International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Tensegrity Truss Model using Fem Applications

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Abstract: ***In this paper, tensegrity structures were formulated on truss by the conventional rolled steel members (RS) namely Type 1 truss and by pipe sections namely Type 2 truss. The Type 1 and Type 2 truss structures was modeled and analyzed using software's (ANSYS and STAADPRO packages). For Type 2 truss, tensegrity model was attained with the self-equilibrium state at various load cases. The members of the truss was designed by IS: 800- 1984 and 2007 methods and compared based on utility ratio. The detailing of Type 1 and 2 trusses were done by TEKLA software. The nodal deflection and member stresses were compared and tabulated by ANSYS and STAADPRO software's.***

Keywords: ***Tensegrity, truss, tension, compression, analysis, design, utility ratio.***

I. INTRODUCTION

Motro (2003): "A tensegrity is a system in stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuum of tensioned components".

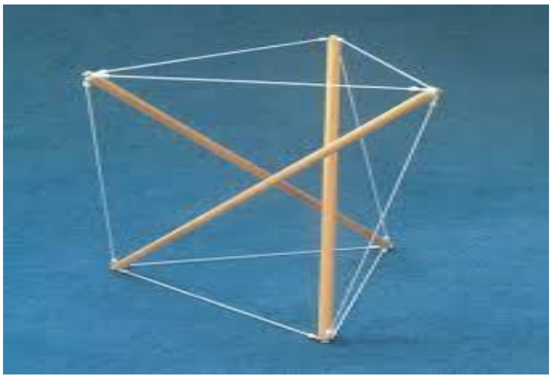

Fig. 1. Tensegrity Structure Model

Belhadjiali.N. and Smith I.F.C.(2010) studied the dynamic behaviour and vibration control of a tensegrity structure was investigated on a full scale active tensegrity structure. Cornel.S. et al. (2002) made study on linear dynamics of tensegrity structures and linearized equations of motion for tensegrity structures around arbitrary equilibrium configurations. Massimiliano.L et.al (2003) investigated on dynamic behaviour of a tensegrity system subjected to static and dynamic analyses of the wind action effects on tensegrity system was investigated. Marc. A. et.al (2006) developed kinematic, static and dynamic analysis of a spatial three-degree-of-freedom tensegrity mechanism was discussed. Irving J. O.and William O.W. (2001) experimented on vibration and damping in three-bar tensegrity structures, in which the most interesting examples of tensegrity structures were under constrained and display an infinitesimal flex. Irving J. O.and William O.W. (2001) investigated on vibration of an elastic tensegrity structure. Koohestan.K. and Guest.S.D. (2013) made an analytical and numerical form-finding of tensegrity structures. Xian.X. and Fengxian.S.(2014) studied on Path planning was a crucial step in shape control of tensegrity structures. Djouadi.S et.al (1998) developed active control of tensegrity system describes about the numerical scheme of active control of tensegrity structures in extra-terrestrial applications. Bernard. A and Ian F.C.S. (2008) made active tensegrity, a control framework for an adaptive civil-engineering structure, was investigated. Etienne.F et al.(2004) active tensegrity structure was investigated. Shekastehband .B et al. (2013) studied the self stress behavior of tensegrity structures under experiment and numerical simulation.

II. MODEL SPECIFICATION

The geometry conditions considered to create model was generally based on the ratio of span to truss depth which should be chosen in the range of 10 to 15. Inclination must be between the angles 35 and 55 degrees. The point loads must be applied only at nodes. In truss we have two kinds of members as longer member (tension) and shorter member (compression). A roof truss for an industrial building with 25 m span and 120 m long was considered.

The roofing was galvanized iron sheeting considered. The basic wind speed was 50m/s and terrain was open industrial area and building was class A building. For the purpose of this design a trapezoidal truss was adopted with a roof slope of 1 to 5 and end depth of 1 m. For this span range the trapezoidal truss would be normally efficient and economical. The spacing of truss was 6m with 20 number of bays. The support conditions provided to the truss model was simply supported. Since the truss has to resist the bending moment (i.e. zero bending). (see Fig 2)

III. MATERIAL PROPERTIES

In general tensegrity model was provided with the light weight material. They composed of cables and strut which includes materials such as mild steel, stainless steel, high strength steel, polyesters or aramind fibre. The strut consists of materials such as pipes and tubes.

The roof cover for the tensegrity member was provided by the membrane materials such as PTFE coated fibre glasses, PVC coated polyester, wrap fibre and ETFE film.

