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Numerical analysis of 3d truss bridge using ANSYS.

Análisis numérico de un puente de celosía 3D usando ANSYS.

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ABSTRACT

Trusses are typically lighter and more cost-effective than alternative structural support systems and are used in a variety of structures. A truss structure takes advantage of the inherent geometric stability of the triangle to evenly distribute weight and to handle changing tension and compression. This project deals with the analysis of a 3D truss bridge which is proposed to be constructed connecting the two platforms of the Tripunithura railway station, with three different deck materials steel, concrete and glass fiber reinforced concrete (GFRC). Analysis and design of the proposed structure is carried out using ANSYS (Workbench) 2022 R2 software. ANSYS is an analyzing software that is used for mechanical product designs and civil structure designs. This software helps to engineer and design complex, nonlinear and large models. Structural performance of 3D truss bridges with three different deck material in terms of axial force, shear stress and deformation are compared in order to find which combination of materials will give better performances. Dynamic analysis is performed to examine the frequency and modes of vibrations caused by the movement of trains.

Keywords: 3D truss bridge, geometric stability, steel, glass fiber reinforced concrete, ANSYS workbench, large models, structural performance, dynamic analysis.

RESUMEN

Las cerchas suelen ser más livianas y rentables que los sistemas de soporte estructural alternativos y se utilizan en una variedad de estructuras. Una estructura de celosía aprovecha la estabilidad geométrica inherente del triángulo para distribuir uniformemente el peso y soportar los cambios de tensión y compresión. Este proyecto trata del análisis de un puente de celosía 3D que se propone construir conectando las dos plataformas de la estación de tren de Tripunithura, con tres materiales de cubierta diferentes: acero, hormigón y hormigón reforzado con fibra de vidrio (GFRC). El análisis y diseño de la estructura propuesta se realiza mediante el software ANSYS (Workbench) 2022 R2. ANSYS es un software de análisis que se utiliza para diseños de productos mecánicos y diseños de estructuras civiles. Este software ayuda a diseñar y diseñar modelos grandes, no lineales y complejos.

Se compara el rendimiento estructural de puentes de celosía 3D con tres materiales de cubierta diferentes en términos de fuerza axial, esfuerzo cortante y deformación para encontrar qué combinación de materiales dará mejores rendimientos. El análisis dinámico se realiza para examinar la frecuencia y los modos de vibraciones causados por el movimiento de los trenes.

Palabras clave: puente de celosía 3D, estabilidad geométrica, acero, hormigón armado con fibra de vidrio, banco de trabajo ANSYS, modelos grandes, desempeño estructural, análisis dinámico.

INTRODUCTION

A truss is a rigid structure made up of straight members i.e., beams. It is a triangular shaped frame that helps spread the compression and tension forces. Here Warren truss with verticals was selected. The Warren truss design uses equilateral triangles in the framework to spread out the load on the bridge. Loads on the diagonals alternate between compression and tension. Application of composite materials, e.g., fiber reinforced concrete (FRC), is one of the potential fields that can be involved in the development of bridge structures. FRCs have appropriate physical and mechanical properties, such as high strength to weight ratio, high impact strength, low electrical and thermal conductivity more corrosion resistance as well as high durability. These advantages lead to low maintenance cost and longer service life of structures.

(Bačinskas et al., 2017) studied a glass fiber reinforced polymer (GFRP) space truss bridge model subjected to static load. The study found that GFRP profiles are suitable for constructing pedestrian bridge superstructures.(Sandovič et al., 2012) presents a new structural system for pedestrian steel suspension bridges, focusing on stress-ribbon bridges. The study examines the behavior of the bridge under different loads, providing analytical expressions for displacements, thrust forces, and bending moments. The study discusses the efficiency of displacement stabilization through bending stiffness in steel stress-ribbon bridges. (Tumbeva et al., 2022) conducted an arithmetic study on the redundancy of steel truss bridges using new modular joints. Numerical results demonstrated that the modular joint system can redistribute the load and exhibit redundancy in the event of member loss. The modular joint system overcomes barriers to truss usage and enhances the qualities of steel trusses, making them suitable for long-span bridges.

I. GEOMETRIC AND MECHANICAL PROPERTIES OF STEELTRUSS BRIDGE

The model of the steel truss bridge had the following dimensions and specifications as shown in Table 1.

Table 1: Dimensions and specifications of the steel truss bridge model.

Parameters	Specification
Type of bridge	Warren truss with verticals
Total Span	27.2m
Carriage width	3.3m
Panel size	3.4 x 3.3m
Number of panels	8
Clearance from center line of rail	2.36m
Height of truss	2.4m
Height from the rails to the base of carriageway	6.56m

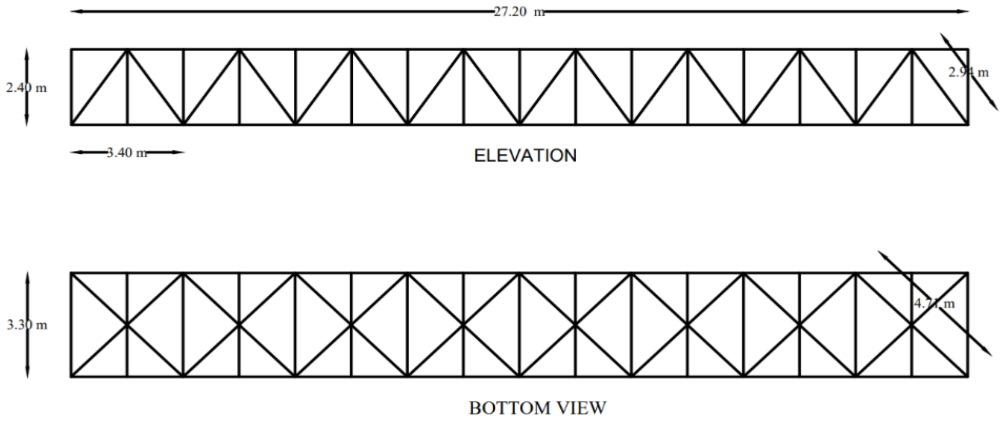


Fig 1. Geometry of proposed truss bridge in AutoCAD

Three types of materials (steel, concrete and glass fiber reinforced concrete (GFRC)) were selected and used to build the deck of the bridge. Table 2: demonstrates the materials properties for steel, concrete and GFRC.

