Comparative Study on Dynamic Analysis of FRP Bridge Deck & RC Bridge Structure

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Abstract— Bridges with FRP decks are gaining quality, and there's a growing ought to perceive the behavior of FRP deck bridges. The characteristics of bridges with FRP decks are considerably completely different from those of bridges with ancient concrete decks. For this reason, careful finite part analyses are employed in the current study to research the load distribution and also the dynamic response of FRP deck bridges.

The present study includes the modal and transient analysis of bridge slabs subjected to moving load by use of ANSYS computer software. Many RCC bridge decks are showing signs of distress because of corrosion of the reinforcements a lot of before their style generation cost.

In this treatise work, the structural behavior of the FRP bridge structure is studied. During this thesis, finite part analysis is conducted by ANSYS on the Boyer Bridge in Pennsylvania.

Indexed Terms-- ***Bridge, Dynamic, Fiber reinforced polymers (FRP), Finite element analysis (FEA), FRP deck, etc.***

I. INTRODUCTION

Bridges with FRP decks are being explored as a possible system with an accelerated constructible feature. The characteristics of bridges with FRP decks, like mass, stiffness, and damping are considerably totally different from those of bridges with ancient concrete decks. Thus the dynamic response of the FRP-deck bridges is of an excellent interest, and is that the objective of the present analysis reportable here. Some researchers have already worked on this space. FRP materials are utilized all the additional typically to present savvy different choices to steel and cement. Potential applications for FRP decks match new outlines, substitution of under-quality decks in existing scaffolds, and therefore in this work, the conduct of FRP scaffold deck of various arrangements is to be considered by ANSYS. In this thesis, a finite element model was built of an FRP deck steel stringer bridge system using ANSYS. The model is verified by a static field test result on the Boyer. Based on the validated model, we further analyze the dynamic characteristics of this bridge, including the frequencies and modal shapes. Then a moving truck load is simplified to add on the bridge in order to analyze the dynamic responses of the FRP deck bridge, including the displacements, stress, strain & safety factor. In this bridge, the FRP deck and steel stringers are connected by shear studs. The number of the shear studs will affect the stiffness of the bridge, which may affect the fundamental frequency and dynamic responses of the bridge.

A. Backgrounds of FRP Bridge Decks

1) FRP material

Different from typical construction materials, FRP is an engineered material. Engineers will style the fabric properties and structural shapes of FRPs supported their requirements. Therefore, it's essential to understand the composition of FRP material. FRP material consists of 2 major components: a chemical compound matrix organic compound and fiber reinforcements. Fillers and additives, as a 3rd element, can improve bound characteristics of the ultimate product. Different from typical construction materials, FRP is an engineered material.

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The main functions of matrix resins area unit making volume, transferring stresses between fibers, protective fibers from mechanical and environmental harm, and providing lateral support to fibers against buckling. 2 sorts of polymeric matrices area unit wide used for FRP composites: thermosetting polymers and thermoplastic polymers.

Thermosetting polymers area unit low molecular-weight liquids with very low consistency, and thermosetting polymers can't be reshaped once natural process, as a result of uncontrolled reheating causes the material to succeed in its decomposition temperature before its increased freezing point.

B. Fundamentals of FRP Composite Bridge Decks

1) FRP bridge deck

Fiber Reinforced polymers (FRP), primarily utilized in the part business, square measure being applied to the planning of bridges. FRP composites square measure primarily created from fibers aligned inside an organic compound material in such the simplest way to create an awfully robust and extremely customizable material. The most common fiber decisions square measure glass and carbon fibers.

FRP product have the advantages of high strength, low weight, high stiffness-to-weight quantitative relation, and corrosion resistance. Efficiencies square measure gained by the deck being ready in panels and within the transporting to job website and putting practices.

Fig.1 FRP bridge deck slabs

C. Benefits and Challenges of FRP Decks

FRP bridge decks have with success transitioned over the past decade from the experimental analysis stage to the sphere application stage. Quite a hundred bridges are designed or repaired with FRP upper deck systems within the USA alone. This section summarizes the most advantages and challenges of FRP bridge decks supported their laboratory results and field performances.

The benefits of mistreatment FRP upper deck systems square measure as Follows:

1. Non-destructive properties of FRP will broaden the administration lifetime of FRP extension deck.
2. Prime quality results from substantially controlled industrial facility setting.
3. Construction of FRP scaffold decks is easier and speedier than normal extension deck development, which prompts less activity management time, and fewer negative natural impact.
4. FRP Bridge decks square measure wonderful replacements for nineteenth and 20th century steel truss bridges and transferrable bridge.

