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

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING
MATERIALS AND STRUCTURE TEST

FINAL PROJECT

Group 03

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1. CONCEPT OF STRUCTURAL DESIGN

Definition:

Structural design therefore concerns the act of making or proposing the layout or framework of any construction or creating project be it a building or infrastructure. Pre-design is the initial step where the engineering principles, codes, and standards are utilized to design safe, functional, and affordable structures.

In structural design, the main goal is typically to be able to demonstrate that a particular structure is capable of accommodating the design loads and forces likely to be impressed on it during its lifetime of use. In the structural design process it is required to calculate and define the loads that the structure will have to endure, choose materials for the construction and design the structural members to support those loads. The following tools will be employed for the development of the structural design At present, both the structural and architectural design can be modeled, analyzed, and simulated using Pisa 3D.

PISA 3D (Performance-based Integrated Structural Analysis 3D) is an application used in the field of structural analysis and design for earthquake conditions. It uses refined modeling approaches and optimization computations, alongside other structural and earthquake loads, to evaluate structures like buildings and infrastructure. PISA3D assists the engineers and researchers to understand the structural behavior, assess the response of structures to the earthquake motion and develop efficient strategies for repairing of structures and making them safe from further damaging earthquakes.

It considers different parameters, for instance, the concrete or steel properties, element shapes, and seismic record to perform computational analyses in order to establish the behavior of structures during earthquakes. It enables assessment of the performance parameters which include deformations, displacements, stresses, etc for assessing the performance criteria and capacity of structures versus the anticipated performance goals and seismic codes.

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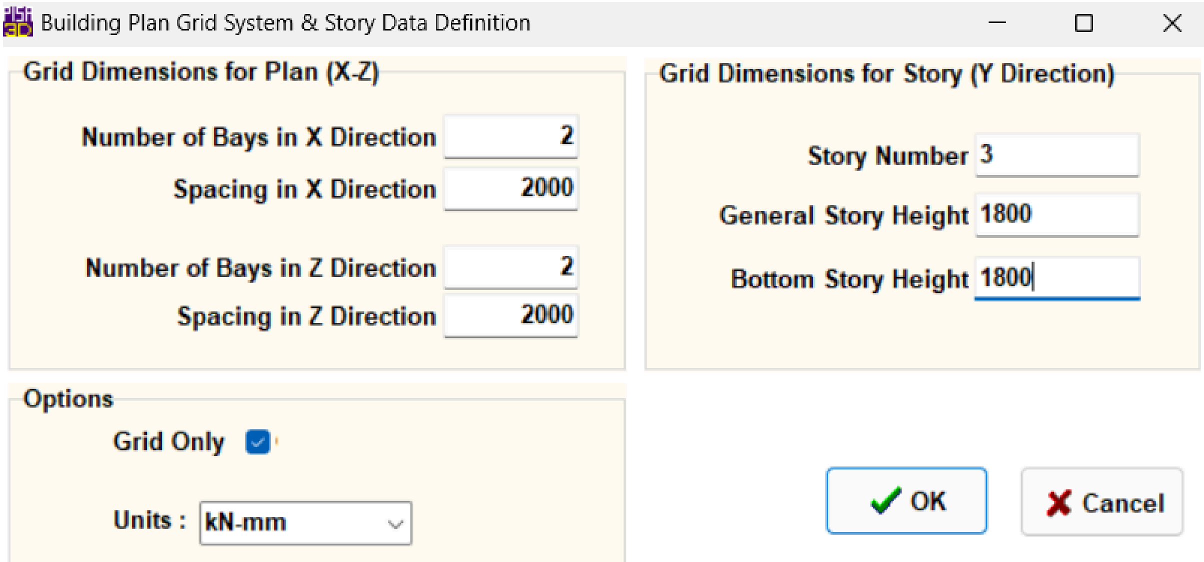
Process of Structural Design:

