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Cyclic behavior of in-situ exterior beam-column subassemblies with cold joint in column

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ABSTRACT

Four sets of exterior-beam-column subassemblies with and without construction joint (cold joint) in column to simulate multistage casting at site were tested under cyclic loading. Flexural strength ratios of the specimens were 1.2, 1.4, 1.7 and 2.0. It was observed that the reduction in energy dissipation capacity of the specimens with cold joint were 24–49% compared to control specimens. It was also found that there was 22–36% decrease in ductility of the specimens with cold joint. Reduction in initial stiffness of the specimens with cold joint in column was found to be significant. Difference of peak loads between control and the corresponding specimens with cold joint were negligible. Four sets of reinforced concrete beam specimens with and without cold joint with different percentage of tension reinforcement were tested for flexural capacities under static load. Reduction in peak load of beam specimens with cold joint in comparison to control specimens was found to be insignificant.

1. Introduction

Beam-column joint is considered as the most critical area in seismic design of reinforced concrete (RC) moment resisting frames. In RC structures, function of beam-column joint is to transfer load from connecting members effectively, when subjected to seismic excitation. Beam-column joint may be defined as the portion of column within the depth of the deepest beam that frames into the column [1]. Beam-column joint may be classified into three types viz. exterior joint, interior joint and corner joint.

Till 1970, little attention was given on the vulnerability of beam-column joint under seismic excitation. Early experiments on the beam-column joint were conducted by Portland Cement Association [2]. Since then, lots of research have been done on beam-column joints for development of theories as well as to evaluate performance of beam-column joint under different loading conditions [2–25].

Seismic design procedure for in-situ construction generally considers that the connection of beam and column that frames into the joint is monolithic in nature [1]. But in actual construction it is not possible to cast columns of multi-story frame in one go and therefore, a construction joint (cold joint) is inevitable in all the upper story columns immediately above the lower story slab (Fig. 1). This construction joint of cast-in-situ structures is not same as that of precast construction joint. In precast construction, different methods are adopted for connecting different components of precast structures. Threaded rebar connection, post-tensioned connection, mechanical connection, wet connection etc. are adopted to impart adequate rigidity and stiffness to the precast connections [26]. The design procedure for different types of connection of precast concrete structures were detailed by Park [27].

Till date, extensive research has been carried out on precast beam-column subassemblies with cold joint to evaluate their performance under cyclic loading. French et al. [28] investigated four different types of connections viz. post-tensioned, threaded rebar, composite post-tensioned and welded connections under cyclic lateral load and concluded that threaded connection and composite connection were better among the four. Cheok and Lew [29], Restrepo [30], Xue and Yang [31] reported that, under cyclic load, performance of precast beam-column connections were at per with monolithic connection in terms of strength and ductility. Joshi et al. [26], Ersoy and Tankut [32] conducted cyclic test on precast concrete specimens with different types of connections and observed that strength, stiffness and energy dissipation capacity of the precast members were comparable to monolithic members. Ozden and Ertas [33] studied the behavior of precast post-tensioned beam-column subassemblies with different mild steel reinforcement content under cyclic load and reported that with the increase in mild steel content the performance of beam-column joint became better and comparable to monolithic joint. Vidjeapriya and Jaya [34] observed a reduction in the performance

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Fig. 1. Photograph of in-situ construction with cold joint in column.

of precast beam-column joint specimens in terms of strength, energy dissipation, and hysteretic behavior. Parasthes et al. [35] observed better performance of precast specimens with construction joint in columns above and below the beam compared to monolithic specimens in terms of ductility and energy dissipation capacity.

Review of literatures reveal that performance of beam-column subassemblies with construction joint in column due to multistage casting at site is not reported till date. An effort has, therefore, been made in the present study to investigate effect of cold joint in column simulating multistage casting of real structures in seismic performance of in-situ beam-column subassemblies.

2. Materials and methods

2.1. Material properties

M20 grade concrete was used for casting of specimen. Ordinary Portland Cement (OPC) 43 grade [36], locally available alluvial medium sand and crushed stone aggregate of size passing through 10 mm were used for production of concrete. Reinforcement steel of grade Fe 500 [37] was used as longitudinal reinforcement and plain mild steel bars of grade Fe 250 [38] was used as transverse reinforcement. Potable water was used for production of concrete and curing. Mixing was done in the laboratory by a pan type concrete mixer of capacity 40 L.

2.2. Description of test specimens

Four sets of exterior beam-column subassemblies (BCJ) were prepared for testing. Specimens were designed following strong-column weak-beam concept [39]. Beams and columns were designed based on procedures laid down in IS: 456-2000 [40]. Four different flexural strength ratios (R) viz. 1.2, 1.4, 1.7 and 2.0 were considered in the present investigation. Flexural strength ratio (R) may be defined as follows [1]:

R = Ratio of sum of the nominal flexural strengths of column sections above and below the joint to the sum of the nominal flexural strength of the beam sections at that joint.

It is worthwhile to mention that, different codes across the globe adopt different R values for seismic design. For example, R = 1.2 [41], R = 1.3 [42] R = $\varnothing_0 \times 1.4$ [43] where $\varnothing_0$ is over-strength factor for beams (Uma and Jain [44] considered R = 2.06 for NZS code) and R = 1.1 [39]. Flexural capacities of beams and columns of BCJs were varied by varying the reinforcement. The joint panel of the beam-column subassemblies were designed for shear as per 'Explanatory examples for ductile detailing of RC buildings' published by IIT Kanpur [45]. The ratio of shear capacity to shear demand of the test specimens is provided in Table 1.

Special confinement reinforcement inside the core area of beam-column joint was provided taking into consideration the provisions of Indian Standard Code of Practice, IS: 13920-1993 [46]. The area of cross-section of the bar (A_{sh}) forming rectangular hoop is calculate by the following equation:

$$A_{sh} = 0.18Sh\left[\frac{A_g}{A_k} - 1\right] \quad (1)$$

where

S = spacing of hoops,
h = longer dimension of rectangular hoop
A_g = gross area of column cross-section
A_k = area of concrete core to the outside of hoop.

The minimum spacing specified by code is 75 mm c/c. In the present study hoop reinforcements were provided with 6 Ø @ 50 mm c/c. (Table 1, Fig. 2).

In test specimens, the anchorage length for both the top and the bottom bars of beam was provided beyond the inner face of column, with 90° bend directed towards joint core. Equation for calculating the development length as per IS: 13920-1993 [46] is as follows:

$$L_d = \frac{\O\sigma_s}{4\tau_{bd}} \quad (2)$$