國立臺灣科技大學
NATIONAL TAIWAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARMENT OF CIVIL AND CONSTRUCTION ENGINEERING

MATERIALS AND STRUCTURE TEST
CT3902301

Final Project Report

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1. Design concept

- **Three Stories:** The structure is composed of three levels.
- **Inverted V Truss:** The main structural element is an inverted V truss, which is crucial for the stability and load distribution of the tower.

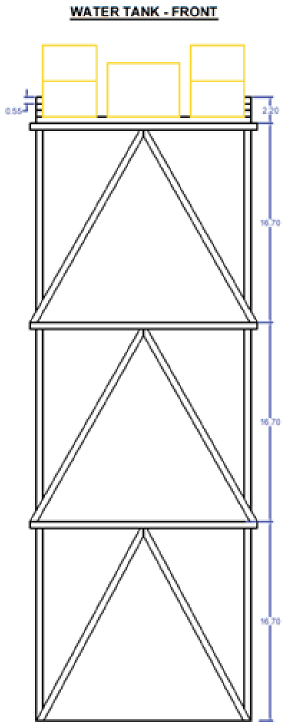


Figure 1. Water tank front view.

- **Roof and Loading Platform:**

o Roof Composition: The roof of the water tower consists of three wooden sticks. This provides a stable and even surface at the top of the tower where the loading platform can sit.

- **Loading Platform:**

o Seven supports: This platform is made up of seven wooden sticks to provide enough space for blocks to sit securely.

o Wall for Safety: A wall is included on the loading platform to prevent blocks from falling, especially if they are not securely glued and tend to swing.

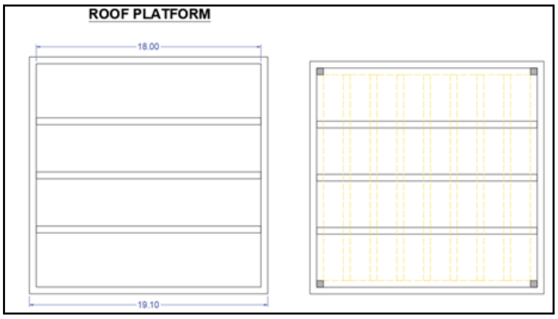


Figure 2. Roof platform.

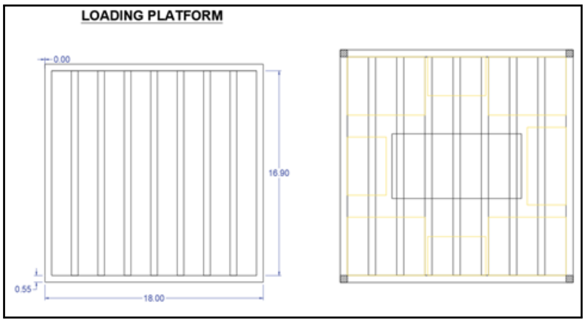


Figure 3. Loading platform.

Joint Reinforcement:

Column Joints:

o Reinforced with Strings and Silicone Glue: This additional reinforcement ensures the structural integrity of the columns, which are critical for vertical load-bearing.

Truss and Beam Joints:

o Not Reinforced: Joints in the truss and beams are not additionally reinforced. This is due to the inherent strength of the truss design and a consideration of flexibility in these areas. The joint must be well glued nevertheless.

Load distribution arrangement:

To make all 12 blocks fit on the platform, two of them were placed on top of each other as we can see in the sketch below.

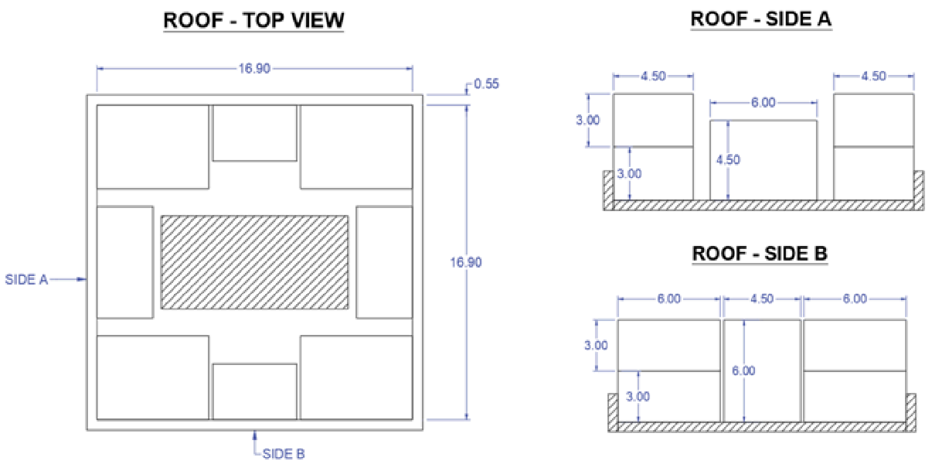


Figure 4. Loading distribution.