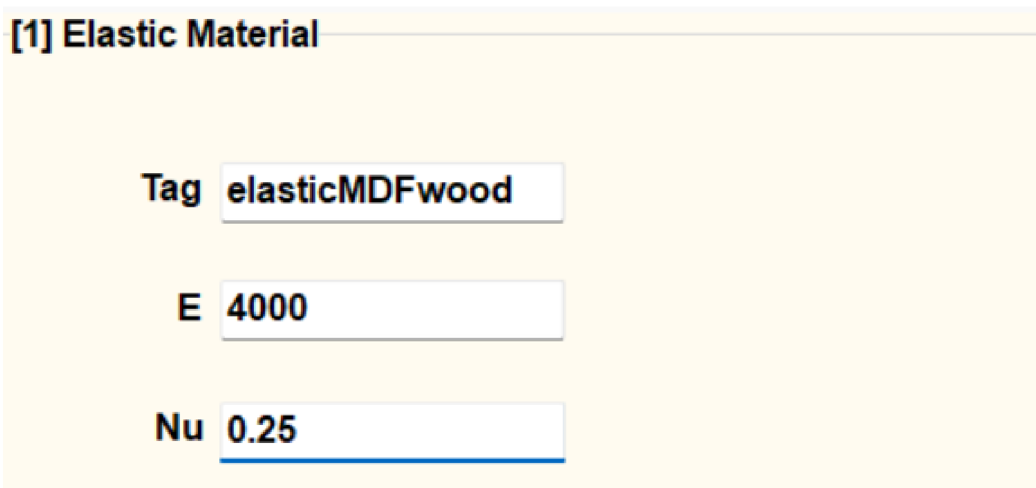
Unit Analysis:

The first step in the modeling design is to define the unit that we are going to work with, for this project we opted to use the unit of N.mm.



Definition of the material:

In this project we selected elastic MDF wood for our material.
We were given wood sticks to work with.



Definition of the height:

According to the allowable limits for the competition (Hmin = 50 cm, Hmax = 65cm), we decided our structure's height to be 55 cm, near the minimum permissible, since we assumed that a relatively low center of gravity will help prevent the structure from collapsing or tipping easily. Also saying that the glue will affect the structure 1mm more.

Number of stories:

Once we defined our building's height, we selected a three story building design, in this way we can place triangular trusses on each rectangular frame of the lateral faces of the structure, reinforcing the stability of the frames against lateral movements.

Type of trusses:

The selection of the triangular shape for the trusses was because triangles distribute forces and help create stable structures by restricting the degree of freedom of the frames. And about the beam in the middle we decided to follow a research in which the structure they analyzed was subjected to 7.2 magnitude on the Richter scale. The real name of the trusses will be Inverted-V-Braced Frames with suspended zipper struts.

Floor supports:

The columns and trusses are fixed at the bottom of the structure to the based plate.

For the second floor:

The trusses get supported by the joints.

Base plate:

The third floor, which is the top and would be the base for the load, our intention here is to make it stronger so it can withstand the direct application of the blocks. So, we opted to locate 9 parallel beams equidistant, holding them together at the girder.

Final structure on PISA 3D:

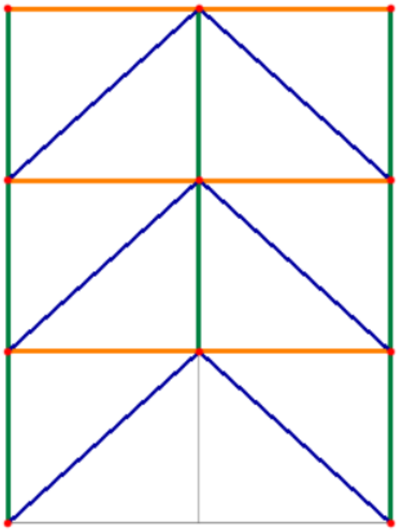


Figure 1: Pisa 3D drawing

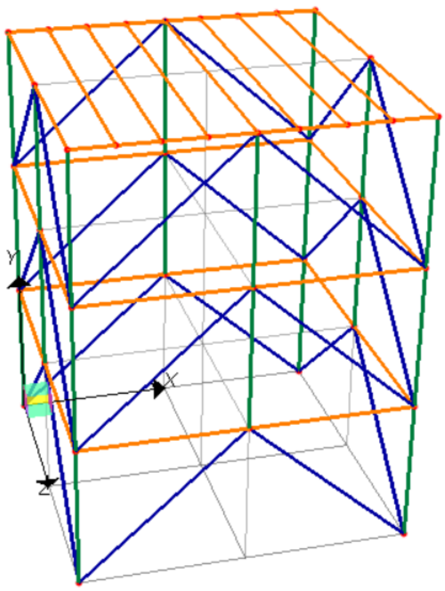


Figure 2: Pisa 3D drawing

2. MODELING DETAILS

- Calculations

Since it is an elastic MDF wood; we use for the density a value of 0.75g/cm3 = 7.3575*10-6 N/mm3

