EXPERIMENTAL EVALUATION OF FRP STRENGTHENING OF LARGE-SIZE REINFORCED CONCRETE COLUMNS

SUMMARY

In recent years the use of Fiber Reinforced Polymer (FRP) wrapping instead of steel jackets has become more popular for external reinforcement, not only for its improved corrosion and fatigue performance, but also for its mechanical properties, light weight and ease of application. This technique has been also extensively studied, in particular the behavior of confined elements of circular cross section subjected to pure axial loads. However, the available models are based on small scale specimens, in most of the cases standard compressive cylinders of 6in by 12in. Limited studies are found for the cases of prismatic members especially on large size.

In order to analyze the behavior of axially loaded large-size reinforced concrete columns confined by means of CFRP wrapping, a test matrix was designed based on the possible effect of different variables, such as the geometry of the specimen (circular, square, and rectangular), the area aspect ratio, the side aspect ratio, etc. A total of 22 specimens were recently tested at two different laboratories: University of California San Diego and the National Institute of Standards and Technology. These two laboratories were selected because of the availability of large capacity equipment. Currently the organization for the proper documentation of the events as well as the analysis of the experimental results is being conducted. In this research update some preliminary outcomes are presented.

Figure 1 – Construction of the Specimens at NIST

BACKGROUND

Confining prismatic columns is generally acknowledged to be less efficient than confining circular columns. This is due to the fact that, with prismatic columns, confinement is concentrated at the corners rather than over the entire perimeter.

Current research on small columns has shown that the maximum achievable increase in compressive stress for FRP confined prismatic columns with reasonable levels of rounding of corners is about 50 percent, compared with up to 200 percent for circular columns. For larger columns, found more often in practice, the level of increase may be less than this. The efficiency may decrease further with columns of rectangular cross-section as a function of the side aspect ratio.

Several models of the strength enhancement of prismatic columns have been proposed and compared with the limited number of experimental results available. Most models are semi-empirical in nature and have been calibrated with small-scale test specimens. As prismatic columns get bigger in size, the length of the unconfined regions along the sides of the column increases creating a size effect, which is not evident for circular columns. The generally accepted theoretical approach is to develop an area of effective confinement defined by four parabolas within which the concrete is fully confined and outside of which negligible confinement occurs. The shape of the parabolas and the resulting effective confinement area is a function of the dimensions of the column and the radius of the corners. Use of any current state-of-the-art explicit method for analyzing strengthened prismatic columns is being challenged.

OBJECTIVE

This project aims at demonstrating the effectiveness of Carbon Fiber Reinforced Polymer (CFRP) strengthening of prismatic columns for the case of large, real size cross sections.

This includes comparisons of performance using three cross section types: square, rectangular with an aspect ratio of 2, and circular. The largest cross-section to be tested has an area of 9ft^2.

The successful completion of this project will allow the following: a) Demonstrate the efficiency of the strengthening of prismatic columns with FRP; and b) The validation of design algorithms for international guidelines such as ACI, fib, TR55, CSA.

EXPERIMENTAL PROGRAM

The test matrix was designed to investigate the influence of different variables: area aspect ratio, side aspect ratio (b/h) and height to side aspect ratio (L/h). The experimental program was divided into two matrices, based on the testing facilities where the experiments were carried out: University of California San Diego (UCSD) with 18 specimens (6 series of 3 specimens each), and the National Institute of Standards and Technology (NIST) with 4 specimens (2 series of 2 specimens each). All the specimens presented a steel reinforcement ratio of approximately 1.5 percent. Regarding the material properties, concrete compressive strength of 4000psi was used, and reinforcing steel Grade 60. The CFRP material, provided by Mapei, is characterized by an ultimate tensile strength of 392ksi and an ultimate strain of 1.2 percent. The corners on all the prismatic specimens were rounded to 1.5in.

SPECIMENS

UCSD specimens were entirely built, instrumented and tested at the laboratory in the aforementioned university. The 18 specimens were composed of 1 series of circular cross section, 1 series of rectangular, and the remaining series of square cross section of different size areas. In each series there is one control specimen, one retrofitted specimen to attain 30 percent increment of capacity, and a third one was wrapped with two plies, which corresponds to the numbers of plies that a circular specimen needs to achieve a 30 increment carrying capacity.

The internal reinforcement and instrumentation of the specimens tested at the structures laboratory at NIST was prepared at the University of Missouri – Rolla. They were transported to NIST to be cast, strengthened (only 2 from the 4 total), externally instrumented, and tested. The complete test matrix is presented in Table 1.

