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CYCLIC ANALYSIS OF A RCC COLUMN AND A STEEL BEAM CONNECTION

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Abstract – *In a Reinforced Concrete Column and Steel Beam (RCS) moment frame system, a RC column is used rather than structural steel column since it can result in substantial material cost savings, increased structural damping and lateral stiffness of the building. In this paper, the main objective is to study the behavior of the connection between a RC column and steel beam. The two connections used are End Plate Moment connection and Connection with Anchor Bolts. The connections are modeled using FEM analysis software ANSYS Workbench 19. The connections are subjected to eccentric loading and cyclic loading. The parameters that were evaluated are Total Deformation, Stress, Strain and Hysteresis Response of the connections.*

***Key Words*: End Plate Moment Connection, Connection with Anchor Bolts, FEM Analysis, ANSYS Workbench, Total Deformation, Stress, Strain, Hysteresis Curves.**

1. INTRODUCTION:

The use of hybrid structures has gained popularity in the last twenty years. One of the most efficient hybrid systems is represented by RCS frames. In typical steel to concrete connection, a steel attachment consisting of a base-plate welded to the attached member, connecting done by anchors and an embedment of the anchors into the concrete are included. A headed anchor installed in position before the concrete is placed is a typical cast-in-place anchor. After the concrete has hardened and can be adhesive, undercut, expanded or grouted retrofit anchors are installed. Hybrid structures (RCS) consisting of R/C columns and steel beams have been developed in Japan. The advantage of these structures is their exquisite combination of R/C columns and steel beams. Many experimental studies have been conducted mainly on the behavior of interior beam-column joints using cross-shaped specimens. However, there have been few experimental and analytical studies on the behavior of RCS frames. It is effective for promoting a greater understanding of the behavior of the RCS frame to investigate them from analytical aspects. Because it is difficult from economical aspects to conduct a lot of experiments, the investigation by the finite element analysis is significant. The beam-column connection in structural typologies provides the structure with lateral stiffness. The connections play an important role in survival of the building during a seismic event. To form a hinge in the connection beam element, to undergo yielding while maintaining its shear transfer capability or to generate the required bending capacity the connections must be strong. The application of seismic performance of steel-concrete composite joints in high rise buildings has caused great concerns. There are different effects on mechanical characters caused due to different constructions of composite joints. The principle of stronger columns, weaker beams and stronger joints for reasonable joints constructions must be consistent with the calculation model. The transmission of forces by beam-column joints should be clear and simple and simple construction should be considered. The cyclic behavior of beam-column connection using ANSYS Workbench which is finite element software for numerical investigation has been used as it is advantageous to visualize the results which cannot be done theoretically. Despite the advantages offered by RCS construction, the lack of a set of recommendations to design RCS joints subjected to severe earthquake loading has limited the use of RCS buildings to low or moderate seismic risk zones. In addition, the study of RCS joint behavior has been limited primarily to interior connections. Therefore, an experimental and analytical program was undertaken at the University of Michigan to develop information on the inelastic cyclic response of RCS joints, especially in exterior RCS connections.

1.1 Literature Review:

The reviewed literature reviews for the study have been listed below:

Gustavo J. Parra-Montesinos and **James K. Wight** (2000), in this paper an experimental program was conducted to study the seismic behavior of the reinforced concrete column to steel beam (RCS) connections. Nine 3/4th scale exterior RCS connections were considered as test specimens which were subjected to lateral cyclic loads. With an increasing lateral displacement from 0.5% to 5.0% storey drift, twenty cycles were subjected to each specimen. To evaluate the shear strength and inelastic cyclic response of the connections, the specimens were designed such that the inelastic activity would concentrate in the joint region. The experimental results concluded that the RCS connections are suitable to be used in high seismic risk zones. A good response was obtained by all the nine specimens to cyclic load reversals. The lateral displacement when increased by 2.0% storey drift showed good stiffness retention. The increase in strength and stiffness retention capacity of RCS connection was due to the addition of steel cover plates. Hence to predict the shear strength of RCS joint a model was proposed.