Table 2: Material Properties for steel, concrete and GFRC

Material Properties	Structural steel	Concrete	GFRC
Density (kg/m^3)	7850	2400	2039.43
Young's modulus (MPa)	$2x10^5$	$3x10^4$	$18x10^3$
Poisson's ratio	0.3	0.15	0.24

METHODS

A. MODELLING

The Fig 2. shows the idealized geometry of truss bridge. A 3D model made up of both line and surface elements was created for static structural analysis. The deck slab is defined as 2D plate geometry, while all other truss and beam components are made up of 1D line bodies. A 100 mm nominal thickness is considered for all deck slabs, but for concrete and GFRC we have used supporting steel plate of thickness 2mm so as to idealize the structural elements into the best model for analysis. This current study uses ANSYS workbench design modeler (one of the 3D modellingand editing module available in ANSYS workbench) to model the 3D truss bridge.

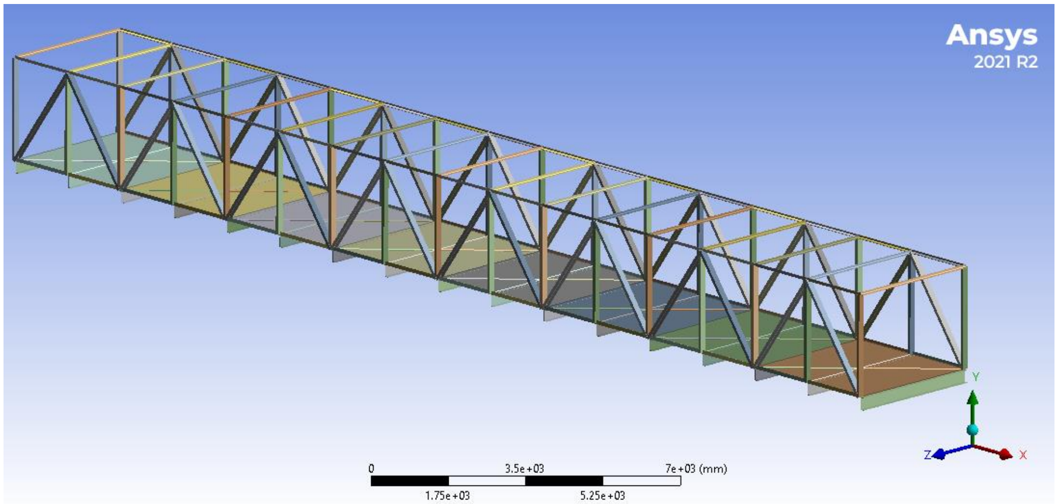
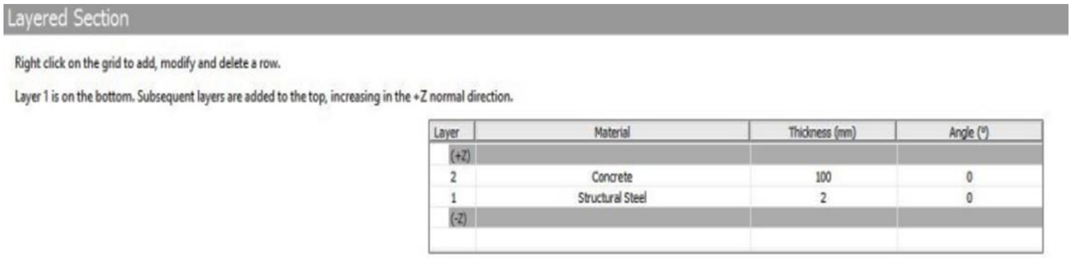


Fig 2. Idealized geometry of truss bridge



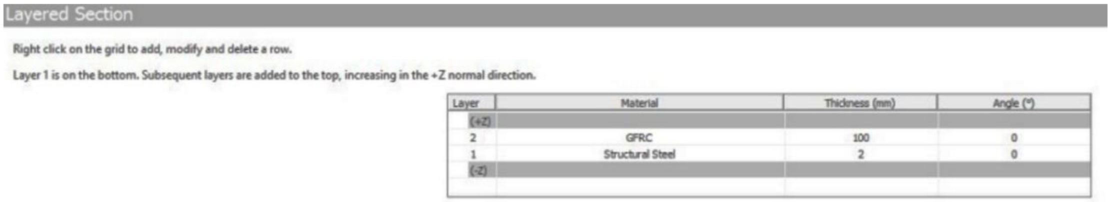
Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
2	Concrete	100	0
1	Structural Steel	2	0
(-Z)			

Fig 3. Layered Section (Concrete + Steel Plate)



Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
2	GFRC	100	0
1	Structural Steel	2	0
(-Z)			

Fig 4. Layered Section (GFRC + Steel Plate)

