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ANALYSIS & DESIGN OF TENSEGRITY WALKWAY BRIDGE

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Abstract: Origins of Tensegrity
The term tensegrity was first used by legendary architect Buckminster Fuller during his experimentation with alternative structural systems. Fuller described works of tensegrity as "self-tensioning structures composed of rigid structures and cables, with forces of traction and compression, which form an integrated whole."
Tensegrity structures are lightweight structures composed of cables in tension and struts in Compression. Since tensegrity systems exhibit geometrically nonlinear behavior, finding optimal Structural designs are difficult. This results in interest concerning possibilities of applying tensegrity as load carrying structure in a pedestrian bridge design. Tensegrity structures are light in Weight therefore very efficient and deployable. As compared to their self-weight they can sustain a large amount of loading if designed properly. Now and further these structures are used in architecture purpose. However, design as well as the arrangement of struts and cable to achieve equilibrium is quite complex and challenging.

KEYWORDS- Tensegrity, Pedestrian Bridge, Walkway Bridge, Tensegrity modules, Design optimization, Dynamic behaviour.

I. INTRODUCTION

Tensegrity structures are spatial structural systems composed of struts and cables with pin-jointed connections. Their stability is provided by the self-stress state in tensioned and compressed members. Although much progress has been made in advancing research into the tensegrity concept, a rapid survey of current activities in engineering practice shows that much of its potential has yet to be accomplished. A design optimization study for a tensegrity–based footbridge is presented in order to further advance the tensegrity concept in modern structural engineering. In the absence of specific design guidelines, design requirements for a tensegrity footbridge are stated. A genetic algorithm based optimization scheme is used to find a cost-effective design solution.

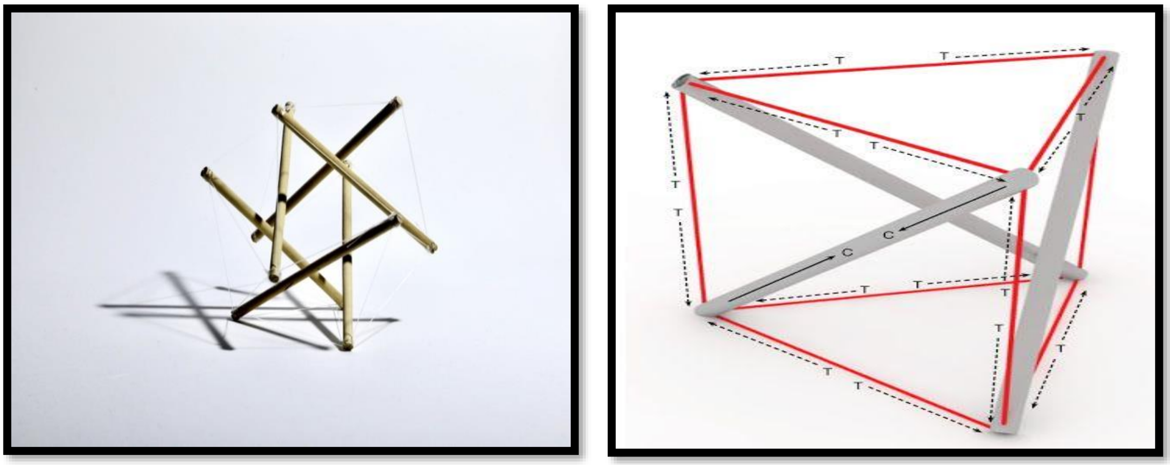


figure 1 : model and behavior of module on the application of load, on a single node or at a joint.

