ME206 Statics and Dynamics

Group 9, Experiment 1

CONSTRUCTING A TENSEGRITY TABLE

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INTRODUCTION

The experiment explores the structure and analysis of the tensegrity table, which enables us to understand the stability of such structures. The goal of this experiment is to determine the cable tensions by increasing the load up to 3kg and to find the torsional frequency for the above loads.

Tensegrity structures, a term coined from "tensional integrity," are a unique form of structural engineering that involves rigid elements like bars connected with tensioned cables, which help to maintain the stability of the structure by balancing the compressive forces exerted by rigid elements. Such an arrangement results in a self-stabilizing structure. Due to their efficient load distribution and flexibility, these systems have found applications in architecture, robotics, and mechanical systems.

The first part of the experiment involves studying the variation of cable tension as the load increases from 0 to 3kg. This is done both experimentally and analytically. The analytical calculations involve deriving equations based on principles of statics, while experimental results are obtained by the methods mentioned in the section on measurement techniques.

The second part of the experiment involves the analysis of the dynamic property of the tensegrity model, which is torsional oscillation. In this section, the frequency of torsional oscillation is experimentally measured for various loads. This gives us the information about the dynamical stability of the structure. It also helps us to understand the natural frequency of the structure and how it changes as the load is increased.

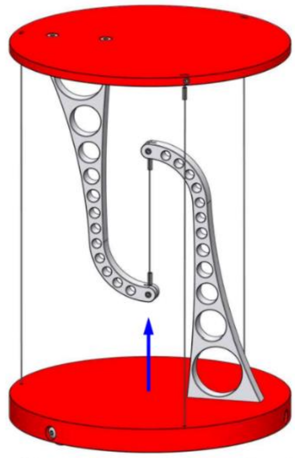
Thus, by Static and Dynamic analysis, the experiment helps us to understand the mechanical behaviour of the tensegrity table under practical loading conditions.

AIM

The aim of this experiment is:

a) Find the cable tensions by increasing the load up to 3kg and plot it. Show its comparison with your analytically obtained results

b) Experimentally find the frequency of torsional oscillations (about the arrow shown) for the above-described loads on the structure



https://www.stirlingengine.co.uk/d.asp?product=TENSEGRITY

EXPERIMENTAL DESIGNS

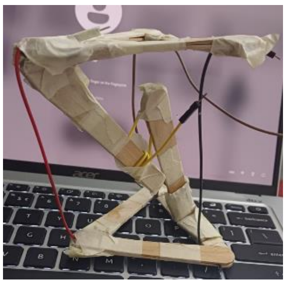
There were a lot of experimental designs that we explored so that the model made was a bit unique and also had better stability.

1) <u>The classic tensegrity table that was given as an example.</u>

We discarded this model as this was given in the problem statement and we wanted to make something unique. Moreover, drilling the holes at exactly 120-degree angle and then aligning the top and the bottom faces seemed a difficult task.

2) <u>The basic triangular tensegrity table</u>

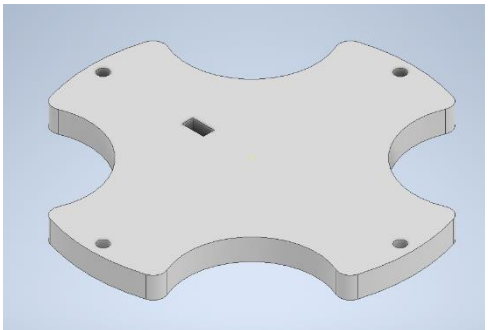
We then searched on the internet for various designs for the table and came across this model. Instead of taking a circle and joining the strings at 120-degree an equilateral triangle seemed a good choice. Also, we have learnt

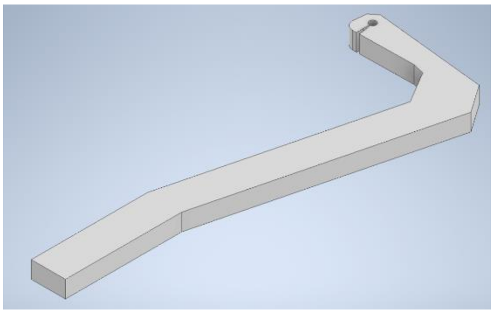


that triangles form a good base for any stable structures (for example trusses). We then discarded it with the view of coming up with something more innovative.

