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OPTIMISATION OF BEAM-COLUMN CONNECTIONS IN PRECAST CONCRETE CONSTRUCTION

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ABSTRACT

This investigation deals with the structural optimization of precast beam to column connections. It presents an up-to-date and most effective method for precast connection in terms of stability and load carrying capacity in response to meet the growing interest of optimization in structural engineering field. Dry connections considered in this investigation are: Hidden Connection, Visible Connection and Connection with Corbel. Models for the precast connections are generated and are analysed with the help of computer aided software ANSYS 14.5. The precast connections are subjected to point loading and controlled reverse cyclic loading at the beam end. The results obtained from the analysis are graphically compared to get the most efficient method of precast connection in terms of maximum displacement, stress generated, strength, hysteretic behaviour and stiffness degradation. The best precast connection determined is then structurally optimised to increase its efficiency.

Key words: Connection with corbel, hidden connection, precast connection, reverse cyclic loading, structural optimization, visible connections.

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1. INTRODUCTION

In order to provide a comprehensive solution catered to satisfy the need for the growing urban population pertaining to infrastructure development, is rapid construction. Many strategies were carried out to enhance the rapid construction cycle and among these the modularization and prefabrication of concrete structural systems proved to be more efficient in terms of structural integrity and economy in the overall project perspective. However a lot of uncertainties and vacillation are there in deciding the connections of precast concrete structures. This research seeks to provide a global solution for determining the adaptability of precast concrete connections using computer simulations.

2. LITERATURE REVIEW

Max T. Stephens et al. (2016) carried out a research study that was focused on the investigation of the concrete-filled steel tube (CFST) column–to-precast cap beam connection by integrating analytically and performing experimental research program with the help of Abacus 6.12 software. To determine the values of the study parameters and to select the experimental specimen continuum finite-element methods were used. Three different types of connections studied were: [1] embedded ring CFST (ER), [2] welded dowel (WD) and [3] interior reinforced concrete (RC) connection. The deductions drawn from the results were that all the three proposed connections sustained large deformations with minimum cap beam damage, although the WD and the RC connections required additional reinforcement in comparison to the ER. These construction methods simplify accelerated bridge construction (ABC). The WD connection facilitates sufficient force transfer between longitudinal dowel and the steel tube. The ER connection can fully achieve ABC and provide superior seismic performance and hence prove more advantageous over WD and RC connections [1].

Yeo-Jin Yun et al. (2015) investigated the joint behaviour and calculated the structural capacity of a Smart frame, which was invented by Hong et al. A smart frame comprises of precast concrete, reinforcement steels and structural tees. A series of cyclic loading test were carried on the three different specimens to examine the joint behaviour and structural performance. The three specimens were selected based on their length and placement of steels. Specimen-1 had no steel section, in Specimen-2 steel section was up to partial span and of Specimen-3 it ran along the entire span. Conclusion drawn from the tests was that flexural performance was enhanced by 46.8% for specimen-2 with respect to specimen-1 [2].

Dicky Imam Wahjudi et al. (2014) modelled a beam-column precast reinforced concrete connection and stimulated the hysteretic response behaviour of the connection subjected to cyclic loading. Computer code SeismoStruct which includes of structural analysis based on finite element method was used to perform the numerical calculations. In order to describe the characteristics of the moment rotation relationship that occur at the plastic hinge region Richard-Abbot model was selected. The results showed that the response history curve has similar characteristics with that of the experimental results. At particular circumstances the beam-column connection specimens with U-bent bar anchorages the analytical results showed a slightly fatter curve but in general both the results have shown decent conformity [3].

R. Vidjeapriya and K.P. Jaya (2013) attempted to develop a one-third scale prototype of beam-column connections for both precast and monolithic specimen (ML) having the equal design strength. Two precast dry connections specimens were designed, for first case the beam was connected to the column with the help if a corbel using cleat angle with a single stiffener (PC-DS). For the second case cleat angle with two stiffeners were used for the precast connection (PC-SS). The specimens were subjected to controlled cyclic displacement lateral loading at the beam end. The conclusions drawn from the experimental investigation were that the load carrying capacity of the PC-DS is 11.76% and 6.25% higher when compared to the PC-SS and 18% and 25% less when compared to the ML in positive and negative direction respectively. Energy dissipation of PC-DS is 22% more than PC-SS and 13% less than ML. The increase in the ductility was observed to be 31% and 8% in PC-DS when compared with PC-SS and ML respectively. Also it was observed that no cracks developed for either of the precast specimen, whereas cracks were found in the column region for ML [4].

