Seismic Resistant Hybrid Precast Beam-Column Connections with Shear Key

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ABSTRACT

The structural elements are factory-made and transported to the site and connected using different mechanisms in precast concrete framed structure construction. The improved quality control, reduced the construction period and the use of alternative construction materials made the precast construction more effective than the cast-in-situ construction. The connection between the structural elements such as beam to column, column to column, column to the foundation, beam to beam, slab to the beam is playing a crucial role in deciding the performance of this type of construction. The reconnaissance survey of many earthquakes shows the susceptibility of these structures under seismic force and shows the importance of connections in seismic resistance. Also, the various structural failures due to man-made mistakes exhibit the importance of proper design, execution with better workmanship. The connections can be categorized into three types such as dry, wet, and hybrid connections and the performances are distinct and vary concerning the materials used and methodology adopted. This article presents an overview of various precast structural failures observed during natural and manmade disasters and discusses the various types of connections and their cyclic behavior. An experimental program is conducted to study the cyclic behavior of indigenous precast beam-column connections with better seismic resistance. Precast column and beams were cast separately and connected using the proposed mechanism and tested under quasi-static loading.

INTRODUCTION

Precast concrete structural members are factory-made and are made ready to install on-site. These structural members have numerous advantages in terms of quality assurance and service by industry when compared with the monolithic construction methodology, precast construction saves time, lesser requirements of scaffolding and formwork, and reduction of labor cost. Due to precast concrete structure advantages, it has been used in many countries. The most vulnerable part in precast concrete construction is the joints between the precast structural members i.e., beam-column connection, beam-beam connection, column-column connection, column to foundation connection, etc. Therefore, the connection area can be well-thought-out as the most critical and weakest part of precast structural elements. Due to this issue, precast frame construction is not widely used in high seismic zones in most countries. When particularly considering connections, the beam to column connection plays the foremost role in precast concrete construction. The biggest challenge is to fulfill the structural fundamentals of the precast concrete frame i.e., every connection should be able to transfer the vertical shear, horizontal shear, axial tension and compression, bending moment, torsion, and sufficient energy dissipation between the precast elements. Therefore, the performance of precast concrete connections is not well-known in general practice.

Objectives

The primary aim of this research is to investigate the inelastic cyclic behavior of precast exterior beam-column joints with the use of high-performance fiber-reinforced cementitious composites and a new connection methodology in precast beam-column connection and also to study the seismic behavior of the precast beam-column connection under revered cyclic loading using seismic parameter and compared with the monolithic joint.

LITERATURE REVIEW

This chapter generally gives a brief overview of various research works which were carried out in the past time by various researchers in the field of precast structures. As it would be a tough task to present a thorough review of the failure of the precast structures either by seismic action or by man-made mistakes. Also, the literature review related to the connection of the precast structural elements and their performance is present in a brief review but deeply explained as possible of the previous studies present on the precast connection techniques and their behavior under various loading conditions. The failure study of precast structures shows how the contribution of the structural elements was under the action of earthquake forces and how man-made mistakes lead the precast structural elements to collapse. This study focuses on the mistakes and precautions to be taken care of while constructing the precast structures and additionally the study tells us the importance of connection in the precast structural members, especially in the precast beam-column connection.

16 May 1968 Ronan Point Apartment Tower Collapse

This apartment tower was build using the Larsen-Nielsen system which was a system of precast concrete factory-built components. This system was introduced for structures not more than six-story buildings. The precast concrete panels were used in the design were combined without the structural frame continuity and faulty connection due to which there was no load-path existed which allowed the distribution of loads.[21]

13 November 2013 Ft. Lauderdale Garage Failure

The precast walls were collapsed at a garage construction site because of the high tensile forces subjected by the temporary pipe which was braced with the wall which majorly leads to the footplate failure of the brace which was supporting the top of the precast wall.[17]

Pittsburgh Airport Precast Parking Garage Defects

International airport precast double T beam in parking garage suffered shear failure cracks because of inadequate pre-stressing and improper bonding between concrete and pre-stressed reinforced strands. [27]

Florida 2012 Parking Garage Failure

The precast parking garage collapsed due to inadequate shear walls. The installation and design of the shear wall in ongoing connection of precast elements and the shear wall were improper as shown in figure 2.11.[23]

Figure 2.11 Failure Due to Shear Wall [23]

MECHANISM OF BEAM-COLUMN JOINTS
GENERAL

This chapter discusses the principle of the conventional and the precast beam-column joint and how much joint shear will be taken by the joints. Also, the chapter explains the design parameters and the mechanism of the beam-column joint, and the parameter which was considered to design the proposed precast connection by adopting the conventional design method. The design also portraits the comparison between the experimental and theoretical joint shear as per ACI and NZS codes.

