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ANALYTICAL STUDY ON PRECAST BEAM-COLUMN CONNECTION

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ABSTRACT: In the recent years, there is enormous infrastructural growth in India. The rapid infrastructural growth together with increasing demand for quality buildings necessitate the construction industry to continuously seek for improvement. This will lead to industrialization in the building industry, which can be achieved in the form of precast concrete construction. A precast concrete component is a construction product produced by casting concrete in a reusable mould or form work which is then cured in a controlled environment, transported and erected into to the construction site. In the International arena precast concrete sector has experienced reasonable growth in the recent years. This is because precast concrete provides high-quality structural elements, construction efficiency, and savings in time and overall cost of investment. Though it has many advantages over the cast-in-situ concrete construction, still there is hesitancy in extensively constructing precast concrete structures in highly seismic areas.

INTRODUCTION

It can be observed that many precast concrete structures have failed mainly due to the poor connections between the precast elements themselves and between the precast elements and lateral load-resisting system. Hence, there is a necessity to carry out more research in this area. For the past four decades though a lot of research has been carried out on the behavior in precast structures, a complete understanding of the behavior of precast beam-column connections to Static loading has not been completely understood. As India is a fast-developing country, there is a large scope for improvement in the construction sector, especially towards development and utilization of factory made quality controlled precast units that provides for faster construction leading to economy.

OBJECTIVE

The objectives of the present work are

Developing and Studying the behaviour of two different exterior precast beam-column connections by considering the following parameters:

a. Ultimate Load and Carrying Capacity
b. Cracking Pattern and Failure Mode
c. Load-Displacement Behaviour

Conducting analytical studies on the monolithic and two precast beam- column connections using finite element package ANSYS. Validating the experimental results with analytical results.

METHODOLOGY

To meet the objectives as mentioned above, the following methodology is adopted.

A typical three storeyed reinforced building is analysed and designed in ETABS Software and an exterior beam column connection is chosen.

Two types of precast connection and a monolithic connection is developed.

Analytical studies were conducted on all the connections using ANSYS and the results are obtained.
The results has to be compared for further studies.

SCOPE OF THE STUDY

The scope of this study is to develop a simple precast beam-to-column connection. The study is limited to evaluation of the strength, load carrying capacity and maximum deflection of the beam-column joints. The research work covers the performance of monolithic connection and precast connection which includes (i) Beam to column connection using grouted dowel pipe (BCJ GDP), (ii) Beam to Column connection using grouted dowel pipe and steel plates (BCJ GDP-P)

LITERATURE REVIEW

GENERAL

The study on behavior of precast joints is of great importance as the connections form the weakest link in the structure. Experimental studies are necessary as it gives the realistic response of the structure. But the use of Finite Element packages to model the structural elements is faster and cost effective. Hence, many parameters can be studied by modelling the structural elements using Finite Element packages. Several researchers worldwide have investigated the behavior of precast beam-column connections both experimentally and analytically. A detailed review of the literature has been` carried out to understand the behavior of precast beam column connections under cyclic loading. Among these the most significant literatures are briefly summarized in this chapter.

OVERVIEW OF LITERATURE

M. N. Kataoka et al (2012) stated that the tests of the connections models tested presented satisfactory behaviour because they reached a load which exceed the maximum load determine in their project, which was 150 kN. This performance can be attributed to the design details and to the care taken during the construction of the models. In order to improve the connection behaviour, a greater number of stirrups at the ends of the beams were concentrate, minimizing the cracking and avoiding the slippage between the precast concrete and the cast on site concrete. In the models the stirrups reached the concrete cover of the slab, were the continuity reinforcement was located at the same level. The transverse reinforcement was used to reduce the stress in the connection and to distribute the cracks. In Model 2, the cracking began on the beams and not in the connection as usual. In the construction of the bending moment versus rotation curve was used the average of the rotations and the bending moments of the right and left sides. Comparing the curves of the two models, Model 2 presented Experimental stiffness higher than Model 1, the difference reached 65%. Comparing the secant stiffness, this difference between the models was lesser, about 22%.

