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Performance of Reduced Beam Sections in Irregular Beam Column Connection

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Abstract: ***The reduced beam section (RBS) moment connection, also known as the "dog bone," is rapidly emerging as a popular choice for seismic-resistant steel moment fames.***
While research and testing on this connection is continuing, prior research and field experience have shown that the RBS is capable of economically providing ductile and reliable performance. This study is conducted to give advantageous factors related to RBS connection in inclined beam column joint. External load leads to shear and flexural forces on the inclined columns joints and its failure mode, resistant strength and ductility capacity is different than those of the perpendicular beam column joint.
In this study analytical work on reduced beam column connection with round cut on the flange of the beam having different beam and column inclination is investigated. These result were compared with double reduced section and triple reduced sections.
The model was created with finite element method (FEM) and analysed by ANSYS workbench 16.1 software. The result from this study show that the column stress gets decreased by providing RBS in beam column joint and ductility of the section increased.
Keywords: Inclined beam column joint, Reduced beam section, ductility, Double reduced section, triple reduced section, Finite element method

I. INTRODUCTION

During the 1994 Northridge earthquake, the bolted web-welded flange moment connections in steel moment-resisting frames suffered unexpected brittle failures in and near the heat-affected zones. A lot of damage of lives and property was observed during this earthquake. Many industrial steel buildings were severely damaged during this havoc. Many modifications have been proposed for post Northridge earthquake new construction and retrofit of steel moment frames. Many of the recommendations in FEMA 350 have since found their way into the Seismic Provisions for Structural Steel Buildings published by the American Institute of Steel Construction (AISC).

All of the connections approved in for Steel Moment Resisting Frames combined improvements in welding along with detailing that induce the beam plastic hinge to form a short distance away from the beam-to-column interface. The type of detailing that shifts the plastic hinges away from the connection region generally falls into two main categories, The one is associated with the strengthening of the connection and the other with weakening the beam framing. The second approach however, referred as Reduced Beam Section (RBS), is based on the selective removal of beam material adjacent to the connection, either from the web or from the flanges as shown in the Fig. 1.

A new cut profile consisting of two and three adjacent radius cuts in the beam flanges is proposed with the aim improve ductile behaviour, higher energy absorption, and less post-earthquake damage to the connection. The seismic moment resisting steel connection consist of two radius cut is named double reduced beam section or DRBS in short and for three radius cut is named triple reduced beam or TRBS. A comparison between the traditional RBS and the proposed DRBS connections has been made using verified nonlinear finite element models.

As RBS connection is studied and used widely in US, Japan and Europe, however its study is limited with respect to Indian profile. and so not found mentioned in any Indian Standards for steel design IS800-2007, IS808-1989, IS1852-1985, IS 2062-1999, IS8500-1991, IS12778-2004 & IS12779-1989. It can be adopted in India for better performance in strong and intermediate earthquakes.

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Fig. 1 Reduced beam section in beam column joint

II. OBJECTIVE

A. To analyse the seismic behaviour of reduced beam section (RBS) in inclined beam column joint
B. To study the ductility demand of beam column connections in inclined reduced beam column connections (for elevation and plan inclination of beam)
C. To determine the stress concentration at beam and column in different column inclination of reduced beam column joints
D. To Compare RBS with double and triple reduce beam section in these inclined beam column connection

III.MODELLING OF BEAM COLUMN JOINT

Beam column joints are the most critical part of a structure and it is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. RBS in the beam column joint which improve the ductility demand of the structure. For beam column models, columns having height of 975mm and beams are provided on either side of column having length of 1000 mm from the centre of the column. Details of specimen given in the Table I and Table II shows the mechanical properties of proposed specimen. Hot rolled parallel flange I section are used for this study as per Indian standard (IS) 12778 and 8500. These sections are classified into three types as, narrow parallel flange beam (NPB), wide parallel flange beams (WPB) and parallel flange bearing pile section (PBP). NPB sections are generally used for beam and WPB sections are used for column. Beam column joints are provided with end plate having thickness same as that of column flange and width same as width of column web.

