<u>A REPORT ON</u>

# ANALYSIS OF
# ADVANCED AND MODERN STRUCTURAL TECHNIQUES


*<u>Submitted by</u>*

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# ABSTRACT

In the modernising world, construction field has a vast growth with more innovative and elegant techniques of construction and analysis of complicated structures has become easy due to the development of software industry.

My work is to choose and analyse a certain type of structure in depth. So I am going to analyse a pentagon module tensegrity-ring pedestrian bridge. The tensegrity pedestrian bridge is designed by assembling elementary self-stressed modules. Tensegrity systems are spatial structures composed of tensile and compression components in a self-equilibrated state of prestress. The tensegrity concept offers good structural efficiency and results in modular and lightweight structures. Research into tensegrity systems has resulted in reliable techniques for form finding and structural analysis. Static and dynamic analysis of the structure is done by software called SAP 2000, and mathematical static analysis is done from the stiffness matrix method.

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# INTRODUCTION

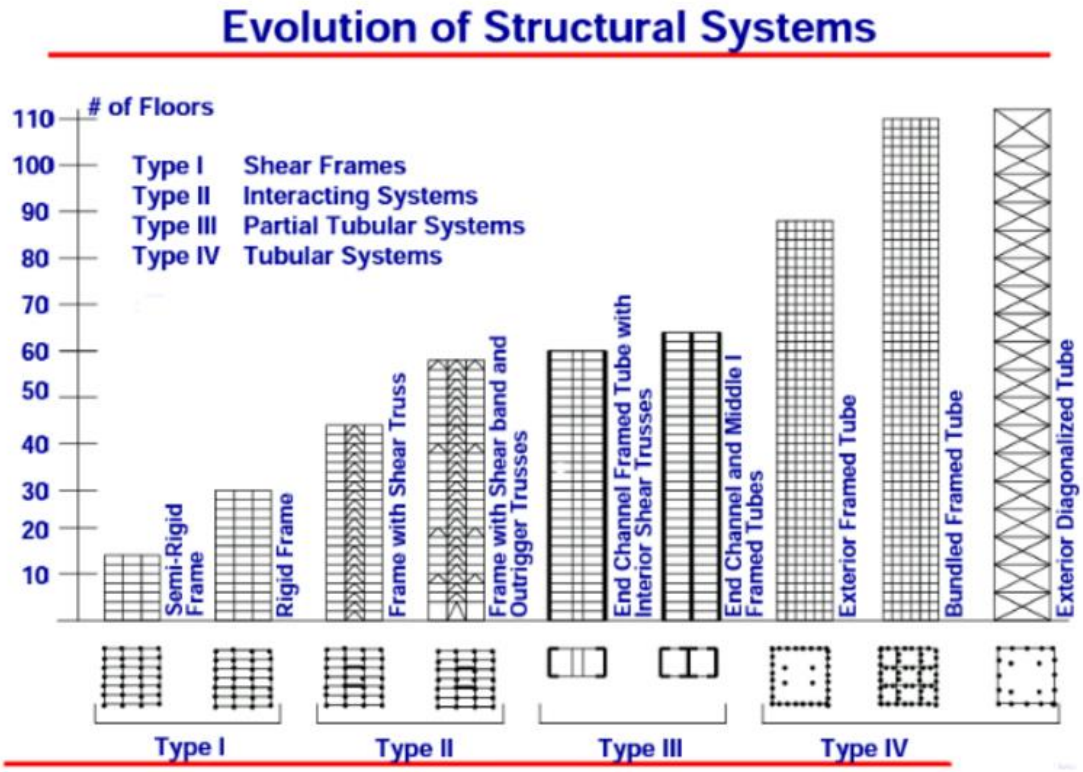
Structural engineers combine science and art to design and build our world's infrastructure to safely resist natural and man-made forces. Buildings, bridges, stadiums, off-shore and other civil facilities define the traditional core focus of structural engineers. At the periphery of the field, structural engineering extends more broadly to share common interests with mechanical, aerospace and naval engineering for the design of often large, complex systems including power plants, pipelines, aerospace vehicles and ships-submarines. So we have an ocean of structural types naming a few,

