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Numerical and Experimental Study on Ductility Improvement in Beam-Column Joint for Precast Structures

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ABSTRACT

In Precast concrete structures, it is essential to enhance the performance of beam-column joint in moderate and severe seismic susceptibility areas. Connection between Precast concrete components Play an important role in determining the strength & stability of Precast structures. The connection between beam-column joint that will affect the load distribution, strength, stability and constructability of the global structures. The understanding on the behavior of the connection is important and can only be assessed by conducting experimental tests. The main objective of this research is to investigate the moment of resistance and the behavior of simple beam-to-column connections in precast concrete frames and monolithic frames. The Proposed experimental test comprises a total of 3 specimens, in two limited to simple beam-to-column connections in precast concrete frames and monolithic frames. The effectiveness of Carbon Fiber Reinforced Polymer (CFRP) Sheets will increasing the load carrying capacity of the beam-column joint will be studied. The stress and deformation result from Numerical and Experimental results were evaluated and computed and compared with conventional connections as per IS CODE 13920:1993 Provisions.

Keywords: Beam-column joint, carbon fibre reinforced polymer, Connections, Constructability, Effectiveness, Precast.

INTRODUCTION

Recent Earthquake have exposed the vulnerability of existing reinforce concrete (RC) beam-column joints to seismic loading. Until early 1990's, concrete jacketing and steel were the two common methods adopted for strengthening the deficient RC Beam-column joints [1]. Precast concrete multi-storey framed buildings are widely used because of its economic, structurally sound and architecturally versatile form of construction. Precast concrete provides high-quality structural elements, construction efficiency, and savings in time and overall cost of investment. It combines the benefits of very rapid construction and high quality materials with the advantages of production line economy and quality assurance. The primary reason for the widespread damage was due to the poor performance of the connections between the structural elements. The function of the joint is to transmit forces between structural members and to provide stability. The satisfactory performance and economy of precast concrete structures in high seismic regions depends on the proper selection and design of the connections [2]. Precast technology offers benefits such as reduce construction period, better quality control, cleaner, and safer construction sites and others. Precast concrete means concrete which has been prepared for casting and the concrete either is statically reinforced or prestressed [3-4-5].

The success of precast concrete buildings depends on the connections of the components in particular beam-to-column connections. Typical precast beam-to-column connection having one or more disadvantages, such as slow erection, no reliable moment capacity, construction tolerance problem and expansive connection hardware[6].

The volumetric changes cause movement between the two elements and internal friction between two elements and internal friction between the two elements surface is provided by using various methods such as inserting dowel between beam-to-column connection. Apart from that, local crushing at the top of column occurs due to the flexural rotation of the beam. Therefore, bearing pad is provided to overcome this problem. Another factor need to be considered is the narrow bearing of the suspended element on the

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vertical element. Consideration for the overall stability of the structure is important too. Precast concrete structure refers to the combination of precast concrete elements and the structure is able to sustain vertical and horizontal loads or even dynamic loads. So the design and construction of the joints and connections is important to ensure the stability and robustness of the overall structure [7-11].

According to Elliot et al. (1998), some 24 tests had been conducted using welded plate and billet connectors, however, research on the concrete corbel with stiffened cleat types have not widely carried out. Although the Prestressed Concrete Institute (PCI) manual contains descriptions of typical beam-to-column connections fulfilling many functions, the published test results are available for only a few of them. Therefore there is still lacking of experimental data for the ductile connection details for beam-to-column connections in precast structure. In addition, reliable connection behavior can only be properly assessed by laboratory testing or proven performance [12]. The design of connection should be able to sustain various kinds of loads (static and dynamics) in terms of strength and ductility [13]. Besides, the connection should be simple for construction. Constructability of connection is important to reduce fabrication period [14]. As lack of knowledge and information on the connection behavior in seismic load, this research is to understand the behavior of several precast connections [15]. From here, the Various types of Connections which will be compared with Monolithic connection, ductility level difference between them will be concluded. And also the various type of connections which one will have more moment of resistance will also be concluded.

TYPES OF CONNECTIONS

Monolithic Specimen (ML)

The monolithic reinforced concrete test specimen (ML) was designed according to IS:13920-1993(16). The Flexural reinforcement for the beam consisted of four bars with one bar at each corner of the transverse reinforcement. Two numbers of 12mm diameter bars were provided as tension reinforcement and two numbers of 12mm diameter bars were provided as compression reinforcement. The shear reinforcement consisted of 8mm diameter 2 legged stirrups spaced at 150mm. The column reinforcement arrangement also consisted of four 12mm diameter bars. Along the column height excluding the joint region, the lateral ties were spaced at 150mm.

In precast structures, there are two types of connections (i) Wet connections, in which fresh concreting or grouting is done at the site to cover the exposed reinforcements in the connection region (ii) Dry connections, in which only mechanical connections are used. A dry connection was chosen.

Precast Connection: Beam-Column Connection using Cleat angle with Stiffeners (PC-1)

This connection consists of two stiffener welded to the cleat angle at both ends of the plates. Two 20mm diameter bolts of grade 4.6 were used. One bolt connects the cleat angle with the column and the other with the beam and the corbel. The stiffener plate is of size 200mm x 200 mm and thickness 10mm. The gap between the bolts and the groove was filled isoresin grouts.

Precast Connection: Beam-Column Connection using Carbon Fiber Reinforced Polymer (CFRP) Wrapping (PC-2)

This connection consists of Carbon Fiber Reinforced Polymer (CFRP) Sheets which will be wrapped in column portion of 600mm in column portion and also in beam portion, the wrapping length will be on 300mm. It will be having the

thickness of 1mm and having young's modulus of 230 MPa. Wrapping should be done by Epoxy resin.

