Linear Static Analysis on FRP Bridges

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***Abstract*— Fibre Reinforced Polymer Composites (FRP) are gradually gaining acceptance from civil engineers, mainly in the field of bridge engineering. The paper presents the linear static analysis of an FRP box girder bridge using the finite element software, ABAQUS. The bridge model consists of 18mm thick laminated FRP box girders with an outer layer of laminate winding all the box girders together.The deck of the bridge made of chopped FRP is supported on the girders.The bridge was subjected to IRC loadings and the deflection and serviceability criteria were studied.It is important to identify the points of maximum stress.**

I. INTRODUCTION

FRP composites have been used in aerospace and marine applications for over 50 years. Most of the bridges in the world are either repaired or in the stage of repairing. This indicates the necessity of development of new structural elements and construction technologies, for use in bridges exposed to aggressive environmental conditions, by using alternative materials, more durable and resistant to corrosion like FRP. Its advantages over conventional materials like its high tensile strength to weight ratio, ability to be moulded to various shapes, corrosion resistance, lower lifecycle cost, good durability and fatigue strength make FRP composite, a good alternative for innovative construction. The reduction in the durability of conventional bridges when exposed to aggressive environment has led to the replacement of concrete decks as well as retrofitting of bridge parts using FRP. The use of FRP could reduce the high self weight , improve the corrosion and impact resistance.

II. LITERATURE REVIEW

Chiewanichakorn et al.[1] (2003) replaced a deteriorated concrete deck by an FRP bridge deck and it allowed for higher live load on the bridge. Chandrashekhara K.et al.[2] (2003) subjected an FRP bridge model to fatigue load of 2 million cycles corresponding to AASHTO requirements and found no loss in stiffness and strength. Kim et al[3].(2003) designed and analyzed GFRP deck for highway bridges and assessed several cellular tube sections to obtain a viable cross sectional profile for the deck. Roy R. J. et al.[4] (2005)designed and fabricated a bridge deck slab made of fiber reinforced polymer composite materials and the prototype deck subjected to static loading using hydraulic jackssupported a total of 515kN (twice the design service load) without any fracture, cracking or damage to the deck elements.K.A. Harries and J. Moses[5](2007)studied the effect on superstructure stresses on replacing a RC deck with GFRP deck and found that GFRP exhibit reduced composite behavior and reduced transverse distribution of forces compared to RC decks.Almansour H. and Cheung M.S.[6] (2010) proposed an iterative performance based multi-scale analysis and design approach for all-advanced composite bridge superstructure. Nicolas J. Lombardi and Judy Liu [7](2010) proposed Glass fiber-reinforced polymer or steel hybrid honeycomb sandwich concept for bridge deck applications and proved that the stiffness of the commercial GFRP honey comb sandwich panel can be increased by the inclusion of steel within the cross section. A.Bali et al[8].(2011) conducted a case study of a 3 span RC bridge in a strong seismic activity area before and after its repair by the application of carbon fiber compositesand found that the application of composite material to strengthen the structure increased the transverse rigidity of the structure and thus its modal frequency.

III. NEED FOR THE STUDY

Design Dynamic behaviour of an FRP bridge is an area which require more research and design recommendations. The DAF is related to the fundamental frequency of the bridge. The most significant traffic-induced vibrations are a combination of many modes, but it is easier for code purposes to relate the dynamic load allowance to the fundamental frequency. Most modern highway bridges were found to have fundamental frequencies in the range of 2 to 5 Hz, corresponding to the resonant frequencies of commercial vehicles. Therefore, it is important to study the free vibration of bridges

In this analysis, the bridge model was taken from the journal paper by Dr.HushamAlmansour published in 2010. Bridge superstructure is formed from laminated FRP box girder and chopped FRP top surface layer. The bridge cross section is shown in Fig.1.

