An experimental investigation on the behavior of circular concrete columns reinforced with Prefabricated Cage Reinforcement System

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Abstract –*A new reinforcement system, Prefabricated Cage Reinforcement System (PCRS), is proposed to perform the function of longitudinal and transverse steel in reinforced concrete members. PCRS is made from a solid steel tube or plate acting as transverse and longitudinal steel connected monolithically. PCRS reinforcement eliminates some of the weaknesses and detailing problems inherent in traditional rebar reinforced concrete construction resulting in easier, more reliable and faster construction. This paper hence studies the axial behavior of circular concrete columns reinforced with Prefabricated Cage system (PCS). A total of five PCS circular columns and one rebar column were constructed and tested under axial compression. The effect of steel sheet thickness and transverse steel width and spacing on the strength and ductile behavior of columns were studied. The results indicate that the overall behavior of rebar and PCS reinforced specimens are comparable. Increasing the steel sheet thickness and decreasing the transverse steel width and spacing resulted in a substantial increase in ultimate load, ductility and absorbed energy.*

Key Words: **PCS, axial compression, steel sheet thickness, transverse steel width, transverse steel spacing, ductility, absorbed energy**

1. INTRODUCTION

The combination of concrete with high compressive strength and steel providing tensile strength lacking in concrete has made reinforced concrete a very common compound in construction of structural and nonstructural members. Conventional rebar reinforced concrete, concrete-filled tubular system, steel–concrete composite system, and welded wire fabric system are examples of such combinations used in structural members.

In this study, a new steel reinforcement system termed Prefabricated Cage System (PCS) is proposed for reinforcing concrete members. The proposed PCS is fabricated by perforating steel tubes or plates using punching, casting, or different cutting methods. The resulting PCS acts as transverse and longitudinal reinforcing steel working compositely with the surrounding concrete to resist applied loads [1,2,3]. PCS can improve the structural performance through improved mechanical interaction between reinforcement and concrete. PCS can develop certain transfer mechanisms that regular rebar reinforced concrete cannot develop or develops under lower amount of Loads [1,2,4,5,].

PCS can also result in major time and cost savings if it is used in reinforced concrete structures. The investigation performed by Shamsai et.al [8] indicates that PCS can provide about 33% time savings and 7% cost savings over rebar for a typical building column. As a result, the construction of PCS reinforced structures can be completed earlier than similar conventional rebar reinforced structures. The study concluded that, considering the effective interest rates over the lifetime of a typical building, utilization of PCS reinforcement in columns can lead to an average of 20% total construction time savings and 4% total cost savings over traditional rebar [8].

This article concentrates on the behavior of PCS reinforced columns with normal strength concrete. The behavior of PCS columns is investigated and is compared with that of similar rebar reinforced columns, considering the effect of several parameters, including steel sheet thickness and transverse reinforcement width and spacing.

2. EXPERIMENTAL INVESTIGATION

The commonly used mix of 25 MPa was used for this study. The concrete mix design was done as per IS 456:2000 and IS 10262:2009. The materials were tested for various properties needed for the mix design. The cement used for the entire experiment is Ordinary Portland Cement of grade 53 cement. The coarse aggregates were of size 20 mm and downgraded and the fine aggregate used was M-sand. Admixture of type MASTER GLENIUM SKY 8433 produced by BASF Incorporation was added to increase the workability of concrete and to minimize the amount of water-to-cement ratio, for obtaining a desired slump range of 75 mm–125 mm for normal RCC work as per IS 456:2000, Clause 7.1.

A total of 6 specimens were constructed and tested. The specimens were 600 mm height and 150 mm diameter with 25 mm clear cover over the reinforcement. The specimen specifications are provided in Table -1. In the specimen names, the first letter indicates the reinforcement system; P for PCS and R for rebar reinforced specimens. The alphabet followed by the first letter indicates the geometry of the specimens- C for Circular. For PCS specimens, the number followed by the second alphabet was used to distinguish each specimen with other; 1 indicates 1.5 mm thick steel sheet with 3 openings, 2 indicates 2 mm thick steel sheet with 3 openings, 3 indicates 2.5 mm thick steel sheet with 3 openings, 4 indicates that 1.5 mm thick steel sheet with 2 openings and 5 indicates that 1.5 mm thick steel sheet with 4 openings. PCS reinforcement was made out of standard mild steel plates and openings were cut by laser. The average yield strength for steel plates and rebar were 250 MPa. The specimens were cast and taken out of the mould one day after casting. They were all cured inside water tank for 28 days. After curing, specimens were taken out to dry for a day and prepared for testing. Axial compressive test was conducted in Universal Testing Machine and the specimen is loaded uniformly over the cross section and height of the specimen till failure.

