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Cyclic and monotonic behavior of FRP confined concrete rectangular prisms with different aspect ratios

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HIGHLIGHTS

- Experimental study of 18 FRP confined concrete prisms under compressive loadings.
- Examination of the effect of aspect ratio on cyclic stress–strain behavior.
- Investigation of the failure area of FRP in prisms with different aspect ratios.
- Evaluation of cyclic and monotonic ultimate condition of rectangular prisms.

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ABSTRACT

FRP confinement of concrete columns is one of the most common methods for enhancing both the strength and ductility. The optimal design of the FRP confined concrete rectangular columns requires a good comprehension of their cyclic and monotonic stress–strain behavior. In this study the results of the tests on 18 rectangular prisms with different aspect ratios are presented and the effects of this parameter on cyclic and monotonic behavior of prisms are investigated. Test results indicate that for prisms with different aspect ratios, the monotonic stress–strain curve is approximately tangent to the upper boundary of the cyclic stress–strain curve. Other important results of this study are linearity of relationship between the plastic strain and the envelope unloading strain, the independence of the plastic strain and stress deterioration ratio from the aspect ratio, increase of the axial strain in the early stage of unloading paths, fixation of the plastic strain after repetition of 8 cycles and expansion of the failure area as a result of a decrease in aspect ratio. Examination of the ultimate condition of rectangular prisms (specimen's failure) shows that the FRP hoop rupture strains of the prisms are smaller than the one obtained from tensile coupon test and also when a prism is under monotonic loading, the ultimate axial strain and confined concrete strength are smaller than when it is under cyclic loading.

1. Introduction

Despite low probability of occurrence, the risk related to the natural disasters is not acceptable. Since there are many structures which are vulnerable in these disasters, different methods have been applied for retrofitting of the structural members. One of the most frequently used methods for retrofitting of the concrete members against the incoming loads is FRP confinement. In addition to the low weight, FRP composites have a high strength and also are corrosion resistant. FRP jacket can totally change the stress–strain behavior of a concrete column. In the past decade extensive studies have been performed on the monotonic behavior of FRP confined concrete specimens (circular, square and rectangular) [1–22]. Unlike monotonic behavior, there are not enough studies investigating cyclic behavior of FRP-confined concrete. In recent years, a few researchers studied the cyclic behavior of FRP confined concrete circular prisms [23–25] and presented models to predict loading and unloading paths. Except in limited cases [26–29], square and rectangular prisms also haven't been considered sufficiently. In this paper the results of a recent experimental study on 18 FRP confined concrete rectangular prisms are presented and the effects of aspect ratio on cyclic and monotonic behavior of prisms are investigated.

2. An overview of conducted studies

In recent years, some researchers have studied the stress–strain behavior of FRP confined concrete circular specimens under the action of cyclic loading. Shao et al. [24] presented a model based on

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regression analysis including loading and unloading cyclic rules, plastic strains and strength deterioration. Lam and Teng [23] also investigated the cyclic behavior of FRP confined concrete by testing circular specimens confined with one and two layers of FRP under cyclic loading. They evaluated the model presented by Shao et al. [24] and concluded that it could not properly predict some of the cyclic aspects like plastic strains, stress deterioration and unloading path. Therefore they provided a more complete model for circular prisms under cyclic loading based on their tests in 2006 [25] and a test database from the published literatures. Abbasnia and Ziaadiny [26] conducted an experimental study and examined different aspects of cyclic stress–strain behavior of FRP confined concrete square prisms like envelope curve, plastic strain and stress deterioration ratio. Abbasnia et al. [27] investigated the stress–strain behavior of rectangular prisms experimentally and studied the effects of confinement level, aspect ratio and concrete strength on different aspects of cyclic stress–strain behavior.

3. Experimental work

3.1. Specimen preparation

In the present study, 18 prisms with aspect ratios of 1, 1.5 and 2 were prepared. For each aspect ratio, six prisms and three different loading types were considered (see Fig. 1). To enhance the accuracy of the results, duplicate specimens were used. The ratio of r/b (corner radius to smaller side of the cross section) was considered constant. To cast concrete specimens, cubic molds were used. All the cubic molds were made from medium density fiberboard (MDF) wood. To obtain the desired corner radius, polyvinyl chloride (PVC) pipes with appropriate radius and height were used. The pipes were divided into four quadrants in cross section by a milling machine and then each quadrant was mounted in one corner of the forms to provide round corners (see Fig. 2).The properties of the prisms and key test results are shown in Table 1.

