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REVIEW STUDY ON TENSEGRITY WALKWAY BRIDGE

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Abstract: Tensegrity structures are lightweight structures created 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 about 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 resist a large number of loading if designed properly. Now and further these structures are used in architecture purpose. However, design as well as the positioning of struts and cable to achieve equilibrium is quite complex and challenging.

KEYWORDS: Tensegrity, Pedestrian Bridge, Walkway Bridge, Tensegrity modules.

I. Introduction

'Tensegrity' is a kind of new concept using which one can create lightweight and adaptable structures, giving the impression of a assembling of struts floating in the air. Tensegrity structures can be defined as a design of results when the 'push' provided by struts and the pull provided by tendons achieve a win-win relationship with each other. While pull is continuous, push is discontinuous, and the two balance each other, producing the integration of tension and compression. Tensegrity structures consist of compression (bars) and tension (cables) members, where the cables surround bars. In 1921, Johanssen presented a sculpture made with three struts and eight cables during an exhibition held in Moscow. This module had no rigidity and mechanism could be activated with one of this cables. In 1948, Kenneth Snelson worked on similar structures with Richard Buckminster Fuller, in Black Mountain College. The first was a balancing shape, the second a linking system with tensile elements and the third an X-shape, The patent awarded to snelson [1965] for the basic tensegrity module in the structure continuous tension and discontinuous compression structure.

Fuller [1962] introduced the term Tensegrity which has been patented in U.S.A. as a contract of the two words "tension" and"integrity". The tension elements provide the structure with a lightweight aspect. Therefore, Fuller characterized these systems as small islands of compression in a sea of tension. Emmerich (1959) claimed himself the inventor of this new structural system. He patented a system called "Pearl Frameworks" at INPL (Institute National de la Propriety Industrially), France. These pioneers i.e. Fuller Snelson and Emmerich patented their systems, all of which indicate a similarity.

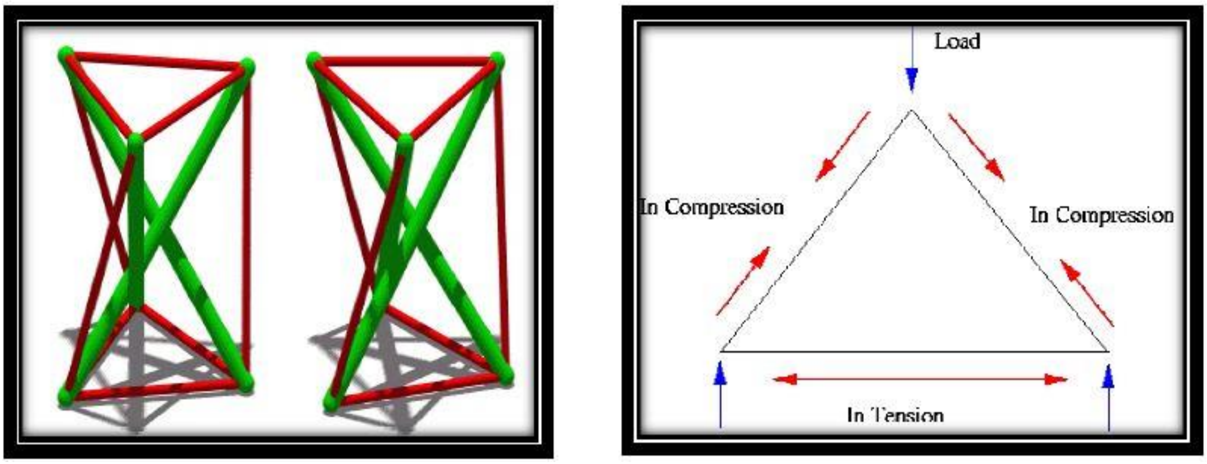

figure: model and behavior of module on the application of load, on a single node or at a joint.

