Load Test Evaluation of FRP Composite Columns

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ABSTRACT

This paper presents an experimental investigation on the behavior of FRP composite columns fabricated from a pultrusion process. The study includes five column cross-section configurations with various lengths. The objectives of the research are to determine the ultimate load capacity for each group, and to evaluate the effect of column slenderness on the mode of failure. A full scale column testing is performed under an axial compressive load condition in a vertical position. The test results and analysis from a large number of specimens have provided a comprehensive evaluation of the FRP composite columns for the application in civil engineering structures

INTRODUCTION

In recent years, the fiber-reinforced polymer (FRP) composites have been used effectively in load-bearing structures such as cooling tower systems, industrial buildings, and pedestrian bridges due to the material characteristics of light weight, high strength-to-weight ratio, corrosion resistance, and low cost of maintenance operation. In addition, the composite materials have a potential application in transportation structures such as highway bridges, guardrails, and longitudinal barriers for the impact energy absorption capability. In these types of structural applications, column member is the most important element; its ultimate load capacity and the structural behavior need to be informed before any design and construction are able to be implemented. For FRP composite columns, physical load tests are necessary for a given section configuration because of the anisotropic nature of the material. An earlier experimental work was done on the behavior of composite column with an universal cross section [1]. The study evaluated the effects of initial curvature, slenderness ratio, and flange crippling on the column ultimate strength. An analytical

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work was also carried out on the thin-walled open sections of composite columns to study the global and local buckling loads [2]

The objectives of this research are:

(1) physical load test evaluation for five different section configurations of FRP composites with various column lengths;

(2) investigation of the slenderness ratio effect for distinguishing short and long columns behavior of FRP composites.

EXPERIMENTAL PROGRAM

The pultruded FRP composite columns studied in this research have five section configurations as shown in Figure 1. Two sections have closed configurations; square tube and round tube, the other three are thin-walled open sections; they are wide-flange, I, and angle sections More than 300 column members were tested with three specimens for each group

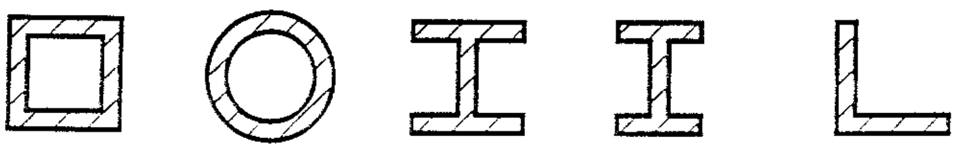

FIGURE 1 - COLUMN SECTION CONFIGURATIONS

For box sections, the thicknesses are 1/8 in (3 mm) and 1/4 in. (6 mm). The dimensions of square tube varies from 1.5 in. (38 mm) to 4 in. (100 mm). For round sections, the thicknesses are 1/8 in. (3 mm) and 1/4 in. (6 mm). The diameters of the round tube are 1.5 in. (38 mm) and 2 in. (50 mm). For wide-flange sections, the thicknesses of flange and web are 1/4 in. (6 mm) and 3/8 in. (9.5 mm). The dimension of the W-section varies from 4 in. (100 mm) to 10 in. (254 mm). For I-sections, the thicknesses of flange and web are 1/4 in (6 mm) and 3/8 in. (9.5 mm). The dimensions of I-section are 4 x 2 in. (100 x 50 mm) and 8 x 4 in (200 x 100 mm). For angle sections, the thicknesses of the flange are 1/4 in. (6 mm), 3/8 in. (9.5 mm), and 1/2 in. (13 mm) The dimensions of the angle section are 3 x 3 in. (76 x 76 mm), 4 x 4 in. (100 x 100 mm), and 6 x 6 in (152 x 152 mm)

The length of the composite column varies from 1 ft. (0.3 m) to 20 ft. (6 m) to include short, intermediate, and long column members. Full scale column tests are performed by an axial compressive load in a vertical position as shown in Figure 2

