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Study on Behaviour of Prefabricated Cage Steel Reinforced Concrete Beam Column Joint

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Abstract:
Prefabricated Cage Steel is fabricated by perforating hollow steel tubes or steel plates. PCS can be used as the entire or part of the reinforcement in concrete columns, beams, beam-column joints, shear walls, foundations, slabs, retaining walls or other structural members. A series of experiments on composite beam column joint reinforced with Prefabricated Cage System is reported. The experiments include two series of composite beams. Companion specimens of concrete cylinders and cubes were tested for compressive strength and splitting tensile strength. Specimens of cold formed steel are reinforced and casted as interior beam column joint. In this study, cyclic loading has been imposed on interior beam joint and its load – deflection behavior has been studied.

Keywords: *Composite interior beam column joint, cold formed steel, cyclic loading, load – deflection behavior, ductility factor.*

1. Introduction

The adoption of cold-formed steel sheeting in the beam column joint is advantageous for the strength and serviceability limit states used in most international limit state or LRFD Structural codes [1]; [2]. The adoption of cold-rolled steel sheeting as a form of reinforcement is now widely used in construction industry. The usage of permanent and integral shuttering made of cold rolled sheet as form and reinforcement in the construction of composite slabs is an example for composite steel and concrete structural members, otherwise known as composite sections [6]. The shapes of composite sections varied as the imagination of the designer. Such composite sections can be made from hot-rolled steel sections by encasing the concrete element with steel or by encasing the concrete within two skins of steel. To improve the structural performance and reduce total construction time, a new reinforcement system, termed as PCS is invented and proposed to perform the functions of both longitudinal and transverse reinforcement in Reinforced concrete members [11]. In PCS, the longitudinal and lateral reinforcement are connected monolithically and made from one solid steel plate. The PCS can be fabricated by cutting out rectangular openings on a steel plate and bending it into a rectangular tube shape with a continuous weld along the edge. The horizontal continuous strips perform the role of longitudinal reinforcement, while the vertical strips acts as transverse reinforcement. This prefabricated cage later on kept within the formwork with suitable cover. The concrete is poured. Such members are referred to as PCRC beams. Since the encasement of a steel shape increases its stiffness, energy absorption, and drastically reduces the possibility of local buckling of encased steel [16], concrete encased composite members are popular now a day. This type of construction has been used in Japan [17] and a design guide for concrete encased composite members was published by Architectural Institute of japan [1]. Recently, such type of composite members with Prefabricated Cage System was introduced and the behavior of Column with Prefabricated Cage System (PCS) was investigated by Halil sezen et al., [8]. The investigation by Mohammad Shamsai et al., [9], shows that usage of prefabricated cage system results in a 33.3% time savings and a 7.1% cost savings over rebar for each column. This results in an average of 3.6% savings on total project cost; an average of 22.2% savings on total column costs; 20.4% savings on total project time period, and 33.3% savings on columns construction time period. The cost savings were estimated based on production of small quantities of PCS reinforcement. Mass production of PCS reinforcement would result in even higher cost savings.

1.1. Types of Joints in Frames

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column1. In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint (Fig.1).

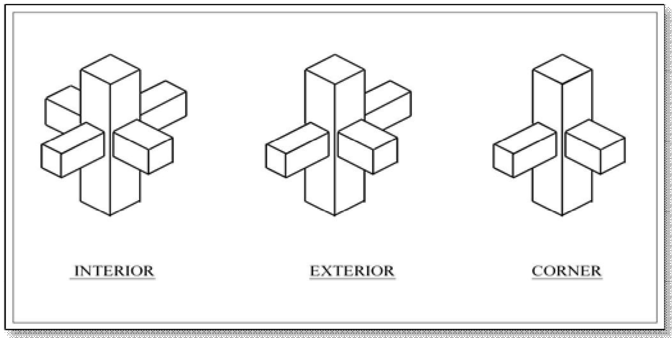

Figure 1: View of Various Types of Joints

When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behavior. These forces develop complex mechanisms involving bond and shear within the joint.