Vasireddy Gangadhara Ramesh Babu et al. (2013) focussed upon the prefabricated concrete beam and column connections. The two types of specimens used were monolithic and precast beams and columns. For the precast specimen a welded steel plate was connected to the end of the beam along its longitudinal section. Dowel bars were welded to steel plates and placed transversely in the column. Connections were achieved with the help of bolting and washers were incorporated at the joints to absorb shocks. The cruciform comprised of one column and two continuous beams. Displacement controlled cyclic load history test was conducted on the specimens which was based on drift angle and represented several loading conditions for the beam-column joint. Study of mechanism of prefabricated connections under several loading conditions lead to the conclusions that in specimens the preliminary shear cracking arises at the lower level of nominal shear stress, the energy dissipation is more for monolithic specimen whereas more damages and formation of wider cracks are observed in precast specimen [5].

Xue and Yang (2010) examined the behaviour of precast concrete connections as moment resisting frames under the action of cyclic loading. Four different types of connections studied were internal connection, external connections, knee connection and T connection. As compared to other connections the knee connection evidenced to be less efficient. Strong column and weak beam failure was exhibited by all the connections. It was observed that seismic performance of all the connections with respect to ductility, strength and energy dissipation capacity was satisfactory [7].

3. METHODOLOGY

The precast beams and columns of dimension 300mmX300mm are designed and detailed according to IS 456:2000 and IS 13920:1993. The beams and columns are connected using hidden, visible and corbel connections and designed according to IS 800:2007. Model generation and analysis of the precast structures were done using ANSYS 14.5. A comparative study is done with the help of graphical representations to find the most efficient precast connection and is further numerically optimised to increase its structural performance as a connection.

3.1. Design and Detailing of Precast Elements

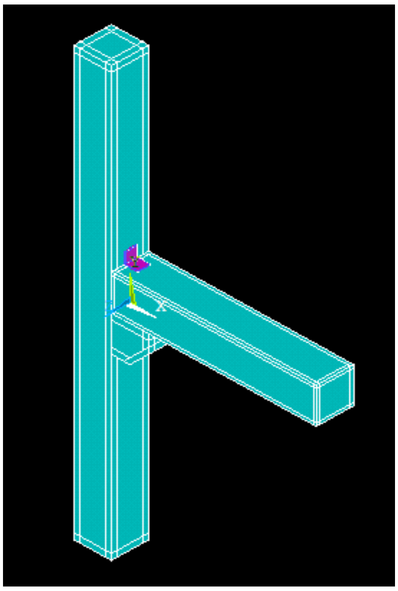
The precast beams and columns are designed and detailed according to IS 456:2000 and IS 13920:1993 respectively. Grade of concrete and steel used are M30 and Fe 415 respectively. The clear span of column is 3600mm and that of the beam is 1650mm. Cross-sectional dimension of both the elements are 300mmX300mm. Four numbers of 25mm diameter bars are used as main reinforcement for columns and for beam the tension and compression reinforcement are provided with two numbers of 12 mm diameter bars each. 2 legged 8mm diameter bar are used for stirrups and lateral ties. Near the connections the spacing of the reinforcement has been reduced to 100mm centre to centre. Spacing provided between stirrups and ties are 200 mm and 250mm respectively.

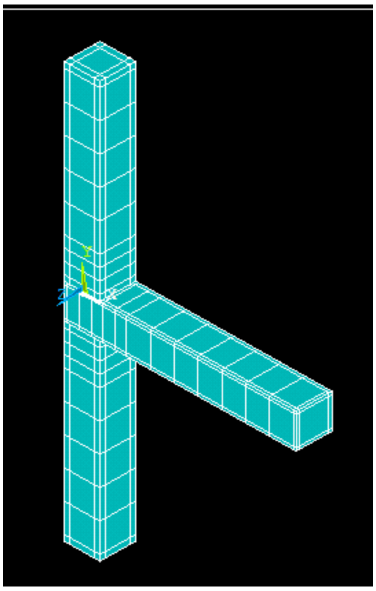
3.2. Design and Detailing of the Precast Connections

