Response of steel deck bridge under influence of moving load using FRP

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Abstract: **This Fiber reinforced polymer (FRP) deck has some significant advantages over concrete deck in use for bridges, such as light self-weight, high stiffness and strength, good durability and easy to install. 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. Compared to field tests, Finite element analysis also has great advantages, such as low cost and convenient to conduct. The finite element model is verified by the static field test result. Then a simplified moving truck load is applied on the bridge model in order to analyze the dynamic responses of the FRP deck bridge, including the displacements and stress of each girder at the middle span. The dynamic effect is shown by comparing the dynamic responses and the static responses of the bridge. FE model ware employed to conduct dynamic time-history analysis with moving AASHTO fatigue truck over the bridge. Replacing of heavy concrete decks by FRP decks reduces dead load and thus increases the live load capacity.**

Keywords: Fiber reinforced polymers, Bridge deck, Finite element analysis (FEA), Vehicles; Load distribution, Moving load response

1. Introduction

Fiber reinforced polymer (FRP) deck has some significant advantages compared to concrete deck in use of bridges, such as light self-weight, high stiffness and strength, good durability and easy to install. 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 AASHTO fatigue truck 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.

Fig.1 FRP Bridge, Bentley Creek Bridge, New York

The important distinctions between FRP deck and conventional decks are the differences in stiffness and geometry. The stress distribution profile for steel patch loading has been explored and its applicability in FRP deck systems examined. Interaction of tire with deck surface develops conformable pressure distribution which is far from uniform.

Fig.2 Roadway for Bentley Creek Bridge

A new simulated tire patch loading has been proposed which mimics the stress profile of actual truck tire. Tire contact area and contact pressure are characterized using pressure sensitive film sensors. Proposed conformable pressure profile has been applied to finite element simulation to further explore the issues and analyze response of FRP composite deck systems.

In this work, the behavior of FRP bridge deck of different configurations is to be studied by ANSYS16.

1.2 BACKGROUNDS OF FRP BRIDGE DECKS

1.2.1 FRP Material

Different from conventional construction materials, FRP is an engineered material. Engineers can design the material properties and structural shapes of FRPs based on their requirements. Therefore, it is essential to know the composition of FRP material. FRP material consists of two major components: a polymer matrix resin and fiber reinforcements. Fillers and additives, as a third component, can improve certain characteristics of the final product.

1.2.2 Matrix Resin

The main functions of matrix resins are creating volume, transferring stresses between fibers, protecting fibers from mechanical and environmental damage, and providing lateral support to fibers against buckling. Two types of polymeric matrices are widely used for FRP composites: thermosetting polymers and thermoplastic polymers. Thermosetting polymers are low molecular-weight liquids with very low viscosity, and thermosetting polymers cannot be reshaped after curing, because uncontrolled reheating causes the material to reach its decomposition temperature before its increased melting point.

1.2.3 Fiber Reinforcement

The main functions of fiber reinforcements are to carrying the applied load, and providing strength and stiffness to the FRP composites. The fiber reinforcements are usually oriented in the direction of the primary loads. There are a large variety of fibers available in the composites industry.

1.2.4 Other Constituents

a. Fillers

b. Additives

1.3 FUNDAMENTALS OF FRP COMPOSITE BRIDGE DECKS

1.3.1 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.