TYPE1- Truss by Rolled steel section: The top and bottom chord were assigned as the double angle section, struts were assigned as the single angle section.

Manuscript published on 30 September 2019.
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TYPE2- Truss by Tensegrity members: The top and bottom chords were provided with pipe section, the material used as the stainless steel and strut as cables.

IV. LOAD CALCULATIONS

The roof truss subjected to gravity loads (dead load and live load) and lateral load (wind load). Dead load on roof truss includes the summation of the weight of roof covering, the weight of bracing and the self weight of truss.
The self weight of truss in kN per square meter of plan area
The imposed (live) loads on various types of roofs other than wind load and snow load, as per IS : 875- Part 2-1987, for roofs with slopes up to and including 10 degrees, was adopted as 1.5 kN per square metre of the plane area, where access provided to roof.
WIND LOAD: The Newtonian theory was used to calculate this wind load which includes the calculation of wind pressure and wind velocity. The pressure is calculated as per the Bernoulli's theorem i.e. the sum of energies at all points. To provide stiffness to the truss members the bracings were provided for stability to the structure and resist the high loads acting on it.

V. FEM APPLICATIONS

A. Using STAADPRO

In general analysis of roof truss 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 of roof truss. The two types of truss namely Type 1 and 2 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 2, 3, 4 shows the modelled truss and design of both types of trusses. The comparison of unity check between the rolled steel truss sections and the tensegrity model truss sections helps to know the economical sections. The two types of the trusses were designed in two methods working stress method and limit state method. The working stress method gives more economical sections than the limit state method. Since the limit state method was high in bending moment, high in the load carrying capacity and low in the deflection and buckling were found when compared with the working stress method (see table I, II, III and IV). As the load carrying capacity was high in the limit state method when compared to the working stress method proves that the cross sectional dimensions provided will be more when the cross sections provided for the working stress method. When dimensions were reduced the cost of the material also gets reduced simultaneously which makes the designer to ultimately prefer the working stress method.

