Indian Institute of Technology Gandhinagar

Compressive load testing on Bitetratruss(Pyramidal truss structure)

Mechanics of Solids [ES 221] - Project Report

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Contents

S No.	Name	Contribution	Signature
1	Bhuvesh Jaiswal	Designing and manufacturing of experimental model ,report	Bhuvesh
2	Mohit Rajput	Simulation of model , report	Mohit
3	Naval Jaggi	Manufacturing of the model	Naval
4	Kamal Vaishnav	Manufacturing of the model, report	Kamal
5	Manish Jangir	Arrangement of material and manufacturing	Manish
6	Mumuksh Tayal	Simulation and report	Mumuksh

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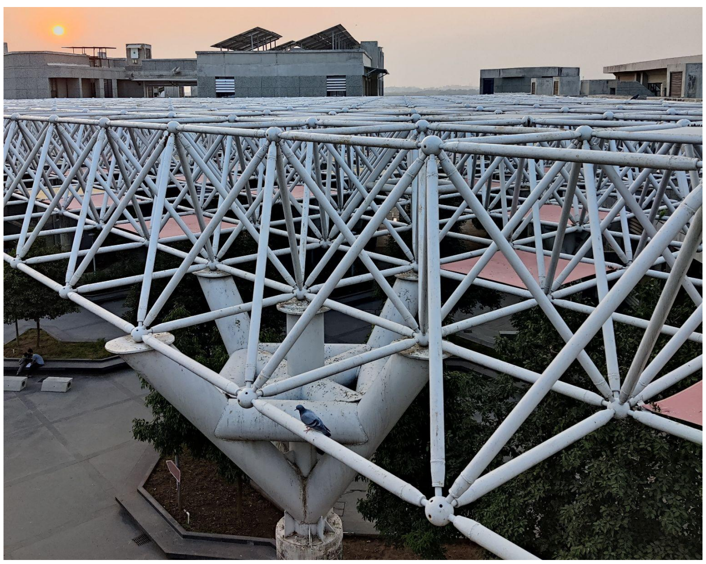
Abstract

The aim of this project was to analyze the strength of joints while performing compression and extension tests. To fulfill the project requirement, we decided to choose a commonly used unit truss structure with a pyramid geometry. We manufactured the truss using processes such as cutting, drilling and welding during the manufacturing of our model. To study the bearing capacity of the trusses, we manufactured two different trusses by changing the joint connection type. For the first sample, we simply joined the member rods with the help of welding. But on the basis of our prior knowledge, we anticipated the welded joints to show a higher resemblance to a pin joint rather than a fixed joint. So for the second sample, we tried to strengthen the joints by welding the member rods with a cube at each junction instead of directly welding them together as was done for the first sample. Doing so ensured a fixed joint at each juncture, thus, making the structure much more reliable in terms of its load holading capacity. As our main aim was to analyze the strength of joints and hence, also the strength of the structure overall, we studied and compared the behaviour of the models under CTM.

Introduction

The main purpose of our project was to construct a mechanical model and then compare it with the analytical results obtained from its simulaution. We decided to work with trusses and study their behavior under different loading conditions.

Since trusses are one of the most commonly used and primary components of a structure, we decided to work on this domain. Trusses are popular for bridge building because they use a relatively small amount of material for the amount of weight they can support.



Talking about the geometry and design of our model, the roof truss structure, situated in the academic block area of IIT Gandhinagar, inspired us to work on a project where we can analyze the joint strength and load distribution in members connected in unit truss structure.

We researched upon different designs and decided to take a basic design of a unit truss structure having a pyramidal shape. As this design and geometry are fundamental and complex enough to analyse them.

1. Experimental Model Development

1.1 Material used

Indian Standard Mild Steel rods were used to fabricate the truss structure.

1.2 Fabrication

The truss structure is fabricated by welding the pieces of hollow steel rods together. The square base of the truss comprises 4 rods of 15 cm each while the other 4 rods which are welded at the apex of the pyramid are 17 cm each.

1.3 Challenges

Welding the rods together in an ideal manner was tough. Also, the heat generated at the time of welding caused the rods to melt before they could be joined. The frequent rise and drop in temperature during the cutting of Mild Steel made the material hard, making it infeasible to drill.

