

Research Article

Seismic Performance of I-Shaped Beam-Column Joint with Cubical and Triangular Slit Dampers Based on Finite Element Analysis

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Article Info

Article History

Received Jan 10, 2022

Revised Feb 22, 2022

Accepted Feb 26, 2022

Keywords

Beam to column connection,
Cubical slit damper
Triangular slit damper
I shape

Abstract

From the layout of a metallic structure's beam-column connection w, while the seismic design is inside the dissipative method, precise contributors and zones ought to admit the growth of plastic deformation, and many metallic second resisting frames fail on the beam-column joints. This examines designed a unique structural machine with diverse slit dampers to triumph over this challenge, which can be easier to deliver overall seismic performance in the structural device that has been proposed. Plastic deformation is confined to the slit dampers at the end flange, which is the machine's key characteristic. The recommended connection's seismic overall performance changed into confirmed the use of the Abaqus software program utility to software systems with diverse slit damper forms. The proposed hyperlink exhibited first-rate hysteretic conduct in accordance to check results. Furthermore, on this machine, strength dissipation and plastic deformation focus on the diverse shapes of slit dampers, while the inelastic behavior of the beams and columns is prevented via a suitable ability layout. The conduct of triangular and cubical shapes of slit dampers withinside the connection among a metallic beam and a container column is defined in this paper.



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1. Introduction

Because of their excellent resistance to biaxial bending, I-formed columns are normally applied in locations with excessive seismic risk. Low and medium-upward push systems frequently use cold-fashioned hole sections, even as excessive-upward push homes normally use built-up sections made from 4 plates welded together [1]. Since the 1994 Northridge earthquake, extensive studies have been undertaken, and numerous modern connection info was proposed to link I-beams to vast flange columns [2-7]. However, a minimum look has been carried out for the relationship of I-beams to the container-columns [8]. Kim et al. [9, 10] built full-scale second connections to US container columns, using pre-Northridge connection facts and examining them. During a story flow perspective of much less than 1% rad, each specimen failed

passive power dissipation gadgets has formerly been asserted to deal with those varieties of difficulties [16]. Passive power dissipation gadgets were proposed as a cost-powerful way to lessen the risk of earthquakes to systems. Since a chain of earthquakes in the United States, passive dampening techniques were broadly considered, and extra homes were equipped with dampers [17, 18].

Table 1. Properties of steel material

Test specimen		Steel grade	σ_y (MPa)	σ_u (MPa)	Y.R(%)	Elo. (%)
Beam	Web(t=12mm)	SS400	339	488	70	27
	Flange(t=17mm)	SS400	318	480	67	30
Column	Web(t=20mm)	SS490	395	554	74	27
	Flange(t=20mm)	SS490	378	551	71	24
Split-T	Web(t=22mm)	SS490	388	577	71	25
	Flange(t=35mm)	SS490	386	573	69	24
Split plate(t=19mm)		SS400	208	464	63	30

We currently utilize two distinct kinds of slit dampers of the flange at of which, wish are triangular and cubical shapes, as shown in the following pictures, which were evaluated using Abaqus software.

