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A Review on Dynamic Analysis of FRP Bridge Deck 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 ABAQUS 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 ABAQUS on the Boyer Bridge in Pennsylvania.**

***Keywords*: Bridge, Dynamic, Fiber Reinforced Polymers (FRP), Finite Element Analysis (FEA), FRP deck.**

1. 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.

Fiber strengthened compound (FRP) will provide points of interest over the customary materials for development of extensions, for instance, diminishment in burden and ensuing increment in super load rating, recovery of unforgettable structure, broadening of a scaffold while not forcing further burden, speedier institution, decreasing price and movement blockage, and improved administration life even underneath brutal setting. The attributes of extensions with FRP decks, like, mass, firmness, and damping are altogether not constant as those of scaffolds with typical solid decks.

The heap appropriation part qualities and component reaction of FRP deck scaffolds are larger than those of solid deck spans. FRP deck spans with incompletely composite conditions have an even bigger brace load dispersion and an even bigger component uprooting than those of the solid deck spans with utterly composite conditions. Utilizing tentatively approved restricted part models to steer dynamic time history examination with Associate in Nursing AASHTO temporary state truck over the extension.

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 the procural short-lived running surfaces.

The essential refinements between FRP deck and routine decks are the distinctions in firmness and pure mathematics. The anxiety appropriation profile for steel patch stacking has been investigated and its relevance in FRP deck frameworks analyzed.

Association of tire with deck surface creates comparable weight dissemination that could be a great distance from uniform. Another reproduced tire patch stacking has been planned that copies the anxiety profile of real truck tire.

Tire contact region and phone weight are delineate utilizing weight delicate film sensors. Planned comparable weight profile has been connected to restricted part re-enactment to advance investigate the problems and break down reaction of FRP composite deck frameworks.

During this work, the conduct of FRP scaffold deck of varied arrangements is to be thought of by ABAQUS. During this thesis, a finite component model was designed of Associate in Nursing FRP deck steel stringer bridge system victimisation ABAQUS. The model is verified by a static test result on the Boyer. Supported the valid model, we have a tendency to more analyse the dynamic characteristics of this bridge, as well as the frequencies and modal shapes.

Fig. 1. Boyer Bridge, Pennsylvania

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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.

Within the use of bridge decking, FRP has been wrought into cellular panels which will be put in as full-depth deck panels. FRP deck panel's square measure used as an alternate to cast-in-place concrete decks.

They supply a driving surface for traffic the panel's square measure designed to interlock with male-female shear keys. Another choice for connecting the panels is that the use of high-quality epoxy adhesives. To attach the panels to the steel framing, pockets square measure fashioned over the beams to permit for welded stud shear connectors and non-shrink grout. Bolts may be accustomed connect the panels to the steel framing.

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. 2. 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.

2. 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 neighborhood 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. The testing of those beams is performed employing a monotonic static three-point loading to failure in accordance with ASTM customary C393-00. Native strain distribution within the mid-span of the beams is obtained exploitation strain gauges. Mid-span deflections of the beams are real-time measured using linear variable displacement transducer (LVDT). 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.

3. Methodology

The research methodology adopted to achieve the targeted aim, started with literature survey, setting up of aim, objectives.

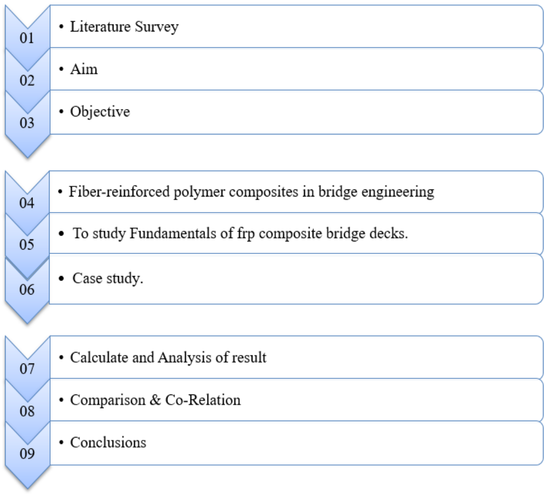

Fig. 3. Methodology

A. *Finite Element Model*

The Boyer Bridge may be a short-span (12.649 m) merely supported composite structure settled in an exceedingly secondary road in PENNDOT Engineering District 10-0. The cut-away read of Boyer Bridge is shown in Figure one. It consists of 5 galvanized stringers acting compositely with 5 FRP deck panels. The FRP deck system is composed of tubes perpendicular to the traffic. The FRP deck and steel girders square measure connected by shear studs that is 610mm spacing between every row. Every row has two shear studs across the steel beam section.

