A comparative study of steel girder bridge with FRP using ANSYS

Abstract—The paper describes the research carried out to examine the performance of steel bridge with FRP in accordance with Indian Road Congress (IRC) codes under moving load. The deformation of bridge subjected to vehicles with different velocities is very complicated, and some attention has been paid to it in the engineering community. Use of fiber reinforced polymer (FRP) bridge deck structures is increasingly rapidly all over the world due to its many advantages over the conventional materials. The FRP bridge deck is lighter, durable, easy to work with, maintenance free and expected to have low life cycle cost. On the basis of typical theory on vibration analysis between bridge and vehicles, finite element model of bridge with FRP is established by ANSYS software. Through the numerical simulation analysis dynamic response characteristics of the bridge body are acquired when the vehicle passes through the bridge at different speeds and different frequencies, and inner force of bridge is gotten. These will provide reference for improving the vibration control measures of bridge under moving loads.

Keywords—Fiber reinforced polymer, Indian road congress, ANSYS

1. INTRODUCTION

Nowadays problems with moving load are fundamental in transportation, since both loads and speed of travelling increase. Especially railway and bridge structures are affected by growing requirements. Dynamic effects in problems with moving load result in increased deformations. In the case of existing structures the load carrying capacity is a serious limit for real applications. There are two solutions: rebuild the structure or apply control system (with active, passive or semi-passive vibration damping). Such solutions have already been applied in experimental scale and in nature. However, the practical limit in the development of this technique is in the computational part of the project. Although limited complexity of the problem (usually reduced to constant travelling speed and simple set of massless or inertial loads) are intensively investigated, real problems with arbitrary loads and marching load function are still hardly treated.

Analytical solutions of beams and plates under travelling loads are widely presented. The reader can find their various problems treated analytically, with broad list of references. Numerical approach to the problem in the case of standing load can be found in numerous academic books. However, numerical treatment of the wave problem in the case of moving force and comparison to analytical solution is rarely published.
Today it is necessary to consider dynamic behaviour of structures that has been induced by loads moving over a structure. Finding innovative, cost effective solutions for the repair and replacement of concrete and steel in bridges is a necessity. The simplest case of a moving load (dynamic) analysis is the case of a simple beam over which a concentrated load is moving, that is represented with a 4th order partial differential equation. P.D.E. for moving load has been solved numerically with many benefits over closed solution (various boundary conditions, introduction of damping and discrete elements like springs and dashpots, additional supports and many more). Average acceleration method has been employed since direct use of finite differences had shown as being practically unusable. Numerical and analytical solutions have been compared. On the basis of the above numerical solution the procedures for finite element analysis have been developed in ANSYS. The result is a F.E. computer program for 2D dynamical analysis that is especially suitable for moving load analysis.

![Fig.1, FRP Bridge, Bentley Creek Bridge, New York](image)

1.2. FIBER REINFORCEMENT

One area of technology that contributed to the space race was the usage of new "high-tech" Materials, including fiber reinforced polymer (FRP) composites. Composites offer inherent Advantages over traditional materials (like steel, concrete, and aluminum) including high strength-to-weight ratio, design flexibility, corrosion and fatigue resistance, low maintenance and extended service life. FRP deck has already been used in some bridge rehabilitation and short span bridges, but for widely used in bridges, FRP deck bridges still need further research. Currently many research efforts focus on the field tests of FRP deck bridges FRP composite can provide significant advantages over conventional materials for construction of bridges such as reduction in dead load and subsequent increase in live load rating, rehabilitation of historic structure, widening of a bridge without imposing additional dead load, faster installation, reducing cost and traffic congestion, and enhanced service life even under harsh environment.

The characteristics of bridges with FRP decks, such as mass, stiffness, and damping are significantly different from those of bridges with traditional concrete decks. The load distribution factor values and dynamic response of FRP deck
bridges are larger than those of concrete deck bridges. FRP deck bridges with partially composite conditions have a larger girder load distribution and a larger dynamic displacement than those of the concrete deck bridges with fully composite conditions. Using experimentally validated finite element models to conduct dynamic time-history analysis with an IRC Class AA Loading over the bridge. FRP materials will be used more widely to provide cost-effective alternatives to steel and concrete. Potential applications for FRP decks are like new designs, replacement of under-strength decks in existing bridges, and the provision temporary running surfaces.

