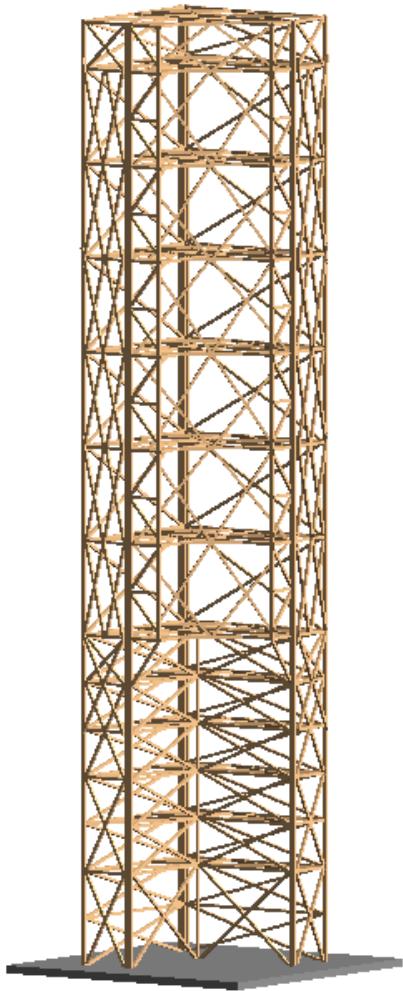
Model: These ideas are modelled using SAP2000 assuming fixed connections, linear elastic behaviour, classic damping, and isotropic material

Converge: The best design is selected and built according to its seismic score, force in members, and performance in the ground motions