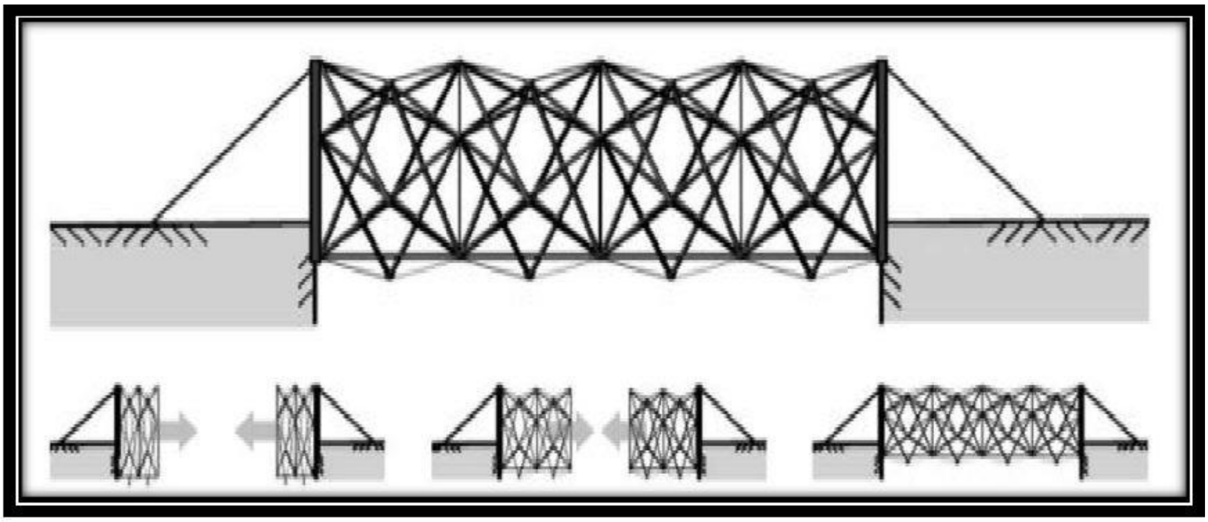

figure: a tensegrity pedestrian walkway bridge made by connecting number of modules each other.

I. PROPERTIES

- Tensegrity structures are light weighted as same as 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.
- 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.

II. ADVANTAGES

- The unidirectional tension network enclosed compressive stresses, so there are no points of local fault into the direction of tension.
- Due to the ability of the structure we can make to respond as a whole, it is possible to use materials in a very economical way as per the design, as per offering maximum amount of strength for a given amount of building material. The construction of towers, bridges, domes, etc. tensegrity principles will make them highly durable and economical.
- Tensile forces naturally transmit them over the shortest distance between two points hence the members are sharp positioned to best resist stress.
- The reality that these structures vibrate rapidly means that they transfer loads very quickly so that the loads cannot stress the structure specific. This is extremely useful in terms of absorption of shocks and seismic vibrations.

III. APPLICATIONS

The concept of Tensegrity was initiated on sculptures but soon found place in architecture and mathematics. Presently, the concept is used in different fields like civil engineering, inorganic chemistry, anatomy, macrocosm, biology, microcosm, mechanical engineering and biomechanics, for research activities. Tensegrity structures are enchanting blend under following circumstances:

- Portable and foldable structures: such as for disaster struck areas, nomadic communities and field hospitals.
- Cost-effective large-scale protection for construction, archaeological storage, agricultural, electrical or electromagnetic shielding or other delicate sites. Refugee or hiking shelters.
- Frames over large areas for environmental control, energy transformation and food production.
- Tensegrity structures can be used as tent like structures and shadow roofs, construction of tensegrity arches, foldable reflector antennas and masts for large retractable appendages in spacecraft, furniture like chairs, tables, lamps, and ornaments, as footbridges.

IV. CONCEPT OF TENSEGRITY DESIGN

Tensegrity structures are 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 design, no structural member experiences a bending moment. This can produce unusually rigid structures for their mass for the cross section of the components.

V. 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 functions.

VI. 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 1). This space can be represented by a rectangle with a height of 2 m and a width of 1.5 m.