Chin-Tung Cheng and **Cheng-Chih Chen** (2004), in this paper an experimental program was conducted to study the seismic behavior of a RCS connection with or without the slab. It was also conducted to act as proof test for a RCS in-plane frame at the NCEER for design of connections. The specimens considered in this paper are six RCS connections. Two retrofit techniques were applied to prevent premature failures. The shear transfer in panel zone was enhanced by fillet welding the beams at column face with face bearing plates (FBP). The constant axial load of 1000kN was applied at top of column by the hydraulic jack. The cyclic load with displacement control was applied by the hydraulic actuators in the form of triangular waves at each beam end. The results from the experiment were such that at beam end a plastic hinge was formed which showed the performance of all the specimens in a ductile manner. The ultimate strength and initial stiffness under positive bending was found to be 67% and 27% which was increased averagely of the beam. The slow deterioration of lateral strength was until fracture of bottom flange. The marginal effect on shear transfer due to cross beams and shape of stirrups in the panel zone was revealed to due to design of strong columns and weak beams for all specimens.

1.2 Objectives:

i. To understand the behavior of different types of connections between a RCC column and a steel beam.
ii. To study the cyclic behavior of the connections.
iii. To perform finite element analysis using ANSYS Workbench software.
iv. To compare the different types of connections.

1.3 Methodology:

i. Thorough understanding of different types of RCC column to steel beam connections.
ii. To select appropriate sections for the analysis.
iii. To model and analyze in ANSYS Workbench software.
iv. To understand the finite element analysis results.
v. To compare the analysis results of the two types of connections.

2. FINITE ELEMENT MODELLING IN ANSYS:

2.1 Element Type:

Concrete: The element type that was used to model concrete is SOLID65. The element has 8 nodes and 3 degrees of freedom translations in x, y and z nodal direction at each node. The element is capable of crushing, cracking and plastic deformation.

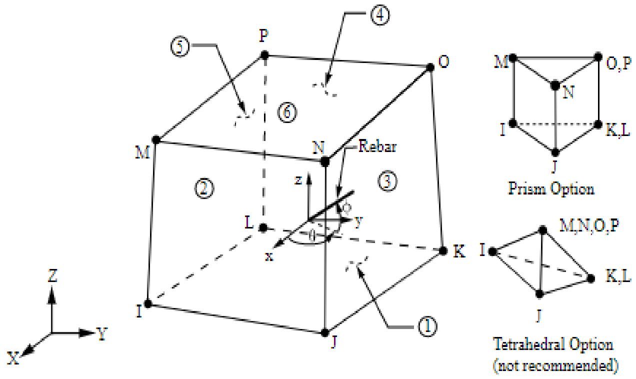


Fig -1: SOLID65 Element in ANSYS.

Steel Reinforcement: The element that was used to model steel reinforcement is LINK180. It is a 3D spar element which has nodal translations in x, y and z directions with 2 nodes. It is capable of plastic deformation.

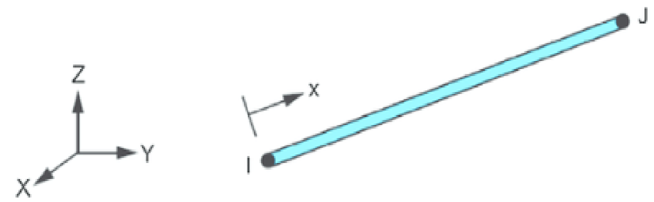


Fig -2: LINK180 Element in ANSYS.

Steel Plates and Beam: The element that was used to model steel plate and beam is SOLID185. It has 8 nodes and 3 degrees of freedom translations in x, y and z nodal direction at each node. It is capable of stress stiffening, large deflection, creep, large strain capabilities, hyper elasticity and plasticity.

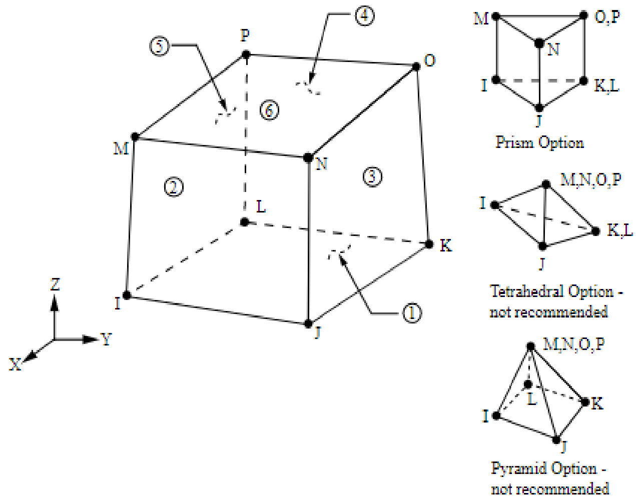


Fig -3: SOLID185 Element in ANSYS

Bolts and Nuts: The element that was used to model bolts, bolt heads and nuts is SOLID45. It is a 3D structural solid element with 8 nodes and 3 degrees of freedom translations in x, y and z nodal directions at each node.