DUCTILITY DEFORRMATION CO EFFICIENT

The Ductility deformation co-efficient is the ratio of the maximum displacement that a structure of element can undergo without significant loss of initial loading to the initial yielding deformation. And also it is the ability of a structure to undergo inelastic deformations beyond the initial yield deformation with no decrease in the load resistance.

$$\text{Ductility Deformation Co – efficient} = \frac{\text{Deformation in ultimate load}}{\text{Deformation at initial yield}}$$

INRODUCTION TO ANSYS

Ansys

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex non-linear, transient dynamic analysis. A typical ANSYS analysis has three distinct steps:

- Building the model
- Applying loads and obtains the solution
- Review the results

Building the Model

Building a finite element model requires a more of an ANSYS user's time than any other part of the analysis. The procedure is

- Specify the job name and analysis title.
- Define the element types, real constants.
- Material property.
- Model geometry.

Defining Element Types

The analysis element library contains more than 100 different element types. Each element type has a unique number and a prefix that identifies the element category. Example: beam, pipe, plant, shell, solid.

Defining Element Real Constants

Element real constant are the properties that depend on the element type, such as cross sectional properties of a beam element. Real constants for BEAM3, the 2-d beam element, or area, moment of inertia (IZZ), height, shear deflection constant (SHEAR Z),initial strain (ISTRN) different elements of same type may have different real constant values. 4. 4.1.4.Defining Material properties:

Most elements types require material properties. Depending on the application, material properties may be:

- Linear or Non linear
- Isotropic, Orthotropic
- Constant temperature or temperature dependent

As with element type and real constant, each set of material properties has material reference number.
Material Property Test

Define material properties separately for each element analysis, the ANSYS program enables to store a material property set in an archival material library file, then retrieve the set and reuse it in multiple analysis. The material library files also enable several ANSYS user to share common used material property data.

Features of ANSYS

- ANSYS contains an extensive library of elements that can model virtually any geometry.
- Can import geometry from a many different CAD software packages.
- Using ANSYS, able to use various different material models to simulate the behavior of most typical engineering materials including metals, rubbers, polymers, composites, reinforced concrete, crushable and resilient foams, and geotechnical materials such as soils and rock.
- Designed as general-purpose simulation tool, ANSYS can be used to study more than just structural(stress/displacement) problems.
- ANSYS offers a wide range of capabilities for simulation of linear and non linear applications.
- Can perform static as well as dynamic analysis.

ANALYTICAL INVESTIGATION

Monolithic Specimen (MS)

