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Nonlinear Behavior of Dogbone Inclined Beam-To-Column Connection

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***Abstract* — Prior to the 1995 earthquake in Northridge, and 1994 earthquake in Kobe, Japan it was assumed that the Moment resisting frame buildings are ductile against earthquakes, while in these earthquakes the buildings had experienced brittle failure in their connections. With laboratory studies on fitting the frames, ductility and very low energy dissipation and brittle failure in the welds of beam flange to the column where the change was small, were observed. In order to improve the performance of these connections, connections with reduced beam sections (RBS) as a Dogbone connectivity was proposed. In this paper, the seismic performance of beam with Dogbone connectivity under different angles relative to the beam column has been studied. In order to analyze the behavior of the specimens, the finite element method was used in which analytical, nonlinear static and material yield criterion, von Mises was selected. The results show that the beam angle changes to the central axis of the column have little effect on the hysteresis response of the specimens. Resistance in the inelastic region increases with increased angle.**

***Keyword* — Dogbone connection, Inclined beam, Nonlinear analysis, Reduced Beam Section, Cyclic loading.**

1. Introduction

In the early 1960s, engineers began using steel Moment resisting frames buildings and it was assumed that the Moment resisting frame connections have a good ductility behavior. However many cases related to the lack of satisfactory fitting behavior were mentioned in the reports published before the earthquake of Northridge. In 1973, Popov and Bertro reported the sudden deterioration of welds of wing. [1] , [2]. Popov and colleagues (1985) reported the sudden deterioration of flexural connection After the experience of repeating a few loading cycles and entering the plastic deformation [3]. An earthquake with Power of 6.7 Richter occurred in the Los Angeles area in the United States on 17 January 1994. The engineers found out that Steel moment frame connections are not ductile to an extent that it was thought. Damages caused by this earthquake were estimated at about $ 20 billion. The occurrence of this earthquake could be the beginning of a review of the flexural frames connections.

The observation of buildings' damages in Northridge in 1994, showed that In many cases, the brittle fracture begins in small amount of plastic deformation before he behavior discussed and even In some cases, when the structure remains elastic this question has occurred. After the earthquake, a special group called the SAC and FEMA investigated the causes of the damage and proposed a solution to improve the behavior of the connections. One of the provided proposals is the connection with reduction in beam section called a Dogbone connection. The idea of this connection was presented by Engelhardt (1998) [5]. This connection was taken into consideration due to the following benefits:

1. to reduce the structural mass
2. to reduce the economic costs
3. to increase the strength and flexibility than other cuts

In this paper, the seismic behavior of the Dogbone connection with balanced connection spring is being addressed under Different angles of beam relative to the column. This case is observed in buildings that are located in the corner of streets or when the beam is located diagonally in the building. For this purpose, a nonlinear finite element analysis was used under cyclic loading.

2. Dogbone Connection Modeling

ABAQUS software was used to analyze the dogbone connection using FEM method. Initially the number of connection specimens that were tested was modeled. The purpose of this modeling was to achieve a proper verification of methodology choice: kind of element, type of loading and ... in ABAQUS software in order to use this method of modeling for other specimens. For example, DB3 Engelhardt moment-rotation diagram is shown In Figure 1. for sampling beam and column, Skin Four-node elements (S4R) were used. in critical areas, Finer meshes were used because plasticity often occurs in the area and needs higher accuracy (Figure 2). To investigate the behavior of this circuit, cyclic loading was used. This loading is the SAC97 standard loading that is recommended in seismic Regulations FEMA-350 and AISC-2005. The loading is shown in Figure 3. Assuming the proper quality of beam-to-column connection this modeling has been ignored and the connection of beam-to-column connections is directly intended.