1.2. International Classification

ACI-ASCE Committee recommendations classify the beam-column joint in two categories based on loading conditions and anticipated deformations:

Type 1 joint – These are designed on the basis of strength without considering special ductility requirements.

Type 2 joints – These joints are designed to have sustained strength under deformation reversals into inelastic range.

There are several different ways to connect PCS beam reinforcement to PCS column

1.3. Types of Connections in Precast Cage Steel Beam Column Joint

1.2.1 Connection of PCS reinforced beams to PCS reinforced columns reinforcement. One method is to connect the longitudinal strips of the two beam PCS reinforcements at the sides of the joint with some steel strips (Figure 2).

In order to construct this connection, the beam PCS reinforcement must be cut at a cross-section with openings letting the beam.s longitudinal strips sit on the openings of the column PCS reinforcement. Steel strips placed above and below beam.s longitudinal reinforcements passing through the column, must be welded to the beam.s longitudinal strips to connect the beam reinforcements on both sides of the column. This joint will perform similarly to rebar reinforced joints, where the rebar of the beams on both sides of the column are connected.

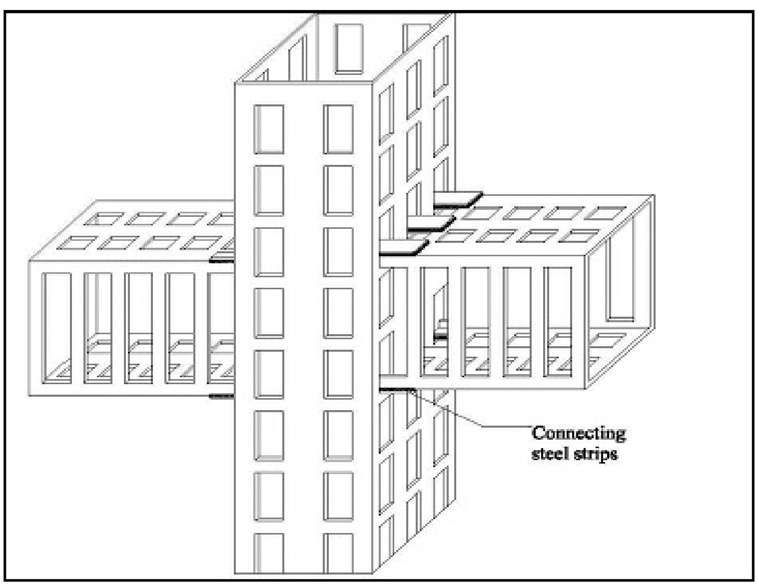

Figure 2: Connection with steel strips and welding the beam transverse reinforcement to the column

To make the joint in Figure perform as a fixed connection and transfer more moment, the transverse strips of the PCS reinforced beams can be welded to the column reinforcement. In order to place the beam reinforcement between two column reinforcements, the beams transverse strips have to be at a short distance from the column reinforcement. This space can be filled with steel wedges that are welded to the column reinforcement to make a fixed connection.

