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

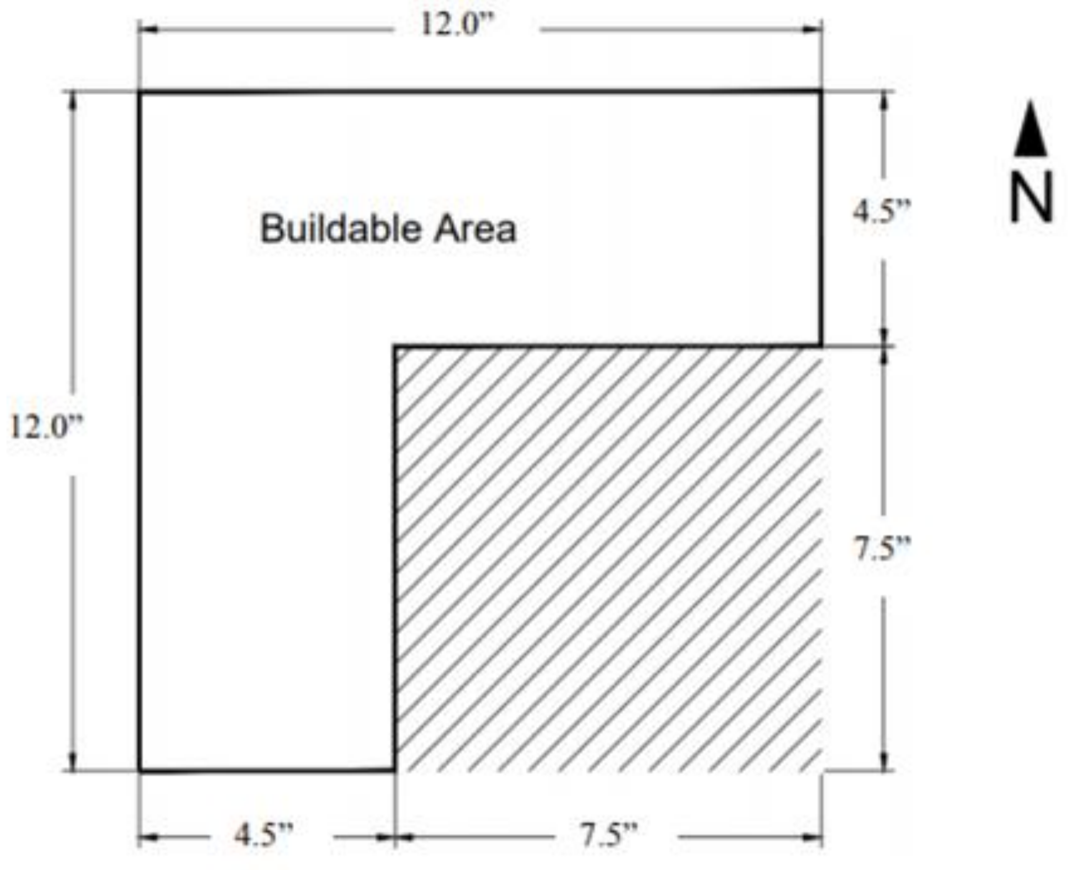
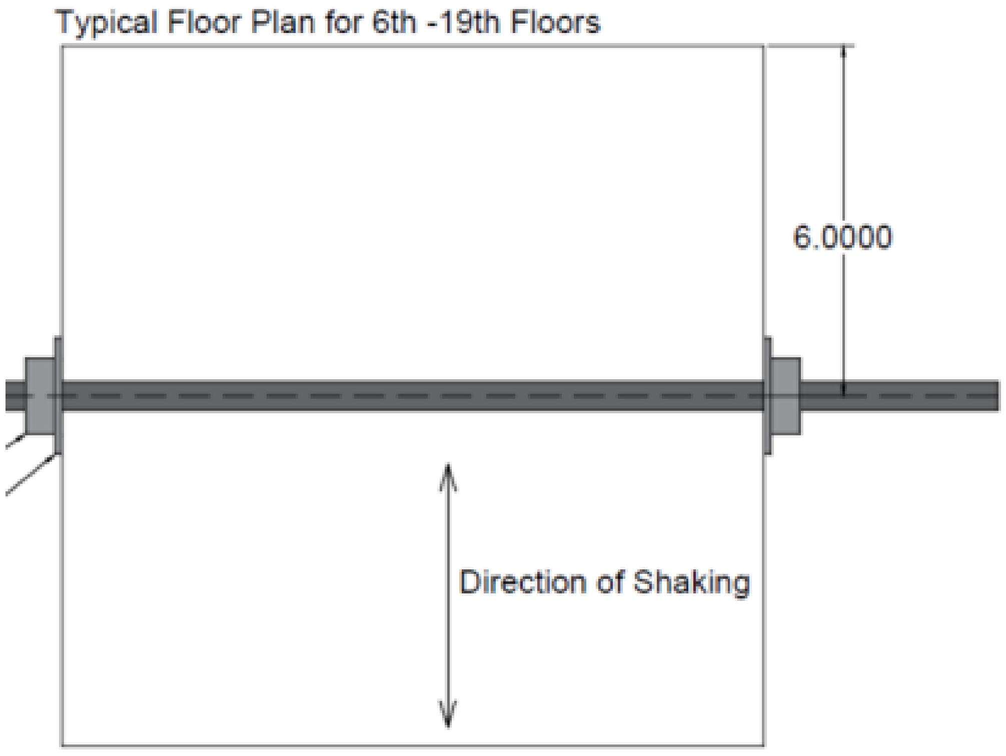
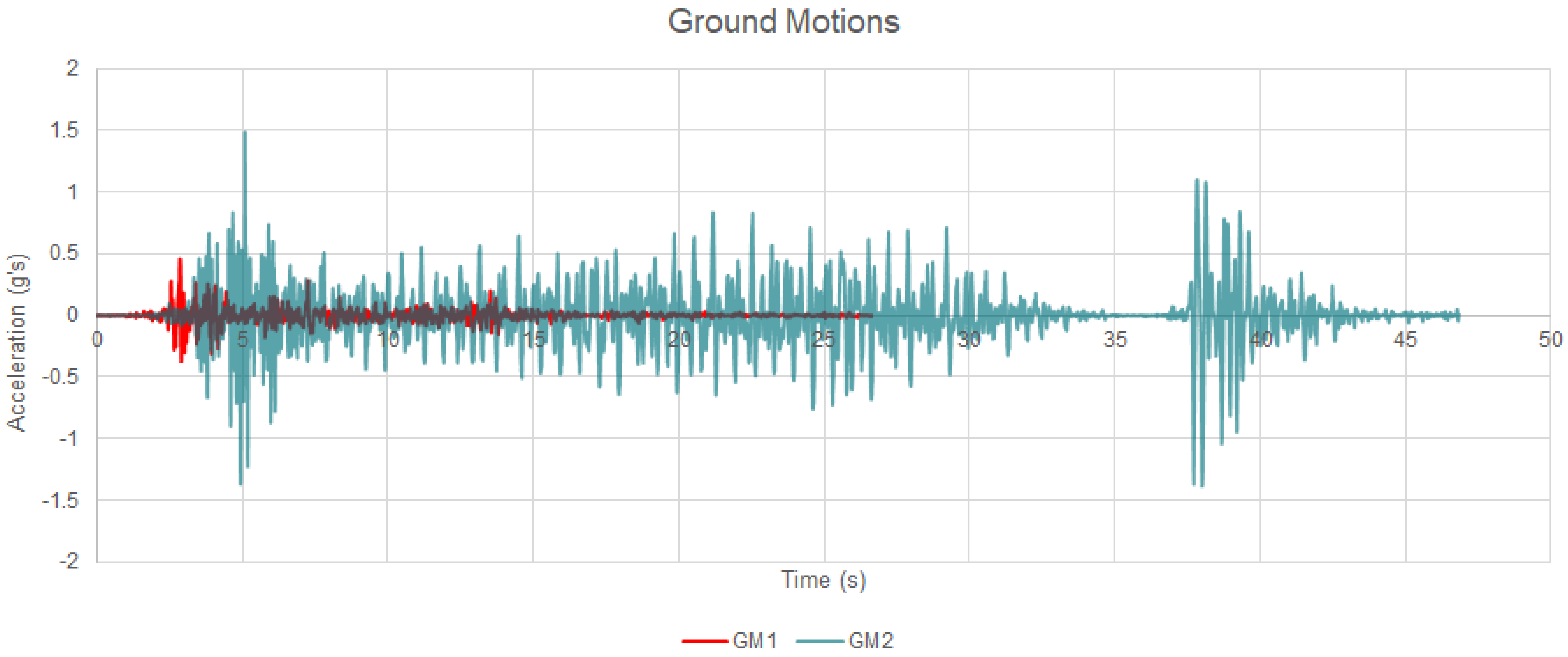


Figure 5-1: Maximum Floor Plan Dimensions Floors 1-5

