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Confinement effect of fiber reinforced polymer wraps in circular and square concrete columns

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ABSTRACT: Brick aggregate concrete, stone aggregate concrete and recycled aggregate concrete columns confined with fiber reinforced polymer wraps were tested under compression to study the axial capacity enhancement due to confinement. Columns made of brick aggregate concrete and recycled aggregate concrete were measured to dilate larger than those from stone aggregate concrete. This resulted in higher capacity enhancement in those concrete columns than stone aggregate concrete columns. Increase in confining radius of curvature was found to be further beneficial in capacity enhancement for all concretes. The P-M interaction diagrams plotted from the test results show the necessity of adopting higher safety factors than those presented in Bank (2006) for square columns of all concrete types.

1 INTRODUCTION

Use of fiber reinforced polymer (FRP) wraps to confine concrete is getting wider acceptance in Bangladesh for enhancing axial capacities of concrete columns. In this technique, FRP wrap installed on the exterior surface of a column with the FRP fibers aligned along the hoop direction confines the concrete and in turn increases the apparent compressive strength. This increased concrete strength, known as the confined compressive strength occurs only after the concrete in the column has begun to dilate and hence cracked (ACI 440 2008). By preventing the cracked concrete from splitting out laterally, the FRP acts to confine the concrete and allows it to carry additional compressive stress. In a confinement mechanism, two conditions need to be satisfied; (1) geometric (strain) compatibility between the core and the confining member, (2) equilibrium of forces in the free-body diagram for any sector of confined section (Mirmiran & Shahawy 1998). The two conditions are interdependent since the confining pressure is a function of lateral strains which in turn depends on the variation of Poisson’s effects for concrete. However, the effect is likely to be governed by the modulus of elasticity of concrete that depends strongly on the aggregate properties (Akhtaruzzaman & Hasnat 1983 & Mansur et al. 1999). Lam & Teng (2003a,b) improved the procedure to predict the confined compressive strengths of stone aggregate concrete circular columns based on wide experimental database for stone aggregate . However, the effectiveness achievable in noncircular columns confined with FRP is not much known. Whereas the dilation property (Poisson’s effect) of FRP confined stone aggregate concrete has not also yet been compared either with brick aggregate concrete or with recycled aggregate concretes, Akhtaruzzaman & Hasnat (1983) and (Mansur et. al. 1999).

In concrete columns with circular cross-section, the effectiveness of confinement is optimal since the geometrical configuration allows fibers to be effective on the entire concrete cross section. Prismatic cross sections behave differently, as it is well recognized that the confining pressure is high at the corners and low along the flat sides. Therefore the cross section is only partially confined (see also Luca et al. 2011). Confining of a noncircular cross section still enhances concrete strength and ultimate strain, but the effectiveness is not as significant as that on a circular cross section. A number of studies have been conducted for predicting confined compressive strength of prismatic sections. Due to uncertainty in the behavioral prediction, the load carrying capacities predicted by existing guidelines differ widely from one another (ACI 440 2008, CSA-S806-02 & ISIS M04-2001). The safety margin of these guidelines may be of interest to the practicing engineers. Furthermore, it is necessary to validate the models for concretes of lower strengths as of the case encountered in rehabilitation of weak structures. Therefore, it is of fundamental interest to generate test results and build a test database to assess and to compare different compressive strength models for FRP confined concrete with local aggregates of Bangladesh origin. The work leads towards constructing P-M interaction diagrams of confined concrete for use in the design desk.

2 EXPERIMENT AND DATA ACQUISITION

Concrete columns were cast with low strength (14 MPa-17 MPa) plain concrete. The approach is relevant in the context of retrofitting existing structural elements that are deficient in strength for the design loads. Four types of coarse aggregates; e.g. crushed stone, crushed brick, recycled stone and recycled brick aggregates having same gradation were used. To study the confinement effect due to FRP wraps, one third of the specimens were confined with carbon-FRP (CFRP) wraps, next one third with glass-FRP (GFRP) wraps while the rest were taken as unconfined (control) specimens. Two basic geometric shapes with three different specimen sizes were considered. The circular concrete columns were 100, 150 and 200 mm in diameter and 200, 300 and 400 mm in height, respectively. The square concrete columns were 100 x 100 x 200 mm, 150 x 150 x 300mm and 200 x 200 x 400 mm in dimensions. The aspect ratios were same for all the cases.