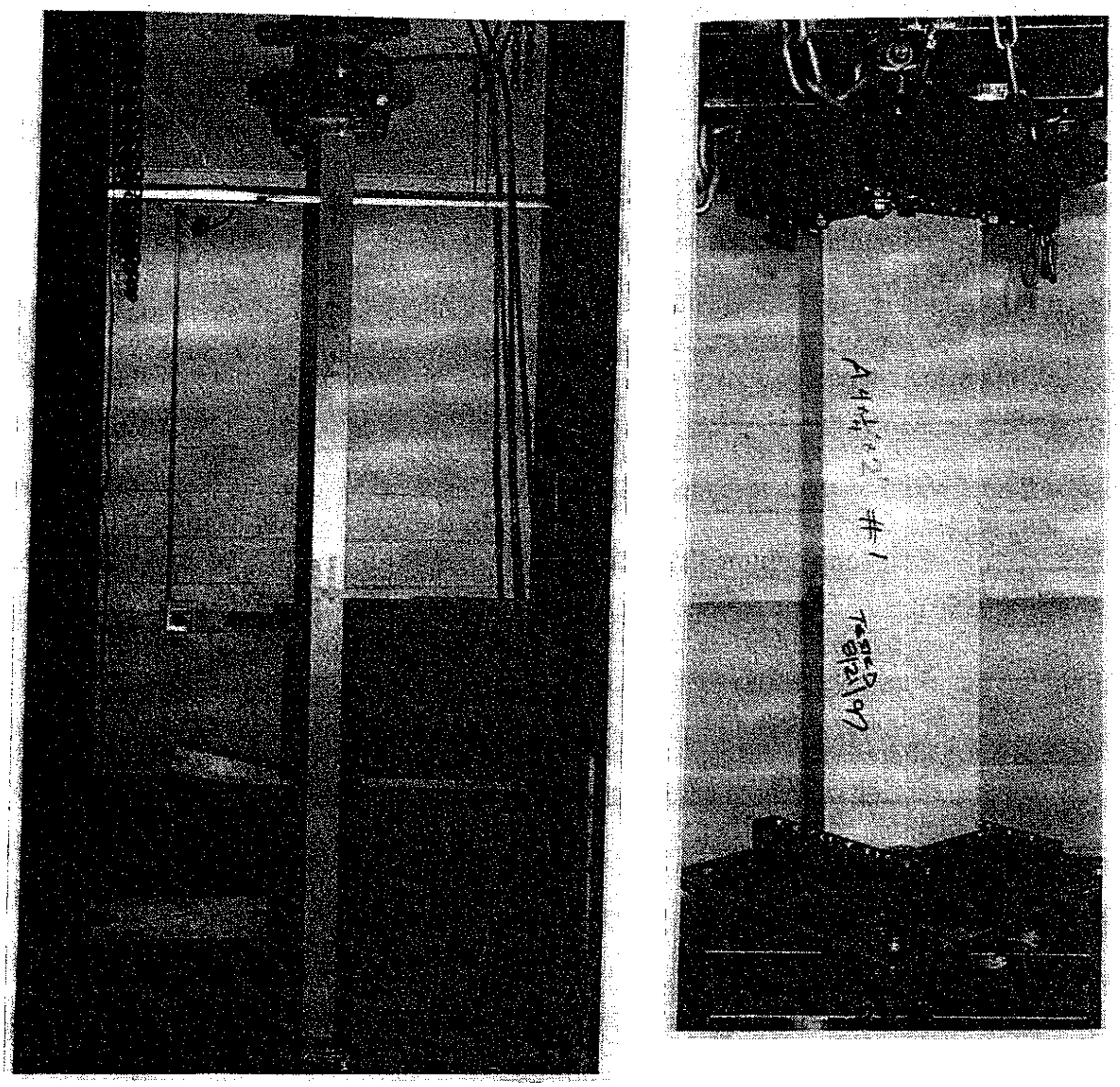

FIGURE 2 - COLUMN LOAD TEST SETUP

Short column members were tested on a MTS machine, long column members were tested in a 30-ft. reaction frame. During the test, a microprofiler was used to generate the displacement rate of loading at a 0.1 in./min. (2.5 mm/min.). The measurements included strains, ultimate loads, axial displacements, and lateral deflections.

The composite materials for the column members are made of polyester-based and vinylester-based resin matrix, with and without fire retardant, reinforced with continuous strand mats and continuous roving E-glass fibers.

RESULTS AND DISCUSSION

Ultimate Load Capacity

For the short column members, the ultimate load capacity is a function of the bearing strength of the composite material and the column cross sectional area. In general, the bearing strength of structural composite is about 30 ksi (200 Mpa), therefore, the ultimate strength of short column members depends upon the cross sectional area, for a given area, the column with box section appears to have a highest ultimate load strength.

For the intermediate length columns with thin-walled open sections, the ultimate load capacity depends on the width-to-thickness ratio (b_f/t_f) of the flange element. In general, the ultimate column strength decreases with an increase of b_f/t_f ratio. According to the test results, for a given cross section shape, the columns with a flange width-to-thickness ratio b_f/t_f less than 8 appear to have the highest ultimate load capacity.

