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Experimental study of hybrid composite beams

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Abstract

In this study, a new type of hybrid confining device, a perforated steel tube that is externally protected by a thin fiber reinforced polymer skin is proposed and experimentally investigated. Hybrid composite beams were fabricated by filling fresh concrete into the hybrid composite tube. Fifteen scaled-down square beams, which had varying numbers of perforated steel faces or 'steel grids' and a dimension of length 55.9 cm, height 10.1 cm, and width 10.1 cm, were prepared. Four-point bending tests were conducted on all the specimens. In addition to the load–displacement curves obtained from the tests, strain gages were installed to monitor the local strain distributions. Test results show that the grid tube encased specimens lead to higher specific strength and ductility than the solid steel tube encased counterparts. Compared to other configurations, the specific strength and ductility are the highest when all the four faces are made of steel grids.

Keywords: FRP; Steel; Concrete; Grid; Tube; Encasement; Beam-column; Hybrid structure

1. Introduction

Over the years, steel tube and fiber reinforced polymer (FRP) tube-encased concrete beam-columns have emerged as a novel alternative for rebuilding and new construction of piles/piers/columns, including manufacturing plants, bridges, high-rise buildings, harbors, water-front fenders, etc. due to their higher strength, higher ductility, and formwork-free construction [1–20].

In engineering structures, most columns are subjected to an eccentric axial load, which can be resolved into a coaxial load and a bending moment. In another word, most real-world columns should be treated as beam-columns. It is well known that interfacial bonding strength plays a critical role for a composite beam-column to carry an applied transverse load or bending moment. With sufficient interfacial shear strength, the transverse load can be effectively transferred from the confining shell to the concrete core, and vice versa; without sufficient interfacial shear strength, the transverse load cannot be effectively transferred between the shell and the core. As a result, the composite beam-column will have a lower stiffness and strength.

In order to provide higher interfacial shear strength, a new confining tube has been proposed [21]. This is a hybrid composite tube, which consists of a lattice of thick steel ribs and rings that is protected by a thin FRP skin. The steel grid tube is fabricated by drilling circular holes through the wall of a circular steel pipe. The hybrid confining device is formed by wrapping a thin layer of FRP onto the surface of the steel grid tube. By filling fresh concrete into the hybrid composite confining device, the concrete flows into the holes or bays formed between and among the surrounding steel ribs. Once the concrete is cured, the concrete within the bays and the surrounding steel grids are mated, forming a mechanical interlocking. This type of physical interfacial connection is durable and permanent in nature. Unlike chemical adhesives, the interfacial shear strength does not degrade or age with time. Test results show that,

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subjected to a coaxial compressive load, the specific strength (MPa/kg) of the grid tube confined concrete cylinders has been increased considerably. This is due to the 3-D compressive stress condition achieved in the concrete core by the more effective confinement of the grid tube. It is found that grid configuration (axial grid versus helical grid) has a significant effect on the structural behavior of the confined concrete cylinders.

The purpose of this study is to experimentally investigate the structural behavior when the encased concrete beam-columns are subjected to a bending moment. A total of 15 square beams have been prepared and four-point bending tests have been conducted. The effectiveness of the grid confinement on the structural behavior has been evaluated based on the test results.

2. Experiments

2.1. Raw materials and specimens preparation

Type I Portland cement, gravel, natural sand, water, and a superplasticizer DAVA 170 were used to prepare the concrete. The mix design followed ACI Standard 211.1 ("Standard" 1991). The mix ratio by weight was cement:water: coarse aggregate:fine aggregate:admixture = 1:0.56:3.80: 2.19:0.001. The maximum coarse aggregate diameter was 25.4 mm. The slump was 140.2 mm; the air content was 6.8%; and the 28-day cylinder compressive strength was 30.1 MPa.