Blaz Zoubek, et al (2013) have developed and tested two types of connections one by using dowel rod and another by using the neoprene bearing pad. The most important observations are: (1) standard theory assuming that the failure mechanism is initiated by flexural yielding of the dowel and crushing of the surrounding concrete has been confirmed, (2) the strength of the connection considerably depends on the depth of the plastic hinge in the dowel, (3) in the case of the cyclic loading the strength is reduced due to the smaller depth of the plastic hinge, (4) neoprene bearing pad can considerably increase the strength of the connection, particularly when large relative displacements between the beam and the column are developed, and (5) in the case of large rotations between the beam and the column, cyclic resistance is reduced by 15–20%, because the dowel is loaded not only in flexure but also in tension.

R. Vidjeapriya and K.P. Jaya. (2012) concluded that the load carrying capacity of the connection with dowel bar and cleat angle exhibited 25.31% and 37.54% greater load carrying capacity than the specimen with dowel bar in the positive and negative direction respectively. This is due to the additional stiffness developed due to the presence of cleat angle. Compared to the monolithic specimen, the specimen with dowel bar and cleat angle exhibited lesser load carrying capacity. The variation is 29.32% and 25.79% in the positive and negative direction respectively. Considering the energy dissipation, the specimen with dowel bar and cleat angle have performed better than the specimen with dowel bar alone and dissipated 10.71% higher energy than specimen PC-DW. The energy dissipation of specimen with dowel bar and cleat angle is about 16.52% lesser than the monolithic specimen. Finally, proposed that the connection with dowel bar and cleat angle can be used for the construction of low rise moment resisting frames.

H.-K. Choi, et al. (2013) have done a five half-scale interior beam-column assembly representing a portion of a frame subjected to simulated seismic loading were tested, including one monolithic specimen and four precast specimens. Variables included the detailing used at the joint to achieve a structural continuity of the beam reinforcement, and the type of special reinforcement in the connection (whether ECC or transverse reinforcement). The specimen design followed the strong-column- weak-beam concept. The beam reinforcement was purposely designed and detailed to develop plastic hinges at the beam and to impose large inelastic shear force

Demands into the joint. The joint performance was evaluated on the basis of connection strength, stiffness, energy dissipation, and drift capacity. From the test results, the plastic hinges at the beam controlled the specimen failure. In general, the performance of the beam to column connections was satisfactory. The joint strength was 1.15 times of that expected for monolithic reinforced concrete construction. The specimen behavior was ductile due to tensile deformability by ECC and the yielding steel plate, while the strength was nearly constant up to a drift of 3.5%. The maximum strength of the specimens with the inside and the outside type connections was improved by 15% when compared with the control specimen and the specimens with the outside type connection showed greater strength and energy dissipation than those with the inside type connection.

Haider Hamad Ghayeb, et al (2017) Stated that two precast and two monolithic concrete joints for exterior beam-to column connection were tested under cyclic loading. The installation of precast specimens was prepared using dry type method while the monolithic joints were cast in-situ. The evaluation of seismic performance of the joints was conducted by applying hysteretic reverse cyclic loading until failure. Information regarding the strength, ductility and stiffness properties of the connection were recorded and analyzed. Based on the test results and damage condition, the initial design of the joint was improved. Consequently, a new joint was constructed and tested, which exhibited a better performance. Precast concrete connections showed stable load–displacement cycles and dissipated a higher energy. The structural drift obtained was up to 9.0%. Pinching and deterioration were attained at a drift ratio of 4.5%. The displacement, drift ratio and elastic range were higher for the PC2 connection in this study compared to PC1 connection. This is attributed to the steel angles and steel studs in the joint area. Also, the drift ratio increased by 1.46 for the PC2 relative to that for PC1. (2) The strength ratio of the PC2 specimen was higher than that of the PC1 by a factor 1.42.

Li Shufeng, et al (2017). Concluded that precast joint has satisfactory ductility and energy dissipation ability by developing a new-type of fabricated beam-column connections with end-plates and the seismic behaviour of the new-type precast connections are tested by pseudo-static test. The hysteresis curves are recorded during the test, and the seismic indicators, such as ductility and energy dissipation capacity, are determined. The test results indicate that the hysteresis curves of precast connection are plump, and all specimens failed in bending in a malleable way with a beam plastic hinge, which is fully consistent with the criterion of strong column weak beams. Additionally, the fabricated connection exhibits satisfactory ductility and energy dissipation capacity, showing better seismic performance. Besides, the flexural capacity of unbonded prestressed confined concrete beam is analysed, and the formula of flexural bearing capacity is proposed based on the theory of concentrated plastic zone. The author concluded that the displacement ductility coefficients of the specimens are between 2.6 and 3.4, and the equivalent viscous damping coefficients are 0.221–0.239.