Table -1: Test specimen specification

Specimen Name	Reinforcement	Plate thickness (mm)or rebar	Height of transverse reinforcement (mm)	Opening dimension (mm)
RC	Rebar	4# 8 dia	6 dia 150 c/c	-
PC1	PCS	1.5	19	43.87 X 158
PC2	PCS	2	14.25	51.84 X 164.5
PC3	PCS	2.5	11.30	56.585 X 168.25
PC4	PCS	1.5	25.5	43.87 X 237
PC5	PCS	1.5	15.2	43.87 X 118.5

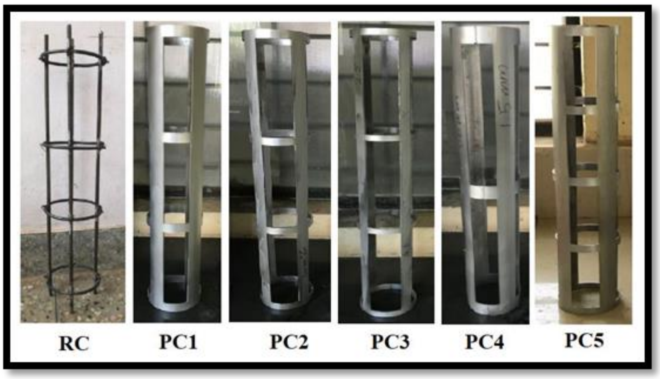

Fig -1: Rebar and PCS reinforcements used for the study

3. RESULTS AND DISCUSSION

3.1 Ultimate load carrying capacity

The rebar column and PCS columns are tested under axial compression and the results are obtained in terms of the ultimate load and deflection at ultimate load. The column test results are tabulated in Table -2.

Table -2: Column test results

Specimen	Ultimate load (kN)	Increase in ultimate load (%)	Deflection at yield (mm)	Deflection at ultimate load (mm)
RC	338	-	2.43	4.5
PC1	432	27.81	1.90	4.62
PC2	462	36.68	1.25	3.96
PC3	552	63.31	2.25	8.30
PC4	404	19.53	2.05	4.50
PC5	438	29.59	1.85	6.30

A significant increase in ultimate load is found in each of the PCS columns. A minimum of 19.53% to a maximum of 63.31% increase in ultimate load is obtained for the PCS columns than rebar columns. This shows that, Prefabricated Cage System is an effective method for reinforcing concrete members.

3.2 Effect of steel sheet thickness

The effect of steel sheet thickness on the axial load carrying capacity is discussed in this section. Three different sheet thicknesses of 1.5 mm, 2 mm and 2.5 mm were provided by keeping area of reinforcement of all the specimens a constant. Same amount of reinforcement were provided for PCS columns by adjusting the dimensions of openings. Table -3 describes the effect of steel sheet thickness on ultimate load carrying capacity.

Table -3: Effect of steel sheet thickness

Specimen	Steel sheet thickness (mm)	Increase in ultimate load (%)
PC1	1.5	27.81
PC2	2	36.68
PC3	2.5	63.31

The load v/s deflection curves for the PCS specimens with three different sheet thicknesses are shown in Chart -1, i.e., for the specimens PC1, PC2 and PC3. From it, we can see that, the ultimate load is greater for PCS columns with sheet thickness of 2.5 mm with an increase in ultimate load of 63.31% compared to the 27.81% and 36.68% increase for specimens PC1 (1.5 mm) and PC2 (2 mm) respectively. Also, from Chart -2 it is understood that, as the thickness of steel sheet increases, its contribution towards the load carrying capacity of the RC column also increases.