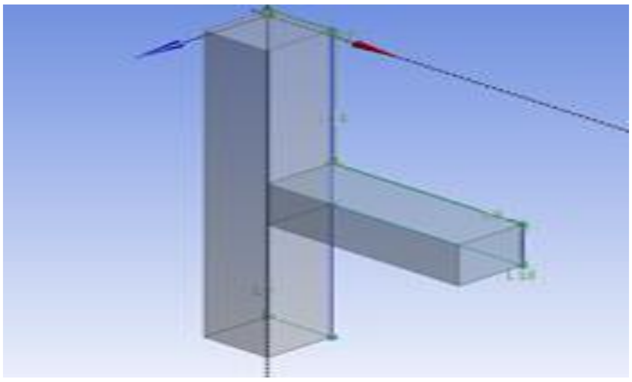


Fig5.1. *ANSYS Workbench Model*

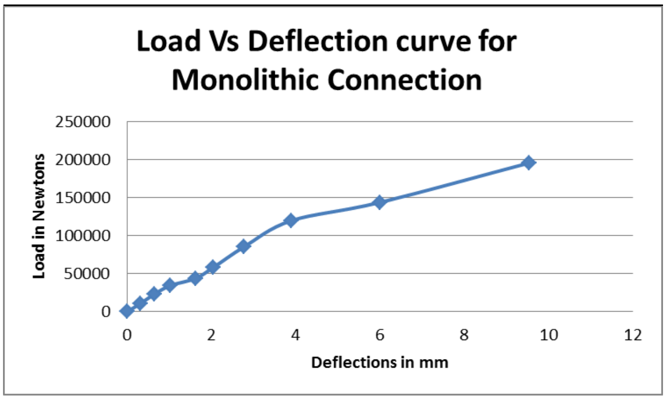


Fig5.2. *Load Vs. Deflection Behavior for Monolithic Connection*

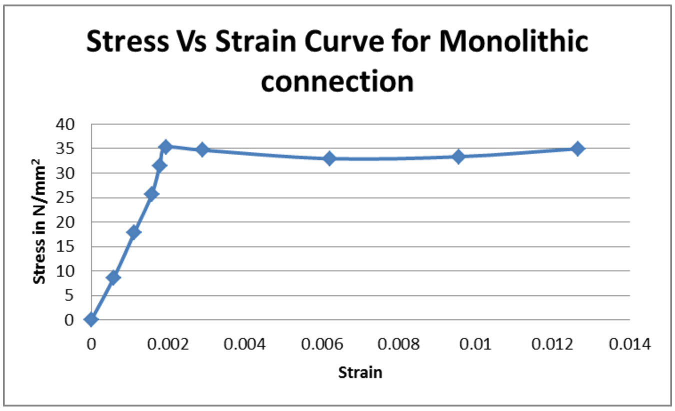


Fig5.3. *Stress Strain Behavior for Monolithic Connection.*

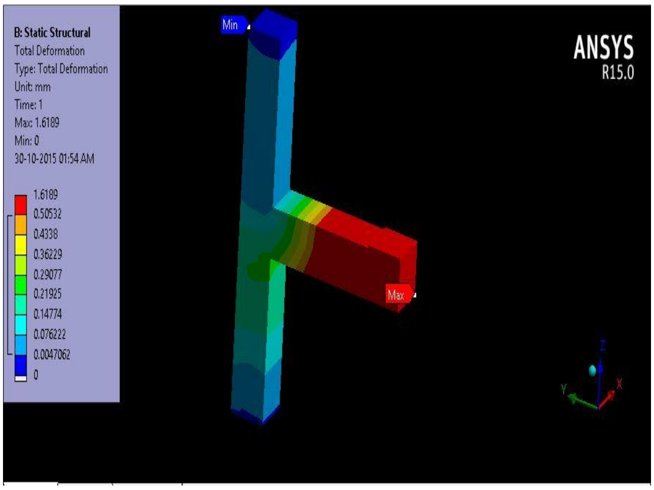


Fig5.4. *Total Deformation in Monolithic Connection*

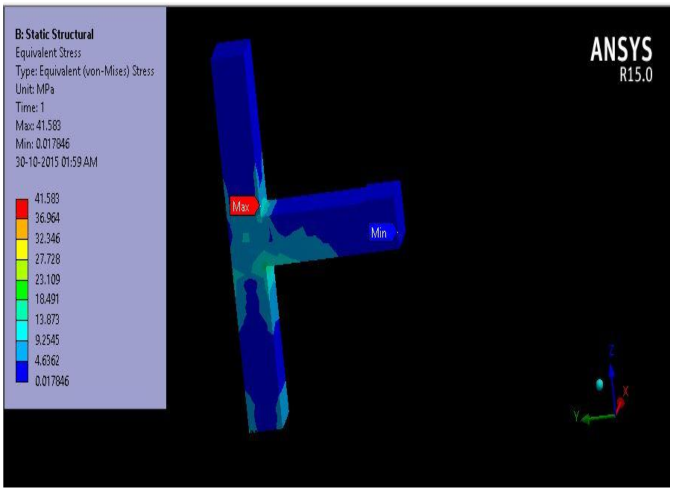


Fig5.5. *Von-mises Stresses for Monolithic Connection*

The structural geometry of the exterior Beam-column joint modeled for the described dimensions using AUTO CAD software. Then exported to ANSYS software in WORKBENCH application. The bottom layer will be constrained with all degrees of freedom. The monolithic specimen will be meshed by automatic meshing concept with element type of TETRAHEDRAL element and it will be sizing of 1:2 Growth ratio.

The loading up to 43KN will be applied on 100mm free from left of the beam.

Fig 5.5 Shows that the maximum stress is 41.583 MPa which is higher than the permissible limit of 30 MPa but not less than that of the stress acting on the joint designed as per IS codes. Since the stress is higher than that of permissible limit the reinforcement have to be modified.

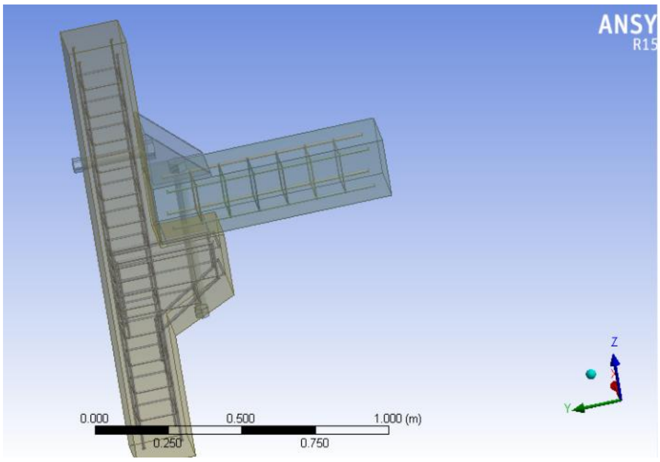


Fig5.6. *ANSYS Model for Angle Connection*

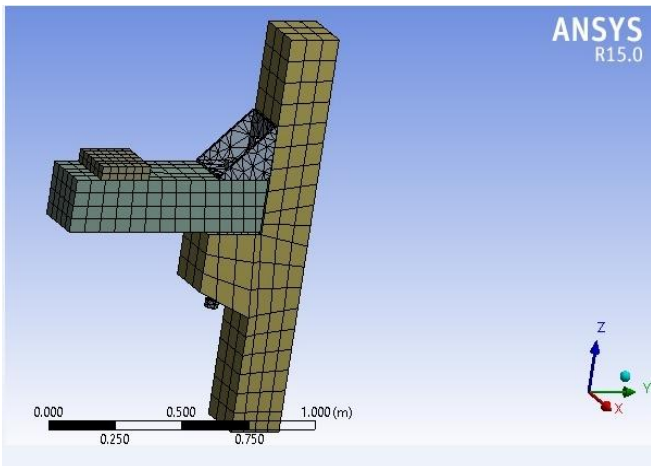


Fig5.7. *Meshing in Angle Connection*

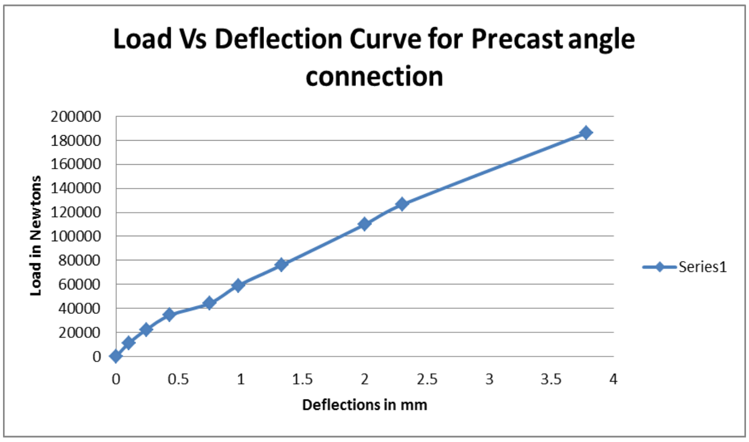


Fig5.8. *Load Vs. Deflection Behavior for Angle Connection*

Precast Connection: Beam-column Connection using Cleat Angle with Stiffeners (PC-1)

The structural geometry of the exterior beam column joint has been modeled for the mentioned dimensions and analyzed using ANSYS. The exterior beam column joint has been analyzed with cleat angle connections. The Bottom layer will be constrained with all degrees of freedom.