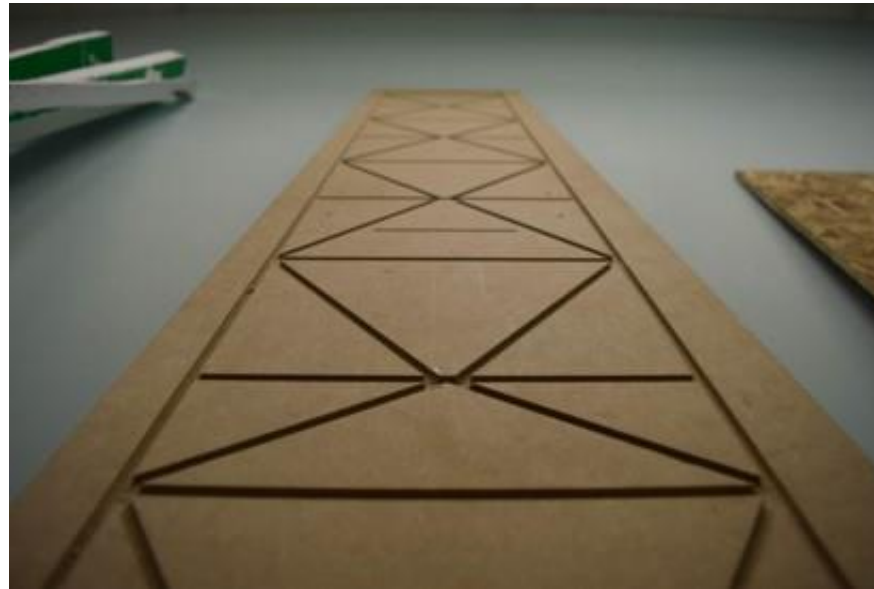
Test, calibrate, iterate

Test Tower Construction

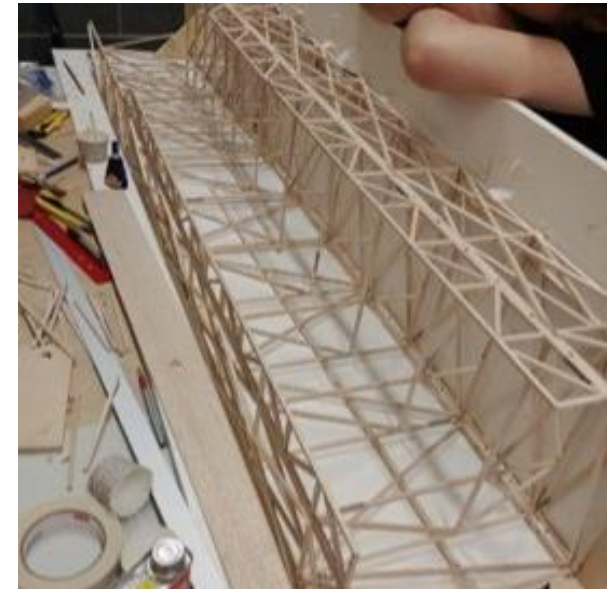
1. Modelled in Revit to lower confusion in construction
2. Each elevation is built in CNC'ed jigs
3. Faces attached with floor beams as supports



(1)



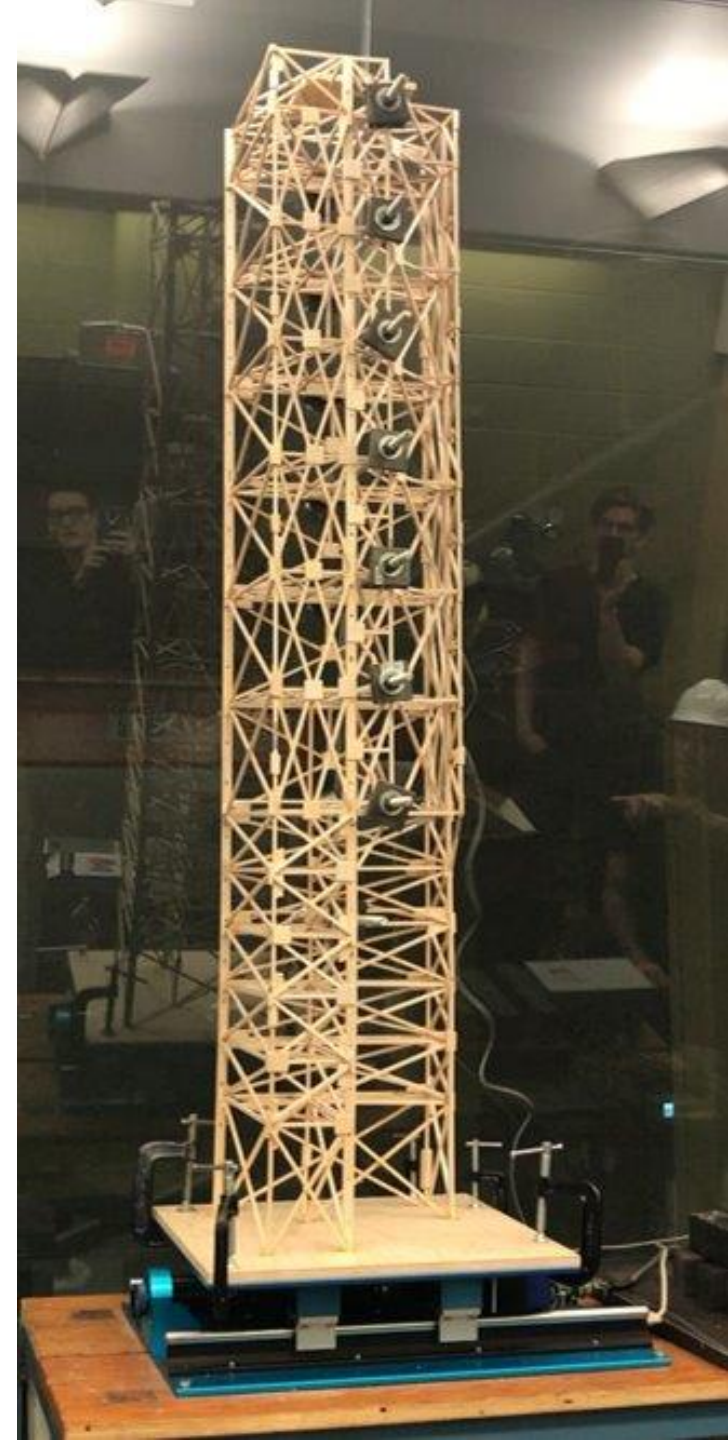
(2)