Structure modeling details

The structure modeling was performed in the software PISA 3D, where the following data was input to create the model:

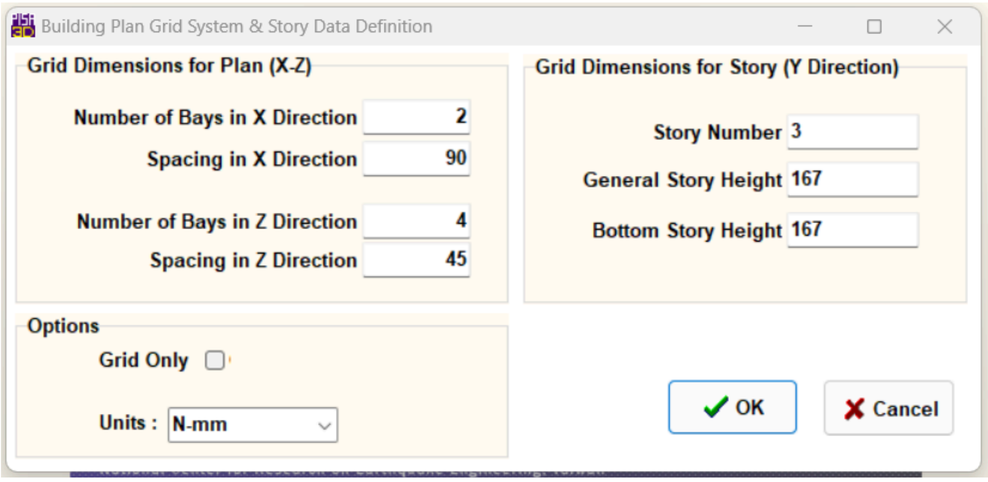


Figure 5. PISA modeling data.

The material properties were selected according to the material of the wood sticks that were given which was Medium Density Fiberboard (MDF), having the following properties:

Elastic Modulus: 4000 MPa

Poisson's ratio: 0.25

Assembly process

The building consists of three floors, and at the top a platform, on which the bricks were placed.

For this process, the following steps are followed:

1- Making the cuts of the beams, columns and braces for the building.

The measures of the same were:

Beams: 19.1 cm

Columns: 50.1 cm

Braces: 18.5 cm

2- The construction process began by cutting the columns and beams to the aforementioned size.

3- To attach the beams to the columns, for each column, each beam was glued at each floor, that is, at every 16.7 cm. The beams were glued on the exterior sides of the columns, not inside, as observed in figure 6.

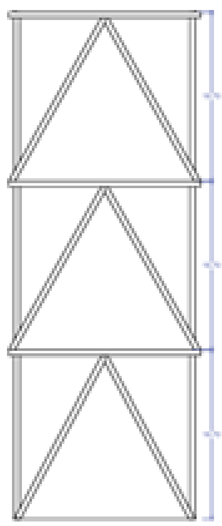


Figure 6. Front view of structure.

4- In this way, the first face of the building was formed, which had two columns of 50.1 cm in height, horizontally spaced by 18 cm, with beams of 19.1 cm in length.

5- The same procedure in steps 2, 3 and 4 were used to make the second face of the structure.

At this time, between the two faces of the developed structure, there were a total of 4 columns of 50.1 cm and 6 beams of 19.1 cm.

***Figure** 7*. Assembly process.

6- After all this process, the elaboration of the braces began. The braces were cut to the size mentioned in step 1, in addition to that, it was necessary to use a file to achieve the desired 45-angle between the diagonals. The amount of braces per floor were 2, giving a total amount of 6 per face. (See figure 8)

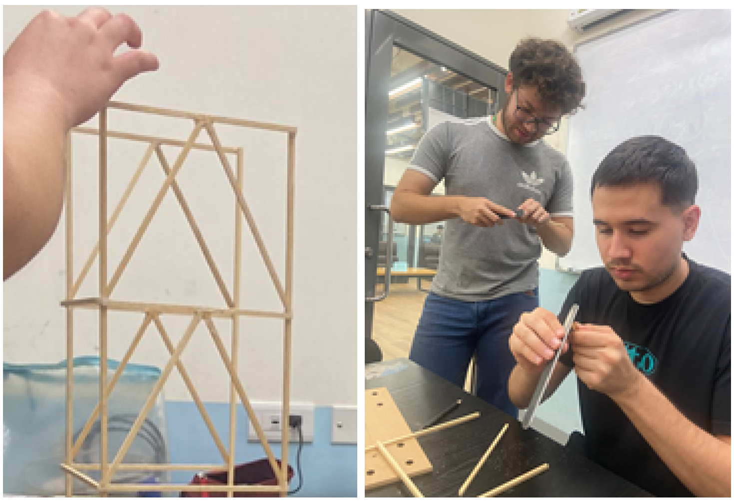


Figure 8. Assembly process.

It can be seen that the braces have been glued with silicone, each one located from one side of the column based on the first beam already placed, and then intercept that brace with the midpoint of the next beam. We repeated this step to make the braces between the second and third beams.