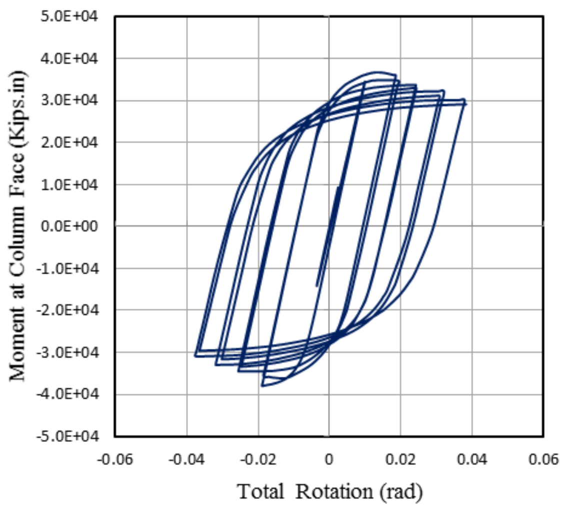

Fig. 1. Analytical hysteretic response of specimen DB3

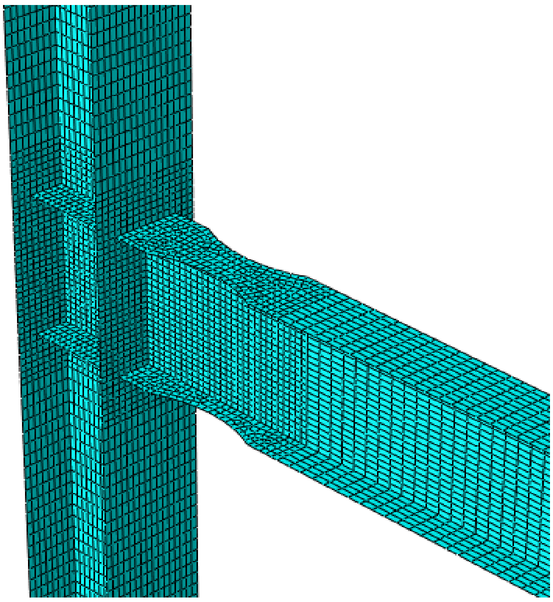

Fig. 2. Three-dimensional finite element model.

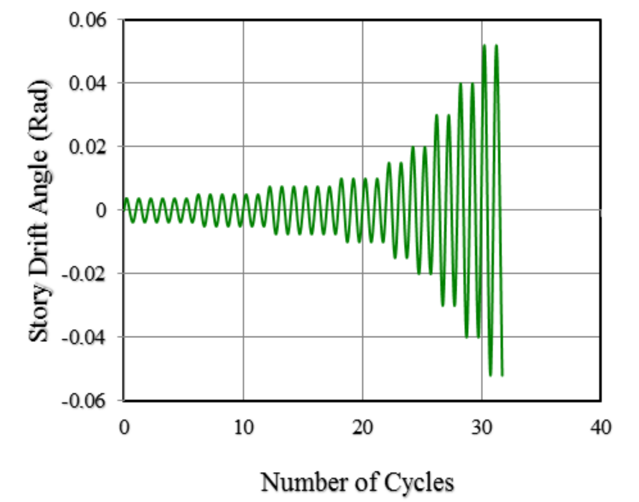

Fig. 3. Loading history.

3. General Characteristics of Specimens

For steel sections used in this project, lobe steel of $A36$ was used. This steel has yield strength of 240 MPa, the ultimate tensile strength of 370 MPa, Poisson's ratio, 0.3 and Young's modulus is 2.1×10^5 MPa. Stress - strain curve of steel was modeled by two lines of those hard choices. Kinematic hardening and yield criterion is von Mises. Based on the dimensions of the beams and columns Figure 4 have been determined [8] along the central axis of the beam in all cases equal to 250 cm. Thickness of beam flange thickness and width equal to the coherence width of the beam flange is connected to the column flange. John thickness reinforcement in columns Springs area connectivity is considered to achieve a balanced condition and 0.6 cm. Other features in the form of cuts Figure 5 is shown the size of each characteristic for all specimens are show in Table 1.

In Table 1, the values of a_1 and a_2 are achieved through the following equations:

$$a_1 = 0.6b_f + \frac{b_f}{2}\tan\alpha$$

$$a_2 = 0.6b_f + b_f \tan\alpha$$

In these equations, b_f is the Beam flange width and α is the Angle between the central axis of the column with the beam central axis. This angle ranges can be from zero to 90 degrees. $(0 \le \alpha < 90)$.