- TUBULAR STRUCTURES
- GRID STRUCTURES
- PRE-STRESSED CONCRETE STRUCTURES
- SHELL STRUCTURES
- TENSEGRITY STRUCTURES
- SPATIAL STRUCTURES

## TUBULAR STRUCTURES

In structural engineering, **tube** is a system to resist lateral loads like wind, seismic, impact loads where a building is designed to act like a hollow cylinder, cantilevered perpendicular to the ground. This system was introduced by Fazlur Rahman Khan while at the architectural firm Skidmore, Owings & Merrill (SOM), in their Chicago office.The first example of the tube's use is the 43-story Khan-designed DeWitt-Chestnut Apartment Building, since renamed Plaza on DeWitt, in Chicago, Illinois, finished in 1966.

The system can be built using steel, concrete, or composite construction (the discrete use of both steel and concrete). It can be used for office, apartment, and mixed-use buildings. Most buildings of over 40 stories built since the 1960s are of this structural type.



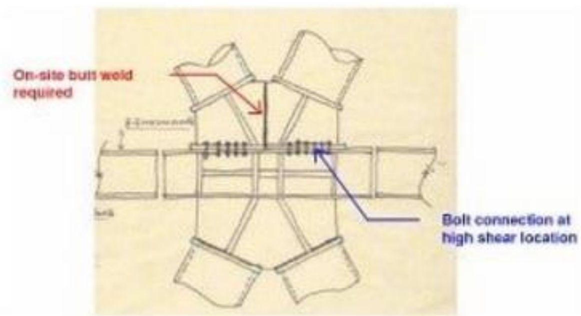

In the simplest incarnation of the tube, the perimeter of the exterior consists of closely spaced columns that are tied together with deep spandrel beams through moment connections. This assembly of columns and beams forms a rigid frame that amounts to a dense and strong structural wall along the exterior of the building.

This exterior framing is designed sufficiently strong to resist all lateral loads on the building, thereby allowing the interior of the building to be simply framed for gravity loads. Interior columns are comparatively few and located at the core. The distance between the exterior and the core frames is spanned with beams or trusses and can be column-free. This maximizes the effectiveness of the perimeter tube by transferring some of the gravity loads within the structure to it, and increases its ability to resist overturning via lateral loads.

# GRID STRUCTURES

The diagrid structural system can be defined as a diagonal members formed as a framework made by the intersection of different materials like metals, concrete or wooden beams which is used in the construction of buildings and roofs. Diagrid structures of the steel members are efficient in providing solution both in term of strength and stiffness. But nowadays a widespread application of diagrid is used in the large span and high rise buildings, particularly when they are complex geometries and curved shapes.

The nodes are the important part of the design of the diagrid system. All the diagonal sections are connected to each other by the help of nodes. These nodes are designed for two types of loads, vertical load and horizontal shear. These nodes are joined to the other sections by welding or bolting. It is made sure that very less amount of weld is to be used in the joining. The vertical load is transferred in the form of axial loads from the diagrid members that are placed above the nodes to the gusset plate and stiffeners, then to the diagrid members below the nodes. The horizontal shear is also in the form of axial loads in the diagrid above the nodes, but here one is in compression and another is in tension. The transfer of load is from above the node member to the gusset plate and stiffener and then from gusset plate and stiffener to the members below the node in pair of compression and tension and a bolt is provided at more shear section.




The advantages of the diagrid in the construction of the structure majorly improve the aesthetic view of the building. The use of diagrid reduces the steel up to 20 percent compared to brace frame structure. It doesn’t need technical labour as the construction technology is easy.

## PRE-STRESSED CONCRETE STRUCTURES

In conventional reinforced concrete, the high tensile strength of steel is combined with concrete's great compressive strength to form a structural material that is strong in both compression and tension. The principle behind prestressed concrete is that compressive stresses induced by high-strength steel tendons in a concrete member before loads are applied will balance the tensile stresses imposed in the member during service.