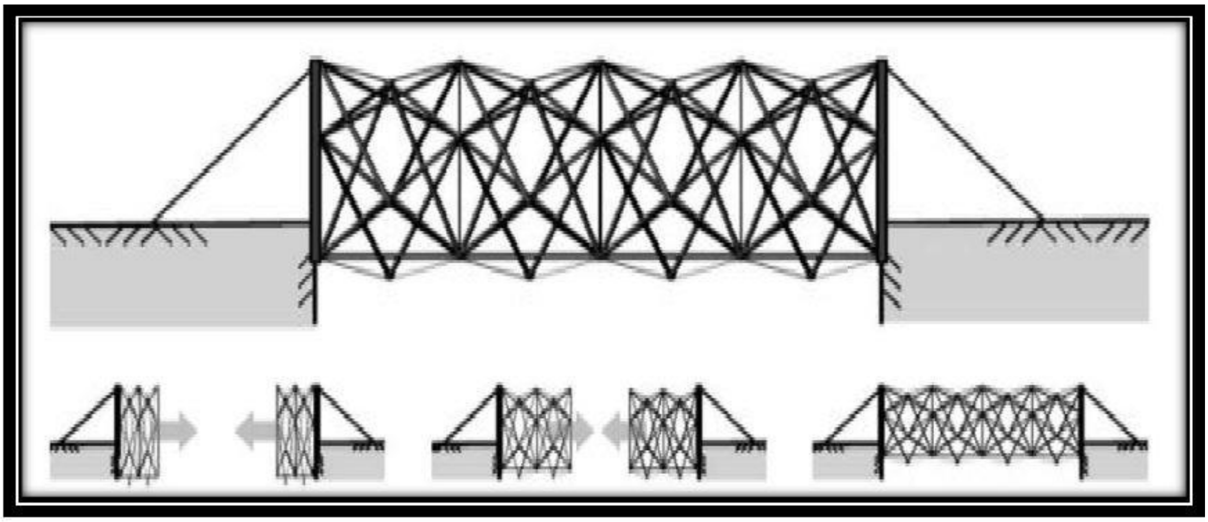


figure 2 : a tensegrity pedestrian bridge made by connecting number of modules of each other.

II. Properties

- Tensegrity structures are very lightweight as compared to conventional structures with similar resistance. In other words, they have a high resistance in comparison to other structures with similar weight.
- They do not depend on gravity due to their self-stability, so they do not need to be anchored or leaned on any surface. The systems are stable in any position. The force of gravity, which is the basis of the conventional architecture,
- Due to the discontinuity in compression, they are not acted by torque at all.
- They have the ability of respond as a whole, so local stresses are transmitted uniformly and absorbed throughout the structure.

III. Advantages

- The multidirectional tension network encloses compressive stresses, so there are no points of local weakness.
- Due to the ability of the structure to respond as a whole, it is possible to use materials in a very economical way, offering maximum amount of strength for a given amount of building material. The construction of towers, bridges, domes, etc. employing tensegrity principles will make them highly resilient and, at the same time, very economical.
- Tensile forces naturally transmit themselves over the shortest distance between two points; hence the members are precisely positioned to best withstand stress.
- The fact that these structures vibrate readily means that they transfer loads very quickly, so the loads cannot stress the structure locally. This is very useful in terms of absorption of shocks and seismic vibrations.

1 CONCEPT OF TENSEGRITY DESIGN

Tensegrity structures are structures based on the combination of a few simple design patterns:

- Loading members only in pure compression or pure tension, meaning the structure will only fail if the cables yield or rods buckle.
- Preload or tensional pre-stressed which allows cables to be rigid tension.
- Mechanical stability, which allows the member to members to remain in tension/compression as stress on the structure increase.
- Because of the patterns, no structural member experiences a bending moment. This can produce exceptionally rigid structures for their mass for the cross section of the components.

1.1 BENEFIT OF TENSEGRITY STRUCTURE

- Tension stabilizes the Structure.
- Tension structures are Efficient.
- Tensegrity structures are Deployable.
- Tensegrity structure is easily Tunable.
- Tensegrity structures can more Reliable Modelled.
- Tensegrity structure can perform Multiple Function.

1.2 SPECIFICATION AND CONSTRUCTION OF TENSEGRITY WALKWAY BRIDGE

A pedestrian bridge composed of tensegrity x shape modules. A span of 8 m and a distance from the ground of 3 m are assumed. The bridge geometry is chosen such that it has the minimum internal space required for two pedestrians to walk side-by-side (Figure 3). This space can be represented by a rectangle with a height of 2 m and a width of 1.5 m.