Table I Beam And Column Specimen Details

Description	Beam	Column
Element	NPB200	WPB150
Depth (mm)	200	162
Web thickness(mm)	5.6	8
Flange width(mm)	100	154
Flange thickness(mm)	8.5	11.5

Table II Mechanical Properties Of Proposed Specimen

Section	WPB150	NPB200
Yield strength (MPa)	334	330
Tensile strength (MPa)	486	484

Round or circular reduced section is used in these beam column joints. Fig. 2 shows typical geometry of reduced section and Table III shows the geometric details of reduced section. An element SOLID45 from ANSYS element library was used for the 3-D finite element modelling of the RBS moment connection. The fundamental assumptions made to idealize steel mechanical properties are including: Young's modulus of 20000 MPa, Poisson's ratio of 0.3. For double RBS and triple RBS each single cut having the same dimension and area of single RBS. And these cut are placed adjacent to each other.

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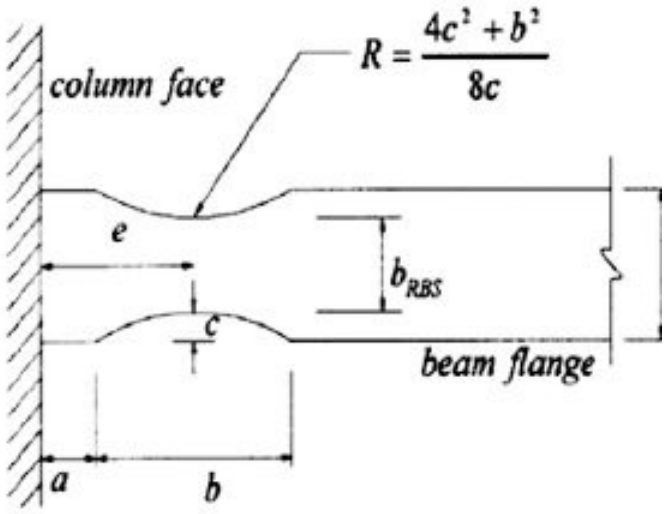

Fig. 2 Typical geometry of round reduced section

Table III Geometric Details Of Reduced Section

Section	a (mm)	b (mm)	c(mm)	R(mm)	Area (mm^2)
Round	60	160	25	140.5	2718.046

For beam column connection, both end of column is fixed and beams towards the column face are fixed by welding and other end makes free. Reverse cyclic load for a fixed deformation of 50mm are applied on both free end of the beams and all are done in ANSYS Workbench 16.1.

Inclined beam column connections are most commonly high storey buildings and stadiums. The load carrying capacity and stress distribution of these elements are differ from ordinary beam column connections. Six different cases are considered in inclined beam column joint.

A. Case 1 Beam Column Joints Having Elevation Inclination Of Beam

For elevation inclination four models are considered, with beam inclination of 5˚, 10˚, 20˚ and 30˚. Model description is shown in the Table IV. ANSYS model of elevation inclination of beam is show in the Fig. 3.

Table IV Model Description Of Elevation Inclination

Model	Details
Model E 5˚	Model with right side of the beam inclined by 5˚
Model E 10˚	Model with right side of the beam inclined by 10˚
Model E 20˚	Model with right side of the beam inclined by 20˚
Model E 30˚	Model with right side of the beam inclined by 30˚

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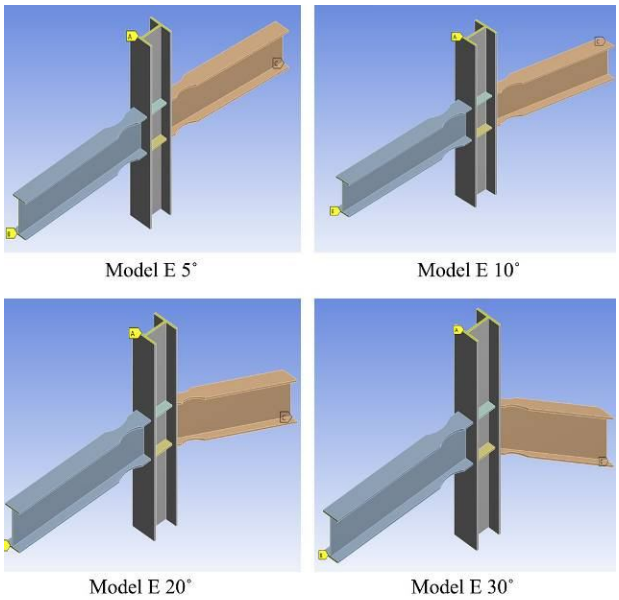