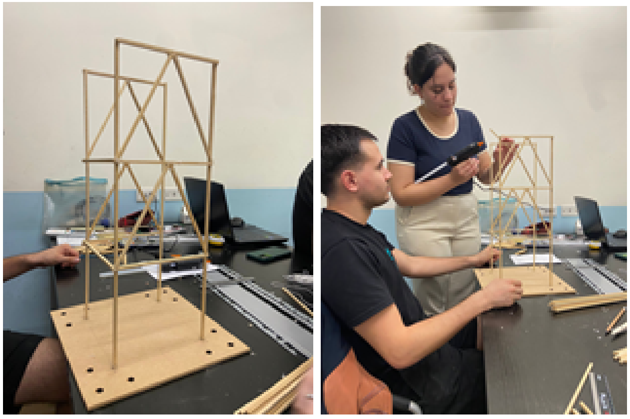


Figure 9. Assembly process.

As can be seen in the figure above, the two faces already made with the columns were glued together at the same height as the other beams, forming the third and fourth faces of the structure. It can also be seen that the braces between the base and the first beam were still missing. The structure was glued to the base after joining the four faces to ensure stability.

7- After the structure was completely assembled, with all the faces glued together, all that remains is to glue the braces between the base and the first beam. This process was repeated for each of the 4 faces, and in the end, the structure was as follows:

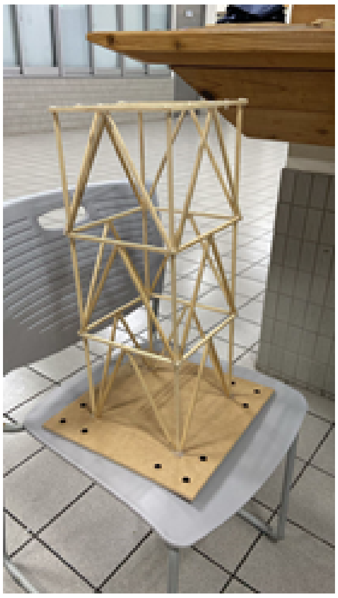


Figure 10. Assembly process.

Note: The braces were glued on the outside of the column and their interception with the beam, the other side of the braces were glued at the midpoint of the upper beam and inside, not on the outside, as seen in the image.

8- Then we proceeded to the elaboration of the roof of the structure, where, as can be seen in the image, the separation between beams was 3.8125 cm apart, since the thickness of the wooden beams is counted, these are glued with silicone, in the way that can be seen in the following image.

Figure 11. Assembly process.

9- Finally, on that roof the loading platform was made, with dimensions of 16.90 cm x 16.90cm and approximately 2.20 cm high since the walls of the platform are made up of 3 wooden rods glued with silicone, as can be seen in the following images:

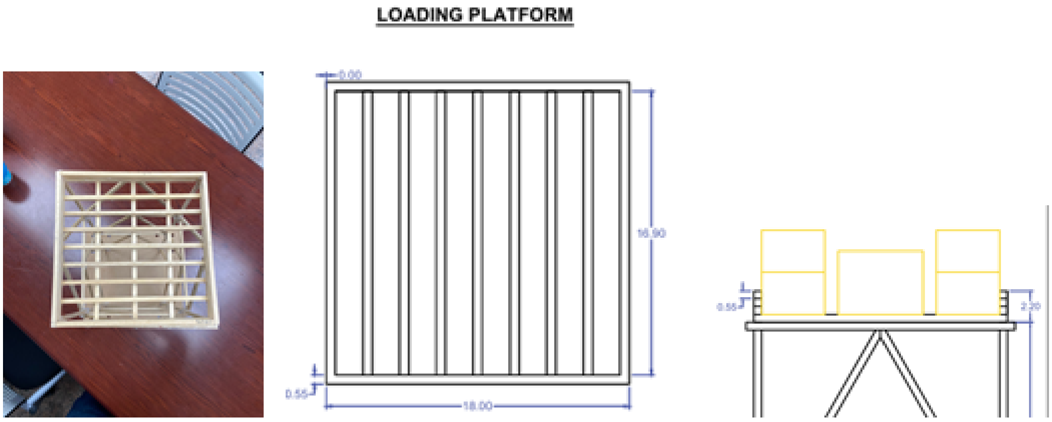


Figure 12. Assembly process.

10- The last step was to tie each joint with the provided thread to ensure its rigidity and stability, and on this knot of thread, more silicone is added to make it even stronger and then let it dry, in this way the construction of the structure culminates.

The culminated structure can be seen in the following image:

Figure 13. Finished structure.

The location of the 12 bricks on the loading platform can be observed in figure 14.

Figure 14. Finished structure with mass blocks.