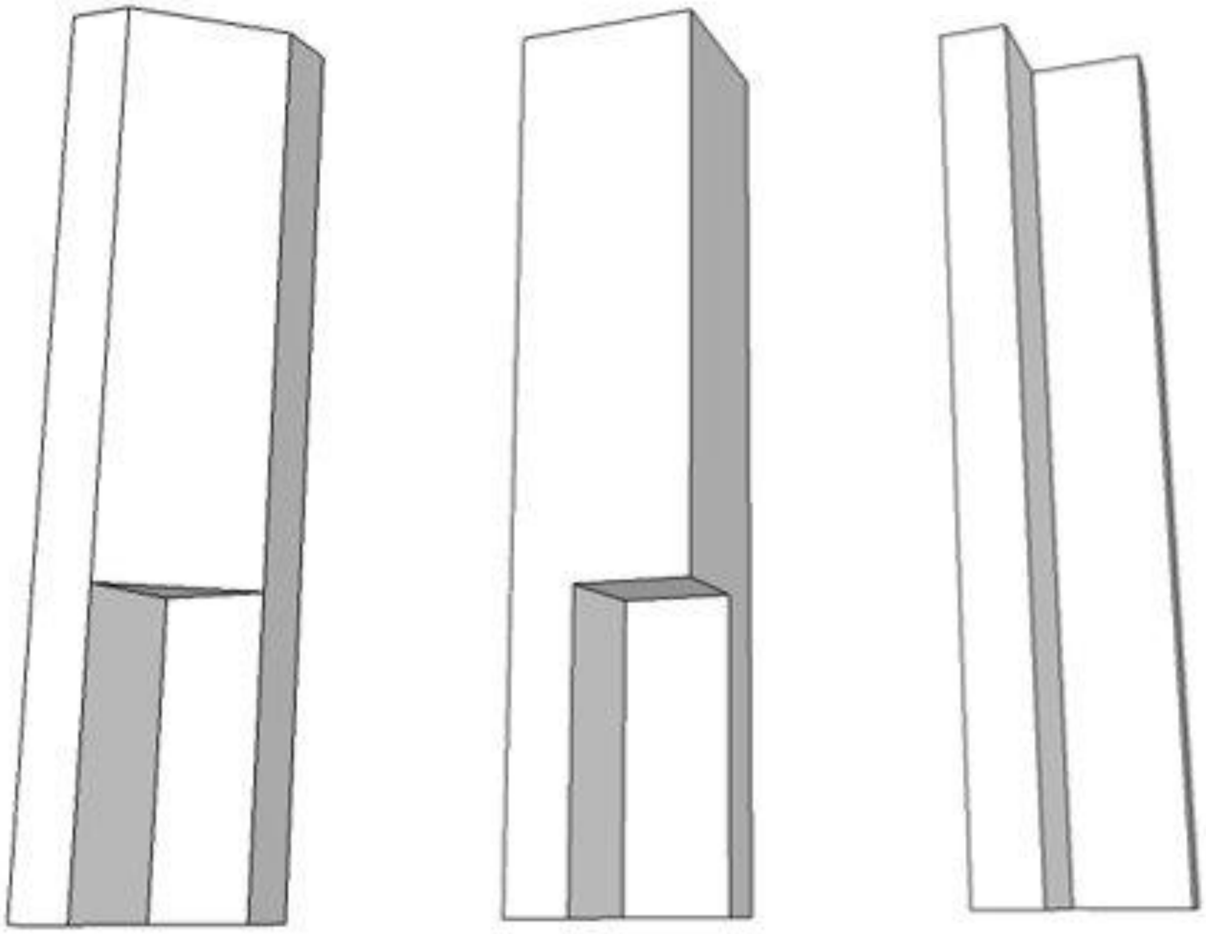


2020 Rule Changes: Ground Motions

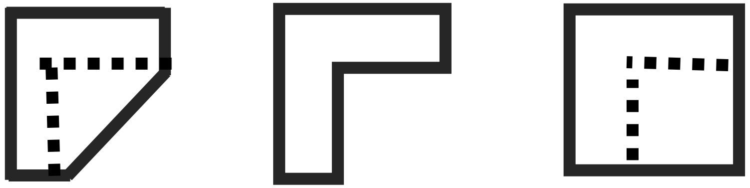


Structural Concept Development

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

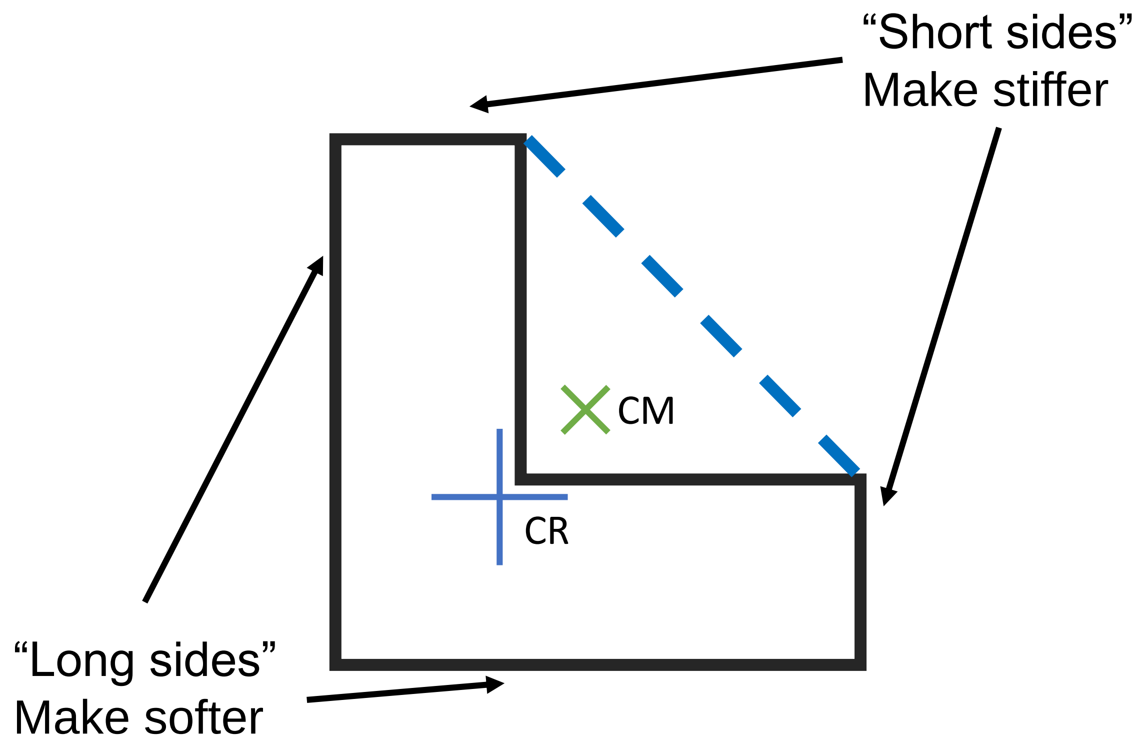


