# CONFINEMENT CAPACITY OF SQUARE AND CIRCULAR CONCRETE COLUMNS REINFORCED WITH PREFABRICATED CAGE REINFORCEMENT SYSTEM

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**Abstract -** *Prefabricated Cage System (PCS) is introduced as a new steel reinforcement system that can be used in reinforced concrete members. PCS is expected to perform as an integral system performing the functions of both longitudinal and lateral reinforcement. The proposed system is anticipated to be a superior alternative to the existing reinforcement systems in reinforced concrete members, most notably in beams and columns. PCS is fabricated by perforating hollow steel tubes or steel plates. Various methods could be used to fabricate PCS reinforcement such as; punching, cutting methods, and casting. PCS reinforcement is prefabricated off-site and then placed inside the formwork eliminating the time consuming and costly labor associated with cutting, bending, and tying steel bars in traditional rebar construction. PCS can be used to reinforce almost any kind of concrete member which involves reinforcement and concrete. In this paper, six concrete columns reinforced by rebar, steel tube, and PCS of square and circular geometry are compared. It was observed that, PCS provided higher confinement to concrete than rebar reinforcement and Concrete Filled Steel Tubes (CFST).*

***Key Words*: Prefabricated Cage System, rebar, CFST, axial compression, confinement capacity**

## 1. INTRODUCTION

Reinforced concrete (RC) has been used in construction of different structures for centuries. Reinforced concrete is defined as concrete which is a mixture of cement, sand, gravel, water, and some optional other admixtures, combined with a reinforcement system, which is usually steel. Concrete is strong in compression but weak in tension, therefore may result in cracking and failure under large tensile stresses. Steel has high tensile capacity and can be used in areas with high tensile stresses to compensate for the low tensile strength of concrete.

The combination of concrete, a relatively cheap material with high compressive strength, and steel, a material with high tensile strength, has made reinforced concrete a popular construction material for structural and nonstructural members. Historically, steel in the form of rebar has been used as longitudinal and transverse reinforcement. Other forms of steel reinforcement systems, such as tubular and composite sections have been introduced in recent decades.

Prefabricated Cage System (PCS) is introduced as a new steel reinforcement system that can be used in reinforced concrete members. PCS is expected to perform as an integral system performing the functions of both longitudinal and lateral reinforcement. The proposed system is anticipated to be a superior alternative to the existing reinforcement systems in reinforced concrete members, most notably in beams and columns. In PCS, the longitudinal and lateral reinforcement are connected monolithically and made from one solid steel plate or tube. As an example, the PCS can be fabricated by cutting out uniform rectangular openings on a steel plate and rolling it into a cylinder with a continuous weld along the edge (Fig -1). The vertical continuous strips perform the role of longitudinal reinforcement, while the horizontal circular strips act as transverse reinforcement. The idea is the same for rectangular sections with a rectangular PCS [1,2,3].

In PCS reinforcement, the longitudinal and lateral reinforcement are located at the same distance from the center of the member, therefore helps provide greater flexural capacity as compared to a rebar reinforced section with the same amount of steel. This also results in a more efficient use of the longitudinal reinforcement. The production of PCS is under better quality control than traditional rebar reinforced system. PCS reinforcement is precisely constructed with higher precision than rebar construction, eliminating any potential construction flaws. This integral reinforcement system has precise longitudinal and transverse steel spacing eliminating some of the potential weaknesses and detailing problems observed in typical rebar reinforced concrete construction. The PCS cage is produced from a steel plate or tube. Therefore, the longitudinal and transverse reinforcements have rectangular cross sections. In this system, a steel plate with uniformly spaced rectangular openings; in rows and columns can be rolled into a cylinder or box and can be welded at the edge. Instead of using plates, the openings can be constructed on a structural steel tube to eliminate the bending and welding procedures [4,6,7].

By changing the opening dimensions, and hence longitudinal and lateral steel spacing, the amount of longitudinal and transverse reinforcement can be changed. PCS reinforcement schemes with different wall thicknesses and opening dimensions can be fabricated to provide reinforcement with different longitudinal and transverse strength and displacement capacities [8,9].

