

## Strengthening RC Columns with Ultra High Performance Concrete

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### ABSTRACT

Ultra-High Performance Concrete is a cementitious material that has a much higher compressive strength than normal concrete and also has a worthwhile tensional strength to some degree. There had been studies and experiments which tried to apply this material in strengthening or retrofitting structural elements such as beams, slabs or columns. This study particularly focuses on strengthening RC columns with ultra-high performance fiber reinforced concrete (UHPFRC) jacket.

For this study, four identical column specimens were manufactured in half scale size (300×300mm). Among four columns, one was chosen as a control specimen and the rest were retrofitted with UHPFRC Jacket using thickness and stirrup as variants. Before retrofitting, surface treatment with sand blasting was applied to get integrated behavior between subjected columns and UHPFRC jackets. The result shows that UHPFRC could be a good alternative for column strengthening method, especially in enhancement of shear capacity.

### 1. Introduction

There are three widely used techniques for retrofitting RC columns; Reinforced concrete jacketing, FRP wrapping, steel jacketing. Concrete jacketing method can increase overall structural capacities such as axial load capacity, shear strength, flexural strength and also deformation capacity. However, it requires jacket thickness higher than 70-100mm, leading to decrease architectural area while increase total mass of structure.

On the other hand, FRP wrapping and steel jacketing have advantages over concrete jacketing method such as much less thickness, lower weight and better constructability. However, strengthening performances are only limited to shear strength and deformation capacity. Axial load capacity can be increased by confinement effect, but is limited to some degree. Besides, durability matters like fire or corrosion resistance should come into consideration when applying these methods.

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Recently, a new retrofit technique using UHPFRC jacket to complement the weak points of existing method has been researched and applied (Beschi 2011). UHPFRC is an ultra-high performance fiber reinforced concrete of which compressive strength can reach over 180MPa and tensile strength over 10MPa by included fiber. This high strength can make it possible to exhibit higher strengthening effect than using normal concrete jacket. Also, due to high fluidity of UHPFRC, jacket thickness can reduce less than 30~50mm, thus, minimize the main disadvantage of normal concrete jacketing method. There are other advantages of UHPFRC retrofit such as high durability, good adjustability with various situations and that it can be combined with other materials like wire mesh or textile mesh for better performances.

In this research, the authors focused on shear enhancement of RC column using UHPFRC jacket. In order to develop appropriate retrofit method and assess strengthening performance of UHPFRC jacket, four identical RC columns were experimented with jacket thickness and stirrup as variants. The experiment was implemented in double curvature cyclic load test set-up to simulate seismic loads applied to building columns.

## 2. Experimental program

### 2.1 Specimen preparation

Four identical RC column specimens were manufactured in half scale. The dimensions adopted for the column cross section and height were 300×300mm and 1260mm. The corresponding span to depth ratio is 4.15. The longitudinal reinforcement consisted of eight 22mm diameter bars and corresponding reinforcement ratio is 3.44%. These relatively small span to depth ratio and large reinforcement ratio were intended to make a shear failure mode both in before and after retrofitting, in order to make it clear to define shear strength of specimens. The transverse reinforcement comprised of 10mm diameter stirrups with 150mm spacing. The column has 500×500mm foundations at both upper and lower ends to have double curvature experiment. Detail geometries of RC column specimen are illustrated in Fig. 1 and material characteristics (experimental results) are specified in Table 1.

Table 1 Material strength of RC column

<b>Concrete</b>		
Compressive strength, $f_c$	29.1	[MPa]
<b>Longitudinal reinforcement (D22)</b>		
Yield strength, $f_{yl}$	490.1	[MPa]
Ultimate strength, $f_{ul}$	627.9	[MPa]
<b>Transverse reinforcement</b>		
Yield strength, $f_{yt}$	460.1	[MPa]
Ultimate strength, $f_{ut}$	568.1	[MPa]