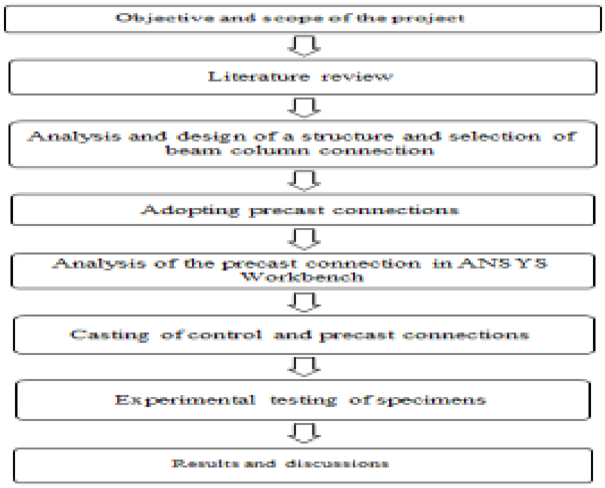
Qiushi Yan, et al (2017). Have done cyclic load tests on both precast and cast-in- place specimens to identify structural characteristics of beam column connection using grout sleeve and stated that when the column to beam strength ratio value is less than 1, the failure mode of the precast specimens is shear failure. As such the column to beam strength ratio needs to be controlled in structure design. For precast specimens, grout sleeves and the cast-in-place part are the two important components which affect the performance of the plastic hinge in the beam. They can improve the stiffness and strength of part of the beam near the joint, which indicates that the yield and ultimate displacement of the precast specimen is higher than that of cast-in-place specimen. Furthermore, the distribution of cracks in precast specimen is sparser (rarely appear in the area of grout sleeve), and the yield range of beam reinforcement extends to the joint more quickly. Rebar holes significantly affect the seismic performance of the joint. Test results show that it can greatly improve the shear stiffness of the joint in precast specimens. However, when the column to beam strength ratio value is less than 1, rebar holes have little impact on the seismic performance of the joint. Some precast specimens develop cracks along the rebar hole and the slippage of rebar in the joint is obvious, which indicates that the integration of both grout and concrete, as well as concrete and rebar is poor. Base on the above findings, it is proposed that the net distance between the inner surface of the rebar hole and the longitudinal reinforcement should increase to achieve better structural performance.

SUMMARY

From the literatures, it is observed that the precast connections can be developed as strong as that of the monolithic connections. It is also understood that the dry connections have better energy dissipation characteristics. Hence, for the present study two types of precast connections have been adopted for the analytical and experimental investigations. From the literatures, it was decided to use the finite element package ANSYS for modelling and analytical study. Information about the elements to be used in modelling the various materials was also studied. It was concluded that, for modelling precast connection in ANSYS the most appropriate element to be used is beam element. Also, data input in material model to simulate concrete to behave in multi-linear, elastic and inelastic stages are decided from the literature study. From the experience of past researchers, possibilities and reasons of error and approximations were also studied.

METHODOLOGY

This research study is carried as per the following method. Based on the literatures studied two types of precast connection were adopted and the specimens are investigated analytically and experimentally. Finally, the results were compared with the control specimen. Below flow chart describes the method adopted in this thesis work.



SELECTION OF EXTERIOR BEAM COLUMN CONNECTION

GENERAL

In a reinforced concrete framed building subjected to lateral loading, the most critical region is the beam column joint. Due to the beam moments and the column moments, the joint experiences large horizontal and vertical shear forces. The joint experiences diagonal cracks when tensile stresses exceed the tensile strength of the concrete. Extensive cracking occurs within the joint due to load reversals, affects its strength and stiffness. Hence the joint becomes flexible and undergoes substantial shear deformation (distortion). If the beam column joint is not designed properly, joint failure will occur which will ultimately lead to collapse of the framed buildings. This chapter discusses about the design of beam column joint for the forces acting at the joint.

