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Studies on Behavior of Bolted Beam-Column Joints

[1] Dr. Aravindkumar. B. Harwalkar, [2] Sunil Police Patil
[1] M. Tech student, [2] Associate Professor
[1][2]Department of Civil Engineering, P.D.A College of Engineering, Kalaburagi-585102

Abstract: **-- The behaviour of joints or connections is very complex due to the various factors which influence them, such as geometric imperfection, lack of fit, residual stresses, connection flexibility, geometric complexity, slipping, and non-linear load deformation characteristics. In bolted joints, a variety of components such as angles cleats, end plates, stiffeners, and bolts are used to transfer and disperse loads from one member to the other. Due to use of bolts continuous load paths are employed to transfer the loads. Connections are often the critical component in a structure, and if they fail, progressive collapse is imminent. Therefore, a test program was aimed at investigating the behavior of a bolted beam-column connection such as unstiffened seated connection, stiffened seated connection, and moment resisting. Non-linear analysis was also performed using ANSYS software to compare the results. The study revealed that stiffened seated connection has got higher load carrying capacity and resilience. The analytical approach by ANSYS method can be adopted using modification factors.**

Keywords:-- **ANSYS, bolted beam-column joints, deflection, slope.**

I. INTRODUCTION

Any steel structure is an assemblage of different members such as beam, columns, and tension members, which are fastened or connected to one another, usually at the member ends. Many members in a steel structure may themselves be made of different components such as plates, angles, I-beams, or channels. These different components have to be connected properly by means of fasteners, so that they will act together as a single composite unit. Connection between different members of a steel frame work not only facilitate the flow of forces and moments from one member to another but also allow transfer of forces up to the foundation level. Connection are also required for extending the length of different types of members, connecting steel columns to footings, and for joining two parts of a structure during erection.

Bolted beam-column connections are commonly used in office buildings and offshore platforms. In recent years, an increased awareness has been on the reliability of these connections in extreme events, such as the loss of a load bearing column in a terrorist attack. A lack of study on bolted connections under dynamic loading has been revealed, and a number of experimental programs have been initiated. The ability to transfer the forces through the joints is key to maintain the structural integrity and prevent a progressive collapse in buildings. Usually two types of forces are transferred by bolted beam-column connections: shear and moment. A connection may be designed to transfer shear force if the beam is supposed to be hinge connected to the column only. If the beam is rigidly connected to the column, the requirement of a moment connection arises.

In recent years bolted beam-to-column connections has drawn themselves more and more attention. Because bolted steel frames are more flexible than welded steel frames and provide much more energy dissipation during an earthquake. But on other hand bolted steel frames will be experiencing much more deformation than welded steel frames. In the places where displacements of frames have limits, design of bolted steel frames will be more challenging than design of welded steel frames. Therefore accurate calculations of displacements are needed in design of semi-rigid beam-to-column connections.

The aim of the project is to study the behaviour of different types of bolted-beam connections such as unstiffened seated connection, Moment Resisting Connection, stiffened seated connection. Using the above connections experimental work is carried out in order obtain the deflection and rotation slope, of the beam-column connections. The connections are modeled and analyzed using ANSYS software, the obtained analytical results are validated with the experimental results.

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II. RELATED STUDIES

In recent years, a number of research works were carried out to study the behaviour of bolted connections. This section deals with the review of the works related to the bolted connections. Cheol and Young et al(1996) conducted experimental investigation on the cyclic load behaviour of steel frames with bolted joints in comparison with welded joints for an exterior beam column joint. Three different types of connections viz. semi-rigid connection using high strength bolts, simple bolted connection and welded connection were considered in the study for varying effect of initial stiffness, maximum flexural resistance, failure modes, ductility and energy dissipation.

Chen et al (2000) discussed a new method of trimming the beam flanges in order to enhance the ductility of beam-column connection keeping the ultimate strengths unaltered and increasing the plastic rotation capacity and energy dissipation capacity. Shemy S. Babul et al (2012), In this paper the ductility and energy dissipation characteristics of semi rigid bolted connections using double web angle with top and seat angles is discussed based on experimental investigation. Non-linear analysis was also performed using finite element method to compare the results. S. Loganathan and C.G.Sivakumar et al (2013), In this paper they studied the behavior of the Steel Beam-Column joint under Quasi-Static load experimentally to study the Ductility Characteristics of Beam-Column joint.