2. Load testing

For the load testing, we chose 12 blocks to place above the loading platform, yielding a total mass of 7.62 kg. The distribution was as follows:

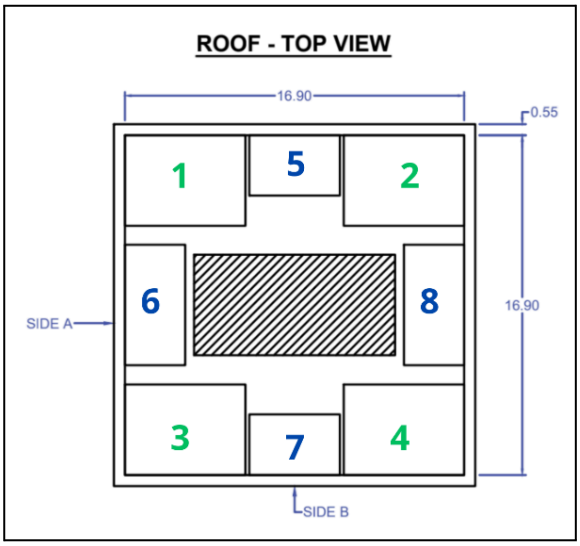


Figure 15. Placement of blocks on 3F.

For the corners (1, 2, 3 and 4), the mass blocks were placed in two layers, that is, one on top of the other.

For the sides (5, 6, 7 and 8), the mass block was placed in one layer; only one mass block per side.

3. <u>Transmission of forces</u>

We calculate the forces applied at *3 top nodes* because of the 12 blocks carried on the top support, in order to analyze the reactions and how they are distributed throughout the structure.

We assume that the supporting base plate acts as a uniform slab (because of many beams), we use the two-way slab because of the surface dimensions.

Two-Way System. If $1 \leq (L_2/L_1) \leq 2$, then the load is assumed to be transferred to the supporting members in *two directions*. When this is the case the slab is referred to as a ***two-way slab.***
have shown that 45° cracks form at the corners of the slab. As a result, the tributary area is constructed using diagonal 45° lines as shown in Fig. 2–13*b*. This produces the dark shaded tributary area for beam AB. Hence if a uniform load of $5\ \text{kN/m}^2$ is applied to the slab, a peak intensity of $(5\ \text{kN/m}^2)(1.5\ \text{m}) = 7.50\ \text{kN/m}$ will be applied to the center of beam AB, resulting in the *triangular* load distribution shown in Fig. 2–13*c*. For

Calculations for distributed load:

$Mass\ of\ each\ block:\ 0.635\ kg$

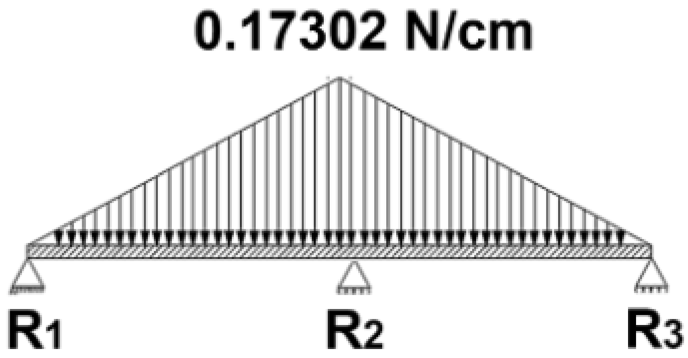
$Weight\ of\ each\ block:\ (0.635\ kg)(9.81\ m/s^2)\ =\ 6.229\ N$

$Surface\ area:\ (18\ cm)(18\ cm)\ =\ 324\ cm^2$

$Uniform\ load:\ \frac{6.229\ N}{324\ cm2}\ =\ 0.01923\ N/\ cm^2$

$Tributary\ load:\ (0.01923\ N/cm^2)(9\ cm)\ =\ 0.17302\ N/cm$

Distribution of loads to one girder (two-way system):

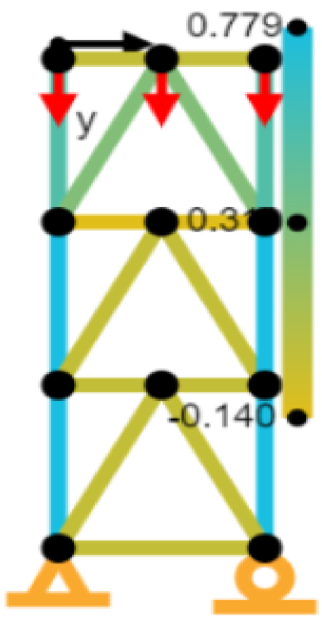


(Where R1, R2 and R3 represents front nodes)

Reactions at the supports:

$+\uparrow \sum Fy = 0$

$$R1 + R2 + R3 - Tributary\ Load = 0$$
$$R1 + R2 + R3 = (0.17302\ x\ 18\ x\ 0.5)\ /\ 3$$
$$R1 = R2 = R3 = 0.51906\ N$$



Now we have the magnitude of three forces to apply to three nodes located at top support (0.51906 N at each one).

- We distribute the load through the **three nodes** located at the top support.
- **By symmetry** we can analyze one side, and its magnitude will represent the other ones.
- **As more:** Blue: Greater force magnitude. Green: No magnitude.

