Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 7, Issue 09, September -2020

Comparative Study on Axially Loaded Fiber Reinforced Polymer (FRP) Strengthened and Simple Tubes in Space Frame

Zeeshan Ahmad[1], Faisal Pervez[1], Bashir Alam[1],

[1] *Department of Civil Engineering, University of Engineering & Technology Peshawar, Pakistan*

Abstract — the aim of this research work is to compare the strength of hot rolled A36 steel tubes being widely use in designing and constructing of modern world space frames. In this study the model will be design by using STAAD Pro structure designing software. After design that model same tubes will be wrapped using suitable FRP, then erect both models with and without FRP rapping tubes. The objective of this research is to compare the tensile and compressive strength of tubes. The scope of this paper is kept limited to the analysis of these tubes in a finite element software ANSYS. It was found that the results of FEA were in close match to experimental results.

Keywords- *FEA- Finite Element Analysis*

1. Introduction

Alexander Graham Bell from 1898 to 1908 developed space frames based on tetrahedral geometry. Bell's interest was primarily in using them to make rigid frames for nautical and aeronautical engineering, with the tetrahedral truss being one of his inventions. Dr. Ing. Max Mengeringhausen developed the space grid system called MERO (acronym of MEngeringhausen ROhrbauweise) in 1943 in Germany, thus initiating the use of space trusses in architecture. The commonly used method, still in use has individual tubular members connected at node joints (ball shaped) and variations such as the space deck system, octet truss system and cubic system. [6]

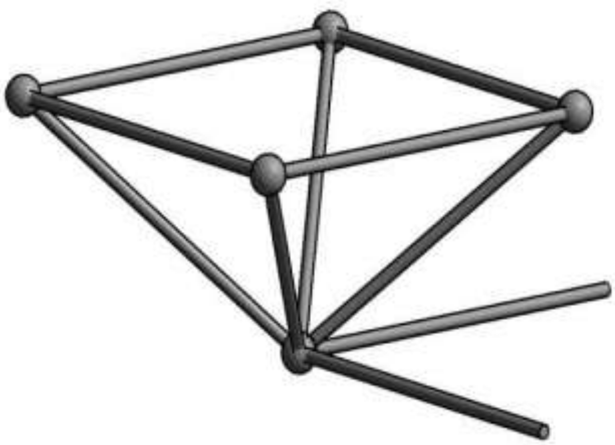
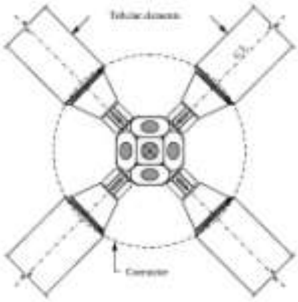


Figure-1: Basic Space Frame Structure Concept

Space Frame Overview:



In architecture and structural engineering, a space frame or space structure is a rigid, lightweight, truss like structure constructed from inter locking struts is a geometric pattern. Space frames can be used to large span areas with few interior supports. Like the truss a space frame is strong because of inherent rigidity of triangles.

Applied loads are transmitted as tension and compression loads along the length of struts. Space. They provide great freedom of expression and composition as well as the possibility to evenly distribute loads along each rod and external constraints. With these features, steel space frames can be used to achieve also complex geometries with a structural weight lower than any other solution.

Figure-2: Large Span Space Frame

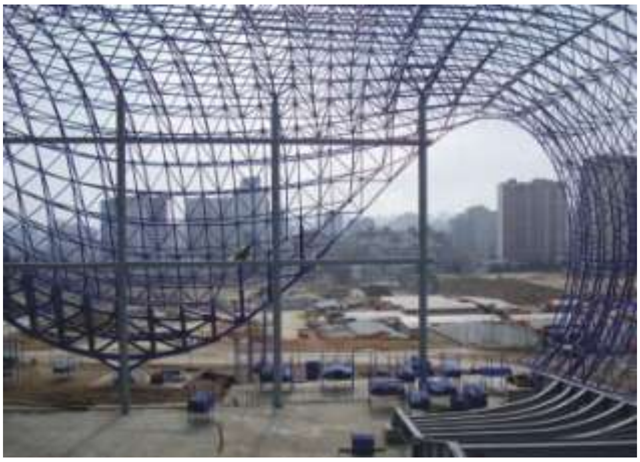
The simplest form of space frame is a horizontal slab of interlocking square pyramids and tetrahedral built from aluminum or tubular steel struts. In many ways this looks like the horizontal jib of a tower crane repeated many times to make it wider. A stronger form is composed of interlocking tetrahedral in which all the struts have unit length. More technically this is referred to as an isotropic vector matrix or in a single unit width an octet truss. [6]