II. LITERATURE REVIEW

Chinmay Thakur, Sumit Pahwa, A Study on Transient Analysis of Bridge Deck Slab under the Action of Moving Load, International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 05, May 2019.

This paper presents the modal and transient analysis of bridge block subjected to moving load by exploitation ANSYS package. The modal analysis results area unit compared with previous literature and shut for resolution. The constant study is in kind of deflection, stress and strain for variation of model's dimension. The study reveals that Finite component methodology is applicable and reliable tool for analysis of bridge block. The aim of this study is to gauge the injury of the chosen deck block and evaluating the cracking and crushing of deck below cyclic wheel hundreds. Nonlinear analysis of structural component exploitation ANSYS worktable is applied. The dynamic response of a bridge block to moving vehicles was studied. The dynamic response was measured in terms of the normalized deflection, stress and strain. Following conclusions were drawn on the premise of results obtained from this study of simplified models of the bridge and therefore the vehicle. Deformation, Shear stress and traditional stresses area unit significantly reduced by increasing depth of deck. The modal analysis result shows that, because the depth will increase, the natural frequencies are will increase. The transient analysis results show that deflection, stress and strain decrease as depth increase. As span will increase deflection, stress and strain decreases.

Ajinkya S. Shah, Yogesh R. Suryawanshi, Response of FRP bridge deck structure under moving load, International Journal of Scientific Development and Research (IJSDR), Volume 1, Issue 7, July 2016.

In this paper the parametric study of steel deck bridge is done using FEA simulation tool ANSYS16.0
Following conclusions can be made after comparison-

- For moving load FRP bridge deck gives better performance
- Deformation, Shear stress and Normal stresses are considerably reduced by using FRP layers on deck
- FRP layers can be used of rehabilitation of bridge deck.

Yin Zhang, C.S.Cai, Load distribution and dynamic response of multi-girder bridges with FRP decks, Engineering Structures, 29 (2007) 1676–1689.

Zhang and Cai studied the load distribution and dynamic response of multi-girder bridges with FRP decks and concrete decks supported a bridge-vehicle coupled model. They found that the load distribution issue values and dynamic response of FRP deck bridges area unit larger than those of concrete deck bridges. And conjointly they found that FRP deck bridges with partly composite conditions have a bigger beam load distribution and a bigger dynamic displacement than those of the FRP deck bridges with absolutely composite conditions. Conjointly they over that road roughness and vehicle speed considerably affected the dynamic performance.

Albert F. Dal, John R. Cuninghame, Performance of a fibre-reinforced polymer bridge deck under dynamic wheel loading, Composites: Part A 37 (2006) 1180–1188.

The paper depicts the examination did to examine the execution of Fiber reinforced polymer (FRP) span decks beneath neighbourhood wheel stacking. The goal of the examination was to deliver a draft normal giving nonexclusive define stipulations for specialised endorsement of FRP deck frameworks The deck was subjected to over 4.6 million cycles of a four t wheel load, similar to 30-40 years of administration movement. A better endorsement check is projected, applying stress cycles to very little segments of deck to reenact the entry of wheels. The paper incorporates an outline of the FRP deck, the testing and a summary of the execution of the deck. The paper describes the analysis allotted by TRL restricted on behalf of the United Kingdom Highways Agency to look at the performance of fibre strengthened compound (FRP) bridge decks beneath native wheel loading. The target of the analysis was to supply a draft normal giving generic style needs for technical approval of FRP deck systems.

David A. M. Jawad and Anis A. K. Mohamad-Ali, Analysis of the Dynamic behaviour of T-beam bridge decks due to heavyweight vehicles, Emirates journal for engineering research, 15 (2), 29-39 (2010).

This study investigates the dynamic behaviour of concrete T-beam bridge decks because of heavyweight vehicles. The three-dimensional model of associate actual T-beam bridge style is enforced at intervals the context of the finite component technique, through use of the ANSYS coding system. The deck is modelled with 20-node brick parts. Shaft hundreds and configurations that correspond to the "permit vehicle" loading model square measure adopted for the vehicle model. The case study is taken into account for static, free vibration, and compelled vibration analysis. The dynamic loading for forced vibration analysis may be a harmonically (sinusoidal) varied load with magnitude capable 100% of the shaft load and a forcing frequency capable the first (fundamental) frequency of the bridge, so simulating a case of resonance.

