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Nonlinear Static and Dynamic behaviour of Tensairity Structures

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Abstract

Tensairity is a new light weight structural concept. It is a unique combination of pneumatic structures and cable-strut structures. The core principle of a tensairity structure is to use the low pressure air inside the hull element to stabilize the compression element from being buckled. The new light weight structure has a variety of applications ranging from wide span roof structures to temporary bridges. In this paper, non-linear static and dynamic analysis of a tensairity spindle shaped beam is done by dividing the thickness of hull element into three layers of equal thickness with different orientation in each layer. The paper also determines the maximum load carrying capacity of a spindle shaped tensairity beam before buckling for different parameters.

Keywords: Buckling, Cable-Strut, Light Weight, Pneumatic, Tensairity

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I. INTRODUCTION

A tensairity structure is a unique combination of a pneumatic structure and a cable-strut structure. Even though both these structures have their own properties and features, tensairity combines both these structural elements to a single structure. A tensairity girder therefore consists of a compression element and a tension element which is separated by a hull element made of fabric material. The hull element is filled with low pressure air which will stabilize the compression element from being buckled. The load bearing capacity of tensairity girder is same as that of a conventional steel girder. In case of a conventional steel girder, the load transfer between compression and tension elements are facilitated through the struts connecting compression and tension element. While in case of a tensairity girder, the load transfer between the compression and tension elements are facilitated by the pressure of air inside the hull element.

An important feature of a tensairity structure is its light weight property. The light weight property of tensairity structure is due to the optimal use of materials used to form the structure. This property of tensairity structure makes it possible to use as a deployable structure since smooth dismantling of tensairity structures are possible. This type of structures can be set up very quickly and is very advantageous during a crisis. Another major feature of a tensairity structure is its aesthetic appearance. Any architectural shape can be constructed by using this technique. The main applications include the roof structures of parking, stadium, temporary bridges, foot bridges, domes etc.

II. SPINDLE SHAPED TENSAIRITY BEAM

The basic form of a Tensairity beam is cylindrical in shape. But further investigations make it clear that a spindle shaped Tensairity beam is much stiffer than a cylindrical shaped Tensairity beam of same length, radius and internal pressure. In a spindle shaped beam, the helical shaped tension cables used in case of a cylindrical shaped tensairity beam is avoided. Instead the curved hull element of the spindle shaped tensairity beam is attached with a compression element at the top and a tension element at the bottom. The compression element and tension element is curved in shape and is fixed together at the ends. The compression element and the tension element of the tensairity beam is fixed at the end either by bolted connection or by welded connection. Generally, the dimensions of compression element and tension element at the ends are made slightly greater than other portion for fixing purposes. The hull element that acts as a spacer between the compression and tension element is pressurized to prevent buckling of the compression element. The Parking garage with Tensairity roof structure in Montreux, Switzerland is one of the first application based on spindle shaped Tensairity girders. The roof structure here is built with twelve spindle shaped tensairity girders of span up to 28m and the girders are covered with a fabric material as weather protection for parked vehicles. To improve the aesthetic appearance, the beams are illuminated by means of lamps from inside.

III. MODELLING OF SPINDLE SHAPED TENSAIRITY BEAM

Modelling of spindle shaped tensairity beam was done using the software ANSYS. The finite element model used BEAM elements (chords) and SHELL elements (fabric) to model the tensairity beam. The air pressure was modeled as a surface load on the SHELL elements. In this study, the fabric was made with same material divided into three layer of equal thickness but with different orientation. The overall thickness of the fabric is 0.5 mm. The length of the beam provided is 5m and central diameter provided is 0.5m. The tension and compression rod is rectangle in shape having a width 0.3m and depth 0.2m and at the support dimensions of 0.4m×0.25m is adopted. Density of fabric material used here is 1440kg/m^3 and density of chord material used is 2700kg/m^3. Internal pressure applied on the hull element is 150mbar. The dimensions of the spindle shaped tensairity beam are shown in Fig.1 and Fig.2.

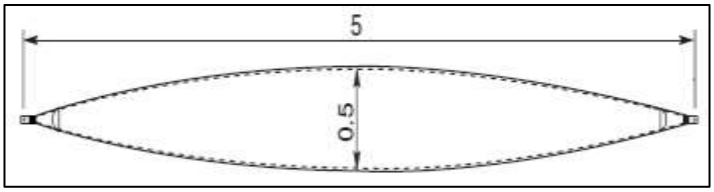

Fig. 1: Longitudinal dimensions of spindle shaped Tensairity beam

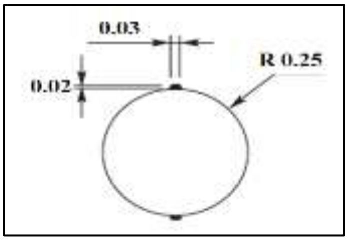

Fig. 2: Cross sectional dimensions of spindle shaped Tensairity beam

For modeling the spindle shaped beam, SHELL 281 is used as the hull element and BEAM 189 is used as the chord element. A mesh refinement study is conducted by varying the element size to create uniform meshes as shown in Fig.3. The meshed model is simply supported at the ends and pressure is applied internally in the form of surface load as shown in Fig.4.