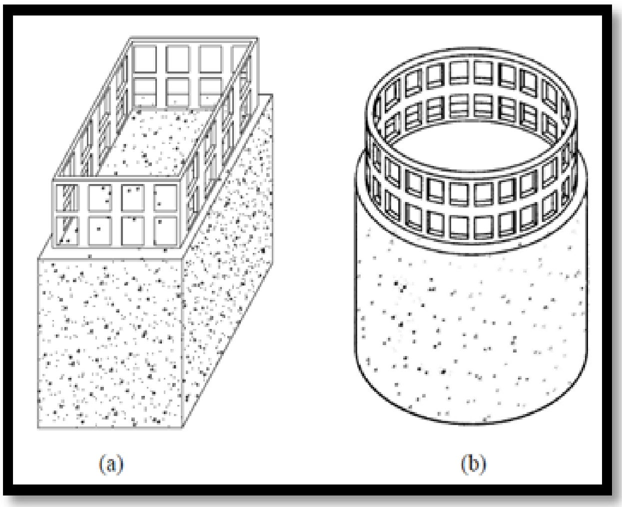


**Fig -1:** PCS reinforced column

Stress concentrations usually occur at corners with sharp edges. Rectangular openings with rounded corners can decrease the stress concentration at the corners. Fortunately, most cutting devices require a minimum cutting radius at the corners when cutting out openings, which helps decrease the effect of stress concentration. Overall Flexure and shear resistances of PCS tend to be better than those of rebar reinforced members due to additional bearing and friction forces acting on the surface of the PCS reinforcement. Especially in members subjected to large cyclic seismic loads, the plate thickness, width and height of the longitudinal and transverse reinforcement of PCS may be designed to provide large displacement ductility [3,5].

## 2. EXPERIMENTAL PROGRAMME

### 2.1 Concrete mix details

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.

### 2.2 Preparation of reinforcement

A total of 6 specimens were constructed including 3 square specimens and 3 circular specimens. The specimen specifications are provided in Table -1. For PCS and concrete filled tubes, the steel sheets were bent or rolled and welded at the edges and the opening windows of the PCS were cut by laser (Fig -2). It was important to have the specimens cut and squared precisely, in order to have them fit well in the formwork before casting concrete. The amount of reinforcement for the rebar reinforced specimens satisfied the requirements of IS: 456 code. Four no:s of 8mm diameter steel bars were used as longitudinal reinforcement and 6mm diameter bars were provided as transverse reinforcement at a spacing of 150 mm c/c. The width of the openings is calculated such that the longitudinal steel area of the PCS is equal to the cross-sectional area of longitudinal rebar in rebar specimen. Following the same concept, the length of the openings is calculated such that the transverse steel area of the PCS is equal to the transverse rebar cross-sectional area. The main purpose of matching the steel area in both reinforcement systems is to evaluate the systems behavior independent of the amount of steel or strength provided by the steel. The average yield strength for steel plates and rebar were 250 MPa. Square reinforcements had 85 mm x 85 mm cross section and 550 mm height, while circular reinforcement had 100 mm diameter and 550 mm height. For rebar and PCS, a clear cover of 25 mm was provided.

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**: Reinforcement details

| Specimen name | Geometry | Reinforcement details |
|---|---|---|
| RS | Square | Main reinforcement- 4# 8 mm diameter bars<br>Transverse reinforcement – 6 mm diameter bars @150 mm c/c |
| PS1 | | Sheet thickness – 1.5 mm<br>Opening dimension – 51 X 158 mm |
| CTS | | Sheet thickness- 1.5 mm<br>No openings |
| RC | Circular | Main reinforcement- 4# 8 mm diameter bars<br>Transverse reinforcement – 6 mm diameter bars @150 mm c/c |
| PC1 | | Sheet thickness – 1.5 mm<br>Opening dimension- 43.87 X 158 mm |
| CTC | | Sheet thickness- 1.5 mm<br>No openings |

**Fig -2:** Rolling process

**Fig -3:** PCS specimens

**Fig -4:** Rebar specimens

**Fig -5:** Concrete filled steel tubes

## 3. RESULTS AND DISCUSSION

The shape and geometry of PCS reinforcement is similar to a steel tube (without openings) and a conventional rebar cage with smaller spacing between the longitudinal rebar and between the transverse steel. At the transverse steel level, PCS is similar to tube and at the openings level, it is similar to rebar reinforcement cage. The confinements provided by PCS, rebar reinforcement and concrete filled steel tubes are compared in this section. The PCS and rebar reinforced specimens have the same amount of longitudinal and transverse reinforcement and CFSTs are made out of sheet having same thickness of PCS. Specimens RS, PS1 and CTS with square section and specimens RC, PS2 and CTC with circular section were used for the study. The load-displacement diagrams of three reinforcement types are compared in Chart -1 and Chart -2.