Prestressing removes a number of design limitations conventional concrete places on span and load and permits the building of roofs, floors, bridges, and walls with longer unsupported spans. This allows architects and engineers to design and build lighter and shallower concrete structures without sacrificing strength.

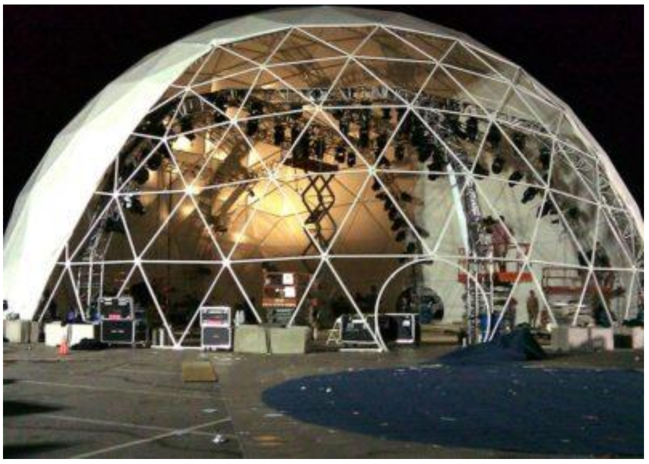
## SHELL STRUCTURES

A thin shell is defined as a shell with a thickness which is small compared to its other dimensions and in which deformations are not large compared to thickness. A primary difference between a shell structure and a plate structure is that, in the unstressed state, the shell structure has curvature as opposed to the plate’s structure which is flat.

- Membrane action in a shell is primarily caused by in-plane forces (plane stress), but there may be secondary forces resulting from flexural deformations. Where a flat plate acts similar to a beam with bending and shear stresses, shells are analogous to a cable which resists loads through tensile stresses.
- The ideal thin shell must be capable of developing both tension and compression. Some popular types of thin-shell structures are:,
- Concrete shell structures are often cast as a monolithic dome or stressed ribbon bridge or saddle roof
- Lattice shell structures, also called grid shell structures, often in the form of a geodesic dome or a hyperboloid structure

Membrane structures, which include fabric structures and other tensile structures, cable domes, and pneumatic structures.

A **geodesic dome** is a hemispherical thin-shell structure based on a geodesic polyhedron. The triangular elements of the dome are structurally rigid and distribute the structural stress throughout the structure, making geodesic domes able to withstand very heavy loads for their size. The major disadvantage of a dome is Air stratification and moisture distribution within a dome are unusual. The conditions tend to quickly degrade wooden framing or interior panelling. A company called New Age Construction in Alabama claims that an addition of a cupola eliminates the moisture condensation that is common in dome.



# TENSEGRITY STRUCTURES

Tensegrity is a portmanteau of tensional integrity. It refers to the integrity of structures as being based in a synergy between balanced tension and compression components. Tensegrity structures are built of struts and cable. ‘Tensegrity’ is a pattern that results when ‘push’ and ‘pull’ have a win-win relationship with each other. Pull is continuous whereas push is discontinuous. The continuous pull is balanced by the discontinuous push, producing the integrity of tension and compression. These fundamental phenomena do not oppose, but rather complement each other. Tensegrity is the name for a synergy between a co-existing pairs of fundamental physical laws of push and pull, or compression and tension, or repulsion and attraction. If one pushes a ping-pong ball on a smooth table with the point of a sharp pencil, the ball would always roll away from the direction of the push, first rolling one way then the other. Push is divergent. On the other hand, if a string be attached to the ping pong ball with tape, then pulling it leads to convergence. So Pull is convergent [2]. Another example from common experience occurs when pulling a trailer with a car.

When driving uphill, one is pulling against gravity, and a trailer will converge toward the same course behind the car. If the trailer begins to sway, increasing pull by increasing acceleration can dampen the swaying motion. Driving downhill, however, the trailer may begin to push, and the trailer will begin to sway from side to side [5].

Two tensegrity are easily recognizable in the systems of the human body.