1.4 Description of Geometry & Material

Triangles and pyramids are usually the best geometrical shapes to construct any structure. This is mainly because of their inherent property to uniformly distribute the load throughout rather than distributing it unevenly as in the case of most other shapes. The property of uniform load distribution allows such truss structures to bear high loading capacities. On the other hand, Mild Steel is the most suited material for construction purposes as it has a thermal coefficient similar to concrete, it also easily binds with concrete, and is relatively affordable.

Figure 1. Two pyramidal structure with different built at joints

1.5 Background Calculation

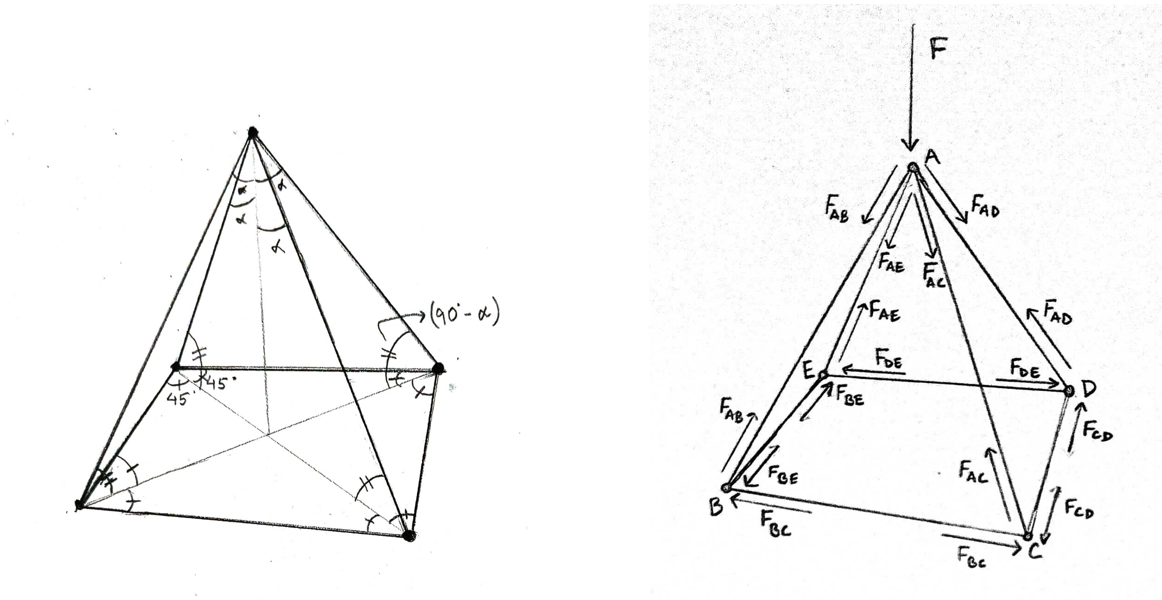


Fig.2 (a & b): Force Distribution in Pyramidal Truss Structure

Calculating each of these forces

For Slant Rods,

$$F = F_{AB}.\,cos(\alpha) + F_{AC}.\,cos(\alpha) + F_{AD}.\,cos(\alpha) + F_{AE}.\,cos(\alpha) = (F_{AB} + F_{AC} + F_{AD} + F_{AE}).\,cos(\alpha)$$

By Symmetry,

$$F_{AB} = F_{AC} = F_{AD} = F_{AE} = F.\,sec(\alpha)/4 \qquad (1)$$

For Rods of Square Base,

$$F_{AB}.\,sin(\alpha) = F_{BC}.\,cos(45) + F_{BE}.\,cos(45) = (F_{BC} + F_{BE})/\sqrt{2}$$

Substituting eq. (1),

$$F.\,tan(\alpha)/4 = F_{BC}.\,cos(45) + F_{BE}.\,cos(45) = (F_{BC} + F_{BE})/\sqrt{2} \qquad (2)$$