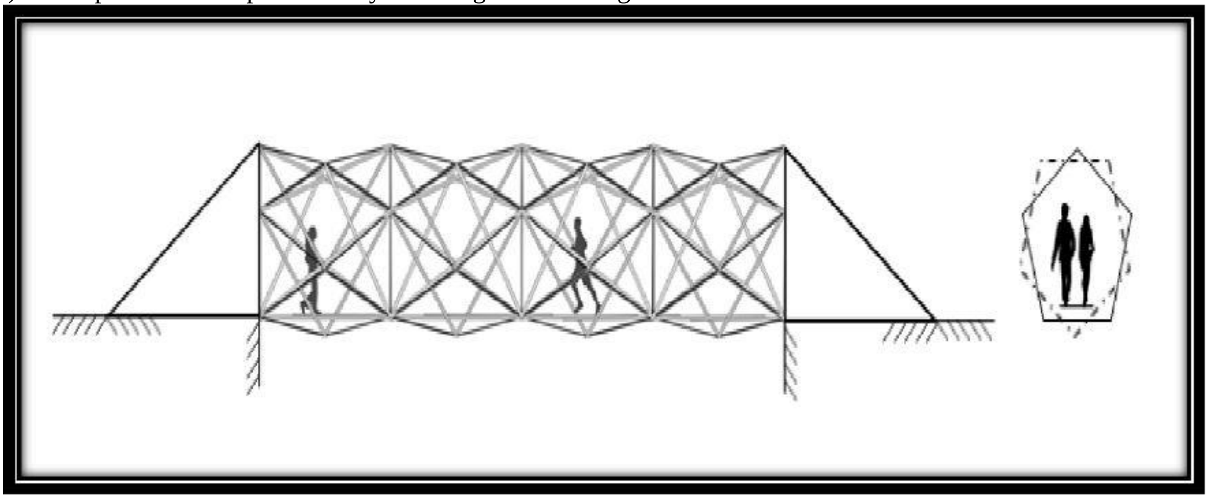


figure 3: a pedestrian bridge composed of tensegrity x shape modules

1.3 DESCRIPTION OF ANALYSED STRUCTURE

A. Material Characterization

Tensegrity structures generally consist of soft members (cables) and hard members (struts). It is essential to determine the material properties i.e. the Young's modulus (E), yield strength and the ultimate strength of both the tension and the compression members before they can be employed for fabrication. In this study Indian Standards IS 4923 (1997) Hollow steel section for structural use (specification), were used as compression members. The market confirming to IS 2365 (1997) Steel wire suspension ropes for lifts, elevator and hoists, were used as tensile members.

table-1: properties of ms tube as per is 4923-1997

PARAMETER	VALUE
Designation	150x150x5 (MM)
Depth Or Width (D)	150
Thickness	5 (Mm)
Weight	22.26 Kg/M
Area Of Section	28.36 Cm^2
Moment Of Inertia	982.12 Cm^4
Radius Of Gyration	5.89 Cm
Elastic Modulus	130.95 Cm^3
Plastic Modulus	152.98 Cm^3

table-2: properties of standerd wire as per is 2365-1997

PARAMETER	VALUE
Nominal bore diameter	20 mm
Thickness	2.6 mm
Mass	1.21 kg/m
Maximum outside diameter	21.8 mm
Minimum outside diameter	21
Tolerance in thickness	-10% to + unlimited
Minimum tensile strength	320 N/mm^2

B. Section Properties

table-3 : material and dimensional parameters of the tensegrity- membrane systems.

Properties	Section (MM)	Area (cm^2)	Iyy (cm^4)	Izz (cm^4)	J (cm^4)	Material
1	TUB150x150x5	28.400	982.000	982.000	1.52 E +3	STEEL
2	PIP88.9M	10.700	96.300	96.300	192.680	STEEL
3	Cir 0.02	3.142	0.785	0.785	1.571	STEEL
4	TUB 40X40X2.6	3.720	8.450	8.450	13.602	STEEL

C. Using Staad.Pro

In general analysis of member consists of two main parts. In first part, the determination of loads and reactions was done. In second part, determination of internal forces in the members. The types of member namely were modelled, analysed and designed through STADD PROv8i software package as per Indian code provisions. The model developed was ensured with stability conditions. See Fig shows the modelled.