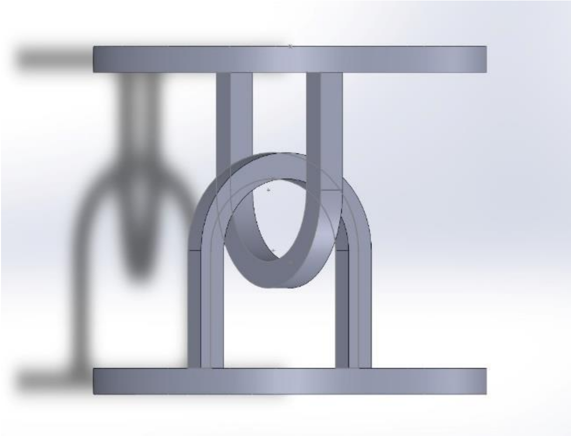
3) Models Designed by Us

a) Table with Flower like base and a side hole. This structure was used to reduce weight and to make it visually appealing. We have taken the thickness of the table to be 10mm for structural stability.





b) Then we designed a model with arms in the shape of semi-circle and interlocked with each other as shown in the figure.



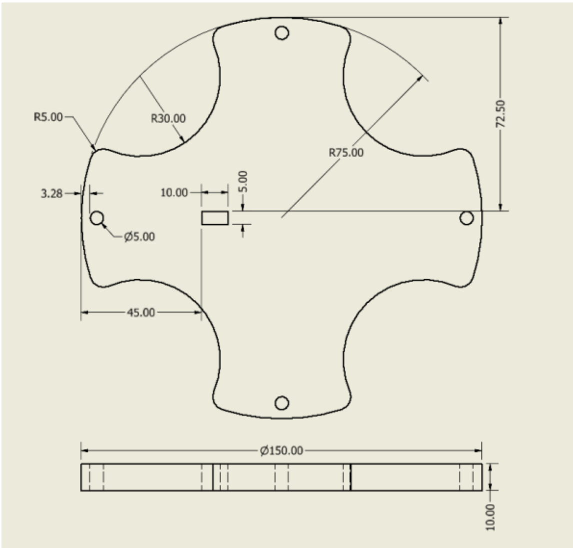
This was done with acrylic and it could bear load up to 3.5kg. We used it as a test model to see how much load will it be able to handle photos of which are attached in Photo Gallery.

While doing this the structure collapsed. This model helped us to limit the weight placed on our main MDF model

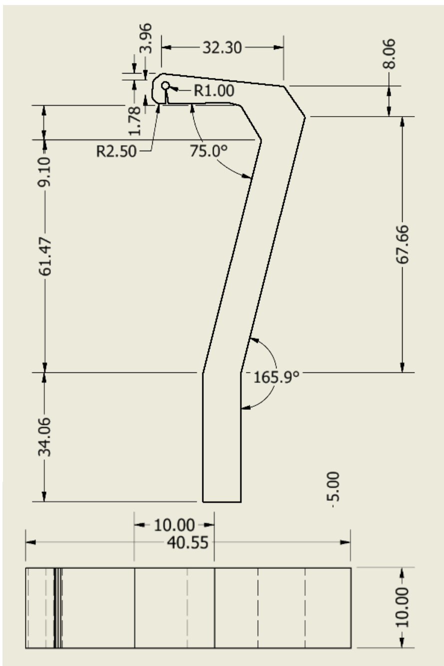
ENGINEERING DRAWINGS

The engineering drawings of the final model as generated in Autodesk are as follows. All the dimensions are in mm

1) The Base



1) The Struts



MATERIAL DATA

To make this tensegrity table we used MDF (Medium Density Fireboard) as the table should be both light and strong. For the experiment the table should bear 3kg of loads thus due to its high strength to weight ration MDF sheet was a perfect fit. In order to increase the strength, we have used 2 layers of 5mm thick MDF sheets.
For the cables we have used rubber strings since they have high tensile strength and are flexible, and for the loads we have used different books.
For adhesive we used Vetra (from machine shop) and fevi-kwik.

FABRICATION DETAILS

The fabrication process was carried out using laser cutter and by carefully attaching the strings for maximum tension.

1) Firstly, Different parts that is base and the struts were designed in Autodesk Inventor
2) Then they were exported as DXF file so that they can be accessed by laser cutting software.
3) Then four disc and four stuts were obtained which were glued together to obtain the required thickness of 10mm.
4) The struts were then glued in the holes at the base.
5) The strings were then carefully tied so that they have maximum tension.