Final Structural Concept



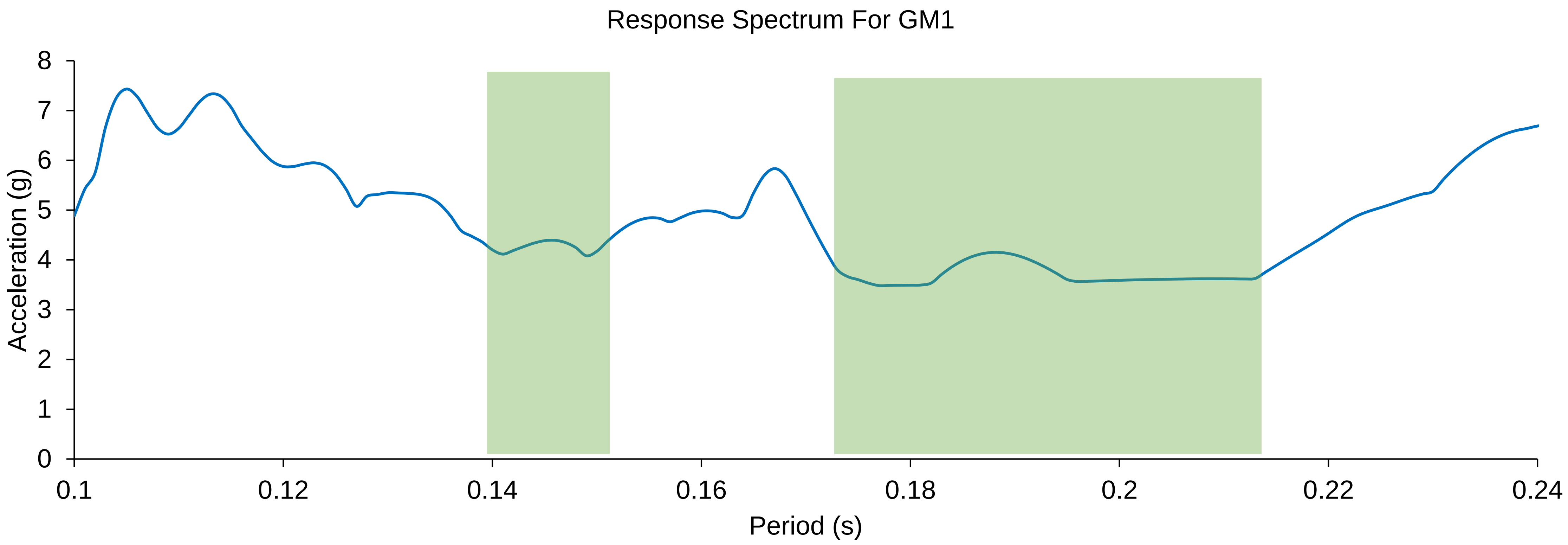
Structural Performance	•Peak Roof Drift •Peak Roof Acceleration	✓	✓	✗
Centre of Rigidity	•Close to centre of mass	✓	✗	✓
Constructability & Weight	•Fewest faces •Easier connections	✓	✓	✗