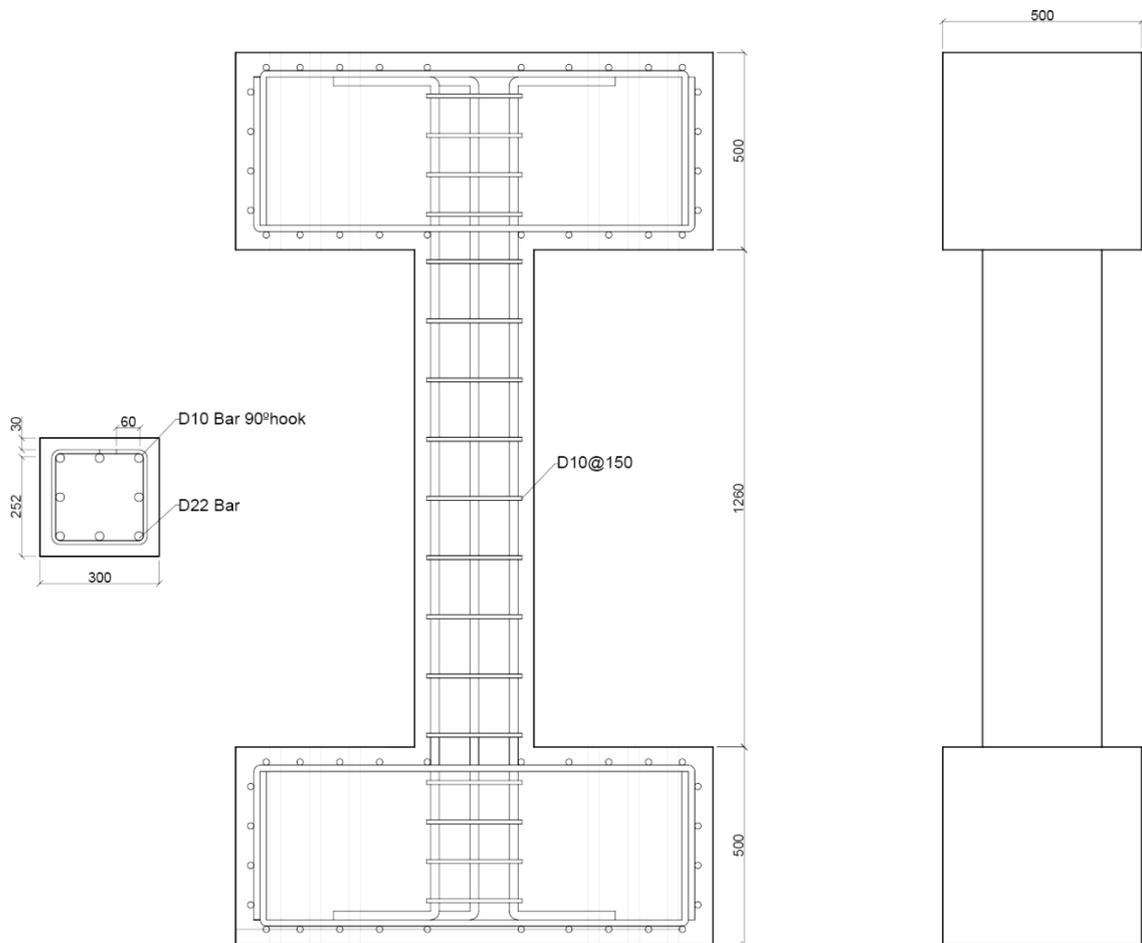
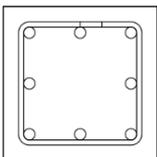
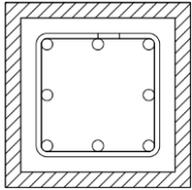
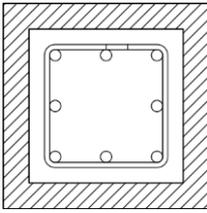
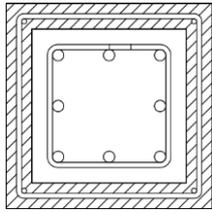
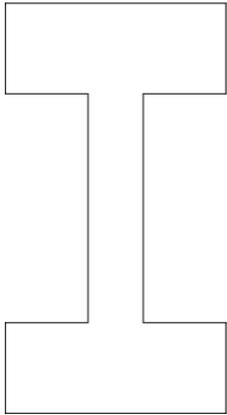
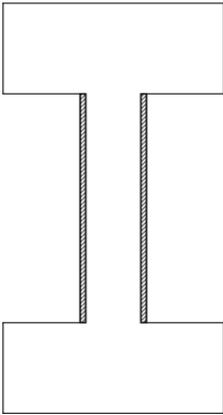
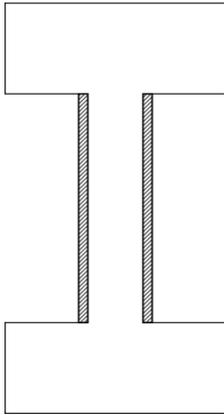
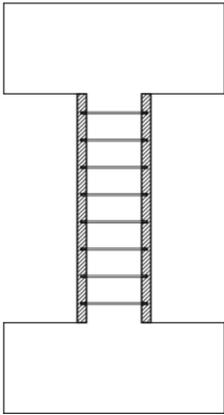