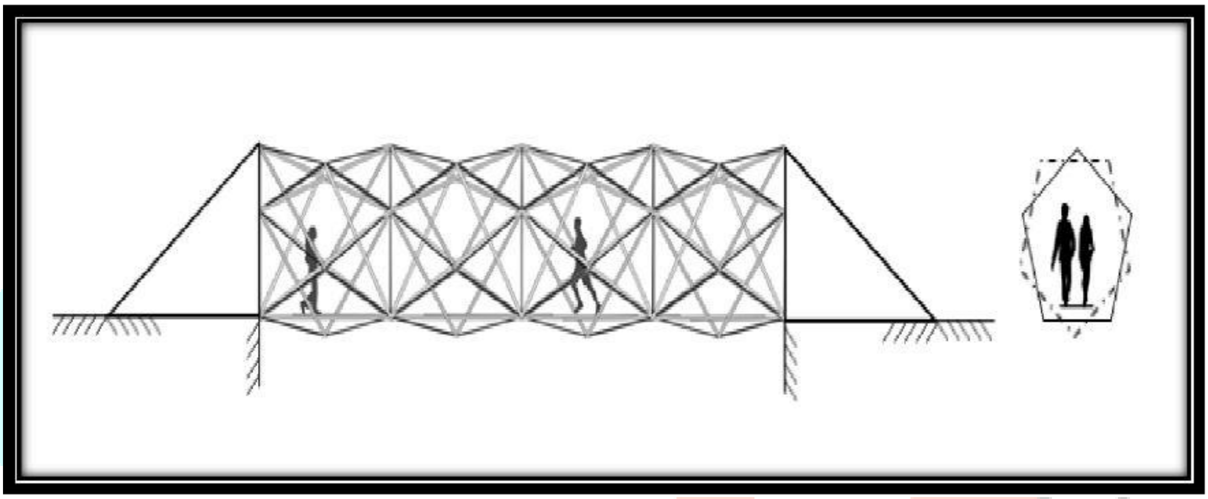

figure 1

VII. LITERATURE REVIEW

Technical paper from India & other countries are examined in order to determine the significance & need of this study in the context of Tensegrity walkway bridge it gives an overview of the literature review.

1. C Plescan, etc. all "A study of a tensegrity structure for a footbridge" Materials Science and Engineering 399 Transylvania University of Brasov, Romania (2018)

Abstract: It is known that tensegrity systems are made of isolated bars subjected only to compression, connected by stretched cables. The use of these structures comes with advantages such as making large openings and low consumption of materials. This paper analyses the problems related to the building and calculation of a 36-meter-long pedestrian bridge. The structure of the bridge is made up of a double arch of compressed bars and tensioned cables, which supports the path by means of cables. The structure has a number of kinematics degrees of freedom and is statically indeterminate in the same time, which means that it can be pretension. Pre tensioning introduces compression efforts in the bars and tension efforts in the cables, which fixes the kinematic degrees of freedom and confers rigidity to the system, thus resulting a structure which can support the external loads. The paper deals with aspects of structural analysis and static calculation of the structure subjected to loads.

Conclusion: Tensegrity footbridges are lightweight and efficient structures with high strength to weight ratio compared with traditional ones. Using only a small number of compressed elements working in isolation one from another by a net of cable elements subjected to tension, less material and respectively less weight of material are used for supporting a given load. The stiffness of the structure is given by the effect of pre stressing of the elements. The main disadvantages of tensegrity bridges consist in large deformations and vibrations. Tensegrity systems can withstand heavy loads, but their flexibility makes them to deflect considerably even under small loads. The stability, stiffness and load carrying capacity of the tensegrity structure studied in this paper were increased by using the supplemental stiffening effect of the longitudinal beams which support the deck.

2. **Pranay Pachare, Anand Randad,"Basic Study of Tensegrity Module Used For Pedestrian Bridge " International journal of innovative research in science, engineering and technology Aurangabad, Maharashtra, India, April 2016**

Abstract: The tensegrity framework consists of both compression members (struts) and tensile members (tendons) in a particular geometric shape in the state of equilibrium by generation of stresses by the structure itself. Tensegrity system development is important for the development and advancement of mankind. 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 biology, architecture and latest robotics.

However, design as well as the arrangement of struts and cable to achieve equilibrium is quite complex and challenging.

Conclusion

After doing the case study of the tensegrity structures we came to know that the structures are quite economical, efficient, deployable and durable. The structures provide high stability and hence safe for structural use. They are very durable and any repair works can be done without dismantling the whole structure. The use of tensegrity structure should be done for bridges which are designed to carry light loads such as pedestrian bridges, etc. Tensegrity structure design is a challenging task due to geometrical complexity and closely coupled behaviour.

The most efficient model is the pentagon ring and the least efficient is hexagon. A useful extension of the tensegrity grid design guideline includes the ratio of rigidity between cables and struts as well as material properties. Increasing this ratio decreases vertical displacement 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. Further work involves construction and testing a prototype of the pentagon tensegrity model.

3. **Wojciech Gilewski ,Joanna klosowska "Applications of tensegrity structures in civil engineering" International journal of multiphase flow, Elsevier Scientific publication, Poland 2015**

Abstract: The objective of the present paper is to describe the applications of tensegrity structures in civil engineering (roofs, domes, stadiums, etc.). The term of tensegrity was introduced by Fuller in the middle 50th of XX century. There are several definitions of this concept. For the purpose of this paper the tensegrity is defined a pin-joined system with a particular configuration of cables and struts that form a statically indeterminate structure in a stable equilibrium. Infinitesimal mechanism should exist in a tensegrity with equivalent self-stress state. Major advantages of tensegrity are: large stiffness-to-mass ratio, deploy ability, reliability and controllability.