Reducing Torsion



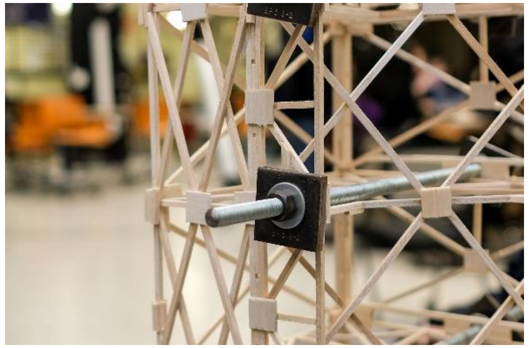
Optimizing Period

- 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

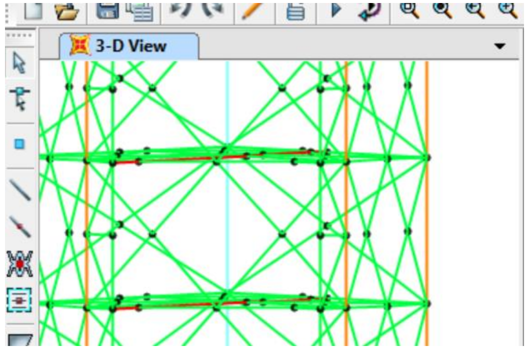
Input →

```
print('\nInitializing SAP2000 model...'