Mass= Density*Volume/9810

$$\textbf{Column}= \frac{7.3575\times10^{-6}\times5.5\times5.5\times18}{9810} = 4.08375\times10^{-7}\text{N*s}^2\text{/mm}$$

$$\textbf{Beam}= \frac{7.3575\times10^{-6}\times5.5\times5.5\times10}{9810} = 2.26875\times10^{-7}\text{N*s}^2\text{/mm}$$

$$\boldsymbol{Truss\ members} = \frac{7.3575\times10^{-6}\times5.5\times5.5\times20.59}{9810}$$

$$= 4.671642176\times10^{-7}\text{N*s}^2\text{/mm}$$

$$\boldsymbol{Mass\ block} = 6.350 * 10^{-4}\ \ \text{N*s}^2\text{/mm}$$

The placing of mass blocks is shown in Fig. 3. With that distribution we calculate the nodal masses.

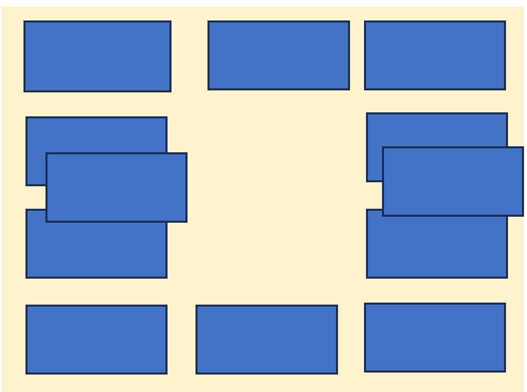


Figure 3: Test loading.

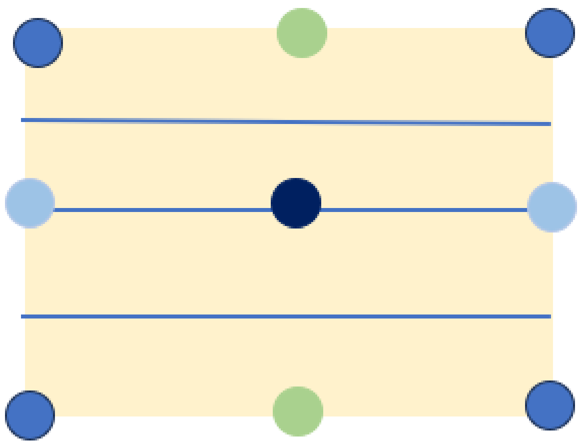


Figure 4: Nodal masses in the top floor

0.5 column+ 1 beam+ 1 mass block

$= 6.354310625*10^{-4}$ N*s^2/mm

0.5 column+1 beam+1 truss member+1 mass block

$=6.358982267*10^{-4}$ N*s^2/mm

1 beam+ 0.5 column= $4.310625*10^{-7}$ N*s^2/mm

0.5 column+1.5 beam+ 1 truss member+ 3 mass block=

$=1.906011664*10^{-3}$ N*s²/mm

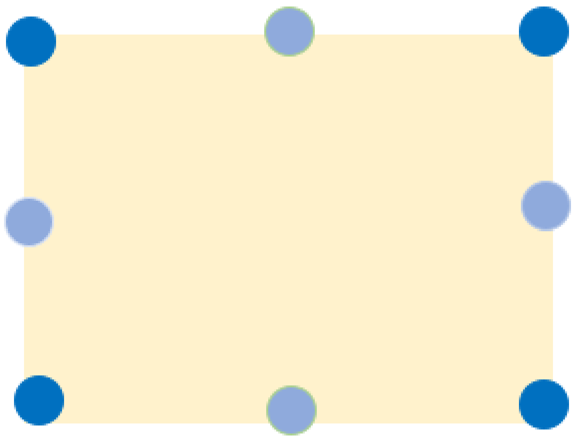


Figure 5: Nodal masses in the 2F and 1F

<u>For the 2F.</u>

1 column+1 beam+ 1 truss member =

$=1.102414218*10^{-6}$ $N*s^2/mm$

1 column+1 beam+ 1 truss member =

$=1.102414218*10^{-6}$ $N*s^2/mm$

<u>For the 1F.</u>

1 column+1 beam+ 1 truss member =

$=1.102414218*10^{-6}$ $N*s^2/mm$

- 0.5 column+1 beam+ 1 truss member =

$=8.982267176*10^{-7}$ N*s^2/mm

Force Transmission

The force is transmitted in a way that the green ones are members in **compression** while the orange and blue ones are in **tension.**