III. PHASE 1- LINEAR STATIC ANALYSIS

A. MESHING

Both surface and line elements are used in meshing. A 100mm global element size with a linear element order is used during the meshing process.The side truss members are considered as tension and compression components. The horizontal C-sections at the bottom are taken as beam elements. The deck plates are meshed with quadrilateral elements. A total of 13708 nodes and 10972 elements were generated for the assembly model. Fig 5. shows the truss bridge after applying meshing process

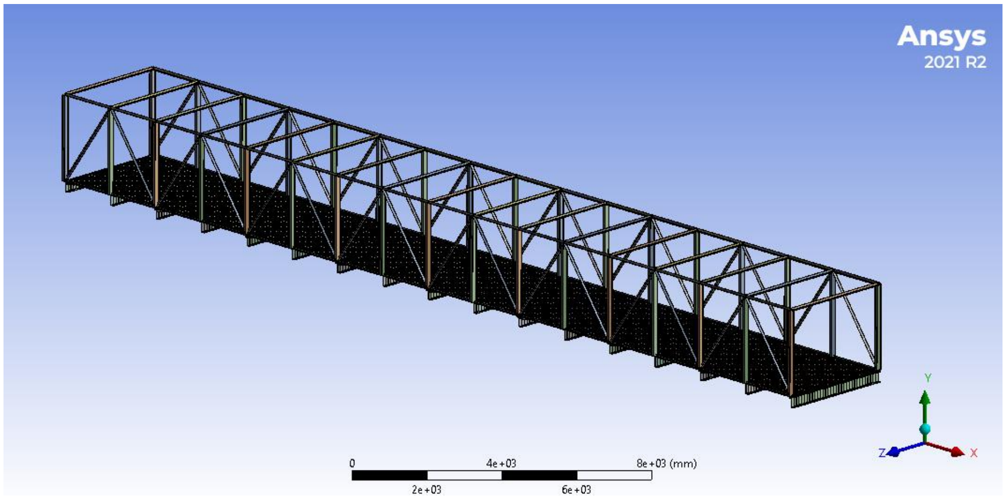


Fig 5. Meshed model

B. LOADING AND BOUNDARY CONDITIONS

The bridge is mainly subjected to loads from the weight of people and Self weight. A pressure of 5000N/m^2 is applied on the deck plate. This is assumed to be the pressure that will be exerted by the weight of 200 people during its fully load operation. Standard earth gravity is introduced in the model to consider the Self weight of the structure. Displacement support is assigned at the four end corners and the mid span of the bridge. One end is fully constrained. Midand the other end is constrained by allowing movement in the X direction. No other external loads are considered in the current study. Figure 6. shows the loading and boundary conditions on the bridge.