For the long columns, the ultimate strength is a function of slenderness ratio kl/r. The column strength decreases with an increase in the slenderness ratio as shown in Figure 3

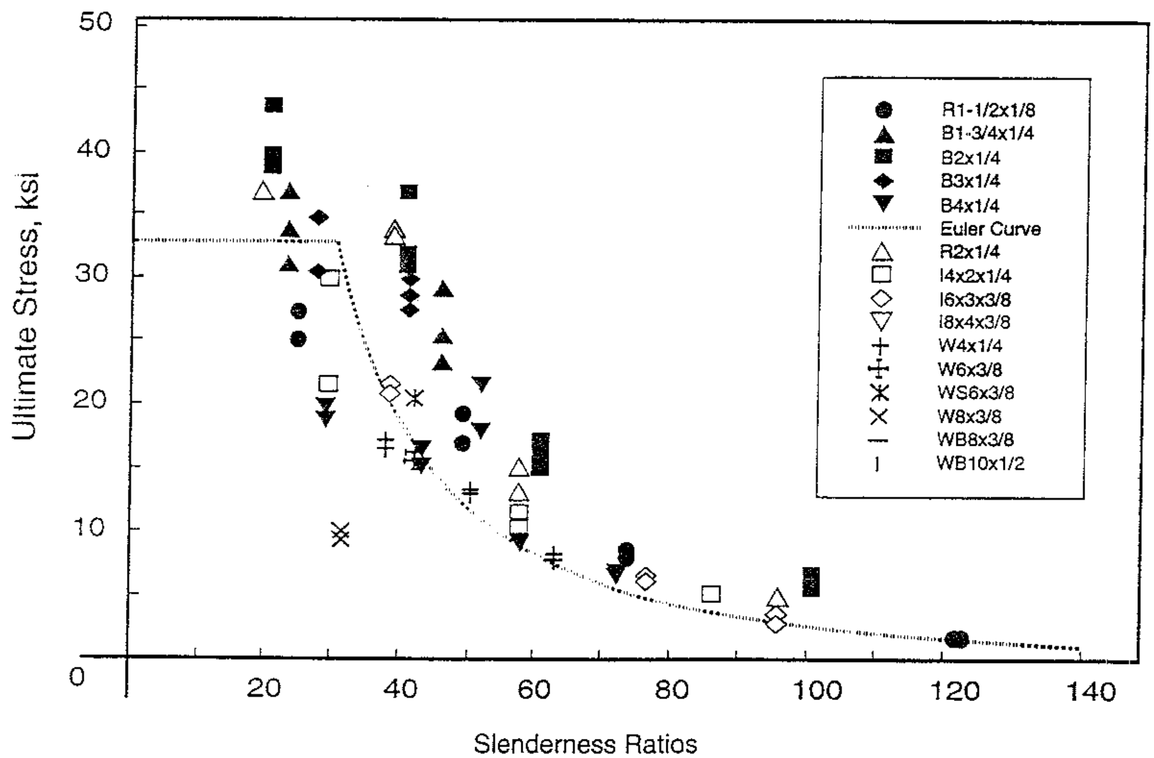

FIGURE 3 - COLUMN ULTIMATE STRENGTH
AND SLENDERNESS RATIO RELATION

Mode of Failure

Based on the experimental results, the failure of column members can be categorized into three modes; bearing failure at the end supports, local buckling or crippling of the column flanges, and global buckling along the column's weak axis

For the short column members with closed section such as square tube or round tube, or the short column with thin-walled open sections, the mode of failure is bearing deformation at the end supports. For the intermediate length columns with thin-walled flanges such as W, I, and angle sections, local buckling or crippling of the flanges dominate the mode of failure. For the long column members with thin-walled open sections, local buckling of the flanges appears first followed by the global buckling along the column's weak axis at a slightly higher load. For the long columns with closed section or long columns with I-section, global buckling occurred at the critical load.

Slenderness Ratio Effect

The results indicate that the effect of cross sectional shape becomes insignificant as the slenderness ratio increases. However, the dividing line at the slenderness ratio for short and long columns appear to be influenced by the cross sectional shape of the column. The dividing slenderness ratios, kl/r, are in the range of 30 to 40 for box, round, and I-sections, 40 to 60 for W-section, and 45 to 60 for angle section. For a column slenderness ratio larger than the corresponding value, it fails mostly in a buckling mode, for a column slenderness ratio less than the corresponding value, it tends to fail by the flange crippling or by the end bearing deformation

SUMMARY AND CONCLUSION

More than 300 column members were tested by an axial compressive load in a vertical position. The column had five sectional configurations with various lengths from 1 ft. (0.3 m) to 20 ft. (6 m) to include short, intermediate, and long members Based on the test results, the following conclusions can be made:

1. The ultimate load capacity and the mode of failure for FRP composite columns depend on the length and cross sectional shape of the member. For a given column length and section shape, the influential parameters are the flange width-to-thickness ratio and the column slenderness ratio.
2. The Euler's curve for FRP composite columns can be divided into short and long columns by the slenderness ratio; the dividing slenderness ratios are in the range of 30 to 40 for box, round, and I-sections, 40 to 60 for W-section, and 45 to 60 for angle section

REFERENCES

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BIOGRAPHY

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