Available online at www.sciencedirect.com
SCIENCE DIRECT®
Construction and Building Materials 20 (2006) 515–526
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Construction and cost analysis of an FRP reinforced concrete bridge deck

Adam C. Berg, Lawrence C. Bank *, Michael G. Oliva, Jeffrey S. Russell

Department of Civil and Environmental Engineering, University of Wisconsin–Madison, 1415 Engineering Drive, Madison, WI 53706, USA

Received 10 December 2003; received in revised form 15 February 2005; accepted 19 February 2005
Available online 7 April 2005

Abstract

This paper describes the use of FRP materials as reinforcements and formwork for a concrete highway bridge deck. It describes the construction process and provides a cost analysis of the project. A continuing research program at the University of Wisconsin–Madison is developing concepts for bridge decks reinforced with fiber reinforced polymers (FRP). This project involved the implementation of one of these concepts in a major highway bridge. Three forms of FRP reinforcing were combined to reinforce the concrete deck: FRP stay-in-place (SIP) forms, deformed FRP reinforcing bars (rebars), and a special prefabricated pultruded FRP reinforcing grid. The research project, supported by the Innovative Bridge Research and Construction Program (IBRC) in the United States, resulted in the construction of a two-span highway overpass on US Highway 151 in Wisconsin. Based on the analysis of the short-term material and labor costs it appears that given the savings in construction time and their potential long-term durability and maintenance benefits, FRP reinforcements for bridge decks may be cost-effective, notwithstanding their currently high initial costs. Optimization of FRP stay-in-place formwork is recommended to decrease the cost of the FRP reinforcing system in the future.

Keywords: Concrete bridge deck; Cost analysis; Construction process; FRP reinforcing; Stay-in-place formwork

1. Introduction

Corrosion of reinforcing steel is a main cause of deterioration of reinforced concrete bridge decks. Freeze–thaw cycles cause concrete cracking followed by corrosion and deterioration, limiting the lifespan of the bridge deck. The University of Wisconsin–Madison has worked in cooperation with the Wisconsin Department of Transportation (WisDOT), the Federal Highway Administration (FHWA), and Alfred Benesch and Company on research projects to extend the lifespan of reinforced concrete bridge decks by using non-corroding materials. The research projects involve the use of Fiber Reinforced Polymers (FRP) in place of conventional steel in bridge decks. A review of recent applications of FRP reinforcements can be found in [1]. While FRP stay-in-place forms and deformed rebar have been used previously in a highway bridge deck [2], this is the first combination of those materials along with a bi-directional FRP reinforcing grid panel selected to reduce construction cost. In addition, this is the first application where prestressed bridge girders were used and where "composite action" was required between the deck and the girders. Details of the design of the two-span reinforced bridge deck using these FRP materials and the development of special provisions that included a material specification for all FRP materials used have been described elsewhere [3,4]. That research culminated in the work reported here on the construction process and cost analysis of the FRP reinforced bridge deck.

* Corresponding author. Tel.: +1 608 262 1604; fax: +1 608 262 5199.
E-mail address: bank@engr.wisc.edu (L.C. Bank).

0950-0618/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2005.02.007

2. Description of the bridge

The FRP reinforced bridge deck is part of a major new interchange on US Highway 151 (average daily traffic – 18,600) over State Route 26 north of the city of Waupun, Wisconsin. It is a two-span continuous bridge with equal spans of 32.7 m (107 ft.) and carries two lanes of traffic in the northbound direction. The bridge deck is 12.75 m (43 ft.) wide with a 32° horizontal skew and is supported by five 1.37 m (54 in.) prestressed concrete girders spaced at 2.65 m (8 ft. 8 in.) on center (Fig. 1). The deck was reinforced with non-metallic glass–fiber reinforced vinylester FRP parts, except for the cantilevered overhangs and the parapet walls which were reinforced with epoxy-coated steel as an FRP reinforced parapet (or guardrail) has not yet been crash tested and approved for use in the US. Constructed adjacent to the FRP reinforced deck was a twin structure that carries two lanes of southbound traffic. This second bridge deck was reinforced with conventional epoxy coated steel rebars. The only other difference between these two bridges was in the thickness of the concrete decks. The steel reinforced deck was 200 mm (8 in.) thick and the FRP reinforced deck was 215.9 mm (8.5 in.) thick. The extra 12.7 mm (0.5 in.) of concrete was needed in the FRP reinforced deck for non-structural reasons to develop the required top cover at the crown of the bridge as will be discussed in what follows.