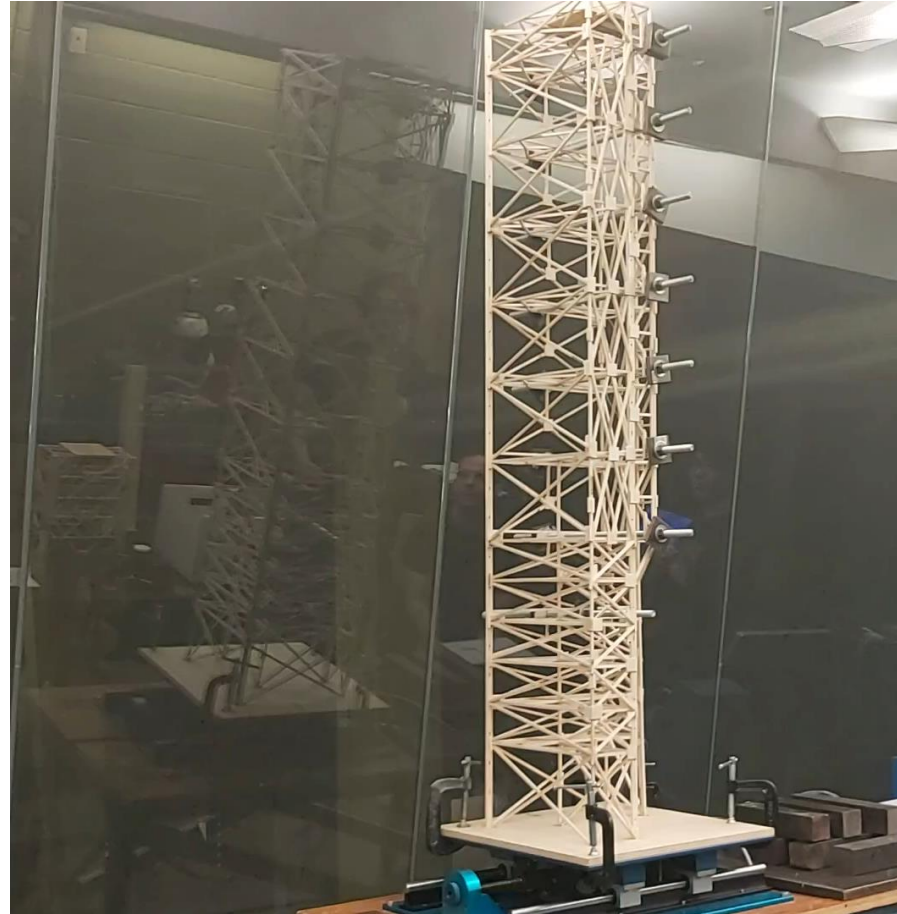
(3)

Testing

- White Noise
 - Small amplitude test with varied frequencies
 - Use Fast Fourier Transform to see dominant frequencies of tower
 - Obtain **tower period**
- Free Vibration
 - Vibrate close to tower's natural frequency, stop suddenly
 - Use log decrement to obtain **damping ratio**