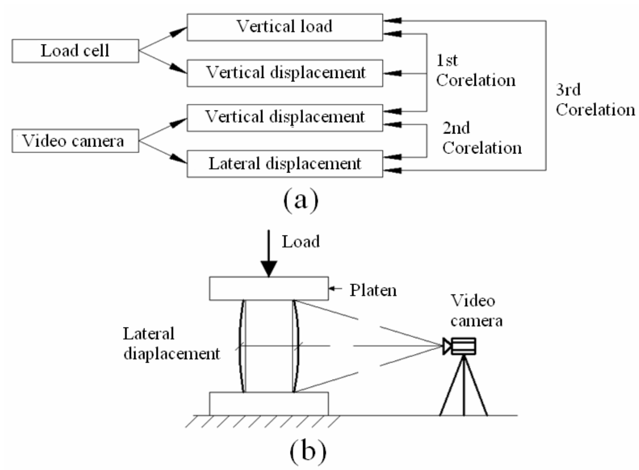


Figure 1. (a) Data acquisition scheme (b) Experimental setup

Square columns were cast in the specially prepared steel moulds rounded at the corners with 25mm corner radius. This was done to reduce the stress concentration at the corners and to avoid the damage to the FRP jacket. All of the specimens were cast according to standard laboratory procedures and cured for at least 28 days. 6 specimens were made for a particular size and type of aggregate. Among them 2 were tested as control specimen, 2 were wrapped with CFRP (LaMaCo Chemie Sdn Bhd, Build Seal CFFS Extra 200) and the rest 2 were wrapped with GFRP (LaMaCo Chemie Sdn Bhd, Build Wrap G 920) by single wrap wet lay up technique. A total of 144 short concrete columns specimens were tested under axial compression a constant rate of 0.21 MPa/s, until their failure in a 2000kN computer controlled universal testing machine. Vertical displacement and axial load were recorded from load cell. The failure location of the columns under compression is unpredictable. To measure the dilation of column at the failure location, lateral displacements were measured by analyzing the image histories obtained from high definition video camera (Fig 1) and employing an image analysis technique.

3 DILATION EFFECT

The lateral dilation of columns under uniaxial compression was measured for both confined and unconfined concretes. Figure 2 presents the stress-axial strain and stress-lateral strain responses for square and circular concrete columns cast with stone aggregates and brick aggregates. The figures show that brick aggregate concrete tested in this paper are generally weaker than stone aggregate concrete. The axial capacities obtained from square columns are also found to be distinctly lower than those of circular columns. However, in all cases, the axial capacity enhancement due to confinement is clearly visible. A detail comparison further shows that ultimate lateral strain in brick aggregate concrete confined with GFRP (Fig 2c) is significantly larger than that in CFRP confinement (Fig 2b). The ultimate lateral strains in unconfined concretes are negligible (Fig 2a). In circular columns, the average increases in axial strength in stone aggregate concrete were in the order of 52% and 93% for columns with CFRP and GFRP, respectively, while the respective values for square columns were 27% and 55%. In brick aggregate concretes, the respective values are 82%, 95%, 33%, 46%. The enhanced dilation effect observed in brick aggregate concrete offers a distinct role to mobilize confinement in FRP wraps, enhances confinement performance and hence increases axial capacities significantly.

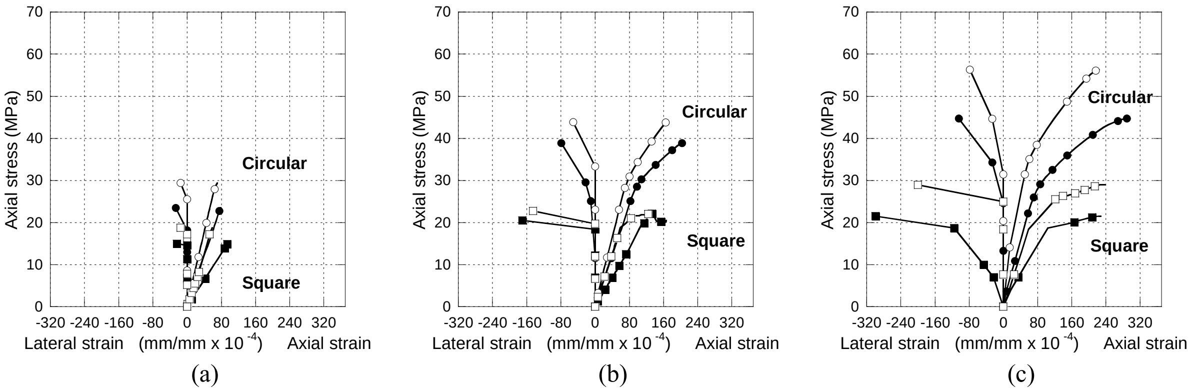


Figure 2. Effect of confinement in columns with different aggregates (a) Unconfined, (b) Confined with CFRP and (c) Confined with GFRP. Circular columns were 150 mm in radius and the square columns were 150 mm on each side. ○: Circular column with stone aggregate concrete; ●: Circular column with brick aggregate concrete ■: Square column with brick aggregate concrete; □: Square column with stone aggregate concrete.