1.3 MATERIALS USED IN FRP BRIDGE

Fiber Reinforced Polymer (FRP’s) composites are engineered materials with their strength dependent on several factors such as fiber type and volume, fiber orientation, resin type, manufacturing method, and the bonding materials used in the final assembly. Properties and structural shapes of these materials can be changed as per the requirement’s to gain strength. Fiber Reinforced Polymer composites are the combination of polymeric resins, acting as matrices or binders, with strong and stiff fiber assemblies which act as the reinforcing phase. The combination of the matrix phase with a reinforcing phase produces a new material system, analogous to steel reinforced concrete, although the reinforcing fractions vary considerably.

Components

1.3.1 Fibers

A fiber is a material made into a long filament. A single fiber usually has a diameter up to 15 um. The aspect ratio of length and diameter can be ranging from thousand to infinity in continuous fibers. They usually occupy 30-70% of the volume of the composite and 50% of its weight. The main functions of fibers are to carry the load and provide stiffness, strength, thermal stability and other structural properties to the FRP.

1.3.2 Matrix

Matrix material is a polymer composed of molecules made of many simpler and smaller units called monomer. The matrix must have a lower modulus and greater elongation than those of fibres, so that fibres can carry maximum load. The important functions of matrix material in FRP composite include, binding the fibres together and fixing them in the desired geometrical arrangement, transferring the load to the fibres by adhesion and/or friction, provide rigidity and shape to the structural member, isolate the fibres so that they can act separately, resulting in slow or no crack propagation, provide protection to the fibres against chemical and mechanical damages, influence performance characteristics such as ductility, impact strength, provide final colour and surface finish for connections.

Components of matrix

Matrix consists

- resins,
- fillers
- Additives

1.4 FUNDAMENTALS OF FRP COMPOSITE BRIDGE DECKS
What is an FRP bridge deck?

A number of terms commonly used to describe a bridge’s superstructure are illustrated in Fig.3. The components of the bridge above the bearings are referred to as superstructure, while the substructure includes all parts below. The main body of the bridge superstructure is known as the deck and girders/beams. An FRP bridge deck in this discussion is defined as a structural element made from FRP materials that transfers loads transversely to the bridge supports such as longitudinal running girders, cross beams, and/or stringers that bear on abutments.

The benefits of using FRP bridge deck systems are summarized as follows:

- Non-corrosive properties of FRP material can extend the service life of FRP bridge deck.
- High quality results from well controlled factory environment.
- Construction of FRP bridge decks is easier and faster than conventional bridge deck construction, which leads to less traffic control time, and less negative environmental impact.
- Lightweight FRP bridge decks make it possible to increase the live load carrying capacity of a bridge without retrofitting its substructure.
- Compared with conventional materials, FRP material has high strength but relatively low stiffness.
- Since the design of FRP bridge deck systems is based on stiffness requirements, this innovative bridge deck has a very high safety factor.

Although many benefits have been proven by laboratory tests and field projects, there are still some challenges in the use of FRP bridge deck systems:

- High initial cost is the major barrier to develop the FRP bridge deck market.
- The design of FRP bridge deck is based on finite element analysis. No official guidelines or specifications for the design and construction of FRP bridge decks are available on the market.
- For field installation, the joint details need to be examined and further developed, which include joints between FRP panels.

1.5 OBJECTIVES
• To perform finite element analysis for Steel deck bridge using ANSYS.
• To study behaviour of bridge deck under influence of Moving load in accordance with IRC Class AA.
• To compare bridge deck with FRP and without FRP Using ANSYS.
• Comparison of normal stress, shear stress, deflection and von-mises stress.

2 MATERIAL MODELING

The definition of the proposed numerical model was made by using finite elements available in the ANSYS code default library. SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behaviour. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials. The geometrical representation of is show in SOLID186.

This SOLID186 3-D 20-node homogenous/layered structural solid were adopted to discretize the concrete slab, which are also able to simulate cracking behaviour of the concrete under tension (in three orthogonal directions) and crushing in compression, to evaluate the material non-linearity and also to enable the inclusion of reinforcement (reinforcement bars scattered in the concrete region). The element SHELL43 is defined by four nodes having six degrees of freedom at each node. The deformation shapes are linear in both in-plane directions. The element allows for plasticity, creep, stress stiffening, large deflections, and large strain capabilities. The representation of the steel section was made by the SHELL 43 elements, which allow for the consideration of non-linearity of the material and show linear deformation on the plane in which it is present.