III. METHODOLOGY

A. Procedure:

The two beams each of section ISMB-150 of length 650mm are connected to a column of section ISMB-150 of length 600mm using top and web cleat angles of sections ISA 40x40x6mm and 10mm dia HSFG bolts of grade 8.8 are used for the connections with a edge distance of 20 mm and a pitch distance of 30mm. Once the connections are completed the whole test set up is tested in the structural loading frame. The one end of the beam is connected to column and the other end is simply supported. A concentrated load is applied centrally at top of the column using a hydraulic jack and proving ring of capacity 250kN was used. Three dial gauges are used to note down the deflection at three different points, Two of them are placed at bottom side of the beam out of which dial 1 is placed closer to the angle section and dial 2 is placed at a distance of 65mm from the dial 1 i.e. as nearer as possible to dial 1 in order to find slope at a point. The dial 3 is placed on top of the beam at a distance of 150mm from the support in order to measure the deflection. A schematic view of a beam column joint along with dial gauges is shown in Fig.1 and also the test set up is shown in Fig.2. After that the load was applied gradually using a hydraulic jack at an incremental load of 1.67kN, at each increment of load corresponding dial gauges readings where noted down and the process is continued until the specimen is failed. The obtained dial gauges readings are used for further calculation, in order to obtain the required objectives. Similarly the above procedure is repeated for all the three type of connections.

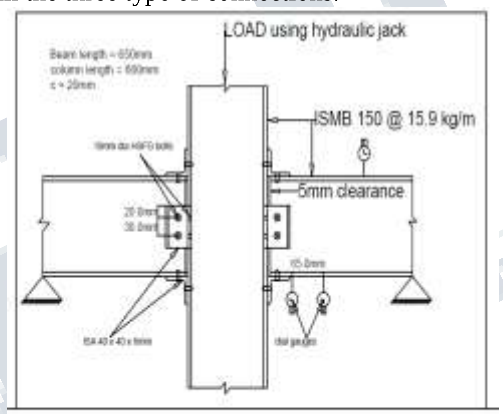

Fig.1. Schematic diagram of test setup

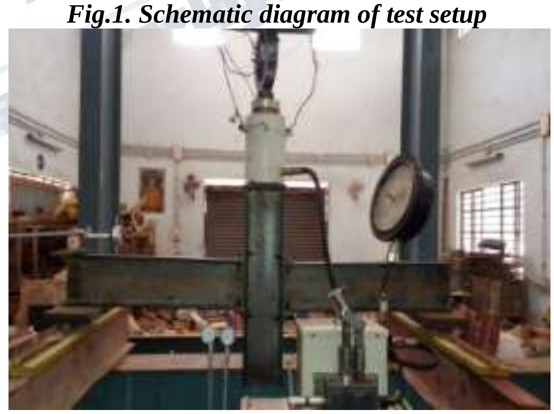

Fig.2. Experimental test setup

IV. RESULTS AND DISCUSSSION

A. Failure modes of Specimens:

i. Unstiffened seated connection:

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Fig.3. Failure of unstiffened seated connection

ii. Stiffened Seated Connection:

Fig.4. Failure of stiffened seated connection

iii. Moment Resisting Connection:

Fig.5. Failure of moment resisting connection

B. Comparative study for ultimate load:

The theoretical load carrying capacity of joint was calculated using classical approach [4]. The theoretical and experimental values of the ultimate load for different types of beam-column joints are shown in Table 1. The strength index which is taken as ratio of experimental to the theoretical ultimate loads is also tabulated in Table 1. It can be observed that for 8mm dia bolt the strength index value is less than 1 for unstiffened and stiffened connection. Also it was observed that the nature of failure of the connection was very brittle. Hence 8mm dia bolts are not suitable for the beam and column sections used in the study hence there is a need for similar study for other size of beam and column sections. For 10mm dial bolt the strength index value was more than 1 for unstiffened stiffened and moment resisting connection.

Table.1. Comparison of ultimate loads

Specimen	Theoretical strength in kN	Experimental strength in kN	Strength Index
Unstiffened connection (8mmbolts)	15.4	13.06	0.85
Unstiffened connection (10mmbolt)	15.4	16.7	1.08
Stiffened connection (8mmbolts)	11.94	8.35	0.69
Stiffened connection (10mmbolt)	19.16	25.05	1.31
Moment Resisting connection (10mmbolt)	4.08	20.04	4.91

C. Comparative study of deflection:

Load versus deflection curves for the three types of connections are shown in Fig.6.