Tomasz Siwowski, Mateusz Rajchel, Dynamic performance of a vehicular bridge with lightweight FRP composite structural elements, MATEC Web of Conferences 285, 00016 (2019).

This investigation centered on evaluating the dynamic performance below proof load of a fresh created hybrid FRP composite-concrete bridge structure. The bridge structure was instrumented with a series of LVDTs and accelerometers to live the relevant dynamic characteristics. The dynamic tests were conducted exploitation single truck consideration 320 KN and moving with numerous speeds. The results obtained from the experimental investigation were accustomed verify 3 key dynamic performance characteristics: dynamic amplification issue, initial natural frequency and damping quantitative relation.

Shah Alam, Guoqiang Li, Flexural and Dynamic Characteristics of FRP Composite Sandwich Beam, International Journal of Engineering Research & Technology (IJERT), 15 (2), 29-39 (2010), Vol. 9 Issue 06, June-2020.

This study presents the flexural and impact testing results of composite sandwich beams. The sandwich beams square measure made from balsa within the core and high strength steel wire and E-glass fiber bolstered compound composite within the facings. From the experimental results, flexural properties of the beams square measure calculated, together with bending stiffness, bending strength, shear strength etc. The experimental results have shown that the beams have all failing within the compression zone native buckling of the highest face and shear of the core.

A. Zhou, Y. Bai and T. Keller, Dynamic characteristics of bridge superstructures with FRP composite structural elements, Composites in Construction 2005-Third International Conference, France, July 11-13, 2005.

This paper reviewed the aspects of dynamic load effects considered in highway and pedestrian bridge design of various national codes, the analysis and characterization of dynamic responses of highway bridges and footbridges, and available activities conducted for dynamic analysis of bridge superstructures that use FRP structural components.

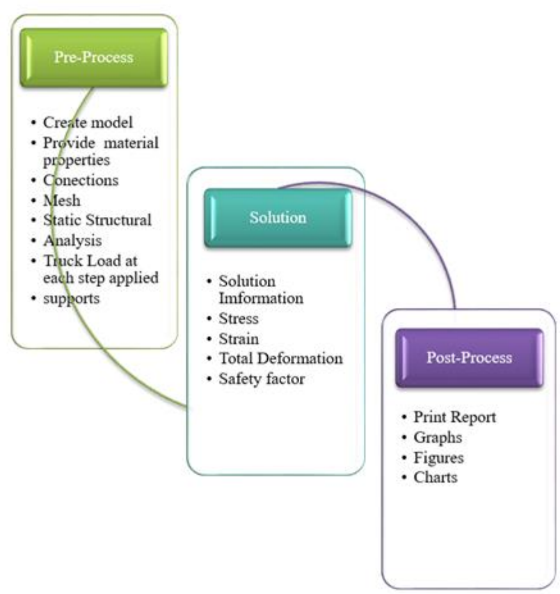
III. OBJECTIVES

- To Analyze dynamic response of FRP deck bridge including displacement, stress, strain and safety factor.
- To validate Response of RCC Bridge deck with manual calculations.
- To Comparing Convectional RC Bridge with FRP Deck Bridge.

IV. METHODOLOGY

A. Modelling and Analysis Procedure

In Ansys the modelling and analysis procedure is divided in three parts as Pre-processing, Solution and Post-processing is shown in figure below:-



B. Overview of the Boyer Bridge

The Boyer Bridge is a short span (12,649mm) simply supported composite structure located on a secondary road in Penn DOT Engineering District 10-0. It consists of five galvanized W610x155 beams acting compositely with five FRP deck panels, as shown in fig. Each panel measures 7,772mm wide and 2.438mm long.

