Analysis of FRP wrapped concrete columns under uniaxial compression

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Fiber wrapping or encasement of columns with fiber-reinforced plastic (FRP) sheets significantly enhances strength and ductility of concrete columns. To investigate the behavior of concrete columns confined by fiber reinforced polymer (FRP) sheets under uniaxial compression, analytical models were solved using Finite Element Method (FEM) against published experimental data. Cross sections of concrete columns in the analysis are categorized into circular, square and rectangular sections. Finite Element Analysis (FEA) can effectively simulate the behavior of concrete columns confined by FRP sheets when the proper numerical model is adopted. Results from a series of the analysis on small-scale specimens showed that confinement increased strength (20-25%) and ductility of concrete columns loaded axially. ANSYS (version 6.0) offers a series of very robust nonlinear capabilities for designs and analyses.

Keywords: Composite columns, FEM, Fiber wrapping, FRP

Introduction

Retrofitting of concrete columns (CCs) by wrapping and bonding of fiber-reinforced plastic (FRP) sheets, straps, belts, or precured shells around the columns has become increasingly popular. Studies of CCs, confined with glass, aramid, or carbon fibers, have been used successfully to retrofit building columns, bridge or expressway piers, and chimneys in Japan. Many researchers have proposed models for concrete cylinders and square columns strengthened with FRP sheets. Rochette & Labossiere used an incremental finite element approach to evaluate response and behavior of square columns confined with carbon and aramid fiber sheets. Huang et al. investigated the axial load behavior of concrete-filled tubular (CFT) columns with the width-to-thickness ratios. Hu et al. proposed proper material constitutive models for CFT columns and verified by the nonlinear finite element program ABAQUS against experimental data. In this paper, finite element method is used to analyze the mechanism and the behavior with more rational model and failure criterion.

Materials and Methods

Column models were made of a normal strength concrete with uniaxial compression strength (fc, 40 Mpa). Two prepreg composite materials, used to confine the column models fully, were unidirectional carbon fibers and bi-directional aramid-woven fabric, which were characterized by ASTM standard D 3039-M89 (Table 1). Stress-strain curve of the carbon lamina (Fig. 1a) and behavior of the aramid-woven fabric (Fig. 1b) illustrate clearly the difference in behavior between the two materials. Carbon fiber lamina is linearly elastic up to failure, whereas nonlinear relationship between stresses and strains in aramid-reinforced product is seen. The progressive tightening of fibers, as the tensile load is increased, leads to a progressive increase of stiffness explaining nonlinear behavior. Initial elastic modulus (Eo) defined as the slope of curve tangent at the origin, is less (50%) than the secant modulus (E), which is measured on a straight line between the origin of the system of axis and the failure point. Strength of carbon sheet is higher than that of aramid fabric.

Specimens

Identification of the specimens (Tables 2&3) is based on a two-part code, which provides condensed configuration details for each of them. The first portion of the code indicates shape of the section (cylinder, square or rectangular), its diam (100 or 150 mm) in the case of circular section, and the radius of the corners (5, 25, or 38 mm) for square and rectangular section (Fig. 2). The second part identifies the confining material (carbon or aramid) and the number plies.
 Finite Element Analysis (FEA)

A series of models of various shapes (circular, square and rectangular) were wrapped with 2-5 plies of carbon fiber. Circular and square models were confined with 3, 6, 9, or 12 plies of aramid fiber-woven around the columns axis, in the 0° orientation. All specimens were simulated in ANSYS (version 6.0), which offers a series of very robust nonlinear capabilities for designs and analyses. SOLID 186 is used for the three-dimensional modeling of solids,
which are capable of cracking in tension, crushing in compression, creep nonlinearity and large deflection geometrical nonlinearity. The fiber sheets as anisotropic material, which adopted SHELL 93 element, is a 3-D element having membrane (in plane) stiffness.

Mesh and Boundary Conditions

Fig. 3 shows meshed columns and boundary conditions. All joints of elements satisfy displacement coordination, including intersections of fiber and concrete. Exploiting symmetry of columns, only a quarter models were used in calculations. One end of columns was fixed where there was no degree of freedom. Uniform compressive loading was adopted in the calculation.

Results and Discussion

FRP wrapped CCs under uniaxial compression were analyzed using ANSYS (6.0) from a series of 32 columns (carbon 18, aramid 14) of square, rectangular and circular cross-section. Parameters that are varied include cross sectional shape, corner radius, and number and types of plies.

Effect of Confinement

Influence of confinement on the behavior of column models are studied by plotting stress-strain curve for various sections with corner radius of 5, 25 and 38 mm. Square column (corner radius, 25 and 38 mm) with varying carbon plies (0, 3, 4 and 5) shows increase in the maximum stress for change in plies from 0 to 3, 0 to 4 and 0 to 5 as 12%, 17% and 5% respectively (Fig. 4a). The decrease in strain for a change in plies from 3 to 4 is 12.5 % and from 4 to 5 is 10%. Square column (corner radius, 5, 25 and 38 mm) with 3, 6, 9, and 12 numbers of aramid fibers shows increase in the maximum stress for change in plies from 3 to 6, 3 to 9 and 3 to 12 as 7%, 8% and
15% respectively (Fig. 4b). The decrease in strain for change in plies from 3 to 6 is 6%, 3 to 9 is 11.2% and from 3 to 12 is 17%. Deformation (Fig. 5), stress (Fig. 6) and strain (Fig. 7) contour along Y-direction for square section with 4 plies of carbon fiber (S25-C4) are shown.

Effect of Corner Radius
Increase in maximum stress (3%) and decrease in strain (5%) are observed for a change in corner radius from 25 to 38 (Fig. 8a). With varying corner radiiuses (5, 25 and 38 mm), increase in maximum stress is as follows: 25 for 5, 13; and 38 for 5, 15% (Fig. 8b). With a change in corner radius, decrease in strain is as follows: 38 for 5, 15; and 25 for 5, 37%. Corner smoothening do not increase elastic limit load (Fig. 9); may be cause of the effect of loss of area due to the corner radius.
Fig. 6—Stress along Y-direction of square column (S25-C4)

Fig. 7—Strain along Y-direction of square column (S25-C4)
Fig. 8—Stress-strain curve for rectangular and square column

Fig. 9—Corner radius - % difference in load for square and rectangular column

Fig. 10—Stress-strain curve for square column with varying ply material (carbon & aramid)
Effect of FRP Materials

Stress vs strain plot (Fig. 10a) for square column having corner radius of 5 mm with 3 plies of carbon and aramid fibers shows an increase in maximum stress (2 %) and in strain (36%) for a change in fiber from carbon to aramid. Stress vs strain plot (Fig. 10b) for square column having corner radius of 25 mm with 3 plies of carbon and aramid fibers shows an increase in maximum stress (4%) and decrease in strain (45%) for a change in fiber from carbon to aramid. The experimental and analytical stresses for carbon and aramid fibers were compared (Tables 4&5).

Conclusions

Multiple placements of FRP plies improve the overall performance for square, rectangular and circular sections. The most effective confinements are obtained for circular section. Carbon fibers are more effective than aramid fibers at increasing the ultimate axial strength and ultimate axial strain of various reinforced concrete columns. Corner radius plays an
important role on the mechanical properties of carbon and aramid fiber. As corner radius increases, the efficiency of the FRP wrapping increases. The experimental and analytical stresses for carbon and aramid fibers were compared and the percentage between them is within 10%.

References