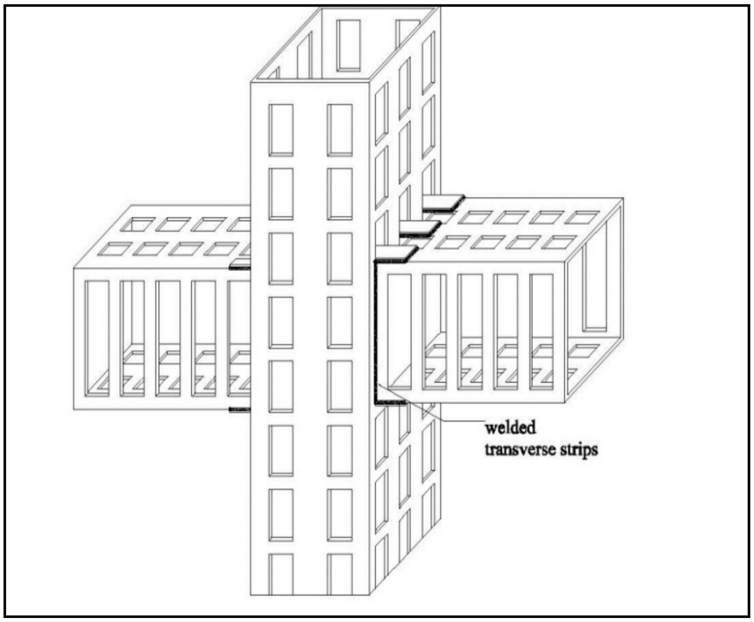

Figure 3: Welding the edges of the beam PCS to column reinforcement

Another way of connecting beam PCS reinforcement to column PCS reinforcement is similar to the connection of beam steel profiles to steel columns in traditional steel structures. As the beam PCS reinforcement can be welded to the column PCS reinforcement on all four sides providing a fixed connection. The welding has to be strong enough to transfer load and moment from the beam to the column. Buckling and tearing of the column reinforcement also has to be considered to avoid column reinforcement failure. Some stiffeners may be required inside the column reinforcement close to the welding region to avoid these failures.

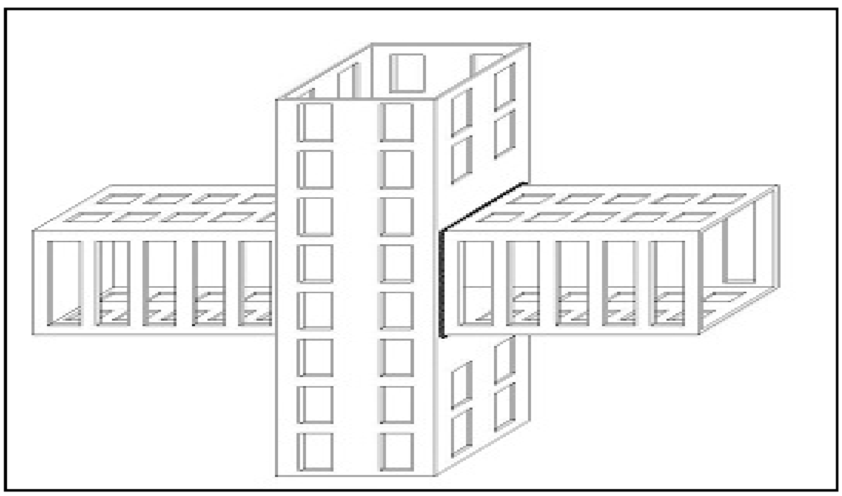

Figure 4: Welding the edges of the beam PCS to column reinforcement

1.4. Parameters to Be Considered in PCS Specimen

The following are the parameters to be considered in the design of the PCS reinforcement:

The thickness of the reinforcement tube (*t*), number of longitudinal reinforcements, width of the openings (*w*), length of the openings (*l*), and height of the transverse reinforcement (*h*) as shown in Fig.

Beam openings can be started at any distance from the joint. In Figure, the first openings are provided at a distance equal to the height of the beam reinforcement to provide a more confined and stronger joint region and consequently form the plastic hinge in the beam away from the joint region. Small openings can be provided on the column PCS reinforcement at the joint region to connect the column and beam concrete, providing a more uniform and integral joint.