Fig. 1 Geometry of RC column specimen

After casting and curing for two weeks, with one column (R0) left unstrengthened, three columns were jacketed with UHPFRC in different ways: first one(R3) was strengthened with 30mm jacket; second one(R5) was strengthened with 50mm jacket; third specimen(R5S) was strengthened with 50mm jacket plus stirrups(D10@150) inside UHPFRC. The details of specimens are summarized in Table 2.

Table 2 Details of specimens

	R0	R3	R5	R5S
Retrofit method	unstrengthened	30mm jacket (10% thickness of column)	50mm jacket (16.7% thickness of column)	50mm jacket + stirrups (D10@150)
Section				
Elevation				

Before casting UHPFRC, the column surface was roughened by sandblasting to achieve a unified behavior between RC column and UHPFRC jacket. After casting, UHPFRC jackets were cured in high temperature(90 °C) for 3 days. The characteristics of UHPFRC are summarized in Table 2. The length of fiber, 13mm was chosen to minimize congestion between steel fiber and reinforcing stirrups in R5S specimen considering the thickness of jacket and stirrup diameter. Compressive and tensile strength test results of UHPFRC are shown in Fig. 2 (a) and (b) respectively.

Table 2 Characteristics of UHPFRC

Compressive strength, $f_{c,UHPFRC}$	144.8	[MPa]
Tensile strength, $f_{t,UHPFRC}$	6.44	[MPa]
Elastic modulus, $E_{UHPFRC}$	45.6	[GPa]
Fibers length	13	[mm]
Fibers volume	1.5	[%]

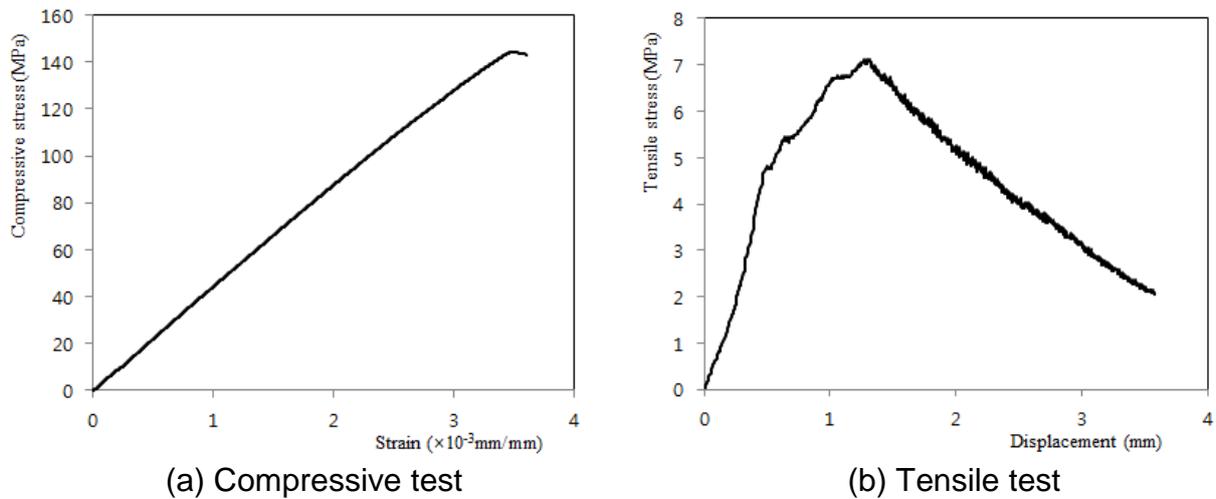


Fig. 2 UHPFRC strength test result (a) compression, (b) tension

## 2.2 Test procedure

The four tests were implemented in same set-up presented in Fig. 3. Initial constant axial load of  $P=0.3f_cA_g$  was applied to column by two 100ton oil jacks and next displacement controlled horizontal cyclic load  $Q$  was applied by a 200ton actuator. The amplitude of imposed displacement of the first cycle was 3mm and increased by 3mm for every additional cycle up to 15mm, and thereafter increased by 6mm.