3. FRP Reinforcing materials

FRP reinforcing materials have been used in numerous concrete structures over the last 20 years. Nevertheless, the combination of FRP materials used in this bridge was unique. The system was developed to reduce construction labor cost to offset the higher initial cost of the FRP materials relative to conventional steel reinforcing. Additional, long-term cost savings due to decreased maintenance or increased service life of the bridge deck in the future are also anticipated from the FRP reinforcing system, however, an attempt to account for these cost savings are not documented at this time. The possible long-term economic benefits of FRP reinforcements in terms of constructibility and service life extensions have been discussed elsewhere [5,6]. The FRP reinforcing system consisted of three different components (Fig. 2); stay-in-place (SIP) FRP pultruded deck panels, pultruded FRP rebars, and bi-directional FRP pultruded grids.

3.1. Stay-in-place (SIP) FRP pultruded deck panel

The SIP FRP deck panels were 457 mm (1 ft. 6 in.) by 2350 mm (7 ft. 10 in.). Each panel was stiffened by two 76 mm (3 in.) square hollow tubular "cells" spaced

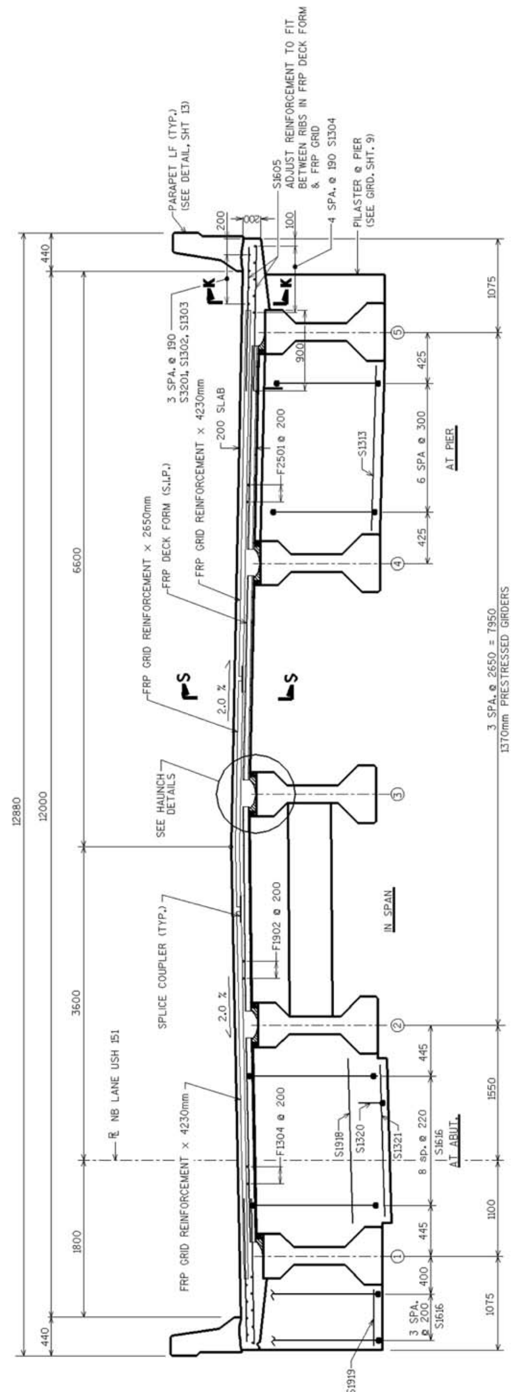

Fig. 1. Cross-Section through roadway.