The muscular-skeletal system is a tensegrity of muscles and bones, the muscles provide continuous pull, the bones discontinuous push. This forms the basis for all human physical mobility.

The central nervous system can also be seen as using the analogy of tensegrity where motor neurons and sensor neurons, complement the other in a balance. A more common example of a tensegrity is in a child's balloon. When examined as a system, the rubber skin of the balloon can be seen as continuously pulling (against the air inside) while the individual molecules of air are discontinuously pushing against the inside of the balloon keeping it inflated. All external forces striking the external surface are immediately and continuously distributed over the entire system, hence the balloon is quite strong despite its thin material.

## ADVANTAGES OF TENSEGRITY STRUCTURES

- They are efficient
- They are deployable
- They are easily tunable
- They can be more reliably modeled
- They Facilitate High Precision Control

### DEPLOYABILITY

Materials of high strength tend to have a very limited displacement capability. Such piezoelectric materials are capable of only a small displacement and “smart” structures using sensors and actuators have only a small displacement capability because the compressive members of tensegrity structures are either disjoint or connected with ball joints, large displacement, deployability, and stowage in a compact volume will be immediate virtues of tensegrity structures. This feature gives operational and portability advantages. A portable bridge or a power transmission tower as a tensegrity structure could be manufactured in the factory, stowed on a truck or helicopter in a small volume, transported to the construction site, and deployed using only winches for erection through cable tension. Erectable temporary shelters could be manufactured, transported, and deployed in a similar manner nothing but tents put up during traveling which is also a type of tensegrid structure.

## DISADVANTAGES OF TENSEGRITY STRUCTURES

- In order to support critical loads, the pre-stress forces should be high enough, which could be difficult in larger-size constructions.
- Tensegrity arrangements suffer the problem of bar congestion. As some designs become larger (thus, the arc length of a strut decreases), the struts start running into each other.

# TENSEGRITY FOOT BRIDGE

## (PENTAGON MODULE)

The model selected for this work, tensegrity footbridge, is made up from struts and cables. Initially, the main and secondary struts and cables were modelled according to the specifications reported in the literature [2] as shown in the table 1. A pentagon configuration was selected being the most efficient configuration. Furthermore this configuration gave the tip of the lead to the modelling; the key issue was to imagine a layer in the middle of the segment which was shifted about half of (360 of angles) of the shape of the layer.