Fig. 3 Elevation Inclination of Beam

B. Case 2 Beam Column joints Having plan Inclination of Beam

For plan inclination of beam, four inclined beam column joints are considered, with inclination of 5˚, 10˚, 20˚ and 30˚. Table V shows the model description of beam column joint with plan inclination. ANSYS model of plan inclination of beam is show in the Fig. 4.

Table V Model Description Of Plan Inclination

Model	Details
Model P 5˚	Model with right side of the beam inclined by 5˚
Model P 10˚	Model with right side of the beam inclined by 10˚
Model P 20˚	Model with right side of the beam inclined by 20˚
Model P 30˚	Model with right side of the beam inclined by 30˚

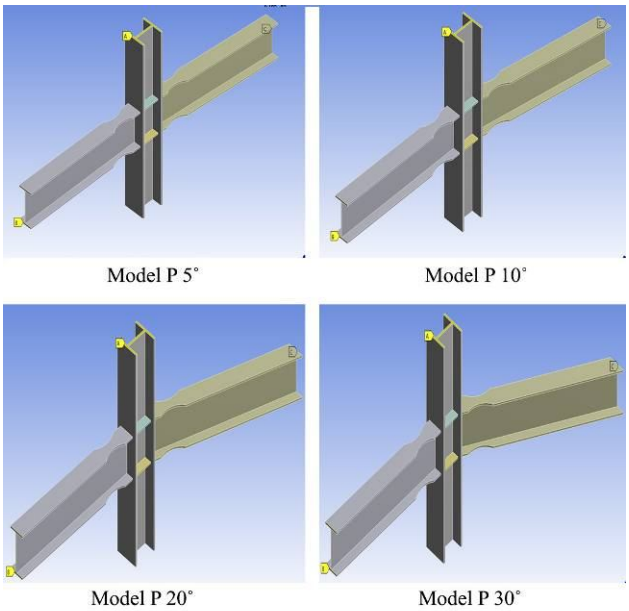

Fig. 4 Plan Inclination of Beam

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C. Case 3 Beam Column Joints having Column Inclination

Inclined column is not vertical which are used in many construction works for aesthetics and architectural requirements. For column inclination, four models are considered with an inclination of 5˚, 10˚, 15˚ and 20˚. Model description is shown in the Table VI. ANSYS model of column inclination is show in the Fig. 5.

Table VI Model Description Of Column Inclination

Model	Details
Model C 5˚	Model with column inclined by 5˚
Model C 10˚	Model with column inclined by 10˚
Model C 15˚	Model with column inclined by 15˚
Model C 20˚	Model with column inclined by 20˚

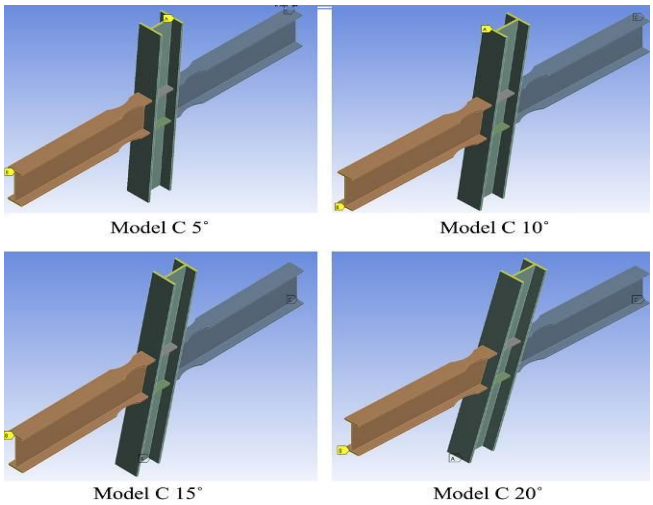

Fig. 5 Column Inclination of Beam Column Joint

D. Case 4 Comparing Elevation inclination of beam with double (DRBS) and triple reduced beam section (TRBS)

For the best elevation inclination of beam, two models of double and triple RBS are considered. Model description is shown it the Table VII and Fig. 6 shows the models developed in the ANSYS software.