# create SAP2000 object
SapObject = win32com.client.Dispatch('S
# 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

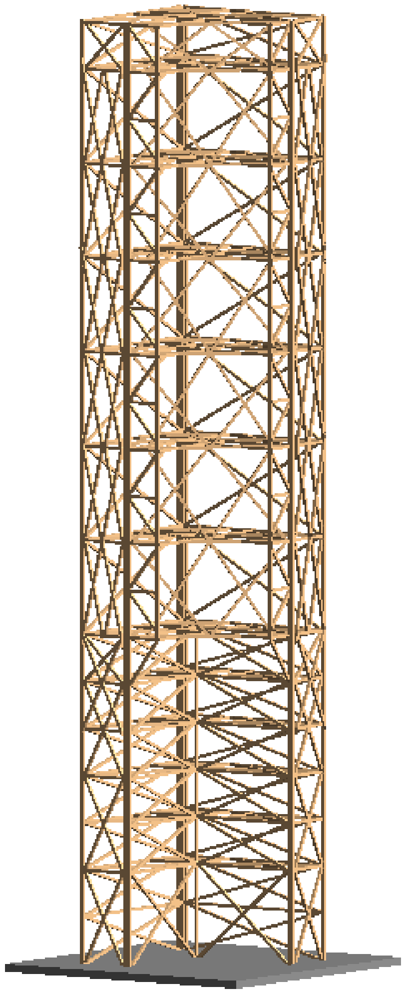
Model: These ideas are modelled using SAP2000 assuming fixed connections, linear elastic bahaviour, classic damping, and isotrophic material

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

