ACTIVE CONFINEMENT OF CONCRETE COLUMNS USING EXTERNALLY FIBER REINFORCED POLYMER SHELLS

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INTRODUCTION

It is well known that externally-bonded Fiber Reinforced Polymer (FRP) confinement is much less effective in increasing the axial compressive strength of square and rectangular columns compared to circular columns [1] due to stress concentrations at the corners and ineffective confinement at the flat sides. Lower FRP confinement effectiveness for square/rectangular columns results in softening behavior and premature FRP composite rupture; therefore, the high tensile strength of FRP composite materials cannot be fully utilized. One approach for improving the effectiveness of FRP jackets for rectangular columns is to use prefabricated (non-bonded) FRP composite shells with expansive cement concrete. A prefabricated elliptical/oval/circular FRP shell may be used as stay-in-place formwork for casting additional expansive cement concrete around the square or rectangular cross-section to achieve shape modification. Expansive cement normally consists of a Portland cement and expansion cement additive. The mechanism of expansive cement concrete can be used with FRP composite shells for improving the confinement effectiveness: when expansive cement concrete is applied to prefabricated FRP shells, expansion of the grout is restrained by the FRP shell, thus creating a post-tensioning effect which confines the original concrete core as well as the expansive grout. It is apparent that this post-tensioning effect would increase the confinement behavior of FRP shells and change the confinement action from “passive” to “active”. Experiments were conducted to investigate the shape modification effect on large concrete specimens and the test results show the effectiveness of the active confinement.

EXPERIMENTAL PROGRAMS

The experimental program included three groups of specimens according to the original cross-sectional shape: (1) square specimens (<u>S</u>), (2) rectangular specimens with sectional aspect ratio of 2:1 (<u>R2</u>), and (3) aspect ratio 3:1 (<u>R3</u>). Each group included a unconfined (baseline) specimen, and two specimens with the original cross-section confined by bonded carbon FRP (CFRP) or glass FRP (GFRP) jackets of equivalent stiffness. For the square and rectangular groups, there were two additional shape-modified specimens using prefabricated CFRP or GFRP shells of equivalent stiffness, post-tensioned with expansive cement grout. The modified cross-section of the original square specimen was circular and that of the original rectangular specimen was elliptical. Figure 1(a) shows a shape-modified section with a post-tensioned FRP shell. All specimens were 914 mm high and no longitudinal or transverse steel reinforcement was provided. Table 1 lists the details of all specimens. The specimens are identified using a three-code scheme. The first part is the shape of the column (Square or Rectangular), and the aspect ratio of the rectangular cross-section (2:1 or 3:1). The second part indicates the type of FRP composite (CFRP or GFRP) and the number of FRP layers (2 or 6, respectively). The third part denotes the type of material used to achieve shape modification; expansive cement concrete is denoted as (E) and (0) denotes no shape modification.

The properties of the two FRP composite systems were: (1) for the CFRP composite, which was cured with epoxy resin, the tensile strength of the FRP composite was 1220 MPa, the tensile modulus was 87 GPa, and the ply thickness was 1.0 mm; and (2) for the GFRP composite, which was cured with urethane resin, the tensile strength was 228 MPa, the tensile modulus was 17 GPa, and the ply thickness was 1.6 mm; for both FRP composite systems, the ultimate tensile strain was 14 mm/m. All concrete specimens were subjected to uniaxial compression until failure. The load was applied using displacement control at a constant rate of 1.3 mm/min.

RESULTS AND DISCUSSIONS

The failure modes differ between specimens confined by bonded FRP jackets and post-tensioned FRP shells. Specimens with bonded FRP jackets experience concrete

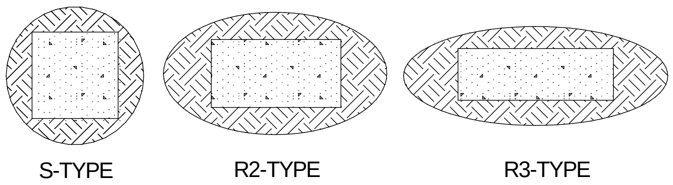

Figure 1. Cross-sections of shape-modified specimens: S-Type (square to circle); R2-Type (2:1 rectangle to ellipse); R3-Type (3:1 rectangle to ellipse).