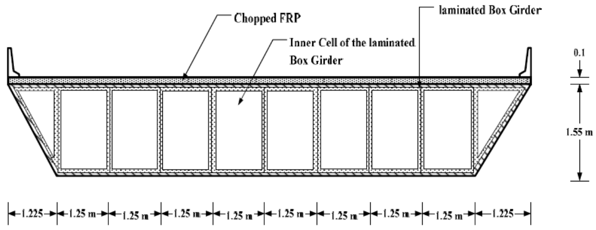

Fig. 1 Deck section of the simply supported two lane FRP bridge

Table 1. Mechanical properties of the lamina- E-Glass fiber and Vinyl ester

Matrix

Longitudinal modulus of elasticity, E_1	60.53GPa
Transverse modulus of elasticity, E_2	15.51GPa
In-plane Poisson's ratio	0.224
In-plane shear modulus	6.619GPa
Longitudinal tensile strength	1104MPa
Longitudinal compressive strength	69.4MPa
Transverse tensile strength	20.56MPa
Transverse compressive strength	29.14MPa
In-plane shear strength	9.46MPa

Table 2. Lamina alignment

Lamina layer	Lamina orientation(Degree)	
	Inner laminate	Outer laminate
1	-10	-10
2	30	45
3	10	10
4	-30	-45
5	10	10
6	45	90
7	45	90
8	10	10

The bridge deck section consists of a FRP box cells surrounded by an outer FRP binding box.The 24.75 m long and 12.45 m wide FRP bridge was modeled in ABAQUS

Homogenized material properties of chopped FRP of the deck slab are,

1) Modulus of elasticity = 9.32GPa
2) Poisson's ratio = 0.276
3) Ultimate strength = 139MPa

The lamina is formed from E-glass fiber and vinyl ester matrix (GFVM). Table 1 gives the mechanical properties of the lamina (GFVM) used in the FRP box girders. Table 2 gives the orientation and number of lamina layers in the 18mm thick laminate.

IV. FREE VIBRATION ANALYSIS

A. Modeling of FRP bridge in ABAQUS

In ABAQUS, an FRP bridge of 24.75m long and 12.45m wide was modeled with a laminate of 18mm thick with 12 layers of lamina in it. The bridge was modeled as a three dimensional, deformable structure. The modeling of the bridge was done mainly using four modules of ABAQUS, viz , the Part module, the Property module, the Assembly module and the Interaction module. The bridge was modeled as five parts, the deck, top flange, bottom flange, inclined web and web in the Part module. The cross section of each part was sketched and extruded to the desired length. In the Property module, the material properties were defined and assigned. The ply count and the lamina orientations were given with the help of the composite layup manager. Each part has being assigned a local coordinate system and the fiber orientations were assigned with respect to the local coordinate system. In the Assembly module, all the parts were created as instances and assembled together to form the bridge structure. In the Load module, various loading conditions can be specified and the boundary conditions were given for the bridge as simply supported. In the Interaction module, each of the parts was tied to the adjacent parts for the structure to act as a continuum and also to avoid the relative motion between the surfaces. The model was meshed using a solid isoparametric element named, C3D8R. It is an eight-noded linear brick element with reduced integration and hourglass control. The meshed model of the bridge is shown in the Fig. 2. The analysis was run and the results were obtained in the visualization module

B. Loading of FRP bridge in ABAQUS

According to IRC 6:2010, page 19, table 2, for a 2 lane bridge, the load combination is either one lane of class 70R loading or two lane of class A loading for a carriage way width of 5.3m and above, but less than 9.6m. Also, a pedestrian load of 4000N/m^2 was applied on the kerbs on either side.

- Two lane bridge subjected to 70R loading

The bridge was subjected to a 70R loading as shown below:-

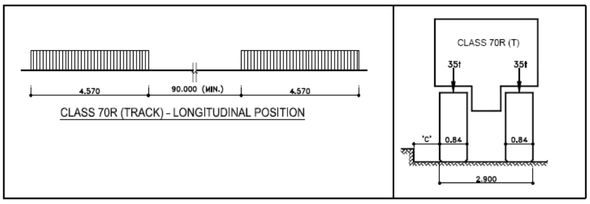

Figure 2:- Wheel arrangement for 70R tracked vehicle.

The load was applied by making suitable cuts of the dimension of the wheel base in the deck surface. The loads were applied as pressure loads in the wheel base area. The load was assigned in the option general, static, in the step module. The figure below shows the ABAQUS model of the 2 lane bridge being loaded by 70R tracked vehicle.