Types of Space Frame:

Curvature Classifications:

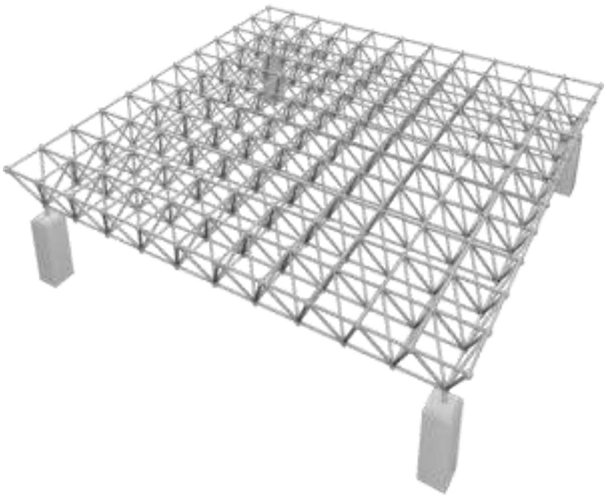
- *Space plane covers.* These spatial structures are composed of planar substructures. Their behavior is similar to that of a plate in which the deflections in the plane are channeled through the horizontal bars and the shear forces are supported by the diagonals.

- *Barrel vaults***.** This type of vault has a cross section of a simple arch. Usually this type of space frame does not need to use tetrahedral modules or pyramids as a part of its backing.
- *Spherical domes and other compound curves* usually require the use of tetrahedral modules or pyramids and additional support from a skin.



Classification by Arrangements of its Elements:

- *Single layer grid*. All elements are located on the surface to be approximated.
- *Double layer grid*. The elements are organized in two layers' parallel to each other at a certain distance apart. Each of the layers form a lattice of triangles, squares or hexagons in which the projection of the nodes in a layer may overlap or be displaced relative to each other. Diagonal bars connect the nodes of both layers in different directions in space. In this type of meshes, the elements are associated into three groups: upper cordon, cordon and cordon lower diagonal.



- *Triple layer grid*. Elements are placed in three parallel layers, linked by the diagonals. They are almost always flat.

There are many other types of space frames being use in modern world construction depending on use and special cases one them is *pleated metallic structures* Emerged to try to solve the problems that formwork and pouring concrete had their counterparts. Typically run with welded joint, but may raise prefabricated joints, a fact which makes them space meshes.

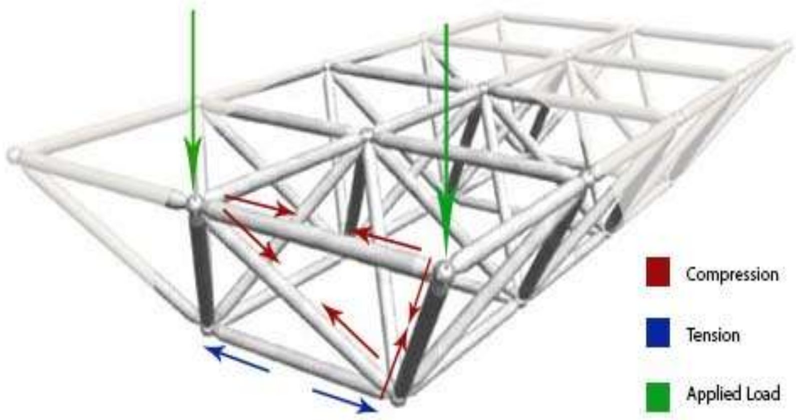
Application of Space Frames

The integrated terminal buildings are designed with a number of structural innovations. The key feature of airport structure is their long span roof covering with massive column spacing at the periphery of structure. Some other uses are given below;