Table (1) Specifications of specimens

specimens	*column*	*beam*	*a*	a_1 *(cm)*	a_2 *(cm)*	*b*	*c*	*R(cm)*	*α(D)*
RBS-ba	IPB300	IPE450	0.6bf	9	9	0.75d	0.2bf	22.59	0
RBS-bb	IPB300	IPE450	0.6bf	10.30	11.60	0.75d	0.2bf	22.59	10
RBS-bc	IPB300	IPE450	0.6bf	11	13	0.75d	0.2bf	22.59	15
RBS-bd	IPB300	IPE450	0.6bf	11.70	14.50	0.75d	0.2bf	22.59	20
RBS-be	IPB300	IPE450	0.6bf	13.30	17.70	0.75d	0.2bf	22.59	30

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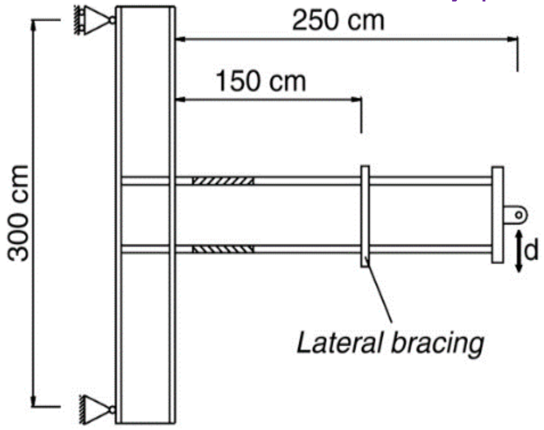


Fig. 4. Configuration dimensions of the subassembly of the zero angle.

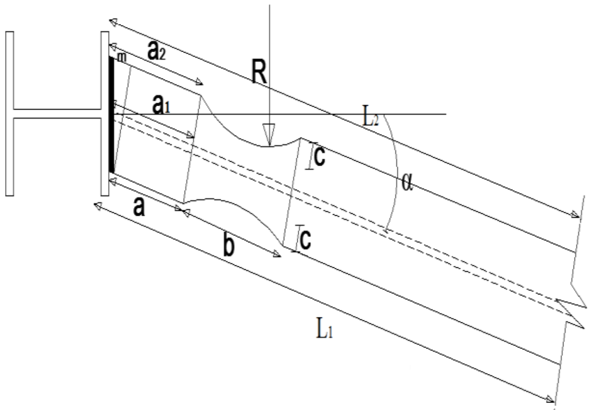
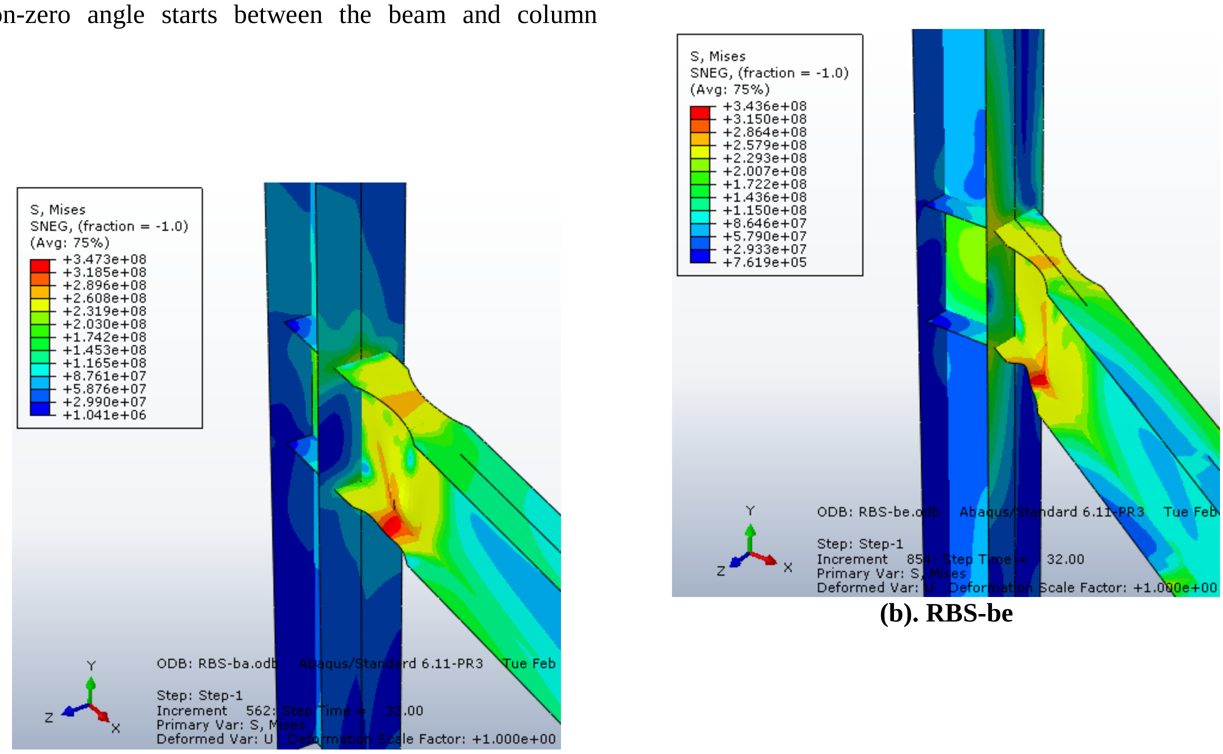