Again by Symmetry,

$$F_{BC} = F_{CD} = F_{DE} = F_{BE} \qquad (3)$$

Therefore, from (3) & (4),

$$F.tan(\alpha)/4 = F_{BC}.cos(45) + F_{BE}.cos(45) = F_{BC} * \sqrt{2}$$

OR

$$F.tan(\alpha)/(4 * \sqrt{2}) = F_{BC} = F_{CD} = F_{DE} = F_{BE} \qquad (4)$$

In this case,

$$\alpha = 38.6^{o}$$

Therefore,

$$F_{BC} = F_{CD} = F_{DE} = F_{BE} = 0.141F$$

And,

$$F_{AB} = F_{AC} = F_{AD} = F_{AE} = 0.32F$$

1. Experimental Results

2.1. List of experiments

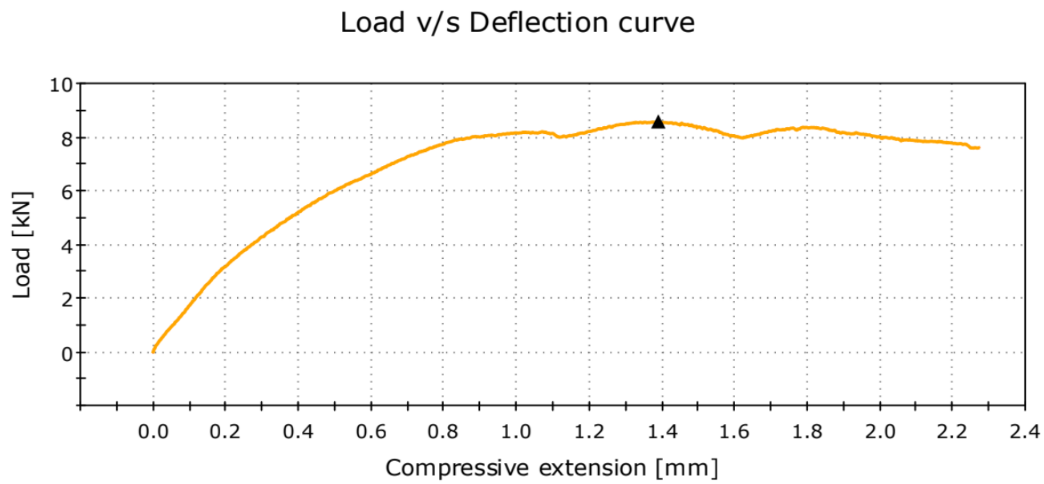
We performed a test under the Cube Testing Machine(CTM). A compressive load was applied by CTM at the top of the pyramid, which had been kept on 4 steel cubes as the base at its bottom four corners.

2.2 Key experimental results

The structure undergoes buckling. We observed and found that the welding of the rods wasn't ideal. The improper welding was causing the majority load to be applied only on 2 of the 4 slant member rods. The graph is somewhat linear initially, which resembles elastic behavior. After 0.8mm, the yield point passes and we observe 2 kinks at 1.1mm and 1.6mm which signifies buckling.

Fig.3 : Model during and after the experiment

Results Table 1				
	Specimen label	Maximum Load	Compressive Strength	Modulus (Automatic Young's)
		(N)	(MPa)	(MPa)
1	Concrete cube	8580.58	0.38	



Sr No.	EXPERIMENT	
	FORCE(kN)	DISPLACEMENT(mm)
1.	0.263	0.00854
2.	0.408	0.01712
3.	0.739	0.03601
4.	1.258	0.07082
5.	4	0.26894
6.	5	0.3736
7.	8.381	0.37253

2.3 Discussions

- As we wanted to test the strength of welded joints and the distribution of loads in respective members, the experimental results showed a somewhat different scenario. The bulking observed during experiments even before breaking of joints lead us to the conclusion that we might observe the same results in the case of our 2nd model.
- We even thought of changing the material or making our second model in a slightly different way so that it may not rupture along the members, but from various discussions with faculty members and lab assistants we concluded the design of our second model. We then decided to make our second model with a slightly different design than the first one.

2. Simulation

3.1. Numerical/analytical model development (software, elements, materials):

Software used: SAP2000

Elements:

1. Axial stress distribution analysis on live-load application.
2. Deflection in the position of joints.

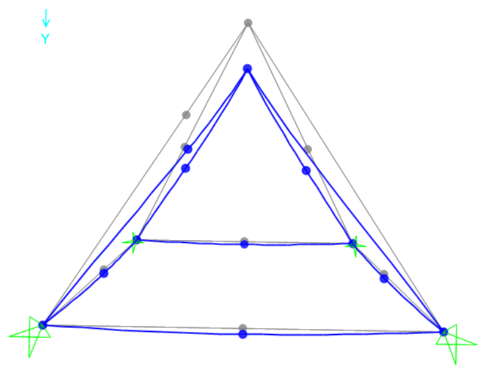
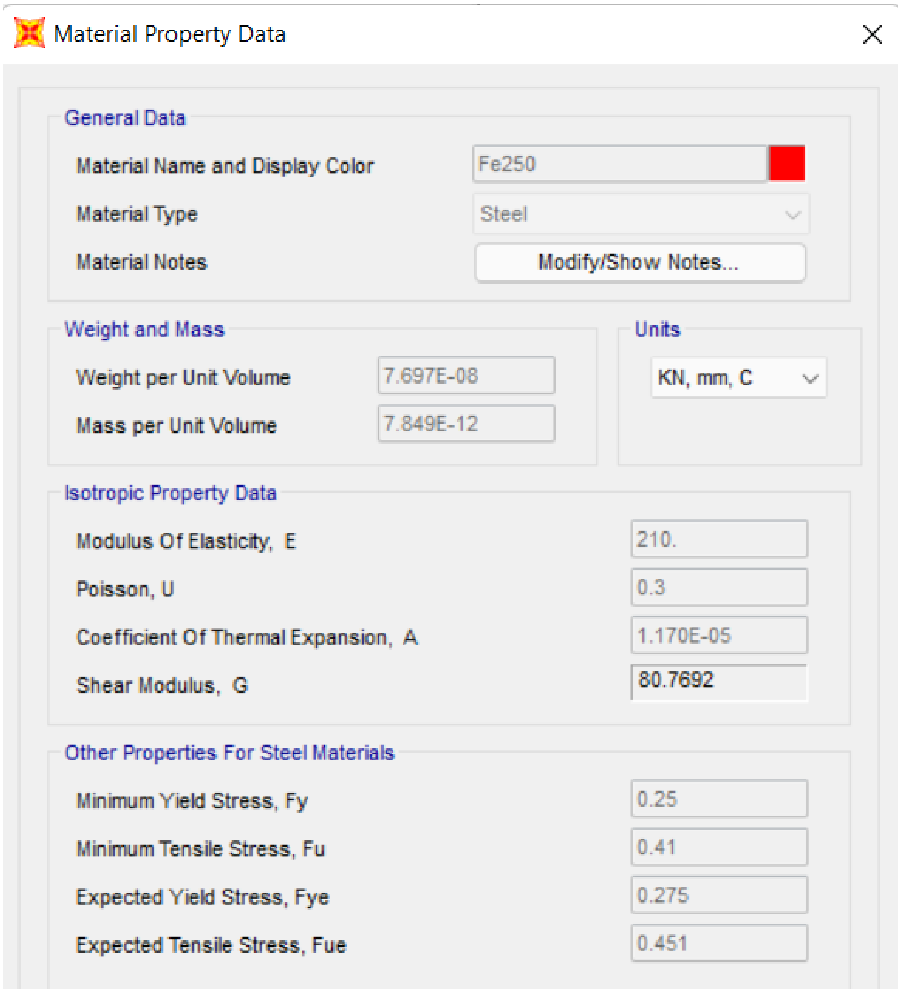


Figure 4: A view of the numerical model and key result

3.2. Formation of the model with appropriate dimensions :
Since the dimensions of the model was considered keeping in mind the base of the UTM , hence a custom grid was made in SAP2000, to make a custom truss structure as per our requirement.

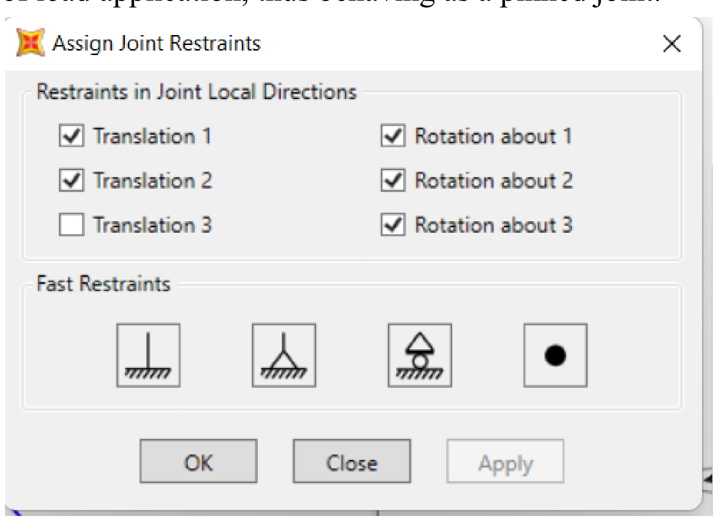
3.3. Material and cross section - selection of the model : After testing the behavior of model made up of hollow pipes and solid pipes, Model made up of hollow pipes was chosen as it showed more significant deflection in the slender members.