- Commercial and Industrial Structures
- Auditoriums
- Sky Lights
- Tool Booths
- Exhibition Halls
- Sports Stadium

Space Frame Structural Behavior

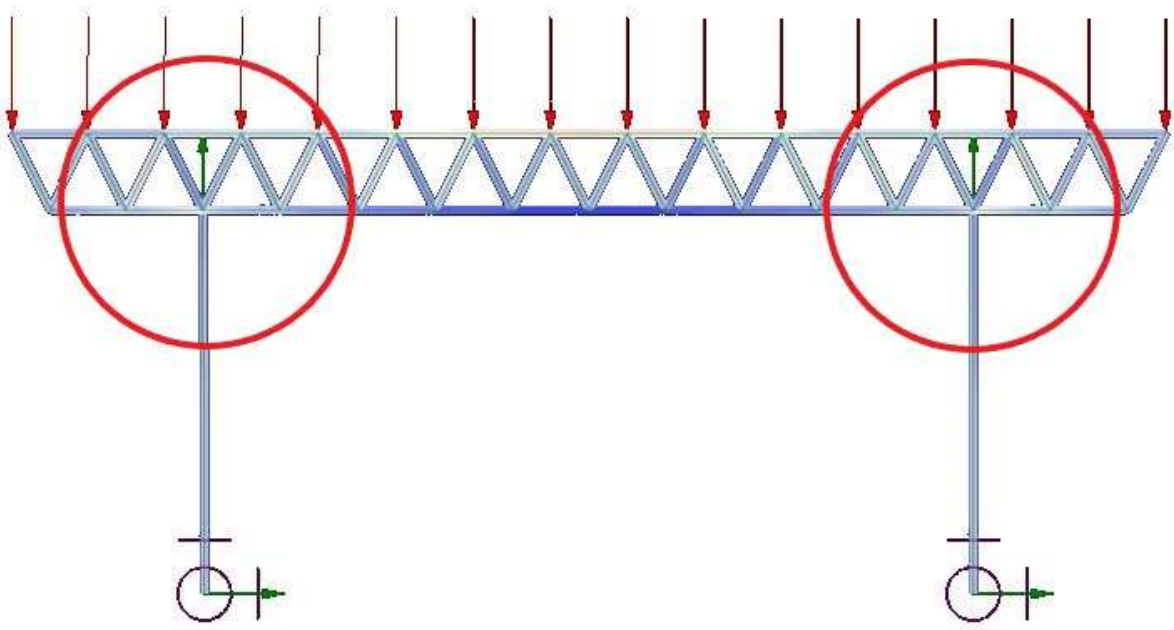
A space frame along spanning three dimensional plate structure based on the rigidity of triangles. Composed of linear element subject only axial tension and compression. Even the case of connection by comparatively rigid joints. The influence of bending or torsional moment in structure is insignificant. In the structural system of space frames one or more members of frame subject to multiple forces i.e. tension, compression, bending and shear. The failure ratio of these tubes became maximize in case of critical load concentration areas, where high strength needed. [6]



A recent technique for strengthening steel and steel-concrete composite structures by the use of externally bonded Fiber Reinforced Polymer (FRP) sheets, to increase the flexural capacity of the structural element, is described. Several researches developed FRP strengthening of reinforced concrete and masonry structures, but few experimental studies about steel and steel-concrete composite elements are available. [6]

Problem Statement

In today's modern world this technology is growing rapidly due its specialty in providing free space, light weight and rapid construction. In designing phase of space frames there are limited sizes locally available in market so that designer has to use these available tubes. The failure ratio of these tubes became maximize in case of critical load concentration areas i.e. near supports which means there is need of bigger sizes tubes or increase the existing member strength to fulfill the needed requirement.



