To Analysis the Strengthening of Square Reinforced Concrete Column with Fibrous Ultra High Performance Self Compacting Concrete Jacketing

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***Abstract*— The major goal of this study is to examine the efficiency of the R.C.C. jacketing method for improving the performance of a damaged structure. This technique was effectively applied to the structure. Due to changes in use that resulted in additional live loads, deterioration of the load carrying elements, design errors, construction problems during erection, ageing of the structure itself, or upgrading to comply with current code requirements, reinforced concrete structures frequently require strengthening to increase their capacity to sustain additional loads. Concrete jacketing, fibre reinforced polymer (FRP) jacketing, UHPSCC, and steel jacketing are all common ways for reinforcing columns. All of these techniques have been proved to increase the axial load capacity of columns effectively. The experimental study was carried out on RC column on designed and detailed using IS 456:2000 provisions.**

In this paper, An RCC structure has been designed and analyzed. The structure's number of floors was increased over the old structure's top floor, and the design loads were increased as a result of the higher number of storeys. The UHPSCC jacketing technology was used to fix some of the old columns in the lower floors that had failed. The effectiveness of strengthening the entire height of As a jacketing material for square RC columns, Forta Ferro Polypropylene Fibrous Ultra High Performance Self Compacting Concrete (Fibrous UHPSCC) was used.

Index Terms: **Design Loads, Flexural Stress, Jacketing, Longitudinal Reinforcement, Retrofitting.**

I. INTRODUCTION

Repairing and strengthening of reinforced concrete (RC) elements is required for several reasons, namely; damages, extension of lifetime and serviceability of structure, lack of structure maintenance and degradation. Other reasons can be considered like the retrofitting of the structure to meet the current design codes and regulations. Structural members may need to be upgraded to current seismic requirements, as existing structural components may be deficient in terms of seismic strength which can be attributed to an inadequate transverse steel reinforcement. Strengthening such elements is a method to increase the flexural, axial and shear strengths.

Strengthening methods depend on the type of the structure and loading, as for structures subjected mainly to static load, increasing flexural and axial compressive strength is more considerable, and for structures subjected mainly to dynamic load, increasing flexural and shear strength is more considerable. Improving column ductility and rearrangement of column stiffness can also be achieved by strengthening. Slight cracks without damage to the reinforcement, surface concrete damage without damage to the reinforcement, concrete crushing, reinforcement buckling, or ties rupture are all possible hazards to RC columns. Based on the degree of damage, techniques such as injections, removal and replacement or jacketing can be applied.

Five commonly jacketing techniques are used for strengthening the RC columns in construction:

1) Concrete jacketing;
2) Steel jacketing;
3) Jacketing by Composite Materials (Carbon Fiber Reinforced Polymer CFRP);

4) Precast Concrete Jacketing;
5) External Pre-stressing Jacketing using Steel Strands;

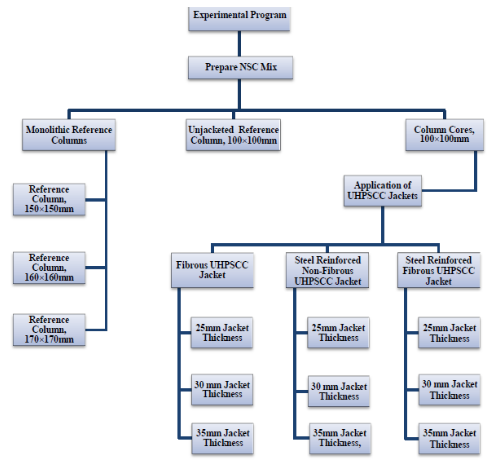
Ultra High Performance Concrete (UHPC) is heavily used in mega structure applications. The strong compressive and tensile strengths enable structural elements to be redesigned and optimised. At the same time, the improved durability features enable for a longer design life and allow for applications such as thin overlays, claddings, column repair, and jacketing.

Despite UHPC has very high compressive strength, it shows very brittle failure behaviour compared to the Normal Strength Concrete (NSC). The UHPC ductility and fracture brittleness can be improved by adding fibers, so the addition of fibers in producing UHPC will add innovative features to the structures and open new areas of UHPC applications.