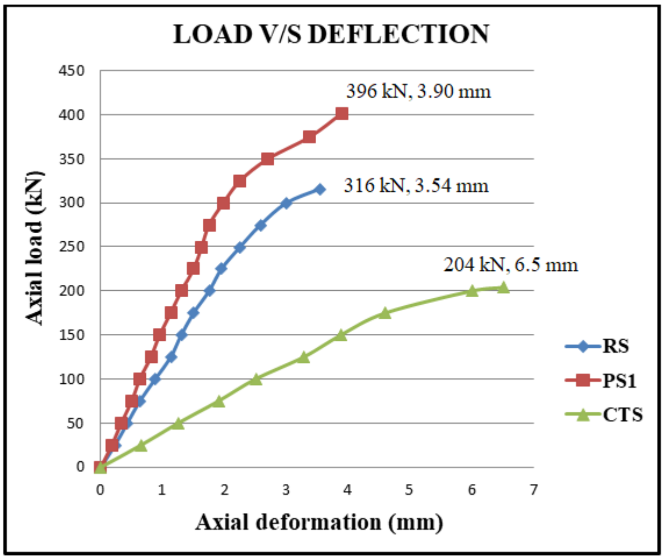


**Chart -1:** Load v/s deflection curves for rebar, PCS and CFST specimens having square geometry

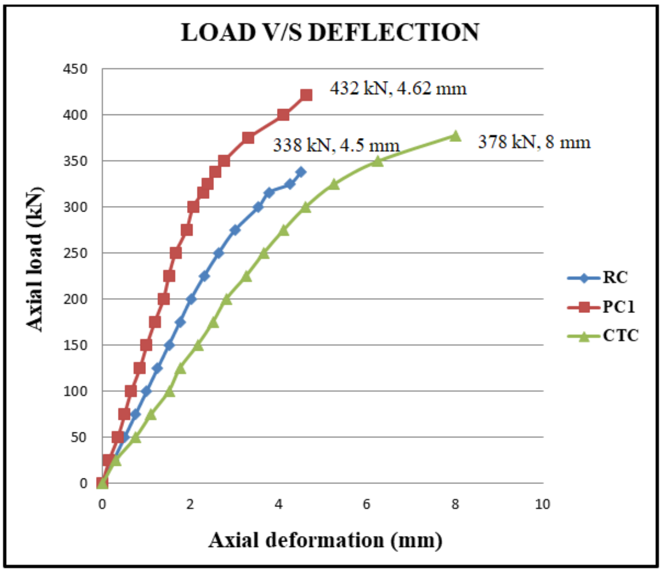


**Chart -2:** Load v/s deflection curves for rebar, PCS and CFST specimens having circular geometry

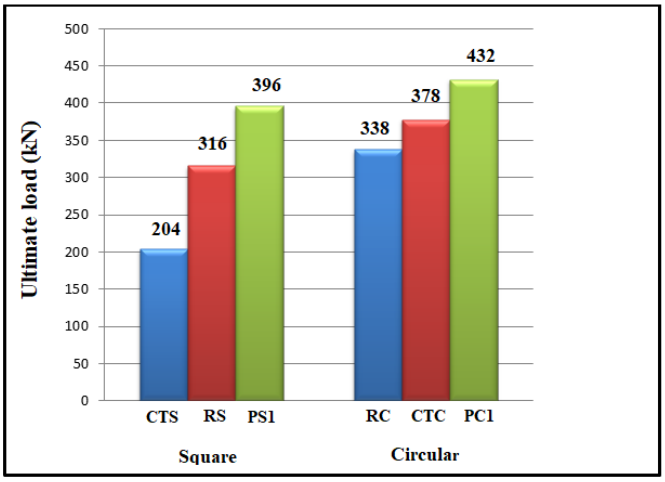


**Chart -3:** Bar chart showing the confinement capacity of Prefabricated Cage Reinforcement System

It can be seen that the PCS confined specimens are capable of resisting much higher loads in comparison to the rebar confined specimen and concrete filled tubular columns. For both the section, the initial stiffness provided by PCS confined specimens is much higher than rebar and CFST specimens.

From Chart -3, for square specimens, PCS shows approximately 26% and 97% increase than rebar confined specimen and concrete filled tubular columns respectively. For circular specimens, PCS shows approximately 28% and 12% increase than rebar confined specimen and concrete filled tubular columns respectively. So it can be concluded that the PCS confined specimens perform better than the tube confined specimen and rebar specimens up to ultimate load.

## 4. 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.

PCS provides considerable confinement for the concrete core inside the steel cage. In PCS, typically the confinement provided is larger than the confinement provided by regular rebar reinforced systems and concrete filled tubes because of the tubular geometry. PCS with small opening provides the greatest amount of confinement. PCS provided higher confinement to concrete than rebar reinforcement and CFSTs. For square PCS specimens, ultimate load carrying capacity was greater by 26% and 97% than rebar and CFST respectively. While for circular specimen, ultimate load carrying capacity was greater by 28% and 12% than rebar and CFST respectively.

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