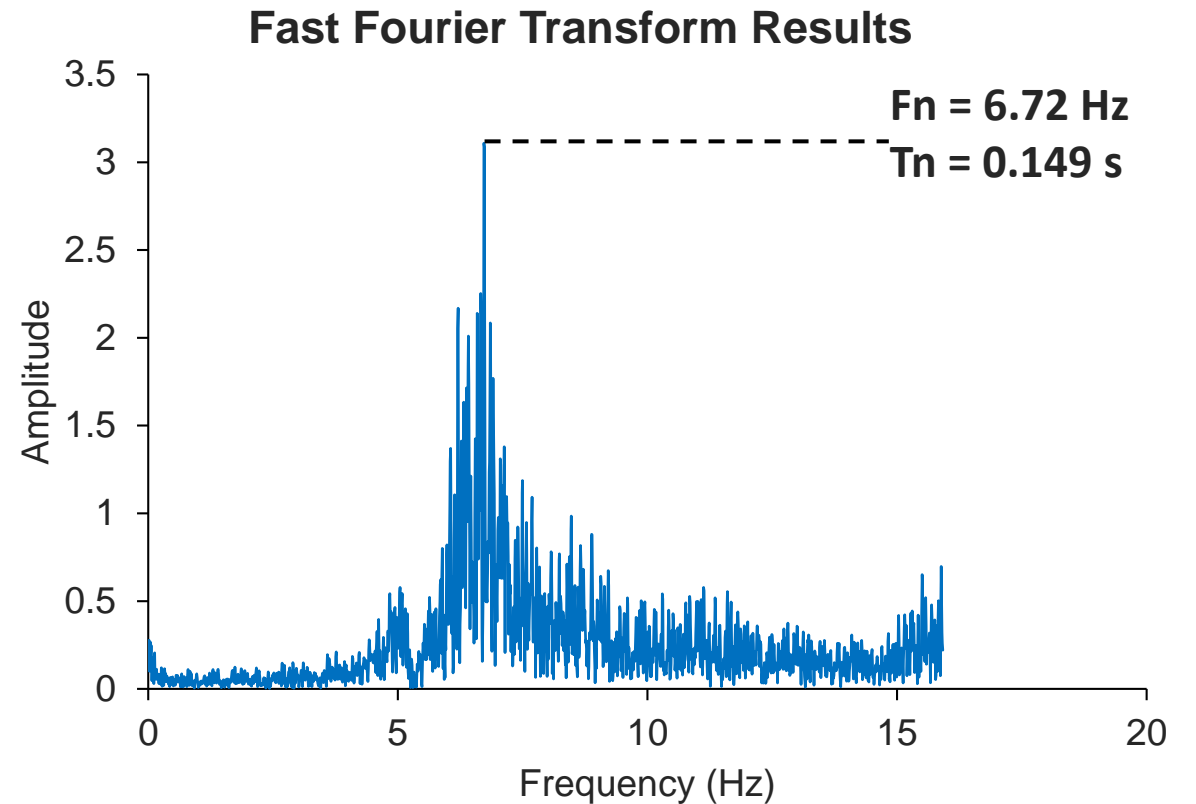
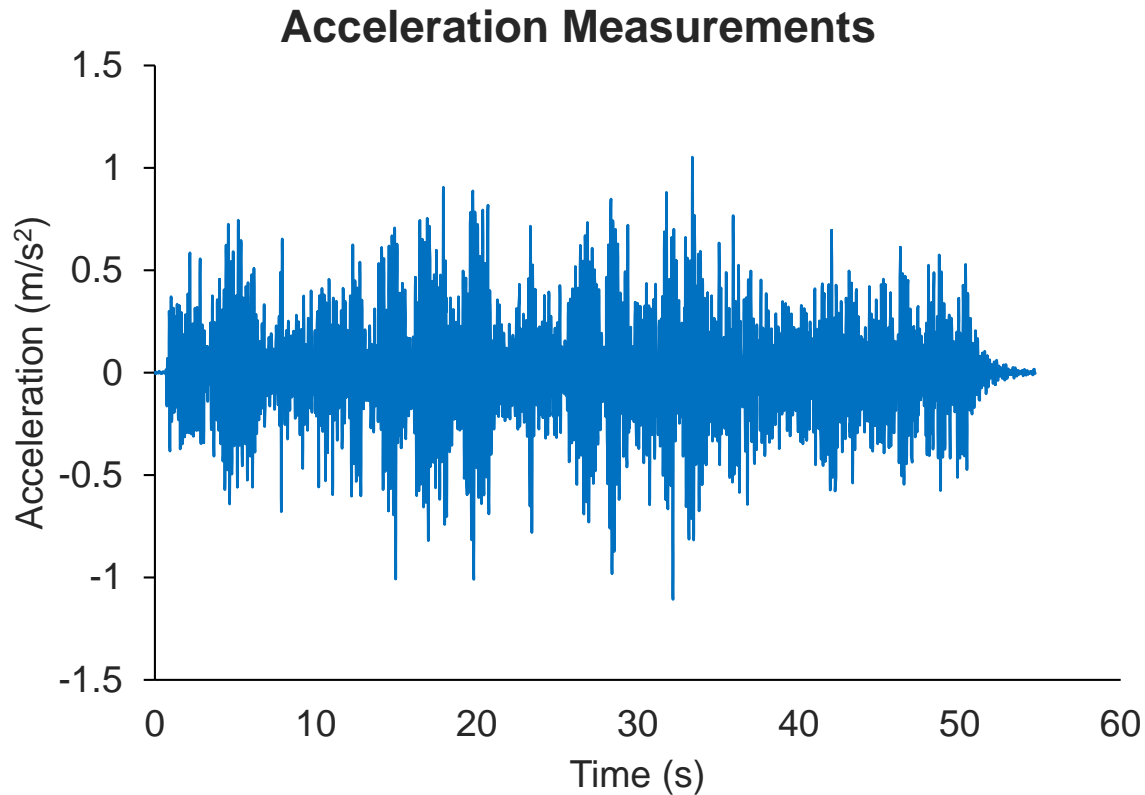