We have explored the steel material in indian as well as american standards , the material with the maximum similarities to the low grade mild steel was Fe250 in Indian standard whose specifications are as shown below :

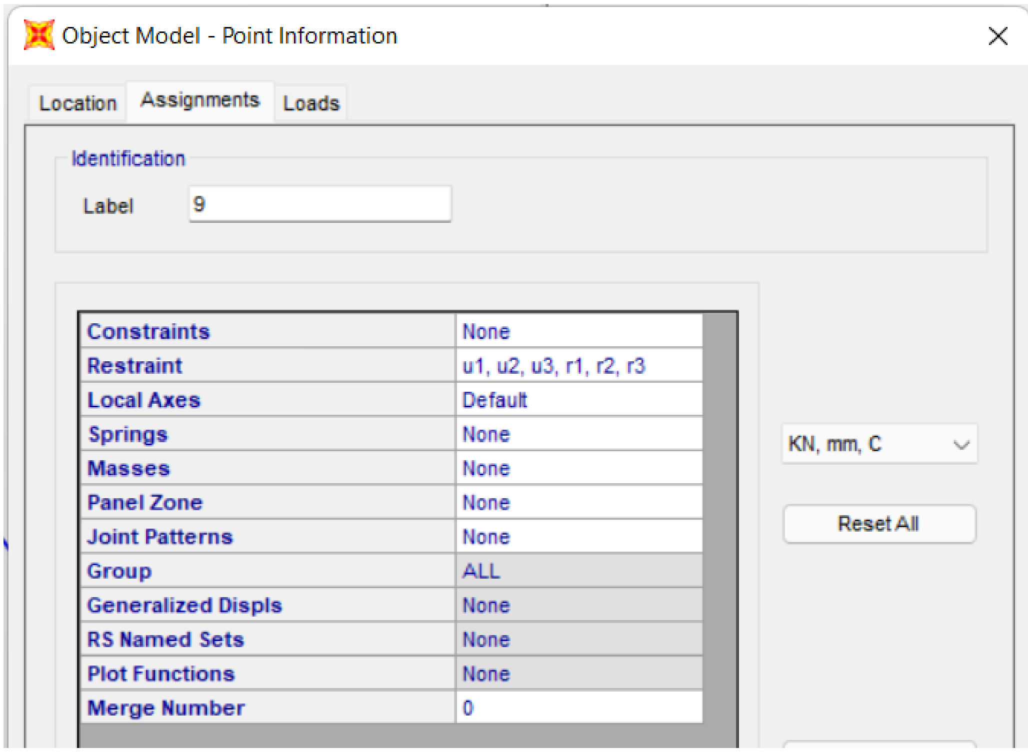


3.4. Constraints on the model :

For the top joint on which the load was applied , the restraints were given to make sure it moves only in the direction of load application, thus behaving as a pinned joint.



While the Joints in the base of the truss were given constraints assuming that the joints does not breaks or move from their position, hence there motion was restricted in all directions as visible in the snapshot shown below (restraints in u1,u2,u3,r1,r2,r3):



These constraints made sure that upon application of compressive load , the deformation was only in the members not in the joints, which turned out to be indeed true, as the joint was strong enough, while the member buckled on compressive load.

3.5. Load application on the model : The compressible load was applied on the top joint of the pyramid which was varied from 1KN to 16KN.