Tensegrity Bridge Specification

1. Geometry:-

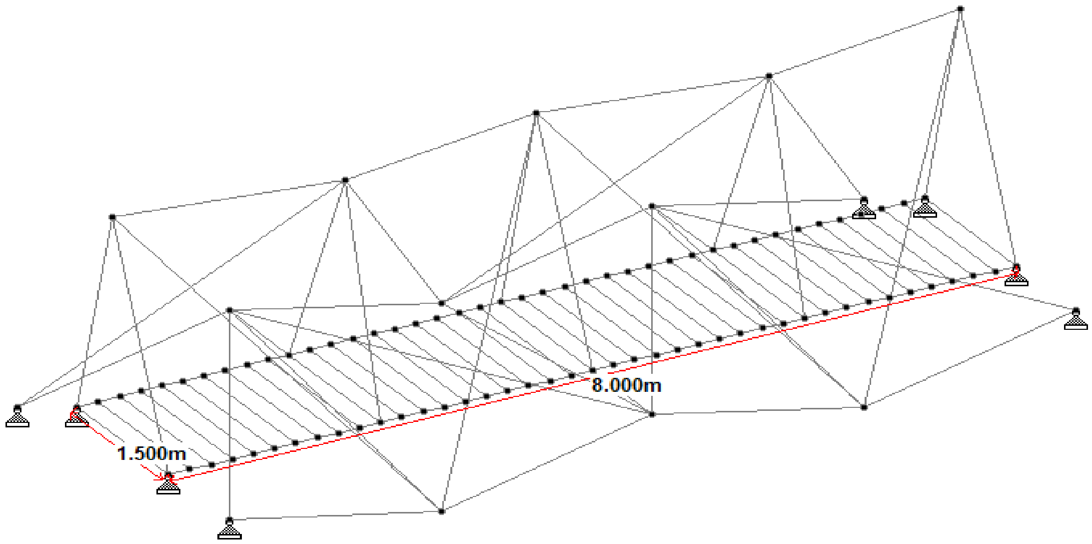


figure 4: the tensegrity walk way bridge

Here,
Length:- 8 meter
Width:- 1.5 meter

2. Properties:-

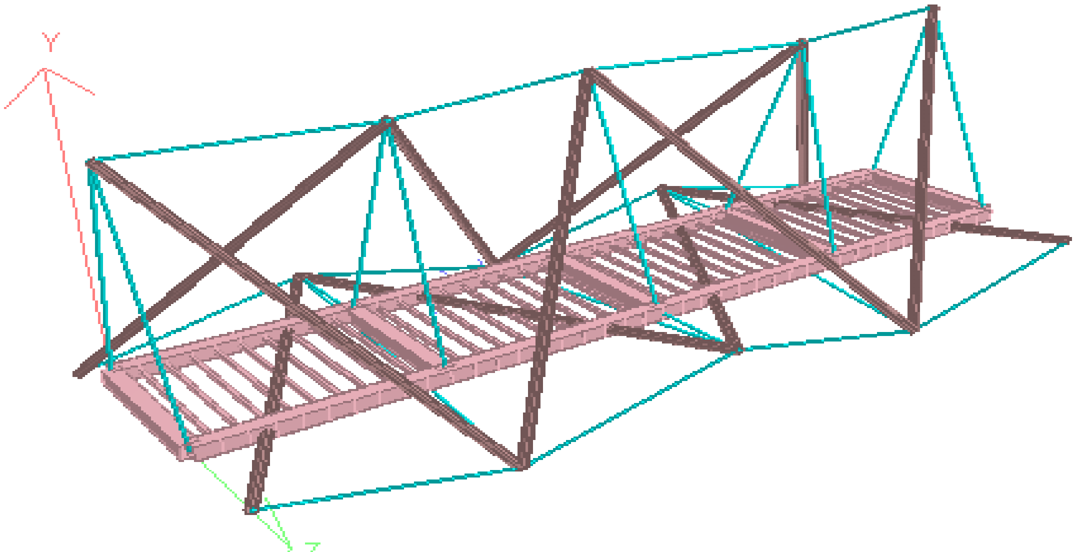


figure 5: 3d render view

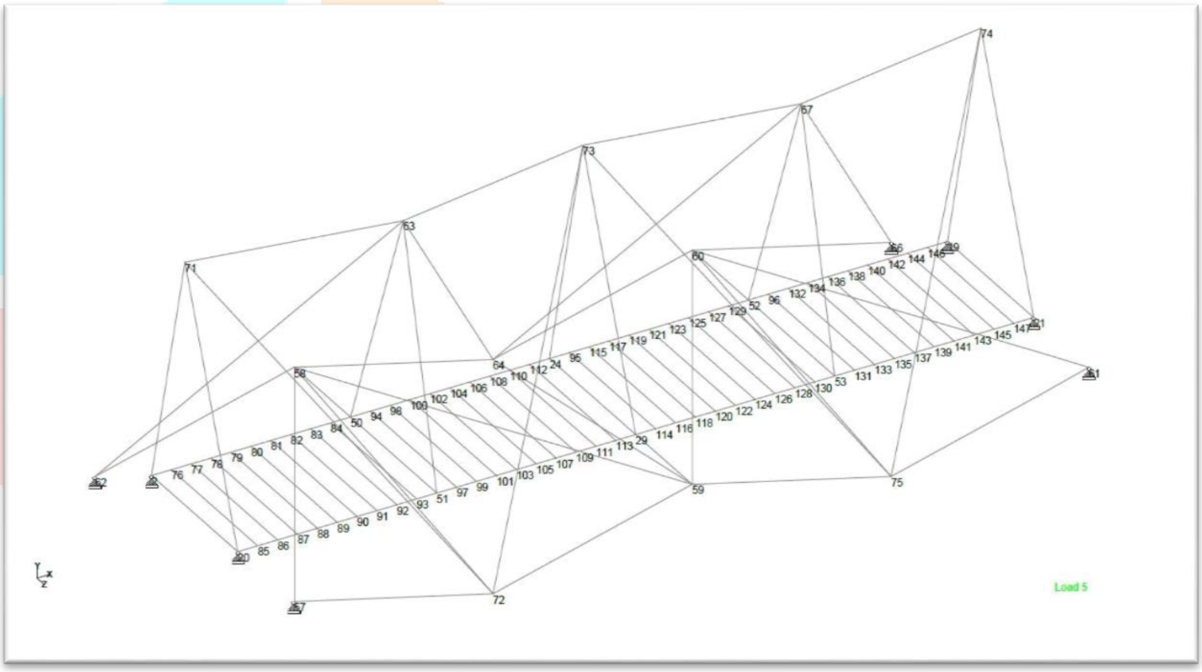


figure 6: a tensegrity pedestrian bridge show node number.