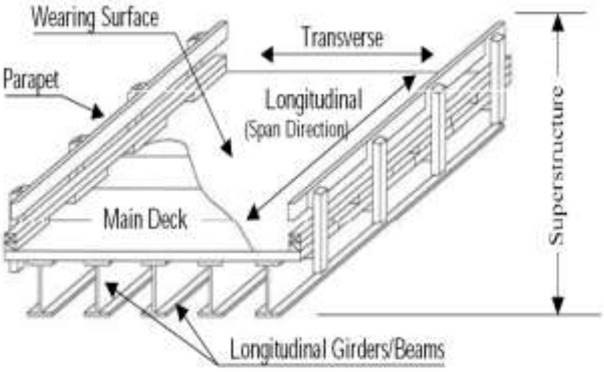

Fig.3 Superstructure of a bridge illustrating bridge engineering terms

1.3.2 Why FRP composite bridge deck

The issue of deteriorating of civil infrastructure is increasingly becoming a critical concern across the world. A 2001 report on America's infrastructure provided by the American Society of Civil Engineers shows that as of 1998, 29% of the nation's bridges were structurally deficient or functionally obsolete. It is estimated that bridges in the U.S. on average last 68 years, whereas their decks last only 35 years; about half of the average bridge life. A similar deterioration and deficiency situation also occurs in many European and Asian countries. In addition to the problem of deterioration and deficiency, renewing bridges today often requires increased load rating over that for which the bridge was initially designed to accommodate increased traffic loads. In addition, the FRP material can be customized to dimensions of traditional decks and allows the economic reuse of existing support structures. The above-mentioned demands in bridge engineering have resulted in a significant deck replacement market and created tremendous opportunities for FRP bridge decks.

1.3.3 Pultruded FRP deck Systems

Current fabrication techniques for FRP vehicular bridge decks include: Pultrusion, Filament Winding, Vacuum Assisted Resin Transfer Molding (VARTM), Resin Infusion and Hand/automated Lay-up. FRP decks commercially available at the present time in the U.S. market can be classified according to two types of construction: sandwich structures and adhesively bonded pultruded shapes. The bridge deck investigated in this research is made from adhesively pultruded shapes. The pultrusion process is the least expensive technique for fabricating high performance, constant cross section FRP structural composite parts.

1.4 FIBER-REINFORCED POLYMER COMPOSITES IN BRIDGE ENGINEERING

Polymer matrix composites is a subdivision of the composites field in which the matrix is a polymer and the reinforcement is a fiber (continuous and discontinous). Fiber-reinforced polymer was patented in 1916 [Munley, 2000]. The first known FRP composite product was a boat hull manufactured in the mid 1930s. In the 1940s and 1950s, FRP composite materials were widely used in the defense industry. Today, FRP composites applications have revolutionized many industries, including aerospace, marine, chemical processing, automobile, and electrical products.

The application of FRP composites in these bridge projects can be summarized as two categories

1) Bridge Renewal: primary areas are bridge structures rehabilitation (repair, strengthening and seismic retrofitting) and bridge superstructures (decks, girders) replacement.

2) New Bridge Construction: bridge structures made entirely of FRP composites (primarily for pedestrian bridges); concrete bridges with FRP rebar reinforcement, FRP wrapped concrete piles or pylons, and external FRP cable stays;

High performance and innovative FRP materials developed in last century are finding further uses in the civil and bridge infrastructures. Currently, there are more vehicular bridge projects using FRP materials in the U.S. than in any other country.

1.5 BENEFITS AND CHALLENGES OF FRP DECKS

FRP bridge decks have successfully transitioned over the past decade from the experimental research stage to the field application stage. More than 100 bridges have been built or repaired with FRP bridge deck systems in the USA alone. This section summarizes the main benefits and challenges of FRP bridge decks based on their laboratory results and field performances.

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

1) Non-corrosive properties of FRP can extend the service life of FRP bridge deck.
2) High quality results from well controlled factory environment.
3) 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.
4) FRP bridge decks are excellent replacements for 19th and 20th century steel truss bridges and moveable bridge.

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:

1) High initial cost is the major barrier to develop the FRP bridge deck market.
2) 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.
3) For field installation, the joint details need to be examined and further developed, which include joints between FRP panels.

Exchange of knowledge is still required between composite engineers and bridge engineers.

1.6 OBJECTIVES

- To analyze dynamic response of FRP deck bridge including displacement and stress.
- Comparing Convectional Bridge with FRP Deck Bridge.