Beam Column Joint (Monolithic)

Beam column joints are a critical region in moment elastic framed structure, during earthquakes joints get subjected to a large number of moments, and because of the positive and negative nature of earthquake waves, moments in column and beams change sign, this creates horizontal and vertical shear forces in joint core region which are higher than adjacent beam and columns. A joint will fail in shear failure if it is not specifically designed for such forces.

Precast Beam-Column Joint With The Design

Similar to the design of the conventional joint, the precast joint was also designed by the same method due to the connection methodology used in the precast beam-column connection which ensures the continuity of the longitudinal reinforcement, the stiffness of the coupled reinforcement is higher than the normal reinforcement and the proper transfer of forces and energy dissipation through key is sufficient to design the precast joint as conventional joint because the composite used in the shear key is successfully transferring the forces with higher strain capacity.

CYCLIC BEHAVIOR OF PRECAST BEAM-COLUMN CONNECTION

General

This chapter focuses on three subdivisions of the study i.e. mechanical properties of the material i.e. compressive strength and flexural strength of HPFRCC and SFRC. Also, the material used to cast the precast elements, experimental work which includes the casting procedure of the precast structural member's beam, the column with shear key,and the monolithic joint, and alsothe proposed connection methodology and how the specimen has performed under reversed cyclic loading. Also, this chapter includes an in-depth discussion of the test results observed by the specimens under reversed cyclic loading to observe the performance of the precast beam-column connection under seismic parameters such as load-displacement curve, strength and stiffness degradation, energy dissipation, backbone curve, ductility, pinching width ratio, damping and damage index to compare the performance of the precast joints with the conventional joint under seismic actions.

MECHANICAL PROPERTIES

Material Used

The ordinary Portland cement (OPC) of grade 43 was used as the cementitious compound for the production of M30 grade concrete to cast the precast structural column and beam elements. In the proposed connection HPFRCC was used. OPC of grade 43 as a cementitious compound, sand, fly ash, GGBS, and steel fibers according to the volume of cement, and polypropylene fiber according to the weight of the cement was used in HPFRCC preparation. Fe500 reinforcement bars were used in joint specimens.

Connection Procedure of Proposed Precast Beam-Column Connection

The precast beam protruding longitudinal bars were joined with the protruding longitudinal bars of the column keeping the bars straight and joined with the hybrid coupler. The bolts were tightening to tight the coupler with the reinforcement bars and epoxy was inserted into the coupler to make a strong bond in the coupler. The upper part of the bolts was removed and to complete the connection HPFRCC was poured into the shear key and the connection region.

CONCLUSIONS

Based on the experimental study the following conclusions are drawn.

1. The hysteresis loop of precast type I and type II specimens is distinct from the monolithic specimen. It portraits that the load-carrying capacity of the precast specimens was higher than the monolithic specimen in positive and negative pull. A certain amount of strength degradation was observed in the monolithic specimen due to its crack pattern observed but the precast type I specimens have shown a lesser amount of strength degradation whereas type II specimens have shown a very lesser amount of strength degradation compared to the monolithic specimen. It is clearly evident that the failure of the monolithic specimen occurred at 6% drift with strength degradation but till 6% drift, all the precast specimens have shown an almost negligible amount of strength degradation. Also, the hysteresis curves manifest the higher displacement ductility in the precast specimens till 9% drift. No pinching was observed in the PJ0 specimen due to its monolithic properties but the precast type I and type II specimen have shown pinching behavior based on their shear key dimensions. The type I specimens have larger shear key size due to which less pinching was observed and type II specimen have smaller shear key size due to which more pinching was observed. The size of the shear key effectively dominates the pinching behavior of the precast specimens due to reduction in the joint area which is clearly evident in the hysteresis curve.

2. The trend of the skeleton curve of all the specimens shows approximately similar initial and post-yield stiffness which shows that the precast type I and type II specimens have monolithic properties as that of the PJ0 specimen and also the precast specimens have shown better resistance to deflection till failure but there is no evidence of stiffness degradation in precast specimen till 6% drift when compare with the monolithic specimen. The post-yield stiffness behavior in positive and negative pull shows that the precast PJ2 and PJ4 have exhibit higher initial stiffness at 1% drift than monolithic joint but the trend changes after 2% drift and shows clear evidence that the precast specimens have shown better initial as well as post-yield stiffness than the monolithic joint.

3.The trend of RED and CED gives clear evidence that the precast specimen started exhibiting higher energy dissipation than the monolithic specimens from the initial stage itself and till 4% drift but at 6% drift the precast type II specimens have shown similar energy dissipation to monolithic joint but higher final energy dissipation due to better displacement ductility and type I specimens have exhibited higher energy at each level of loading.

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