Main Member :- Tube 150x150x5 mm
Secondary member:- Tube 40x40x2.6mm
Strud:- Pipe 89 mm Dia
Cable:- 0.02 m Dia

3. Loading:-

    1. Dead Load:-
        1. Selfweight:- 1.1
        2. Weight of Steel Sheet plate of 10mm thk.:- 78.50 kN/m^3 x 0.010mm = 0.785 kN/m^2

    2. Live Load:-
    Weight of Human = 75 kg = 0.75 kN/m^2

4. Load Combiination:-
    1. DL+LL
    2. 1.5(DL+LL)

5. Spring Force in Cable :- 1 kN in Tension

6. RESULT:-

Value on node

The node numbers and the loading for case 1(load cases detail 2 kN) are shown in table. The structure was analysed and the maximum deflection and forces in elements for different cases are presented in tabular form in Table.

table 4: the maximum deflection and forces in elements for different cases.

		Horizontal	Vertical	Horizontal	Moment		
Node	L/C	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
58	2 DL+LL	0	5.35	-15.918	-0.115	0	0
59	2 DL+LL	0	5.338	15.918	0.095	0	0
60	2 DL+LL	0	5.35	-15.918	-0.115	0	0
63	2 DL+LL	-0.006	15.573	3.625	0.058	0.004	0
67	2 DL+LL	0.006	15.573	3.625	0.058	-0.004	0
71	2 DL+LL	-7.897	15.444	-2.299	-0.02	-0.008	0
73	2 DL+LL	0	15.564	-3.625	-0.049	0	0

The maximum deflections obtained in analysis for different load case are shown in Table Maximum vertical deflection is observed in Case for the central top node and maximum deflection in horizontal direction at node 63 for Case. As per the codal practice, the value should be within span/250, which is 32 mm. Hence, the maximum deflection is 40% of allowable limit. Similarly, the maximum forces in elements for different load case are shown in deflection Table. The results show that the maximum values are less than maximum carrying capacity. Though some of the cables are loosen due to less force than the prestressed equilibrium value, the structure will remain stable due to inherent redundancy.

table 5: minimum breaking strength, safe load and weight

Rope Diameter	Minimum Breaking Strength (kN)	Safe Load (kN)	Weight (Kg/M)
13 mm	95.2	19	0.63
16 mm	149	29.7	0.98
19	212	42.3	1.41
22	286	57.4	1.92

For Major Span Member

1. Displacement:-

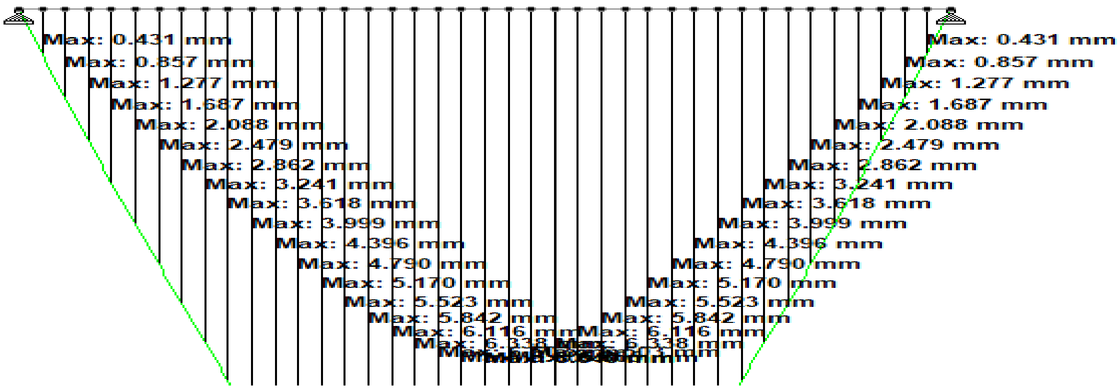


figure 7: the complete length of bridge (8 m) has deflection of 6.64 mm which is gradually increasing from corner to centre region.