THEORITICAL ANALYSIS

Tensegrity table is based on the principles of equilibrium, where the external loads are balanced by internal forces like tension in cables and compression in struts. This equilibrium conditions can be represented mathematically by force balanced equation.

As the structure is in equilibrium,

$\Sigma F = 0$ & $\Sigma M_c = 0$

① $\Sigma F = 0$

$$T_5 - T_1 - T_2 - T_3 - T_4 - \underbrace{M_T g}_{-W} - M_{arm} g = 0$$

$$= T_5 = T_1 + T_2 + T_3 + T_4 + 0.086 \times 10 + 1.3 \times 10^{-5} \times 10 \text{ N}$$

$$\approx T_1 + T_2 + T_3 + T_4 + 0.86 \text{ N} + W \quad -① \quad (\text{Arm mass is negligible})$$

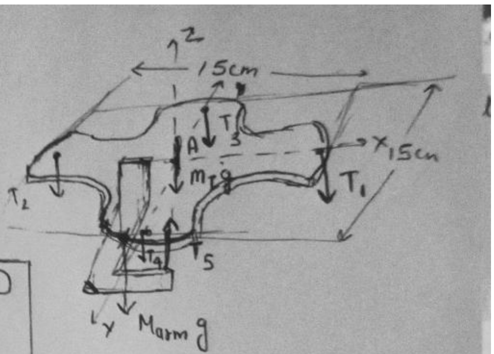
② $\Sigma \vec{M} = 0$

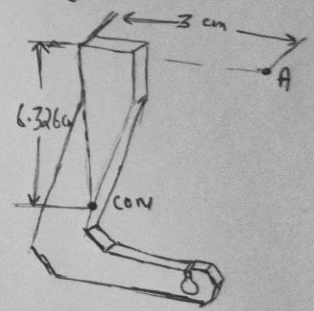
$$= \vec{r}_1 \times \vec{T}_1 + \vec{r}_2 \times T_2 + \vec{r}_3 \times T_3 + \vec{r}_4 \times \vec{T}_4 + \vec{r}_{arm} \times (M_{arm} \vec{g})$$

$$= (7.5\hat{i}) \times T_1(\hat{k}) + (-7.5\hat{i}) \times T_2(\hat{k}) + (-7.5\hat{j}) \times T_3(\hat{k}) + (7.5\hat{j}) \times T_4(-\hat{k}) + (-3\hat{i}) \times 1.3 \times 10^{-4}(-\hat{k}) = 0 \quad -②$$

As relative to respective tensions, the force due to gravity on arm is many order of magnitude smaller, it can be neglected.

So





Volume of Top ≈ 123×10^{-6} sq m^3

Volume of Arm ≈ 13×10^{-6} sq m^3

Density of MDF = 700 kg/m^3

Mass of Top = 0.086 kg

Mass of Arm - 1.3×10^{-5} kg

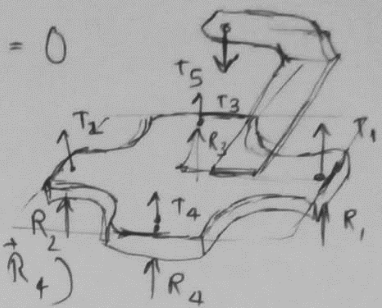
Accordingly $T_1 = T_2 = T_3 = T_4 = P/4$ from (2)

from (1) $\Rightarrow$ $T_5 - P = \text{Weight}_{top} = 0.86\,N + W$

• Equilibrium for bottom part.

$\sum \vec{F} = 0 \Rightarrow T_1 + T_3 + T_3 + T_4 + R_1 + R_2 + R_3 + R_4 - T = 0$

$\Rightarrow R_1 + R_2 + R_3 + R_4 = T - P - 0.86\,N$



$$\sum \vec{M}_2 = \vec{r}_1(\vec{T}_1 + \vec{R}_1) + \vec{r}_2(\vec{T}_2 + \vec{R}_2) + \dots + \vec{r}_4(\vec{T}_4 + \vec{R}_4)$$

$$= (+7.5\hat{i}) \times (T_1 + R_1)\hat{j} + (-7.5\hat{i}) \times (T_2 + R_2)\hat{j}$$

$$+ (-7.5\hat{j}) \times (T_3 + R_3)\hat{k} + (7.5\hat{j})(T_4 + R_4)\hat{k} = 0$$

$$\Rightarrow R_1 = R_2 = R_3 = R_4 = \frac{W + 0.86}{4}\ N$$

MEASUREMENT TECHNIQUES

In this experiment we are measuring Tension in the middle cable and the frequency of torsional oscillations.