GM 2 Testing



Calibration

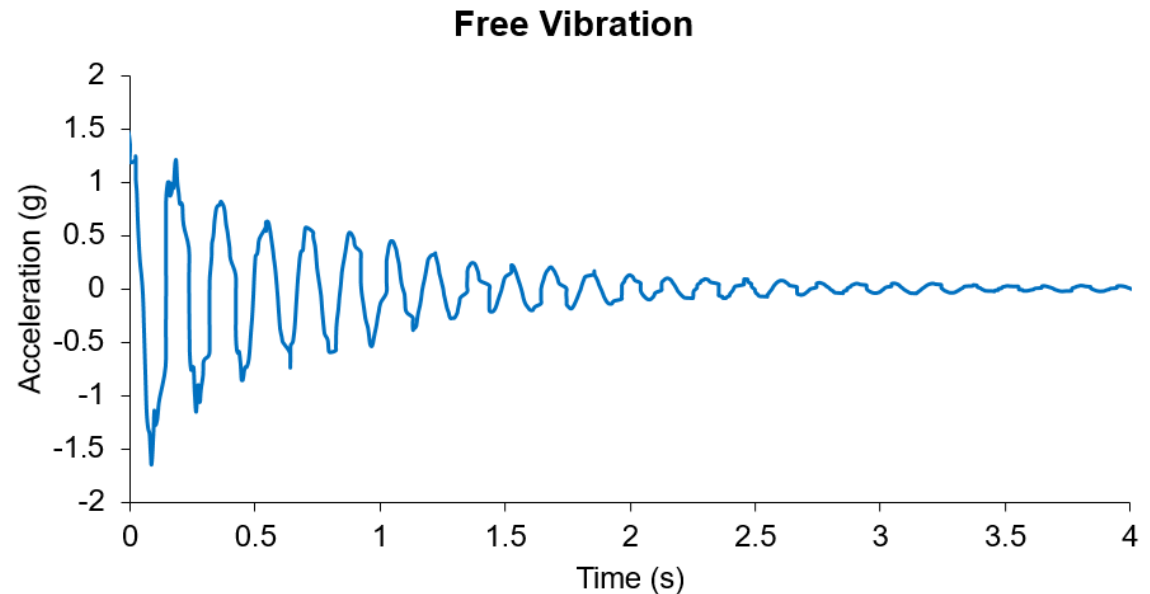
- Adjust Young's Modulus (E) of Balsa to match **period**
 - 0.1488s \rightarrow 1.6 GPa