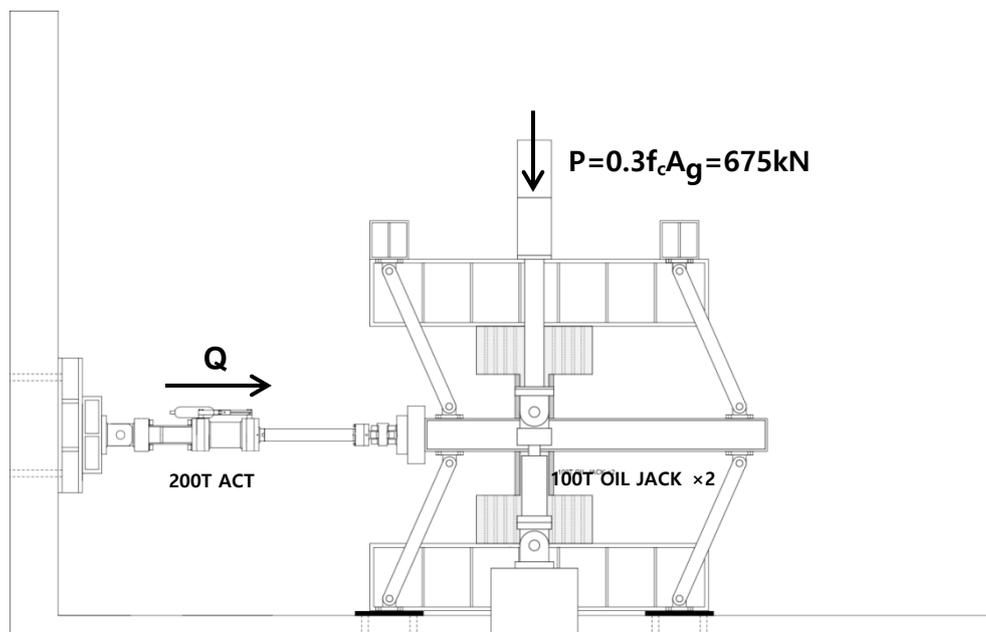


Fig. 3 Test set-up

### 3. Results and discussion

The load-displacement curves of four test results and crack patterns are presented in Fig. 4 and in Fig. 5 respectively. In specimen R0, initial cracks appeared as flexural crack around both end when the drift ratio was 0.46% and thereafter, cracks propagated in flexural shear crack patterns. However, as the drift ratio reached 1.16%, vertical splitting cracks at the locations of longitudinal reinforcements noticeably occurred, leading to sudden strength degradation. From these crack patterns, it is concluded that the column had failed by bond splitting failure between longitudinal reinforcements and cover concrete.