Fig 5.6, 5.7 Shows that the precast specimen will be meshed by automatic meshing concept with element type of TETRAHEDRAL element and it will be sizing of 1:2 Growth ratio.

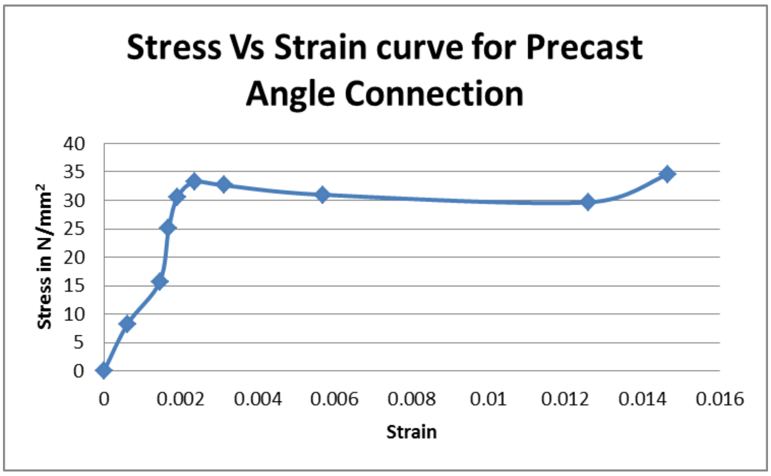


Fig5.9. *Stress Vs. Strain Behavior for Angle Connection*

The loading of 40KN will be applied on 100 mm from free end of the beam.

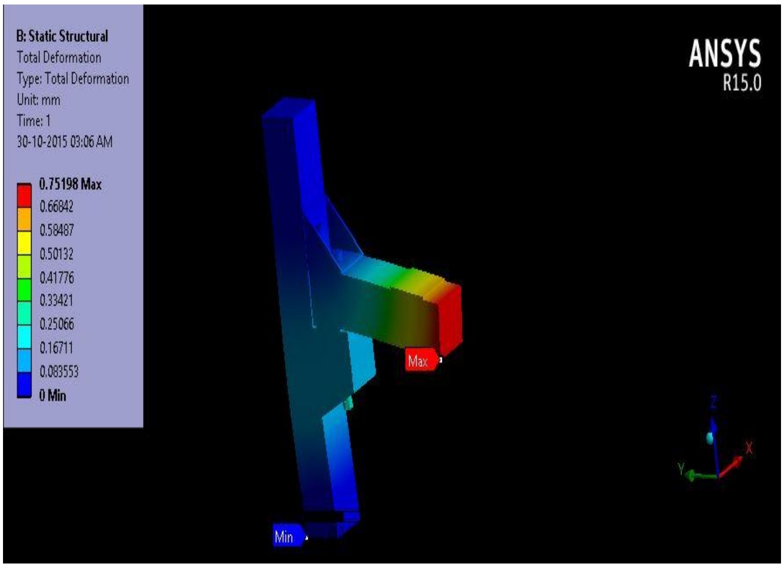


Fig5.10. *Total Deformation for Angle Connection*

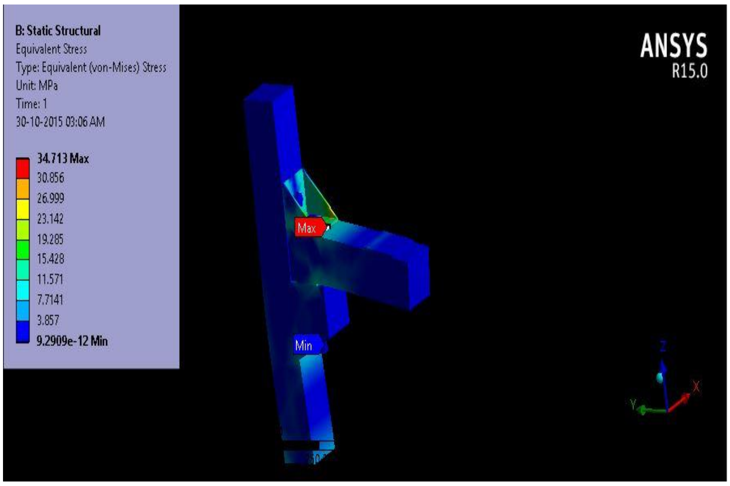


Fig5.11. *Von-mises Stress for Angle Connection*

Shows the maximum stress acting on the maximum stress acting the concrete in the precast beam-column connection of about 34.713 MPa which is higher than the permissible limit of 30 MPa but it is less than that of the stress acting on the joint designed as per IS codes.

C. Precast Connection: Beam-column Connection using Carbon Fiber Reinforced Polymer (CFRP) Wrapping (PC-2)

The structural geometry of the exterior Beam-column joint modeled for the described dimensions using AUTO CAD software. Then exported to ANSYS software in WORKBENCH application. The bottom layer will be constrained with all degrees of freedom.