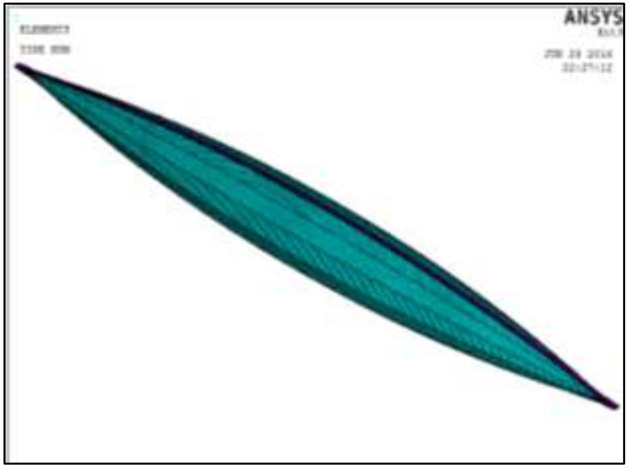

Fig. 3: Meshed model of Tensairity beam

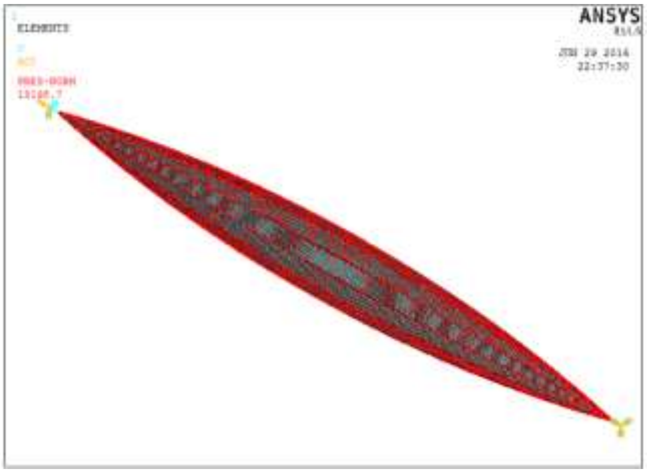

Fig. 4: Tensairity beam with internal pressure

IV. RESULTS AND DISCUSSIONS

The results of analysis conducted are discussed in detail. The static and modal analysis of spindle shaped tensairity beam was done.

A. *Modal analysis with different layers of same fabric material at different orientation*

Modal analysis of spindle shaped tensairity beam is done by dividing the fabric material of the hull element into three layers of same material of equal thickness but by varying the orientation of fabric in each layer. The total thickness of the fabric is 0.5mm. For the analysis, aluminium is taken as the tension and compression element and PVC coated polyester is chosen as the fabric material and an internal pressure of 150mbar is provided in the hull element. The dimensions of the chord element used is 30mm×20mm. At the support, dimension of 40mm×25mm is used. The first four natural frequencies are obtained for different orientation and are shown in Table-1.

Table - 1
Comparison of frequencies for different orientation of fabric

$45^0, 0^0, -45^0$	$0^0, 45^0, 0^0$	$60^0, 0^0, -60^0$	$0^0, 60^0, 0^0$	$30^0, 45^0, -30^0$	$30^0, 0^0, -30^0$
9.2421	*9.2352*	*9.1202*	*8.9256*	*8.6643*	*9.1263*
10.7260	*10.7466*	*10.5625*	*10.2420*	*10.1236*	*10.4234*
28.7362	*28.6953*	*27.5864*	*27.1222*	*27.4444*	*27.4352*
29.1250	*29.2242*	*28.1252*	*28.4262*	*28.8562*	*28.4256*

The frequencies corresponding to orientation 45^0,0^0,- 45^0 and 0^0 ,45^0 ,0^0 are the highest and are found close to each other. Considering symmetry, orientation of 0^0 , 45^0 , 0^0 is chosen for further analysis.

B. Maximum load carrying capacity of tensairity spindle beam before buckling with different hull material

The maximum load carrying capacity of a spindle shaped tensairity beam before buckling with different material for the hull element is determined by non-linear static prestressed analysis and linear perturbation analysis. For the analysis, the tension and the compression chord of the beam is made with aluminium and the maximum load carrying capacity before buckling is determined at different pressure for different hull material. The dimensions of the chord element used is 30mm×20mm. At the support, dimension of 40mm×25mm is used. The different fabric material used were PVC coated polyester, nylon and polypropylene. The maximum load carrying capacity before buckling of spindle shaped tensairity beam with different fabric material for varrying pressure is shown in Table-2 and Fig.5.

