iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VII **Month of publication:** July 2020

DOI: https://doi.org/10.22214/ijraset.2020.30612

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

A Review Study on Seismic Response of Steel Building Frames with Different Beam – Column Connections

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Abstract: ***The past review works show preference of steel structures over RCC structures due to ease on fabrication, lesser weight and better ductility which enhances seismic performance of these structures. The review of previous steel codes shows that beam column connections are assumed to be rigid. However, in reality beam – column connections do passes some degree of flexibility which needs to be incorporated in formulating the seismic design methodologies for the steel sections. In this research work an effort has been made to study the effect of beam – column connections on seismic response. The steel building frames ranging from 5 storey to 10 storey height has been selected for the analytical study. The connection flexibility has been varied in these building frames and these frames have been subjected to an ensemble of 100 ground motions to determine the seismic response. The seismic response has been studies in terms of response parameters like storey shear, storey moment, storey drift and fundamental time period. The analysis results have been tabulated to create the seismic response databank and non linear regression analysis has been conducted on this response databank to propose new equations to estimate the fundamental time period. These equations have been compared with the code equations to prove the accuracy of the proposed equations.***

I. INTRODUCTION

Steel frames are most efficient in minimizing the earthquake forces because of their ability to dissipate the seismic energy due to which they are often used in seismic prone regions. The multistory steel frames under seismic excitations has been the subject to intense research for decades. However, majority of the researchers assume connections to be rigid during their analysis but the rigid connection behavior is merely an idealization of the actual behavior. Generally Most of connections are neither fully rigid and do represent some degree of flexibility. The ignorance of connection flexibility may induce noticeable error in estimation of the seismic response. The classification of beam column connection has been presented in the subsequent section[5].

A. Classification of Beam Column Connections

Beam-column connections can be broadly classified into three categories namely
Rigid connection
Semi-rigid connection
Flexible connection
The rigid connections are those which transfer large moments to the columns and are assumed to undergo less deformation at the joint. Semi-rigid connections or partially restrained connections are those which transfer comparatively less moments to the columns and undergo considerable rotation and deformation at the joint whereas the flexible connections does not transfer any moment to the columns and undergo greater displacement and rotation at the joint. But still flexible connections are used because under the action of dynamic forces such as an earthquake, they experience very little damage as they exhibit improved energy dissipation characteristics. Indian standard code of practice (IS 800:2007) classifies the connections according to their ultimate strength or in terms of their elastic stiffness[5].

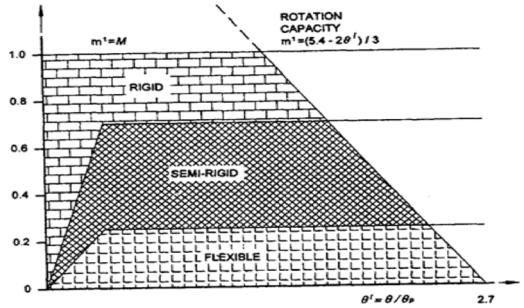


Figure 1.1. Classification of beam-column connections (IS 800 :2007)

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B. RIGID Connections

The beam-column connections that are classified as rigid essentially does not permit any rotation, displacement or moment release. High-rise and slender structures preferably have rigid connections. These connections transfer significant moment to the columns and are assumed to undergo negligible deformations at the joint. These are most efficient in resisting lateral loads in frames with and without sway. Beam-column connections shown in Figure 1.2 represents the rigid beam-column connections.

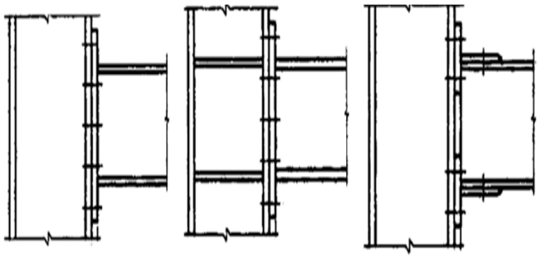


Figure 1.2. Various types of rigid connections (a) End plate without column stiffener (b) End plate with column stiffener (c) T-Stub connection (Subramanium 2007)

