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Hybrid FRP-Concrete Structural Member: Research and Development in North America

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ABSTRACT In recent years, fibre reinforced polymers (FRPs) have become the focus of numerous research projects in the field of civil engineering. FRPs are a structural material known to possess high strength, high resistance to corrosion and high strength-to-weight ratio. It is also easy to install in both new as well as existing structures. Hybrid FRP-concrete structural members, in particular, have shown significant promise in a wide range of applications. This paper will investigate and discuss in detail the research performed on hybrid FRP-concrete structural members in North America. Emphasis will be placed on the design philosophies and results from both experimental and analytical testing.

1 INTRODUCTION

Considerable research has been performed on Fibre Reinforced Polymers (FRPs) as a viable alternative to reinforced concrete, which is the primary material currently used in construction today. Over the years, it has been found that reinforced concrete structures require a great deal of maintenance, repairs, strengthening and other engineering works throughout its design span due to its susceptibility to corrosion. This leads to the increasing spending that is directly dedicated to maintaining existing structures.

FRP material exhibits high strength, high strength-to-weight ratio as well as exception corrosion resistance qualities. In addition, the nature of the material allows for easy installation in both new construction and existing structures. Many different types of hybrid FRP-concrete structural members have been investigated internationally with the objective of replacing reinforced concrete as the main structural material in a variety of applications. Current research performed on hybrid FRP-concrete structural members in Europe and Asia was presented in the companion paper (Chen and El-Hacha, 2010). This paper will focus on the research that has been completed in North America. For each research, design details and results from experimental tests and analytical modeling will be explained and summarized.

2 CURRENT RESEARCH AND DEVELOPMENT

2.1 Hybrid Concrete-Filled GFRP Tubes - University of Manitoba

Fam and Rizkalla (2000) tested the performance of concrete-filled GFRP tubes under axial loadings for applications as piles, poles, highway overhead signs and bridges. The GFRP tube serves three main functions: 1) stay-in-place concrete formwork, 2) non-corrosive reinforcement and 3) concrete confinement. The concrete mixes were prepared with CONEX, an expansive additive that prevents separation to occur between the concrete and the FRP tube as a result of shrinkage. For a period of seven weeks after casting of concrete, the hoop strains were monitored in the specimen. Regardless of the type of configuration, maximum hoop strains were recorded at approximately 20 days after curing, showing that the period of expansion is smaller than the period of shrinkage. A large variety of tubes were tested, incorporating different combinations of tubes sizes, fabrication types as well as concrete shapes, with a total of 11 different specimens.

In general, concrete filling significantly improved the strength of the specimen. Increases of 49.5%, 212% and 250% were obtained for the steel tube, the filament wound GFRP tube and the pultruded GFRP tube, respectively, when compared to their hollow strength capacities. The increases can be partially attributed to the elimination of large deformations, buckling and ovalization that occurs with the hollow tubes. Depending on the orientation of the fibres in the GFRP tube, different failure modes occurred. GFRP tubes, left hollow without concrete, failed due to local buckling. Concrete-filled GFRP tubes with fibres oriented close to the hoop and axial direction failed in tension by fibre rupture in its axial direction. Concrete-filled GFRP tubes with fibres oriented in larger angles failed in compression due to cracking of the matrix and buckling of the fibres. Pultruded GFRP tubes, where all the fibres were aligned in its axial direction, failed in horizontal shear.

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The effect of cross-sectional configuration was analyzed. Test results confirmed that under pure flexural loading, the presence of a solid core does not significantly increase the strength of the specimen. There is a slight increase in strength if the concrete is confined between two GFRP tubes, given all other parameters are maintained the same. Strength could further be increased if the inner tube is positioned off center towards the tension side. However, due to the fact that most loadings are expected to occur in a variety of directions, this type of design was not considered feasible for applications. The fabrication process of the GFRP tube also has an effect on the strength, stiffness and failure mode experienced by the hybrid member. Fibres in the pultruded tubes were all aligned in the axial direction and therefore allowed for greater stiffness along its length; however, due to this property, shear failure in the horizontal direction is more likely to occur. The concrete strength obtained in the filament wound specimen was 32% greater than specimens with pultruded FRP tubes.