Results obtained:

Member ID	Start -> End Node	Length (mm)	Axial Force (N)
0	0 → 2	167	0.7786
1	0 → 4	189.7	0
2	2 → 4	90	0
3	1 → 3	167	0.7786
4	1 → 4	189.7	0
5	3 → 4	90	0
6	2 → 5	167	0.7786
7	2 → 7	189.7	0
8	5 → 7	90	-0.1399
9	3 → 7	189.7	0
10	3 → 6	167	0.7786
11	6 → 7	90	-0.1399
12	5 → 8	167	0.5191
13	5 → 9	189.7	0.2948
14	8 → 9	90	0
15	6 → 9	189.7	0.2948
16	6 → 10	167	0.5191
17	9 → 10	90	0
18	0 → 1	180	0

- The column members supporting the first and second floor **are the most influenced ones**, meaning that a reinforcement in those will enhance overall load capacity.
- **The inverted V-Brace members** distribute the loadings effectively. Meaning that it´s inclusion and location are correct decisions.
- Because of the magnitudes, **the loads do not represent a threat** for the structure integrity.
- Positive members are in tension and negatives in compression.

4. Modal Analysis

To perform the modal analysis, the nodal mass was calculated as follows:

Unit weight = 7.1×10^{-6} N/mm^3

Column:

Weight = 5.5 x 5.5 x 167 x 7.1 x10^{-6} = 0.035867425 N

Mass = 0.035867425 / 9810 = **3.656210499 x 10^{-6} N-s^2/mm**

Beam:

Weight = 5.5 x 5.5 x 180 x 7.1 x10^{-6} = 0.0386595 N

Mass = 0.0386595 / 9810 = **3.940825688 x 10^{-6} N-s^2/mm**

Brace:

Weight = 5.5 x 5.5 x 189.7 x 7.1 x 10^{-6} = 0.040704446479 N

Mass = 0.040704446479 / 9810 = **4.153360325 x10^{-6} N-s^2/mm**

Mass block:

Mass = **6.250 × 10^{-4} N-s^2/mm**

Nodal mass distribution on 3F:

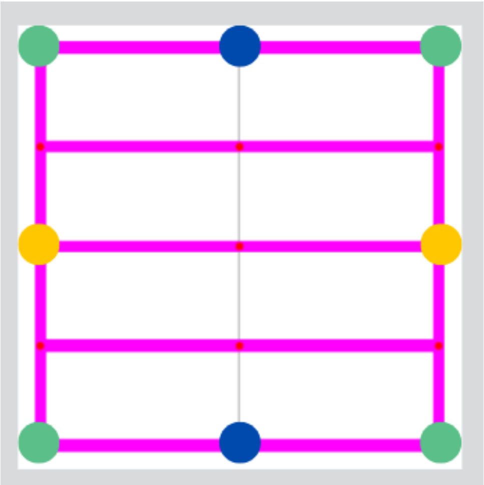


Figure 16. Nodal mass distribution.

Corners (green circles):

0.5 column + 1 beam + 2 mass blocks

$0.5(3.656210499 \times 10^{-6}) + 1(3.940825688 \times 10^{-6})$

$+ 2(6.250 \times 10^{-4}) =$ **$1.255768931 \times 10^{-3}$ N-s²/mm**

Middle-sections (yellow circles):

1.5 beam + 1 brace + 1 mass block

$1.5(3.940825688 \times 10^{-6}) + 1(4.153360325 \times 10^{-6}) + 1(6.250 \times 10^{-4})$

$=$ **$6.350645989 \times 10^{-4}$ N-s²/mm**

Middle-sections (blue circles):

1 beam + 1 brace + 1 mass block

$1(3.940825688 \times 10^{-6}) + 1(4.153360325 \times 10^{-6}) + 1(6.250 \times 10^{-4})$

$=$ **$6.33094186 \times 10^{-4}$ N-s²/mm**

To plot the graphs of displacement and acceleration, the node N60 was taken as reference:

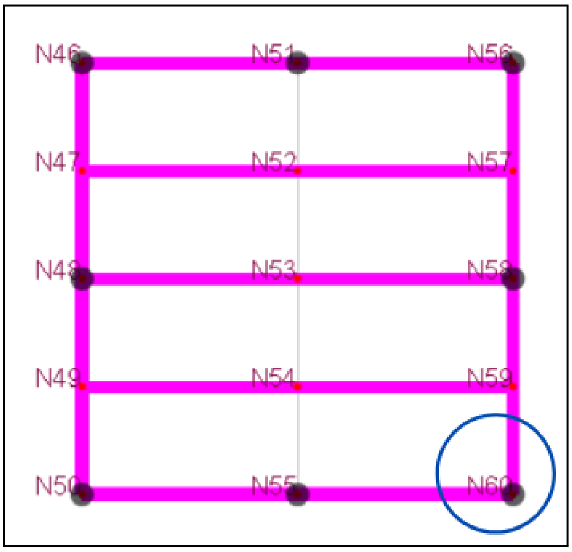


Figure 17. Nodes on the top floor.