C. SEMI-RIGID Connections

In semi-rigid beam column connection rotation, displacement and moment release can be permitted up to a certain limit. Semi-rigid frames are also known as partial moment release frames[6]. IS 800:2007 defines the semi-rigid connections as the connections in which the value of non-dimensional moment parameter has the value ranging between 0.7-0.2. In terms of rotational stiffness semi-rigid connections can be defined as the connections in which rotational stiffness varies from 2.5θ to 0.5θ[7]. Fryre- Morris connection model is frequently used to model the semi-rigid connections and gives relationship between moment and curvature as

$\theta_1 = C_1(KM)^1 + C_2(KM)^3 + C_3(KM)^5$

where ,

θ_1 = Rotational parameter

M = Moment at the joint

K = Standardization parameter

C_1, C_2, C_3 = Curve fitting constants

The values of the constants for various types of semi-rigid connection are mentioned in IS 800:2007. In practical consideration most of the beam-column connections are neither fully flexible nor fully rigid. So, they can be termed as semi-rigid connections (Figure 1.3)

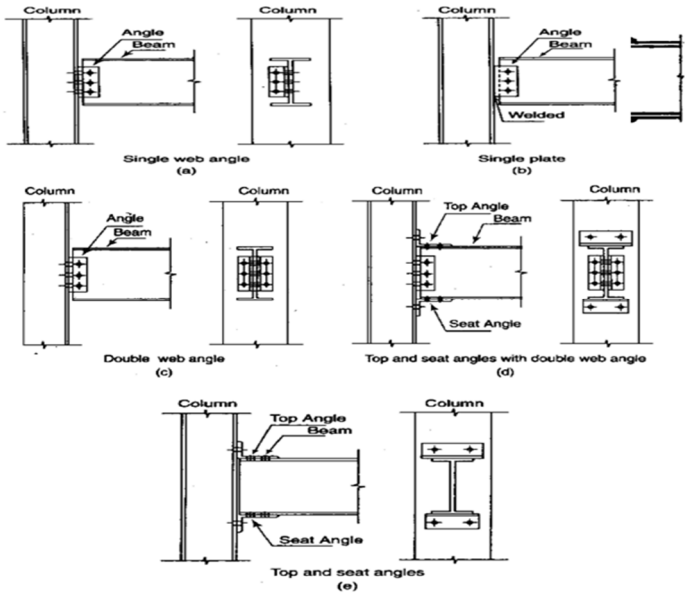


Figure 1.3. Various types of Semi- rigid connections (a) Single web angle (b) Single plate (c) Double web angle (d) Top and Seat angle with Double web angle (e) Top and seat angles (Subramanium 2007)

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D. Flexible Connections

The flexible connections can be defined as the connections which allows the rotation and moment release more than 75%. In flexible beam-column connections, moment from beam to column can be neglected. Indian code of practice is silent about the flexible connections. As per Australian code of practice flexible connections can be classified as: a) Angle seat connection b) bearing pad c) flexible end plated d) angle cleat connections[1]. These connections are shown Figure 1.4. The angle seat connection transfers the beam reaction to the column using angle seat The upper cleat is for angle restrain only, and it should be bolted may be top of web or to the flange. On the other side also, the angle seat should be bolted or fillet welded to the column. The reaction of beam is transferred by bearing, shear and bending of horizontal leg of angle, or by vertical shear through connectors. The beam is designed for zero end moment and eccentric beam reaction. In a bearing pad connection, the end plate provided with a fillet welded to the beam web and bearing pad is fillet welded to the column. The end plate is fixed to the column by the bolts. In this case the reaction of beam is transferred by welded shear to the end plate and by bearing to the bearing pad. In case of flexible end plate connection, the end plate is provided with fillet welded to the beam web and bolted to the supporting member. The reaction of beam is transferred by weld shear to the end plate and by shear and bearing to the web bolts. In angle cleat connection, one or two angle cleats may be used. These angle cleats are bolted to the beam web and to the supporting member. The beam reaction is transferred through shear and bearing of the web. The designed of beam is for zero end moment, with angle resisting the shear web and the supporting members are designed for the eccentric beam reaction. This connection has a very little moment capacity due to flexibility of connection between angle legs and supporting member. Flexible connections are found more suitable to resist seismic loading as they undergo elastic deformation under seismic excitation as compared to rigid and semi-rigid connections which undergo inelastic deformation during occurrence of an earthquake. After review of literature regarding the works done on flexible connections it was found that most of the works done were based on Euro code and Australian code. A very few of them have used non-linear dynamic analysis procedures. Also most of the works have used single bay frames for their analytical study. In the present study modeling and analysis of steel multistory frames with flexible beam-column connections has been done. Present study is based on Indian standard code of practice and Time history method (which is a non-linear dynamic analysis method) has been used for the analytical study.