To measure the tension in the middle string we have used the below formula:

$$\boxed{F = \frac{\Delta x \times A \times E}{x}}$$

Where Δx is the change in the length of nylon string, A is the area of cross-section which is assumed to be 0.78×10^{-6} (diameter is 1mm(approx)), E is modulus of elasticity which for rubber string is 0.05×10^{9} Pa, x is the initial length which is 0.73 m and F is the tension in the middle string.

In order to calculate frequency of torsional oscillations, we used a gyroscope for measuring the approximate angle by which we rotate the top of the table (that is 8 to 10 degree) and then count the number of oscillations in 5 seconds. The frequency is then given by the below formula:

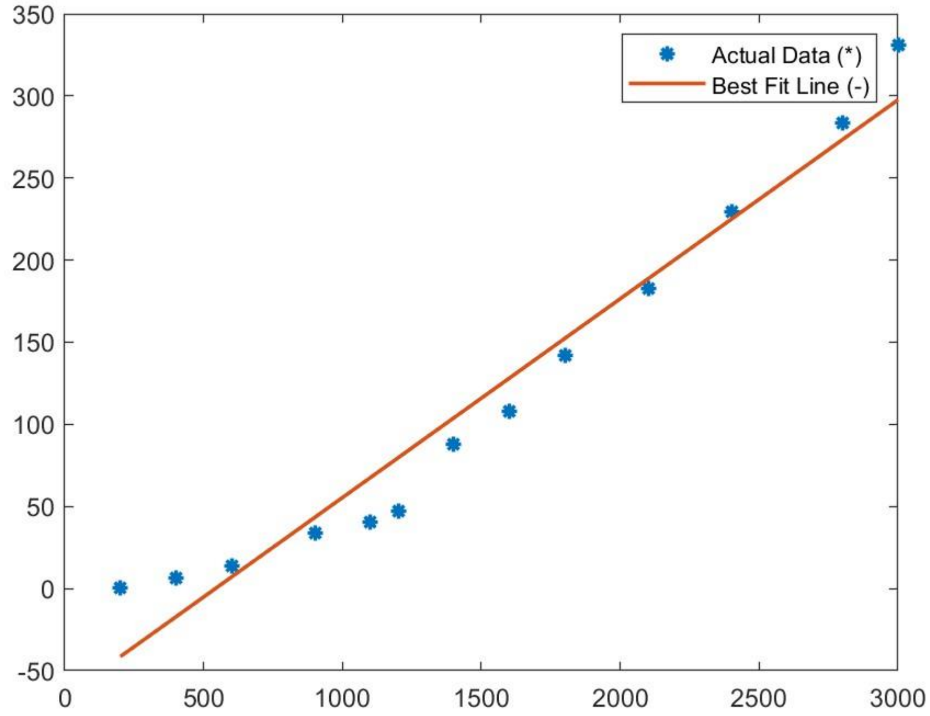
$$f = \frac{number\ of\ oscillation\ in\ 5\ sec}{5}$$