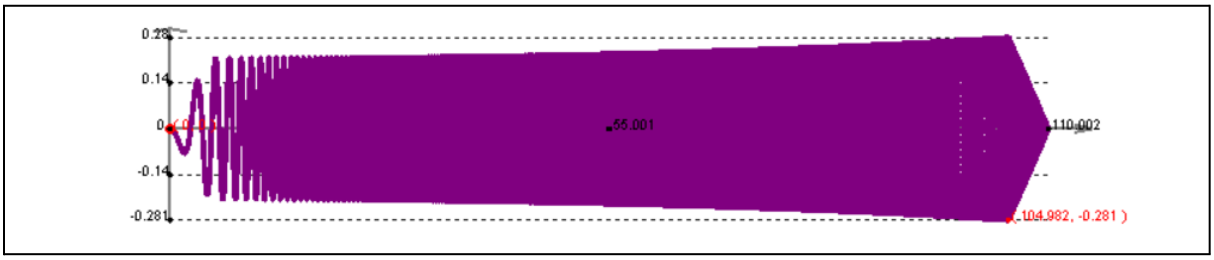
The natural period was found as **0.069 seconds**, and the frequency was **14.5 Hz**.

These values imply that our structure is moderately stiff, which could present a disadvantage since the stiffness of the structure does not allow a large range of deformation, and therefore the risk of collapsing in large artificial earthquakes is higher.