Table VII Models Description With Drbs And Trbs Having Elevation Inclination Of Beam

Model	Details
Model ED 20˚	Model with right side of the beam inclined by 20˚with double RBS
Model ET 20˚	Model with right side of the beam inclined by 20˚ with triple RBS

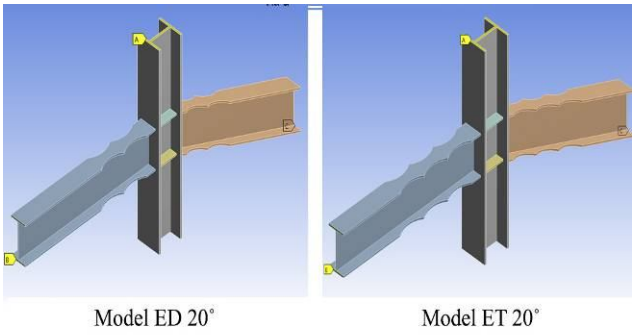

Fig. 6 Elevation inclination with DRBS and TRBS

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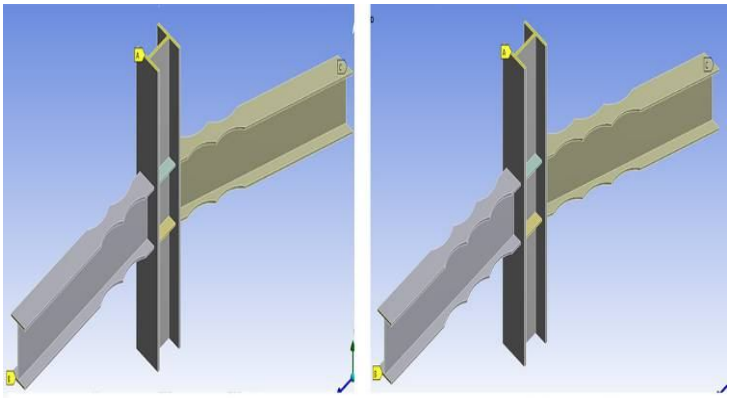
E. Case 5 Comparing Plan Inclination of Beam with double (DRBS) and triple Reduced beam Section (TRBS)

For plan inclination of beam, two models of double and triple reduced beam section are considered for comparing the best inclination of beam. Table VIII shows the model description of DRBS and TRBS. And Fig. 7 shows the ANSYS models of the same.

Table VIII Models Description With Drbs And Trbs Having Plan Inclination Of Beam

Model	Details
Model PD 20˚	Model with right side of the beam inclined by 20˚ with DRBS
Model PT 20˚	Model with right side of the beam inclined by 20˚ with TRBS



Model PD 20˚ Model ET 20˚

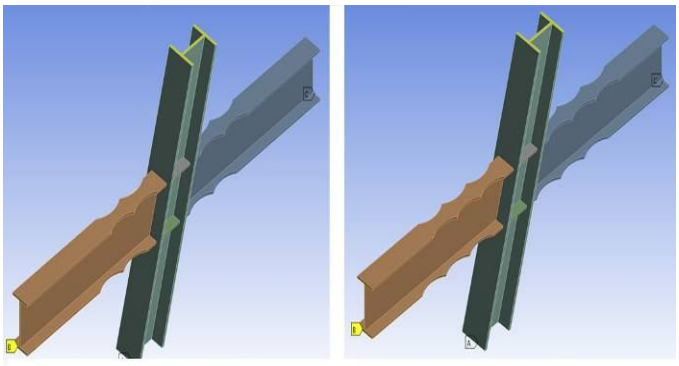
Fig. 7 Plan inclination with DRBS and TRBS

F. Case 6 Beam column joint having column inclination with double (DRBS) and triple reduced beam section (TRBS)

For the best column inclination double reduced section and triple reduced section are provide in the beam flanges. Two such elements are modelled in ANSYS software and its models description shown in Table IX. Fig. 8 shows the ANSYS model of the same.

