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Effect of Fire on Prefabricated Concrete Beam Column Connections

Ch.Subramanyam Teja, Tej Sai Moturu, G.Yaswanth Kumar, Haroon Ali Khan

Abstract**: *The objective of this work is to study the performance of the beam column connections in precast structures exposed to fire. Three different connections were considered for the study. The first one is monolithic and the remaining two are precast specimens joined through hybrid and corbel connections. This study is carried out in two phases. The first part of this study is experimental investigation of three beam-column specimens subjected to axial load until failure. The second part is experimental investigation of the beam-column specimens exposed to fire and axial load. The results suggest that irrespective of the fire, among the monolithic, hybrid and corbel connections of beam-column specimens, the specimen with corbel connection has the best performance in terms of toughness of the joint.***

Index Terms**: *Prefabricated Concrete, Beam-Column Connections, Fire, Hybrid, Corbel, Monolithic.***

I. INTRODUCTION

Prefabrication is the process of developing the structural elements at the site or at the factory and assembling the components at the required location. Complex structures can be constructed by connecting prefabricated concrete elements like precast beams, columns, slab panels, stairs etc. in less duration with desired quality. Due to improved mechanization and standardization techniques, prefabrication has become sustainable and has been increasingly adopted worldwide. [2]

In any concrete structures, the load is transferred from beam to column through beam column connections. These connections are subjected to compression, tension and shear force making them more vulnerable. Connections play a most crucial role in the performance of a joint. There are numerous studies involved in the research field with regards to the connections. In prefabricated structures, connections were installed in three different methods like dry, semi-dry and wet methods. For this evaluation, the present study considers three different exterior beam column connections. One is monolithic connection which is cast in-situ and wet method. Another one is corbel connection which is a semi-dry method involving in-situ casting of a small volume of special mortar for completion. The last one is hybrid connection which is a dry connection [3],[5].

Fire could significantly reduce the strength of the reinforced and precast concrete components as well as the connections in precast structures. The literature illustrates that the surface cracks initiate at nearly 300 ^{o}C and consequently cracks propagate with an increase in temperature leading to the spalling of concrete cover [1]. The failure of joints can happen due to different reasons such as reduction of bending or tensile strength, decrease of compressive strength, loss of shear or torsional strength and more. The failure modes of concrete exposed to fire may vary according to nature of fire, loading system and type of structure. As per the previous research, the beam column joints subjected to fire damages the structural stiffness of the beam and also damages the integrity between beam end and the column faces which consequently decreases the toughness of the connections [1]. Though there is significant work has been carried out on concrete with respect to effect of fire, the studies performed on effect of fire on hybrid and corbel connections are scarce. Thus, the present study aims to investigate the influence of fire on three different aforementioned connections to improve the stiffness and toughness of the beam-column joint.

II. BEAM COLUMN CONNECTIONS

There are numerous types of connections to join precast beams and columns. For this investigation three types of connections were selected. All the specimens were designed for same loads.

A. Monolithic Specimen

The monolithic specimens were developed to compare the results with the results of the precast specimens. The monolithic specimen consists of one column and one beam in the form of T shape connected monolithically as shown in Fig. I (a). The reinforcement cage was placed in the mould and then casted monolithically using wet method. The reinforcement details are illustrated in Fig. I (a).

B. Precast Specimen (Corbel Connection)

The first precast connection is a semi-rigid exterior beam column connection formed by a precast concrete beam supported on a precast concrete column corbel as shown in the Fig. II. The gaps between the rebar and concrete are filled using grout.

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* Correspondence Author
Ch.Subramanyam Teja*, Department of Civil Engineering, V R Siddhartha Engineering College, Vijayawada, India.
Tej Sai Moturu, Department of Civil Engineering, V R Siddhartha Engineering College, Vijayawada, India.
G.Yaswanth Kumar, Department of Civil Engineering, V R Siddhartha Engineering College, Vijayawada, India.
Haroon Ali Khan, Department of Civil Engineering, V R Siddhartha Engineering College, Vijayawada, India.

Towards the top of the beam a cleat angle with stiffeners on either side is provided. The cleat angle is vertically anchored into the beam and horizontally anchored into the column restraining the upward lifting of the beam. The grout was provided in vertical interface to increases the rotational flexural stiffness and flexural strength capacity of the connections [3]. The reinforcement details are illustrated in Fig. I (b).