ANALYSIS AND DESIGN OF THREE STORIED STRUCTURE

A three storied reinforced concrete building with plan dimensions 9m x 9m, is considered for the present study. Figure 4.1 shows the plan and elevation of the building showing the exterior beam-column joint (joint A) considered. Figure 4.1 (a) and Figure 4.1 (b) shows the elevation of frame in transverse and longitudinal directions respectively. Figure 4.1 (c) explains the details of the joint 'A' considered for the present study.

The beam and column dimensions were 300mm X 360mm and 360mm x 300mm, respectively. A live load of 2kN/m^2 and 1.5kN/m^2 has been adopted for the floors and roofs respectively. The floor finish was 1kN/m^2. The storey height adopted was 3.5 m for all the three stories. The thickness of the peripheral and internal brick wall was taken as 230 mm and 150 mm respectively. M40 grade concrete and Fe415 grade steel has been used for design. The three storey RC building was analyzed using ETABS software. The shear forces, axial forces and bending moment in the exterior beam-column joint in the first floor had been calculated for the various load combinations. Seismic analysis had been performed using equivalent lateral force method recommended by IS: 1893-2002. The analytical model employed in ETABS is shown in Figure 4.2. The shear force, bending moment and axial force developed at joint A has been retrieved from the analysis. Then the joint A has been designed and detailed as per IS: 456-2000 an IS: 13920-1993 respectively.

4.1 DESIGN OF BEAM- COLUMN JOINT

The beam column joint has been designed in ETABS and the required area of reinforcement for the selected sections were chosen. The beam-column joint has been modelled to a scale of 1/3rd and the dimensional details are given in table 4.1. The reinforcement details of scaled down specimen according to IS 13920 are shown in table 4.2.

CONNECTION DETAILS OF SPECIMENS

Control Specimen

The monolithic reinforced concrete test specimen was designed according to IS: 456-2000 and detailed according to IS:13920-2016. The flexural reinforcement for the beam consisted of four bars with one bar at each corner of the transverse reinforcement. Two numbers of 10 mm diameter bars were provided as tension reinforcement and two numbers of 10 mm diameter bars were provided as compression reinforcement for beam. The shear reinforcement contains 6 mm diameter two legged stirrups spaced at 100 mm. For a distance of 200 mm from the column face the spacing of the lateral ties were decreased to 50 mm. The column reinforcement arrangement is provided with 4 numbers of 12 mm diameter bars. Along the column height excluding the joint region, the lateral ties were spaced at 100 mm. At the joint region the spacing of the lateral ties were reduced to 50 mm. The schematic representation of the isometric view of control specimen is shown in Figure 4.3.

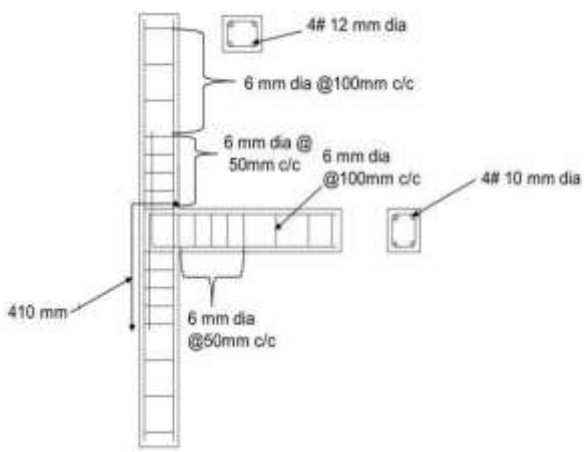


Figure 4.3 Control specimen

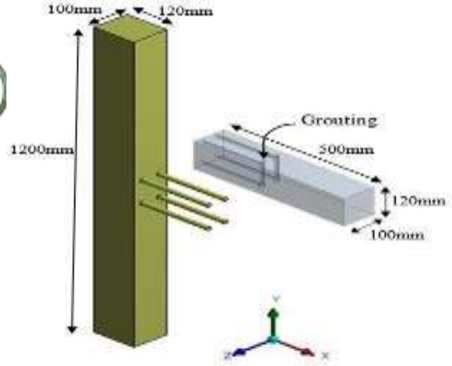


Figure 4.4 Reinforcement details of Control specimen

Precast Concrete Connections

Two types of precast beam column connections considered for the present study are,

(i) Connection using grouted dowel pipe (BCJ GDP)

(ii) Connection using grouted dowel pipe and steel plates (BCJ GDP-P)

The details of the two connection types are discussed in the following section.