Calibration

- Adjust constant damping ratio & damping ratio for spectra based on measured **damping ratio**
 - Damping ratio used: 4%

Method	Positive Peaks	Negative Peaks
ConsecutivePeaks	3.89	4.02
From 1 st Peak	4.09	4.32
From 2 nd Peak	4.47	3.71



Tower Progressions

Issues

- Significant variability in balsa wood materials
- Variability in construction (connection quality)
- Period may fall into suboptimal range

Plan

- Scan through auto-builder results to find towers of various stiffness
- Find a progression that stiffens the tower with structural additions
- Ensure ease and feasibility of additions during construction

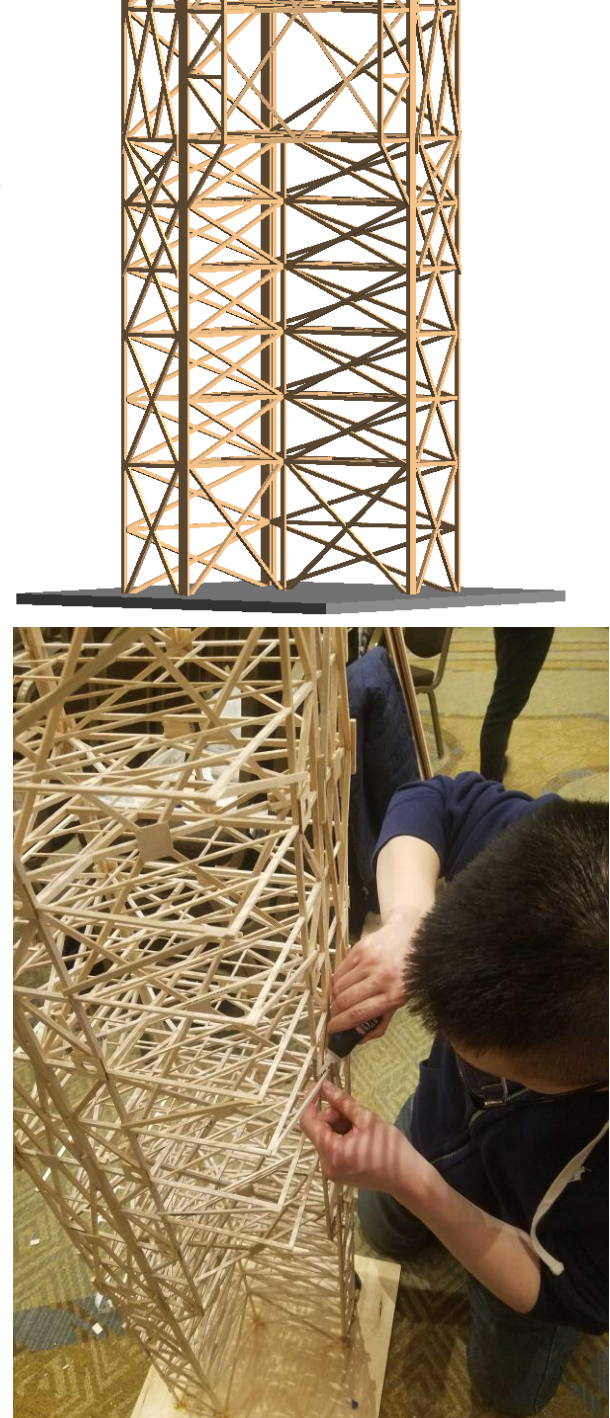
Tower Progressions

Progression	Period (1 GPa)	Cr Error	Change
Base	0.1872	1.811	
1	0.1749	0.443	Add 6" shear wall
2	0.1685	0.384	Increase to 9" shear wall
3	0.1633	0.087	Double Columns on Short Side Bottom
4	0.1535	0.099	Quad Columns on Centre Bottom
5	0.1519	0.081	Double Columns on Short Side Top
6	0.1488	0.082	Quad Columns on Centre Top

↑ in Stiffness ← + Components

2020 Competition Tower

- Using information from testing and calibration, found optimal base tower
- Built this tower and tested to find frequency
- Compared the base model with the first progression and found that the base tower performed better in GM1 (acceleration and displacement less)
- Finished architectural pieces and shipped to competition in San Diego!