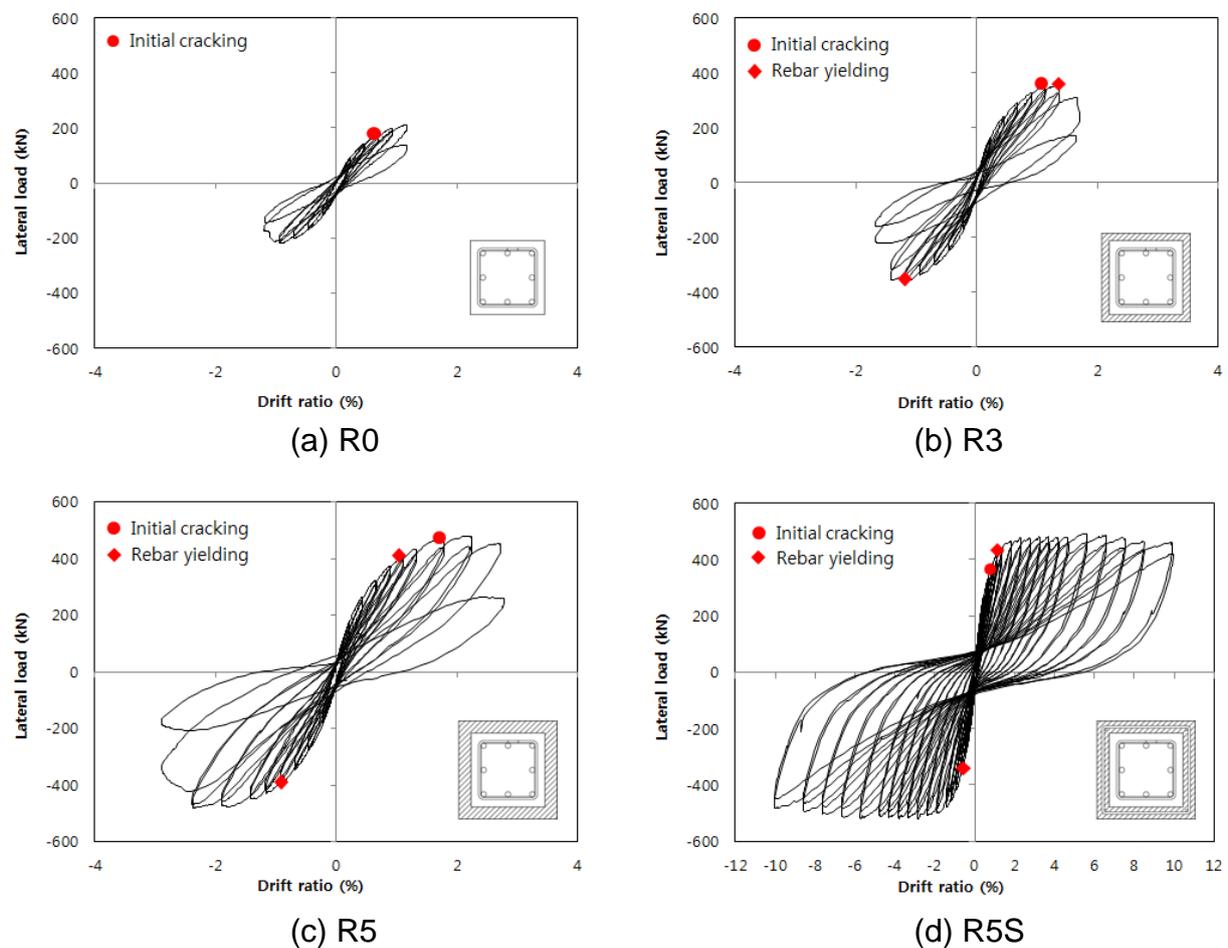


Fig. 4 Load-displacement curve

In specimen R3, no cracks had appeared before the large diagonal tension cracks occurred at 1.16% drift ratio. The subsequent loadings made the diagonal crack extend. As the cracks opened more than fiber's pull-out length, the strength drastically degraded leading to shear failure mode.

R5 specimen showed similar behavior with R3 except several things. The longitudinal reinforcement yielded before crack occurred and showed flexural yielding behavior. The first main crack appeared in diagonal tension cracks when the drift ratio was 2.20% and consequently resulted in flexural-shear failure. Unlike R3 specimen, there appeared two diagonal cracks in both directions.

R5S showed unexpected behavior. Unlike R3 and R5 specimens, the initial cracks didn't extend to large diagonal tension cracks due to transverse reinforcements inside jacket and the column went to flexural yielding. However, after yielding point, the column itself behaved almost like rigid body, without further damages observed, while large cracks propagated on relatively weak bases. Eventually, the test was terminated without column failure when the drift reached 10% of column height.