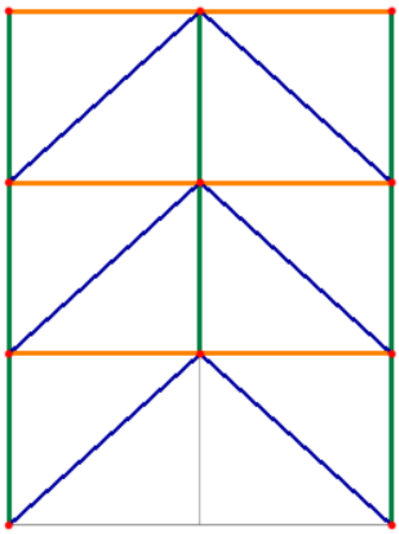


Figure 6: Forces in tension and compression.

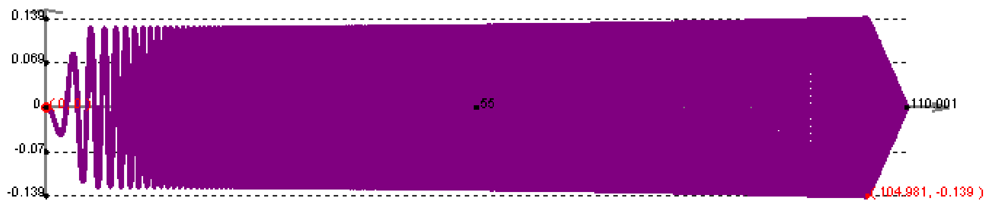
- Expected Natural Frequency

The natural period found in PISA 3D: 0.044sec
The expected natural frequency of the structure is *f = 22.73 Hz.*

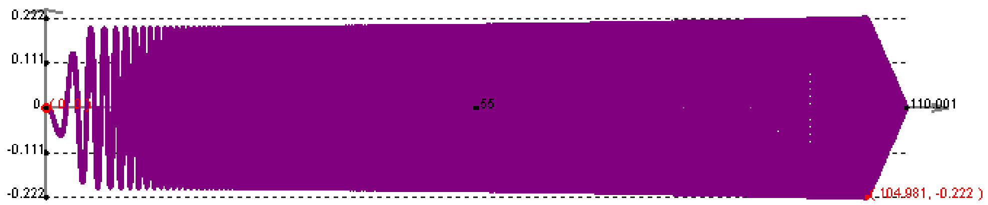
- Expected Response of Structural Design

In the graphs provided below, it shows the expected displacement/deformation based on the center node on the top floor of our model with respect to time to the intensities of 250, 400, and 700 gals. It is important to keep in mind that the graphs and model itself may show some discrepancies due to several factors such as the real elastic modulus of wood and the assumption that the structure, including all the nodes and beam members, are fully constricted. The high rigidity of our structure played a factor in its response to the increasing intensities of the shake table. In the end, our structure's bottom supports weren't strong enough to withstand the testing and thus, we couldn't witness its response to higher intensities.

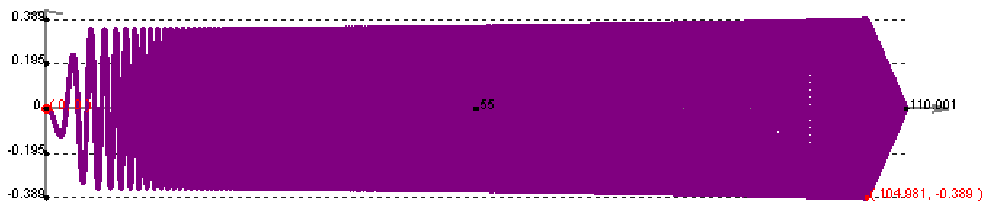
250 gales



400 gales



700 gales



3. POSSIBLE FAILURE:

Our structure was designed and built to withstand lower seismic forces, specifically at 250 gals and 400 gals. At these levels, it showed acceptable resistance and remained stable. However, when the frequency increases to 500 gals or higher, there is a significant change in behavior.

