

Structural behavior of hybrid FRP composite I-beam

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ARTICLE INFO

Article history:

Received 16 June 2009

Received in revised form 27 September 2009

Accepted 19 November 2009

Available online 21 December 2009

Keywords:

Hybrid FRP
Carbon fibers
Glass fibers
Volume content
Best composition

ABSTRACT

This paper presents the structural behavior of an innovative hybrid Fiber Reinforced Polymers (FRP) beam consisting of carbon/glass fibers and vinyl-ester resin. The advanced feature of this hybridization is the optimum use of carbon and glass fibers in the flanges to maximize structural performance while reducing the overall cost by using only glass fibers in the web section. A series of beam tests were conducted under four-point bending varying ratio of flange to web width (b_f/b_w) and volume content of carbon and glass fiber in the flanges. Experimental investigations revealed that the ratio of flange to web width of hybrid FRP I-shaped beams plays an important role in their structural behavior. Small flange beams ($b_f/b_w = 0.43$) showed stable and linear behavior under bending moment and failed in a brittle manner by delamination of the compressive flange at the interfacial layers while wide flange beams ($b_f/b_w = 1.13$) exhibited unstable and nonlinear behavior in the buckling and post-buckling region leading to delamination failure of the compressive flange. The experimental and analytical results discussed in this paper emphasize on the best composition of carbon and glass fibers for the optimum design of such hybrid beams. It is found that the maximum strength of hybrid FRP beams can be obtained with the volume content of carbon fiber to be 25–33%. Furthermore, the results of this study show the potential of applying hybrid FRP beams for bridge components.

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1. Introduction

FRP composites have been increasingly used in civil infrastructure applications due to their advantageous properties such as high specific strength/stiffness, lightweight, and corrosion resistance. The apparent initial high cost of FRP materials has been a major obstacle for the widespread use in bridge applications. However, they are very competitive in term of durability.

The application of FRP in civil engineering was first introduced in Japan about two decades ago with the development of FRP reinforcement and tendons. The first JSCE standard specification for the design of FRP reinforcements was published in 1997, which has been adopted in various other countries [1]. Since then, a wide range of applications of FRP materials have been implemented including strengthening of structures using FRP sheets and using FRP rods as reinforcement instead of steel bars.

In the last decade, the research and development of all FRP structures in civil engineering has progressed substantially in several countries [2,3]. The first all FRP bridge in Japan was constructed in Okinawa prefecture in 2001 [4]. This bridge is a two

span continuous girder pedestrian bridge as shown in Fig. 1. All the structural members have been made with Glass Fiber Reinforcement Polymers (GFRP). The all GFRP solution was chosen for this bridge because it is surrounded by heavily corrosive environment. Though GFRP is cheaper than Carbon Fiber Reinforced Polymers (CFRP), it has smaller stiffness and strength than CFRP. There may be some difficulties in using all GFRP for bridges because the ratio of deflection to span is a critical issue for designing bridges. One possibility to overcome the above problem is to utilize GFRP combined with high strength and stiffness of CFRP.

In this study, a hybrid FRP beam that combines GFRP and CFRP was developed. The advantage of using this hybridization is to utilize the superior strength of CFRP in the flanges while keeping the material costs low by using GFRP in the flanges and web. By incorporating appropriate amount of CFRP/GFRP in hybrid composite, a better performance in fatigue can be achieved [5,6]. However, the most important advancements of the hybrid beam are the ability of tailor-made/rapid construction, corrosion resistance, and reduction of carbon dioxide (CO₂). These are of considerable significance in Japan because of the large number of bridges corroded by the severe environment that will need to be replaced in the near future.

Over the last decade, there has been significant growth in the research and development of hybrid FRP composites. Numerous theoretical and experimental investigations have been conducted worldwide regarding the combined use of carbon/glass/matrices

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Fig. 1. Okinawa road park bridge (all GFRP bridge).