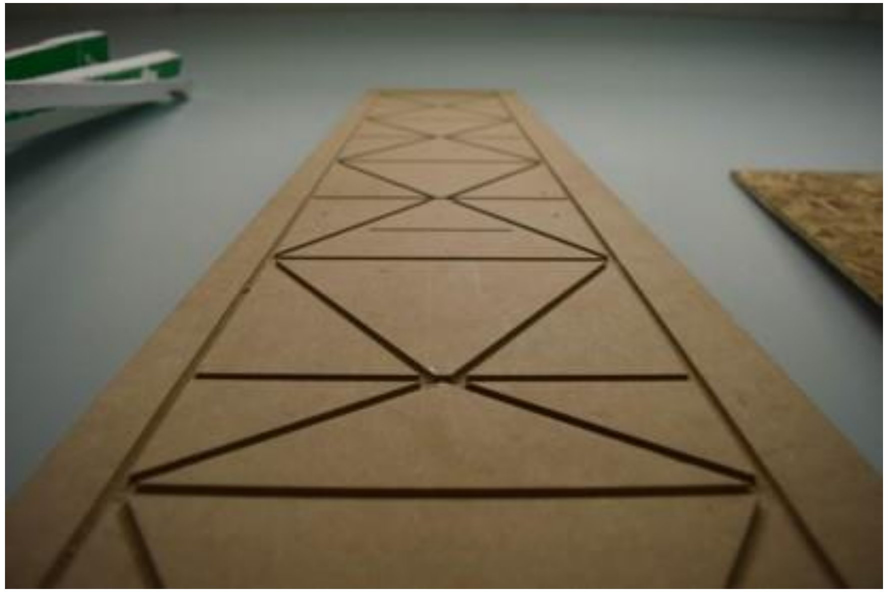
Test, calibrate, iterate

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)



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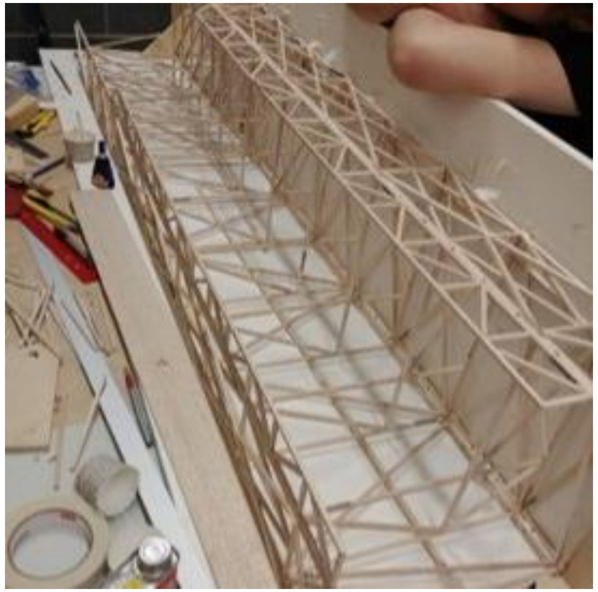
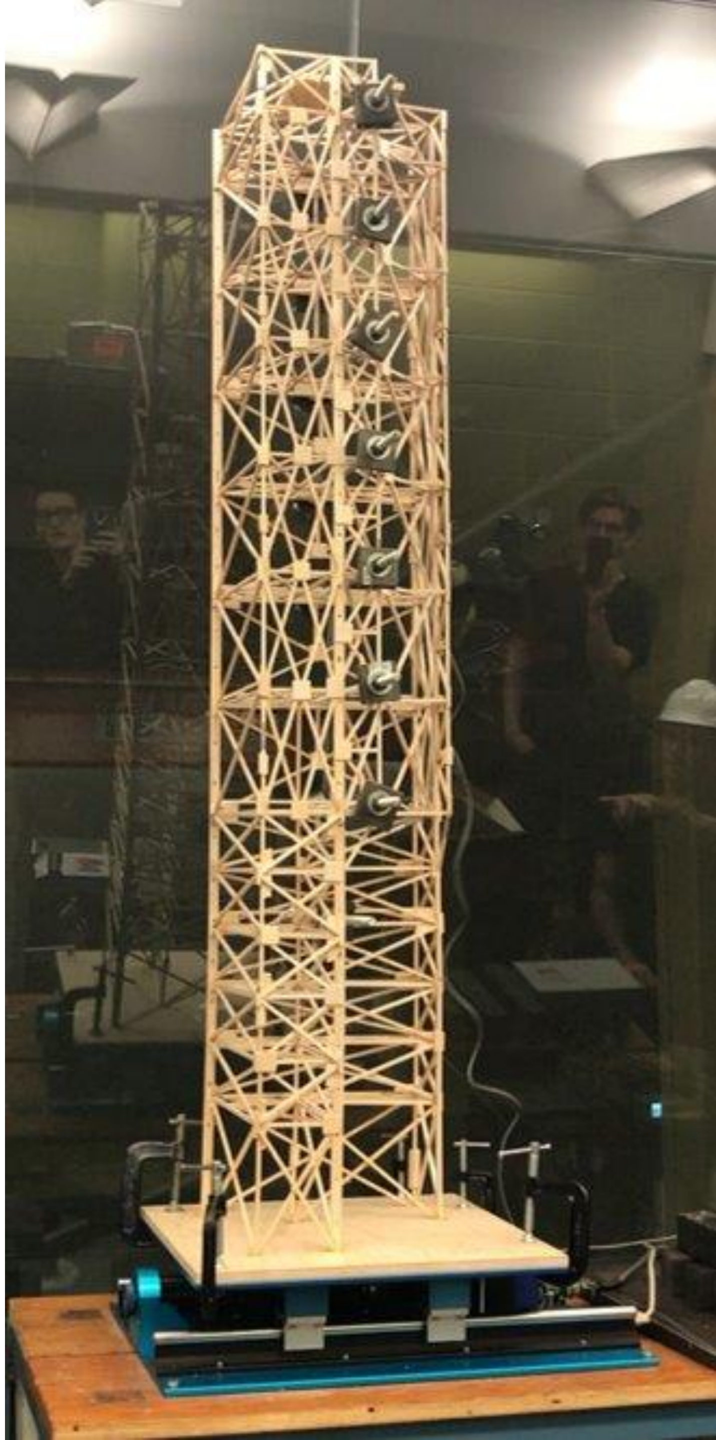


(3)

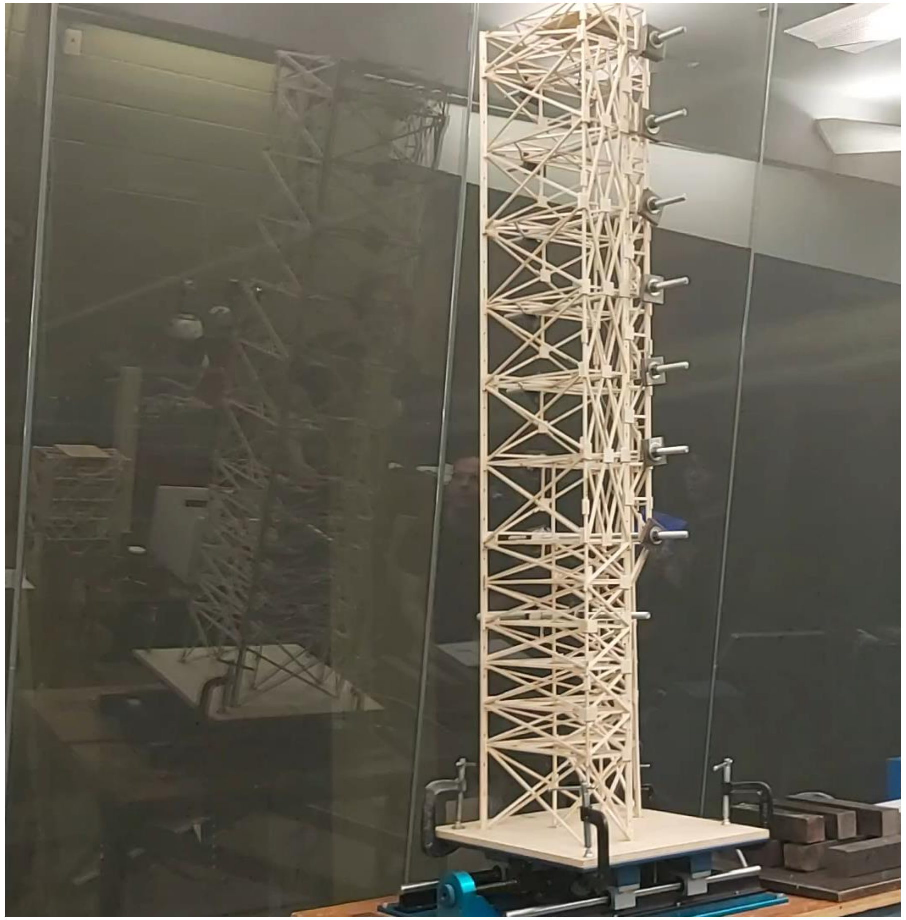
Testing

- 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**