During the last two decades, increased productivity and improved working environment have had high priority in the development of concrete construction, so there is another new concrete produced which is Self-Compacting Concrete (SCC). The main goal behind the rapid growing of SCC is the easiness in placement and casting in heavily reinforced and inaccessible areas. In addition, SCC increasing productivity levels and leading to shortened concrete construction time and reducing the effort of concrete compacting which leads to reduction in honeycombing and segregation problems. The addition of fibers reduced plastic and hardened concrete shrinkage, improves impact strength, increases both fatigue resistance and toughness of the UHPSCC. Moreover it greatly improves the tensile strength of the UHPSCC as well as the ductility.

II. EXPERIMENTAL PROGRAM

The experimental work carried out in this research has been planned to investigate the ultimate load carrying capacity and longitudinal axial strain of uniaxially loaded square RC columns strengthened using three jacketing styles. The obtained results were compared with that of the reference columns. Figure 3-1 presents the experimental plan of column specimens' fabrication.



III. CATEGORIZING THE COLUMN SPECIMENS

The current study included fabricating a total of 39 column specimens; 12 column specimens were fabricated to act as reference columns, while 27 column cores were fabricated to be strengthened later in this study by applying the three jacketing styles using Fibrous and Non-Fibrous UHPSCC jacket.

All column specimens were designed in compliance with the ACI 318-11 code requirements. The adopted steel reinforcement ratio of all RC column sections was not less than 1%. Details of the fabricated column specimens are as follows:

1) A square RC column specimen (UC) was casted monolithically to act as an unjacketed reference column (similar to the column core). This reference column has a cross sectional dimensions of 100×100mm and a height of 300mm, with 4Ø10 mm longitudinal steel reinforcement and 4Ø4 mm steel stirrups.

2) Three square RC column specimens (MC1, MC2 and MC3) were casted monolithically to act as reference columns. These reference columns have cross sectional dimensions of 150×150, 160×160 and 170×170mm respectively, and a height of 300mm, with 4Ø10 mm longitudinal steel reinforcement and 4Ø4 mm steel stirrups.

3) Three jacketing styles were applied on three groups of column cores (G1, G2 andG3); Group1 (G1) consisted of nine column cores jacketed by Fibrous UHPSCC without steel reinforcement, Group2 (G2) consisted of nine column cores jacketed by Non-Fibrous UHPSCC with steel reinforcement, and Group3 (G3) consisted of nine column cores

jacketed by Fibrous UHPSCC with steel reinforcement.
4) Three jacket thicknesses of 25, 30 and 35mm were applied for the three groups of column cores (G1, G2 and G3).
5) The overall cross sectional dimensions of G1, G2 and G3 jacketed column specimens became 150×150, 160×160 and 170×170mm having jacket thicknesses of 25, 30 and 35mm respectively and fixed height of 300mm.
6) The test result of every column specimen was the average of three samples of column specimens (S1, S2 and S3). This is to increase the confidence in the measured results.
7) Mechanical bonding technique was considered in this study by applying post installed shear connectors to bond the new and old concrete.
8) L-Shape shear connectors were applied on the four faces of the column cores and inserted in drilled holes with epoxy bonding agent as will be discussed later in this chapter.

IV. MIXING PROCEDURES

The required amounts of the NSC constituent materials were weighed accurately. The aggregates were mixed homogeneously with the cement paste using a tilting revolving drum mixer as shown in Figure 3-6. The mixer has an arrangement of interior fixed blades to ensure end to end exchange of material during mixing, having the advantage of a quick and clean discharge. The mixing procedures were included in the following steps:
1) Place all dry materials (cement, sand and coarse aggregate) in the mixer, and mix for 2 minutes.
2) Add the water to the dry materials, slowly for 2 minutes.
3) Continue mixing as the NSC changes from a dry state to a thick paste, all mixing procedures were carried out at room temperature of about (20-25°c).
4) The mixer was stopped after completing mixing and turned up with its end right down and the fresh homogeneous concrete was poured into a clean plastic pan.
5) Casting NSC mix in the timber moulds of column specimen's and standard test cylinder was completed within 20 minutes.