Table - 2
Maximum load carrying capacity before buckling with different fabric materials

Pressure(mbar)	*Maximum load carrying capacity before buckling(KN)*		
	PVC coated polyester	*Nylon*	*Polypropylene*
50	*3.47*	*3.30*	*3.24*
100	*5.25*	*4.82*	*3.57*
150	*5.82*	*5.13*	*3.74*
200	*6.12*	*5.37*	*3.85*
250	*6.31*	*5.49*	*3.92*
300	*6.45*	*5.61*	*3.98*

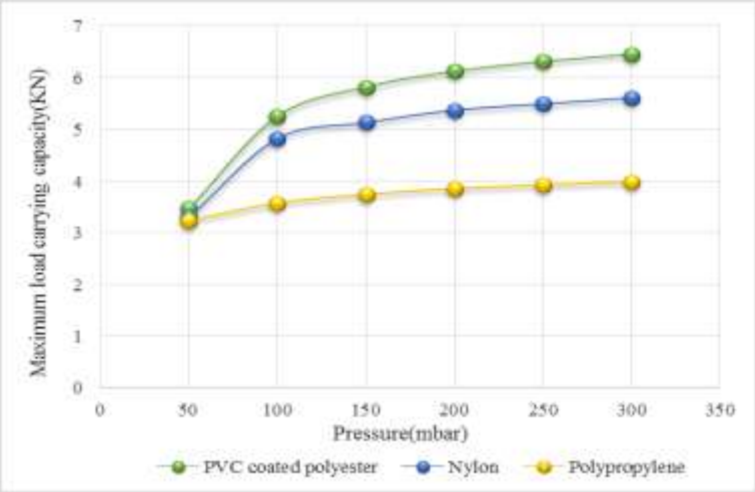

Fig. 5: Pressure versus Maximum load carrying capacity

From the above graph, it is found that the maximum load carrying capacity before buckling of a spindle shaped tensairity beam increases with increase in pressure for all the three fabric material selected for the hull element. Among the three fabric material used, the maximum load carrying capacity before buckling of spindle shaped tensairity beam with PVC coated polyester as fabric material is found to be the highest and the maximum load carrying capacity before buckling of spindle shaped tensairity beam with polypropylene as fabric material is found to be the lowest.

C. Maximum load carrying capacity of tensairity spindle beam before buckling with different chord material

The maximum load carrying capacity of a spindle shaped tensairity beam before buckling with different chord material is determined by non-linear static prestressed analysis and linear perturbation analysis. For the analysis, fabric of the hull element is made with PVC coated polyester divided into three layers of equal thickness but with different orientation. The orientation of fabric used is 0^0, 45^0, 0^0. The maximum load carrying capacity before buckling is determined at different pressure. The dimensions of the chord element used is 30mm×20mm and 40mm×25mm at the support. The different chord materials used for the analysis are aluminium, steel and copper. The maximum load carrying capacity before buckling of spindle shaped tensairity beam with different chord material for varrying pressure is shown in Table-3 and Fig.6.

Table - 3
Maximum load carrying capacity before buckling with different chord materials

Pressure(mbar)	*Maximum load carrying capacity before buckling(KN)*		
	Aluminium	*Steel*	*Copper*
50	*3.47*	*6.37*	*4.65*
100	*5.25*	*9.37*	*6.95*

150	*5.82*	*10.40*	*7.73*
200	*6.12*	*10.89*	*8.08*
250	*6.31*	*11.25*	*8.35*
300	*6.45*	*11.54*	*8.55*