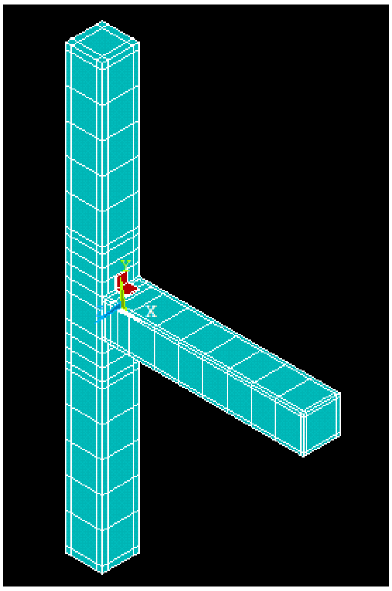
Connections are provided according to IS 800:2007. For the connection with corbel the column is constructed along with the corbel. The hidden connection is provided using a solid steel section (billet) of dimension 300X100X100. In both the cases beams are held in position using steel angle of dimension 100X100X12 and 12mm bolts. Visible connection is provided with the help of a 25mm rod.

3.3. Load and Support Conditions

An axial load of .1f_{ck}Ag i.e. 270KN has been applied along the axis of the column to stimulate the dead load transferred from the upper floors. Loading are applied at a distance 300 mm from the extreme end of the beam. The columns are attached to fixed support at the bottom. Connections are the precast elements that determine the structural performance of the whole precast system. To determine the effect of the earthquake on the connection reverse cyclic loading is applied on the structures.







(1) (2) (3)

Figure 1 ANSYS model of precast beam and column connection with corbel (S1). Figure 2: ANSYS model of precast beam and column connection with beam-column visible connection (S2). Figure 3: ANSYS model of precast beam and column connection hidden connection (S3).

4. RESULTS AND DISCUSSIONS

4.1. Static Analysis Results

The analysis results show that subsequent to the application of the point load the structure S1 can resist maximum deformation of 2.97mm without cracking, which is 2% and 32% more than the S2 and S3 respectively. Fig 4 illustrates the maximum displacement a structure undergoes for every unit increase in the magnitude of the point load.

The ultimate load carrying capacity of the structure S1 is 44.4% and 73.3% more than S2 and S3 respectively. Table 1 displays the ultimate load carrying capacities of the structures.

Stress generated near the connection is least in case of structure S1. Fig 5 points to the stress generated near the connections for each precast concrete structure.