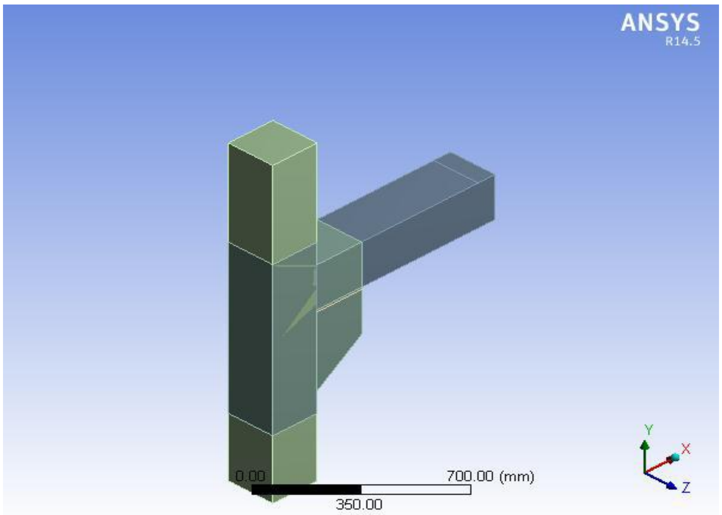


Fig5.12. *ANSYS Modeling for Precast Beam-Column CFRP Wrapping Connection*

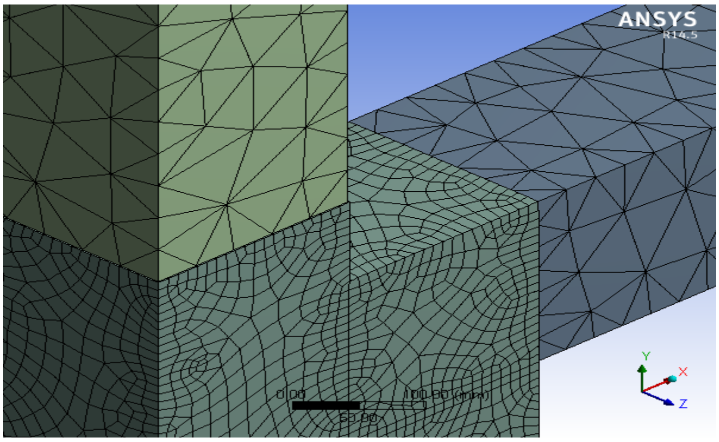


Fig5.13. *Meshing of the Wrapping Element*

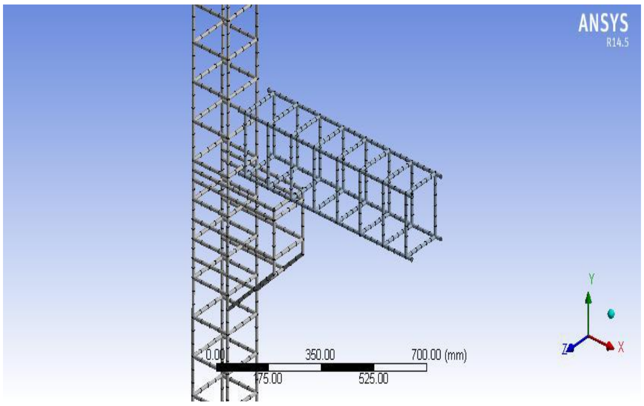


Fig5.14. *Meshing of Reinforcement Bars*

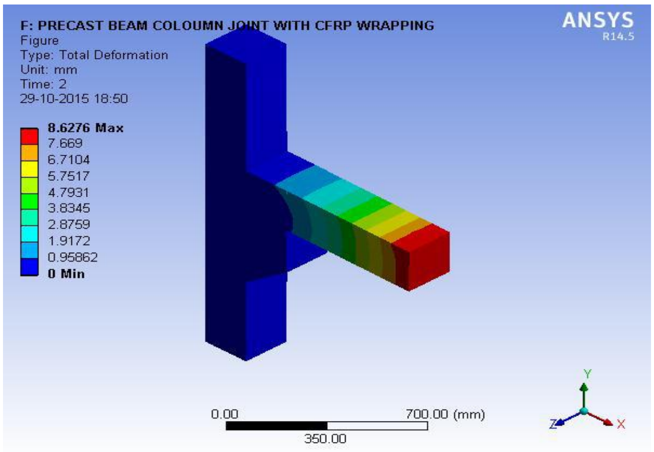


Fig5.15. *Total Deformation for CFRP Wrapping Connection*

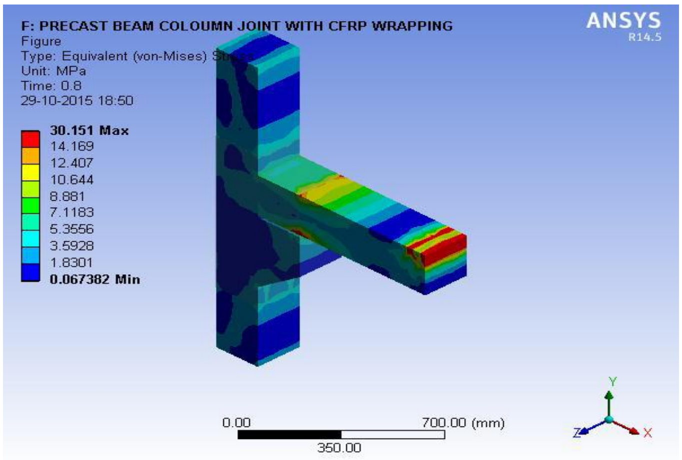


Fig5.16. *Von-mises Stress for Wrapping Connection*

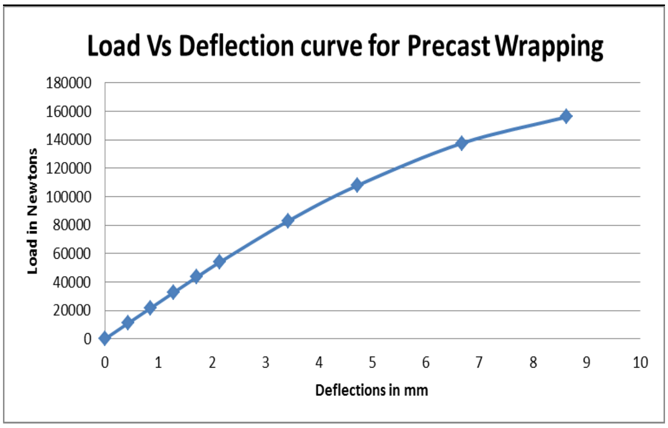


Fig5.17. *Load Vs. Deflection for Wrapping Connection*

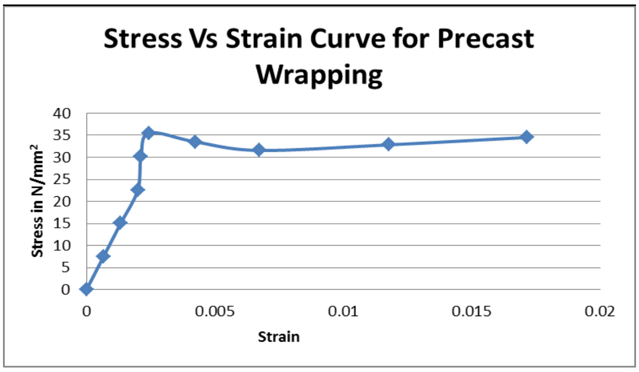


Fig5.18. *Stress –Strain Behavior for Wrapping Connection*

TableI. *Stress in Various Connections for Ductility Deformation Co-efficient*

Specimen	Yield stress in N/mm²	Ultimate stress in N/mm²
Precast Wrapping connection	30.151	35.528
Precast Angle connection	30.596	34.570
Monolithic connection	31.513	34.985

TableII. *Ductility Deformation Co-efficient*

Specimen	Ultimate Deformation in mm	Yielding Deformation in mm	Ductility deformation co efficient
Precast Wrapping	8.6276	1.7129	5.037
Monolithic	9.5392	1.6189	5.8924
Precast Angle connection	3.7849	0.752	5.033

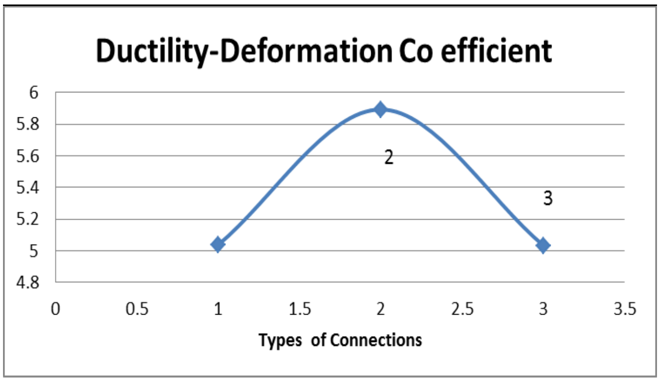


Fig5.19. *Graph plotted between Ductility-Deformation Co-efficient for Various Connections.*

The loading up to 43KN will be applied on 100mm free from left of the beam.

Fig 5.18 Shows that the maximum stress is 30.151 MPa which is nearly equal to the nominal strength of the concrete of 30 MPa. The maximum stress is acting on the top and bottom of the joint region of the beam-column joint. Table I Gives the yield stress and ultimate stress values in various connections for calculation of ductility deformation co-efficient used for which will have more ductile. The yield stress will be more in monolithic connection when compared with precast connections. But in precast specimens, the ultimate stress will be more in Precast wrapping connection because of its bonding strength of the CFRP Sheets. From Table II, Fig 5.19 Shows the ductility deformation co-efficient of various connections, monolithic connections will have more value when compared with precast connections. But in precast specimens, wrapping have more ductile when compared with Angle connections.

MATERIAL CHARACTERISTICS

Portland Pozzolona Cement (PPC) 53 grade was used for the monolithic and also precast specimens. M30 Grade concrete with the water-cement ratio of 0.394 has been used. The deformed bars designated as Fe 415 were used as longitudinal and also transverse reinforcement. Control cubes and three cylinders of 150mm diameter and 300mm height were cast and tested for compressive as well as split tensile strength. The 28th day average compressive strength was 38.8 MPa. The split tensile strength of concrete was 3.45 MPa.