2020 Competition Results

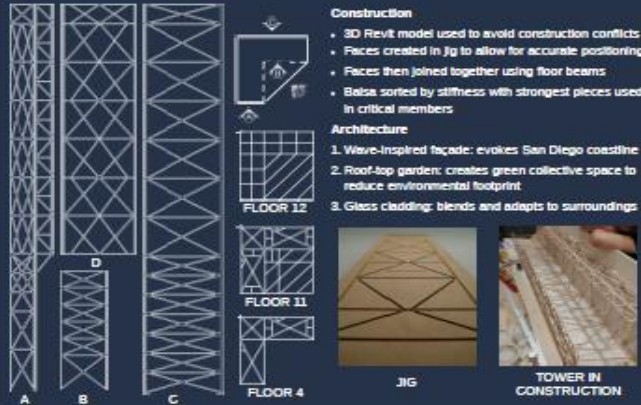


Construction

- 3D Revit model used to avoid construction conflicts
- Faces created in Jig to allow for accurate positioning
- Faces then joined together using floor beams
- Balsa sorted by stiffness with strongest pieces used in critical members

Architecture

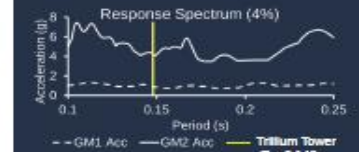
- Wave-inspired façade: evokes San Diego coastline
- Roof-top garden: creates green collective space to reduce environmental footprint
- Glass cladding: blends and adapts to surroundings



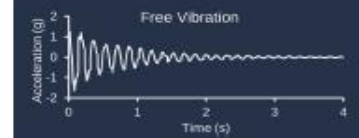
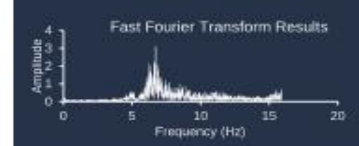
FLOOR 12
FLOOR 11
FLOOR 4

JIG
TOWER IN CONSTRUCTION

- Design**
- Asymmetrical structure with stiff L-shaped base
 - Closed tube structure with exterior bracing
 - Bracing schemes and column sections chosen for optimal centre of rigidity and period
 - Floor plans provide continuous torsional load paths
 - Detailed connections to prevent local failure & increase connection stiffness to match model
 - In-house Python program which creates and models permutations of parameters such as column section and bracing schemes in SAP2000. Over 15,000 towers modelled and analyzed
 - Python script for centre of rigidity calculations
 - Response spectra used to determine optimal period
- Analysis**
- SAP2000 Model Time History Analysis
 - Fixed connections
 - Constant Damping
 - Linear behaviour, confirmed by checking maximum member stresses
 - Response Spectrum Analysis:
 - 4% damping ratio obtained from free vibration
 - CQC used as modes are closely spaced and interact heavily
 - Using 5 modes, 98% mass participation



- Testing + Calibration**
- White Noise Test
 - FFT to obtain fundamental frequency
 - Adjust Young's Modulus of Balsa in SAP2000 to match period of constructed tower
 - Free Vibration Test
 - Damping ratio, obtained from log decrement of exponential decay in test, used to calibrate SAP2000 model and response spectra



Ground Motion	Peak Roof	
	Disp. (in)	Peak Roof Acc. (g)
GM1	0.234	1.19
GM2	1.05	4.86
Score	Value	
FAR	+\$619,962	
FABC	-\$131,268	
FASC	-\$103,000	
FABI	+\$373,695	

Future Projects - Dampers

- Viscoelastic Rubber material
- Shear-deformation based viscous damping (material dissipates energy via heat loss)
- Across all tests:
 - $c \sim 1500 - 2000 \text{ Ns/m}$
 - $k \sim 15000-18000 \text{ N/m}$



Future Projects - Dampers