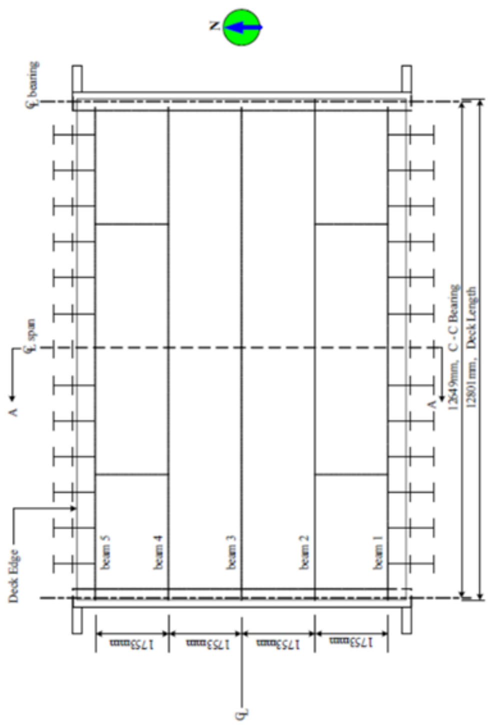


Fig.2 Plan view of the Boyer Bridge

C. Finite element model

The Boyer Bridge is a short-span (12.649 m) simply supported composite structure located in a secondary road in PENNDOT Engineering District 10-0. The cut-away view of Boyer Bridge is shown in Figure.It consists of five galvanized stringers acting compositely with five FRP deck panels.A tandem-axle dump truck loaded with sand was chosen as test vehicle. Wheel loads were shown in the table. The truck was located on the second girder.

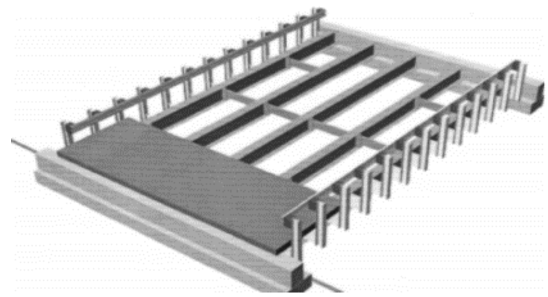


Fig.3 Cut-away view of Boyer Bridge

SR NO	Material	Property	Value
01	Structural steel	Flange Thickness (T_f)	19.05 mm
		B_f	323.85 mm
		T_w	12.70 mm
		Spacing	1753 mm
02	FRP Deck	Deck thickness (T_d)	194.56 mm
03	Modulus of Elasticity	E_{steel}	200000.00 MPa
		$E_{concrete}$	26300 MPa
		E_{frp}	17241.40 MPa

Table 1 Material Properties

Side	Axle 1(kg)	Axle 2(kg)	Axle 3(kg)
Left	3409	4273	4136
Right	3409	4273	4136
Total	6818	8546	8272

Table 2 Vehicle Axle Load

Figure shows the profile, boundary condition and the load condition of the bridge. In the model the total number of nodes is 728620 and total number of elements is 117775.

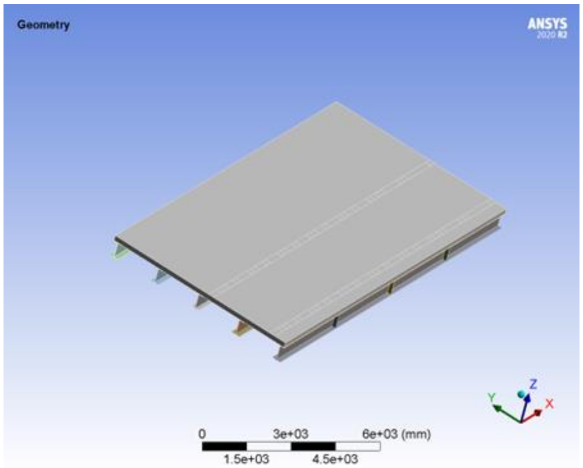


Fig.4 Model of the Bridge

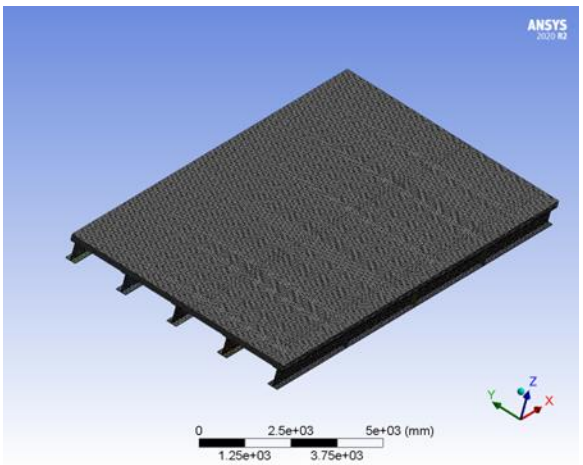


Fig.5 Mesh of the Model

V. DYNAMIC ANALYSIS

The mass and stiffness between the FRP deck and concrete deck are quite different, which result the frequencies of the bridge system are different. Therefore this may generate dynamic problems when the bridge is subjected to live load, such as moving trucks. Therefore, in this we analyze the frequencies and modes of this particular FRP deck bridge to find out whether the high mode affects the dynamic response.