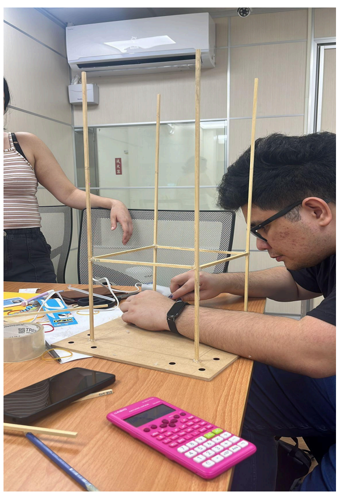
The structure's high rigidity, initially thought to be beneficial, became a liability under higher frequency forces. As these forces increased, the structure began to deform and show stress. Despite its initial robustness, it eventually reached a threshold where it can no longer withstand the intense vibrations.

4. ASSEMBLY OF THE MODEL:

Materials:

Materials	Quantity used	Note
Base plate	1	Give by professor
Hot-melt Adhesive	4	Give by professor
Wood Strips	19	Give by professor
Scissors	2	
Rulers	2	
Cutter	1	
Cotton Rope	4m	Give by professor
45° Cutter	1	
Melting Gun	1	

5. ASSEMBLY PROCESS:



1. First of all, the TA started by drilling holes in the base according to the Teacher's instructions, 3cm from the corners.
2. Then we proceeded to make holes in the base separated by 20cm each, where our columns would later go
3. We proceeded to cut the wood according to the measurements we needed
4. Once we had the quantities of wood of 54cm,20cm,20.6 cm we began the construction

5. First we placed the 4 columns in the holes that we had made
6. Then every 18cm we put the 20cm reinforcements that served to indicate the floors of our building.
7. Once we had defined all the floors, we first started with the truss on the lower floor, which consisted of a Howe-type truss that started at each corner and went to the middle of the 20cm support between each floor.
8. We followed this process until we finished the first floor, and we continued doing the same on each upper floor, with the only difference that from the 2nd and 3rd floors we added a back-up column in the middle of the structure, which served for the best distribution of loads.
9. Once we finished with the trusses, we proceeded to reinforce the upper part of the structure, where we put cross bars that would later be used to put the basket that would help contain the extra weights that would be added in the competition.
10. Once the entire structure was finished, we added a box on top where the weights would go and finally we put our team flag
11. Lately, on the day of the competition, we secure the loads with the thread provided among the materials to use.

Figure 7: Assembly process

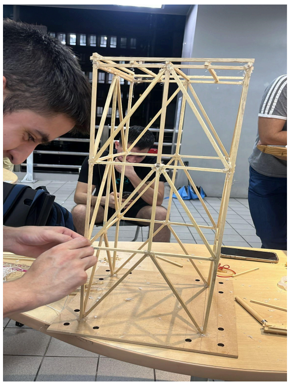


Figure 8: Assembly process

6.

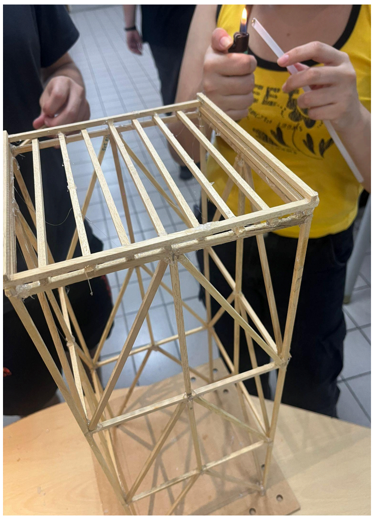


Figure 9: Assembly process

Figure 10: Assembly process

PERFORMANCE OF THE STRUCTURE

Right after all of the corresponding measurements of the Water Tower were done, the structure needed to be placed on the shake table.

Once we selected a spot to place our structure, the adversities happened such as two of the screws would not fit into the corresponding holes. There was the option of changing the location of our structure in the shaking table, but the remaining spots were right next to the structure from the other contestants and there was the risk that their bricks could fall into our structure or even their whole structure could collapse and damage our Water Tower. Therefore, the best choice we had at that moment was to place it in the original spot and have two screws a little bit loose.