RESULTS

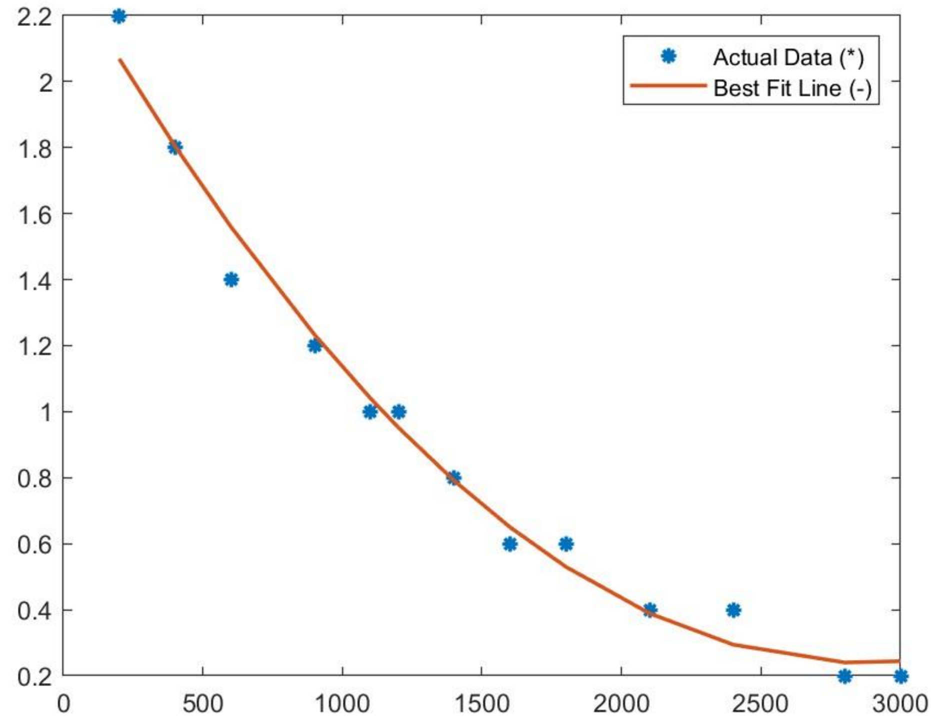
The experimentally results obtained for the tension in the middle string is as follows.
The modulus of elasticity is taken to be 0.05 GPa and the diameter is taken to be 1mm

Weight (g)	Normal Length (cm)	Extended Length (cm)	Extension (cm)	Torsional Frequency (Hz)	Tension (N)
200	7.4	7.5	0.1	2.2	0.6757
400	7.4	7.5	0.1	1.8	6.7568
600	7.4	7.6	0.2	1.4	13.5135
900	7.4	7.9	0.5	1.2	33.7838
1100	7.4	8	0.6	1	40.5405
1200	7.4	8.1	0.7	1	47.2973
1400	7.4	8.7	1.3	0.8	87.8378
1600	7.4	9	1.6	0.6	108.1081
1800	7.4	9.5	2.1	0.6	141.8919
2100	7.4	10.1	2.7	0.4	182.4324
2400	7.4	10.8	3.4	0.4	229.7297
2800	7.4	11.6	4.2	0.2	283.7838
3000	7.4	12.3	4.9	0.2	331.0811

Graph showing relation between Tension (N) and Weight (g)



Graph showing relation between Torsional Frequency (Hz) and Weight (g)



DISCUSSIONS

When conducting this experiment, it was observed that due to the load the outer rubber string develops a slack and the middle string is extended. This implies that the outer strings are in compression and the middle string is in tension.

The tension vs weight graph should have been a straight line however we got a deviation from straight line. This deviation can be due to multiple factors such as dampening, a mismatch between assumed and actual values of material properties, deviations in string lengths as some extra string goes in for knots etc.

As the load is increased the torsional frequency decreases. This is because increased load increases the stiffness of the structure leading to lower frequencies of torsional vibrations.

SHORTCOMINGS

We tried to analyse tension using a spring however the spring that we used did not have sufficient rigidity so it collapsed even under a small weight like 200g. Thus, we used strings. Due to which we took some approximations which may reflect in the final answer.

While calculating torsional oscillation we used physics toolbox available on play store however we don’t know its accuracy so we cannot entirely rely on it.

SCOPE FOR IMPROVEMENT

1) The design of a tensegrity table can be enhanced in a number of ways. Initially, accuracy and strength in construction are guaranteed when premium materials with exact shapes are used rather than discarded ones.
2) Second, using advanced equipment can result in more precisely placed holes, improving the stability and aesthetics of the table.
3) Lastly, investigating new methods for fixing strings and hooks might improve utility and durability.
4) In conclusion, improved materials, careful measurement, advanced equipment, and creative assembly techniques can all lead to a more efficient and advanced tension table.

REFERENCES

1) https://www.researchgate.net/publication/366832325_Design_of_a_Movable_Tensegrity_Arm_with_Springs_Modeling_an_Upper_and_Lower_Arm
2) https://youtu.be/RlVM-us6WW4
3) https://m.youtube.com/watch?v=PwU3NkPMQV4
4) https://en.wikipedia.org/wiki/Tensegrity
5) Lecture Slides.

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PHOTO GALLERY