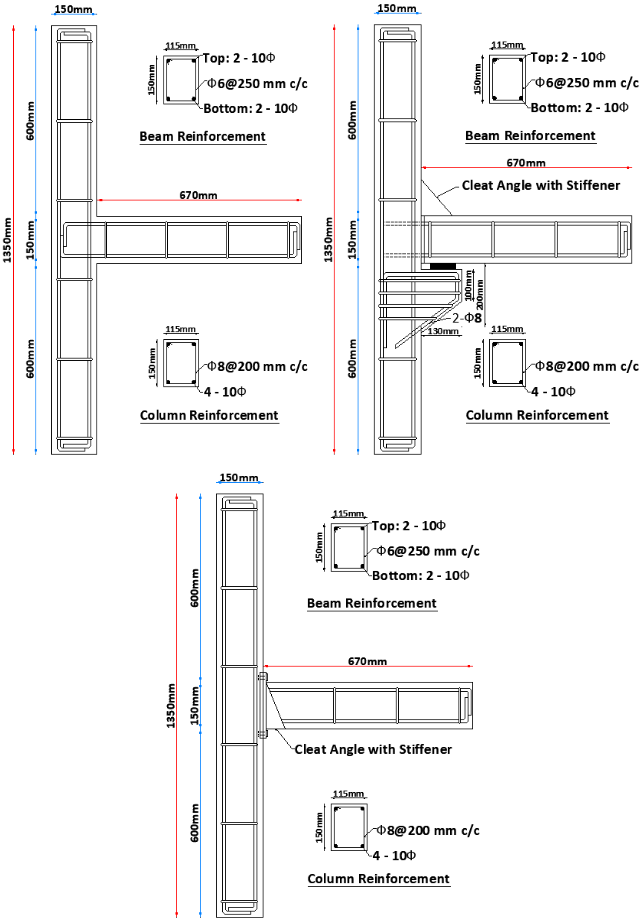

Figure I (a) Monolithic Specimen, (b) Precast Specimen with Corbel Connection, (c) Precast Specimen with Hybrid Connection

C. Precast Specimen (Hybrid Connection)

The second precast specimen is a semi-rigid exterior beam column connection formed by precast concrete beam joined to a precast concrete column through hybrid connection as shown in the Fig. III. The hybrid connection consists of a cleat angle with two stiffeners on both edges and a small stiffener at the middle [4]. The beam reinforcement is linked to the cleat angle using arc welding in vertical face and then casted in a mould. Another Plate is welded at the center of the main reinforcement of the Column and casted. After curing both the specimens was joined using bolted connection which is a dry method. The reinforcement details are illustrated in Fig. I (c).

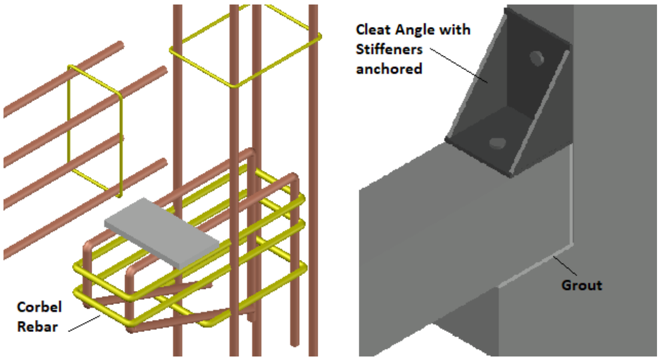

Figure II - Precast Specimen with corbel connection

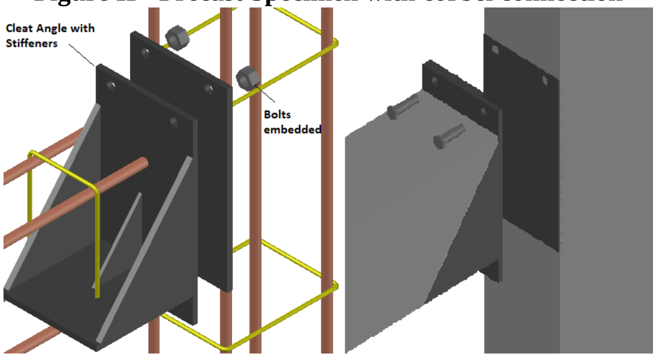

Figure III - Precast specimen with Hybrid Connection

III. EXPERIMENTAL INVESTIGATION

The experimental program consists of two monolithic specimens (M1 to M2), two precast specimens with hybrid connection (H1 to H2) and two precast specimens with corbel connection (C1 to C2). These specimens were divided into two groups as follows:

Group 1: consisted of two specimens of each type of connection (M1, H1, C1), to study the performance of connections subjected to axial load.