A. Natural Frequencies

Natural frequencies and modal shapes are basic dynamic characteristics of a system. The modal vibration test data, such as fundamental frequencies and modal shapes has been successfully used in bridge damage supervision. In ANSYS, we can easily use the "linear perturbation analysis step" to get the natural frequencies of the bridge. In the frequency extraction model, the FRP deck is fully composite with steel girders.

The first ten frequencies are 3.6151, 12.777, 16.686, 22.856, 23.289, 31.286, 38.101, 44.468, 45.503, and 46.398 (unit: Hz). The first three mode shapes of the bridge are shown in Figures 6-8.

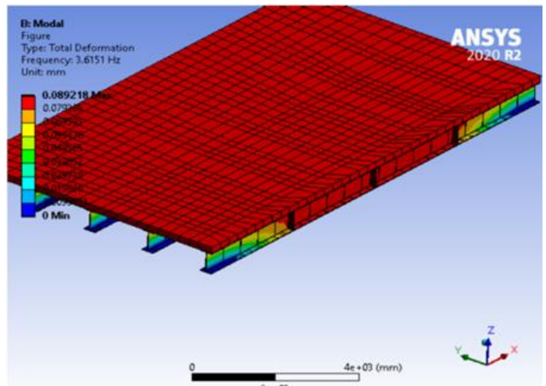


Fig.6 First modal shape (Frequency = 3.6151 Hz)

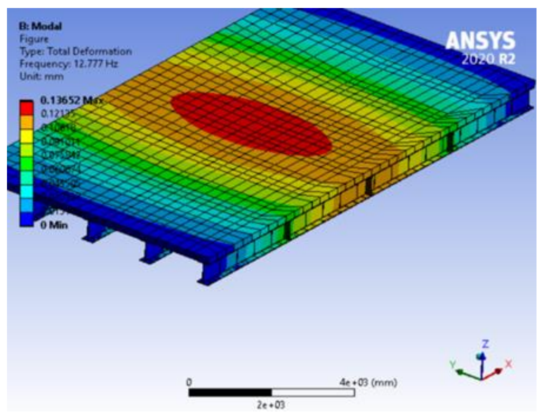


Fig.7 Second modal shape (Frequency = 12.777 Hz)

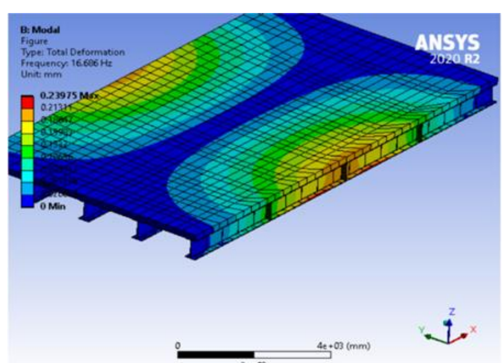


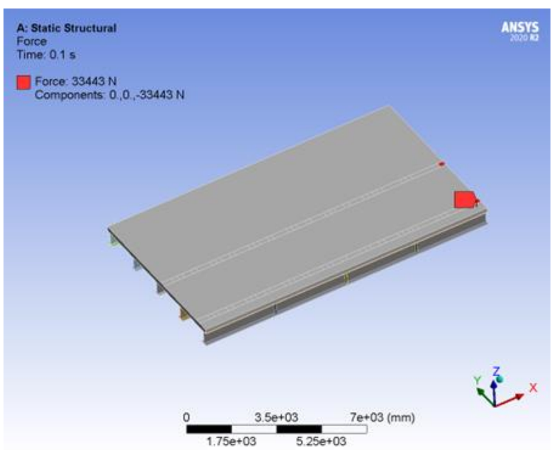
Fig.8 Third modal shape (Frequency = 16.686 Hz)