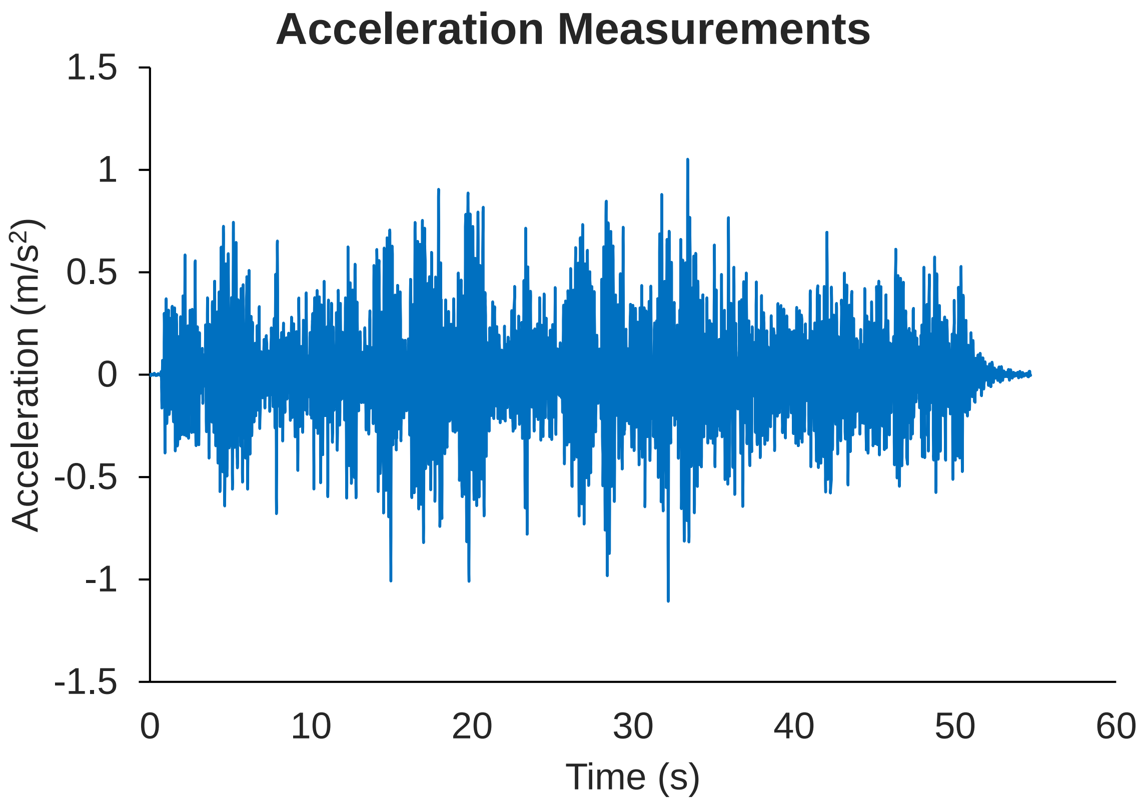


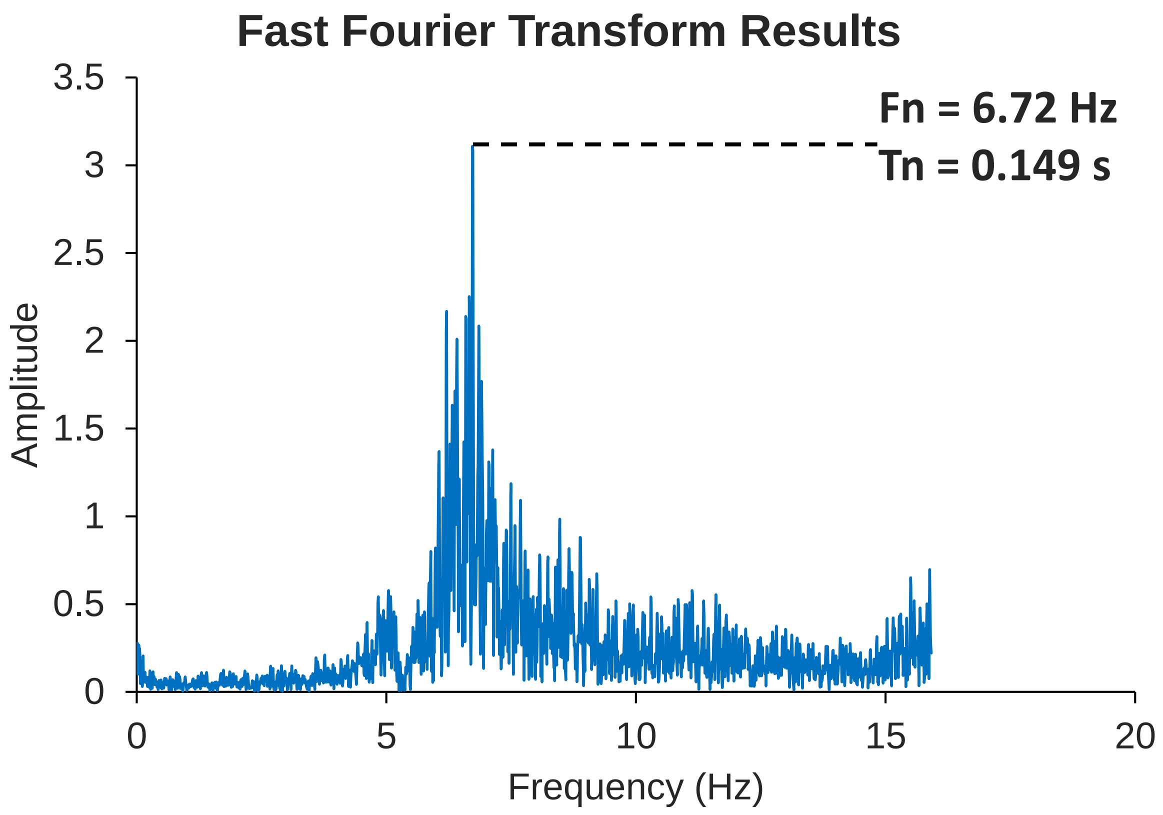
GM 2 Testing



Calibration

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



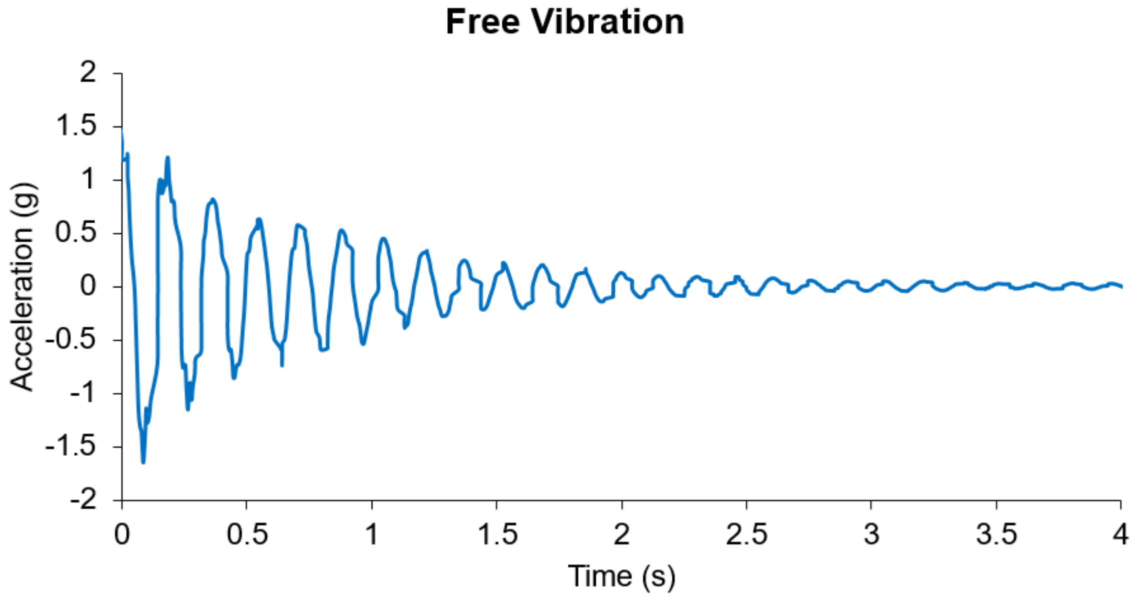


Calibration

- 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 1st Peak	4.09	4.32
From 2nd 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