Fig. 5. View specifications cuts of the RBS connection.

4. RESULTS

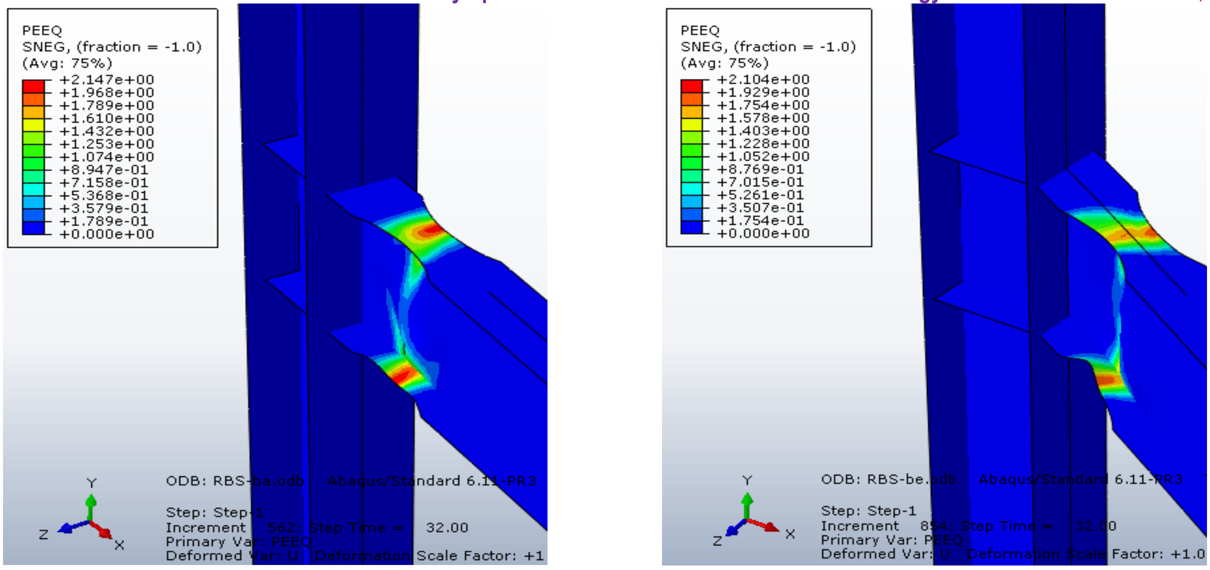
I. *stress distribution*

In Figure 6 von Mises stress contours in Figure 7 equivalent plastic strain (PEEQ) for two of the specimens studied are shown in the last cycle loading. According to the distribution of stress and equivalent plastic strain can be observed that when the angle between the beam and column is zero (Figure (6-a) and (7-a)), Plastic joint occurs in decreased areas. Failure starts in the beam flange simultaneously on both sides. However, in the case non-zero angle starts between the beam and column (Figure (6-b) and (7-b)), the failure of one of the wings begin shooting, Also according to the least beginning has been considered as a , Diagonal tension failure does not tend at the weld therefore Welded beam to column flange connection penetrating the danger does not threaten. In subjects with moderate spring connection spring connection was not observed in any submission Elastic springs connecting the left; So John stiffener rigidity column RBS connection has a considerable impact.



(a). RBS-ba **(b). RBS-be**

Fig. 6. Von Mises stress distribution at the end of the loading cycle.