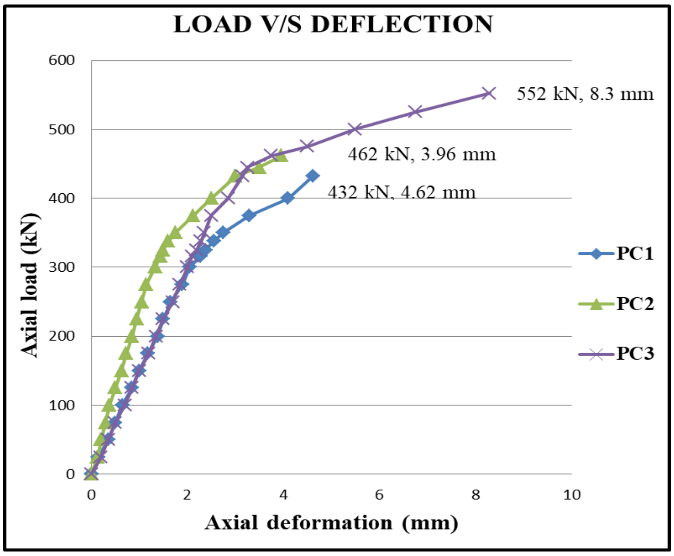

Chart -1: Load v/s deflection curve showing the effect of steel sheet thickness

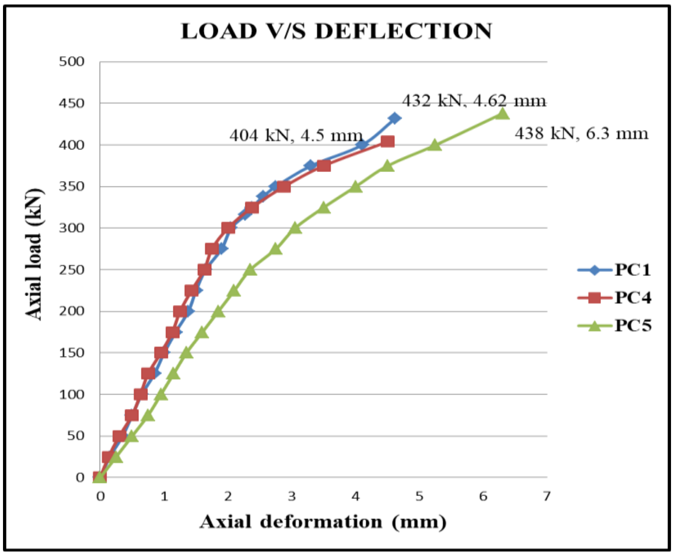

Chart -3: Load v/s deflection curve showing the effect of transverse steel width and spacing