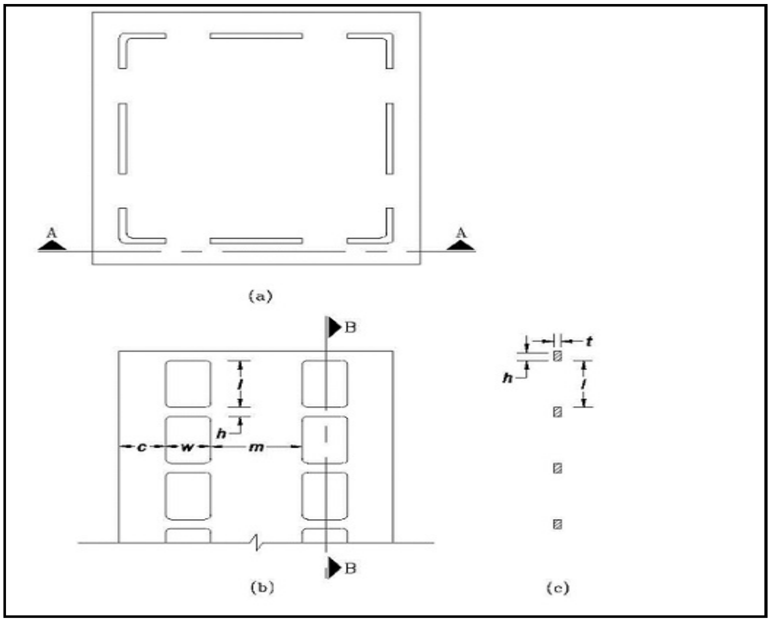

Figure 5: Parameters used in PCS specimen:
(a) plan section, (b) section A-A, (c) section B-B.

The width of the openings, *w* must be calculated to have longitudinal reinforcement equivalent to similar rebar reinforced specimen considering the parameters; tube thickness and number of longitudinal reinforcements. The length of the openings, *l* was calculated to have equivalent stirrup spacing as in the equivalent rebar reinforced specimen considering the height of the transverse reinforcement, ***h***. The height of the transverse reinforcement, ***h*** was calculated to have the same amount of transverse reinforcement as in the equivalent rebar reinforced specimen considering the transverse steel spacing. In other words, all the specimens have the same amount of transverse reinforcement per inch of transverse steel spacing.

2. Experimental Investigation

The experimental study on interior beam column joint of a multistory reinforced concrete building in Salem Zone falling under the seismic Zone – III has been analyzed using STADD.pro. The specimens were designed for seismic load according to IS 1893(PartI): 2002 & IS 13920: 1993. The structure is five storey two bay frames including 1.5 m foundation depth. The maximum moment is occurred at the ground floor roof level.

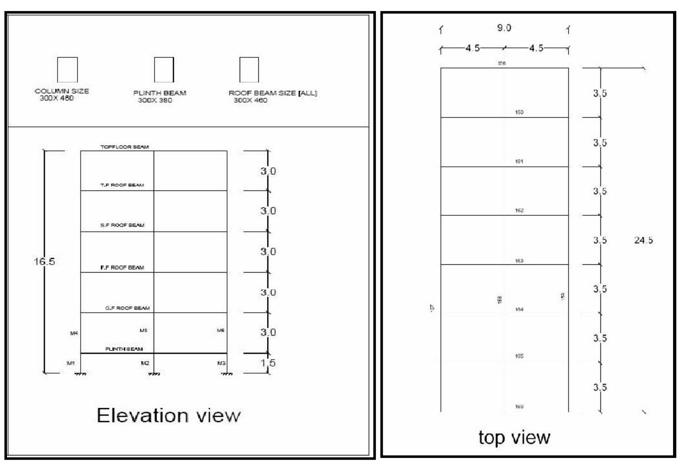

Figure 6: Elevation and plan view of two bay frame (G+4)

We are considering that particular joint for the experimental study.

2.1. Details of Control Specimen

The test specimen was reduced to 1/5 th scale to suit the loading arrangement and test facilities. Prototype specimen having beam dimension of 305 X 460 including slab thickness and column dimension of 305 X 460. For testing model the dimension of beam was 120 X 170 mm without slab thickness and beam length of 450mm and that column size was 120 X 230 mm. Height of the column was 600mm.