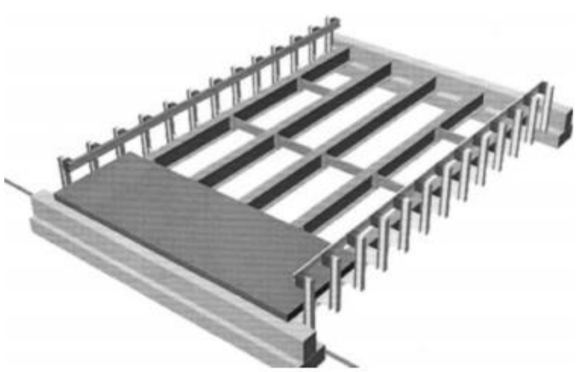

Fig. 4. Cut-away view of Boyer Bridge

The section and material properties are shown in the Table 1. A tandem-axle dump truck loaded with sand was chosen as test vehicle. Wheel loads were shown in the table 2. The truck was located on the second girder. From the field test, strains at the middle span of each girder were obtained.

Table 2
Test vehicle axle load

	Axle 1 (Kg)	Axle 2 (Kg)	Axle 3 (Kg)
Left Side	3409	4273	4136
Right Side	4273	4702	4750
Total	7682	9000	8886

4. Result

A. *Dynamic Analysis*

The mass and stiffness between the FRP deck and concrete deck square measure quite different, that result the frequencies of the bridge system square measure completely different. So this may generate dynamic issues once the bridge is subjected to measure load, such as moving trucks.

Additionally, thanks to massive variations of mass and stiffness between FRP deck and steel beam, the dynamic response of the bridge is also influenced by the high mode effect. Therefore, during this paper we tend to analyze the frequencies and modes of this specific FRP deck bridge to search out whether or not the high mode affects the dynamic response.

Furthermore, the dynamic response of the FRP deck bridge beneath a moving truck is analyzed. By examination the static response and dynamic response, the dynamic influence of a moving truck to the present bridge are often obtained.

B. *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.

The first mode shapes of the bridge are shown in Figure 5.

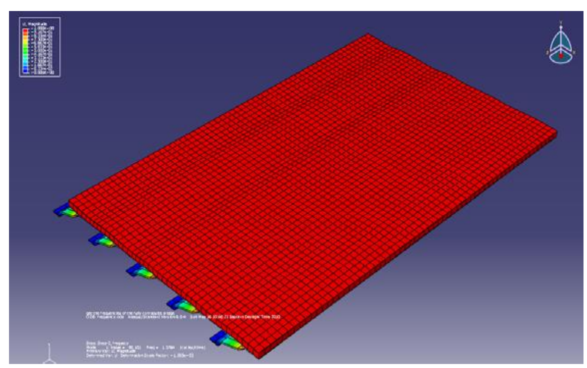

Fig. 5. First modal shape (Frequency =1.5764 cycles/time)

Table 1
Material properties

Steel stringers (mm)		FRP Deck (mm)		Modulus of Elasticity (Mpa)	
T_f	19.05	T_{haunch}	12.70	E_{steel}	200000.00
B_f	323.85	FRP Flange thk.	16.76	E_{grout}	31841.70
T_f	12.70	T_d	194.56	E_{frp}	17241.40
Spacing	1752.60				

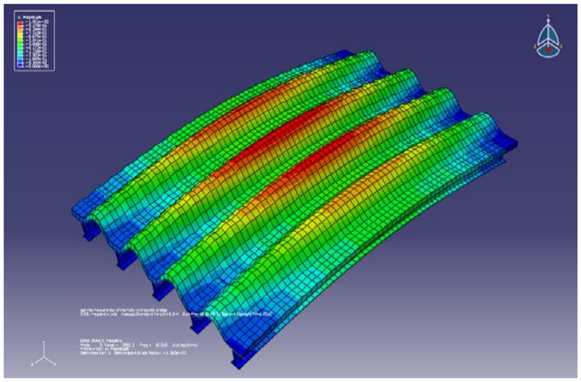

Fig. 6. Second modal shape (Frequency=10.018 cycles/time)

C. *Truck Load*

Assume the truck travels at 20m/s across the bridge. The bridge length is 12.649m. The truck length is 5.68m. Thus total time of the truck to cross this bridge would be

Travelling time = (12.649m+5.68m)/20m/s=0.92s

To simulate a moving truck, the truck is taken into account to find at different (completely different) positions at different time periods. Within the finite component analysis, the whole time interval is about tube 3s so as to look at the response when the truck obtaining off the bridge. The whole time is split into ten steps. The length time of the primary nine steps is 0.1 second at every step. The last step is 2.1s length time. The truck is loaded at totally different position at every step. Considering the truck starts to travel on the bridge from one finish to a different at 0s. At every step, the truck load is simplified as a step load lasting 0.1s.

D. *Dynamic Responses*

The FRP deck and girders square measure totally composite with shear studs within, meted out by using "tie" constraint between the FRP deck and girders in ABAQUS.