Table 1 Ultimate load carrying capacity of the precast concrete structures

STRUCTURE	LOAD (kN)
S1	26
S2	18
S3	15

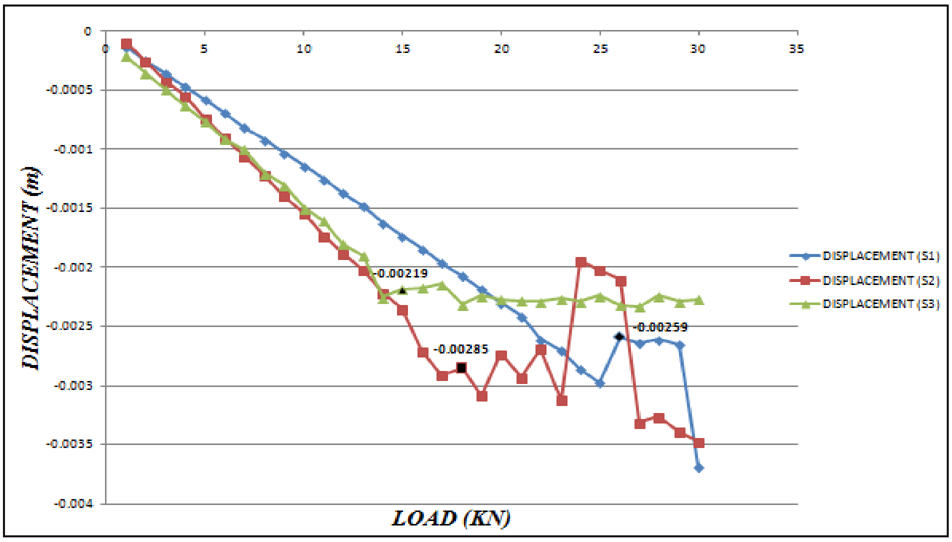


Figure 4 Load vs Displacement curve for all the three connections

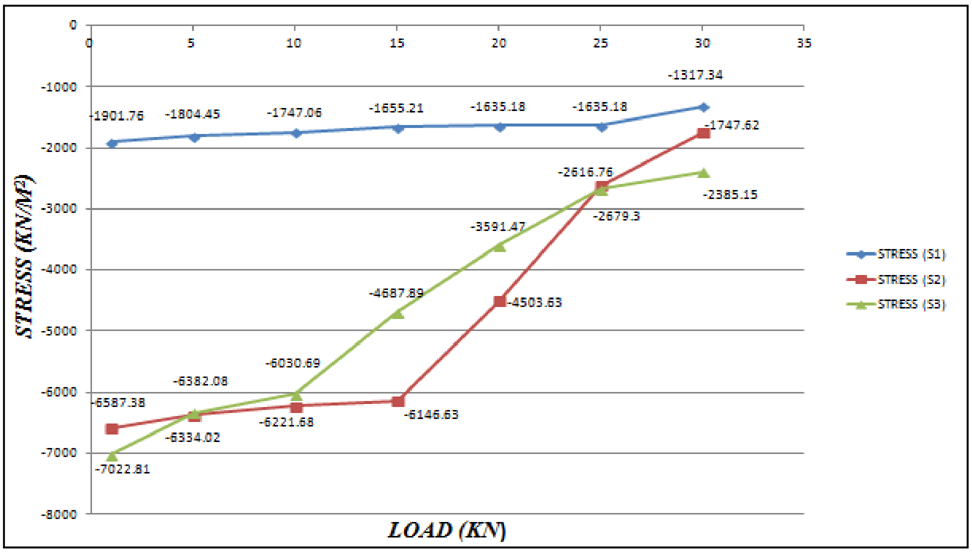
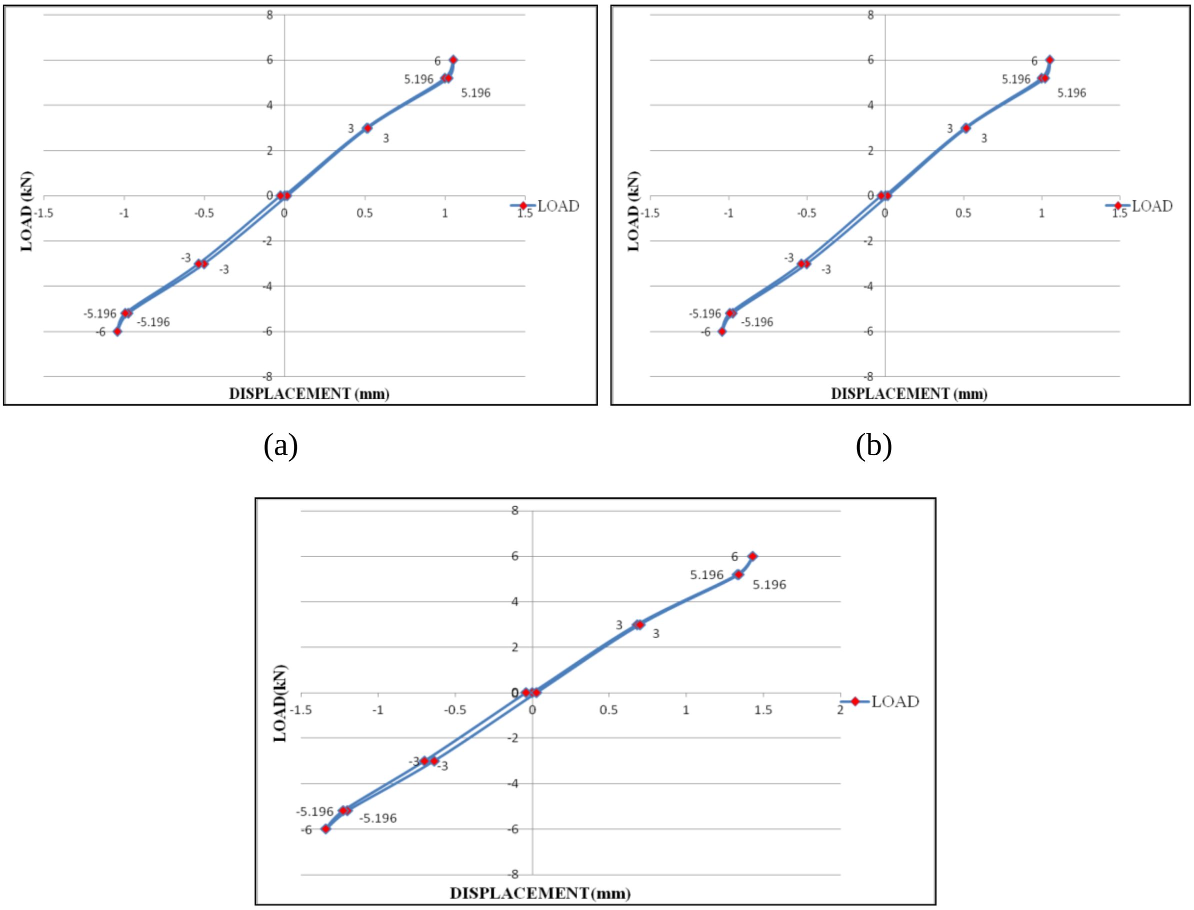