2.1.1. Reinforcement Details for PCS Beam Column Joint

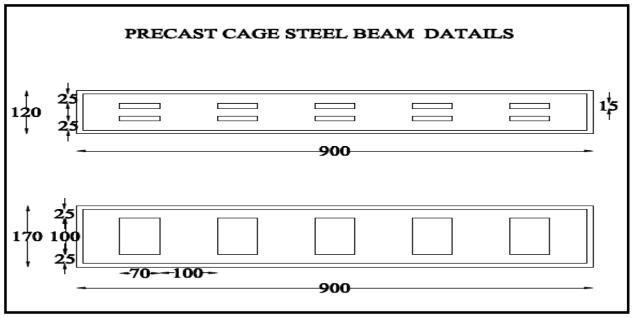

Figure 7

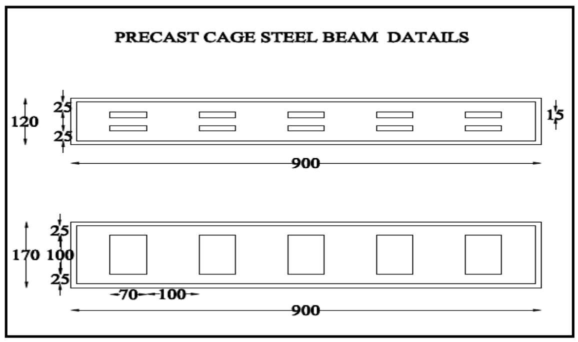

Figure 8

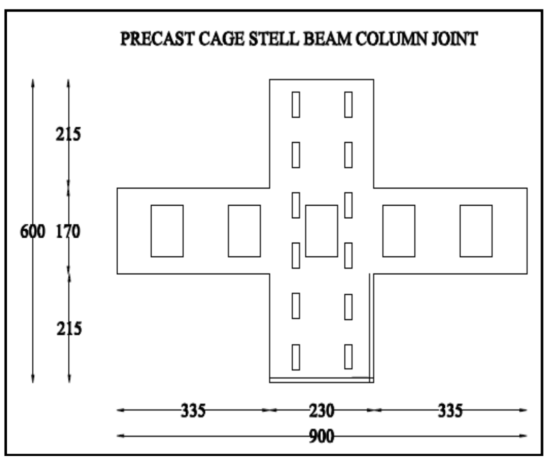

Figure 9

3. Casting of Specimen

Two series of specimen were casted one set of control specimen and other set of test specimen of PCS.