Table 1 – Test Matrix

Specimen cross-section type and size	Code & No. of Specimens
$\rho = 1.53\%$ 20in; Area: 314in^2; Height: 44in	**A** **3**
$\rho = 1.56\%$ 12.5in × 25in; Area: 312in^2; Height: 54in	**B** **3**
$\rho = 1.48\%$ 18in × 18in; Area: 324in^2; Height: 40in	**C** **3**
$\rho = 1.48\%$ 25.5in × 25.5in; Area: 650in^2; Height: 54in	**D** **3**
$\rho = 1.53\%$ 12.75in × 12.75in; Area: 162in^2; Height: 27in	**E** **3**
$\rho = 1.53\%$ 12.75in × 12.75in; Area: 162in^2; Height: 54in	**F** **3**
$\rho = 1.52\%$ 36in × 36in; Area: 1296in^2; Height: 78in (6.5ft)	**G*** **2**
$\rho = 1.50\%$ 25in × 50in; Area: 1250in^2; Height: 108in (9ft)	**H*** **2**

Note: * Specimens tested at NIST

TEST SET UP AND INSTRUMENTATION

All the specimens were axially loaded in 5 cycles of increments of 1/5 of the expected ultimate capacity. The specimens at UCSD were tested under displacement control at a rate of 0.001in/sec.

Regarding the instrumentation, besides the strain gages attached to the internal reinforcement (ties and longitudinal bars), two potentiometers were placed on two sides of each specimen in order to measure the axial shortening. Additional strain gages were attached on the surface of the FRP jacket of the strengthened specimens. Finally, 4 Linear Variable Differential Transducer (LVDT) transformers were fixed in corner angles to measure the overall crosshead displacement. See Figure 1.

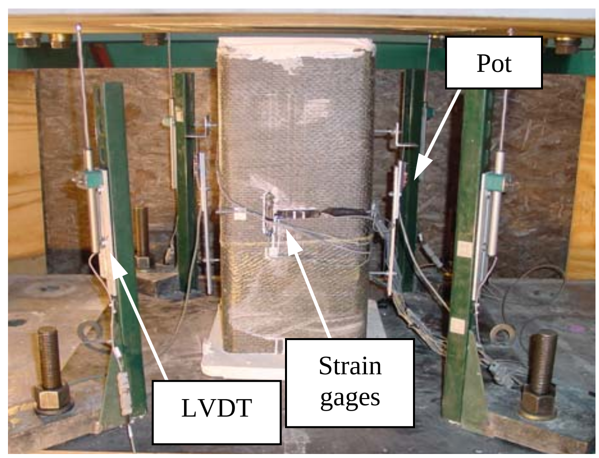

Figure 2 – Test Setup at UCSD Laboratory

With respect to the specimens at NIST, due to the features of the testing machine, the load was applied under load control. As for the smaller specimens (UCSD), these specimens were instrumented with strain gages on the reinforcing steel (ties and longitudinal bars). The external instrumentation consisted of 5 Temposonic transducers, from which 2 were placed on the horizontal direction to measure the bulging of the faces of the specimen, and the other 3 were placed on the vertical direction to measure the axial shortening. See Figure 2.

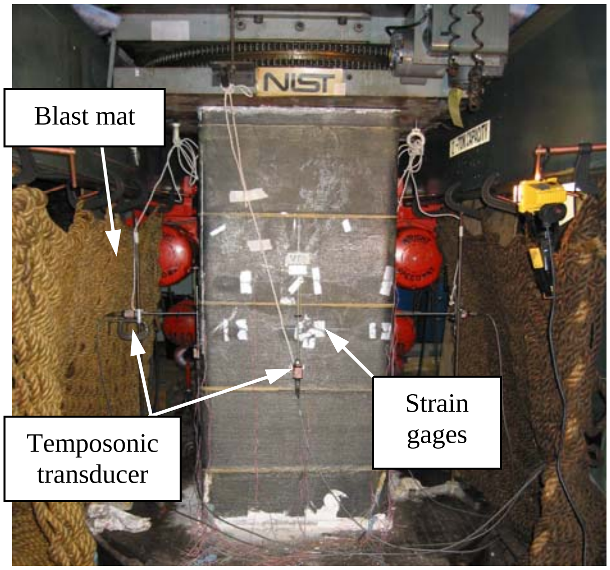

Figure 3 – Test Setup at NIST Laboratory

PRELIMINARY RESULTS AND DISCUSSIONS

The experimental results are currently being organized and analyzed. As preliminary results, in Table 2, the experimental values of ultimate capacity are presented along with the corresponding field cured concrete compressive strength.