2. Bending Moment

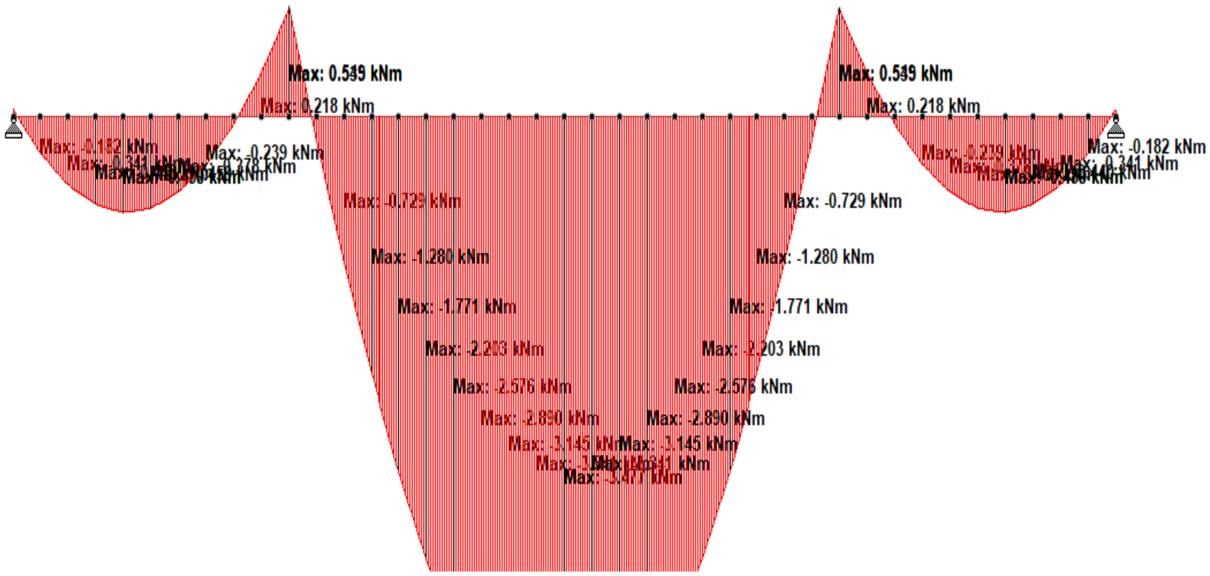


figure 8:the maximum bending moment occurred is 3.47 kN-m

3. Shear Force

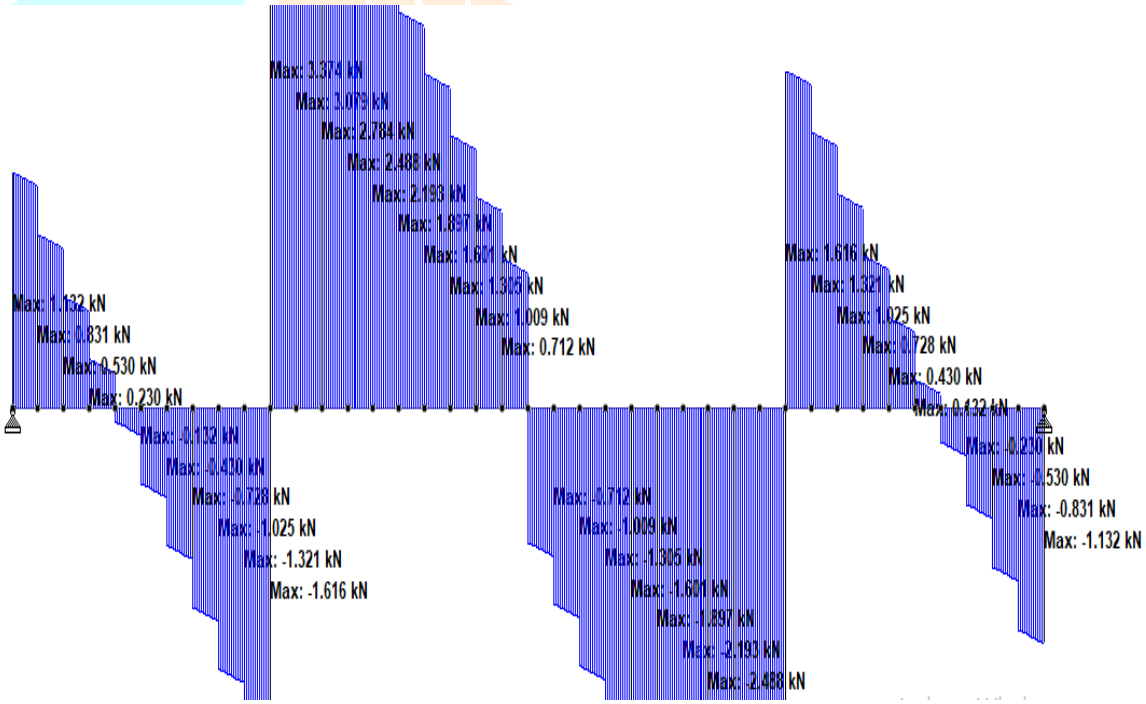
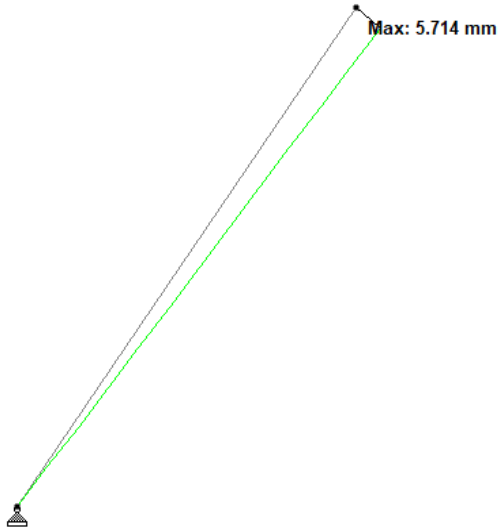