Figure 10: Test specimen of precast cage steel

Figure 11: Control Specimen

Figure 12: Casting of Test Specimen

Figure 13: Casted Specimens

Figure 14: Curing of Specimens

3.1. Test Setup

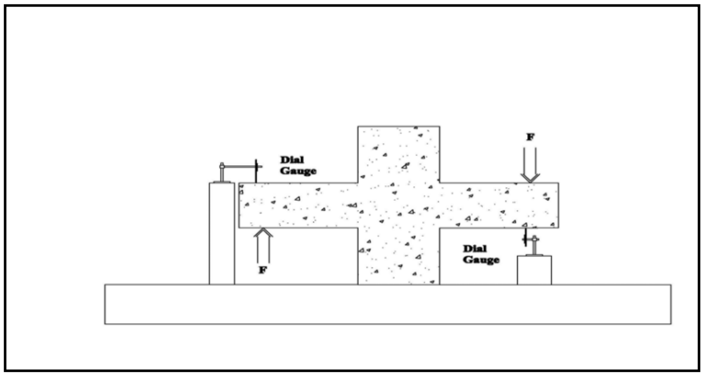

Figure 15: Test setup for cyclic loading

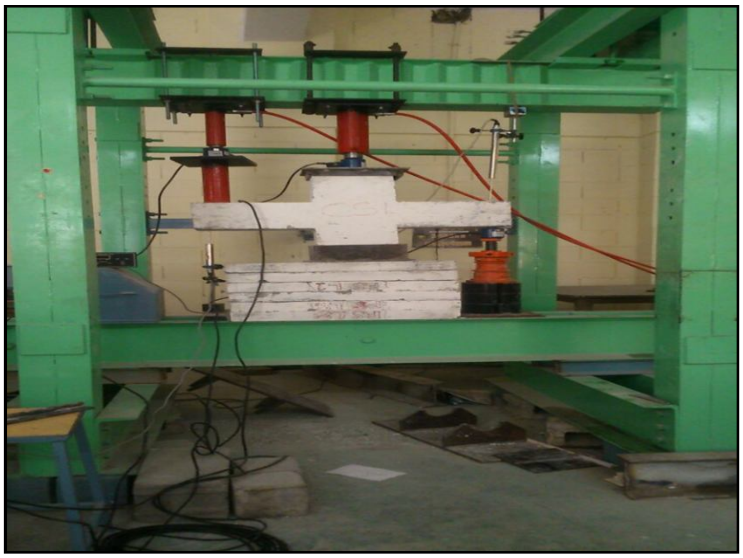

Figure 16: Testing of beam column joint

3.2. Test Procedure for Cyclic Loading

The specimens were placed in loading frame of 30 tonne capacity. The column ends are confined by means of a steel casing at top and bottom. Axial load of 0.1fck was given to top of one end of column. Cyclic load was applied at the free end of all the beams by using a hydraulic jack through load cell. Linear Variable Differential Transducers (LVDTs) were placed on the extreme edge of the both beams to show the deflection that occurred at the point of application of load on the beam. Load was applied in increments of 2KN, 4KN, 6KN etc….. corresponding deflection readings are noted done for each cycle.

3.3. Load Measurements

The load was applied at the beam end through hand operated screw jack. To avoid local stress failure, bearing plate of 6mm thickness was provided at the point of loading. The proving ring was placed between loading point and screw jack and used to measure the applied beam forces as shown. Proving ring capacity of 100 tones and 50 tonnes is used to measure the load applied on the specimens.

3.4. Deflection Measurements

Dial gauge was used for measuring deflection at necessary points of the specimen. The positions of dial gauge at measuring deflection below the load points are shown. Dial gauge was used to measure the downward displacement in beam at a distance of 285mm from the clear face of column.

4. Results

The results of Compressive Strength test, Splitting Tensile Strength of self compacting concrete are discussed. The experimental result of interior RC beam-column joint under cyclic loading has been enumerated.

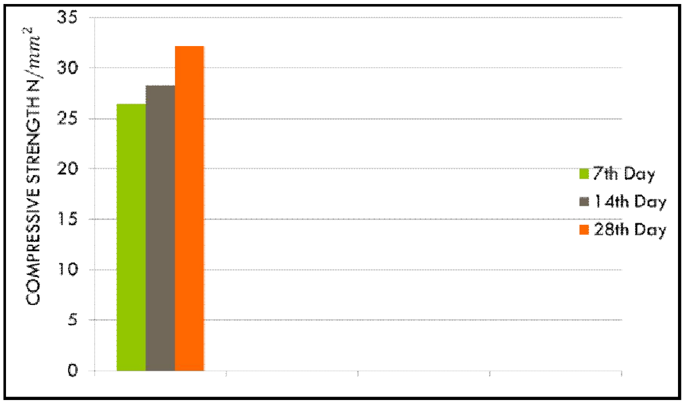

Figure 17: Compressive Strength

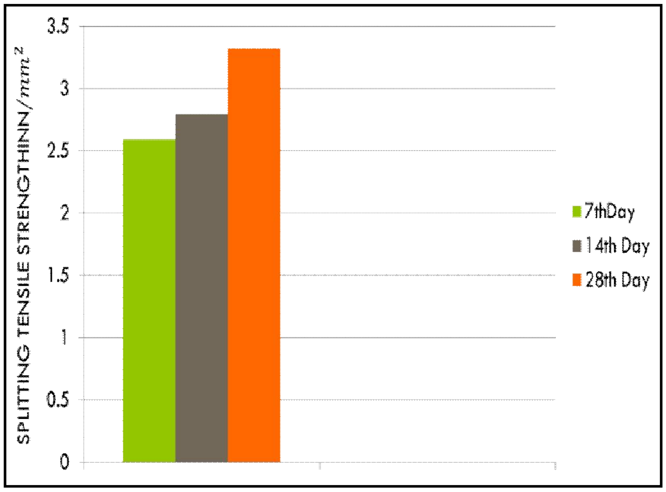

Figure 18: Splitting Tensile Strength

4.1. Ductility Factor

Ductility is an important characteristic of any structural element. It was described as the capacity f a structural element to undergo deformation beyond yield without losing much of its strength. Ductility has generally been measured by a ratio called ductility factor. It is usually expressed as a ratio of deflection (Δ) at ultimate stage to the corresponding property at yield as shown below.

Displacement ductility factor μΔ = Δu / Δy Where Δu – Ultimate displacement and Δy – Yield displacement From the experiment it was observed that the Ductility factor of PCS interior beam column joint specimen is more when compared to conventional interior beam column joint specimen.