Once our structure and the structure of the other contestants were all settled into the shaking table, as can be seen from Figure 1, the contest was about to start.

Figure 11.

The intensity of the shaking table was supposed to start at 250 gal and increase until the last structure remained still. But, there was a really strong shake in the table of an intensity much bigger than 250 gal, which lasted around two to three seconds. This said shake was not expected by any of the contestants. Because of this shake is that the columns from our structure detached from the base, as it can be seen from Figure 2.

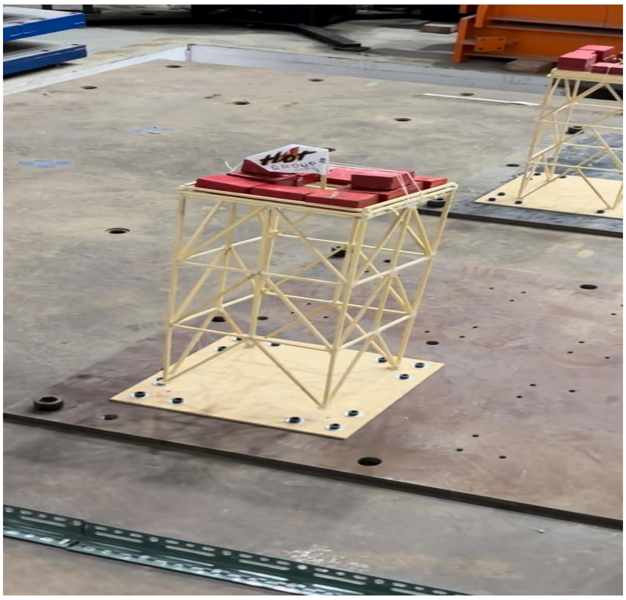


Figure 12.

This affected the performance of our structure when the actual contest started, because our structure was already damaged due to that unexpected shake. This was an error which was later on recognized even by the Professor.

Before the actual contest started, once the columns of our structure were already detached from the base, it was asked by our group to the TA that they give us the chance to fix the problem by gluing our structure back into the base plate. Even though we tried to fix this problem, because of the short time we had to fix it and because we were not given the chance to let the glue dry into the base plate, the performance of our structure was affected later.

Our Water Tower was able to sustain the intensity of 250 gal, once the intensity of 400 gal began, our structure started to show some problems.

During the 400 gal intensity, the columns of our structure detached from the base plate but the integrity of our structure was intact, meaning that all of our beams and braces showed no trouble at all, as can be seen from Figure 3.

Figure 13.

Because of the detachment of two of our columns from the base plate, our structure could no longer be part of the contest even though it remained with its structural integrity and could have lasted more if that unexpected nig shake did not happen and damaged our structure.

7. SUMMARY AND CONCLUSION

This project aimed to design and build a structural model capable of withstanding simulated earthquake forces. We utilized PISA 3D software instructed by the TA for the design process, and figure out its natural frequency, which is how easily it vibrates. This helped us predict where it might fail, which enabled us to analyze the structure's behavior under seismic loads.

Our model was designed with a three-story structure of 18cm height each story, and a width of 20 cm, incorporating triangular trusses for stability and a reinforced base plate to support the weight. However, during the construction phase, we prioritized connections between beams and columns, neglecting the importance of the base plate's attachment.This oversight proved crucial during the shake table test.

Despite a successful initial performance, the model experienced significant damage due to an unexpected, intense shake beyond the anticipated intensity. This unexpected shake caused the columns to detach from the base plate, compromising the structure's stability.

While the remaining structure remained intact, the damage from the initial shake prevented further participation in the competition.

When we actually built the model, we focused too much on connecting the beams and columns and not enough on how the base was attached. We learned that how the base is attached is super important in earthquake-proof structures. Even small mistakes in design or building can have big consequences. This experience showed us how careful we need to be when building things that need to withstand powerful forces.

This experience highlighted the critical importance of meticulous attention to detail, particularly in base plate attachment, when designing earthquake-resistant structures. Even minor flaws can have significant consequences, underscoring the need for thorough planning and quality control in structural engineering projects.