Table IX Models Description Of Beam Column Joint Having Column Inclination With Drbs And TRBS

Model	Details
Model CD 20˚	Model with column inclined by 20˚ with double RBS
Model CT 20˚	Model with column inclined by 20˚ with triple RBS



Model CD 20˚ Model CT 20˚

Fig. 8 Column inclination with DRBS and TRBS

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IV. ANALYSIS

Deformed shape of different inclined beam column connections with reduced beam section is analysed using ANSYS. Fig. 9 and Fig. 10 shows the deformed shape of elevation inclination and plan inclination of beam column joint respectively. And Fig. 11 shows the deformed shape of inclined column in beam column joint having RBS. Fig. 12 and Fig. 13 shows deformed shape of double and triple RBS with elevation and plan inclination of beam and column inclination respectively and fig 14 shows double and triple RBS in inclined column. From the deformed shape it is clear that the plastic hinges are formed with in the beam which is away from the column face. So the column is more safe from seismic action.

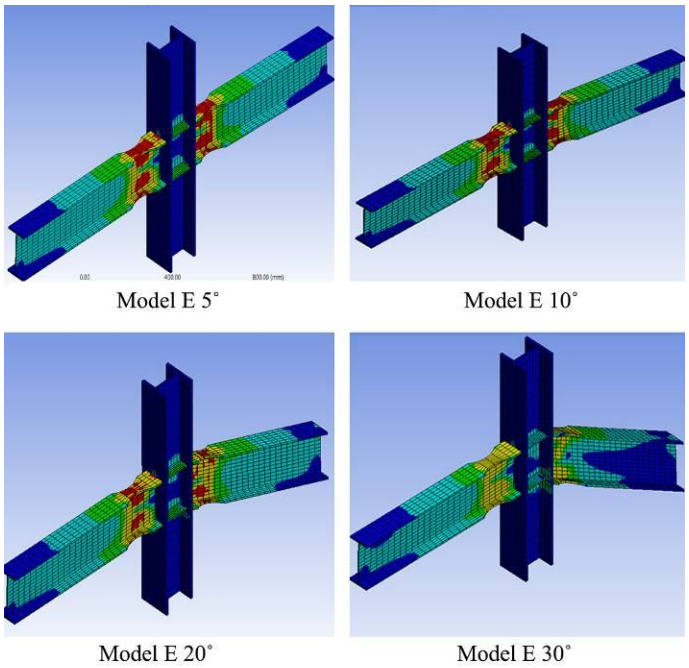