Stiffened seated connection has larger load carrying capacity compared to unstiffened seated connection and moment resisting connection. The area under load deflection curve is more for stiffened seated connection compared to unstiffened and moment resisting connection which. Hence stiffened seated connection has high resilience.

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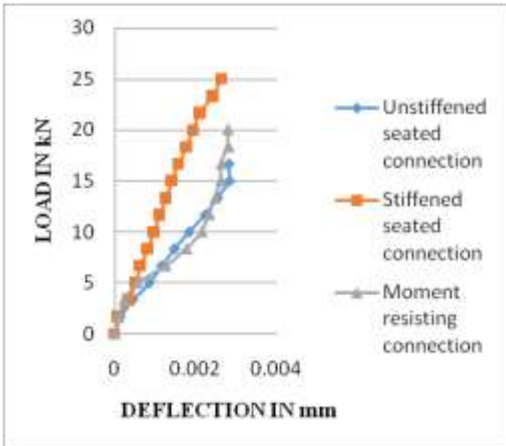

Fig.6. Load versus deflection curve

D. Comparative study of slope:

Load versus slope curves for the three connections are shown in Fig.7. Slope values increased with load values up to ultimate load. There is sudden drop in the slope near ultimate load for all the three connections.

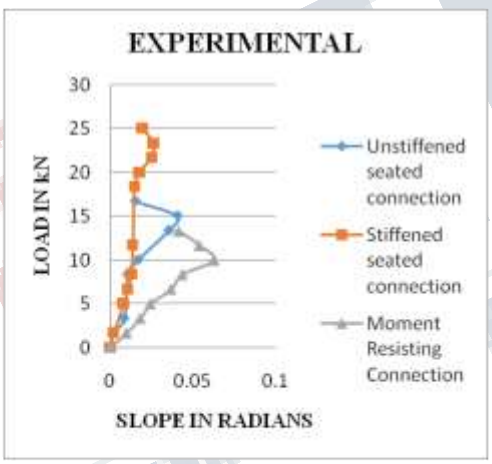

Fig.7. Load versus slope curve

E. Comparative study of variation of slope from rigid and semi-rigid concepts:

The slope of the beam column joints from the concept of semi-rigid joint was calculated using the approach mentioned in the literature [6]. The slope values from rigid concept were determined from classical theory of slope and deflection. The comparative study of the two approaches is shown in Fig.8.

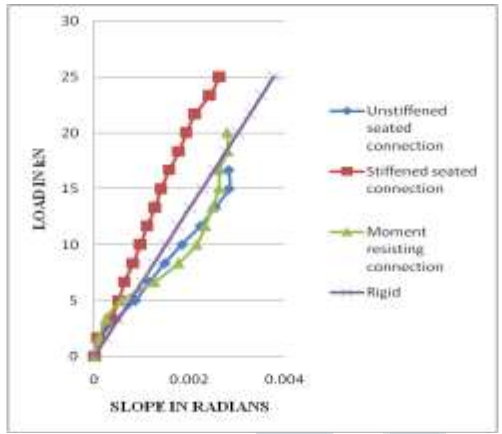

Fig.8. Load versus slope curves from semi-rigid and rigid concept

V. FINITE ELEMENT MODELING USING THE SOFTWARE ANSYS:

In the present study, rotation behaviour of bolted beam-column connection is studied numerically. As the members associated with the connection undergo large deformations and rotations, geometric and material non-linearity are to be accounted in the problem. Since all the experiments are performed under static loading condition, a static non-linear structural analysis is required for simulating the real problem. Conventional 3D brick elements are inadequate to represent the realistic contact behaviour in the column-beam interface and bolt-plate interface under incremental loading conditions. Contact problems can be efficiently handled with ANSYS.

Brick elements with 8 nodes, SOLID 45 available in the ANSYS element library, were used in the three dimensional modeling of beam, column angles and bolts. The contact surfaces including the areas anticipated to be in contact were defined and paired using contact elements, CONTA174 and TARGE170. For structural steel used, the yield stress was taken as 250 N/mm2, ultimate tensile strength as 410 N/mm^2. For the high strength bolts used, yield stress of 640 N/mm^2, ultimate stress of 800 N/mm^2 was taken. The modulus of elasticity of steel was taken as 2×105 N/mm^2. The column and beam members were modeled and coarse free meshing was performed.