V. REINFORCEMENT DETAILS

Two diameters of steel bars were used to prepare the jacket steel cages, main steel reinforcement of 4Ø10 mm and steel stirrups of 4Ø4 mm. The properties of the jacket steel cages were similar to that of reference and column cores steel cages. Steel cages were located for only two groups of column cores G2 and G3, while G1 column cores were jacketed without jacket steel cages, as shown before in Table 3-10. Shear connectors were used with the three groups of column cores G1, G2 and G3 for the purpose of interface bonding. The spacing was carefully maintained between old concrete and the jacket steel cages with external concrete cover not less than 10mm.
The following points summarize the carried out experimental steps of jacketing:
1) 4Ø10mm main steel reinforcing bars were used at the four corners of column cores, having a length of about 250mm and a diameter of 10mm.
2) 4Ø4mm transverse steel stirrups were used and fixed to the longitudinal steel bars (not welded) with a vertical spacing of 60mm.
3) Mechanical bonding technique (post installed shear connectors) was applied to bond the old concrete to the new concrete.
4) Concrete substrate was not roughened in order to eliminate the influence of friction when assessing the effectiveness of shear connectors.
5) Drilling machine with 6mm diameter drilling bit was used to perforate a hole having a diameter of 6mm and a depth of 25mm based on ASTM A 307 standards.
6) Drilled holes were filled with Sikadur 31CF bonding material which is supplied from SIKA Company to confirm the good bonding between shear connectors and old concrete.
7) The L-shape shear connectors were used having a diameter of 4mm and a length of 40mm. 25mm long of the shear connector was inserted in the drilled hole and the remaining length of 15mm was not inserted.

8) Four shear connectors were fixed with the jacket steel cage in a staggered horizontal alignment on every column face with a vertical spacing of 60mm, and edge distance of 30mm based on ASTM A 307 standards

VI. NSC COMPRESSIVE STRENGTH

The compressive strength of the normal strength concrete (NSC) was obtained by testing four standard test cylinders (300 mm high and 150mm diameter) at 28 days. The test results are shown in Table

Table Compression Test Results of NSC

MIX TYPE	Notification	Cylinder Compressive Strength, MPa
Normal strength concrete (NSC)	S1	21.2
	S2	21.9
	S3	24.3
	S4	21.3
	Average	22.2

Table shows the average compressive strength of the four tested standard cylinders that almost equals the targeted NSC cylinder compressive strength of 20MPa. The experimentally obtained results represented the realistic concrete compressive strength after being damaged throughout its working life, and thus required strengthening.

4.3. UHPSCC Compressive Strength

The Compressive strengths of Fibrous and Non-Fibrous UHPSCC were obtained by testing eight standard test cylinders (300 mm high and 150mm diameter) at 28 days.

The test results are presented in Table 4-2.

Table 4-2: Compression Test Results of Fibrous and Non-Fibrous UHPSCC.

Mix Type	Notification	Cylinder Compressive Strength, Mpa
Fibrous UHPSCC Mix	S1	118.5
	S2	118.0
	S3	107.3
	S4	112.6
	Average	114.1
Non- Fibrous UHPSCC Mix	S1	104.5
	S2	99.7
	S3	101.4
	S4	95.4
	Average	100.3

Table 4-2 revealed that the average compressive strength of Fibrous and Non-Fibrous UHPSCC are 114.1MPa and 100.3MPa respectively. The obtained result of Fibrous UHPSCC compressive strength was almost similar to the targeted compressive strength of 125MPa.

4.4. UC Reference Column

The UC reference column was casted using NSC mix to act as a reference unjacketed column specimen, and to obtain the column core ultimate load carrying capacity before being jacketed. A uniaxial monotonic compression load was applied on the UC reference column to obtain the average ultimate load carrying capacity.

4.4.1. Results of UC Ultimate Load Carrying Capacity

The ultimate load carrying capacity of the three samples (UC-S1, UC-S2, and UC-S3) of UC reference column was obtained at 28 days, as presented in Table 4-3.