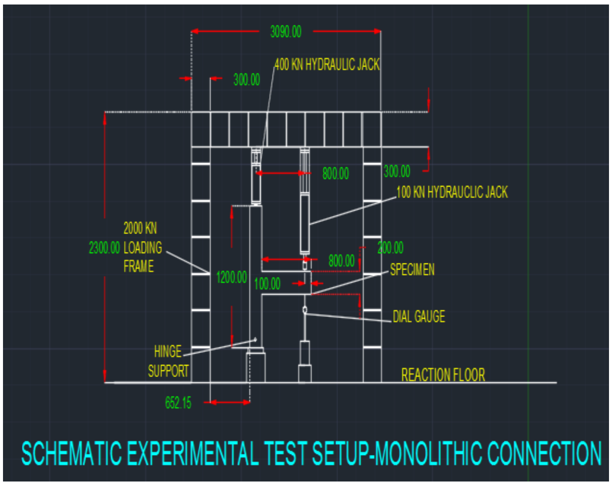


Fig7.1. *Schematic Experimental Test Setup for Monolithic Connection*

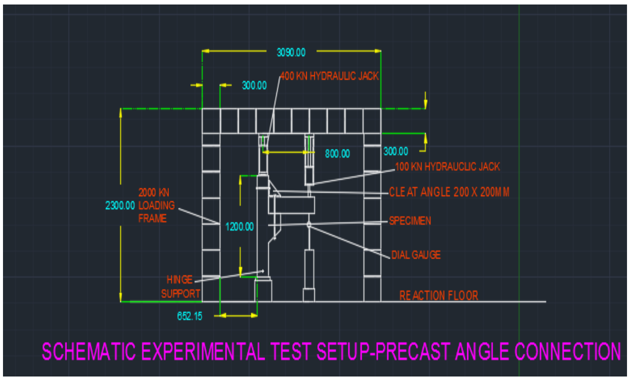


Fig7.2. *Schematic Experimental Test Setup for Angle Connection*

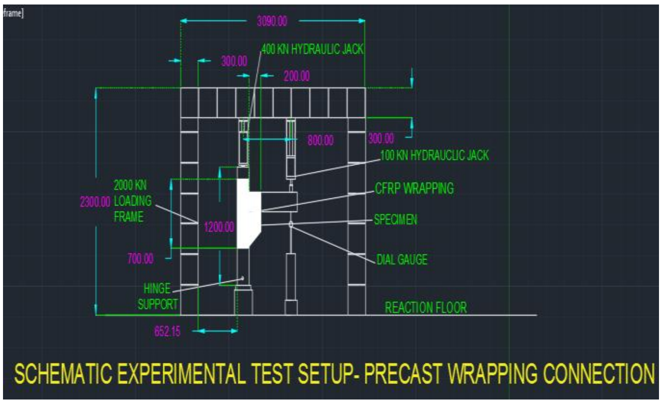


Fig7.3. *Schematic Experimental Test Setup for Wrapping Connection*

EXPERIMENTAL TEST SETUP

Fig 7.1,7.2,7.3 shows the schematic Experimental test setup for Monolithic, Angle and Bolt , and Wrapping connection. The beam-column joint specimens were tested in the Structural Engineering Laboratory in Sri Krishna college of Technology, Coimbatore. Both the column ends will be hinged. In order to apply axial compressive load on the column, the column is to be held in position with suitable arrangement. At one of the column end, a constant load of 500 KN was applied through which a hydraulic jack having capacity of 2000KN on the one end of the column and the load was measured using an electrical load cell. The load on the beam was also measured using an electrical load cell. The deflection at the free end of the beam was recoded at regular load intervals. The strains in the longitudinal reinforcement and stirrups of the column and the strain in the main tension reinforcement of the beam were also recorded at regular time intervals. The loading will be continued till when the ultimate load will occur. The deflection at the free end of the beam was measured using a dial gauge during the test.

Test Specimen

The experimental work consisted of testing of four beam-column joint. All columns cast were of size 200 x 200 x 1200mm square in cross section and beams of size 200 x 200 x 800mm from the face of the column. Plywood moulds were used for casting the specimens. Reinforcement cages were fabricated and placed inside the moulds. Required quantities of cement, sand and coarse aggregate were mixed thoroughly in a mixer machine. Mixing was done till a uniform mix was obtained. The mixes were poured into moulds in layers, and the moulds were vibrated for though compaction. After 24 hours, specimens were demoulded and submerged in clean fresh water for 28 days.

Crack Propagation

The crack load of specimens are found in all the specimens. From this study results shows that cracks are delayed in the Wrapping connections compared to that Angle and bolt connection & Monolithic connection designed as per the code provisions.

Load Carrying Capacity

The entire exterior beam column joints are subjected to gradually increasing vertical loading. In all exterior beam column joint, the first crack load is observed. The behavior of the exterior beam column is studied by measuring deflection using Dial gauge and observing crack pattern. In all specimens, cracks appeared near the joint after the first crack load. With further increase in loading, the cracks propagated up to the beam and initial cracks started widening. The typical crack pattern for the beam column joints are shown.

Table7.1. *Load Deflection Parameter*

SPECIMENS	LOAD IN KN	YIELDING DEFLECTION IN mm	ULTIMATE DEFLECTION IN mm
MONOLITHIC CONNECTION	195	4.661	24.657
WRAPPING CONNECTION	178	5.085	26.311
ANGLE AND BOLT CONNECTION	159	4.789	24.056

The ultimate load of Monolithic joint is 195kN and the corresponding deflection is 24.657mm which will have yielding deflection is 4.661mm. From Wrapping connection having the ultimate load of 178kN and the corresponding deflection is 26.311mm which will have yielding deflection is 5.085mm. In Angle and Bolt connection, the ultimate load is 159kN and the corresponding deflection is 24.056mm which will have yielding deflection is 4.789mm.

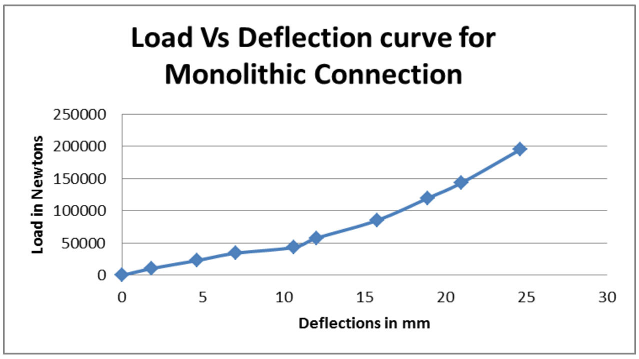


Figure7.4. *Load Vs Deflection Curve for Monolithic Connection*

Fig 7.4 shows the graph of Load-deflection curve for Monolithic connection which has the maximum ultimate deflection of 24.657mm for 195kN applied.