Sl. No.	BEAM DIRECTION	DEFELECTION (mm)		
		At yield Δ_y	At ultimate Δ_u	Ductility Factor$\mu_\Delta=(\Delta_u/\Delta_y)$
1.	Right side beam	11	25.79	2.34
2.	Left side beam	10	24.59	2.45

Table 1: Ductility factor for conventional interior beam column joint

Sl.No.	BEAM DIRECTION	DEFELECTION (mm)		
		At yield Δ_y	At ultimate Δ_u	Ductility Factor $\mu_\Delta=(\Delta_u/\Delta_y)$
1.	Right side beam	8.78	27.5	3.13
2.	Left side beam	8.04	26.4	3.28

Table 2: Ductility factor for PCS interior beam column joint

4.2. Loading and Load Deflection Behaviour

The interior beam column joint specimen was subjected to cyclic loading. The load versus deflection behavior has been presented in as follows totally 4 cycles of load were imposed.

4.2.1. Load Vs Deflection for Control Specimen

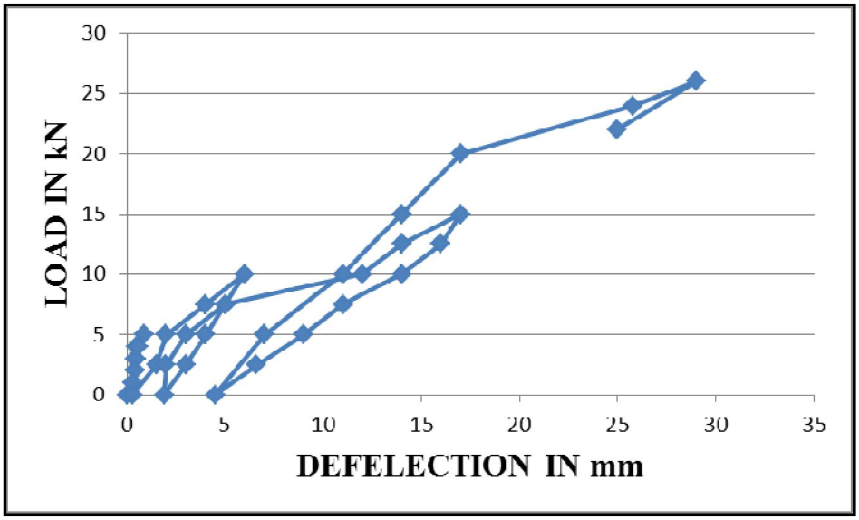

Figure 19: Load Vs Deflection curve for right side beam

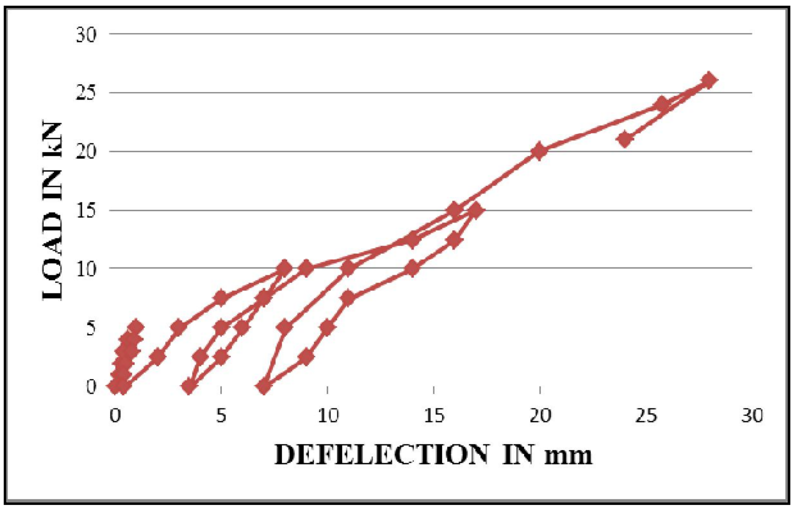

Figure 20: Load Vs Deflection curve for left side beam

4.3.2. Load Vs Deflection Curve for PCS Specimen