Figure 5 Load vs Stress curve for all the three connection

4.2. Quasi-Static Analysis Results

Application of the reverse cyclic loading reveal that, the ultimate load carrying capacity of the structures S1, S2 and S3 reduces to 7kN, 3kN and 7kN respectively which is way below as compared to when it was acted upon by point loading. The reason behind the decrease in the load bearing capacity is fatigue failure of the structures. Fig 6 illustrates the hysteretic behaviour of the precast beam-column connections.

Stiffness degradation is determined by calculating the slope of the line joining the positive peak and the negative peak of the response cycle. Fig 7 shows the stiffness degradation with respect to the increase in displacement for structure S1 and S2.



(a) (b)

(c)

Figure 6 Hysteretic behaviour of structure (a) S1 (b) S2 (c) S3

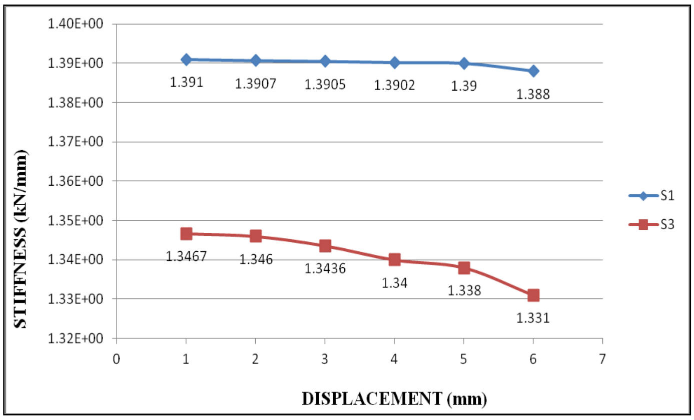


Figure 7 Stiffness vs Displacement graph for structures S1 and S3

4.3. Structural Optimisation Results

The structural optimisation increased the efficiency of the precast beam-column connection with corbel in terms of its structural performance. Table 2 lists down the difference between the responses of the un-optimised and optimised precast corbel connections.

Table 2 Difference of responses between un-optimised and optimised connection

LOAD	CRITERIA	100X100X12#12	150X150X18#20
POINT LOADING	STRENGTH	26 kN	30kN
	MAX DISPLACEMENT	.00297m	.0034m
	STRESS	-1317.34kN/mm^2	-894.175kN/mm^2
REVERSE CYCLIC LOADING	FATIGUE FAILURE	7kN	9kN
	MAX DISPLACEMENT	1.05mm	1.72mm
	STIFFNESS DEGRADATION	1.391-1.388 kN/mm	1.407-1.404 kN/mm

5. CONCLUSIONS

Application of the point loading and the reverse cyclic loading at the beam edge, points out to some of the specific characteristics which the precast beam-column connection exhibits.

- The structure having precast beam-column connection with corbel can tolerate 2% and 32% more displacement than the structure connected with visible and hidden precast connections respectively.
- Connection with corbel generates the least stress near the beam-column connections.
- Ultimate load carrying capacity of the connection with corbel and the hidden connection is the same during reverse cyclic loading.
- Stiffness degradation is 4.1% and maximum displacement at the beam end is 36.2% higher in case of hidden connection when compared to connection with corbel.
- Considering the typical structural behaviour of the connections towards point loading and reverse cyclic loading, precast beam-column connection with corbel proves to be the most efficient in terms of superior structural performance.
- By changing the angle's size to 150x150x18 mm^3 and increasing the bolt diameter to 20mm the structural performance of the precast beam-column connection is enhanced.
- Structural optimisation increased the ultimate load carrying capacity, maximum displacement at the beam end by 15.38% and 14.48% respectively and decreased the stress generation at the connection by 32.12% during application of point load.
- For reverse cyclic loading, structural optimisation increased the strength and maximum displacement (without cracking) by 28.57% and 63.81% respectively, where as stiffness degradation decreased by 5.33%.

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