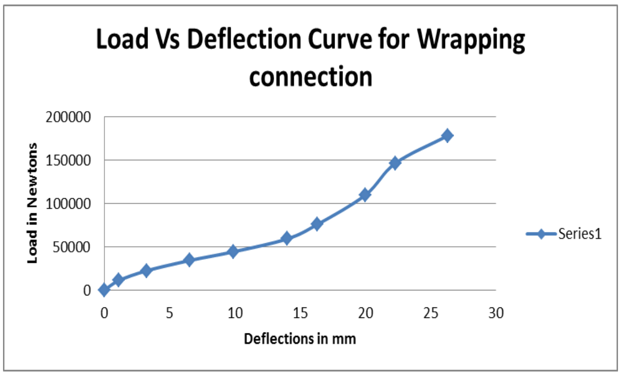


Figure7.5. *Load Vs Deflection Curve for Wrapping Connection*

Fig 7.5 shows the graph of Load-deflection curve for Wrapping connection which has the maximum ultimate deflection of 26.311mm for 178kN applied.

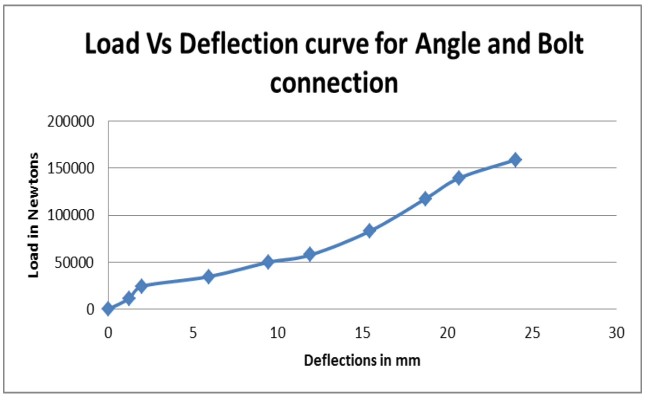


Figure7.6. *Load Vs Deflection Curve for Angle And Bolt Connection*

Fig 7.6 shows the graph of Load-deflection curve for Angle and Bolt connection which has the maximum ultimate deflection of 24.056mm for 159kN applied.

Table7.2. *Deflection Ductility Parameter*

SPECIMENS	ULTIMATE DEFLECTION IN mm	YIELDING DEFLECTION IN mm	DUCTILITY DEFORMATION CO-EFFICIENT
MONOLITHIC CONNECTION	24.657	4.661	5.290
WRAPPING CONNECTION	26.311	5.085	5.174
ANGLE AND BOLT CONNECTION	24.056	4.789	5.023

Table 8.2 shows that the ductility has improved to greater extent for Monolithic connection when compared with Angle and Bolt connection & Wrapping connection.

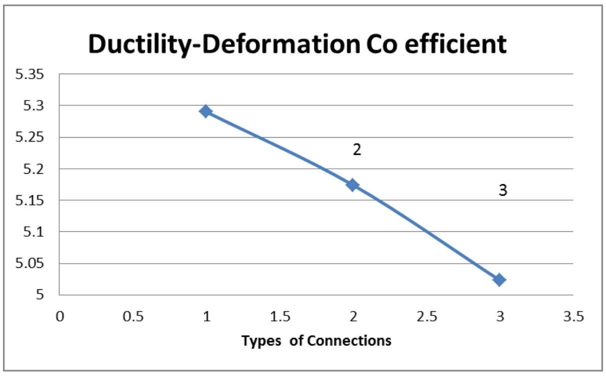


Figure7.7. *Ductility Deformation Co-Efficient*

EXPERIMENTAL RESULTS AND DISCUSSION

Thus from this chapter the behaviors like Load-deflection, first crack load and ultimate load, ductility deformation co-efficient of beam column joints are analyzed. The behavior of beam column joint categorized as Monolithic connection, Angle and Bolt connection and Wrapping connection are compared with the experimental results.

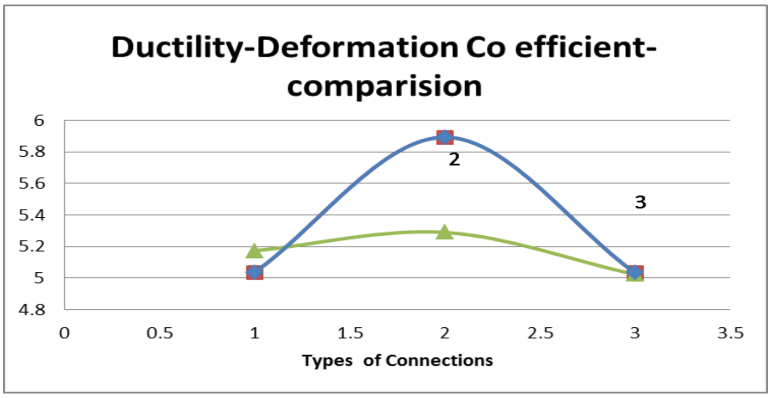
SUMMARY AND CONCLUSION

General

This chapter deals with the conclusions of the experimental and analytical investigation on exterior beam column joint under vertical loading made and also some of the scope for the further work. It gives the brief descriptions about the works done. Scope for further work gives suggestion for further researches that can be carried out corresponding to the present area of study.

Conclusion

Table8.1. *Comparison of Ductility-deformation co efficient*



From the results, it was observed that the ultimate load carrying capacity of the monolithic connection specimen is more than the Angle and Bolt connection and Wrapping connection. The monolithic specimen is more ductile and dissipates more energy compared with Angle and Bolt connection and Wrapping connection. In Wrapping connection is more ductile and dissipates more energy compared with Angle and Bolt connection and also Angle and Bolt connection shows greater initial stiffness when compared to the Wrapping connection but it will be also greater initial stiffness with Monolithic connection. The ductility deformation co efficient is slightly higher than Wrapping connection when compared with Angle and Bolt connection. But overall three specimens, Monolithic joint will have higher value. This behaviour satisfies the fundamental requirement of strong column-weak beam theory. Considering the total performance of the precast connection future scope of study has been planned to improve the ductile detailing of joints.

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