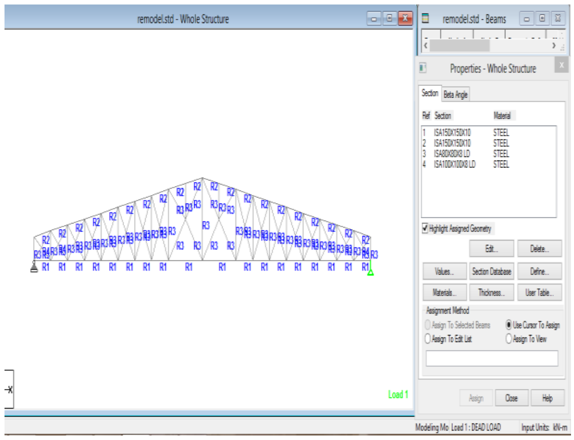

Fig. 2. Truss Configuration with material properties

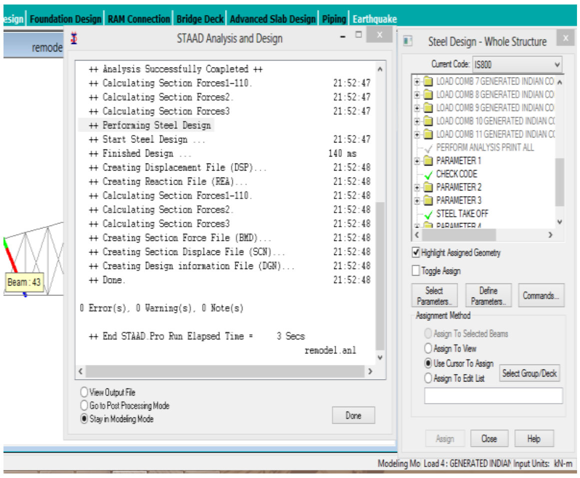

Fig. 3. Type 1 truss by STAADPRO

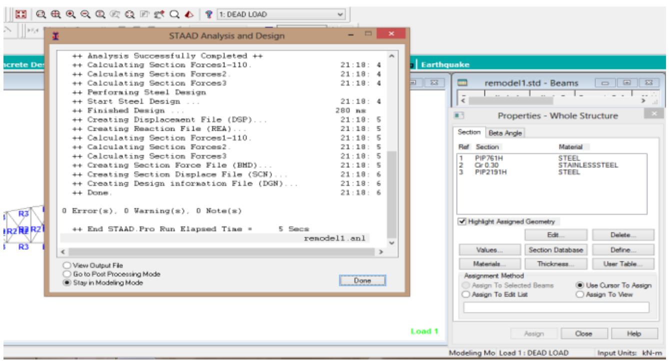

Fig. 4. Type 2 truss by STAADPRO

B. Using ANSYS

Type 1 and type 2 trusses was modelled in the ansys software. The model was created as key points by providing co-ordinates and they are connected by lines. The above calculated loads are applied to the created model and the element type is assigned as link–2d spar. The cross sectional area is provided as 55mmx55mm. The element property is assigned as isotropic with young's modulus of 200GPa. The constraints were given as simply supported with Ux and Uy constrained at one end and Uy constrained at another end. The analysis type was static analysis. See Fig 5, 6 illustrates the stress pattern for the type 1 and type 2 trusses.

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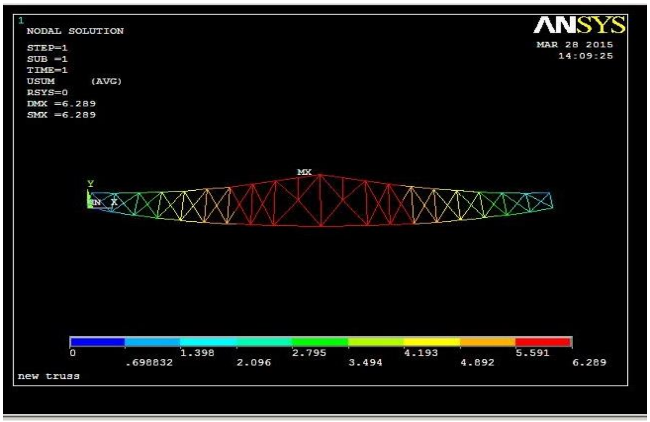

Fig. 5. Type 1 truss by ANSYS

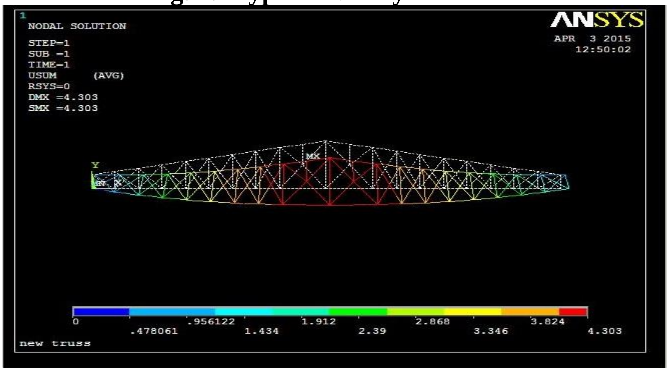

Fig. 6. Type 2 truss by ANSYS

C. TEKLA DETAILING

When the model is imported into the TEKLA STRUCTURES SOFTWARE PACKAGE as FEM model was shown see Fig 7. The load cases are assigned for the model and the analysis is performed by the integration of the other software packages such as staad pro, sap 2000, and auto desk revit and ansys.

The detailing report was prepared for type1 and type 2 trusses. The detail drawing includes dimensions, type of bolts and plates, angles, and various views. The report includes ifc imported model, design check, quantity survey, material list, bolt list, status report.

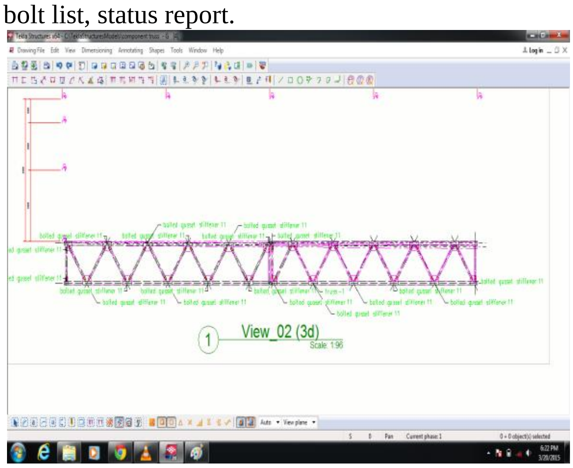

Fig. 7. Tekla- Steel Detailing of Type 1 and Type 2 truss

VI. RESULTS AND DISCUSSION

An industrial building provided with roof consists of a span 25 m was modelled, analysis and design was carried out through finite element packages. Further structural steel detailing was obtained using TEKLA software.

Structural analysis for the truss was compared between ANSYS and STAADPROV8i softwares by the parameters namely, stress and deflection respectively.