3.6. Axial force and Bending moment analysis on the model :

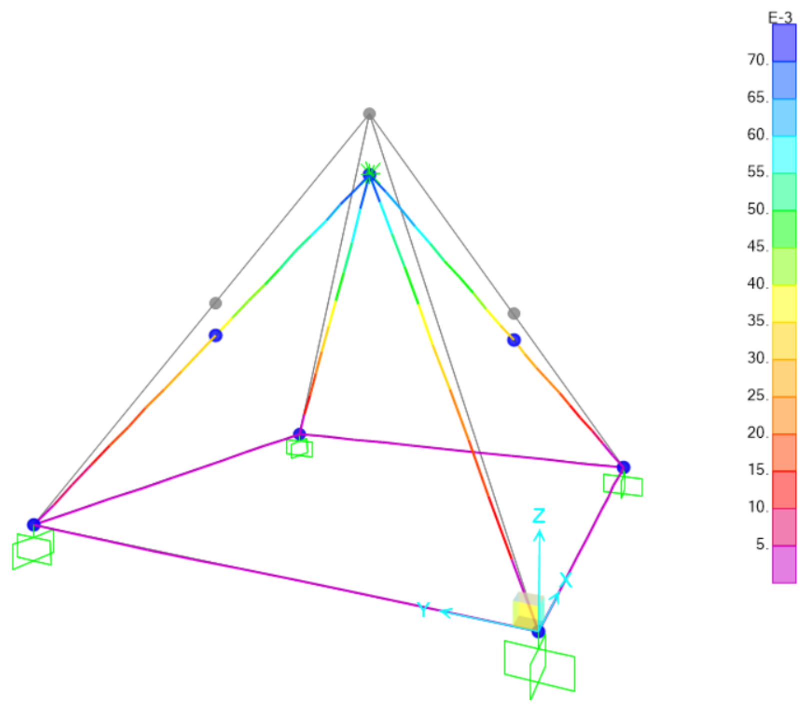


Figure 5: Distribution of Axial force amongst the members

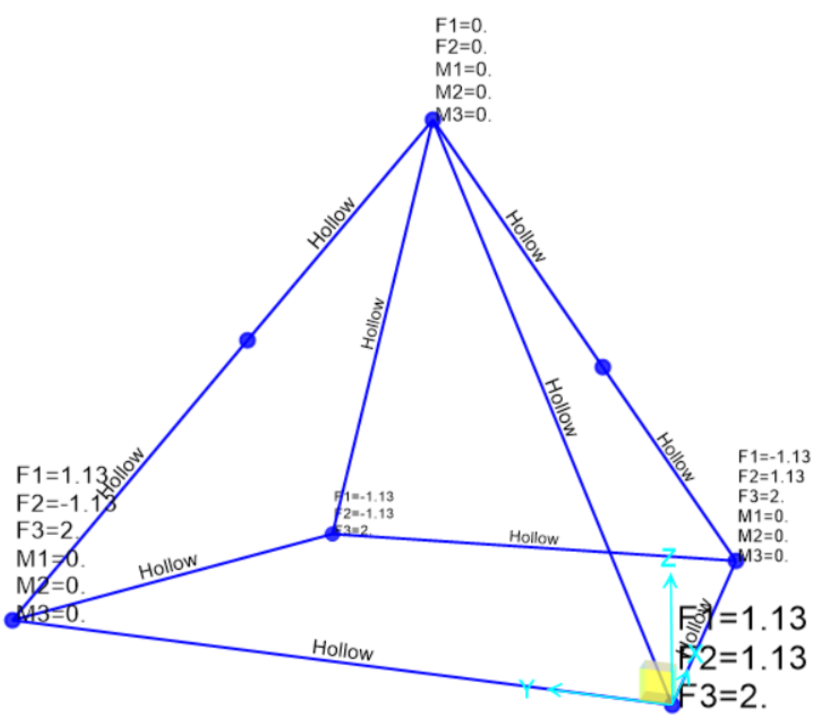


Fig.6 **:** Resultant force and moment on each of the joints due to loading of 8KN.

3.6. Deflection/ Buckling in the model : for solid cross section the deflection for same load was observed significantly less , hence after testing the model with solid cross section for variety of loads we concluded to use a hollow cross section in the physical model as it was likely to show more visible deflection than the solid cross section member.

3.7.Results obtained: only axial force was observed amongst all the members which were equally distributed between them. As a result of which only axial stress was acting on the members which resulted in buckling after the load of 16KN.

Sr No.	SIMULATION		
		Hollow cross section	Solid Cross section
	FORCE(kN)	DISPLACEMENT (mm)	DISPLACEMENT (mm)
1.	1	0.00879	0.066
2.	2	0.0175	0.0132
3.	4	0.0351	0.0264
4.	5	0.0439	0.033
5.	6	0.0527	0.0396
6.	7	0.0617	0.0461
7.	8	0.0703	0.0527

3.8.Key Findings (insights regarding the behavior of the model, influence of assumptions, etc.):

No internal moment among the slender members of the model. Only axial load among the members. Less Buckling of the members was observed in the simulated model at 10KN. This might have happened due to the fixed constraints on the joints and variation from the actual material.