B. Truck Load

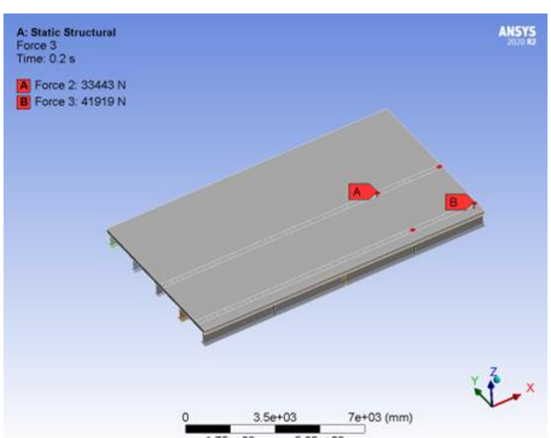
Assume the truck travels at 18 m/s across the bridge. The bridge length is 12.649m. The truck length is 5.68m. Therefore the total time for the truck to cross this bridge would be

Travelling time = (12.649m+5.68m)/18m/s=1.08s

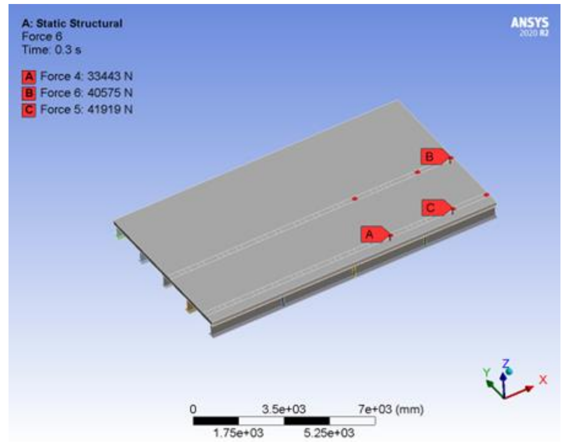
To simulate a moving truck, the truck is considered to locate at different positions at different time periods. In the finite element analysis, the total response time is set to be 3s in order to observe the response after the truck getting off the bridge. The total time is divided into 10 steps. The duration time of the 10 steps is 0.1 second at each step. The truck is loaded at different position at each step. Considering the truck starts to travel on the bridge from one end to another at 0s. Figure shows the position of the truck for first four steps. At each step, the truck load is simplified as a step load lasting 0.1s.



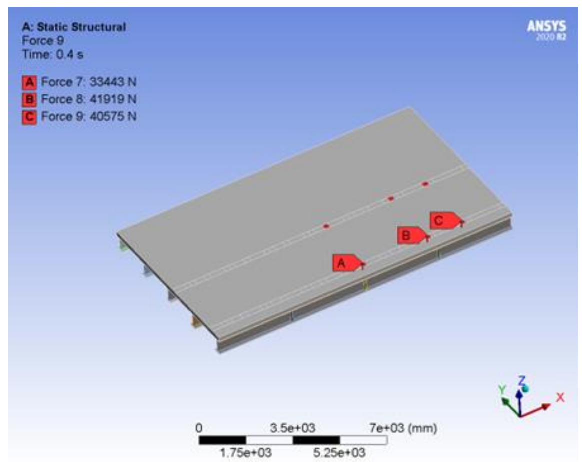
Step 1 t=0-0.1s only the front wheel is on the bridge



Step 2 t=0.1-0.2s



Step 3 t=0.2-0.3s

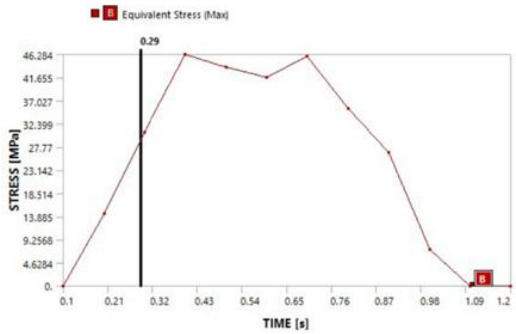


Step 4 t=0.3-0.4s

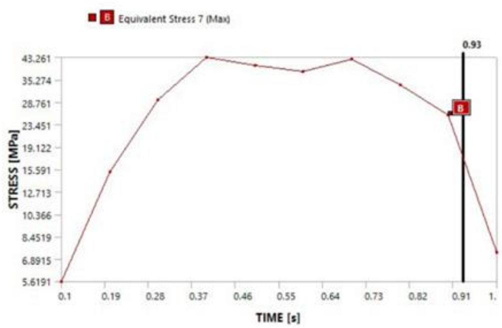
VI. RESULTS & COMPARISON

The simplified moving truck load is added on the verified bridge model to obtain its dynamic responses. Then results for Deformation, normal stress, Strain and safety factor are obtained.