- Similar with case one, however while not shear studs within.
- The FRP deck and girders are part composite by shear studs, meted out by using "contact "interaction between the FRP deck and girders in ABAQUS.
- The FRP deck and girders are part composite with the quantity of shear studs reduced by 0.5. Under static load, the displacement at middle span of the second beam is 7.2mm in fully-composite condition of the bridge.

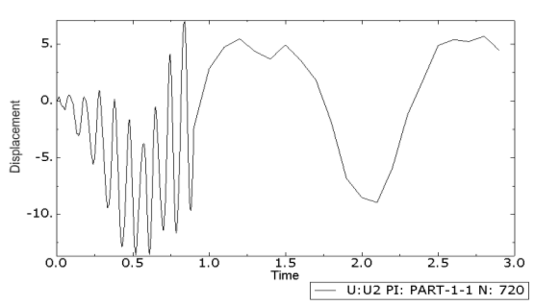

Fig. 7. The displacement of girder 1 at middle span in case 1

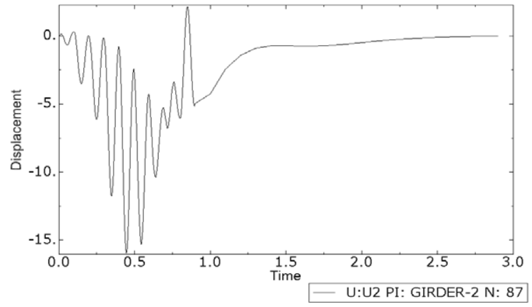

Fig. 8. The displacement of girder 1 at middle span in case 2

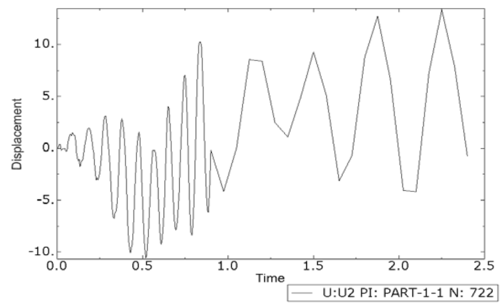

Fig. 9. The displacement of girder 1 at middle span in case 3

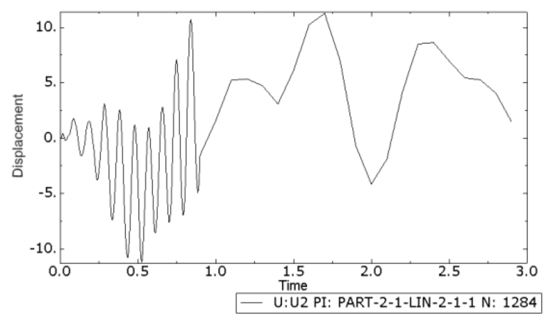

Fig. 10. The displacement of girder 1 at middle span in case 4

5. Conclusion

A three-dimensional finite component model of a fiber-reinforced compound deck bridge is developed supported the utilization of business software system ABAQUS.

A simplified static truck load is additional on the bridge to get its response. Comparison of finite element analysis results against field trial results indicates that the model may be used to perform in depth constant quantity study. Supported the verified model, a moving truckload is supplementary to research dynamic responses of the bridge. This study investigated its dynamic responses in four conditions: deck and beam totally composite with/without shear studs within, deck and beam part composite, deck and beam part composite with shear studs reduced by half. From finite component analysis the following conclusions may be drawn:

- In static analysis, finite component results show that the bridge possesses 95%composite action. However, the finite component results of dynamic response in absolutely composite condition and partly composite condition have vital variations.
- This indicates that the association standing between

FRP deck and beam has rather more influence on the bridge responses below dynamic load than that below static load. This also shows finite element model accustomed conduct dynamic analysis needs a lot of attention to form certain it correct.

- In dynamic responses, the moving truck causes downward displacements however additionally massive upward displacements in partly composite condition.
- The downward displacements of every beam are larger in absolutely composite condition than those in partly composite condition. However, distinction between the upward and downward displacements of girder a pair of is 54 larger in partly composite condition than those in fully composite condition that cause a lot of discomfort to passengers.
- In free vibration phrase when the truck load removed, the displacements of bridge in absolutely composite condition damps out quickly. However, the bridge in partly composite condition still has massive vibration in this period.

Based on the analysis results, once the FRP deck used in bridges, it is recommended that affiliation between FRP deck and girders ought to be strengthen to have a completely composite condition so as to reduce the dynamic responses. In addition, within the dynamic analysis with finite part model, the calculation takes concerning four days to end 3 seconds response of the bridge.

Therefore, it's important to simplify the model so as to cut back the calculation price. If the time is enough, we can extend the reaction time of the bridge till the dynamic response damps out.

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