4. Details of experiments and simulations from two other project groups.

4.1. Group Number: C3

Details of experimental model development :

Their model used wooden sticks in different orientations. They used advanced machines like laser cutting for upper and lower bases and used the wood cutting machine to cut various pieces and assemble the model.

Numerical/analytical model development (software, elements, materials):

They have applied uniform compressive stress on the models on ANSYS. For vertical structure in Figure 7, They have considered all the vertical beams to be our test subjects.

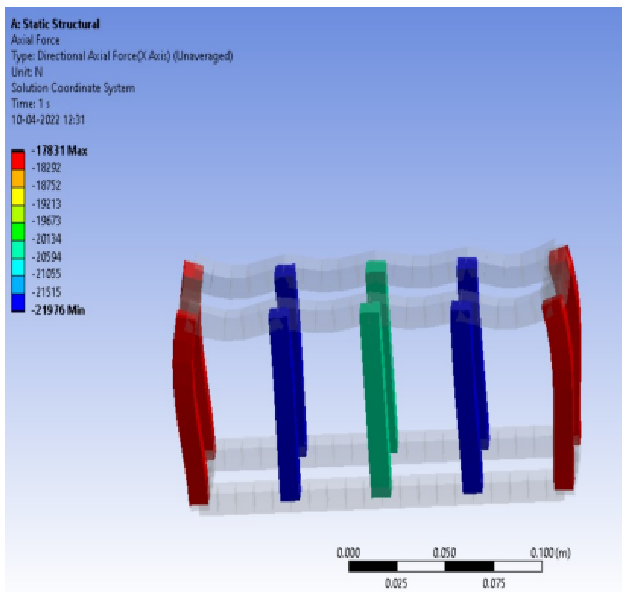


Figure-7

They assumed that the glue-wood adhesive strength is comparable to wood's strength and the lower surface to be a fixed support and they haven't considered the plate on top because the load could be applied directly for more accurate results.

4.2. Group Number D7

A detailed description and study of the infill parameters involved in the process of 3D manufacturing by taking cubic shape; -

1. The group looked at a variety of additive manufacturing infill schemes. They focused on two key aspects associated with infills during additive manufacturing: pattern of infill and density of infill.
2. They also created 11 other cubes with different infill concentrations and patterns, each with a 2.5 cm side. Their interest was attracted by cubic, line, and triangle patterns. The researchers tried two alternative levels of infill: 35 percent and 70 percent.
3. The blocks were then placed in the compressive testing machine and subjected to a force of 15kN. The cubic design was discovered to be the strongest. The cube bore a load of 13608.78 N with cubic infill and 70% density.
4. They developed a variable called Maximum Stress and scaled it by the time it has taken to print it. The variable was highest inside the cubic design with 70% infill density and lowest in the triangular infill pattern with 35% infill density.

Figure 8: (a) All 3D Samples (b) Deformation in sample after compression testing.

5 . Summary and conclusions

We found that when the load was increased on top of the unit, the inclined rods of the truss unit buckled because the strength of the welding at the joint was too high, and breaking of the welding will require a high amount of stress at the joint. Initially, we thought that the welding joint will have low strength and consequently on increasing load, the welding at the joint would fail before buckling of the rods. We also used mild steel cubes for increasing the weld strength at the joint.

A major key finding of our experiment was that, if the joint strength is high, a portion of the vertical load will be distributed across the horizontal cube of the rod. Since the inclined rods have a net compressive force in the direction of inclination. The horizontal component of the load on the inclined rods will tend to stretch the horizontal rods through the connections at the joint. Thus, this unit of truss can distribute the load throughout the body and will be able to withstand higher load. That is why this unit is most commonly used in truss structures.

In conclusion , Trusses are always used where the bear load such that there members are in tension. If the load is compressive and is more than the strength of the joints ,then the members of the truss are subject to failure and the members may buckle. This same phenomenon was observed in the structural lab while performing the experiment as the compressive load was increased , the joints were strong enough to withstand the load , as a result of which the members were overloaded , which led to buckling.