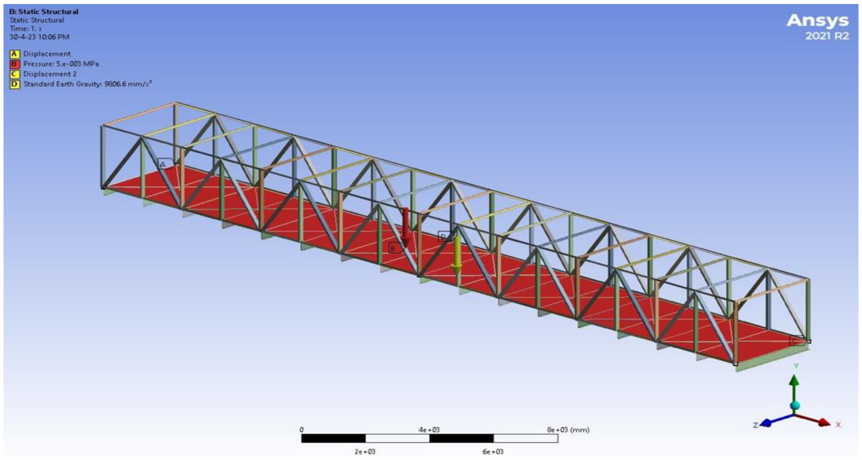


Fig 6. Boundary conditions on Model

C. STATIC STRUCTURAL ANALYSIS RESULTS

STEEL DECK

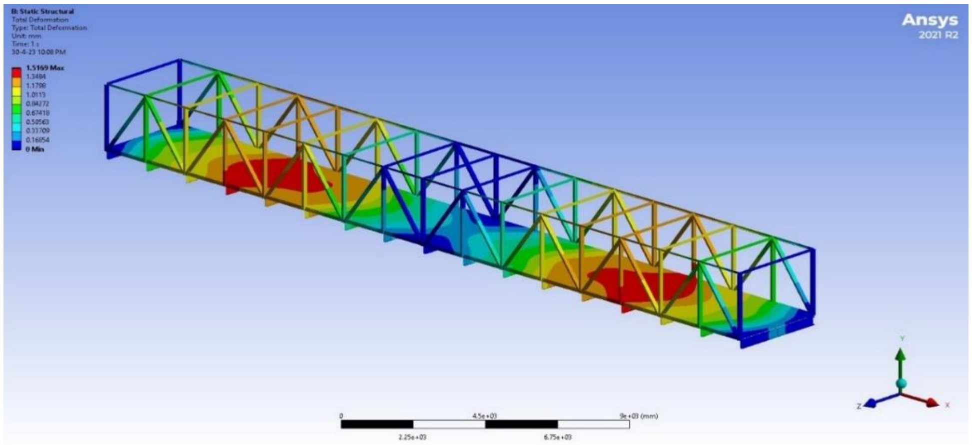


Fig 7. Total Deformation

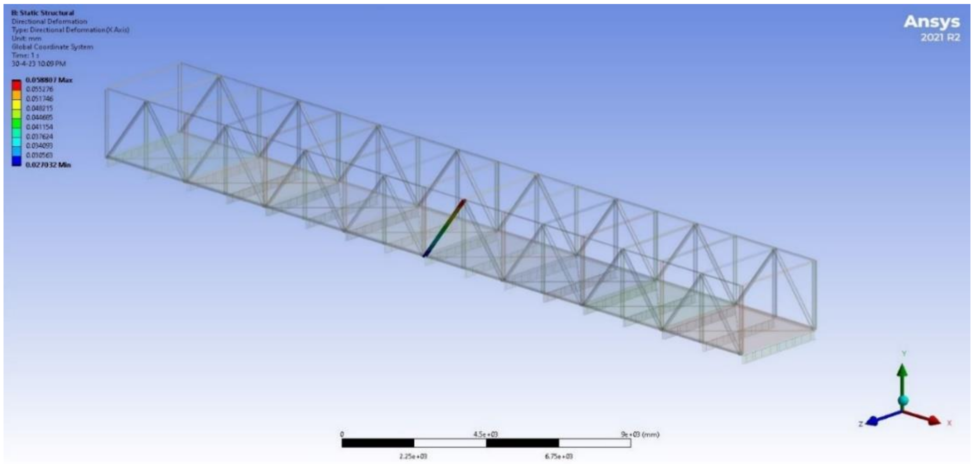


Fig 8. Total Deformation of selected member

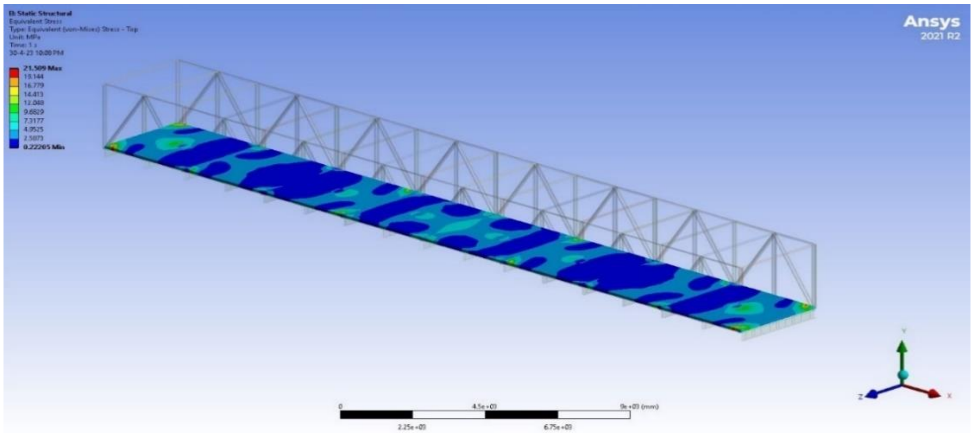


Fig 9. Equivalent Stress

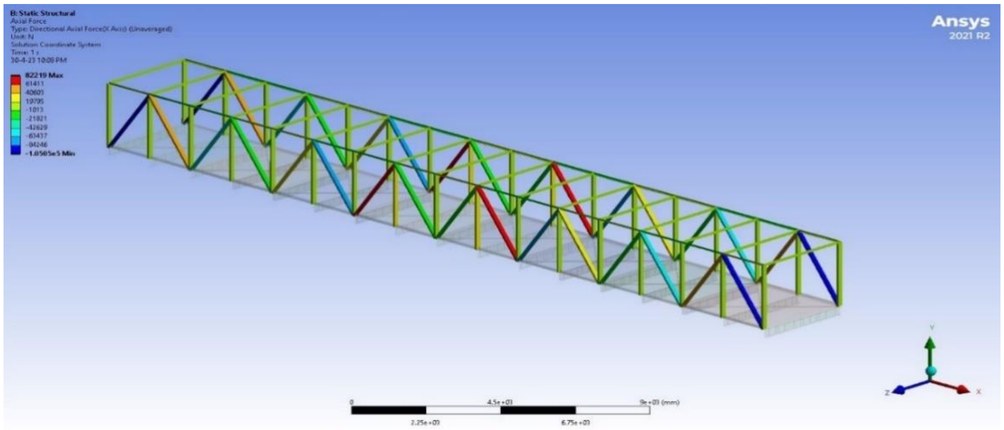


Fig 10. Axial Force

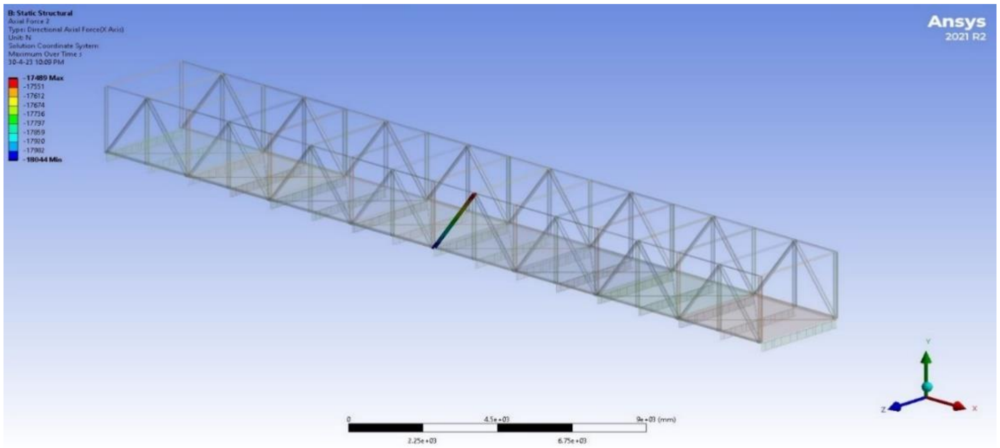


Fig 11. Axial force of selected member

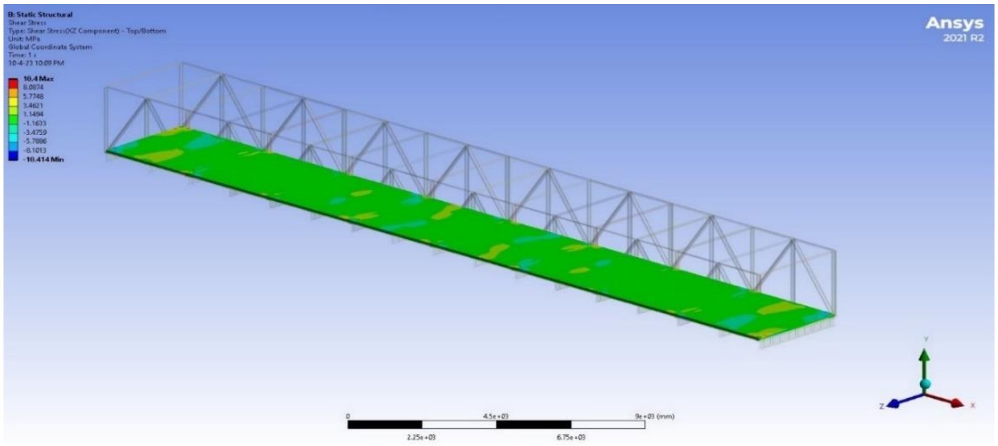