Response of the structure due to the artificial earthquakes in PISA 3D

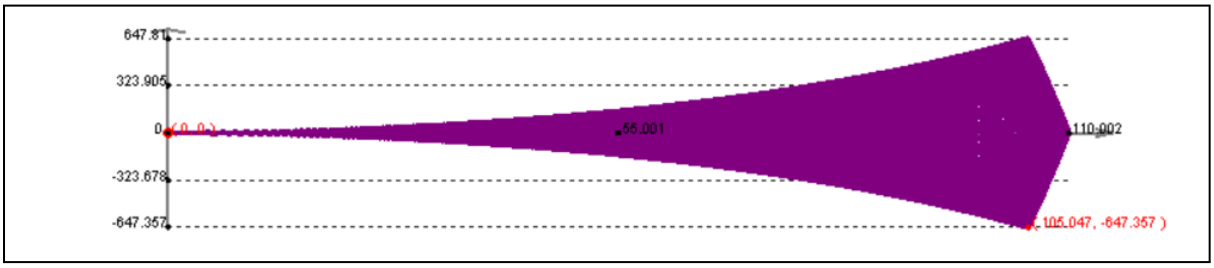
2500 mm/s²

Displacement



Maximum displacement: 0.281 mm

Acceleration



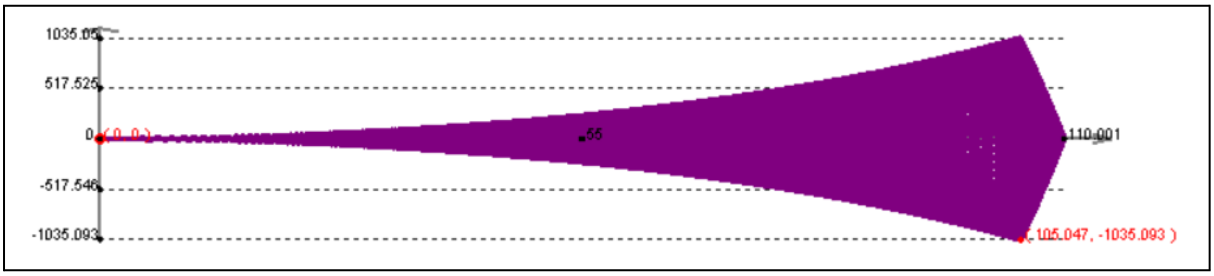
Maximum acceleration: 647.357 mm/s²

4000 mm/s²

Displacement

Maximum displacement: 0.449 mm

Acceleration



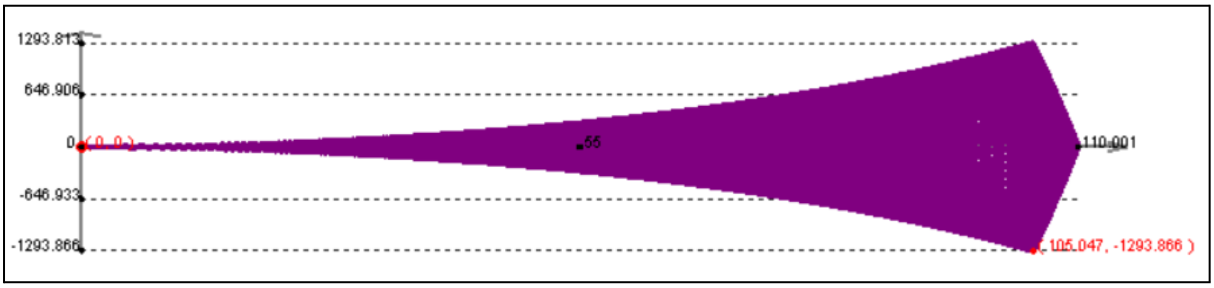
Maximum acceleration: 1035.093 mm/s²

5000 mm/s²

Displacement

Maximum displacement: 0.561 mm

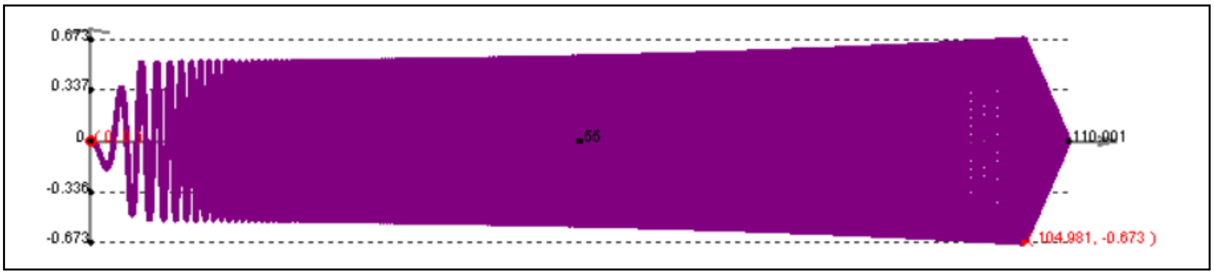
Acceleration



Maximum acceleration: 1293.866 mm/s²

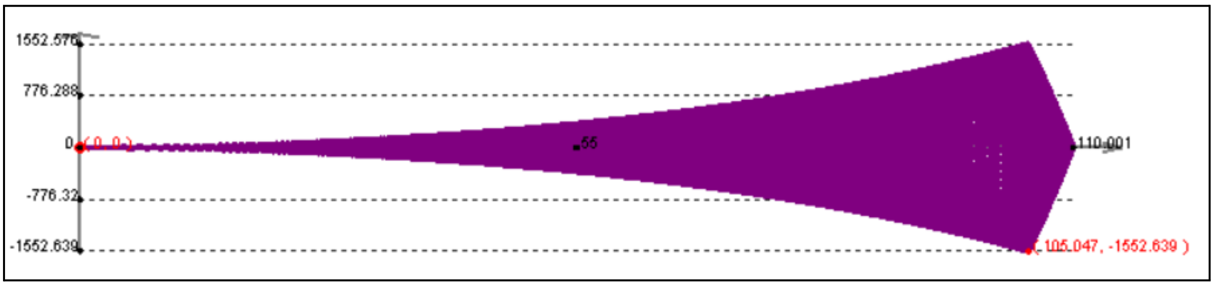
6000 mm/s²

Displacement



Maximum displacement: 0.673 mm

Acceleration



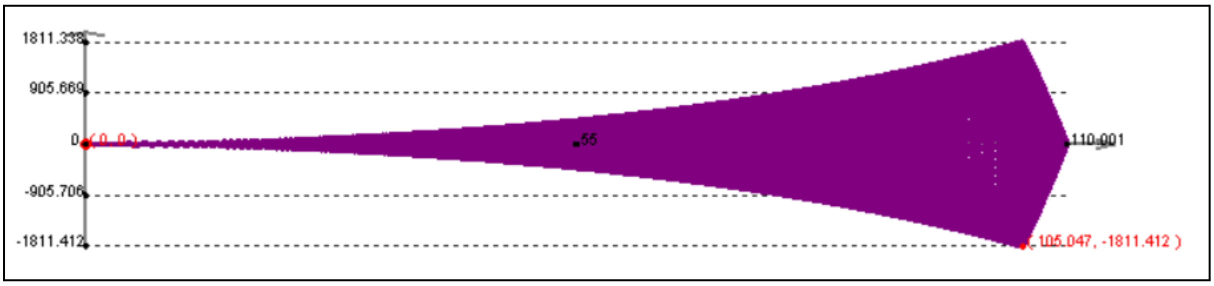
Maximum acceleration: 1552.639 mm/s²

7000 mm/s²

Displacement

Maximum displacement: 0.785 mm

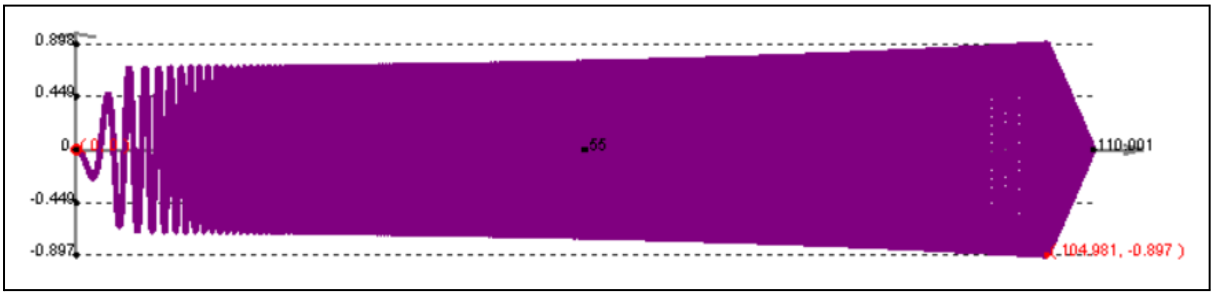
Acceleration



Maximum acceleration: 1811.412 mm/s²

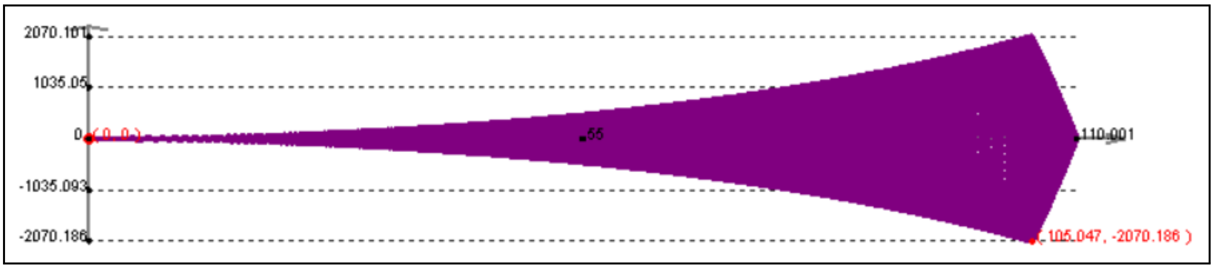
8000 mm/s²

Displacement



Maximum displacement: 0.897 mm

Acceleration



Maximum acceleration: 2070.186 mm/s²

5. Performance of the structure

During the test in the shake table, when the first 250 gal was applied, our structure showed a very elastic behavior, having among the other 3 structures the most displacement, however no sign of failure was visible in columns, this was not the case for one of the trusses on the first floor. For the second test of 400 gal, our structure suffered several failures in the trusses, especially on the first floor, and even failure on one of the beams was visible, however the structure did not