Table 1. Dimensions of column specimens.

Specimen	Original cross-section (mm)	Modified cross-section (B_jxD_j)* (mm)
S-C2-0	279×279	-
S-G6-0	279×279	-
R2-C2-0	203×381	-
R2-G6-0	203×381	-
R3-C2-0	152×457	-
R3-G6-0	152×457	-
S-C2-E	279×279	406×406
S-G6-E	279×279	406×406
R2-C2-E	203×381	635×387
R2-G6-E	203×381	660×362
R3-C2-E	152×457	775×279
R3-G6-E	152×457	762×298

* Denote major axis length (B_j) and minor axis length (D_j)

crack propagation and growth, crushing and fracture of the FRP composite jacket at one of the corners; failure is brittle and the concrete damage was observed. By contrast, the post-tensioned FRP shell participates immediately after loading and protects the core concrete by exerting an inward pressure, which postpones crack formation and growth; failure is initiated by fracture of the FRP shell with simultaneous vertical cracks in the expansive cement grout and concrete core; FRP fracture extends over the entire height of the specimen, showing participation of the post-tensioned FRP shell in active confinement. At the end of the test, vertical and diagonal cracks were observed in the expansive cement concrete, but the original concrete column cross-section was protected. This is very important for the engineering practice because it demonstrates the potential application of expansive cement concrete that could be used to protect original concrete columns from the damage under the severe applied load. The dilatancy behavior of FRP-confined concrete is represented by the volumetric strain versus axial strain relationship. Volumetric strain is defined as the FRP area strain minus the axial strain in the concrete column. The FRP area strain is defined as the additions of strains measured in the two transverse orthogonal directions. Figure 2 shows the typical volumetric strain versus axial strain relation for shape-modified specimens which obtained from the experiments. Since the FRP shell was already post-tensioned prior to axial loading through chemical post-tensioning, the amount of radial expansion was smaller compared to bonded FRP jackets. Therefore, the axial strain was larger than the hoop area strain instead of otherwise shown in Fig. 2 for bonded FRP-jacketed specimens; this reveals that the axial strain was dominant in the volumetric strain versus axial strain curve. This dilatancy behavior is extremely important for shape-modified FRP specimens with expansive cement concrete because in this case the FRP confinement becomes "active" instead of "passive". It is also noted that by transforming the confinement mechanism, columns confined by post-tensioned FRP shells can reach a significant axial strain deformation compared to bonded FRP-jacketed columns. More details of the experimental program and the results were described elsewhere [2].

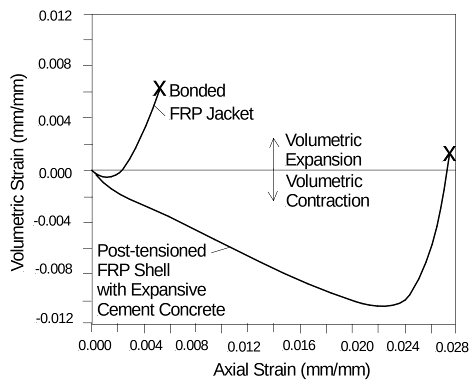

Figure 2. Volumetric strain versus axial strain relations for FRP-confined columns

CONCLUSIONS

Shape modification using expansive cement concrete and prefabricated FRP composite shells can effectively restore the membrane effect; in addition, it can change FRP confinement from passive to active which is induced by the unrestrained expansion of the grout before the column is loaded, thus an ideal deformation or ductility can be achieved.

REFERENCES

[1] Karbhari, V.M. & Gao, Y. 1997. Composite jacketed concrete under uniaxial compression-verification of simple design equations. *Journal of Materials in Civil Engineering ASCE 1997;* 9(4): 185-193.

[2] Yan, Z., Pantelides, C.P., Reaveley, L.D. 2006. Fiber-reinforced polymer jacketed and shape-modified compression members: I-experimental behavior. *ACI Structural Journal 2006*; 103(6): 885-893.