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Constructability, Maintainability, and Operability of Fiber-Reinforced Polymer (FRP) Bridge Deck Panels

Introduction

Recent advances in composite materials for civil engineering have created interesting possibilities for replacing conventional structural forms with components made out of fiber reinforced composite materials. Composite materials offer several advantages over conventional materials such as a superior strength/weight ratio, a better stiffness/weight ratio, a high degree of chemical inertness, and flexible custom design characteristics. In a recent article in the Engineering News Record, James Roberts of the California Department of Transportation was quoted as follows: "Quick-setting concrete, nighttime work, composite materials for both decks and whole structures, and large incentives for contractors will be tools for faster construction…" (ENR, June 11, 2001).

Some of the potential down-stream benefits include lower life-cycle costs, lighter members, high corrosion and fatigue resistance, and higher live load capacity (Seible and Karbhari 1996). The mass production capabilities of composite members offer possibilities for schedule compression, productivity and quality improvement, savings in labor and material costs, enhanced durability, and performance reliability (Mirmiran 1995, Kelly 1989, Gall 1986). Weight reduction and modular properties of composite members also lend to improved transportability, ease of installation, and less need for heavy equipment. Although initial investment for the production of composite members may be higher than conventional materials, it is likely to fall as the demand for composites increases (Goldstein 1996, Partridge 1989).

Composite materials are clearly having a major impact on how facilities are designed, constructed, and maintained. In order to enhance the application of fiber-reinforced composites in infrastructure renewal, it will be important to understand the constructability, maintainability and operability issues related to the use of Fiber Reinforced Polymer (FRP) structural components. This research report evaluates the constructability, maintainability and operability issues related to FRP bridge decks as compared to conventional deck construction.

Comprehensive literature review was conducted to understand FRP composite materials for bridge application, composite manufacturing processes, composite manufacturers, installation procedure of FRP bridge deck panels, etc.

Questionnaire survey-I was used to identify data on (i) standard techniques and material for FRP deck construction, (ii) man-hour requirement, cost, duration, productivity required for individual projects as well as any barriers encountered in installing FRP decks and (iii) constructability, operability, and maintainability of FRP decks. Questionnaire-II assisted research team in collecting information from the manufacturers with respect to the constructability, maintainability, operability, and life cycle cost issues related to their products and the manufacturing process.

In addition to the questionnaires, five case studies were conducted for candidate projects in Ohio that have used FRP bridge deck panels. Also, construction simulation study was performed to determine the productivity, man-hour requirement and system bottlenecks that were important for understanding the construction process in both FRP bridge deck panels and Conventional bridge deck panels. The detailed data required for the simulation study were collected through questionnaire-III and interviews.

Findings

In terms of challenges and technical issues in the application of FRP bridge deck panels, more efficient manufacturing and effective production methods should be explored and developed to enhance their application in civil infrastructure.

Constructability issues of FRP bridge deck panels:

(a) Based on results of questionnaire survey-I sent to bridge engineers of each State DOT, concrete cast-in-place and wood or timber were ranked as the deck structure types that have been frequently replaced by FRP bridge deck panels. Most manufacturers have developed their own technology to provide the connection between decks and between deck and girder. Until now, the FRP bridge deck panels produced by Martin Marietta Composites, called *DuraSpan*^{TM}, have been ranked as the most popular product. The products of Hardcore Composites, Kansas Structural Composites, and Creative Pultrusion have been used by several State DOTs. Bridge engineers indicated that Bituminous and Polymer concrete are the most preferred materials. Latex Modified Concrete was the least preferred by the State DOTs. Pultrusion has been ranked as the most used manufacturing process. Hand Lay-up and Vacuum Assisted Resin Transfer Modeling (VARTM) processes are also used by many manufacturers. Five respondents indicated construction and design barriers encountered while installing FRP bridge deck panels whereas, three indicated vendor as the barrier and one of them mentioned labor barriers. Usually, flat bed trucks were used to delivery the FRP panels from factory to the job site and their maximum deliverable sizes were variable depending on project requirements. It took usually a few days to deliver the panels.

(b) Questionnaire survey-I was also sent to county engineers of candidate projects identified in this research. Based on their responses, mostly concrete cast-in-place decks have been replaced by FRP decks. Only one of the candidate projects' deck structure type was wood or timber. Three out of five candidate projects used Hardcore composites' product using VARTM manufacturing process whereas, the remaining two candidate projects utilized Martine Marietta Composites' product (*DuraSpan*^{TM}). Bituminous has been ranked as the most important wearing surface material. Only one candidate project employed polymer modified asphalt. In terms of the method for guardrail installation, most of the respondents preferred the 'Guardrail attached to the deck'. Design barriers encountered in installing FRP decks were the most important problem.

Operability and Maintainability of FRP bridge deck panels:

(a) The results of questionnaire survey-I that was sent to bridge engineers of each State DOT indicated that in terms of maintainability issues, deteriorated conventional bridge decks have been mostly replaced by FRP bridge deck panels when their condition rating reached 4 whereas condition rating 6 or 7 for bridge substructure. The durability of wearing surface particularly delamination has been indicated as the highest maintenance problem. Most respondents expected 75 years as service life of FRP bridge deck panels while they mentioned 25 – 50 years as average service life of a concrete bridge deck.

(b) The results of questionnaire survey-I sent to county engineers of candidate projects indicated that in terms of condition rating of existing bridge structures, deteriorated conventional bridge decks have been replaced by FRP bridge deck panels when the condition rating for decks reached 2 to 4 and that for a bridge substructure reached 7. Two counties have not established a specific analysis procedure or method to inspect, maintain and repair the FRP bridge deck panels. One county has performed visual inspection three to four times per year. The county engineer for this county indicated that any repairs to the panels would be undertaken based on discussion with the manufacture. Another county has performed visual inspection only once every year. Three counties did not have any plan to monitor the service of FRP bridge deck panels. One of the counties has performed tap test once every year. Clark county engineers indicated that there were no problems with regard to maintenance and operation after FRP bridge deck panels were installed. However, fire damage was found on the bottom of panels in

this county as a probable cause of vandalism. The maintenance problems commonly generated in other counties were delamination, debonding, and cracking of wearing surface and some minor gaps between the bottom of FRP deck and the concrete beams.

Future research direction:

(i) Innovative modular systems to reduce high initial cost. If the material cost of FRP bridges will not decrease, their application may be limited to bridges of low volume rural types

(ii) Research on failure of the wearing surface

(iii) Integration of FRP bridge design, i.e., efficient design and characterization of panel-to-panel joints and attachment of deck-to-girder is required

(iv) Development of design standards and guidelines

(v) Benefit-Cost analysis for economical engineering

(vi) Develop an analytical model to predict the FRP bridge deterioration over time.

(vii) Develop an analytical model to assess life cycle cost of FRP bridge deck panels.

Implementation

This research provides construction guidelines for FRP bridge deck panels that could be effectively used by INDOT. These guidelines identify (i) construction sequence, (ii) constructability issues, (iii) maintainability issues, (iv) operability issues, and (v) construction cost issues. Also this research provides information on the state of the art and manufacturing processes currently in use.

The productivity, man-hour requirement, and system bottlenecks for FRP bridge deck construction are determined by construction simulation study. The results obtained from this study could be used by INDOT to improve the productivity of FRP bridge deck construction in the future.

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