Group 2: consisted of two specimens of each type of connection (M2, H2, C2), to study the performance of connections subjected to 400^{O}C constant temperature fire and axial load.

The specimens were casted using Ordinary Portland Cement of 53 Grade with specific gravity 3.1 and confirming to IS 269:2015. Natural river sand of Zone III with specific gravity 2.64 was used as fine aggregate. Crushed granite stone of maximum size not exceeding 10 mm was used as coarse aggregate confirming to IS 383:2016. The mix proportion of 1:1.85:3.65 with water cement ratio of 0.45 was adopted. The 28 days average compressive strength of cubes tested was 24.4 N/mm^2. The yield stress of the reinforcement used is 535.05 N/mm^2. All the specimens were casted in moulds under controlled environment and de-moulded after 24 hours. The specimens were then cured using gunny bags. Flogrout 60 was used as grout chemical to fill the gaps between the precast elements and connections.

IV. TEST PROCEDURE

The specimens in the Group 1 were tested using hydraulic loading frame of 50-ton capacity.

The load was controlled manually through testing machine and the displacements were measured using a Linear Variable Differential Transformer which can measure displacements up to 50mm. The both ends of the column specimen were fixed. The load was applied at the end of the cantilever portion of the beam. The test setup is diagrammatically illustrated in Fig 4.

The specimens in the Group 2 were subjected to 400 ^{O}C fire temperature for duration of 60 minutes near the connection using a gas burner. Initially the specimen attained the 400 ^{O}C temperature in 20 minutes. Then the temperature is maintained constant for another 60 minutes. The temperature variation in the specimens was captured using thermal imaging camera as shown in Fig. V, VI and VII respectively.

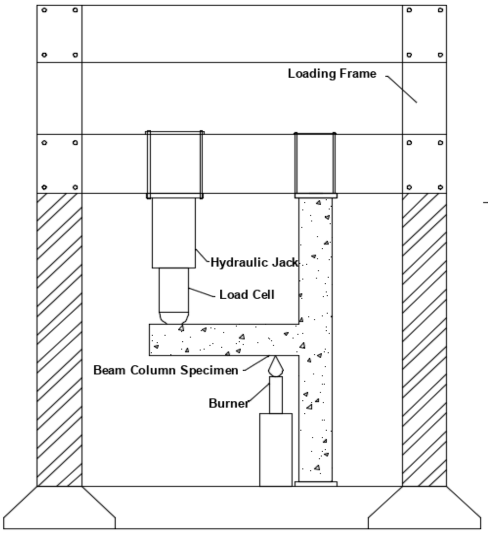

Figure IV - Experimental Setup

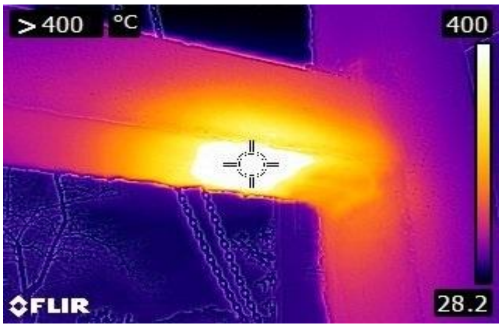

Figure V - Temperature variation near Monolithic connection

Figure VI - Temperature variation near Corbel Connection

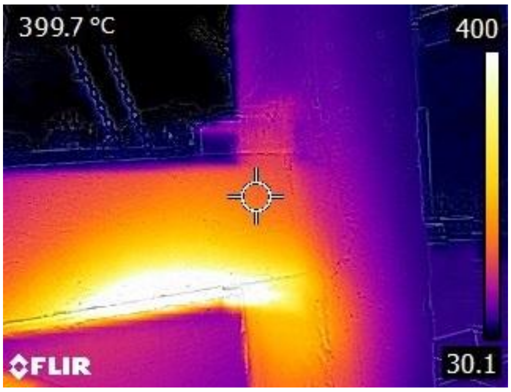

Figure VII - Temperature variation near Hybrid Connection

V. RESULTS AND DISCUSSION

The load and displacement values were recorded for each beam column specimens and average curves were plotted as shown in Fig. VIII. The important properties were noticed at the first crack level and load at ultimate were given in the Table 1. The toughness was evaluated from the area under the load vs displacement curves and these values are given in column 6 of Table I.