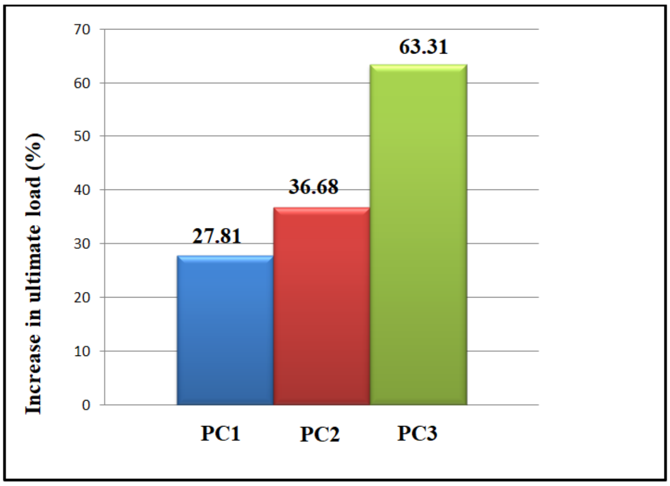

Chart -2: Bar chart showing the effect of steel sheet thickness

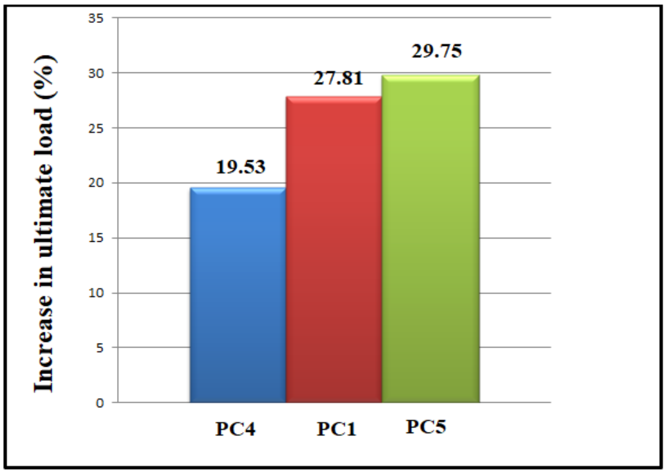

Chart -4: Bar chart showing the effect of transverse steel width and spacing

3.3 Effect of transverse steel width and spacing

The effect of steel sheet thickness on the axial load carrying is discussed in this section. Transverse steel width and spacing of PCS specimens were varied by keeping the area of reinforcement a constant (Table -4). Specimens having 2 openings, 3 openings and 4 openings per face are compared here.

Table -4: Effect of transverse steel width and spacing

Specimen	Transverse steel width (mm)	Spacing (mm)	No of openings	Increase in ultimate load (%)
PS4	25.5	237	2	27.81
PS1	19	158	3	19.53
PS5	15.2	118.5	4	29.75

The specimen PC5 (4 openings) has an increase in ultimate load of 29.75% compared to the 27.81% and 19.53% increase for the specimen PC1 (3 openings) and PC4 (2 openings) respectively. It is evident from Chart -3 which shows the load V/s deflection curves for the PCS specimens with same reinforcement area but varying transverse steel width and spacing. From Chart -4, we can see that, the ultimate load and confinement capacity is greater for the PCS column with 4 openings, i.e.; specimen with thinner and closely spaced stirrups.

3.4 Ductility and energy absorption

It can be seen that from Table -5, the PCS reinforced specimens provide much higher ductility and absorb much higher amounts of energy than the rebar reinforced specimens. Deflection ductility ratio of PCS reinforced specimens are 1.18 to 1.99 times of that of the rebar specimens and the energy absorption ratio of PCS reinforced specimen is 1.45 to 3.67 times that of the rebar specimens.

Table -5: Deflection ductility and energy absorption

Specimen	Deflection ductility ratio	Energy Absorption ratio
RC	1	1
PC1	1.31	1.62
PC2	1.71	2.34
PC3	1.99	3.67
PC4	1.18	1.45
PC5	1.84	2.58

Steel sheet thickness and transverse steel width and spacing have an influence on ductility and energy absorption of PCS reinforced specimens. Increasing the steel sheet thickness and decreasing the transverse steel width and spacing resulted in a substantial increase in ductility and absorbed energy.

4. CRACK PATTERN

Fig -2: Crack pattern PCS circular specimens

Fig -3: Crack pattern for rebar specimen

Carefully observing the crack patterns in the Fig -2 and Fig -3 we can see that, the columns reinforced with prefabricated cage have lesser intensity of cracks than those rebar columns. For all specimens, cracking initiated, starting from corners at top of the specimen expanding to the bottom of the specimen. For rebar specimens, the initial vertical cracks were expanded followed by cover failure, while for PCS specimens cover failure was prevented.

5. CONCLUSIONS

A new reinforcing system, PCS, is introduced to be used to reinforce various concrete members. Overall, PCS is found to be a superior alternative for reinforced concrete structures that enables easier, faster, and more reliable construction.

i. Reinforcing of RC circular columns by PCS method is very effective in increasing its load carrying capacity. The PCS reinforced columns have 19.53% to 63.31% increase in ultimate load compared to the conventional rebar columns.

ii. The effect of steel plate thickness on the axial load carrying capacity was significant. Load carrying capacity has got increased as the steel sheet thickness increased. There was an increase in ultimate load by 63.31% when compared to rebar specimens.

iii. The load carrying was affected by the transverse steel width and spacing. PCS specimens with thinner and closely spaced transverse steel provided higher confinement and load carrying capacity. There was an increase in ultimate load by 29.75% when compared to rebar specimens.

iv. PCS reinforced specimens on average had much higher displacement ductility and absorbed more energy than similar rebar specimens. Ductility and energy absorption increases as the steel sheet thickness increases and transverse steel width and spacing reduces.

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