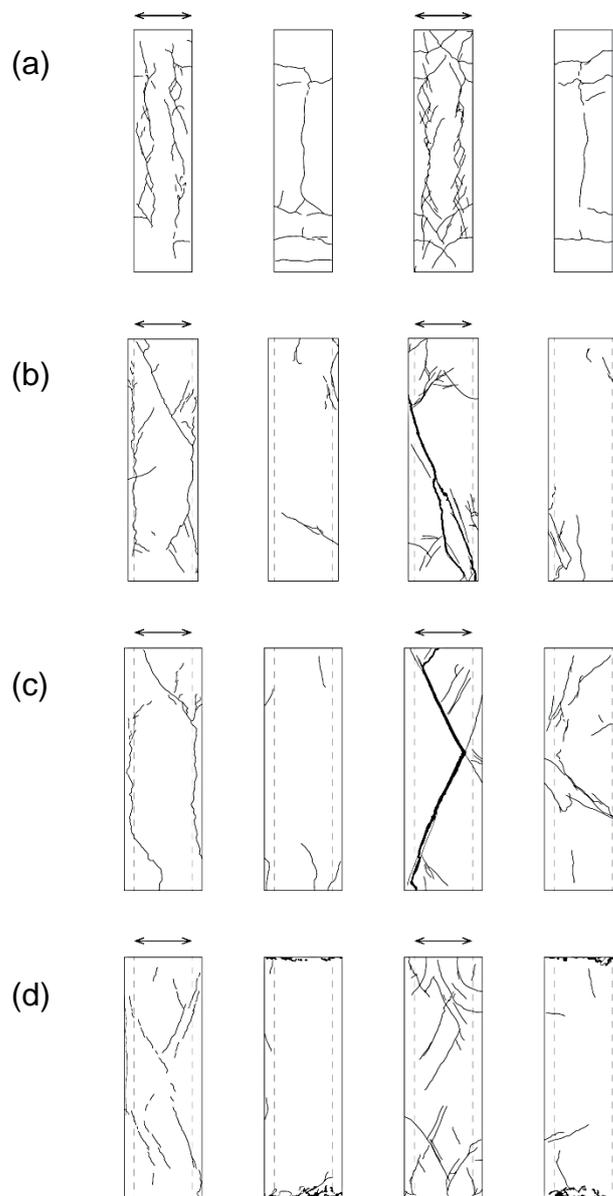


Fig. 5 Crack patterns after test (a) R0 (b) R3 (c) R5 (d) R5S

The load-displacement envelop curves of four specimens are presented in Fig. 6 and the test result of four specimens are summarized in Table 3. The maximum load has increased from 210.4kN (R0) to 359.8kN (R3) or 478.9kN (R5).

The envelop curves of R5 and R5S are almost same before the occurrence of diagonal crack in R5. This shows that the additional transverse reinforcements don't influence on the stiffness or flexural strength that much, however, these prevents large diagonal tension crack so that increase the consequent shear strength and ductility.

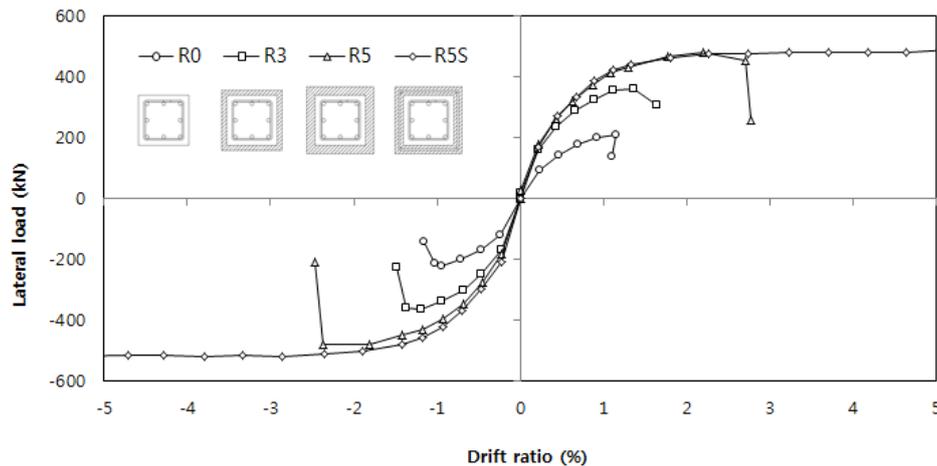


Fig. 6 Load-displacement envelop

Table 3 Test result

	R0	R3	R5	R5S
Failure mode	bond	shear	Flexure-shear	-
Jacket thickness	-	10%	16.7%	16.7%
Area increase	-	44%	77%	77%
Max. strength	210.4 kN	359.8 kN	478.9 kN	491.8kN
Max. drift ratio	1.16 %	1.65 %	2.72 %	10%
Strength increase	-	149.4kN	268.9kN	281.4kN
	-	71.0%	127.8%	133.7%

#### 4. Conclusion

From the experimental research, the UHPFRC jacketing method shows high strengthening effect. The result shows that 10% of column thickness jacket brought over 70% shear strength increase and 16.7% thickness brought over 125% strength increase. Additional strength can be achieved by adding transverse reinforcement, if needed. Although in this experiment retrofitted specimens (R3, R5) show brittle shear failure mode, in actual applications the jacket would play a role to change failure mode from shear to flexural shear failure and consequently improve ductile behavior of columns. The UHPFRC jacketing could be a good alternative for RC column retrofit

method if high strength increase is required without excessive column size increase.

## **REFERENCES**

- C. Beschi, A. Meda & P. Riva, (2011), "Column and joint Retrofitting with High Performance Fiber Reinforced Concrete Jacketing", *Journal of Earthquake Engineering*, 15:7, 989-1014, DOI: 10.1080/13632469.2011.552167
- Martinola. G., Meda. A., Plizzari. G. A. and Rinaldi. Z., (2007), "An application of high performance fiber reinforced cementitious composites for R/C beams strengthening," *FRAMCOS 6*, Catania, Italy, June 18–21.