2. Literature Review

- Degradation of steel structures, such as old industrial buildings and bridges, and increased load requirements have led to the need for structural rehabilitation and strengthening. Application of bolted or welded steel plates to the original structure is sometimes used as a strengthening technique. This technique has some negative aspects, while alternate of this technique is Fiber Reinforced Polymer (FRP), these materials have a high strength-weight ratio, do not give rise to problems due to corrosion, are extremely manageable and are commonly used for strengthening structural reinforced concrete members. [7]

  At present the scientific literature on the experimental and analytical structural behavior of flexural steel elements. Current design guidelines for FRP strengthened metal structures can only be applied to flexural elements strengthened at the lower part of the tensile flange, and are usually based on the hypothesis of the linear elastic behavior of steel. As far as can be found, analytical methods for the behavior of steel-concrete composite elements with any kind of FRP reinforcement configuration (on both flange and web), taking into account material non-linearities, have not been developed in depth. [1]

- Fibre-reinforced polymer (FRP) jackets have been widely used to confine reinforced concrete (RC) columns for enhancement in both strength and ductility. Circular hollow steel tubes are widely used as columns in many structural systems and a common failure mode of such tubes when subjected to axial compression and bending is local buckling near a column end. [2]
  In this research work, the use of FRP confinement to enhance the ductility and seismic

resistance of circular steel tubes has been explored. A series of axial compression tests has been presented to demonstrate the effectiveness of FRP confinement of steel tubes.

The FRP jacket leads to only limited increases in the ultimate load but still large increases in the energy absorption capacity. The steel cylindrical shells can also be used in the construction of new tanks and silos to enhance their performance. [2]

- The behavior of pultruded glass fiber reinforced polymer (GFRP) pipes, which are the members of long-span lattice structures, under axial compression was investigated by tests. Short GFRP pipes were first tested to determine the basic mechanical properties. Then the stability of long GFRP pipes was studied by axially compressive tests in four groups with different slenderness ratios. The maximum variation coefficient reaches 20%, but the dispersion of its elastic constant is smaller relatively as its variation coefficient is within 6%. [3]

  In long GFRP pipes relationships of axial load to lateral displacement, vertical displacement and strain are obtained and the pipes with smaller slenderness ratio can be compressed to fracture at the ultimate strain. the pipes with larger slenderness ratio buckle in elastic and fail in oversize deformation. [3]

- Steel structures may be subjected to impact actions from different sources such as vehicle collisions, debris, rock falls, and blast events. In this research work carbon fibre reinforced polymer CFRP configurations used, it was found that applying the fibres in both the longitudinal and transverse directions had the greatest effectiveness compared to other strengthening configurations. The configuration with fibres oriented only in the transverse direction has the lowest contribution compared to other arrangements, even when the same overall volume of CFRP was used in all wrapping configurations. [4]

  In quantitative terms, in the case of the quasi-static loading rate, the increase in load carrying capacity of the sample strengthened with fibres oriented in both directions was 26% compared to the un-strengthened sample, while the enhancement was round 11% when the transverse orientation was used. The CFRP strengthening with fibres oriented in both directions had an ability to increase both flexural and shear resistance which normally govern global and local buckling of the sections respectively. [4]

- Tubular pieces are widely used in different structures. Nowadays, using fiber reinforced polymer (FRP) laminates, as external reinforcement of concrete structures has been proved to be an efficacious alternative method of repairing it. However, researches related to FRP applications into steel structures have recently started fairly and there have still been few practical applications. [5]

This research explains the effect of using FRP laminates around the steel tube on the parameters of stiffness, strength and stress distribution in the steel tube were examine. By wrapping FRP laminates around steel tubes, oval shaping tendency was reduced in the mid-span by 4.3%, relating to the bare steel tube. [5]

3. Finite Element Analysis

Finite element Modeling was conducted in software package ANSYS. Nonlinear analysis was performed taking in account material non-linearity. The material non-linearity was modeled using Stress-strain plot collected from the testing of plain steel control section of each category. The load displacement curves were then plotted for all the test samples comprising of both wrapped and unwrapped steel sections.