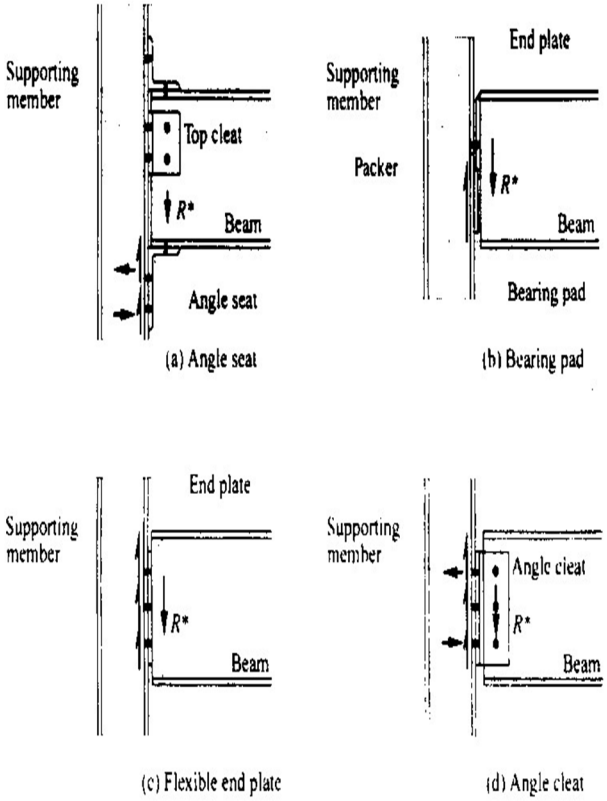


Figure 1.4. Various types of Flexible connections (a) Angle seat (b) Bearing pad (c) Flexible end plate (d) Angle cleat (Subramanium 2007).

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E. Moment – Rotation Behavior Of Different Beam – Column Connections

Figure 1.5 shows the moment-rotation behavior of different types of semi-rigid connections. The behavior moment rotation for semi-rigid connection follows a non-linear approach. Single web angle connection undergoes a lot of rotation on application of least moment. So, this connection decreases the lateral stability of the joint whereas T-stub connection undergoes least rotation on application of moment. So it gives maximum stability to the beam-column connections. After review of literature on past studies it was concluded that most of the works have not taken the Indian codes into consideration and the extent of semi-rigidity (in terms of %) has not been specified. Most of the earlier works have conducted the analytical study using static method of analysis only. In the present work analytical study on beam-column connections (which have extent of semi-rigidity as 50%) has been done using static and dynamic methods. The present study is based on Indian standard code of practice.The moment distribution pattern with magnitude of moments for rigid, semi-rigid & flexible beam-column connections. The end moments in case of rigid connections ($WL^2/12$) are largest because rigidity of beam-column connections does not allow any moment release which causes maximum moment concentration at the beam-column junction[12]. These end moments are reduced in case of semi-rigid connections because partial fixity of joints allow some degree (Figure 1.5 and Figure 1.6).