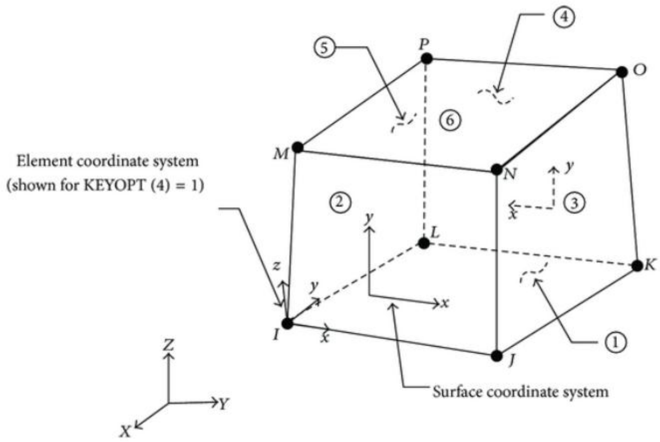


Fig -4: SOLID45 Element in ANSYS.

2.2 Material Properties:

Concrete: It is quasi-brittle material having high non-linear and ductile stress-strain relationship. The tensile strength of concrete is mainly 8-15% of the compressive strength. In compression, the stress-strain curve for concrete is linearly elastic up to about 30% of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength. After it reaches the maximum compressive strength σ_{cu}, the curve descends into a softening region, and eventually crushing failure occurs at an ultimate strain ε_{cu}. In tension, the stress-strain curve for concrete is approximately linearly elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually to zero.

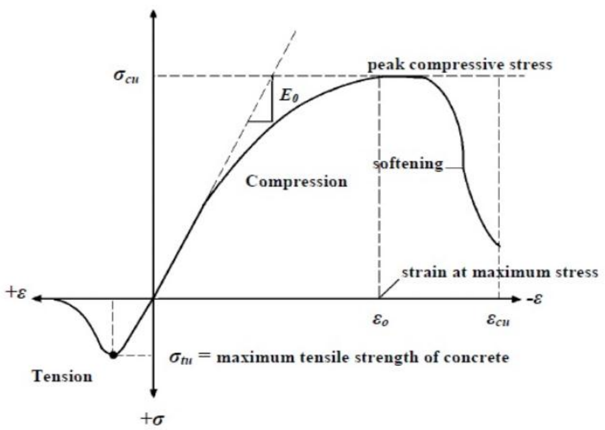


Fig -5: Typical Uni-Axial Compressive and Tensile Stress-Strain Curve for Concrete.

Steel Reinforcement: The mechanical behavior of reinforcing steel bar is assumed to be elastic bilinear under monotonic tension. The steel bar initially exhibits linear elastic portion followed by a yield platue, strain hardening and then stress drops till fracture occurs. For incorporating steel material model, the essential inputs are modulus of elasticity, tangent modulus and the yield strength.

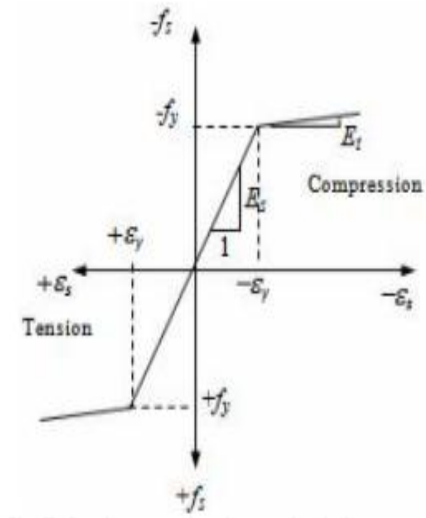
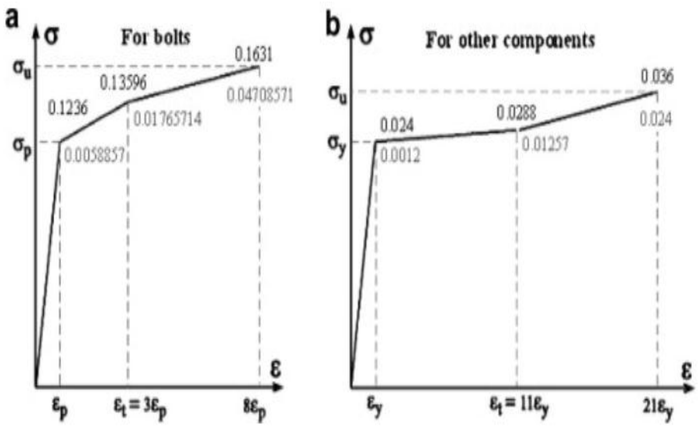


Fig -6: Strain curve for the steel reinforcement.