figure 9: the maximum shear force is 3.374 kN

STRUD

1. Displacement:-
2. Bending Moment:-



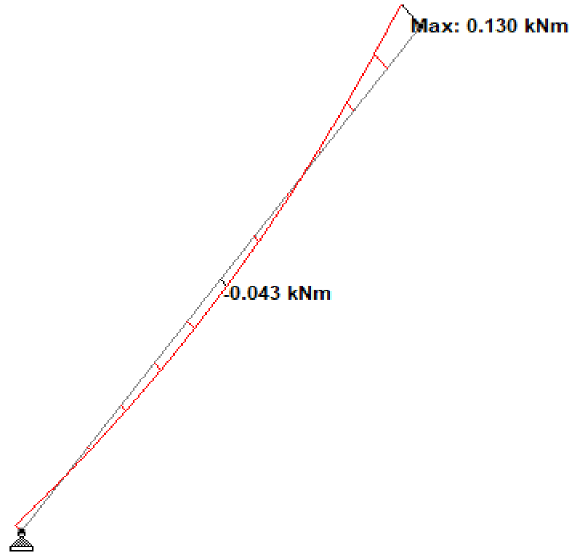
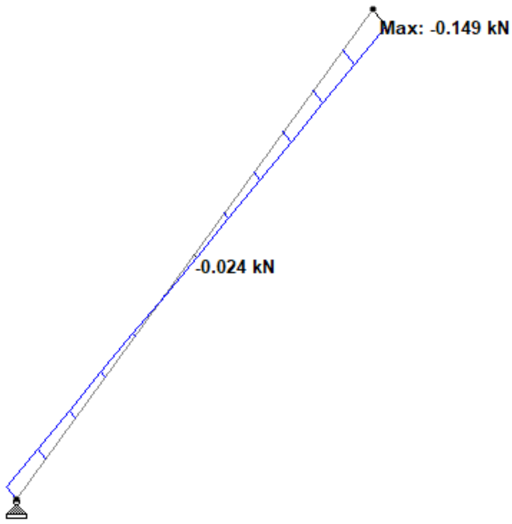


figure10:the maximum displacement is 5.714mm figure11: the maximum bending moment found in strud occurred is 0.130kNm

3. Shear Force :-
4. Axial Force :-



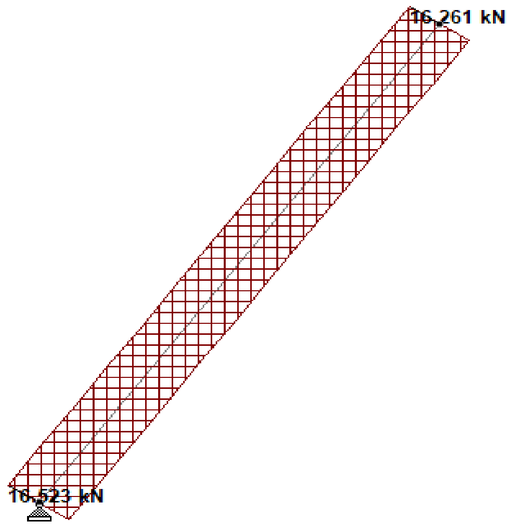


figure 12: the maximum shear force is 0.149 kN figure 13: the maximum axial force is 16.261 in compression