Precast connection: Connection using grouted dowel pipe (BCJ GDP)

In this connection, the main connecting element was the grouted steel dowel pipe. Dowel pipe of 15 mm diameter was cast inside the precast beam for a length of 200mm from the connecting face. The column was cast with a beam reinforcement projecting for a length of 200mm. The beam was inserted on to the projecting reinforcement bar of 10 mm diameter. Cementitious high strength non-shrink grout was filled into dowel pipe hole to complete the connection. The schematic representation of the BCJ-GDP is shown in Figure 4.5

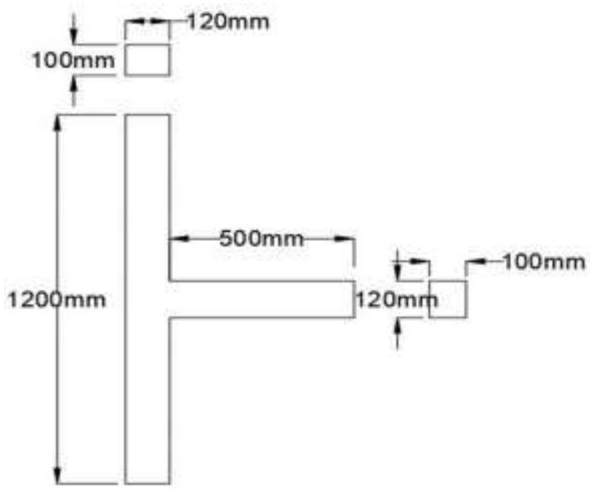


Figure 4.5 Connection using grouted dowel pipe

Precast connection: Connection using grouted dowel pipe and steel plates (BCJ GDP-P)

In this connection, the main connecting element was the grouted steel dowel pipe along with metal plates and steel rod. Dowel pipe of 15 mm diameter was cast inside the precast beam for a length of 200mm from connecting face. The column was cast with a beam reinforcement projecting for a length of 200mm. The beam was inserted on to the projecting reinforcement bar of 10 mm diameter then the metal plates are fitted in its respective places. The metal plate of size 320mm x 100mm fixed at the column face opposite to the connecting face and the folded metal plates of dimensions 100mm x 100mm on each folded face is connected in top and bottom

of the Beam and the other face of column then the rod is fixed. Cementitious high strength, non-shrink grout was filled into dowel pipe hole to complete the connection. The schematic representation of the specimen BCJ GDP-P is shown in Figure 4.6 (a) and (b).

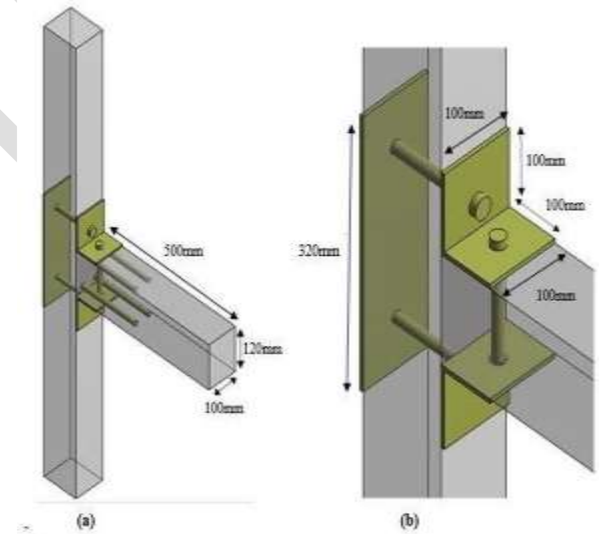


Figure 4.6 Connection using grouted dowel pipe and steel plates

SUMMARY

The modelling of a three storey RC building was analysed and designed using ETABS software was described in this section. From the analysis the area of reinforcement of an exterior beam-column joint considered for this study is obtained. The beam, column and joint dimensions and reinforcement details were arrived from the results obtained. Using the scale factor of 1/3, the reinforcement details and dimensions of the beam, column and joint were arrived. This section also describes the monolithic specimen and two types of precast beam column connections used for this study.