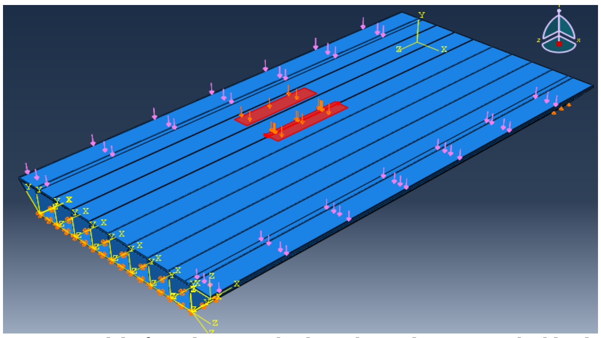

Figure 3:- Model of two lane FRP bridge subjected to 70R tracked loading

- **Results of two lane bridge subjected to 70R loading**

For a 70R tracked loading and the lamina orientation from the literature, the maximum Von-Mises stress and deflection were found to be $1.199 \times 10^7 N/m^2$ and 1.046cm respectively. The stress and deflection contours are given in the following figures.

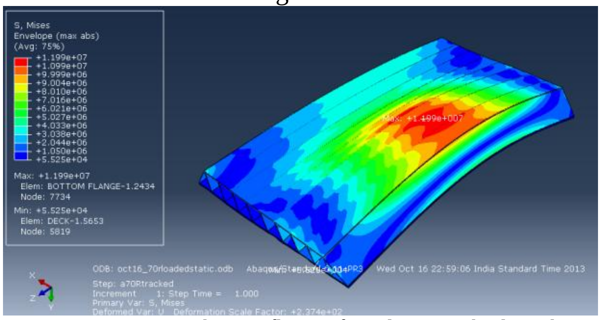

Figure 4:- Stress contour in bottom flange of two lane FRP bridge subjected to 70R tracked loading.

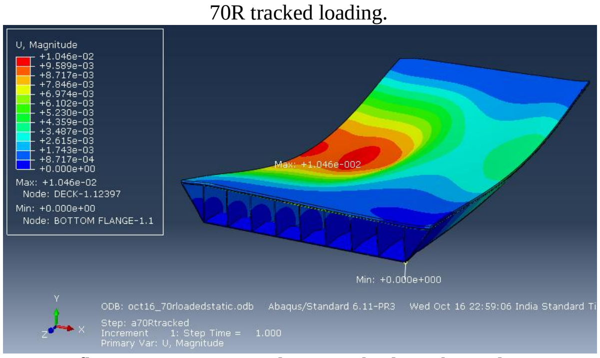

Figure 5:- Deflection contour in two lane FRP bridge subjected to 70R tracked loading.

- Two lane bridge subjected to class A loading

A two lane FRP bridge was subjected to class A loading such that cuts were made on the deck surface with the dimensions of the wheel bases and the loads were applied on the deck surface as pressure loads. Here also a pedestrian load of $4000 N/m^2$ was applied on kerbs on either sides. Suitable mesh size were adopted to avoid distorted elements and easy convergence. The solid element C3D8R was assigned. The wheel load was placed such that maximum moment occur at the midspan of the bridge. The two axles of 114kN were placed equally from the midspan of the bridge. The IRC class A loading on the bridge is shown in figure 5.5. The ABAQUS model of the bridge being modelled by class A loading is shown in figure.

- **Results of two lane bridge subjected to class A loading**

Maximum stress and deflection were obtained when the bridge was subjected to IRC class A loading. The maximum Von-Mises stress and deflection were found to be $1.566 \times 10^7 N/m^2$ and 1.653cm respectively.