While modeling in ANSYS geometric imperfection was important, this is to take in account the minor imperfection in test samples. This modeling of imperfection exhibited the true behavior of the actual samples; as can be seen in Figure 3, which illustrates the deformation of a plain steel tube i.e. C-PS. compared with experiments. This authenticates the replication of imperfection in FEA. Figure shows the failure pattern and deformed shape in FEA model, which resembles the actual failure in test samples shown in figure 4; it was observed that the liner seam on the UD 2 layer CFRP ruptured before the steel tube ultimate failure.

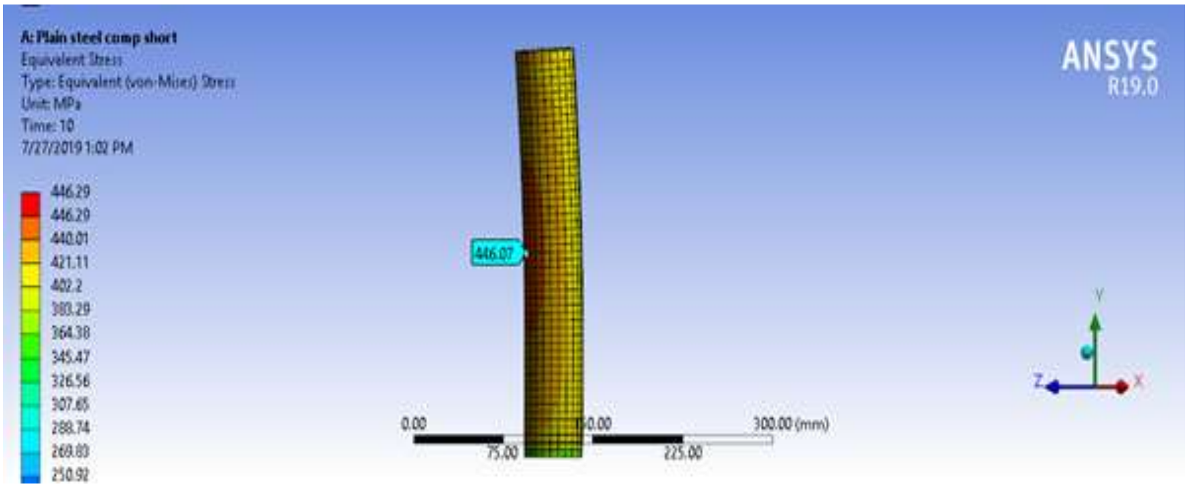


Figure: 1 FEA Analyses

4. Conclusion:

The CFRP wrapping on steel tubes proved beneficial however, the percentile increment in strength was different in tension and compression. The CFRP wrapped on slender tubes provided the most strength in term of percentage. While increasing the number of layers did not increased strength proportionally which means that there is no linear relationship between the increment in strength and number of layers.

5. References

[1] C. P. a. E. Maiorana, "FRP strengthening of steel and steel-concrete composite structures: an analytical approach," *Materials and Structures* , January 2009.

[2] Y. H. J.G. Teng, "Behaviour of FRP-jacketed circular steel tubes and cylindrical shells under axial compression," *Construction and Building Materials 21,* pp. 827-838, 2007.

[3] P. F. L. Y. Peng QIAN, "Experimental study on GFRP pipes under axial compression," *Frontiers of Architecture and Civil Engineering China,* vol. 2, no. 1, pp. 73-78, March, 2008.

[4] Z. W. L. S. C. Majid M.A. Kadhima, "Loading rate effects on CFRP strengthened steel square hollow sections under lateral impact," *Engineering Structures,* pp. 04-66, 2018.

[5] A. V. O. a. S. R. Laya Zahedi, "A Numerical Study on Steel Tubes Wrapped with CFRP Laminates: Carbon Fibre Reinforced Polymers Applications on Offshore Marine Structures," *The International Journal of the Constructed Environment,* vol. 3, 2013.

[6] H. N. a. P. D. Gerard Parke, Space Structure 5, Guildford, UK: Thomas Telford Publishing , 2002.

[7] L. H. a. J. Teng, Strengthening and Rehabilitation of Civil Infrastructures using Ribre-Reinforced Polymer (FRP) Composites, Cambridge England : WoodHead Publishing and CRC Press, 2008.