Structural Steel: The stress–strain curves are taken as elastic-strain hardening. This is acceptable since strain hardening is paired with excessive yielding in large areas and a large deflection criterion governs the ultimate strength design. However, in end-plate connections excessive strain is mostly local and besides considerable shear stresses occur in the region between the top bolts and the beam tension flange which necessitates considering strain hardening.



(a) (b)

Fig -7: Tri-Linear Stress–Strain Curve: (a) For High Strength Bolts (b) For Steel Sections.

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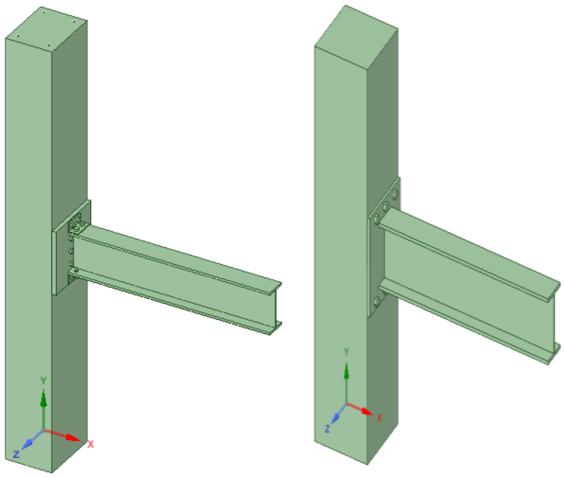
2.3 Section Properties:

Table -1: Section Properties

BEAM	COLUMN
ISMB200@0.249kN/m	250mmX250mm
Length = 800mm, Height = 200mm	Height = 1200mm
Flange Thickness, tf = 10.8mm	Steel Reinforcement is 4#12mm diameter bars
Web thickness, tw =5.7mm	8mm diameter stirrups
Yield Strength = 250N/mm²	Characteristic Strength = 25kN/mm²
M20 High Strength Bolts of 4.6 grade	
Steel Plate: C/S = 250mmX300mm Thickness = 10mm	

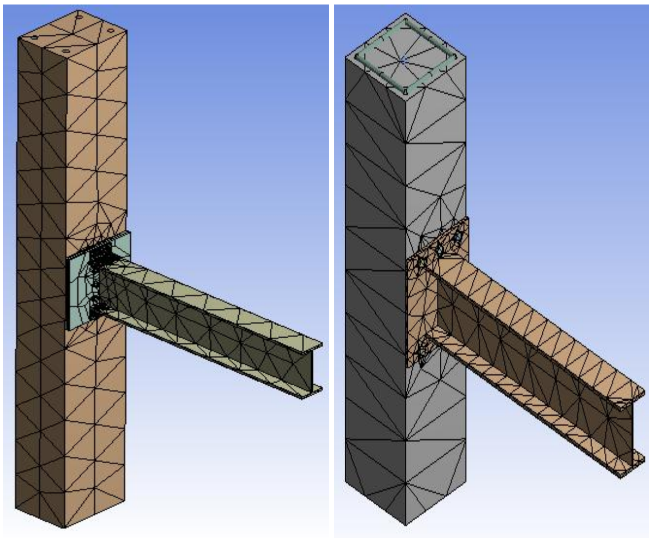
2.4 FEM Modelling and Meshing:

The FEM software used for modeling is ANSYS Workbench. The finite element modeling is done using elements Solid65 for column, Link180 for steel reinforcement, Solid185 for beam and plates and Solid45 for bolts and nuts. Descretization of model into elements is known as modeling in FEM. Two types of connections such as End Plate Moment connection and Connection with Anchor bolts are modeled for this study. The models were meshed with element size 100mm. The meshing is done to provide robust to the model.



(a) (b)

Fig -8: FEM Models: (a) End Plate Moment Connection. (b) Connection with Anchor Bolts.