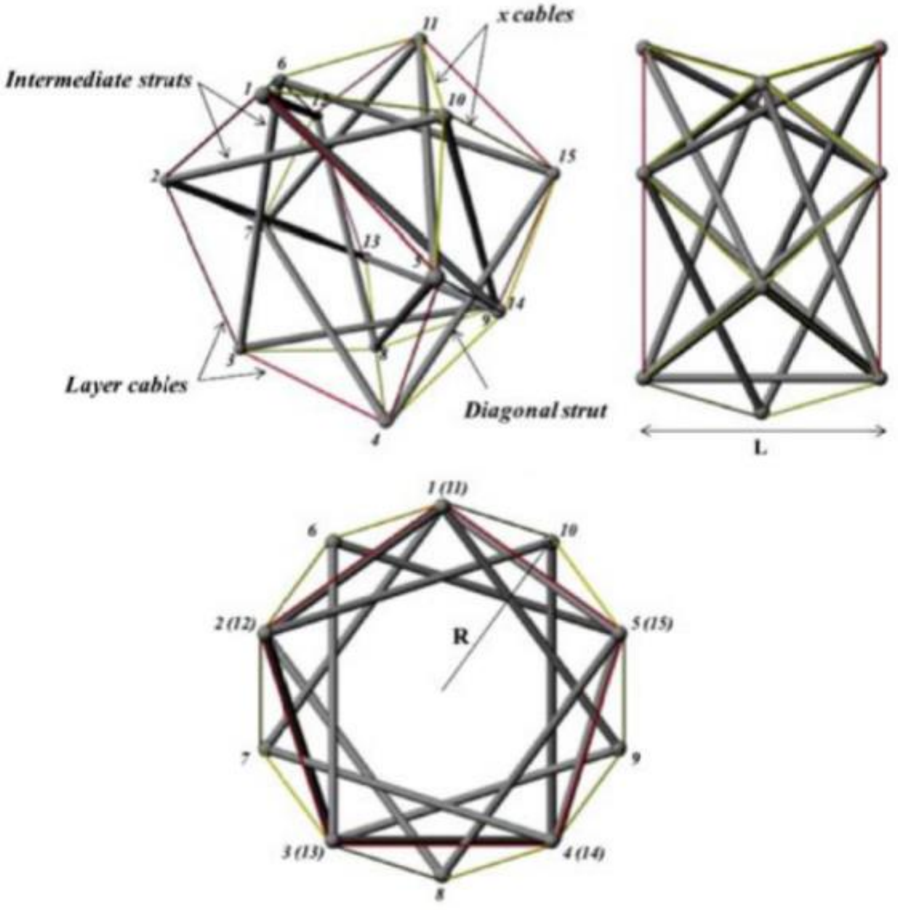
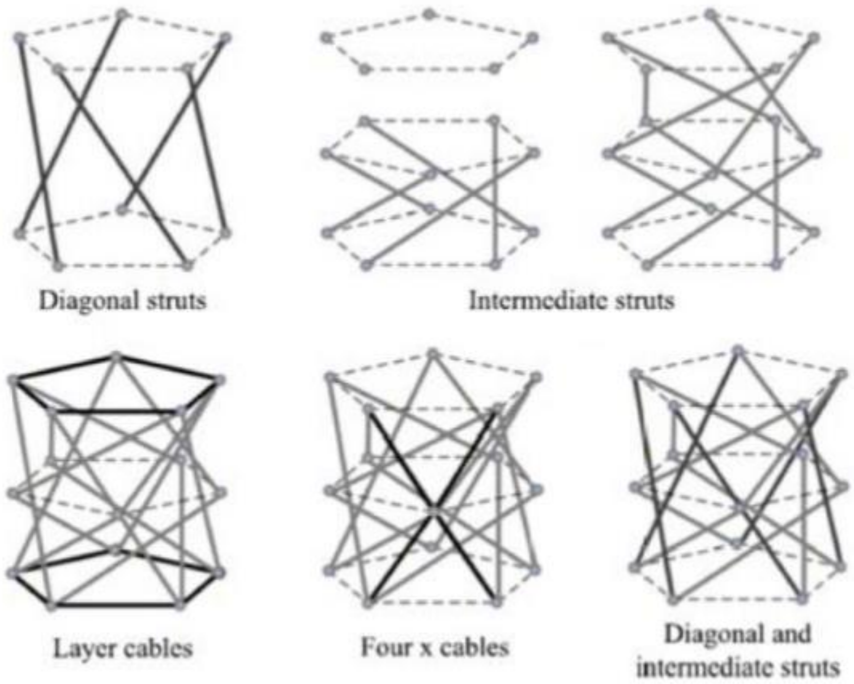