Fig 11. Shear Stress

CONCRETE DECK

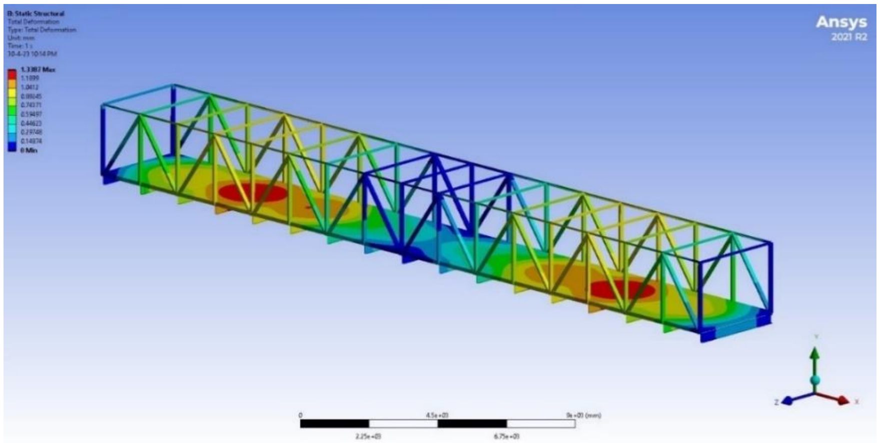


Fig 12. Total Deformation

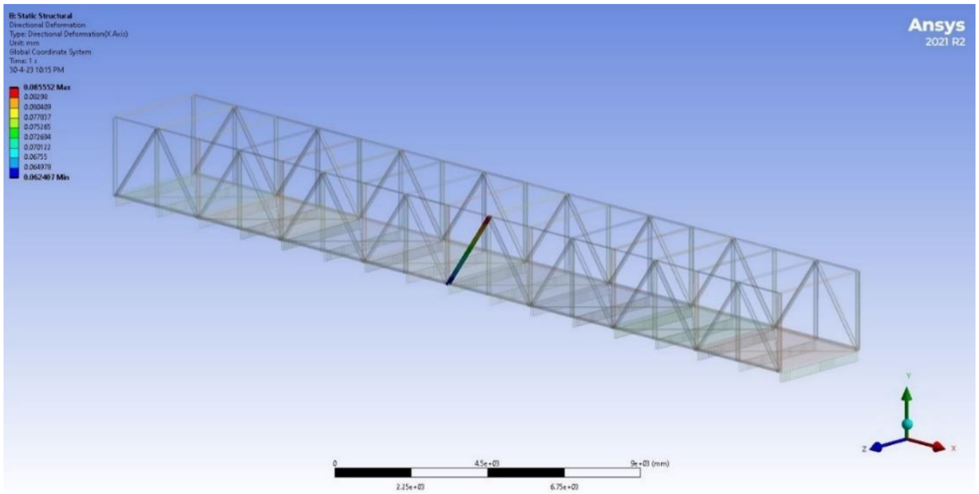


Fig 13. Total Deformation of selected member

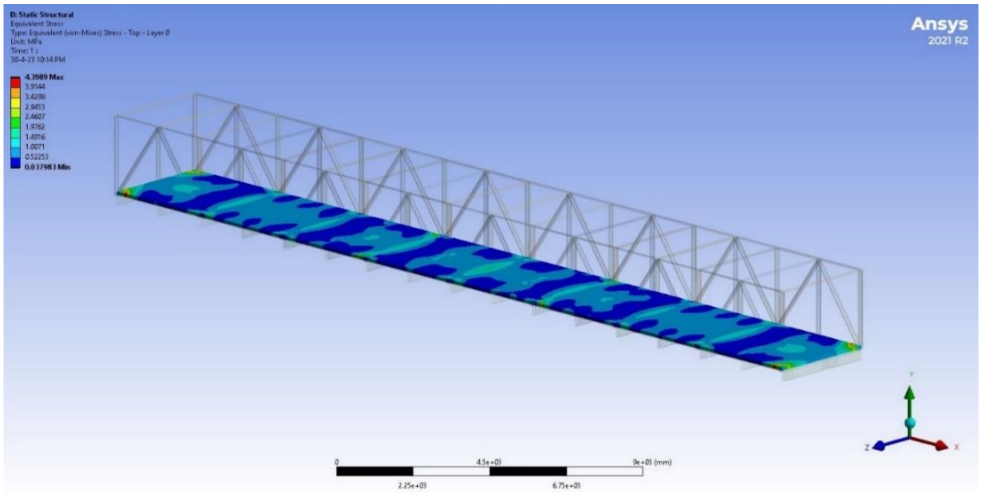


Fig 14. Equivalent Stress

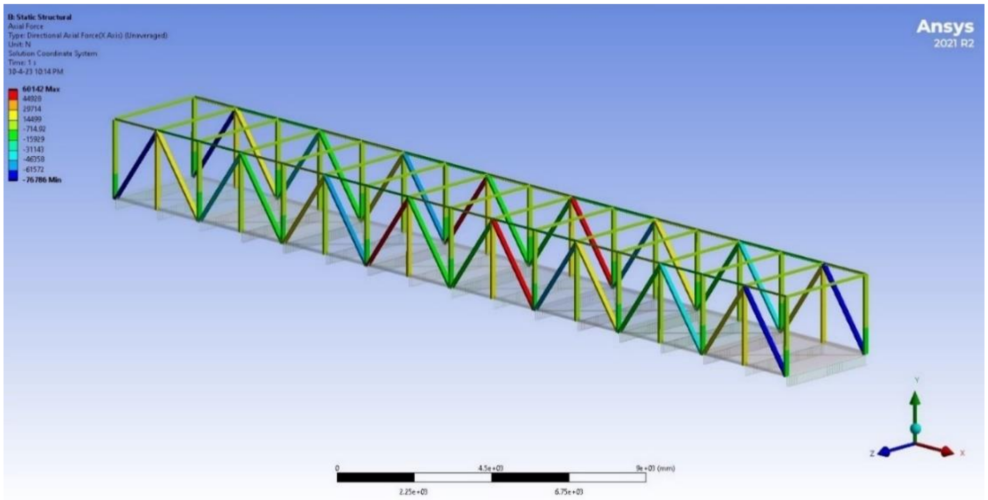


Fig 15. Axial Force

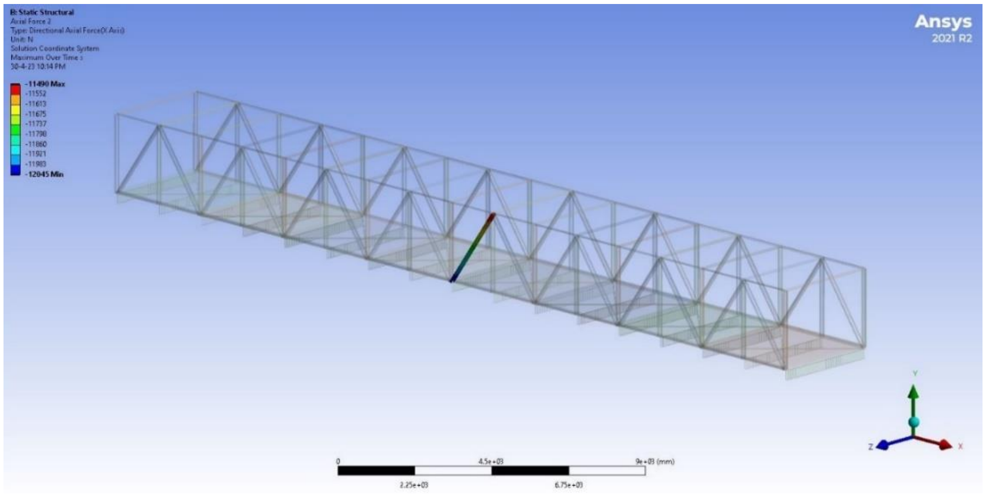


Fig 16. Axial force of selected member

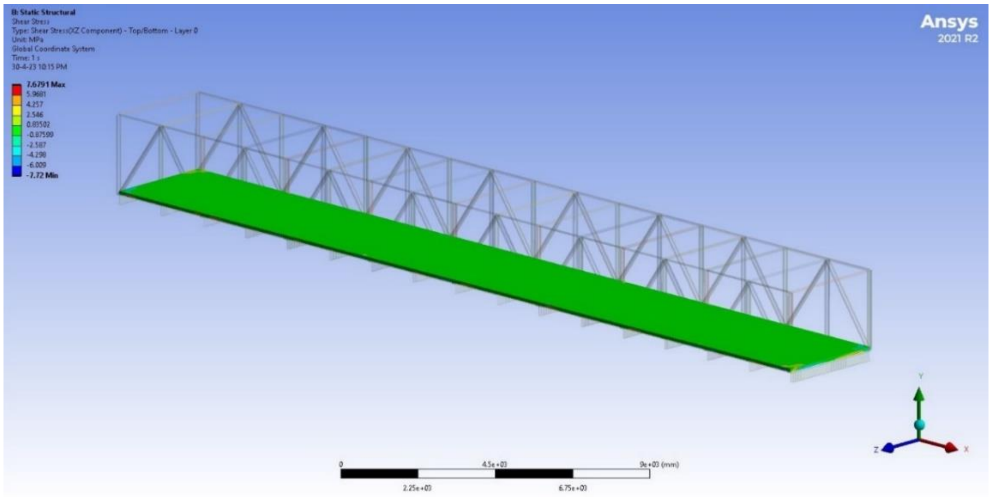


Fig 17. Shear Stress

GFRC DECK

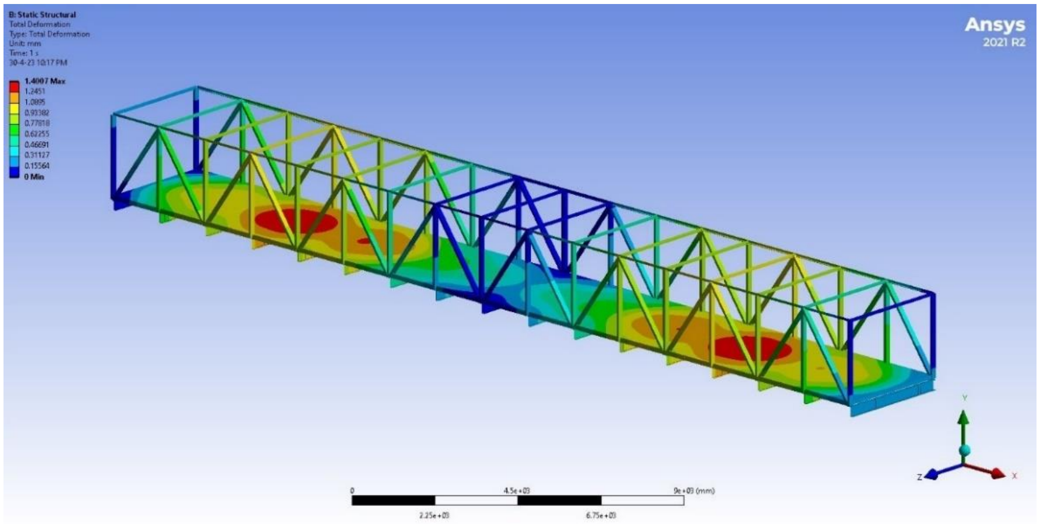