Fig. 9 Equivalent stress diagram of elevation inclination

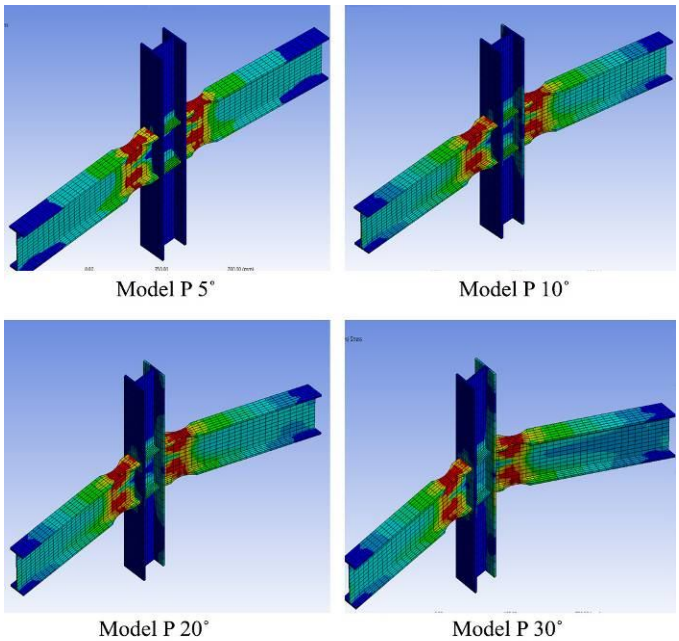

Fig. 10 Equivalent stress diagram of plan inclination

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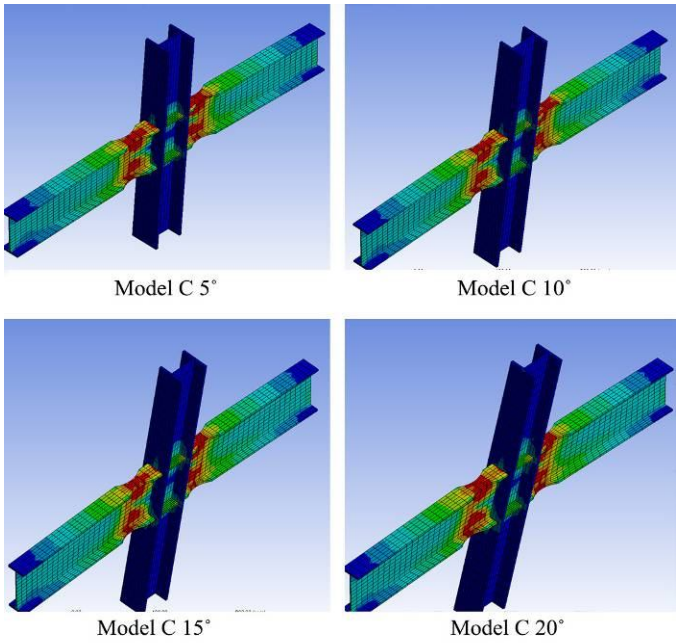

Fig. 11 Equivalent stress diagram of column inclination

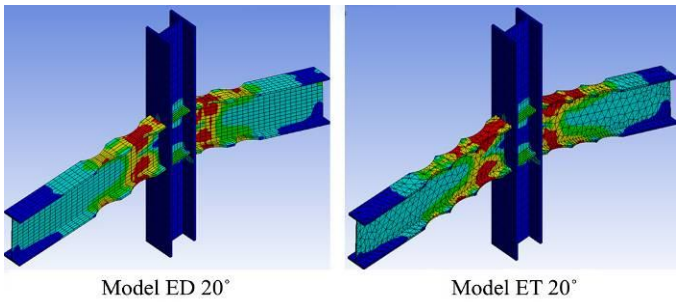

Fig. 12 Equivalent stress diagram of elevation inclination with DRBS and TRBS

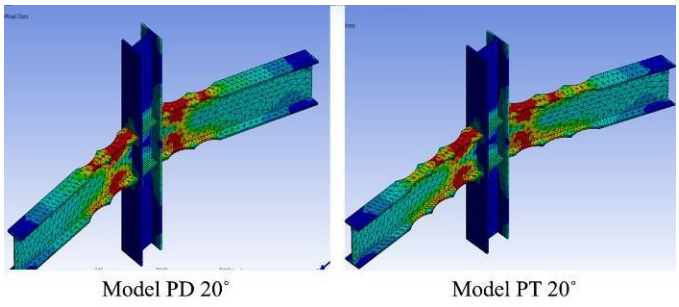

Fig. 13 Equivalent stress diagram of plan inclination with DRBS and TRBS

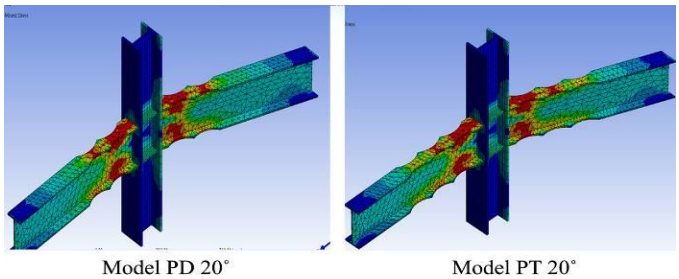

Fig. 14 Equivalent stress diagram of column inclination with DRBS and TRBS

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V. RESULT AND DISCUSSION

Table X shows the result obtain from ANSYS software for elevation inclination of beam in beam column joint. Beam can be inclined up to 20˚ after that column stress get increased highly and storey drift get reduced. Within the same cycles of time Model E 20˚ having higher storey drift and load carrying capacity as compared to other models.

