Experimental evaluation of strength and ductile behavior of square concrete columns reinforced with Prefabricated Cage Reinforcement System

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Abstract - *Nowadays the non-conventional reinforcement system is widely used reinforcement system for RC column reinforcement instead of conventional reinforcement system. A new type of steel cage- Prefabricated Cage Reinforcement System (PCRS) has recently been proposed by Halil Sezen and Mohammad Shamsai, both of The Ohio State University. PCRS is fabricated by perforating steel tubes or plates using punching, casting, or various cutting methods. This paper hence studies the axial behavior of square concrete columns reinforced with Prefabricated Cage system (PCS). A total of five PCS square 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

A Column is a structural element that transmits, through axial compression or tension, the weight of the structure above to other structural elements below. Other compression members also often termed as "column" because of the similar stress condition. Nowadays columns made of steel and reinforced concrete columns are widely used. Steel is also used in the form of rebar, as longitudinal and transverse reinforcement systems such as tubular and composite sections have been introduced in recent years. Prefabricated Cage System (PCS) is a new non-conventional steel reinforcement system that can be used in reinforced concrete columns. PCS is expected to perform as an integral system performing the function of both longitudinal and lateral reinforcement. The system is supposed to be a superior alternative to existing conventional reinforcement system in RC columns. The openings on the PCS can be provided either by punching methods or by various cutting methods such as laser cutting, plasma cutting [1,2,3].Manufacturing small quantities of PCS reinforcement by any of these methods may be more expensive than rebar production; mass production of PCS can result in smaller cost differences. Mass production of PCS can be accomplished by punching holes in the steel tube during the hot rolling process. The soft steel can be punched easily, and extra steel pieces can be recycled during the hot rolling process. This could result in even more economical PCS production [8]. In general, PCS can be used as the reinforcement in reinforced concrete columns. Two similar reinforced concrete columns, one with columns reinforced with PCS and the other reinforced with conventional rebar, are compared in this paper.

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 135 mm x 135 mm cross section 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- S for Square. 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)
RS	Rebar	4# 8 dia	6 dia 150 c/c	-
PS1	PCS	1.5	19	51 x 158
PS2	PCS	2	14.25	59 x 164.5
PS3	PCS	2.5	11.30	65 x 168.5
PS4	PCS	1.5	25.5	51 x 237
PS5	PCS	1.5	15.2	51 x 118.5

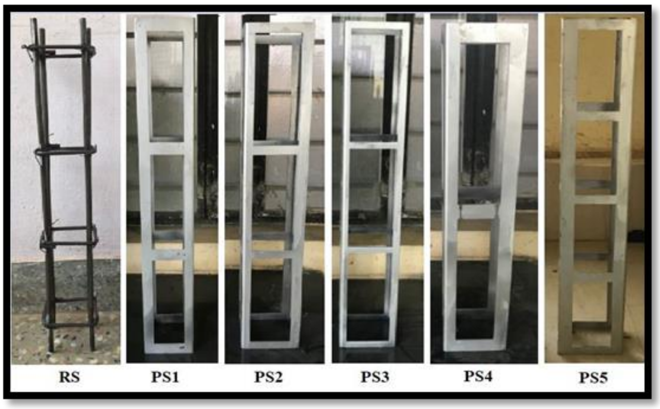

Fig -1: Rebar and PCS reinforcements used for the study

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)
RS	316	-	2.00	3.54
PS1	396	25.31	1.88	3.90
PS2	418	32.28	1.63	4.56
PS3	472	49.37	1.75	6.00
PS4	370	17.08	1.71	3.38
PS5	402	27.21	1.74	5.50

A significant increase in ultimate load is found in each of the PCS columns. A minimum of 17.08% to a maximum of 49.37% 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 (%)
PS1	1.5	25.31
PS2	2	32.28
PS3	2.5	49.37

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 PS1, PS2 and PS3. 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 49.37% compared to the 25.31% and 32.28% increase for specimens PS1 (1.5 mm) and PS2 (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.