Fig 18. Total Deformation

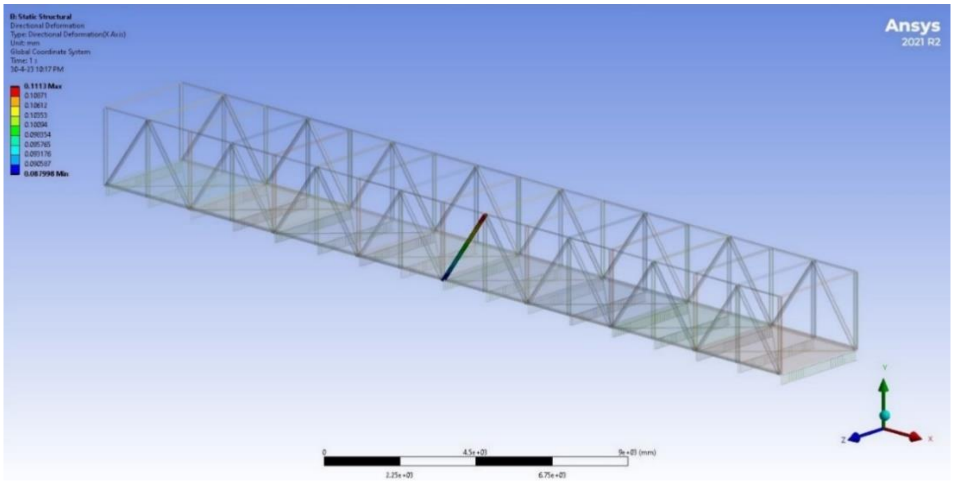


Fig 19. Total Deformation of selected member

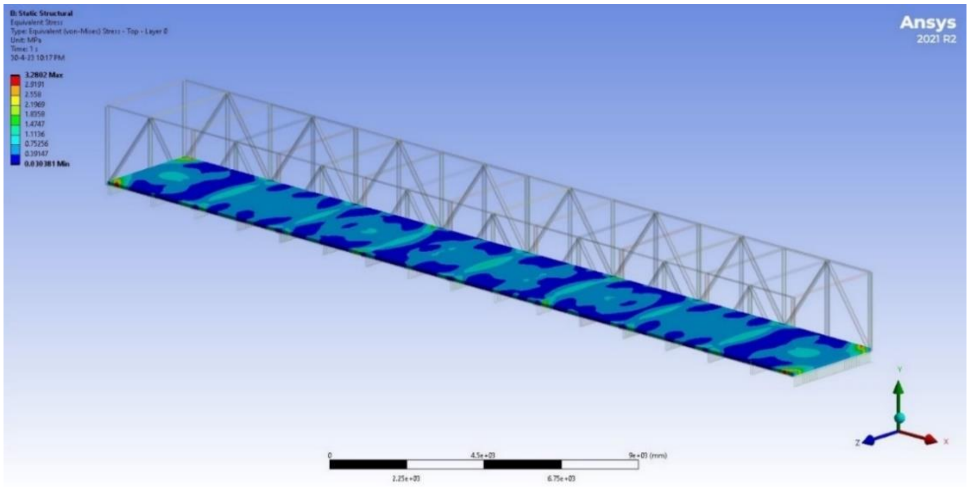


Fig 20. Equivalent Stress

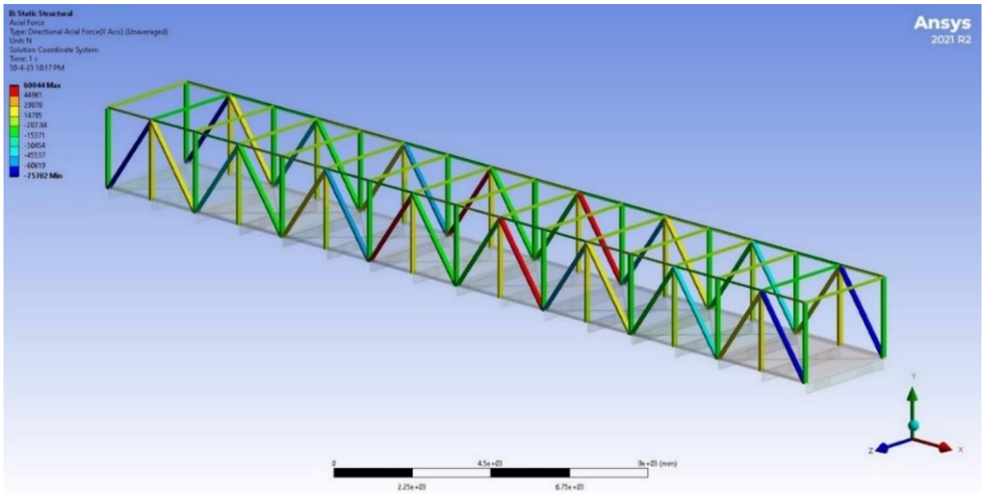


Fig 21. Axial Force

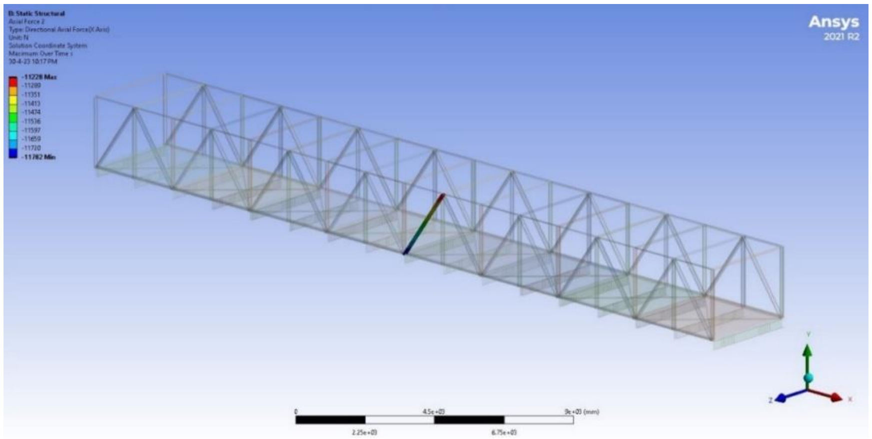


Fig 22. Axial force of selected member

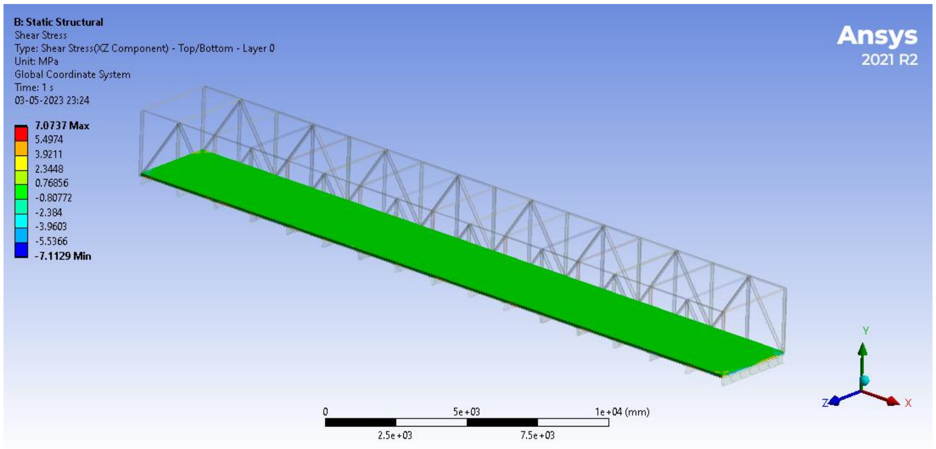


Fig 23. Shear Stress

Table 3: Comparative statement of different deck materials

Deck Material	Total Deformation (mm)	Deformation of selected member (mm)	Equivalent Stress (MPa)	Axial Force (N)	Axial Force of selected member (N)	Shear Stress (MPa)
Steel	1.52	0.058	21.52	82219	-17489	10.4
Concrete	1.34	0.085	4.39	60142	-11490	7.68
GFRC	1.40	0.111	3.28	60044	-11228	7.07

RESULTS AND DISCUSSION

Static analysis of 3D truss bridge with three types of materials (steel, concrete and GFRC) for deck is carried out in ANSYS workbench software. All the materials passed analysis under the given loading conditions. From the data, it is found that all components have minimum values for total deformation and equivalent stress. Therefore, the models can withstand the applied loads successfully. Steel deck has the maximum mass and it exhibits more deformation, but in this case, thinner plates can be used. 10mm steel plate also meet safe conditions for specified loading. Steel is a good material option from a manufacturing point of view but concrete deck plate is 10 times less expensive than steel plate and 50% less expensive than GFRC. Hence concrete is a good option since it is more economical.

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