(a) (b)

Fig -9: Meshed FEM Models: (a) End Plate Moment Connection. (b) Connection with Anchor Bolts.

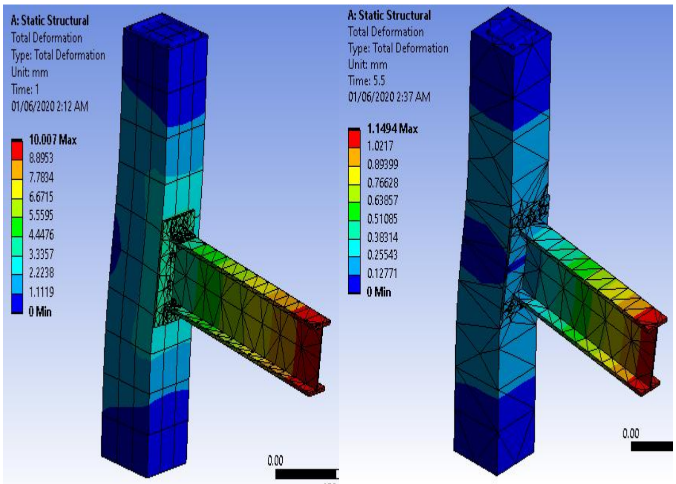
3. FEM ANALYSIS AND RESULTS:

3.1 Preliminary Analysis:

a) Boundary Conditions and Loading:

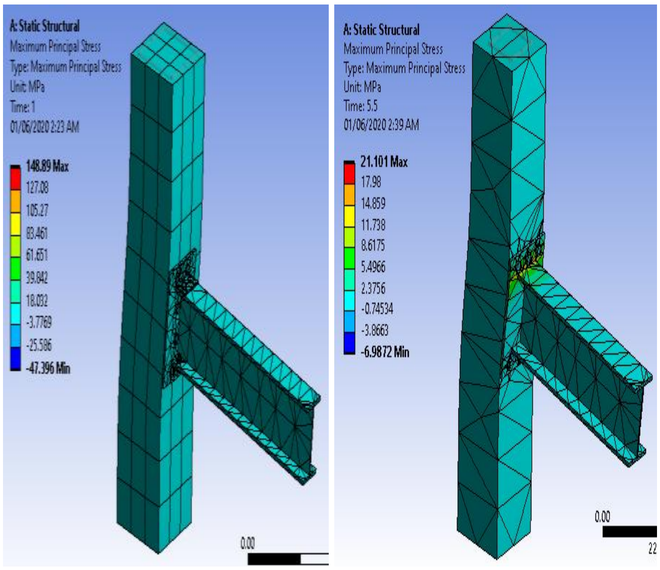
- The column is fixed at both the ends.
- The connection is eccentrically loaded with a point load of 250kN which is applied at the beam end.
- The parameters that were considered are: Total Deformation, Maximum Principal Stress and Maximum Principal Strain.
- The preliminary analysis is done to understand the behavior of these connections under normal loading conditions.

b) Results:



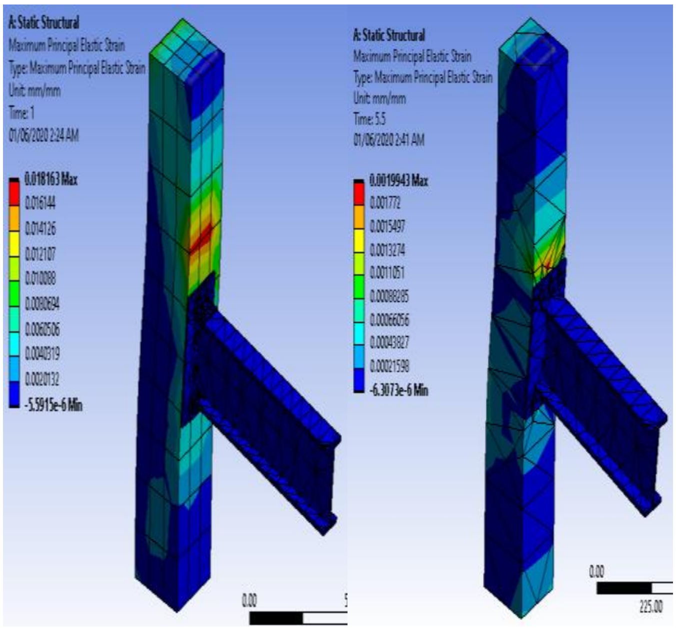
(a) (b)

Fig -10: Comparison of Total Deformation of a) End Plate Moment Connection b) Connection with Anchor Bolts.