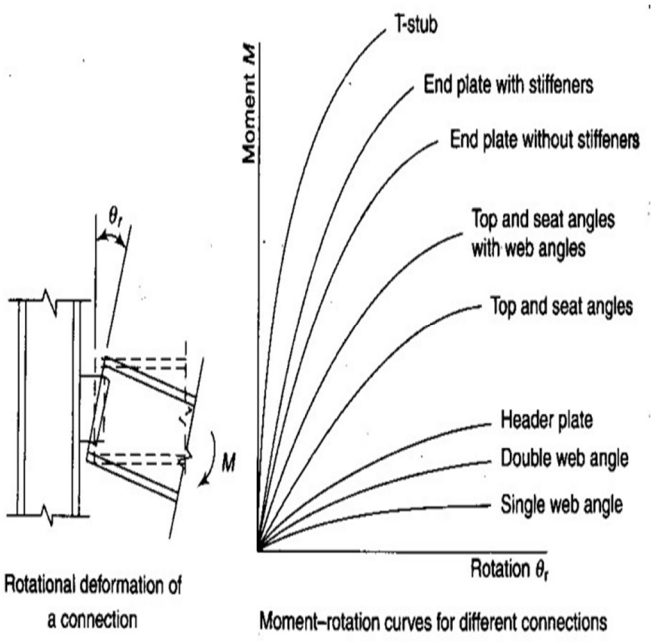


Figure 1.5. Moment - Rotation behavior of various types of semi-rigid connections (Subramanium 2007)

F. IS 800:2007 Provisions for Beam- column Connections

Indian standard IS 800:2007 classifies beam – column sections into rigid, semi rigid and flexible connections. This section discusses about Indian standard provisions for rigid, semi rigid but is silent about flexible connections.

1) *Rigid Connections:* The rigid connections should be checked for both moment and shear. These shear and moment transfer are assumed from beam to column. Fully welded connection can also be treated as a fully rigid connection. The rigid connection should be designed for a minimum of 1.2 times either of the full plastic moment of the connected beam and also for the maximum moment that can be delivered by the beam to the joint due to induced weakness at the end of joint, whichever is less. When a reduced beam section is opted, the minimum strength of beam-column joint shall be equal to 0.8 times the strength of unreduced section. The rigid connection should be able to resist the shear and the load combination is 1.2DL+0.5LL and the shear resulting from the application of 1.2 M_p in the same direction at each end of the beam (causing double curvature bending).
2) *Semi-rigid Connections:* Semi-rigid connections are to be designed to resist either a moment of at least 0.5 times. The full plastic moment of the connected beam or the maximum moment that can be delivered by the system, whichever is less. The design moment shall be achieved within a rotation of 0.01 radian. The strength and stiffness of semi-rigid connection should be calculated for in design and overall stability of the structure[10].

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II. LITERATURE SURVEY

The steel frames are often used in seismic prone regions due to their enhanced capacity of energy dissipation. However, the classical method of analysis assumes the connections to be rigid which is unrealistic from practical consideration. The detailed literature review has been presented in the subsequent section.

A. Literature Review

Arbabi (1981) considered the connection flexibility in analysis of a 3 storey frame. The authors had used classical approach for analysis of the frame. The classical approach was compared with the analysis results obtained from the SAP software. The comparison showed close agreement between both approaches. Wai-Fah and Lui (1986) proposed a new analytical method for analysis of the steel frames incorporating the aspect of connection flexibility. The authors used the proposed method to analyze a single storey, single way frame and a four storey, single sway frame by modeling them as rigid and flexible frames.The authors observed the increase in drift with connection flexibility and consideration of connection flexibility aggravated the drift. The same observation was reported by Lui and Chen (1987) for analysis of two single storey steel frames subjected to static loading. Wald (1991) observed the geometric irregularities in columns to aggravate the drift response of flexible connections.