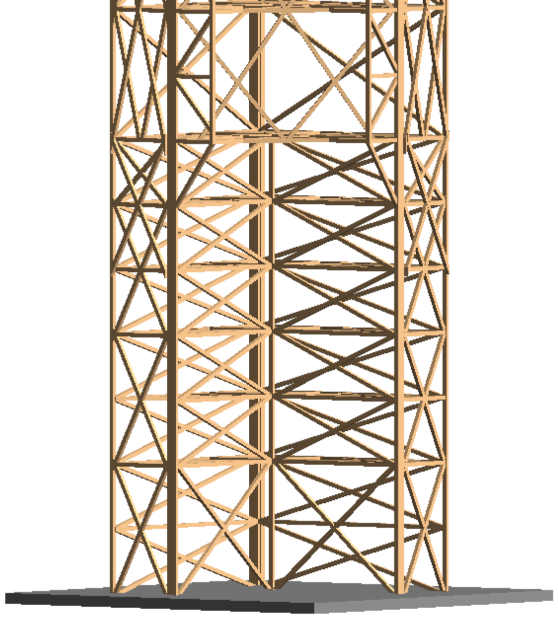
Tower Progressions

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

Future Projects - Dampers

- Viscoelastic Rubber material
- Shear-deformation based viscous damping (material dissipates energy via heat loss)
- Across all tests:
  - c ~ 1500 – 2000 Ns/m
  - k ~ 15000-18000 N/m

Future Projects - Dampers