The maximum and minimum normal equivalent stress are drawn, shown in graph 1-2.

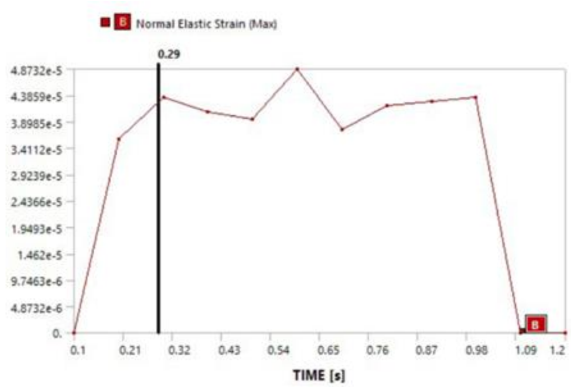


Graph 1 Stress vs time for RCC deck

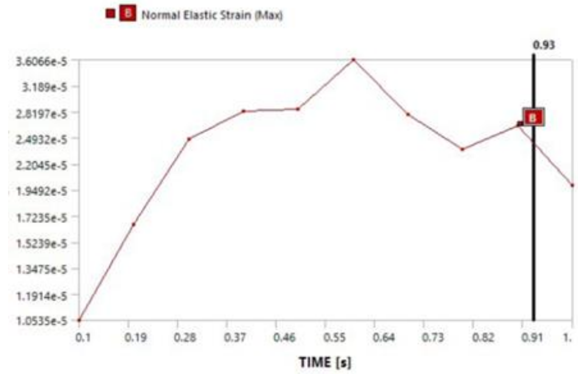


Graph 2 Stress vs time for FRP deck

The Normal Strain maximum over time for RCC deck and FRP deck and graph 3 and 4 shows strain maximum over time.

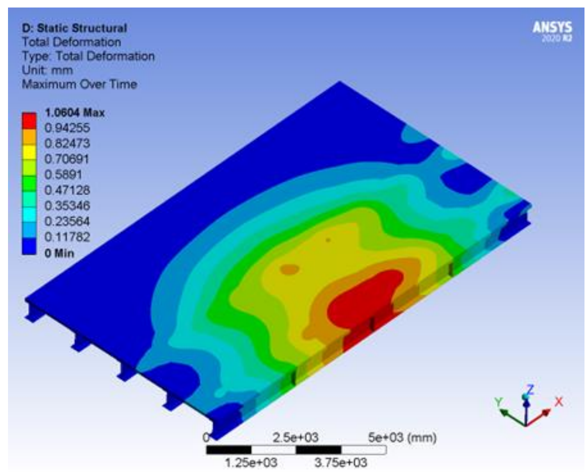


Graph 3 Strain vs time for RCC deck

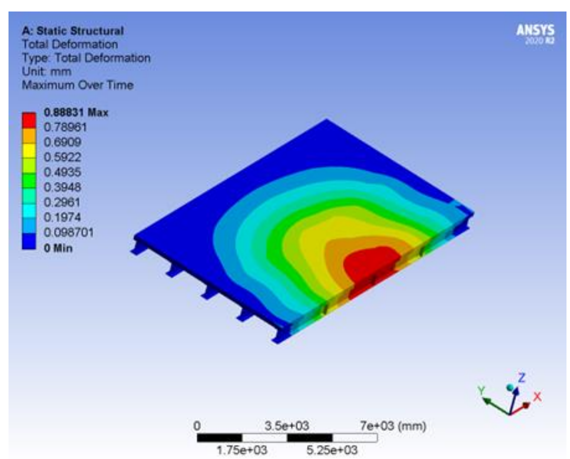


Graph 4 Strain vs time for FRP deck

Figure 9 shows the total deformation maximum over time for RCC deck and FRP deck and graph 5 and 6 shows total deformation at each step.