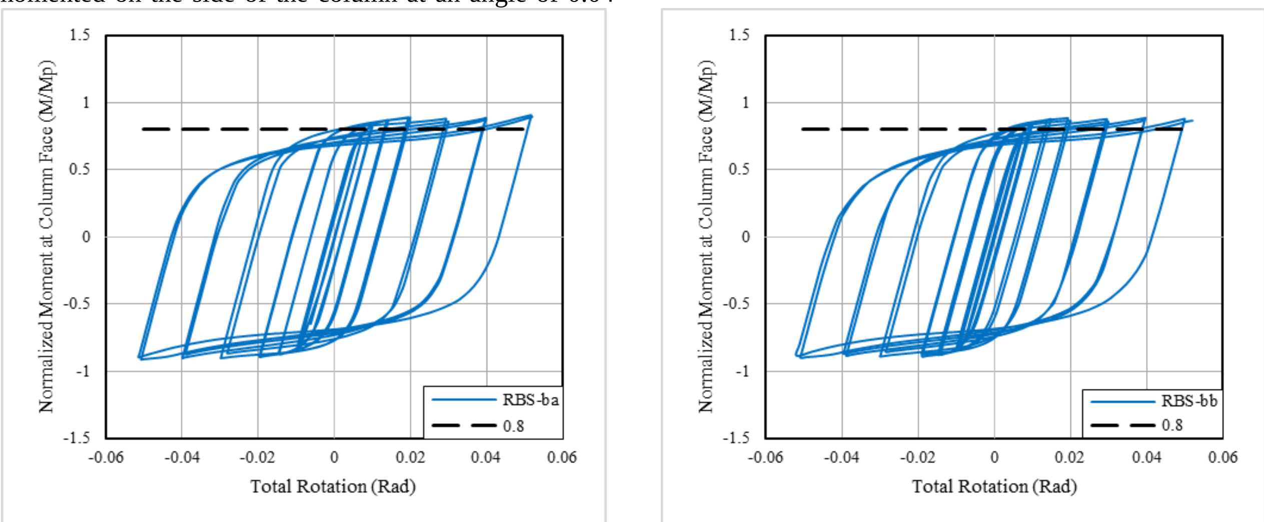
(a). RBS-ba (b). RBS-be

Fig. 7. Equivalent plastic strain at the end of the loading cycle.

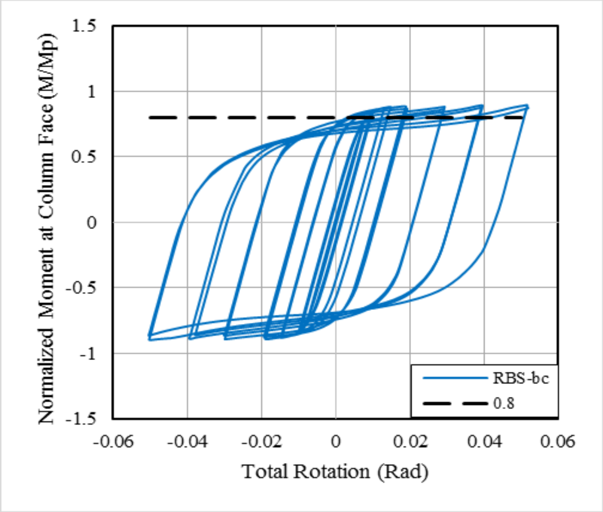
II. Hysteresis curves of moment –rotation

Hysteresis curves obtained from finite element analysis for all specimens are depicted in the shape of the curve Figure 8. In these curves, the moment and the aspect ratio is a calculated column. This is the moment of all specimens based on the beam central axis that is earned during the 2.50 meters. The vertical axis are coequal moment (M/M_p) which obtained by dividing the moment values resulting from column analysis over the plastic moment of beam. Based on seismic regulations AISC-2005 [7] For Special moment resisting frames should be momented on the side of the column at an angle of 0.04 radians, more than 80% of the plastic moment and is also not binding declines.

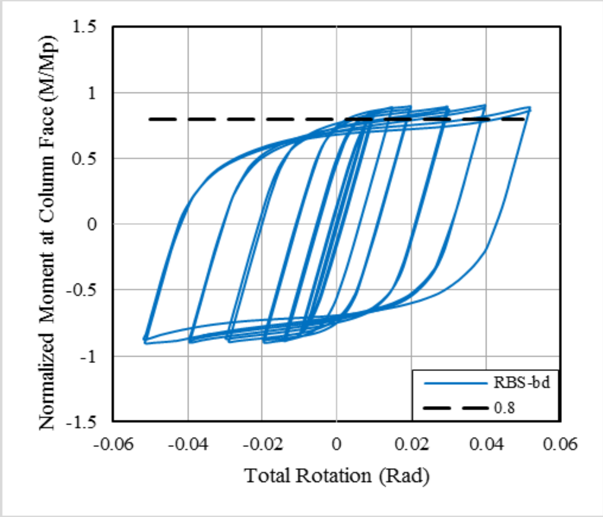
As it can be seen that this condition is satisfied for all specimens, but the buckling occurred in the beam and thereby develop a drop chart, and decreased resistance that the amount of negligible. Chart loss and strength reduction, increasing the angle increases. The occurrence of deterioration in steel structure mainly due to local buckling and brittle failure is binding. However, the results show that the degree beam angle relative to the central axis of the column specimens hysteresis cycle has little effect on the response.