[7–16]. Summerscales and Short [7] have reviewed a number of studies of hybrid carbon–glass composites in which a phenomenon termed “hybrid effect” has been found. The essential observation of the hybrid effect is that the failure strain of carbon fiber becomes greater in a hybrid composite than that in an all-carbon fiber composite. Observation of the hybrid effect was first credited to Hayashi [8] and has subsequently been reported by several researchers [9–15]. Although a great deal of information is available on the coupon test results of hybrid composites, little work has been done on the structural behavior of hybrid beam. In addition, studies in literature cover a wide range of fiber and matrix types, fiber lay-up and stacking sequences, etc., which result in different structural behavior. Thus, additional investigations are required to enable the civil engineers to have confidence in designing of hybrid beams for real bridge application. This study focuses on the structural behavior of hybrid FRP beams consisting of multi-layer carbon/E-glass (woven fabric and continuous strand mat)/vinyl-ester. An I-shaped section of FRP beam was developed as the first step of the ongoing research project since it is easily manufactured and

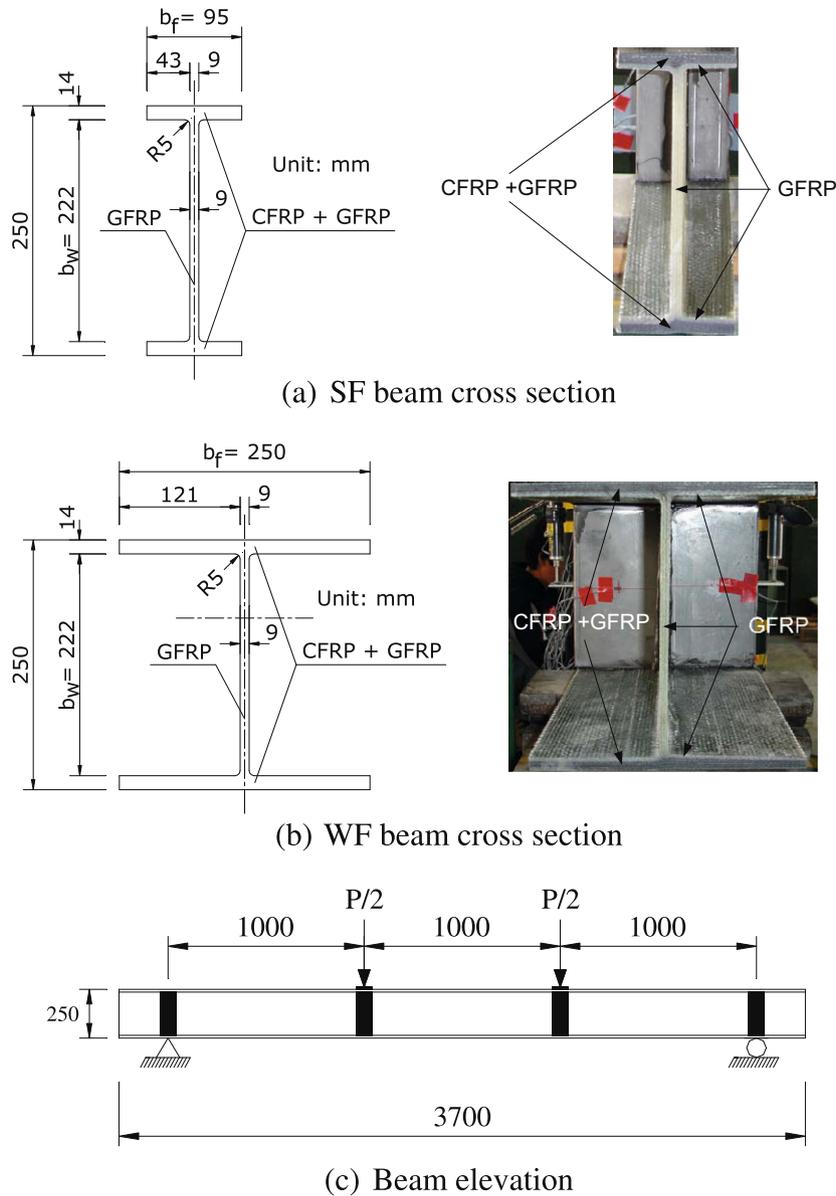


Fig. 2. Dimensions of hybrid FRP beams.

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