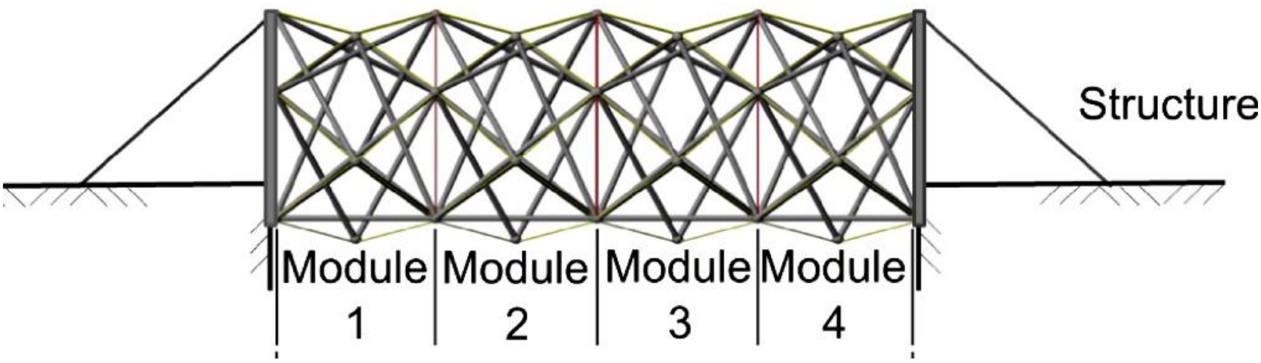

Figure 1. Pentagon module

A pentagon module contains 15 nodes forming 3 pentagonal layers. The middle pentagonal layer nodes are rotated about the longitudinal axes with respect to outer pentagon by 36° in the counter-clockwise direction.




The pentagon module comprises 15 struts held together in space by 30 cables forming a ring shaped tensegrity unit. Struts can be separated into diagonal and intermediate struts based on their topology. Diagonal struts connect outer and inner pentagon nodes while intermediate struts connect middle pentagon nodes to outer and inner pentagon nodes. Similarly, cables are separated into 10 layer cables and 20 xcables. Layer cables connect nodes of the two outer pentagons while x-cables connect middle pentagon nodes to inner and outer pentagon nodes.

Now the footbridge is a four segmented structure with each segment representing an individual pentagon module of tensegrity structure.



# MATHEMATICAL STUDY

To solve this footbridge problem we need to get the displacements of the nodes corresponding to the loads applied, so we have the relation between force and displacement matrix with the tangent stiffness matrix as the multiplier, we can use the stiffness method to solve.

- AS WE KNOW , $F=K_t * D$
- Where f= force matrix ,$K_t$ = tangent stiffness matrix
- D= displacement matrix
- $K_t$ = K + stress matrix , K = modulus stiffness matrix
- AND force matrix $f= f_l – f_i$ where

  $f_l$ = force due to loads

  $f_i$ = force due to pre stress

FINALY $d= K^{-1} * f$

The modulus stiffness matrix can be obtained from the member stiffness matrix of the members and so deduced. So the member stiffness matrix for each member in space can be represented as,

$$\mathbf{k} = \frac{AE}{L}\begin{array}{c} \begin{array}{cccccc} N_x & N_y & N_z & F_x & F_y & F_z \end{array} \\ \left[\begin{array}{cccccc} \lambda_x^2 & \lambda_x\lambda_y & \lambda_x\lambda_z & -\lambda_x^2 & -\lambda_x\lambda_y & -\lambda_x\lambda_z \\ \lambda_y\lambda_x & \lambda_y^2 & \lambda_y\lambda_z & -\lambda_y\lambda_x & -\lambda_y^2 & -\lambda_y\lambda_z \\ \lambda_z\lambda_x & \lambda_z\lambda_y & \lambda_z^2 & -\lambda_z\lambda_x & -\lambda_z\lambda_y & -\lambda_z^2 \\ -\lambda_x^2 & -\lambda_x\lambda_y & -\lambda_x\lambda_z & \lambda_x^2 & \lambda_x\lambda_y & \lambda_x\lambda_z \\ -\lambda_y\lambda_x & -\lambda_y^2 & -\lambda_y\lambda_z & \lambda_y\lambda_x & \lambda_y^2 & \lambda_y\lambda_z \\ -\lambda_z\lambda_x & -\lambda_z\lambda_y & -\lambda_z^2 & \lambda_z\lambda_x & \lambda_z\lambda_y & \lambda_z^2 \end{array}\right] \end{array} \begin{array}{c} \\ N_x \\ N_y \\ N_z \\ F_x \\ F_y \\ F_z \end{array}$$