3.2. Material

The prisms were prepared in six batches and for each batch of concrete, two unconfined concrete cylinders were prepared and used as control specimens. The nominal 28-day design strength of the concrete was 25 MPa. A summary of concrete mix design proportions, obtained based on Iranian Concrete Code (ABA) [32], is presented in Table 2. In this study unidirectional carbon fiber sheets and epoxy-based primer and resin were used. Flat coupon tests were conducted in accordance with ASTM D3039 standard [33] to get the mechanical properties of CFRP. These properties are summarized in Table 3.

3.3. FRP jacketing

Before jacketing, the surface of the specimens was smoothed and then cleaned with water and left to dry. Then CFRP was wrapped around the specimen in two layers and a single lap of 150 mm by the wet lay-up procedure. To ensure that enough time had passed for the epoxy to cure, the prisms were exposed to the laboratory environment at a temperature of 25 °C for 10 days before testing.

3.4. Testing procedure

In this study, two linear variable displacement transducers (LVDTs) and two strain gauges, mounted at 180° apart, were used to measure the axial and lateral displacements respectively. The strain gauges were mounted on the prisms and to mount the LVDTs, a frame similar to that designed by Wang and Wu [2], was used (see Fig. 3). The loading and unloading in the compression tests was achieved with load control and had a rate approximately equal to 4 kN/s. To measure the axial load, a load cell was used and the readings of the strain gauges, LVDTs and load cell were recorded by a data logger (Fig. 4).

4. Test results and discussion

The compressive strengths of control specimens, measured along with the tests of confined prisms at test day, were 30 and 33 MPa. The failure of the prisms was characterized by tensile rup-

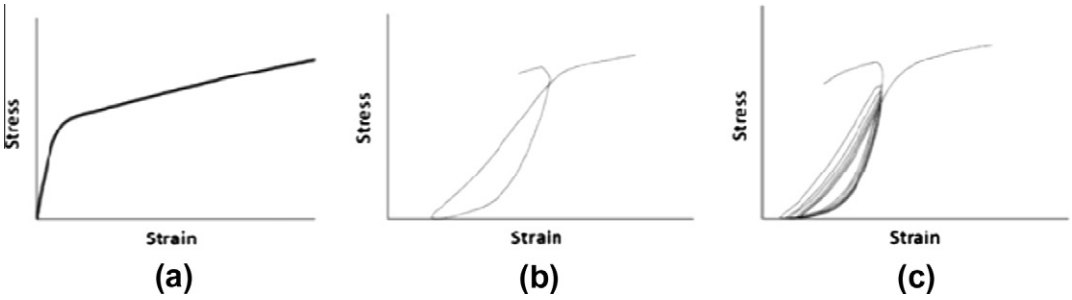

Fig. 1. Loading types. (a) Monotonic loading, (b) cyclic loading involving a single complete unloading/reloading cycle at each prescribed displacement level, (c) cyclic loading involving several complete unloading/reloading cycles at each prescribed displacement level.

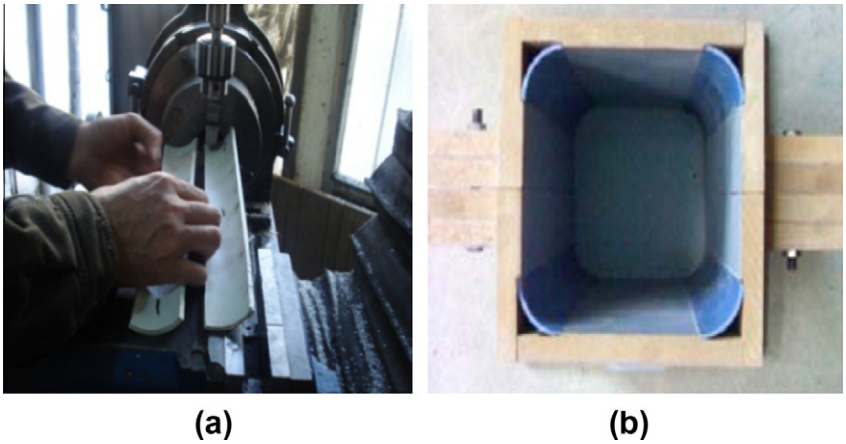

Fig. 2. Forms preparation. (a) Dividing the pipes into four quadrants by milling machine and (b) rounded corners of the forms.