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Retrofit of Circular Reinforced Concrete Columns using FRP, Steel and Concrete Jackets

Halil Sezen and Eric Miller

Halil Sezen, Ohio State University, 470 Hitchcock Hall, Columbus, OH sezen.1@osu.edu
Eric Miller, Michael Baker Jr. Columbus, Ohio

INTRODUCTION

A large number of reinforced concrete (RC) buildings and bridges is deemed structurally deficient. This is either because the infrastructure continues to age and deteriorate or the strength or deformation capacity of the existing older infratructure does not meet the current code requiremetns, e.g., in high seismic regions. Thus, the need for more efficient retrofit methods has increased in recent years. Currently, there are only a few methods used for strengthening or retrofitting columns. Steel jackets and Fiber Reinforced Polymer (FRP) composites are the two most commonly used methods. In this study, along with these two retrofit methods, concrete jackets reinforced with spiral rebar, Welded Wire Fabric (WWF), and a new steel reinforcement termed PCS are investigated under different axial load conditions.

EXPERIMENTAL PROGRAM

Seventeen identical circular column specimens were constructed, retrofitted, and tested: one column without retrofit; three columns retrofitted with FRP; two with steel jackets; nine with concrete jackets (two reinforced with WWF, three with spiral rebar, and six with the new reinforcement). The 254 mm diameter retrofitted specimens were 762 mm tall. This paper summarizes the results from this experimental program The specimen without any retrofit application was named BASE and had non-seismic reinforcement details. Six 9.5 mm diameter (No.3) deformed steel bars were used as longitudinal reinforcement. Smooth 6.4 mm diameter wire was used as transverse spiral reinforcement with a spacing of 76 mm and a clear concrete cover of 12.7 mm. Concrete strength for the base column was 28.6 MPa on the day of testing. The yield strengths of steel bars were 399 and 481 MPa, and the ultimate strengths were 545 and 775 MPa, for the 6.35 mm diameter smooth wire and No.3 deformed rebar, respectively. To prevent premature end failure, two 76 mm wide 610 mm long GFRP strips were applied at the top and bottom of all concrete jacketed specimens (Figure 1e and 1f). Detailed description of material properties, specimen design and construction, test setup, and test results can be found in Miller (2006).

Glass and carbon fiber reinforced polymer (GFRP and CFRP) composites were used to retrofit three specimens. Steel tubes with an outside diameter of 219 mm and a thickness of 4.95 mm were used for jacketing two base columns (C-CFT). The 31 mm thick gap between the existing

column and steel tube was filled with concrete, which had a compressive strength of 22.5 MPa on the day of testing. The same concrete was also used in concrete jackets. All concrete jacketed

specimens had an outside diameter of 254 mm including a 51 mm thick jacket. The reinforcement was placed in the center of the jacket with approximately 20 mm thick concrete inside and outside of the reinforcement cage. The WWF reinforcement included two overlapping 152 x 152 mm grids of W1.4 gauge welded wire mesh. Concrete jackets were also reinforced with No.3 or No. 4 spiral rebar (C-REB#3 and C-REB#4). Eight 102 mm diameter (No.4) longitudinal bars were used to reinforce concrete jackets. Six columns were strengthened with concrete jackets reinforced with a new steel reinforcement, PCS. The reinforcement cage is produced by cutting a grid of small rectangular pieces out of a solid steel tube. Detailed information on the production, structural performance, and economic evaluation of PCS can be found elsewhere [1].