$$\lambda_x = \cos\theta_x = \frac{x_F - x_N}{L}$$

$$= \frac{x_F - x_N}{\sqrt{(x_F - x_N)^2 + (y_F - y_N)^2 + (z_F - z_N)^2}}$$

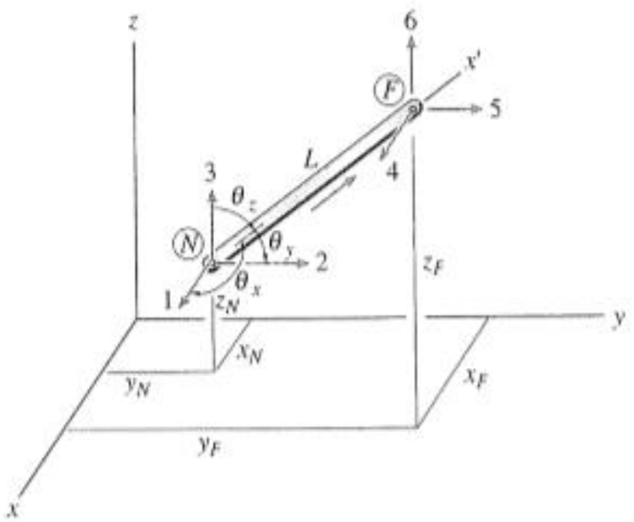
$$\lambda_y = \cos\theta_y = \frac{y_F - y_N}{L}$$

$$= \frac{y_F - y_N}{\sqrt{(x_F - x_N)^2 + (y_F - y_N)^2 + (z_F - z_N)^2}}$$

$$\lambda_z = \cos\theta_z = \frac{z_F - z_N}{L}$$

$$= \frac{z_F - z_N}{\sqrt{(x_F - x_N)^2 + (y_F - y_N)^2 + (z_F - z_N)^2}}$$

No we have the lambda values from the co-ordinates or the node position, to get the tangent stiffness matrix and for the nodes we have standard node data with respect to some span lengths which are used to analyse the structure mathematically.



# NODE DATA

| x [cm] | y [cm] | z [cm] |
|---|---|---|
| 0.00 | 0.00 | 389.40 |
| 0.00 | 370.30 | 120.30 |
| 0.00 | 228.90 | -315.00 |
| 0.00 | -228.90 | -315.00 |
| 0.00 | -370.30 | 120.30 |
| 250.00 | 0.00 | -389.40 |
| 250.00 | -370.30 | -120.30 |
| 250.00 | -228.90 | 315.00 |
| 250.00 | 228.90 | 315.00 |
| 250.00 | 370.30 | -120.30 |
| 500.00 | 0.00 | 389.40 |
| 500.00 | 370.30 | 120.30 |
| 500.00 | 228.90 | -315.00 |
| 500.00 | -228.90 | -315.00 |
| 500.00 | -370.30 | 120.30 |

So we have a 6*6 member matrix for each member with the corresponding degrees of freedom which can be combined to form a 45*45 matrix, as we have 15 nodes with 3 degrees of freedom for each node, to get the modulus stiffness matrix of a single pentagon module.

# CONCLUSION

Tensegrity-structure design is a challenging task due to geometrical complexity and closely coupled behaviour. The most efficient module is the pentagon ring and the least efficient is the hexagon. This conclusion employed a newly developed structural efficiency index.

A useful extension of the tensegrity grid design guideline includes the ratio of rigidity between cables and struts as well as material properties. So analysis is done assigning certain properties to the bridge and based on the results the struts and the cable properties are changed. Increasing the ratio of rigidity decreases vertical displacements until reaching a limit that varies with material properties. Tensegrity structures are efficient when properly designed. Further work involves construction and testing a prototype of the pentagon Tensegrity Bridge.

# REFERENCES


[1] Rhode-Barbarigos L, Bel Hadj Ali N, Motro R, Smith IFC. Designing tensegrity modules for pedestrian bridges. Engineering Structures, 2010;32(4):1158–67

[2] Skelton RE, de Oliveira MC. Tensegrity systems. Springer; 2009

[3] Static Analysis of a Tensegrity Bridge using the Finite Element Method,M.H. Zgoul*A. Alzamer, M. R. Elayyan, M. A. Quran ,Department of Mechanical Engineering, Faculty of Engineering University of Jordan Amman 11942, Jordan.