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ANALYTICAL INVESTIGATION ON EXTERIOR BEAM-COLUMN JOINTS IN ANSYS

GENERAL

Different methods have been utilized to study the response of structural components. Experimental based testing has been widely used as a means to analyse individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming, and the use of materials can be quite costly. But with the help FEA software versatile analysis is possible for any number of samples. The use of finite element analysis to study these components has been used. Finite Element Analysis can be used more efficiently to predict the behaviour with small acceptable approximations. The use of computer software to model these elements is much faster, and extremely cost-effective. Results from this work will be useful in implementing the most efficient precast beam-column joint in construction industry.

FINITE ELEMENT MODELLING

The one third scale model of exterior beam-column joint has been modelled and analysed using the finite element software package ANSYS WORKBENCH (Version 16). ANSYS is the commonly used finite element analysis software that for the research-oriented studies.

MATERIAL PROPERTIES

Three model properties are important to simulate perfect concrete behaviour in ANSYS. They are

- Density
- Isotropic Elasticity
- Strength

Density

Concrete

The density of concrete is a measure of its unit weight. Concrete is a mixture of cement, fine aggregate, coarse aggregates, water and sometimes some supplementary materials like fly ash, slag, and various admixtures. A normal weight concrete weighs 2400 kg per cubic meter or 145 lbs per cubic foot. The unit weight of the concrete depends on the amount and density of the aggregate used and the amount of air entrained in it. Here the density of concrete used were 2400kg/m^3.

Steel

Steel is not a uniform metal technically. It is an alloy of different kinds of metals and made according to the hardness and other physical properties needed for the fixed purposes. Therefore, the ultimate alloy has to share the values and thence the density variation becomes automatic. The density of the steel was taken as 7850kg/m^3 for all the steel elements.

Isotropic Elasticity and strength

Isotropic elasticity consists of Youngs modulus of the material considered and the Poisson's ratio. The characteristic compressive strength of the concrete considered is (fc) 40 N/mm^2 which was obtained from experiments and the Poisson's ratio were 0.15.

$E_C = 5000\sqrt{fc} = 5000\sqrt{40} = 31622.78$ N/mm^2

The Youngs modulus and Poison's ratio used for steel were $E_C = 2 \times 10^5$ Mpa and Poisson's ratio = 0.3

MODELLING OF CONTROL SPECIMEN

To model a monolithic beam column connection, Properties of concrete and reinforcement are used and reinforcement was provided by discrete modelling method. i.e., The reinforcement in the discrete model uses bar or beam elements that are connected to concrete mesh nodes. Therefore, the concrete and the reinforcement mesh share the same nodes and concrete occupies the same regions occupied by the reinforcement. There are other methods of reinforcement modelling available like embedded and smeared model. The discrete model was found to be better than the other two methods as it was widely adopted by many researches.

MODELLING OF PRECAST SPECIMEN BCJ GDP

Precast beam-column connection BCJ-GDP were modelled in ANSYS using similar discrete reinforcement technique as used for control specimen. The contact faces between column and beam face are provided with contact and target elements.

MODELLING OF PRECAST SPECIMEN BCJ GDP-P

The precast specimen BCJ GDP-P consist of connecting the beam and column by using grouted dowel pipe and steel plates fitted with steel rods. The specimen BCJ GDP-P was modelled same as BCJ-GDP in addition to that steel plates were modelled. Contact were given to the beam and column face at the junction and the grout pipe with the beam concrete face.

BOUNDARY CONDITIONS

Displacement Boundary Conditions

The column is fixed at the base (the translations are restrained in x,y and z directions)The free end of the beam is restrained against x-direction.

Force boundary Conditions

The exterior beam column connection is subjected to Static loading. The axial load of column is applied as pressure of 50 kN for all the testing specimens. The loading on beam is applied as displacement-controlled loading. At the loading face a metal plate is modelled for application of load. Figure 5.6 shows the schematic representation of loading pattern.

RESULTS

The finite element analysis was carried out on the one-third scale model of an exterior beam-column connection. Loading was applied as displacement and the amount of load applied were taken as total force reaction at the displacement location. The observations were made from the analytical investigations are presented in the following sections. The parameters considered for the present study are

- Ultimate Load Carrying Capacity,
- Cracking Pattern and Failure Mode,
- Load-Displacement Behaviour,
- Stiffness degradation.
- Ultimate load carrying capacity

The ultimate load carrying capacity for the control and two precast specimens are presented in Table 5.1. The particulars of each specimen are discussed in the following sections.