Conclusions

The tensegrity concept has found wide applications within architecture and civil engineering, such as towers, large dome structures, stadium roofs, temporarily structures and tents. There are many advantages of this kind of structures. The definition of tensegrity structures has evolved in last 50 years what is the reason why there are some structures which are called "tensegrity", but they don't meet requirements. In this paper a few models of structures were analysed and checked if they are really tensegrity type. According to a qualitative analysis of trusses we concluded that White Rhino structure should not be named tensegrity, because of three additional elements caused that the structure had lost features which are typical for tensegrity. Based on the analysis of models consist of one trusses Simplex and two trusses Simplex, it can be assumed that War now Tower which consist of six tensegrity trusses Simplex has got six mechanism of geometrical variation and six self-stress states balancing these mechanisms of truss. War now Tower can be classified as tensegrity structure. More over domes which consist of interconnected two-dimensional truss showed in have got feature which are characteristic for tensegrity.

4. **Jan De Boeck "Concept design of pedestrian bridges using tensegrity as load carrying system" Delft University of Technology, The Netherlands 2013**

Abstract: Tensegrity corresponds to a structural principle consisting of strut and tie elements forming a 3D ensemble. The amazing, impressive and unusual character of tensegrity leads to the wondering of structural and functional performance of tensegrity. This results in interest concerning possibilities of applying tensegrity as A concept presenting potential of tensegrity in bridge design is developed and analysed. History of tensegrity, existing project, known shape, an over-view of information gained by sculpting 3D models are presented. A presentation of a 3 strut tensegrity module (module A), modelled with a FEM-analysis program follows. Combining several modules A leads to a first concept proposition for a bridge design.

Conclusion: Feasibility of tensegrity as principal structural system for pedestrian bridges has been proven. Presented concept result in design configurations reducing moments to a minimum. Confidence in system is crucial during development and assembly.

5. **J.Michielsen, R.H.B.Fey, H.Nijmeijer "Steady-state dynamics of a 3D tensegrity structure: Simulations and experiments" International journal of multiphase flow, Elsevier Scientific publication, The Netherlands, Jan 2012**

Abstract: This paper considers a modeling and analysis approach for the investigation of the linear and nonlinear steady-state dynamics of a base excited 3D tensegrity module carrying a top mass. The tensegrity module contains three compressive members, which may buckle and six cables (tendons). First, a dynamic model of the system is derived using Lagrange's equation with constraints. The buckling modeling of the compressive members is based on the assumed-mode method with a single mode discretization. The tendons are modeled as piecewise linear springs, which can only take tensile forces. This research focuses on the dynamic stability of the tensegrity structure by defining the geometrical and material properties in such way that the system is just below the static stability boundary. Static and linear dynamic analysis is performed .In the nonlinear steady-state analysis, frequency-amplitude plots, power spectral density plots, bifurcation point continuation diagrams, and Point care maps are presented. A tensegrity structure is designed and manufactured and an experimental set-up is realized in order to validate the model by comparing experimentally and numerically obtained responses. In the validation stage, the numerical results are based on an amplifier-shaker-tensegrity structure model. It can be concluded that the numerical results match partly quantitatively and partly qualitatively with the experimentally obtained responses.

Conclusions

In this paper, the numerical and experimental linear and nonlinear steady-state dynamics of a base excited 3D tensegrity structure carrying a top mass (and a top mass supporting structure) are examined. The equations of motion are derived by using Lagrange's equation of motion with constraints. In this model, the compressive members (beams Ai Bi) of the tensegrity module are allowed to buckle and the tendons are modeled by piecewise linear springs, which can only take tensile forces. Top mass, pretension in the tendons, and geometrical and material properties of the tensegrity structure are chosen in such a way that the system is close to the static stability boundary. The effect of additional harmonic base excitation is investigated in order to study the dynamic stability of the structure.

6. **Landolf Rhode-Barbarigos, Rene Motro and Ian F.C. Smith "Deployment aspects of a tensegrity-ring pedestrian bridge" Structural Engineers World Congress,p.hal-00857252 Italy May 2011**

Abstract: Tensegrity structures are spatial systems that are composed of tension and compression components in a self-equilibrated pre stress stable state. Although tensegrity systems were first introduced in 1950s, few examples have been used for civil engineering purposes. In this paper, tensegrity-ring modules are used for a deployable pedestrian bridge. Ring modules belong to a special family of tensegrity systems composed of a single strut circuit. Assembled in a "hollow-rope" structure, ring modules were shown to be a viable system for a tensegrity pedestrian bridge. Furthermore, ring modules are deployable systems that can change shape by adjusting cable lengths (cable actuation). This paper focuses on the deployment of a tensegrity-ring pedestrian bridge. A geometric study of the deployment for a single module identified the solution space that allows deployment without strut interference. The optimal deployment path is identified amongst hundreds of possible solutions. Moreover, the number of actuators required and their placement in the module are determined by the deployment path that is applied.