Al dbermani and Zhu (1993) based on their analytical study on two storey, single bay and three storey, single bay frame with flexible and rigid connections observed that stiffness and energy dissipation capacity of the frame to be sensitive to vibration characteristics of the frame. Loi and Vimonstait (1994) performed non-linear elastoplastic analysis of steel frames incorporating the effect of connection flexibility. The authors proposed a new mathematical approach for semirigid connections. The authors compared it with the dynamic analysis results and observed it to be in close agreement. Al Bermani and Zhu (1995) determined the dynamic response of flexible connection frames using flexible connections like end plate connection, T- stub connection etc. The authors conducted the numerical study on two single storey frames without bracing (one symmetrical and other unsymmetrical) with different types of flexible connections were modeled. Time history analysis of these frames was carried out to determine the vibration characteristics of the frame and it was found that connection flexibility magnifies the frame response. Lui and Lopes(1996) have discussed dynamic response of semi-rigid frames using a computer model. Awkar and Lui (1997) have discussed the response of multistorey flexible connected frame subjected to earthquake excitations using a computer model. The model takes into account connection flexibility as well as material and geometric nonlinearity. Response characteristics of two multistorey frames with rigid, semi-rigid and flexible connections subjected to two different earthquakes were studied with reference to their modal attributes. The study indicates that connection flexibility tends to increase the upper storey drift and causes the frame periods to spread over a wider spectrum and it increases the importance of higher modal contributions to the structural response. Lima *et al.* (2002) conducted series experiment with finite element simulations to determine rotation capacity and moment resistance of semi-rigid connections. Based on the investigations a a mechanical model to assess the connection‘s structural response was developed. The model was based on the component of mechanical model method of design, in accordance with the Euro code 3 specification. As per the proposed model, each joint is represent by a non-linear force divided by displacement curve. Darı´o Aristiza´bal-Ochoa (2004) conducted elastic analysis of semi-rigid beam-columns with symmetrical column cross sections including the effects of geometric non-linearity. The method had the limitation that it considered flexural strains ignoring the effects of axial and shear strains. The proposed method is observed to be more accurate for very large curvatures and for structural members with horizontal and vertical displacements under the bending actions. Al-Jabri*et al.* (2005) determined moment–rotation relationships for different types of connections subjected to thermal loading. The results of analytical study indicate the sensitiveness of beam – column connections to rise in temperature Dario Aristizabal-Ochoa (2007) conducted nonlinear large deflection-small strain analysis andpost buckling behavior of Timoshenko beam–columns of symmetrical cross section with semi-rigid connections subjected to conservative and non-conservative end loads (forces and moments) including the combined effects of shear, axial and bending deformations, axial load eccentricities, lateral bracing and out-of-plumpness are developed in a simplified manner. A new set of stability functions based on the ―modified shear equation‖ that includes the effects of shear deformations and the shear component of the applied axial forces is derived. Also, an expression for the axial displacement δ_b caused by the ―bowing‖ of the beam–column subjected to end forces and moments with generalized end conditions is derived in a classic manner. Ali Abolmaali (2009) conducted 48 full cyclic tests and determined the energy dissipation characteristics of semi-rigid connections. From the analysis study it was observed that shape of the hysteresis is dependent upon plasticity and pinching which governs the energy dissipation capability of the connections. Valipour and Bradford (2012) proposed a new 1D frame compound-element considering geometric and material nonlinearity incorporating the effects of connection flexibility. The formulated element was based on the force interpolation concept and the total secant stiffness approach. The proposed element was implemented in a FORTRAN computer code. The accuracy and efficiency of

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the formulation was verified through some numerical examples. Nguyen and Kim (2013) proposed a simple effective numerical procedure based on the beam–column method for nonlinear elastic dynamic analysis of three-dimensional semi-rigid steel frames. The geometric nonlinearity is considered by using stability functions and geometric stiffness matrix. An independent zero-length connection element comprising six translational and rotational springs is used to simulate the steel beam-to-column connection. The dynamic behavior of rotational springs is captured through the independent hardening model. The Newmark numerical integration method combined with the Newton–Raphson iterative algorithm is adopted to solve the nonlinear equations. The nonlinear elastic dynamic analysis results are compared with those of previous studies and commercial SAP2000 software to verify the accuracy and efficiency of the proposed analysis. Varadharajan *et al.* (2014) through their study on multi storey steel frames with different beam column connections observed seismic response to be sensitive to degree of connection flexibility. Yassami and Ashtari (2015) propose a new method using of genetic algorithm(GA) and fuzzy logic for optimizing the weight of steel frames with different connections. The genetic algorithm used employed a uniform crossover and binary coding for better convergence. The authors observed beam – column connection to significantly influence the behavior of steel frames. Pirmoz and Liu (2017) proposed a hybrid method incorporating the advantages of both FBD and DBD to design the semi–rigid connections based on plastic method of design in comparison to traditional methods of design. The semi-rigid steel frames were observed to be a cost-effective alternative to conventional fully rigid steel frames and the proposed method is observed to be under conservative as compared to code methods and hence yields economy.