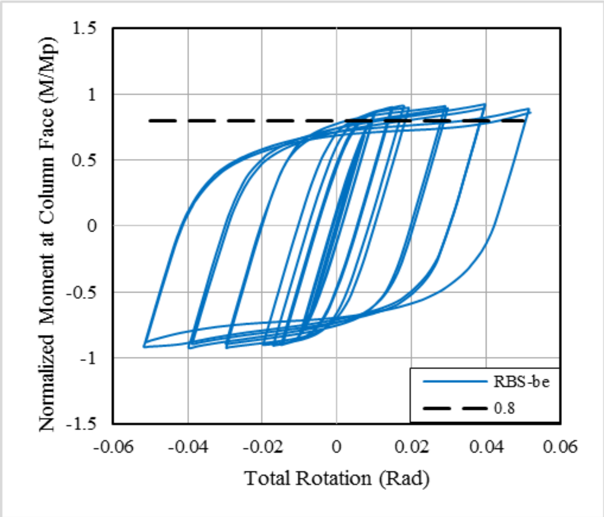
(a). RBS-ba (b). RBS-bb



(c). RBS-bc



(d). RBS-bb



(e). RBS-be

Fig. 8. Hysteretic response of the specimens.

III. Push curves of moment –rotation

To compare the specimens together, dressed Hysteresis curve to 0.04 radians is drawn together, in the form of Figure 9 is significant. According to Push figure it is determined based on charts that show specimens of equal treatment. In fact, the degree beam angle relative to the central axis of the column, for example - a significant change in terms of hardness and plasticity does not, but the increasing angle slightly increased resistance in the inelastic region can be seen. Hysteresis curve fitting undergarment level will show the amount of energy absorbed and it becomes clear that the energy absorbed in all the specimens tilted beam, are assessed appropriately.

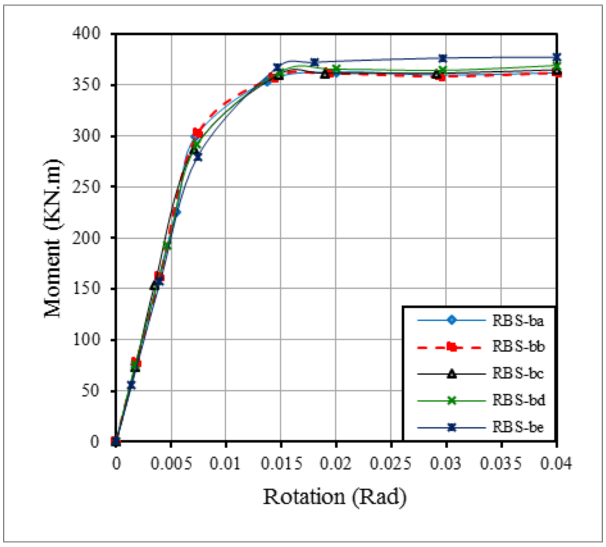


Fig. 9. Envelope curves the hysteresis response of the specimens.

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5. Conclusion

According to studies on Dogbone junction, when the beam is obliquely, the following general conclusions can be derived:

- The interval of starting cutting from the columns must be considered equal to a and other dimensions can be obtained accordingly.
- Changes in the angle of impact does the system behave linearly increasing resistance area is inelastic.
- The reduced area starts from one side in the connection of a diagonal beam, while in the flexural resistance connection it starts from both sides simultaneously to the angle of zero degrees.
- Due to the formation of plastic hinges in the beam and reducing area, connection models have a reasonable plasticity model.
- In the case of a curved beam to column connections, by increasing the angle between the beam and the central axis of the column, beam reaches to the yield point at the RBS declined faster and at a lower rotation limit.

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