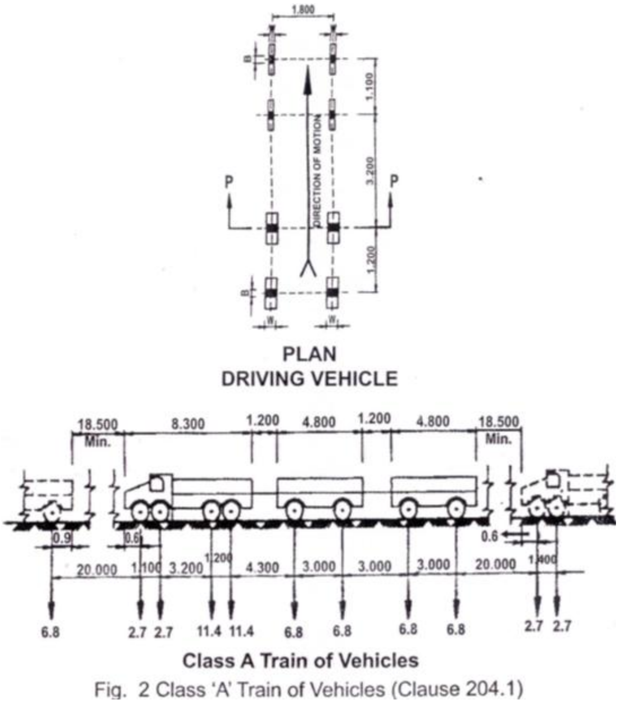

Figure 6:- IRC Class A loading

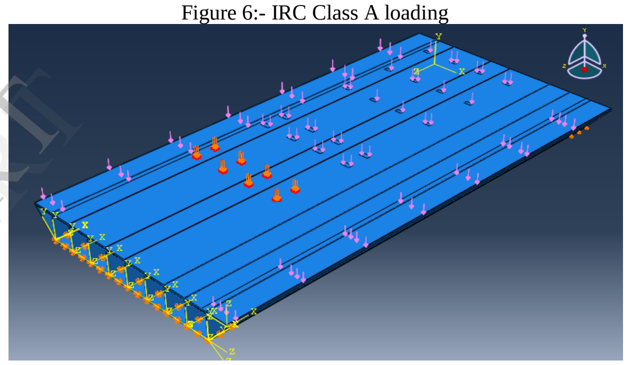

Figure 7:- Two lane FRP bridge subjected to IRC class A loading .

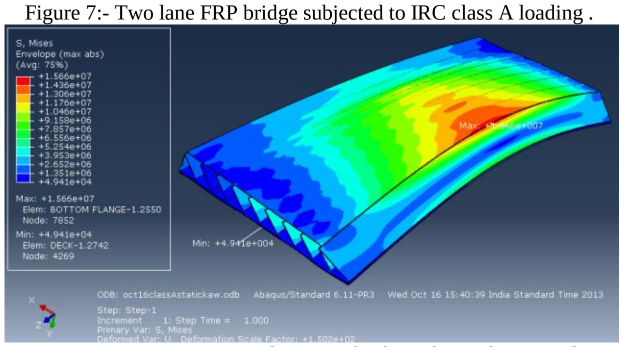

Figure 8:- Stress contour in two lane FRP bridge subjected to IRC class A loading.

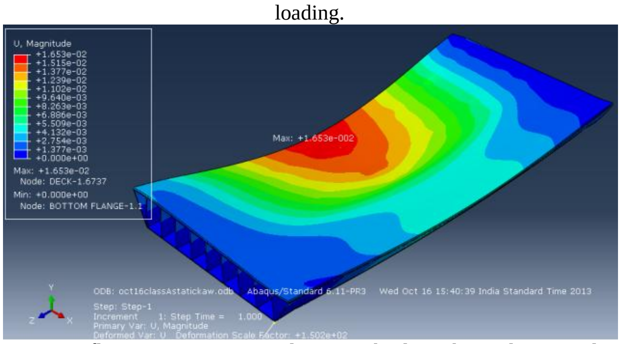

Figure 9:- Deflection contour in two lane FRP bridge subjected to IRC class A loading.

V. CONCLUSIONS

Maximum stress and deflection were obtained when the two lane bridge was subjected to IRC class A loading. The maximum Von-Mises stress and deflection were found to be 1.566×10^7 N/m^2 and 1.653cm respectively. The maximum deflection was found to be around 1/1500 times the span of the bridge, which is well within the acceptable limits of serviceability. The deflection criteria for normal RCC bridges amounts to span/350.

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