(A) (B) (C) (D) (E) (F)

FIGURE 1 - DAMAGED SPECIMENS AT THE END OF TESTS: A) BASE, B) GFRP, C) CFRP, D) C-CFT, E) C-REB#4, F) C-PCS-1/4

TEST RESULTS

Figure 1 shows the damaged bare RC specimen and five other retrofitted specimens at the end of the tests. The base column first experienced vertical cracks in the concrete cover followed by cover spalling, longitudinal bars buckling and transverse steel fracture (Figure 1a). FRP retrofitted specimens showed no sign of damage until a brittle failure occurred when the FRP wraps fractured suddenly. Both the deformation and strength capacity increase in the steel jacketed specimens were the largest. Steel jacketed columns experienced local buckling around mid-height of the specimens, which eventually led to global buckling at very large axial displacements. Concrete cracking and spalling occurred in C-WWF simultaneously at a load slightly smaller than the maximum axial capacity, which was immediately followed by concrete crushing and brittle failure. Initial damage to all concrete jacketed specimens was similar and included typical longitudinal cracks with ensuing cover concrete spalling. The longitudinal steel buckling and the subsequent fracture of transverse reinforcement typically resulted in a significant strength drop and failure.

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CONCLUSIONS

Figure 2 compares the measure axial load-displacement relations for the base specimen and seven other representative retrofitted specimens. The experimental data indicates that the in the strength and deformation capacity was the lowest for the WWF reinforced concrete jacketing and FRP composite retrofit methods. Both methods resulted in brittle failure immediately after the maximum strength was achieved. Evidently, the steel tube jacketing was the most effective retrofit method to enhance the strength and deformation capacity. PCS reinforced concrete jacketing was as effective as the steel jacketing prior to cover concrete cracking and spalling. In other words, the increase in the initial stiffness was similar whether the solid steel tube or PCS reinforcement was used for confinement. The initial stiffness of the specimens with concrete jackets reinforced with rebar and WWF were very similar prior to cover concrete concrete cracking. The overall behavior of specimens with rebar and PCS reinforced concrete jackets were somewhat similar, however a large variation in the post-cracking behavior of concrete jackets with rebar was observed.

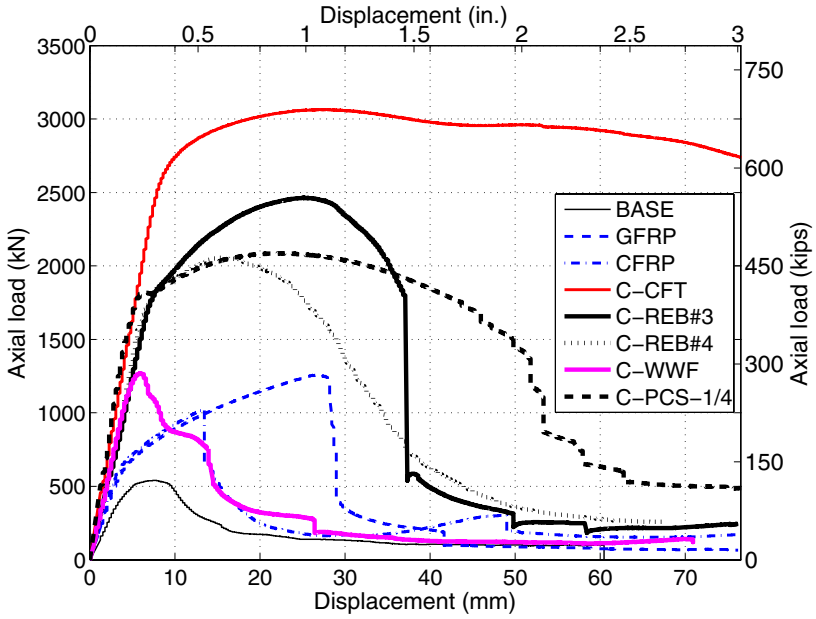


FIGURE 2 - COMPARISON OF MEASURED AXIAL LOAD-DISPLACEMENT RELATIONS FOR THE BASE COLUMN AND REPRESENTATIVE RETROFITTED SPECIMENS

REFERENCES

[1] Shamsai M "Prefabricated Cage System for Reinforcing Concrete Members" *Ph.D. Dissertation*, Ohio State University, 2006, pp. 340

[2] Miller AE "Experimental Research of Reinforced Concrete Column Retrofit Methods", *Master Thesis*, Ohio State University, 2006, pp. 249