collapse and the beams stayed intact, it was during the 500 gal test when the columns of our structure fail, with three out of four breaking and causing the structure to collapse, during the collapsing we could see that the base of the structure was still attached to the base indicating a well-designed foundation, so the causing of collapsing was the columns breaking on the first floor. Our structure sustained the 250 gal, 400 gal, and it failed during the 500 gal test.

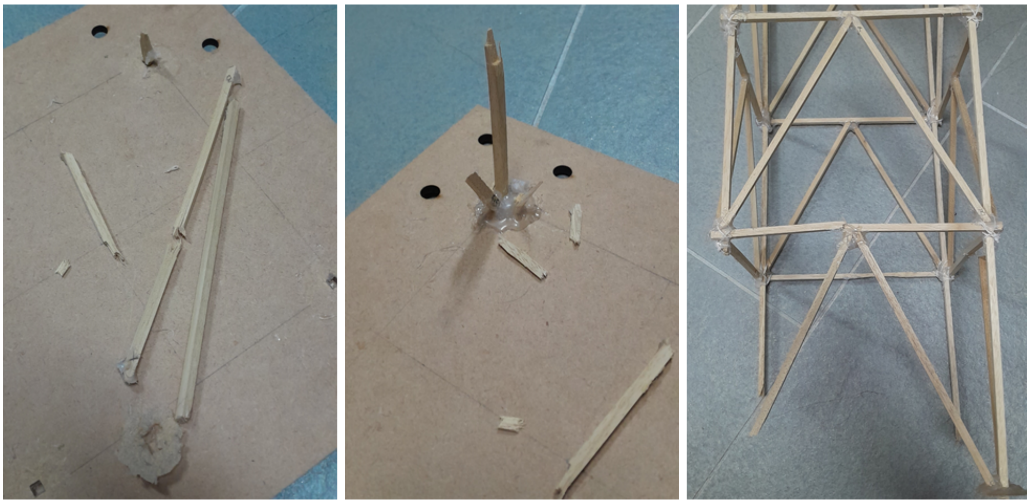


Figure 18. Failure points of the structure.

6. Conclusions and discussions

Our project aimed to test our ability to design, construct, and analyze a structure capable of withstanding simulated earthquakes. Initially, we designed a structure with thicker columns at the base, recognizing that the lower levels would endure greater stress. However, due to the challenge of properly joining columns with different cross-sectional areas using only hot silicone, we revised our design to feature uniform 5x5mm columns, aiming to minimize material usage.

Unfortunately, our structure failed during testing, with columns breaking in half. This failure highlighted the importance of column thickness in withstanding seismic forces. Additionally, we observed that trusses at the base failed while those on upper floors remained intact, suggesting weak joints in the base trusses. Strengthening these joints could have improved the structure's resilience.

This project underscored how seemingly minor design choices can significantly impact a structure's ability to withstand earthquakes.