Table X Result For Elevation Inclination Of Beam In Beam Column Joint

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam Stress (MPa)
Model E 5˚	57319.5	4.75	1.75	230.59	397.8275
Model E 10˚	57888	4.75	1.75	230.085	381.992
Model E 20˚	59882.75	4.75	2.25	280.67	386.975
Model E 30˚	63647.25	4.67	2	488.9025	369.36

Table XI shows the results obtain from ANSYS software for plan inclination beam column joint models. From the table it is clear that column stress gets increased than permissible limit of material after 20˚ inclination of beam. Model P20˚ takes more cycle of time with high storey drift and also high load carrying capacity as compared with model P 30˚.

Table XI Result For Plan Inclination Of Beam In Beam Column Joint

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam Stress (MPa)
Model P 5˚	57930.5	5.25	1.87	231.67	394.88
Model P 10˚	57971.1	4.75	1.75	232.49	383.48
Model P 20˚	59031.75	7.25	2.75	240.81	384.48
Model P 30˚	54928.25	5.75	2.3375	369.23	386.285

Result of column inclination is shown in Table XII. For column inclination maximum storey drift and cycle are obtain for 20˚ inclined column.

Table XII Result For Column Inclination Beam Column Joint

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam Stress (MPa)
Model C 5˚	57460.25	4.75	1.625	246.84	397.93
Model C 10˚	57855	4.75	1.625	246.292	385.212
Model C 15˚	58308.5	4.75	1.75	247.18	372.98
Model C 20˚	59259.5	5.25	1.875	247.94	371.125

Comparison result of single, double, triple RBS with elevation inclination of beam in beam column joint is shown in the Table XIII. It shows the average drift increased and also load carrying capacity increased for triple reduced beam section.

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Table XIII Comparison Of Elevation Inclination Of Beam With Single, Double, Triple Rbs In Beam Column Joint

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam Stress (MPa)
Model E 20˚	59882.75	4.75	2.25	280.67	386.972
Model ED 20˚	60993.25	5.75	2.25	238.21	339.36
Model ET 20˚	62219.25	5.75	2.5	237.21	360.29

Table XIV shows comparison result of single, double and triple RBS having plan inclination. Within the same storey drift and column stress, the load carrying capacity of triple reduced beam section with 20˚ inclination get increased.

Table XIV Comparison Of Plan Inclination Of Beam With Single, Double, Triple Rbs In Beam Column Joint

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam Stress (MPa)
Model P 20˚	59031.75	7.25	2.75	240.812	384.48
Model PD 20˚	56702.25	7.25	2.75	241.025	328.50
Model PT 20˚	60099	7.25	2.75	241.51	360.29

Column inclination with single, double and triple RBS is compared in the Table XV. Column stress slightly gets decreased for double and triple RBS. And within same column stress for double and triple RBS, the load carrying capacity of triple reduced beam section increased.

Table XV Comparion Column Inclination In Beam Column Joint With Single , Double , Triple Rbs

Model	Load (N)	Cycles	Drift	Column Stress (MPa)	Beam stress (MPa)
Model C 20˚	59259.5	5.25	1.875	247.94	371.125
Model CD 20˚	59266.75	5.25	1.875	247.92	359.08
Model CT 20˚	59287.5	5.25	2.125	247.67	360.0375

VI. CONCLUSION

The study of Seismic performance of Reduced Beam Section (RBS) in beam column connections were done. The main conclusion obtained from the analysis are summarized below:

A. Maximum drift shows when the beam is inclined by 20˚ for both plan and elevation wise

B. For slightly variation of column stress model with 20˚ elevation inclination have high drift and load carrying capacity increased by 6.2%

C. For plan inclination of beam in beam column joint, 20˚ inclined beam have better performance, its load carrying capacity increased by 2% and these members takes 3 extra cycle with high storey drift

D. Load carrying capacity increased by 2.7% and have high storey drift and cycle of time for 20˚ column inclination

E. As compare with DRBS and TRBS in 20˚ elevation inclination, the load carrying capacity is increased by 4% and it take one more cycle than single

F. With same values of column stress, drift and cycle of time, triple reduced section 20˚ plan inclination can take 2% extra load which makes the section more effective