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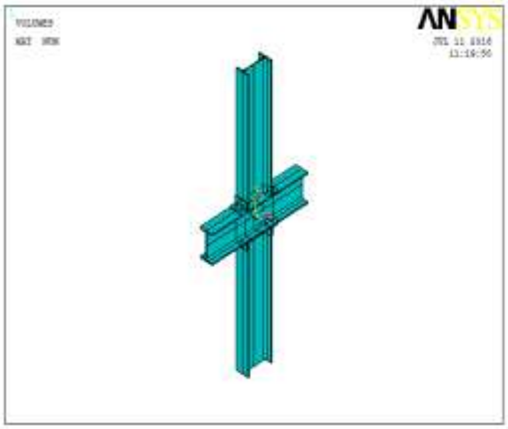

Fig.9. Ansys model for unstiffened seated connection

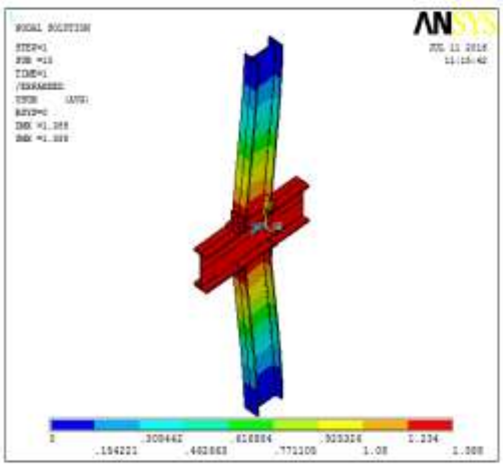

Fig.10. ANSYS Deformed model for unstiffened seated connection

A. Comparative study between Experimental and ANSYS Results:

Due to limitation of link element, gluing and defining of degree of freedom for restrain, there is necessity of using modification factor for the ANSYS results. A multiplication factor of 20 was satisfactory for determining deflection values and the corresponding value for slope determination is 25. ANSYS approach is most versatile and can be applied for any kind of complex loading.

i. Unstiffened seated connection:

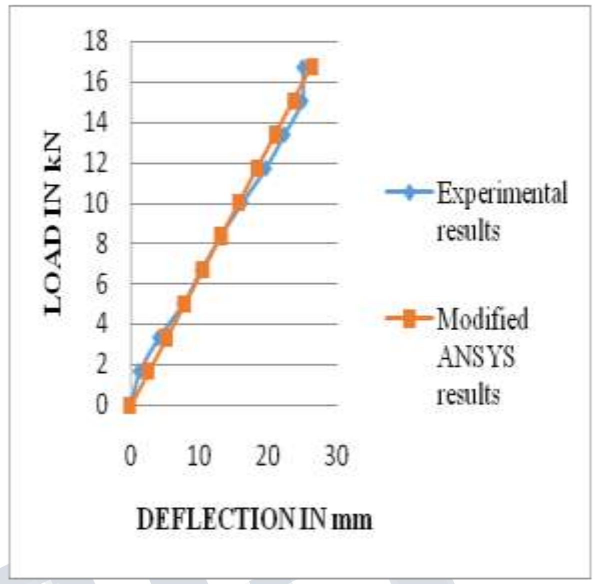

Fig.11. Load versus deflection curve

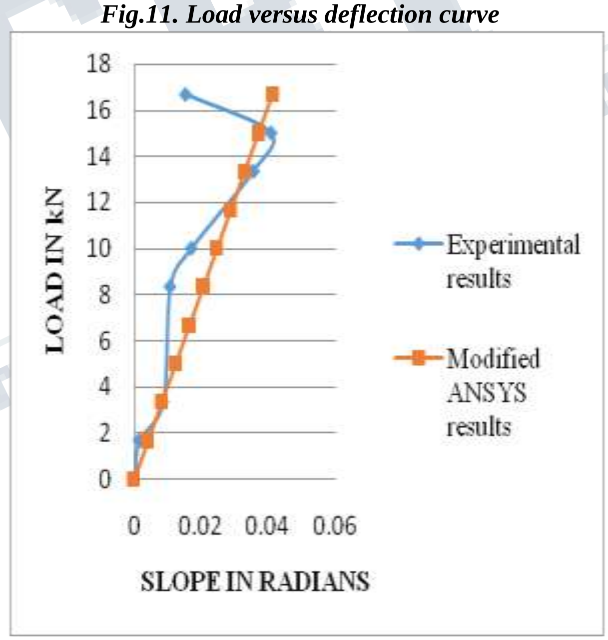

Fig.12. Load versus slope curve

ii. Stiffened seated connection:

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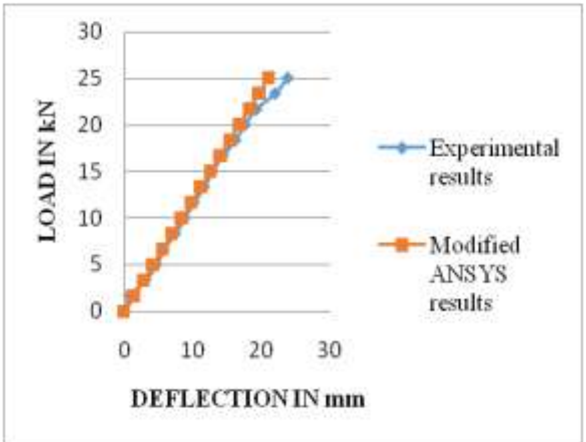

Fig.13. Load versus deflection curve

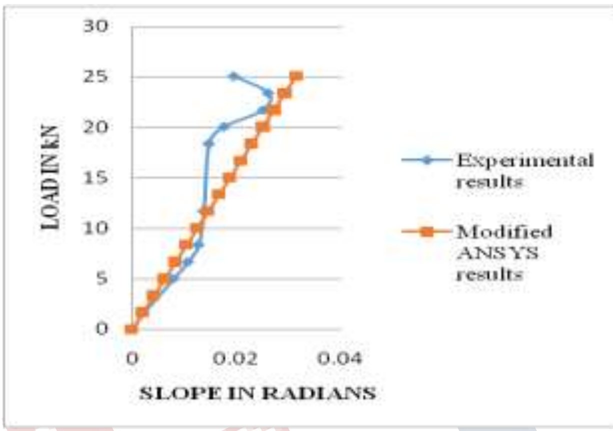

Fig.14. Load versus slope curve

iii. Moment resisting connection:

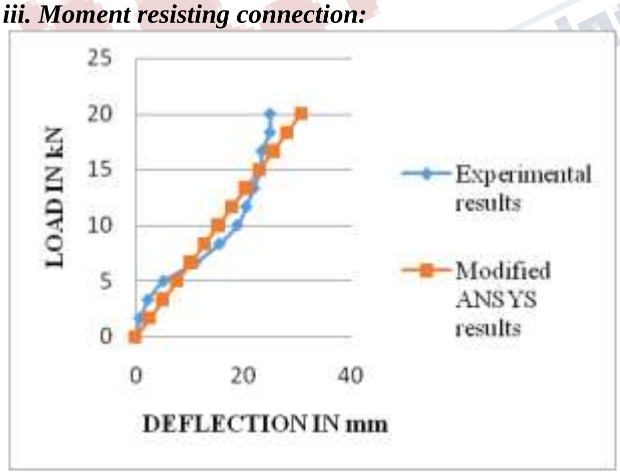

Fig.15. Load versus deflection curve

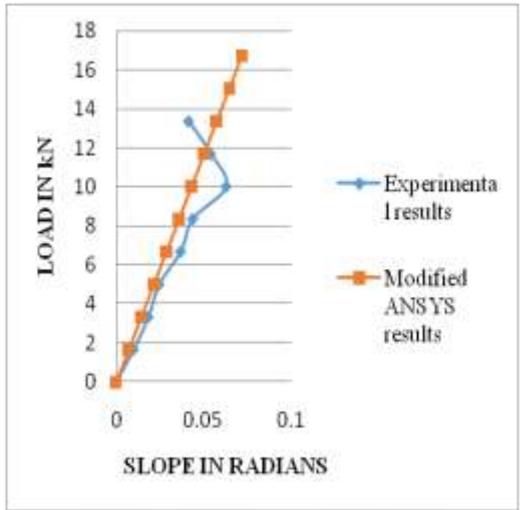

Fig.16. Load versus slope curve

V I. CONCLUSIONS

Based on the experimental and analytical investigation conducted on bolted steel beam-column joints, the following conclusions are drawn.

- Strength index values are more than 1 except in the case of connections using 8mm dia bolts.
- Use of 8mm dia bolts are not recommended for the beam and column sections used in the study because of brittle failure at a low load levels .
- Stiffened seated connection has higher load carrying capacity compared to unstiffened and moment resisting connection.
- Stiffened seated connection shows high resilience than unstiffened seated and moment resisting connections.
- Stiffened seated connection can be used to resist small amount of moment also.
- Clip angle type of moment resisting connection behaves like a semi-rigid connection.
- ANSYS method of analytical approach can be adopted for determining deflection and slope values using multiplication factors of 20 and 25 respectively.

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