3 FINITE ELEMENT ANALYSIS FOR FRP DECK BRIDGE STRUCTURES

3.1FINITE ELEMENT METHOD

Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. The method is illustrated with the help of the plane stress and plane strain formulationThe finite element method originated from the need for solving complex elasticity and structural analysis problems in civil and aeronautical engineering. Its development can be traced back to the work by Alexander Hrennikoff (1941) and Richard Courant (1942). While the approaches used by these pioneers are different, they share one essential characteristic: mesh discretization of a continuous domain into a set of discrete sub-domains, usually called elements.

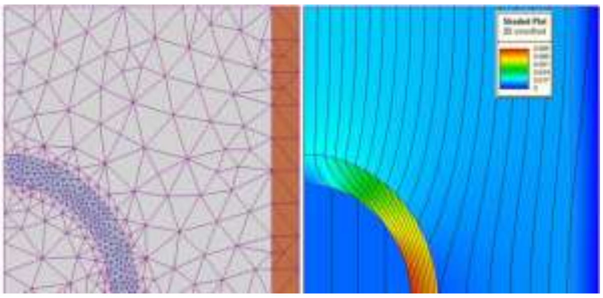

Fig.4 Finite Element Method

3.2 Finite Element Analysis

The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions **to** partial differential equations (PDE) and their systems, as well as (less often) integral equations.

In simple terms, FEM is a method for dividing up a very complicated problem into small elements that can be solved in relation to each other. FEM is a special case of the more general Galerkin method with polynomial approximation functions. The solution approach is based on eliminating the spatial derivatives from the PDE. This approximates the PDE with FEM mesh created by an analyst prior to finding a solution to a magnetic problem using FEM software. The solution approach is based on eliminating the spatial derivatives from the PDE.. The Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. Finite element analysis (FEA) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. The method is illustrated with the help of the plane stress and plane strain formulation. The Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. FEA is a tool used for the evaluation of structures and systems. It is useful for problems with complicated geometries, loadings, and material properties where analytical solutions can not be obtained.

FEA is a tool used for the evaluation of structures and systems. The finite element method has been an obvious choice for the modeling and analysis of reinforced concrete systems for many years. Finite elements have the unique capability to conform to virtually any geometry that could be physically implemented. Thus, the finite element method has gained acceptance as an appropriate tool for the analysis of flat plates, especially those with highly irregular or unusual geometries where the direct design and equivalent frame techniques are not valid. The finite element method can be shown to accurately solve for the distribution of stress. Few of these achievements have been implemented in practical applications for structural engineers in the design office. While much analytical work has been focused on the application of nonlinear constitutive modeling of reinforced concrete, most software packages currently implemented offer only linear elastic finite element capabilities.

4 PROBLEM STATEMENT

Fiber-Reinforced Polymer Bridge Superstructure

4.1 Geometric Properties

Bridge has following dimensions:

Length 35m Width 5m

Height 8m FRP thickness 15mm

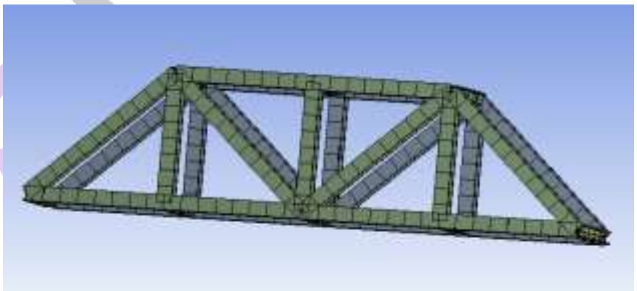

Fig. 5 FRP Bridge

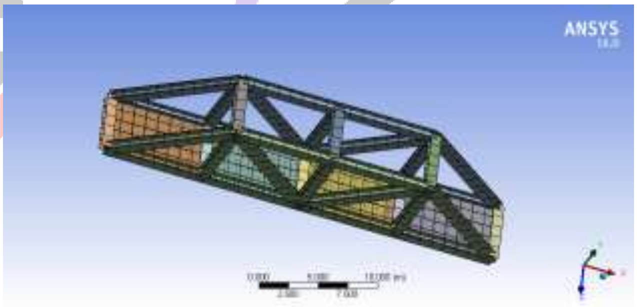

Fig. 6 FRP Bridge mesh

I section properties

W1 0.9
W2 0.9
W3 0.8
T1 0.09
T2 0.09
T3 0.09

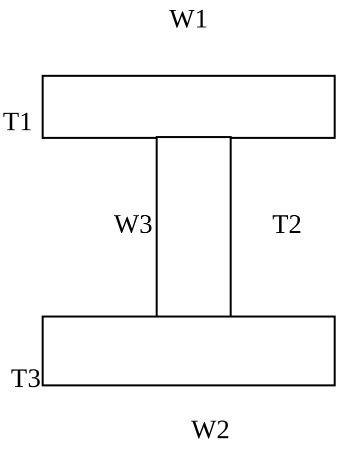

Fig.7 I section

4.2 Material Property:

STEEL
Yield strength, fy 248 MPa (33 ksi)
Modulus of elasticity, Es 200 GPa (29,000 ksi)

CONCRETE
Modulus of elasticity, Ec 26.3 GPa (3.81 ksi)

FRP
Modulus of elasticity, E 29,724 MPa (4310 ksi)
Shear modulus, G 6206 MPa (900 ksi)
Ultimate tensile strength, Xt 621 MPa (90 ksi)
Ultimate compression strength, Xc 476 MPa (69 ksi)

4.3 Loading Consideration

In this paper transient analysis is performed in ANSYS.16 which is time dependent. A moving load of 10 Kn is passing through bridge deck for a time period of 1.2 seconds. Hence the time interval is taken as 0.2 seconds for each step.

5 RESULT

The graphs of moving loads are as follows:

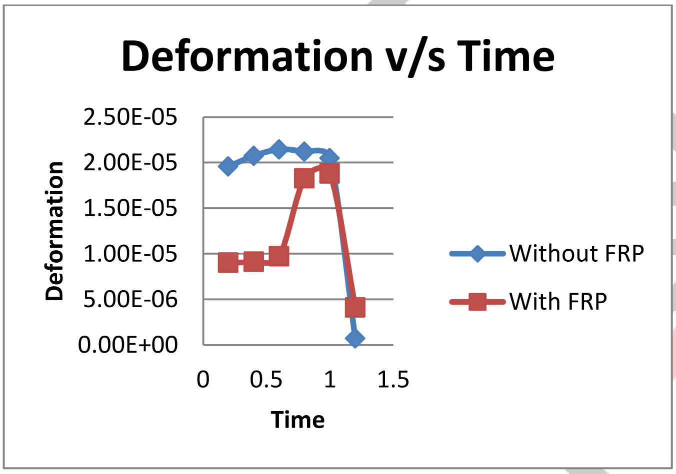

Fig 8-graph for Deformation v/s Time

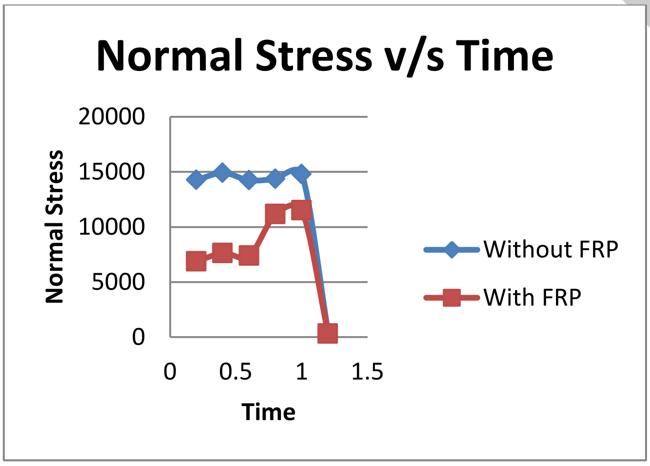

Fig 9-graph for Normal Stress v/s Time

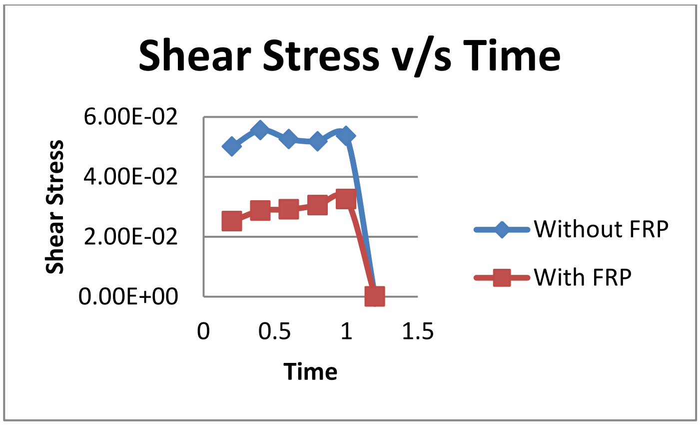

Fig 10-graph for Shear Stress v/s Time

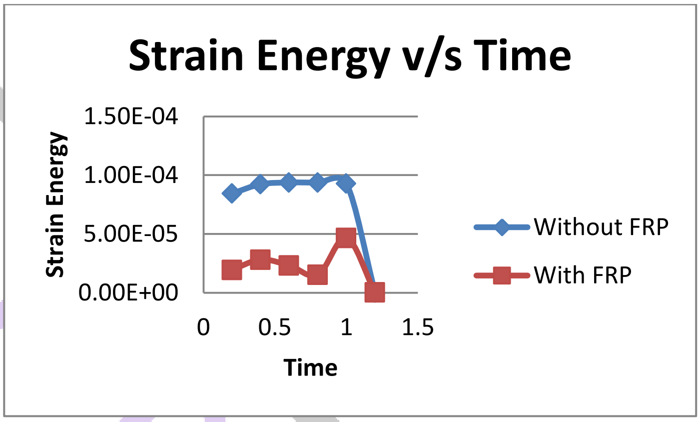

Fig 11-graph for Strain Energy v/s Time

The models after loading are as follows:

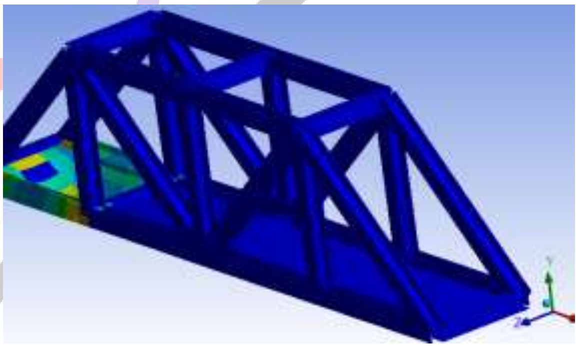

Fig 12-Model for Deck without FRP

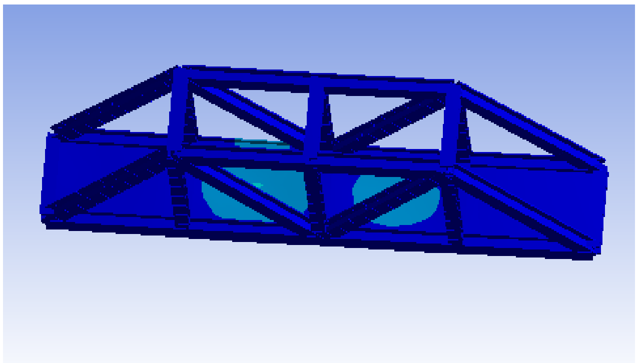

Fig 13- Model for Deck with FRP

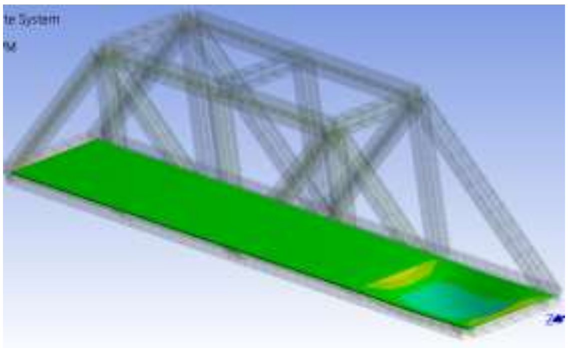

Fig 13- Model for Deck without FRP for Shear Stress

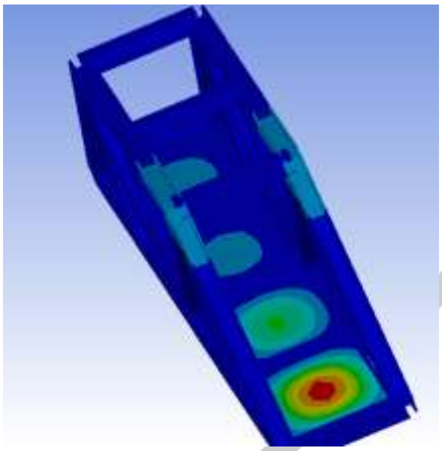

Fig 14- Model for Deck with FRP for Shear Strain

6 CONCLUSIONS

In this paper the parametric study of steel deck bridge is done using FEA simulation tool ANSYS.16
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

7 FUTURE SCOPE

- Comparison can be made for seismic performance combined with moving load
- Different type of bridges can be analyzed in same manner
- Skew angle effect need to be studied

REFERENCES

[1] Albert F. Daly*, John R. Cuninghame [April 2005] “Performance of a fibre- reinforced polymer bridge deck under dynamic wheel loading”

[2] Methee Chiewanichakorn a,*, Amjad J. Aref b, Sreenivas Alampalli c [October 2006] “Dynamic and fatigue response of a truss bridge with fiber reinforced polymer deck”

[3] Yin Zhanga,1, C.S. Caib, [September 2006] “ Load distribution and dynamic response of multi-girder bridges with FRP decks”

[4] Wael I. Alnahhal1; Methee Chiewanichakorn2; Amjad J. Aref3; and Sreenivas Alampalli4 [July 2006] “Temporal Thermal Behavior and Damage Simulations of FRP Deck”

[5] Zureick, Abdul-Hamid., Shih, Ban-Jwu., Munley, E. (1997). Fiber-Reinforced Polymeric Bridge Decks. Structural EngineeringReview, Vol. 7, No. 3, pp. 257-266.

[6] Harik, I., Alagusundaramoorthy, P., Siddiqui, R., Lopez-Anido,R., Morton, S. Dutta, P., Dutta, P., and Sharooz, B. (1999). StaticTesting on FRP Bridge Deck Panels. Proceedings of the 44th International Sampe Symposium and Exhibition, Long Beach,California, U.S., pp. 1643-1654.

[7] Henry, J.A. (1985). Deck-girder Systems for Highway BridgesUsing Fiber Reinforced Plastics. M.S. Thesis, North CarolinaState University, Raleigh, U.S.

[8] Karbhari, V. M., Seible, F., Hegemier, G. A., and Zhao, L. (1997).Fiber Reinforced Composite Decks for Infrastructure Renewal-Results and Issues. Proceedings of the International Composites Expo'97, Composite Institute, Nashville, TN, pp. 3-C(1-6).

[9] Lopez-Anido, R., and GangaRao, H. V. S. (1997). Design and Construction of Composite Material Bridges. Recent Advances inBridge Engineering, Urs Meier and Raimondo Betti (Eds), pp. 269-276.

[10] Hibbitt, Karlsson and Sorensen (2000), “ABAQUS/Standard User’s Manual (Version 6.1)”, Habbitt, Karlsson & Sorensen, Inc. Hyer, M.W. (1997), “Stress Analysis of Fiber–Reinforced Composite Materials”, McGraw-Hill, 627p.

[11] Aref, A. J., Chiewanichakorn, M., and Alnahhal, W. I. 2004. “Temporal thermal behavior and damage simulations of FRP deck.” Rep., Transportation Research and Development Bureau, and Transportation Infrastructure Research Consortium, New York State Dept. of Transportation, Albany, New York.