G. For 20˚ column inclined beam column joint with triple reduced section is more effective as compare to single and double reduced beam section

H. Triple RBS in column inclination having higher storey drift and load carrying capacity

I. Triple reduced beam section is more efficient as compared to single and double RBS for both beam and column inclination

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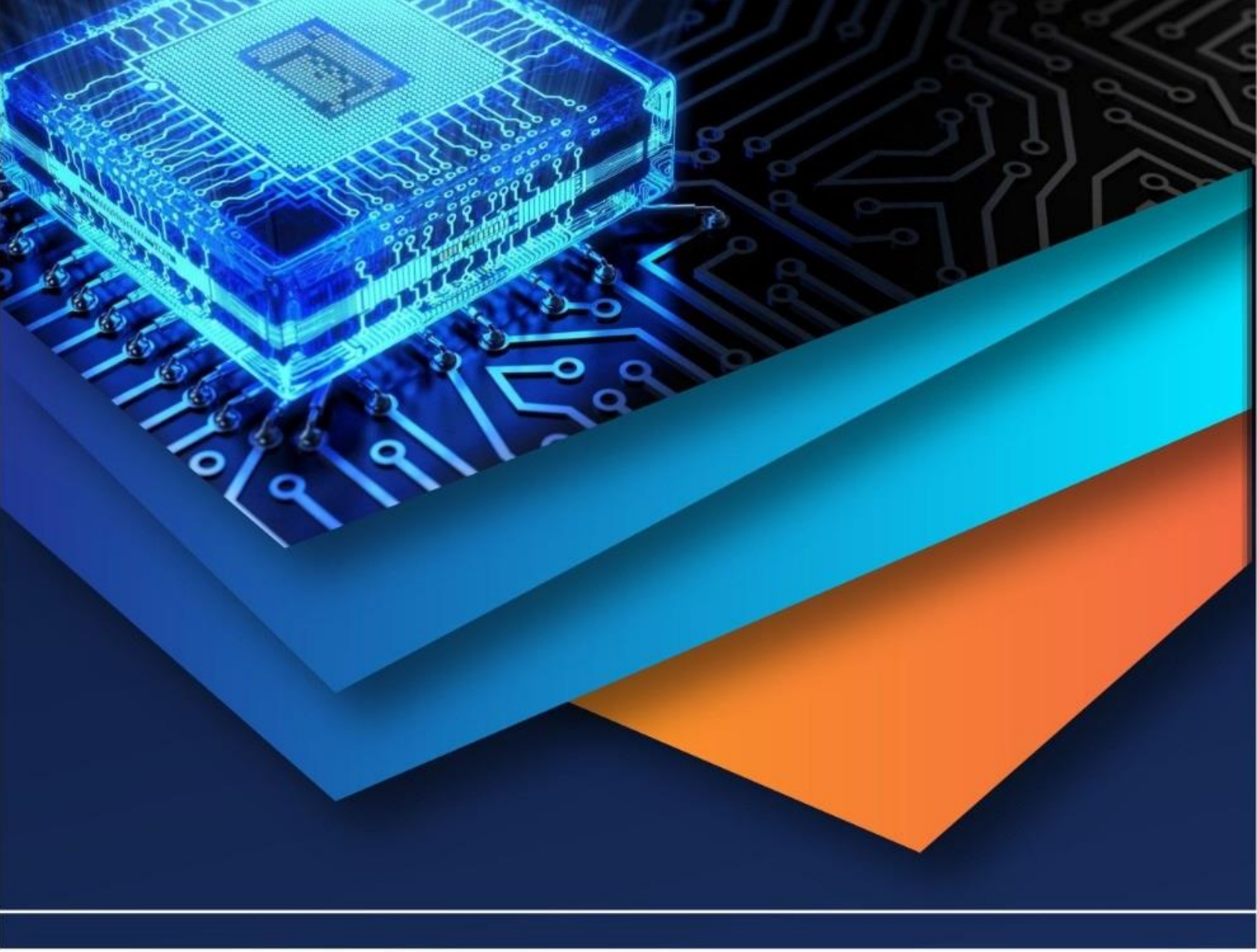

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