A. Load displacement behavior of beam column specimens (without fire)

The average load displacement curves of different beam column joints of specimens i.e. M1, H1 and C1 are shown in Fig. VIII. In the Monolithic specimens (M1), the first crack is initiated at load which is nearly 54% of the ultimate load. The displacement at the first crack is nearly 30% of the displacement at ultimate load. In the precast specimens joined using corbel joints (C1), the first crack is initiated at load which is nearly 60% of the ultimate load. The displacement at the first crack is nearly 22% of the displacement at ultimate load. In the precast specimens joined using Hybrid joints (H1), the first crack is initiated at load which is nearly 53% of the failure load. The displacement at the first crack is nearly 42% of the displacement at ultimate load. Among all the beam-column specimens, the specimen with corbel connection has shown the best performance in terms of toughness of the joint.

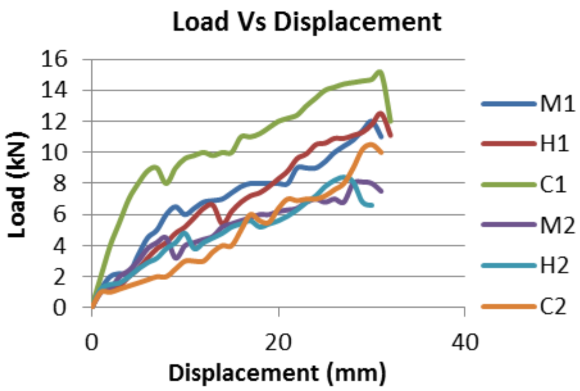

Figure VIII - Load vs. Displacement Graph

B. Load displacement behavior of beam column specimens (with fire)

The average load displacement curves of different beam column joints of specimens i.e. M2, H2 and C2 are shown in Fig. VIII. In the Monolithic specimens (M2), the first crack is initiated at load which is nearly 55% of the ultimate load. The displacement at the first crack is nearly 28% of the displacement at ultimate load. In the precast specimens joined using corbel joints (C2), the first crack is initiated at load which is nearly 53% of the ultimate load. The displacement at the first crack is nearly 56% of the displacement at ultimate load. In the precast specimens joined using Hybrid joints (H2), the first crack is initiated at load which is nearly 58% of the failure load. The displacement at the first crack is nearly 37% of the displacement at ultimate load. Among all the beam-column specimens, the specimen with corbel connection subjected to fire has shown the best performance in terms of toughness of the joint.

Table I - Load-displacement of beam-column connection at different loading

Specimen (1)	At First crack Load, kN (2)	At First crack δ, mm (3)	Ultimate Load, kN (4)	Ultimate δ, mm (5)	Toughness $x10^6$N-m (6)
M1	6.5	9.0	12	30.0	1.94
H1	6.6	13.0	12.5	31.0	2.11
C1	9.0	7.0	15.1	32.0	2.36
M2	4.5	8.0	8.1	29.0	1.54
H2	4.8	10.0	8.4	27.0	1.89
C2	5.6	18.0	10.5	30.0	2.09

δ - displacement

VI. CONCLUSIONS

In this investigation, three different types of beam-column connections were studied and important conclusions were obtained. The performance of the monolithic and hybrid beam-column connections is almost nearly similar, whereas the corbel beam-column connections have shown the better performance when compared to others. Irrespective of the fire, among all the beam-column specimens, the specimen with corbel connection has shown the best performance in terms of toughness of the joint.

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AUTHORS PROFILE

Ch.Subramanyam Teja is pursuing M.Tech Structural Engineering at V R Siddhartha Engineering College, Vijayawada, India. He completed his B.Tech in NRI Institute of Technology in the year 2017.

Tej Sai Moturu is currently working as Assistant Professor in V R Siddhartha Engineering College has completed his M.Tech in 2014. He has 4 years of experience in academics and 3 publications in various journals.

G.Yaswanth Kumar, is currently working as Assistant Professor in V R Siddhartha Engineering College has completed his M.Tech in 2015. He has 3 years of experience in academics and 2 publications in various journals.

Haroon Ali Khan has completed his Masters in Texas A&M University, Kingsville in the year 2016. He is working as Assistant in V R Siddhartha Engineering College.