Figure 3 presents a characteristic Load vs. Vertical displacement. It corresponds to one retrofitted specimen of series F tested at the laboratory in UCSD. Two curves are plotted based on potentiometers placed at two opposite faces.

Figure 4 shows the failure of the retrofitted square specimen tested at the laboratory at NIST. The FRP jacket failed at mid-height, at one corner and laminas of approximately 16in wide delaminated along the sides. These pieces were extracted from the column specimen and reconstructed it as it can be seen in Figure 5.

Table 2 – Observed Ultimate Capacities

Specimen	# plies	f'_c (psi)	P_u (kip)
A1	0	4720	1493
A2	2 (CW)	4540	2014
A3	4 (PW)	4540	2069
B1	0	4260	1331
B2	7 (CW)	4350	1674
B3	2 (CW)	4350	1423
C1	0	4440	1515
C2	4 (CW)	4450	1659
C3	2 (CW)	4440	1592
D1	0	4300	2981
D2	5 (CW)	4390	3444
D3	2 (CW)	4300	3154
E1	0	4450	601
E2	2 (CW)	4730	893
E3	4 (PW)	4650	927
F1	0	4420	775
F2	2 (CW)	4420	863
F3	4 (PW)	4720	861
G1	0	4600	6349
G2	8 (CW)	4600	6935
H1	0	4430	6200
H2	19 (CW)	4430	7000

Note: CW-Constantly Wrapped; PW-Partially Wrapped

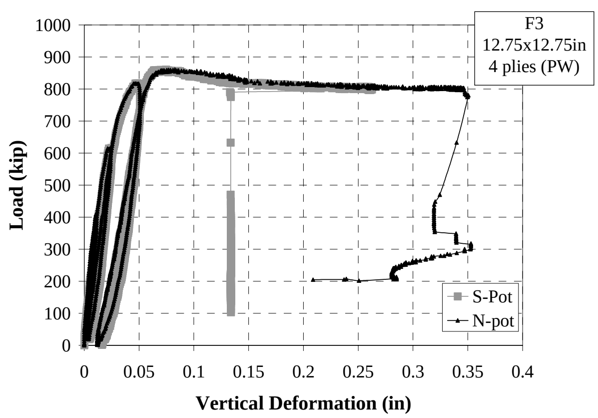

Figure 4 – Load vs. Vertical Deformation

Figure 5 – Failure of Strengthened Square Specimen 36in x 36in at NIST

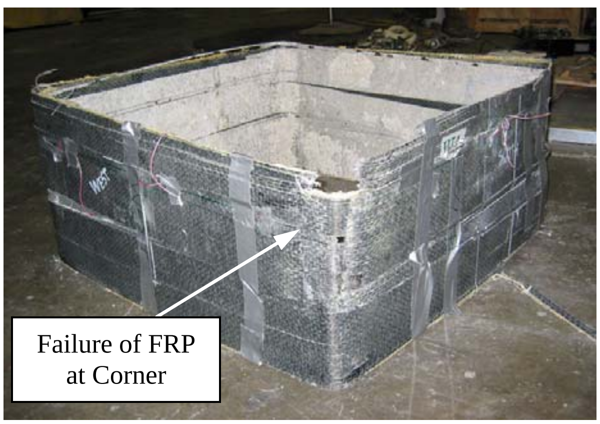

Figure 6 – Reconstructed FRP Jacket

PRELIMINARY CONCLUSIONS

This research project is currently starting its second phase, which is composed of the analysis of the experimental data, comparison with available models and related tasks. However, the following preliminary conclusions can be drawn from the up-to-date conducted part of the project.

- All the retrofitted specimens, in particular the ones of prismatic cross section, showed significant ductility enhancement, although they did not exhibit a significant increase in ultimate capacity. The failure of the CFRP occurred at post-peak stages of the loading path.
- A series of variables affecting the performance, in particular the size effect of the cross sectional area, as well as the volumetric strain ratio, especially after cracking of the concrete, should be considered in the analysis and design of axially loaded members retrofitted with FRP. An algorithm that represents more accurately the behavior of this type of members is needed.

WANT MORE INFORMATION?

Details on this research project and additional information will be available in the final report.

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