The modelling of the shear connectors was done by the BEAM 189 elements, which allow for the configuration of the cross section, enable consideration of the non-linearity of the material and include bending stresses. CONTA174 is used to represent contact and sliding between 3-D "target" surfaces (TARGE170) and a deformable surface, defined by this element. The element is applicable to 3-D structural and coupled field contact analyses. The geometrical representation of CONTA174 is show in fig3. Contact pairs couple general axisymmetric elements with standard 3-D elements. A node-to-surface contact element represents contact between two surfaces by specifying one surface as a group of nodes. The geometrical representation of is show in TARGET 170.
The TARGET 170 and CONTA 174 elements were used to represent the contact slab-beam interface. These elements are able to simulate the existence of pressure between them when there is contact, and separation between them when there is not. The two material contacts also take into account friction and cohesion between the parties.

Sometimes it is not always an easy task for an engineer to decide whether the obtained solution is a good or a bad one. If experimental or analytical results are available it is easily possible to verify any finite element result. However, to predict any structural behaviour in a reliable way without experiments every user of a finite element package should have a certain background about the finite element method in general. In addition, he should have fundamental knowledge about the applied software to be able to judge the appropriateness of the chosen elements and algorithms.

This paper is intended to show a summary of ANSYS capabilities to obtain results of finite element analyses as accurate as possible. Many features of ANSYS are shown and where it is possible we show what is already implemented in ANSYS.16 Workbench.

3. IRC LOADING

In India highway bridges are design in accordance with IRC bridge code. IRC: 6-1966-section-ii gives the specification for various loads and stress to be considered in bridge design. There are three types of standard loadings for which the bridges are design mainly IRC Class AA loading, IRC Class AA loading and IRC Class B loading. IRC Class AA loading consist of either tracked a vehicle of 70 tonnes or a wheeled vehicle of 40 tonnes with the dimensions as shown in Fig.s. The units in the Fig. are mm for length and tonnes for loads. Normally, bridges on national highways
and state highways are design for these loadings. Bridges design for Class AA loadings should be checked for IRC Class AA loading also. Since under certain conditions larger stresses may be obtain under Class A loading sometimes Class 70 R loading given in the Apendix-1 of IRC: 6-1966-Section 2 can be used for IRC Class AA loading. Class 70 R loading not discussed further here.

Class A loading consist of a wheel load train composed of a driving vehicle and two trailers of specified axel spacing’s. This loading is normally adopted on normal roads on which permanent bridges are constructed. Class B loading is adopted for temporary structures and for bridges in specified areas. For Class and Class B loadings, reader is referred to IRC: 6-1966-section 2. In this paper we have loaded bridge in accordance with IRC Class AA loading.

![Fig.5, IRC CLASS AA loading](image)

4. PROBLEM STATEMENTS

FIBER REINFORCED POLYMER BRIDGE STRUCTURE

- Geometric properties

Bridge has following dimensions

- Effective Span: - 30m
- Width: - 7.5m
- Height: - 5m
- GFRP Thickness: - 0.10 m
- Steel section: - ISMB450
4.1 Material Property

STEEL

Yield strength, $f_y = 248 \text{ MPa (33 ksi)}$

Modulus of elasticity, $E_s = 200 \text{ GPa (29,000 ksi)}$

CONCRETE

Modulus of elasticity, $E_c = 26.3 \text{ GPa (3.81 ksi)}$

FRP

Modulus of elasticity, $E = 30 \text{ GPa}$

Ultimate tensile strength, $X_t = 1700 \text{ MPa}$

Ultimate compression strength, $X_c = 639.54 \text{ MPa}$

Density = $2100 \text{ kg/m}^3$

Poisson’s ratio = 0.22
5. RESULTS

Fig. 8, graph of total deformation after loading

Fig. 10, graph of normal stress

Fig. 11, graph of strain energy

Fig. 12, graph of von mises stress

The models after loading are as follows
6. CONCLUSION

In the present study finite element modelling of steel deck bridge is proposed using ANSYS workbench and it is concluded that

- The use of GFRP in Deck Bridge reduces the longitudinal deformation by 10-15%.
- However von mises stress does not change significantly the difference is observed up to 4-5% only.
- The normal stress and strain energy got reduced to 20-30% GFRP Deck Bridge.

7. FUTURE SCOPE

- The same study can be performed for RCC Bridge, prestressed bridge and Box culvert.
- Comparison can be made for seismic performance combined with moving load.
8. REFERENCES