2.2 Three-Dimensionally Woven Hybrid GFRP/Concrete Bridge Deck - North Carolina State University

Johnson et al., (2008) researched the structural performance of Glass FRP-only bridge decks as well hybrid GFRP-concrete bridge decks fabricated using the 3-D weaving process. The weaving process uses E-glass FRP to produce fabric skins, where each skins is made up of two layers of fabric. During fabrication, one layer of skin was cut, detached and folded until it was parallel to the z-axis. By assembling two of these sections together, one inverted over the other, the folds became the webs of the deck system. To complete the FRP section, balsa wood cores were inserted in the openings along with other final preparation details such as vacuum infusion with epoxy resin and post curing. By applying the 3-D weaving technique, it was expected that delamination, particularly at section joints, would be greatly reduced, compared with the use of unidirectional and bidirectional FRP material. Figure 1 is a series of diagrams graphically depicting the fabrication steps.

The hybrid GFRP-concrete bridge deck system was composed of the 3-D woven GFRP section with a 46mm thick layer of concrete cast on top, and anchored together by a series of shear connector placed throughout the width of the deck. The concrete topping included internal steel reinforcement; however, it was explicitly stated that for real applications where exposure to the elements may occur, it would not be recommended to include any steel reinforcement. The total depth of the deck slab section was 163mm. A diagram of the hybrid section is shown in Figure 2.

Two hybrid deck specimens were tested, one to examine the shear effects under flexural loading and the other to study the behaviour of the deck under a predominately flexural load. The first specimen failed by shear failure in the concrete, with visible signs of cracking and delamination of concrete from the top skin of FRP over more than 50% of the span. For the second specimen, through the loading scheme up to failure, partial delamination of the concrete topping progressed from midspan outwards towards the ends, until complete detachment at the ends occurred at failure. Both specimens behaved linearly without exhibiting large deformations under service conditions.

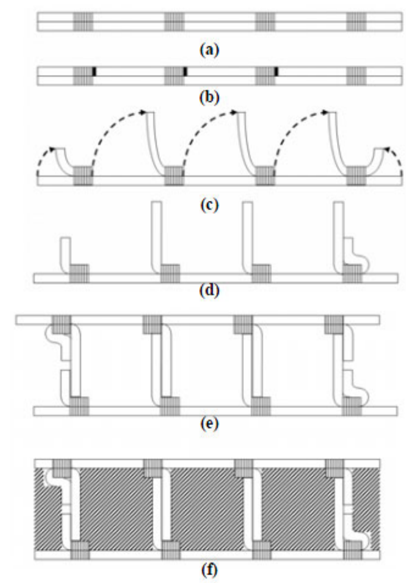

Figure 1 Assembly steps for FRP-only panels (Johnson et al., 2008)

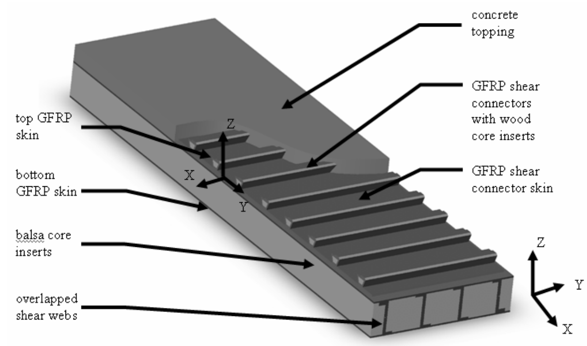

Figure 2 Schematic of GFRP/concrete hybrid deck panel (Johnson et al., 2008)

From the experimental results, delamination of the concrete from the top of the GFRP showed that the bond at the interface was inadequate. It was recommended that, for future studies, roughening the surface of the GFRP or the additional application of a bonding agent be used to reach the full flexural potential of the hybrid deck system. It was estimated based on the concrete strain prior to delamination that enhancing the bond strength would increase the section strength by approximately 50%.