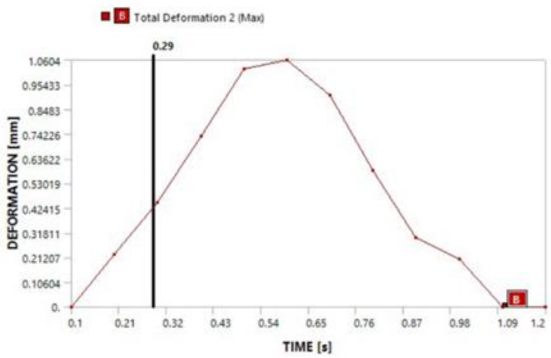


RCC deck

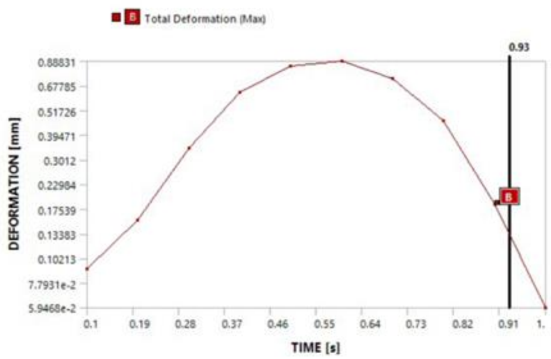


FRP deck

Fig.9 total deformation maximum over time

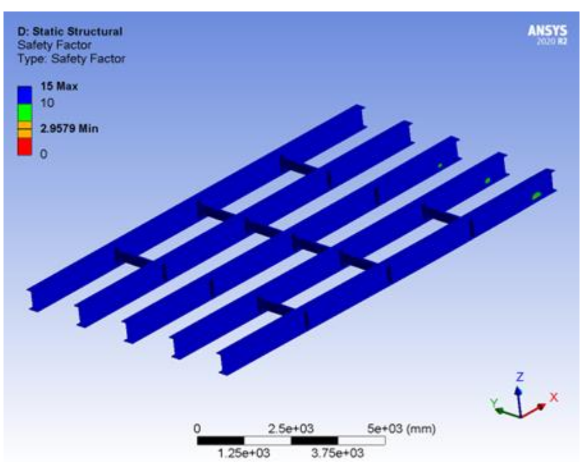


Graph 5 total deformation vs time for RCC deck

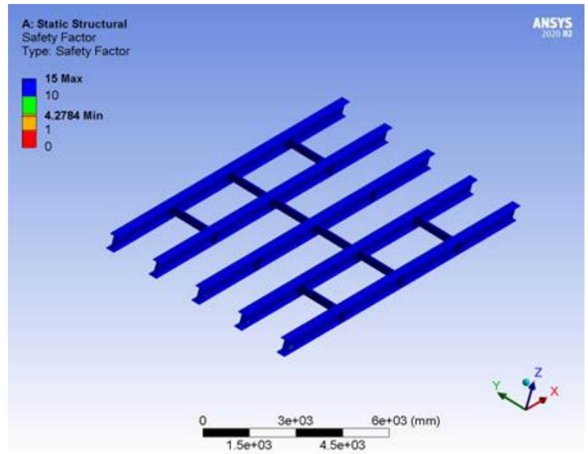


Graph 6 total deformation vs time for FRP deck

Figure 10 shows the safety factor for RCC deck and FRP deck.



RCC deck



FRP deck
Fig.10 Safety Factor

The above diagram and graphs give us information about the stress, strain, Deformation and Safety factor for RCC and FRP deck structure.

CONCLUSION

In this paper the parametric study of steel deck bridge is done using FEA simulation tool ANSYS. A moving truck load is added to analyze dynamic responses of the bridge.

Following conclusions can be made after comparison of RCC deck and FRP bridge deck structure:-

- For moving load FRP bridge deck gives better performance than the RCC bridge deck.
- Equivalent stresses, Strain & total deformation are considerably reduced by using FRP layers on deck. The values are decreased for FRP bridge deck structure by 94.15%, 64.78% and 80% resp.
- The safety factor is most critical and important part of the highly loaded structure. The SF of FRP deck is 69.08% better than the RCC bridge deck structure.

VII. FUTURE SCOPE

Although there exist a large number of studies, dealing with the dynamic moving load problem According to this study, following aspects may be considered in further studies.

- Comparison can be made for seismic performance of bridge combined with moving load.

- Different type of bridges can be analyzed in same manner at different loading conditions and at different positions.
- The vibrations caused by heavy moving vehicles at high speeds can propagate in the ground and have a significant influence on the surrounding area. Further research on ground vibrations may be carried out.

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