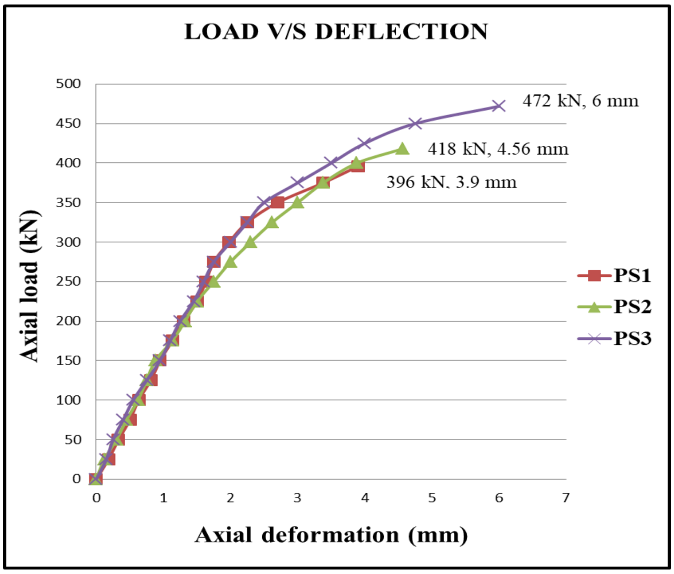

Chart -1: Load v/s deflection curve showing the effect of steel sheet thickness

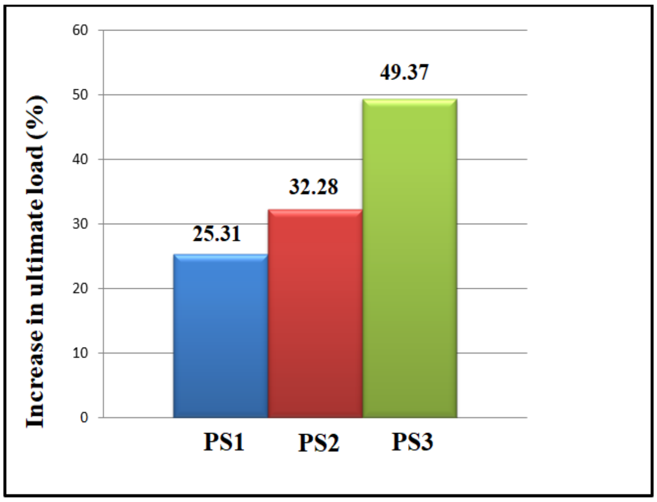

Chart -2: Bar chart showing the effect of steel sheet thickness

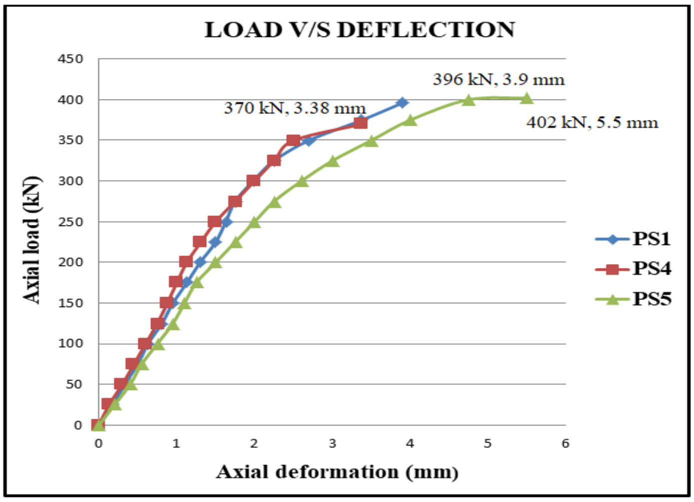

Chart -3: Load v/s deflection curve showing the effect of transverse steel width and spacing

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.

The specimen PS5 (4 openings) has an increase in ultimate load of 27.21% compared to the 25.31% and 17.08% increase for the specimen PS1 (3 openings) and PS4 (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.

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	17.08
PS1	19	158	3	25.31
PS5	15.2	118.5	4	27.21

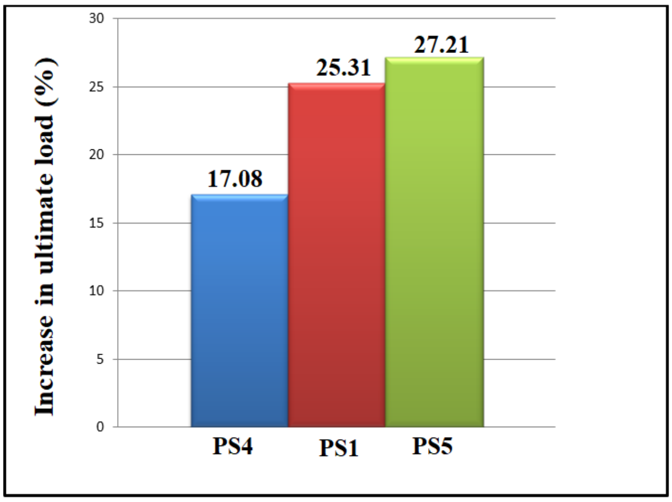

Chart -4: Bar chart showing the effect of transverse steel width and spacing

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 1.12 to 1.94 times of that of the rebar specimens and the energy absorption ratio of PCS reinforced specimen is 1.22 to 2.97 times that of the rebar specimens.

Table -5: Deflection ductility and energy absorption

Specimen	Deflection ductility ratio	Energy Absorption ratio
RS	1	1
PS1	1.17	1.49
PS2	1.58	1.85
PS3	1.94	2.97
PS4	1.12	1.22
PS5	1.78	2.26

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

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.

Fig -2: Crack pattern PCS square specimens

Fig -3: Crack pattern rebar specimen

Fig -4: Cover failure and reinforcement exposure of rebar specimens

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 columns by PCS method is very effective in increasing its load carrying capacity. The PCS reinforced columns have 17.08% to 49.37% 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 49.37% 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 27.21% 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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