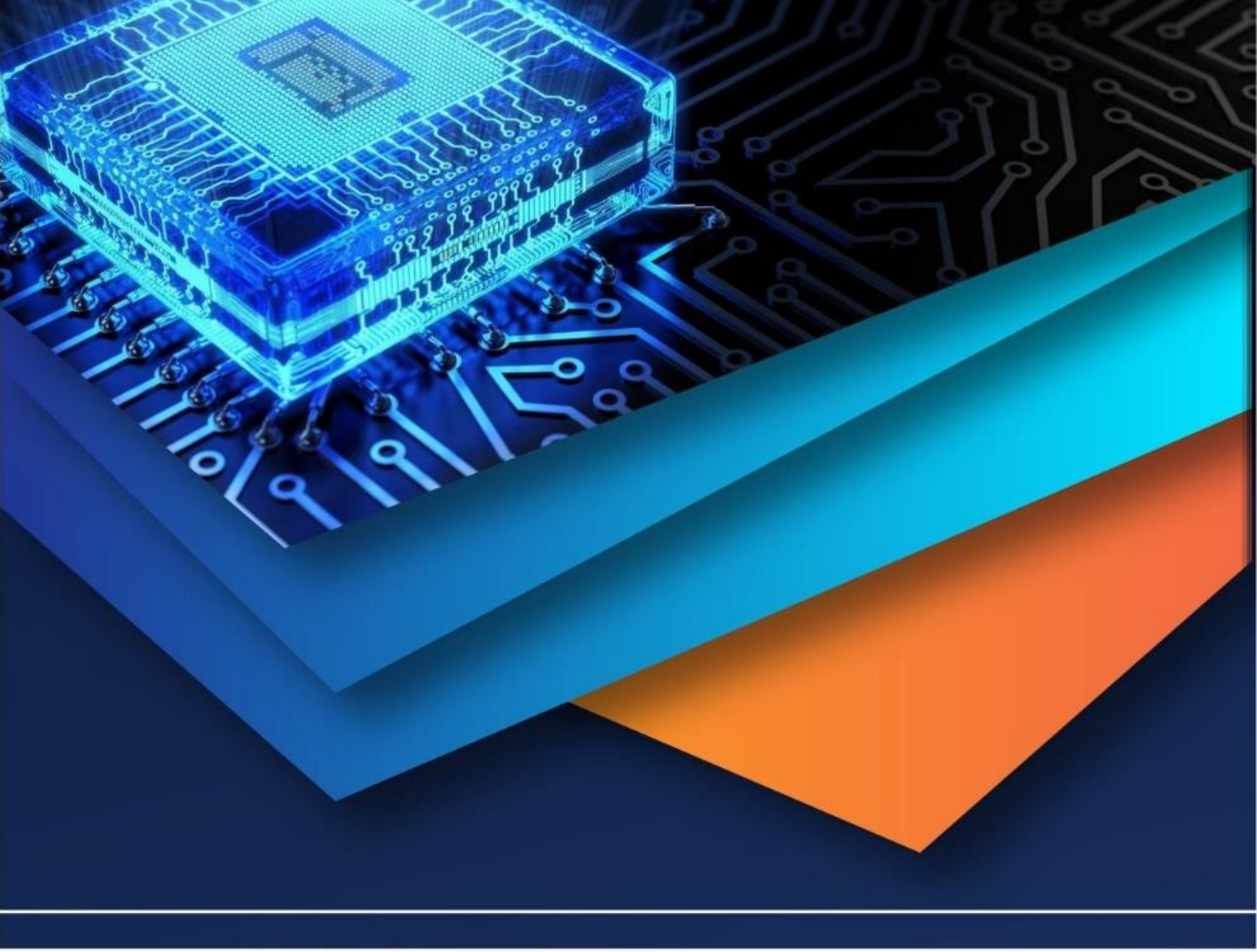
III. CONCLUSION

The past literature review shows a large number of studies devoted to multi storey steel frames. However, Majority of the research studies assume beam – column connections to be rigid and ignore the aspect of connection flexibility. However, in reality every connection do posses some degree of flexibility which needs to be incorporated in analyzing the steel braced frames. In this research works at first effect of connection flexibility on seismic response has been studied on large number of building models. The results of analytical study show that connection flexibility has a significant impact on the seismic response as under Connection flexibility increases the storey drift with maximum value for flexibly connected frames. However, storey shear follows an increase with connection flexibility with moment variation following a reverse trend .

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