Secondary Members

1. Displacement:-

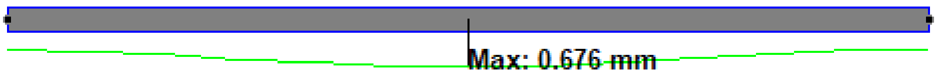


figure 14: the maximum displacement found in secondary members is 0.676 mm

2. Bending Moment:-

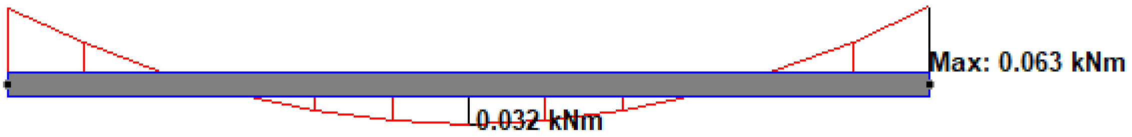


figure 15: the maximum bending moment occurred is 0.063 kn-m

3. Shear Force:-

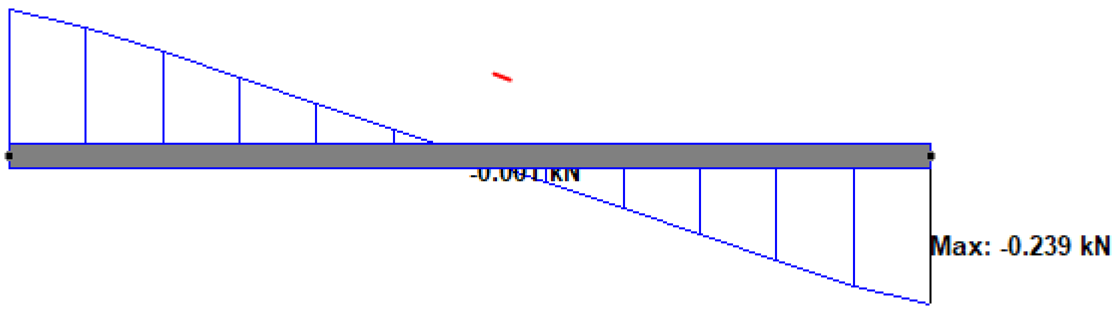


figure 16 :the maximum shear force is 0.239 kn

Types of member & classification different types of Main member

- BENDING MOMENT

table 6: comparisons between main member section verse loading.

Types	Section (mm)	Bending Moment (kN-m) Load - 2 kN/M^2	Bending Moment (kN-m) Load - 4 kN/M^2
1	TUB150x150x5	6.463	8.962
2	TUB125x125x5	4.727	6.925
3	TUB100x100x5	3.378	4.178

I. It is seen that the bending moment first section excites 2 kN/M^2 for 6.436 kN-m and for 4 kN/M^2 for 8.962 kN-m.
II. Analysis shows that the main member type 1 and type 2 are liable to bear a permissible load as per the codal requirement for the both loading configuration.

- SHEAR FORCE

table 7: Comparisons between Main member section verse loading.

Types	Section (mm)	Shear Force (kN) Load - 2 kN/M^2	Shear Force (kN) Load - 4 kN/M^2
1	TUB150x150x5	10.340	10.145
2	TUB125x125x5	7.074	9.429
3	TUB100x100x5	5.827	7.626

- DEFLECTION

table 8: Comparisons between Main member section verse loading.

Types	Section (mm)	Deflection (mm) Load - 2 kN/M^2	Deflection (mm) Load - 4 kN/M^2
1	TUB150x150x5	13.888	20.172
2	TUB125x125x5	15.269	22.176
3	TUB100x100x5	17.098	24.923

I. It is seen that the deflection for type 1 and type 2 are satisfied with in the permissible limit.
II. Analysis show that the main member type 3 are not liable to bear a permissible load As per the codal requirement for the both loading configuration.
III. At central node, the stress values are unmatched between type 1 and 2 trusses when analyzed through STAAD.
IV. Section needed to modified the structure for type 3 so that the deflection is in the permissible limit.

- WEIGHT OF STEEL

table 9: Weight comparisons between Main member

Types	Section (mm)	Weight of Steel (kg)
1	TUB150x150x5	23.550
2	TUB125x125x5	19.625
3	TUB100x100x5	15.700

CONCLUSION

- By using a Tensegrity structures we can make a light weight structure with the proper dimension and analyses.
- After doing the study of the tensegrity structures it came to know that the structures are quite economical, efficient, deployable and durable.
- The use of tensegrity structure should be done for bridges which are designed to carry light loads such as pedestrian bridges.
- Tensegrity structure design is a challenging task due to geometrical complexity and closely coupled behavior.
- Analysis shows that stress reversal occurs in some cables at loads higher than the load corresponding to deflection of L/250.
- By providing additional support on periphery, the deflection and strut force decreases and the load carrying capacity increases.
- All the deflections and member forces are within permissible value.
- The maximum deflection is less than allowable deflection, hence the cable is safe.

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