In type 1 &2 trusses, the stress and deflection at end supports obtained through STAAD and ANSYS shown slight difference in their values. At central node, the stress values are unmatched between type 1 and 2 trusses when analyzed through STAAD. But the stress values from ANSYS results for type 1 and 2 were almost nearer values.

The deflection values for type 1 and type 2 trusses obtained by two FEA packages were almost the same at support and central nodes. The reason for the above will be the formulation of K-matrix for the soft computing program and the boundary conditions with constraints provided for the finite element packages.

After carrying out through working stress and limit state method of design using IS: 800- 1984 and 2007, the load carrying capacity of member was enhanced by limit state method.

Thus detailing of steel was effectively carried out by TEKLA in which bolts and stiffener details were obtained for the entire span of the truss.

Table- I: Support reaction and Deflection by STAADPRO

DESIGN METHODS	Node no	SUPPORT REACTION (Fy) (kN)		DEFLECTION (mm)	
		Type 1	Type 2	Type 1	Type 2
LIMIT STATE METHOD	1	126	140	11.46	8.33
	23	107	107	10.6	8.12
WORKING STRESS METHOD	1	140	140	11.46	10.46
	23	107	107	9.39	6.39

Table- II: Stress and Axial force by STAADPRO

DESIGN METHODS	Node no	STRESS (N/mm2)		AXIAL FORCE (kN)	
		Type 1	Type 2	Type 1	Type 2
LIMIT STATE METHOD	1	27.597	24.176	23.92	21.258
	23	81.73	57.893	84.324	16.589
WORKING STRESS METHOD	1	25.30	22.186	28.1	21.258
	23	80.30	53.983	82.43	13.953

Table- III : Stress obtained through FEM applications

ANALYSIS OF TRUSS	STRESS(N/mm^2)		
	NODE NO	TYPE 1	TYPE 2
STAAD PRO	1*	$-23.9x10^{-3}$	$-68x10^{-3}$
ANSYS	1*	$-33x10^{-3}$	$-55x10^{-3}$
STAAD PRO	23**	$84x10^{-3}$	$780x10^{-3}$
ANSYS	23**	$30.1x10^{-3}$	$38x10^{-3}$

Table- IV : Deflection obtained through FEM applications

ANALYSIS OF TRUSS	DEFLECTION(mm)		
	NODE NO	TYPE1	TYPE 2
STAAD PRO	1*	1.654	3
ANSYS	1*	1.52	4.3
STAAD PRO	23**	10	42
ANSYS	23**	10.03	38

Node 1* represents end support and Node 23** represents centre node.

VII. CONCLUSION

The structural analysis of truss using STAADPRO and ANSYS, Design by STAADPRO and detailing of truss using TEKLA software, the following conclusions were made:

- The analysis and design of truss in STAADPRO in two different design methods exhibits that, the working stress method of designing as the utilization of steel was less than in the limit state method of design since serviceability state was not considered.
- The Basic influence line equations for n number of truss members was used to calculate the deflection of the modeled truss that was obtained as 5.37mm. The deflection obtained from staad pro and ansys are 10 mm and 6.28 mm respectively. This shows that the ansys deflection value was close to the calculated value and becomes safe for design. This variation of deflection values in two different software was because of the forces acting on the nodes of the member.
- The stress obtained from STAADPRO and ANSYS were $84x10^{-3}$ and $30.1x10^{-3}$ respectively. The variation in result was due to the method of approaches and applying of boundary conditions was different in each of the software's used.
- Based on materials used for type 1 and type 2 trusses the angle section was preferred for 25 m span. Even though the weight of pipe section was less than angle sections because of the difficulty in the connection of the pipe sections.
- The roof structures such as skyscrapers, large roof coverings, etc., the light weight structural sections were preferred. In this case Type 1 truss will be obsolete.

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- Tekla structures used for steel detailing, in which the detailing of type 1 and type 2 trusses were done. The material property provided for type 2 truss was not steel and the cross section used were not angle sections so the detailed view for type 2 and type 1 trusses were similar.

ACKNOWLEDGMENT

The authors would like to thank the Vice Chancellor of SASTRA DEEMED UNIVERSITY for having provided facilities in the School of Civil Engineering to do this research work and also for the continuous support and encouragement given throughout this research work.

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Dr.S.S.Vivek, working as an Assistant Professor in SASTRA DEEMED University, specialized in the area of structural engineering and carried out research work in the area of self compacting concrete. Published 11 nos. of research papers in International Journals under the topic "Self-Compacting Concrete".