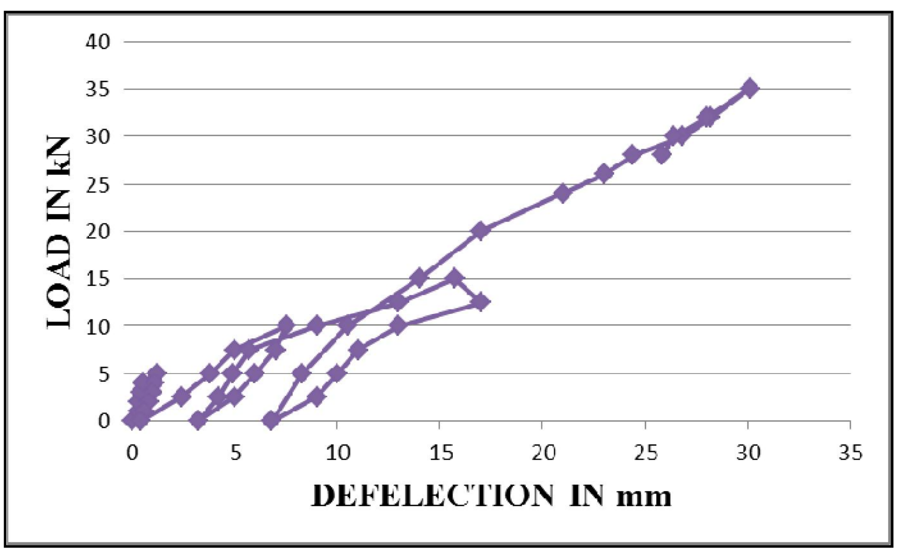

Figure 21: Load Vs Deflection curve for right side beam

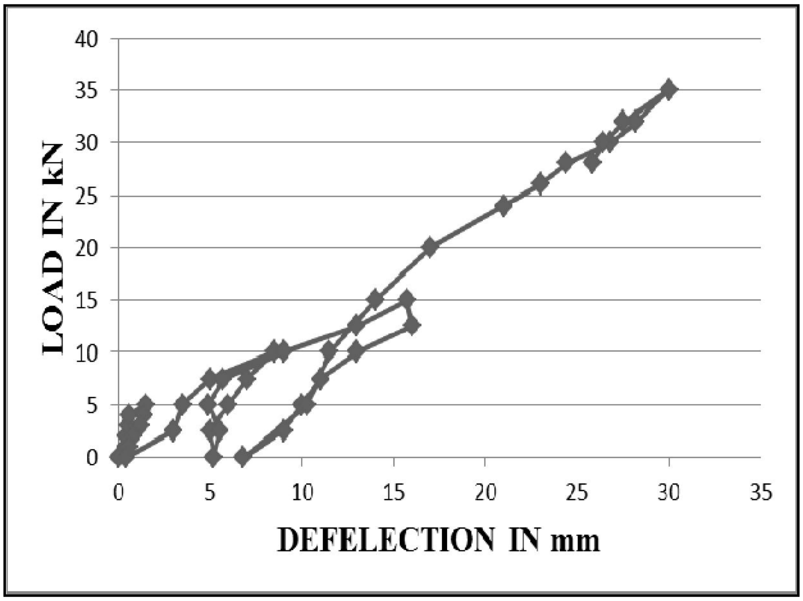

Figure 22: Load Vs Deflection curve for left side beam

5. Conclusion

The results of the experimental work have been compared and the important conclusions are

i. Prefabricated cage steel reinforced beam column joint showed better performance with delayed initial cracks than the control specimen.
ii. The ultimate load carrying capacity of prefabricated cage steel reinforced beam column joint is about 1.34 times that of control specimen.
iii. PCS confinement proves better load carrying capacity, better overall performance and provides good confinement compare to that of control specimen.
iv. The load carrying capacity of PCS interior beam column joint test 34.615% higher than conventional beam column joint.
v. The ductility factor of PCS beam column joint is more than that of conventional beam column joint.

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