Conclusion

The deployment movement of the tensegrity footbridge can be described using three geometrical parameters. There is no explicit relation between the parameters for deployment as many paths can lead to the same module length.

The deployment path with minimum jamming risk was identified based on the computation of strut distances. Nevertheless, this path requires the actuation of all 30 cables for a single module. A deployment path with minimum actuation was found based on observations on this path. Actuation is reduced by 50% for a single module when minimum actuation path and continuous cables are employed. Deployment was successfully validated without any strut interference in a small scale physical model. The deployment path is composed of a series of intermediate equilibrium configurations. Deployment-actuation step size is an important parameter for the deployment analysis. Large steps result in unstable configurations, while small steps are computationally expensive.

Due to mechanism-based deployment, internal forces remain lower compared with service self-stress values and actuation energy is not high. Consequently, actuated deployment is not critical for the design of the tensegrity footbridge.

7. **Rhode-Barbarigos, L., Bel Hadj Ali, "Designing Tensegrity Modules For Pedestrian Bridges" Engineering Structures, Vol.32, No.4, 2010, PP.11581167, Switzerland (2010)**

Abstract: Tensegrity systems are spatial structures composed of tensile and compression components in a self-equilibrated state of pre stress. The tensegrity concept has already been studied by researchers in various fields over the past decades. A family of tensegrity modules that can offer promising solutions for civil engineering applications such as tensegrity domes, towers and bridges is analyzed. Research into tensegrity systems has resulted in reliable techniques for form finding and structural analysis. However, the tensegrity concept is not yet part of mainstream structural design. This paper presents a design study of a tensegrity-based pedestrian bridge. Structural performance of the bridge using three tensegrity modules is evaluated through parametric studies. Design requirements for pedestrian bridges and results of parametric studies are used to define a design procedure that optimizes section sizes for this type of structure. A structural efficiency indicator is proposed and used to compare proposals for feasible bridge configurations. Design results illustrate that the hollow-rope tensegrity bridge can efficiently meet typical design criteria.

Conclusions

Tensegrity-structure design is a challenging task due to geometrical complexity and closely coupled Behavior For applications of tensegrity ring modules in large-scale construction such as bridges, this work results in the following conclusions.

• A novel tensegrity bridge has been developed through a parametric design study of three potential module configurations: square, pentagon and hexagon. All modules were designed under similar criteria related to span, internal pedestrian space and loading. A structural efficiency index takes into account self-weight and deflection to assess the ability of these modules to satisfy design criteria. It was shown that the most efficient module is the pentagon ring and the least efficient is the hexagon.

• The existence of helical strut topologies in the ring configuration and the observation of differential vertical displacements confirm that there is torsion within the structure. The cause of torsion is the lack of symmetry about the y-z plane (x: longitudinal axis and z: vertical axis). However, feasible configurations with negligible effects of torsion can be found.

• A useful extension of the tensegrity grid design guideline includes the ratio of rigidity between cables and struts as well as material properties. Increasing this ratio 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.

8. Bel Hadj Ali, N., Rhode-Barbarigos, "Design optimization and dynamic analysis of a tensegrity-based footbridge" Engineering Structures, Vol.32, No11, 2010, pp 3650-9. Switzerland (2010)

Abstract: 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. The dynamic performance of the tensegrity footbridge is studied through parametric studies. Design results illustrate that the proposed tensegrity-based footbridge meets typical static and dynamic design criteria.

Conclusions

The tensegrity concept presents new opportunities for structural expression in civil engineering offering safety and serviceability together with an elegant appearance and high strength-to-weight ratio. Although, tensegrity have been around for fifty years, tensegrity systems are not yet recognized as feasible engineering solutions. In this paper, the feasibility of using the tensegrity concept in a footbridge structural system is investigated through design optimization and a dynamic study. A GA is employed to find minimal cost design solutions.

VIII. CONCLUSION

From a review of Literature revealed that

- By using a Tensegrity structures we can make a light weight structure with the proper dimension and analyses.
- It may be possible to achieve optimum performance by positioning a relatively small number tension and compression member into to the direction of equilibrium with load carrying structure in a pedestrian bridge design.
- After doing the study of the tensegrity structures we 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 behaviour.
- Further work involves construction and trail a prototype of the pentagon Tensegrity Bridge.

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