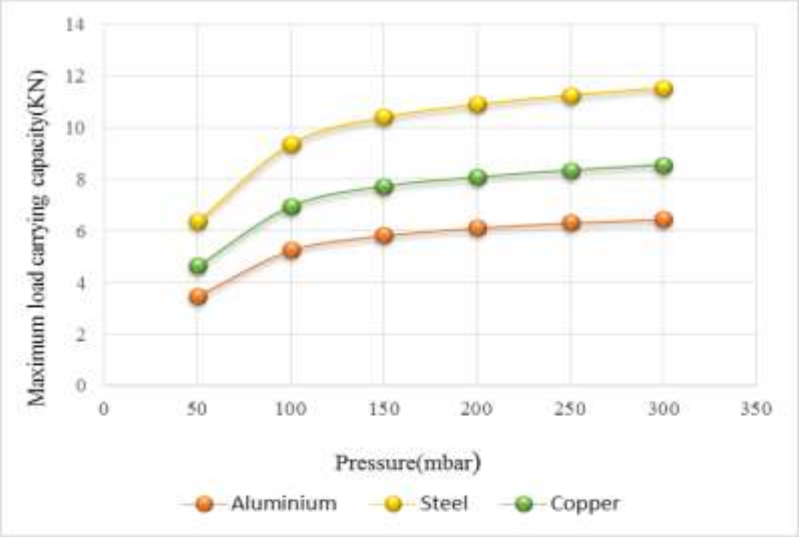

Fig. 6: Pressure versus Maximum load carrying capacity

From the above graph, it is found that the maximum load carrying capacity before buckling of a spindle shaped tensairity beam with different chord materials increases with increase in pressure for all the three cases. Among the three chord materials used, the maximum load carrying capacity before buckling of spindle shaped tensairity beam with steel as chord material is found to be the highest and the maximum load carrying capacity before buckling of spindle shaped tensairity beam with aluminium as chord material is found to be the lowest.

D. Maximum load carrying capacity of tensairity spindle beam before buckling with different area of cross section for chord element

The maximum load carrying capacity of a spindle shaped tensairity beam before buckling is determined by non-linear static prestressed analysis and linear perturbation analysis. For the analysis, fabric of the hull element is made with PVC coated polyester divided into three layers of equal thickness but with different orientation and aluminium is used as the chord material. The maximum load carrying capacity before buckling of sppindle shaped tensairity beam is determined at different pressure.The different area of cross section used for chord element are 30mm×20mm, 25mm×25mm, 35mm×15mm. The dimensions at the supports remains 40mm×25mm for all the three cases. The maximum load carrying capacity before buckling of spindle shaped tensairity beam with different area of cross section of chord element for varrying pressure is shown in Table-4 and Fig.7.

Table - 4
Maximum load carrying capacity before buckling for different area of cross section of chord element

Pressure(mbar)	*Maximum load carrying capacity before buckling(KN)*		
	30mm×20mm	*25mm×25mm*	*35mm×15mm*
50	*3.47*	*4.12*	*2.42*
100	*5.25*	*5.52*	*3.70*
150	*5.82*	*6.12*	*4.80*
200	*6.12*	*6.62*	*5.32*
250	*6.31*	*6.98*	*5.66*
300	*6.45*	*7.20*	*5.90*

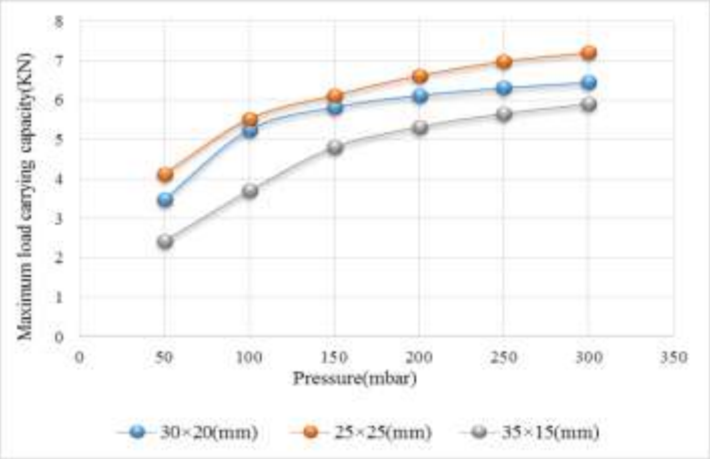

Fig. 7: Pressure versus Maximum load carrying capacity

From the above graph, it can be seen that the maximum load carrying capacity before buckling of a spindle shaped tensairity beam increases with increase in pressure for all the three cases. Among the three dimensions used for chord element, the maximum load carrying capacity before buckling of spindle shaped tensairity beam with dimension 25mm×25mm is found to be the highest and that with dimension 35mm×15mm is found to be the lowest.

V. CONCLUSIONS

The important conclusions drawn from the various parametric studies are as follows:

- The maximum load carrying capacity before buckling of a spindle shaped tensairity beam increases with increase in pressure inside the hull element. So spindle shaped Tensairity beam with higher internal pressure will produce greater stiffness.
- The maximum load carrying capacity before buckling of spindle shaped tensairity beam with PVC coated polyester as hull element is found to be the highest and that with polypropylene is found to be the lowest. So spindle shaped tensairity beam with hull element made with high modulus of elasticity material shows greater load carrying capacity before buckling.
- The maximum load carrying capacity before buckling of spindle shaped tensairity beam with steel as chord material is found to be the highest and that with aluminium as chord material is found to be the lowest. So spindle shaped tensairity beam with chord element made with high modulus of elasticity material shows greater load carrying capacity before buckling.
- The maximum load carrying capacity before buckling of spindle shaped tensairity beam with dimension 25mm×25mm for chord element is found to be the highest and that with dimension 35mm×15mm for chord material is found to be the lowest. So while designing spindle shaped Tensairity beam the area of cross section of tension and compression elements should be considered into account.

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