Table: UC Ultimate Load Carrying Capacity.

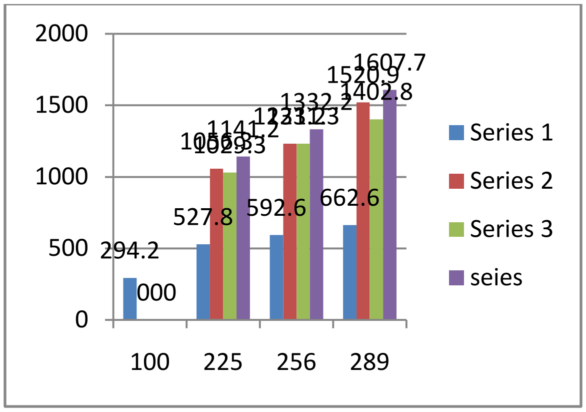
Notification	Pu	Column sectional area	Calculated Pu
UC-S1	291.6	All UC sample have column sectional area of 100cm2	179.5
UC-S2	296.7		
UC-S3	294.2		
Average			

Table shows that the average ultimate load carrying capacity of UC reference column is 294.2 KN, and the calculated nominal load carrying capacity of a corresponding column using ACI 318-11 is 179.5 KN. The difference between the experimental Pu and the calculated nominal Pu can be attributed to the factor of safety provided by ACI code for designing the RC short columns.

The results showed that the UC reference column has satisfied the code requirements in representing column cores before being jacketed. Figure 4-1 shows the failure modes of UC reference column.

4.9. Ultimate Load Carrying Capacity of G1, G2 and G3 Columns with Respect to UC and MC

Strengthening column cores using UHPSCC jacketing by applying three jacketing styles namely G1, G2 and G3 has improved significantly the column ultimate load carrying capacity as observed in Figure 4-47 especially when comparing with the results of UC and MC reference columns. The Figure 4-47 also shows that there was no significant difference between the results of G1, G2 and G3 ultimate load carrying capacity. The rate of increase in ultimate load carrying capacity was almost similar to the increase in jacket thickness.



VII. CONCLUSION

The following concluding remarks were drawn from the obtained experimental observations:

(1)Strengthening RC columns by applying Fibrous UHPSCC as a jacketing material was effective and has reduced the total strengthened column sections.

(2)The Fibrous UHPSCC can flow easily into narrow form sections without segregation or honeycombing problems, even in cases of steel congested sections.

(3)The relationships between the applied load and axial strain of the tested column specimens were typical, a linear behavior up to one third of the ultimate load carrying capacity followed by a non-linear behavior until failure.

(4)The slope of the first part of the plotted load strain curves of UC and MC reference columns was almost the same, while being steeper slope when strengthened with Fibrous and Non Fibrous UHPSCC. Steeper slope means that the modulus of elasticity of strengthened columns has increased.

(5)Strengthening by applying Fibrous UHPSCC jacket increased significantly the ultimate load carrying capacity and the longitudinal axial strain with respect to UC and MC reference columns.

(6)The ultimate load carrying capacity of G1, G2 and G3 jacketed column specimens increased linearly having the same rate of the increase in jacketing area.

(7)Applying several jacket thicknesses of 25, 30 and 35 mm with G1, G2 and G3 jacketing styles improved considerably the ultimate load carrying capacity in almost a similar rate with respect to the rate of increase in jacketing area.

(8)The G1-25, G1-30 and G1-35 gained significant increase in the ultimate load carrying capacity higher 3.6, 4.2 and 5.2 times than the results of UC reference column respectively, and higher about 2.0 times than the corresponding MC reference columns.

(9)The longitudinal axial strain of G1-25, G1-30 and G1-35 increased significantly to about 2.1 times the axial strain of UC and MC reference columns.

(10)The G2-25, G2-30 and G2-35 also gained significant increase in ultimate load carrying capacity higher 3.5, 4.2, and 4.8 times than the UC reference column respectively and higher about 2.0 times than the MC reference columns.

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