To fabricate steel grid tubes, a low carbon steel plate, which had a thickness of 6.35 mm, an yield strength of 308 MPa, and a modulus of elasticity of 200 GPa, was obtained. The plate was cut into sixty 55.9 cm long by 10.1 cm wide steel sheets. Circular holes with a diameter of 25.4 mm were drilled through the steel sheets. The smallest spacing between the neighboring holes was 6.35 mm. Fig. 1 shows a schematic of grid pattern in one piece of steel sheet. From Fig. 1, 17 rows and three columns of holes were drilled and uniformly distributed, resulting in 51 holes in one piece of steel sheet. A total of 30 pieces of steel sheets were drilled with the same pattern. Once the steel sheets were drilled, they were welded using stitch welding to form 55.9 cm long, 10.1 cm wide, and 10.1 cm high square tubes. Each stitch weld was about 2.5 cm long and five or six stitch welds were used for each connection. Tests results show that the stitch welds had sufficient strength. No failure was observed at the welds.

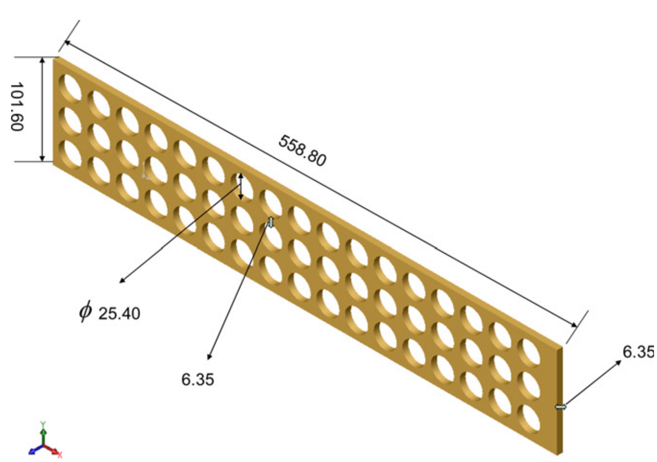

Fig. 1. A schematic of steel grid sheet.

In order to better understand how the steel grids affect the structural behavior of the confined concrete beams, the steel tubes were divided into five groups. In Group 1, only the bottom face used a steel grid sheet; in Group 2, both the bottom and the top faces used grids; in Group 3, both the bottom and the two side faces used grids; in Group 4, all the four faces used grids; in Group 5, which was also the control group, all the four faces used solid steel sheets. Each group contained three identical specimens. A total of 15 tubes were prepared. The side view of each group of tubes is shown in Fig. 2. The corresponding top view is shown in Fig. 3.

Once the steel tubes were prepared, all of them were wrapped using an ultraviolet (UV) curing E-glass 7715 fabric reinforced vinyl ester composite to form the FRP skin. The hand lay-up technology was used. The 7715 style fiber reinforcement was a unidirectional fabric. In this study, the fiber was aligned along the transverse (hoop) direction to provide the maximum confinement. Each tube was wrapped using two layers of FRP with a 25.4 mm overlap. The cured thickness is 0.738 mm. In a previous study [21], the mechanical properties of the FRP skin were obtained using coupon tests. These are given in Table 1. Because the steel sheets were stitch welded, the corners were sharp, which may cause stress concentration on the FRP skin. To provide a smooth corner, the space between every two stitch welds were filled with FRP. The FRP was prepared using glass fiber bundles wetted by the same UV curing resin. After wrapping, the specimens were moved to a UV-A light source for curing. The curing was completed within 1 h. The details of the UV-A light source can be found elsewhere [21,22].

Before casting concrete, one end of the tube was capped using a plastic tape. Fig. 4 shows the prepared tubes were standing on a vibration table before casting concrete. The concrete was then mixed, cast, compacted, finished, and cured for 28 days in a standard wet curing room.

2.2. Instrumentation and testing

In order to gain an in-depth understanding of the composite structural behavior, strain gages were used to obtain local strain distributions. Three pairs of strain gages were used for each group of specimens, mounted at the bottom face, side face, and top face, respectively. Each pair contained two strain gages mounted at the mid-span of the beam aligned along the transverse and longitudinal (axial) directions, respectively. For the grid tubes, all the strain gages were mounted on the surface