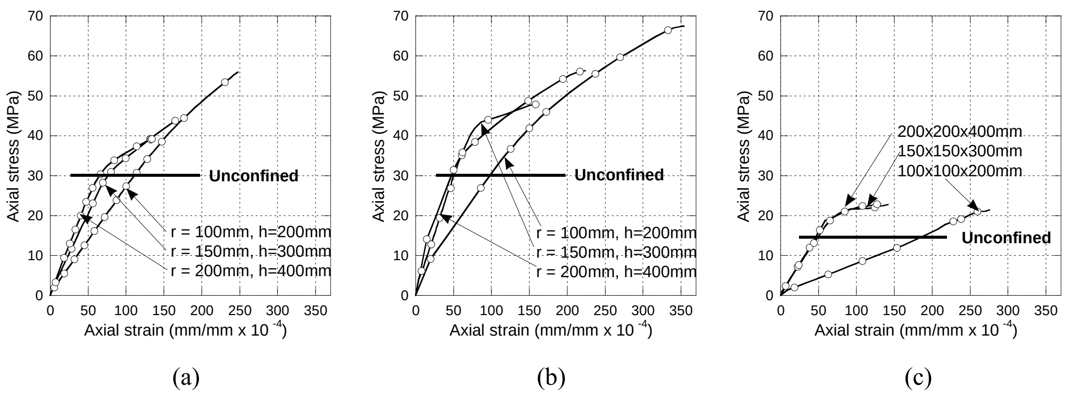


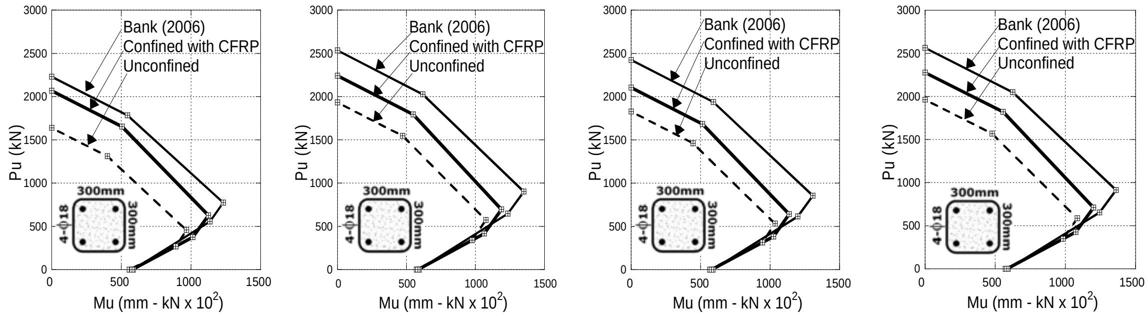
Figure 3. Size effect of stone aggregate concrete (a) Circular column confined with CFRP, (b) Circular column confined with GFRP (c) Square column confined with CFRP.

4 EFFECT OF CURVATURE AND SIZE OF COLUMN CROSS SECTION

The Figure 3 presents the increase in axial capacity in circular and square columns of different sizes due to confinement. It is clear that the increase in strength provided by confinement is sensitive to the cross section geometry and the amount of this increase drops sharply as the geometry deviates from the circular one (Fig 3a,b,c). Furthermore, decrease in curvature reduces the axial capacity enhancement in circular columns (Fig 3a, b). However, axial capacity enhancement in square columns was found to be very much comparable for all specimen sizes (Fig 3c). The uniform corner radius maintained in the square columns may have played a vital role for this observed effect.

5 P-M INTERACTION DIAGRAMS

P-M interaction diagrams are presented in Figure 4 for different concrete types and compared with those suggested in Bank (2006). Comparison with the unconfined cases indicates the achievable capacity enhancement in the compression side of the diagram. The capacity enhancement in the tension side is not noticeable, as expected. The P-M Interaction diagrams plotted from the test results indicate the necessity of adopting higher safety factors than those suggested in Bank (2006).



(a) (b) (c) (d)

Figure 4. P-M Interaction diagrams for CFRP confined concretes (a) Brick aggregate concrete confined (b) Stone aggregate concrete (c) Recycled brick aggregate concrete (d) Recycled stone aggregate concrete.

6 CONCLUSIONS

144 short concrete columns confined with FRP wraps were tested under axial compression to assess the enhancement of axial capacities achievable due to confinement. The concretes having higher dilation property were found to offer better capacity enhancement. A reduced confining radius of curvature was found to have further beneficial effect. In contrast, the *P-M* diagrams constructed from the measurements suggest for adopting higher safety factors in the Bank (2006) proposals.

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