(a) (b)

Fig -11: Comparison of Maximum Principal Stress of a) End Plate Moment Connection b) Connection with Anchor Bolts.



(a) (b)

Fig -12: Comparison of Maximum Principal Strain of a) End Plate Moment Connection b) Connection with Anchor Bolts.

Table -2: Analysis Results

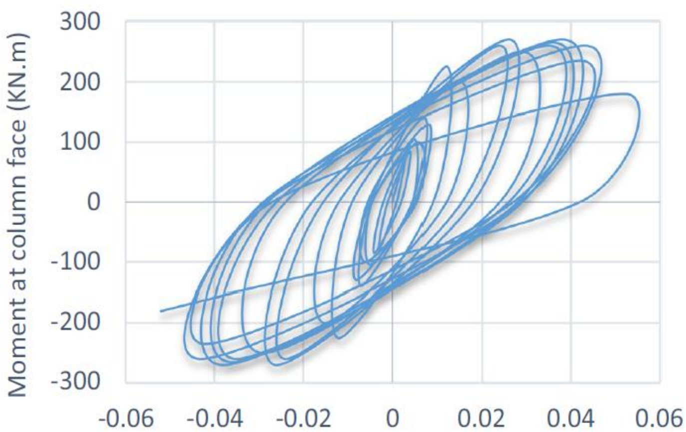
Parameters	End Plate Moment Connection	Connection with Anchor Bolts
Total Deformation	10.001mm	1.1494mm
Max. Principal Stress	148.89MPa	21.101MPa
Max. Principal Strain	0.018163	0.0019943

3.2 Cyclic Analysis:

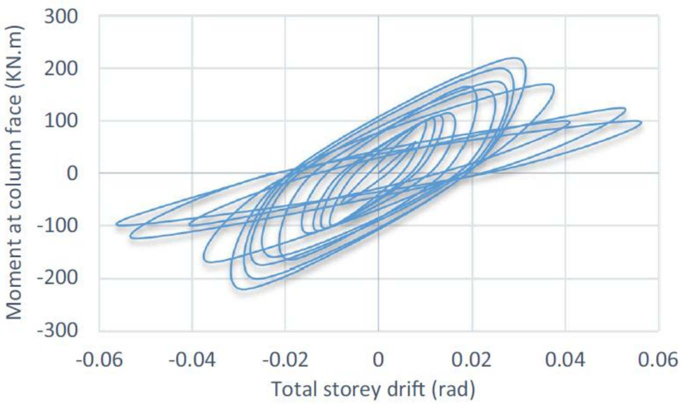
a) Boundary Conditions and Loading:

- The column is fixed at both the ends. .
- The loading sequence used for the seismic evaluation was that prescribed by the AISC Specifications 2010. The AISC protocol identifies a number of loading cycles at each inter-storey drift angle.
- The inter-storey drift angle capacity is believed to be the key parameter in evaluation of the cyclic performance of the specimens.
- The loading is applied as a displacement of 2mm/s.
- The load steps are performed on the ANSYS Workbench Software and the results are plotted as graphs.

b) Results:



(a)



(b)

Fig -13: Comparison of Hysteresis Response of a) End Plate Moment Connection b) Connection with Anchor Bolts.

4. CONCLUSIONS:

In this study, a preliminary and cyclic analysis of a specimen with RCC columns and steel beams with two types of connection using ANSYS Workbench has been conducted.

a) From the preliminary analytical results, the following conclusions were obtained:

- The analysis considering the interaction between reinforcing bars and concrete and between steel and concrete simulated the behaviors of RCS specimens well.
- The analysis results show that the end plate moment connection undergoes a larger total deformation when compared to the connection with anchor bolts.
- The analysis results also show that the maximum principal stress is larger in end plate moment connection when compared to the connection with anchor bolts.
- From the analysis it can be observed that the maximum principal strain in end plate moment connection is less when compared to the connection with anchor bolts.

b) From the cyclic results, the following conclusions were obtained:

- The hysteresis curves obtained from the cyclic analysis show us that the moment generated at the column face is higher in the End Plate Moment Connection when compared to the Connection with Anchor Bolts.
- It can also be observed from the hysteresis curves that the inter-storey drift is less in End Plate Moment Connection when compared to the Connection with Anchor Bolts.

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