Monolithic Specimen

From the analytical study on monolithic specimen the ultimate load carrying capacity of control specimen was 22.3kN with a maximum deflection of 12.7mm.

Precast specimen BCJ-GDP

It was observed that in the precast connection, BCJ GDP which was connected by using the dowel pipe exhibited 13.45% more load carrying capacity than the control specimen which is 25.63 kN with a maximum deflection of 13.04mm.

Precast specimen BCJ GDP-P

It was observed that in the precast connection, Specimen BCJ GDP-P which was connected by using the dowel pipe and steel plates exhibited 53.8% more load carrying capacity than the control specimen and 33.42% more load carrying capacity than BCJ-GDP which is 34.06 kN with a maximum deflection of 11.97mm. Table 5.3 shows the load deflection values and stiffness degradation of the Precast specimen BCJ GDP-P.

SUMMARY

The analytical investigation focused on developing a mechanical exterior precast beam-column connection that emulates the monolithic beam-column connection. Finite element models were developed using the ANSYS software to study the response of exterior beam-column connection. The element types, sectional and material properties adopted for the finite element modelling in ANSYS WORKBENCH were discussed in detail. The analysis results were presented in the form of ultimate load carrying capacity, load-displacement curves and stiffness degradation. The analytical study shows that the precast specimen BCJ GDP-P connected using plates and dowel pipe performed well when compared to the other specimens

DISCUSSION OF RESULTS

GENERAL

This chapter discusses the results of the performance of various exterior beam- column connection such as

(i) Monolithic specimen

(ii) Precast specimens (2 types)

Subjected to static loading. The various parameters considered for the study are Ultimate Load Carrying Capacity, Cracking Pattern and Failure Mode, Load-Displacement Behaviour, and Stiffness Degradation.

COMPARISON OF RESULTS.

It was observed that from both the analytical studies, the ultimate load carrying capacity of the specimen with plates (BCJ GDP-P) were higher compared to other precast specimens. It had 38% and 33% greater load carrying capacity in comparison with the monolithic specimen in the Analytical and Experimental investigation respectively as shown in

SUMMARY

The analysis results of two precast specimens and control specimen are compared by considering load deflection curve and stiffness degradation in this chapter. The failure load obtained in analytical and experimental investigation

CONCLUSIONS

Following are the conclusions drawn based on the analytical investigations carried out to study the behavior of exterior precast beam-column connections.

- Analytical Investigation has been carried out for monolithic and precast specimens using the finite element software ANSYS.
- The load carrying capacity of the connection with grouted dowel pipe and steel plates is higher when compared to all other specimens. Compared to the monolithic control specimen the precast specimen BCJ GDP-P exhibited 38% more load carrying capacity analytically using ANSYS.
- The load carrying capacity of the BCJ-GDP is 18% more compared with the monolithic control specimen in ANSYS.
- There was a reduction in load carrying capacity by 14.7% Analytically with the Precast specimen BCJ GDP-P.
- It is observed that in analytical investigation the maximum deflection of precast specimen BCJ-GDP observed were 8.5% greater than the monolithic control specimen
- The maximum deflection of the specimen BCJ GDP-P was observed to be 0.15% reduction by ANSYS.
- On comparison of two precast specimens, specimen BCJ GDP-P performed well. Also, it is observed that the precast specimens BCJ GDP-P exhibited satisfactory behaviour in comparison with the monolithic Control specimen.
- The precast connection Specimen BCJ GDP-P is simple connections that can be used for the construction of low rise moment resisting frames.

SCOPE OF FUTURE WORK

- In the present work, the two types of connections have been studied only for exterior sub-assemblages. The studies can be extended for specimens of interior and top exterior sub-assemblages.
- In the present study, the exterior precast concrete beam-column joint is tested under normal loading. This study can further be extended to seismic loading.
- Only scaled models of specimens could be included in the present work. This work can be extended to test full scale specimens.
- The joint performance of beam-column connection could be investigated with the measurement of crack width.
- The same type of connections can be cast and tested with the corbels.
- Same type of connections can be tested with different grout materials and different mix proportions.

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