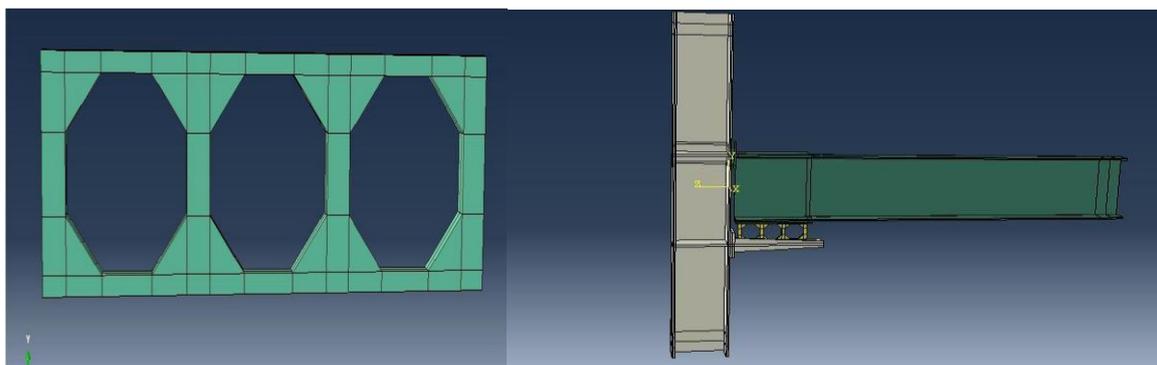


Figure 2. Cubical shapes of slit beam-column joint

Plastic deformation is contiguity to the slit dampersAthenaenof foam, which is one of the key characteristics of these systems. This study discusses the suggested structural system's structural shape and mechanical characteristics. As the beam to column joint in the recommended structural configurations, a mechanical joint was used accordingly with various LLC damper shapes. These types of dampers were analyzed and designed by program Abacus.

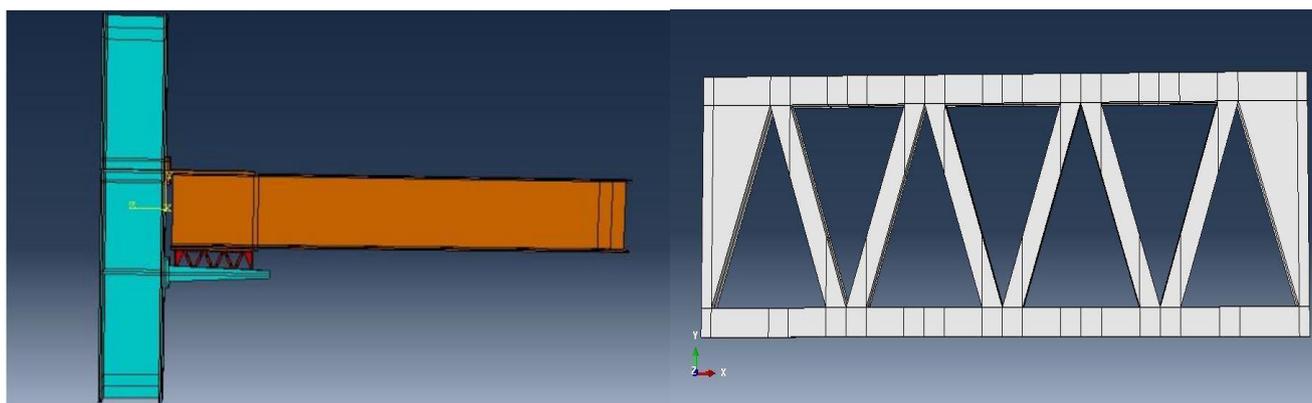


Figure 3. The triangular shape of slit damper whitebeam-column joint

2. Slit Damper Design

2.1. Structural Configuration

It is desirable to develop easily repairable structures and modify replacement after the earthquake by limiting damage to the energy absorption devices to identify the best damage control design of the frame structures (slit dampers). It is possible to restrict damper damage by designing dampers that are weaker than the beam and column. While the simple construction and better stiffness of this connection are positives, the compression force might induce local buckling on the beam flange. During an earthquake, it is preferred for damage to be limited to energy absorption elements with good hysteretic properties rather than being transmitted to the mainframe, such as the beam and column. Figure 2 depicts the new form of slit damper presented in this study, a cubical shape connection system with an energy absorption element. Before the main structural members, the slit damper on the bottom flange of the beam is actively plasticized. Figure 3 depicts a triangular-shaped second slit damper for energy absorption during earthquake threats. All columns and beams are connected using high-strength bolts. The upper split is connected to the top of the beam with high-strength bolts to act as the connection's rotating center, while the lower split is connected to the bottom flange's slit dampers with high-strength bolts. Because the rotation points on the left and right sides remain at the top flange, damage to the split on the top flange, which is difficult to exchange, is avoided, as shown in Figure 1.

Suppose the slotted damper shows the same behavior with positive deflection (when the upper flange is compressed) and negative deflection (when the lower flange is compact). In that case, the structural deformation will be concentrated in the slot. You can expect it. Lower chord damper (when tension is

applied to the upper belt). As a result, in the event of large bullet transport, the drag can bend slightly at the bottom flange of the beam without causing significant damage.

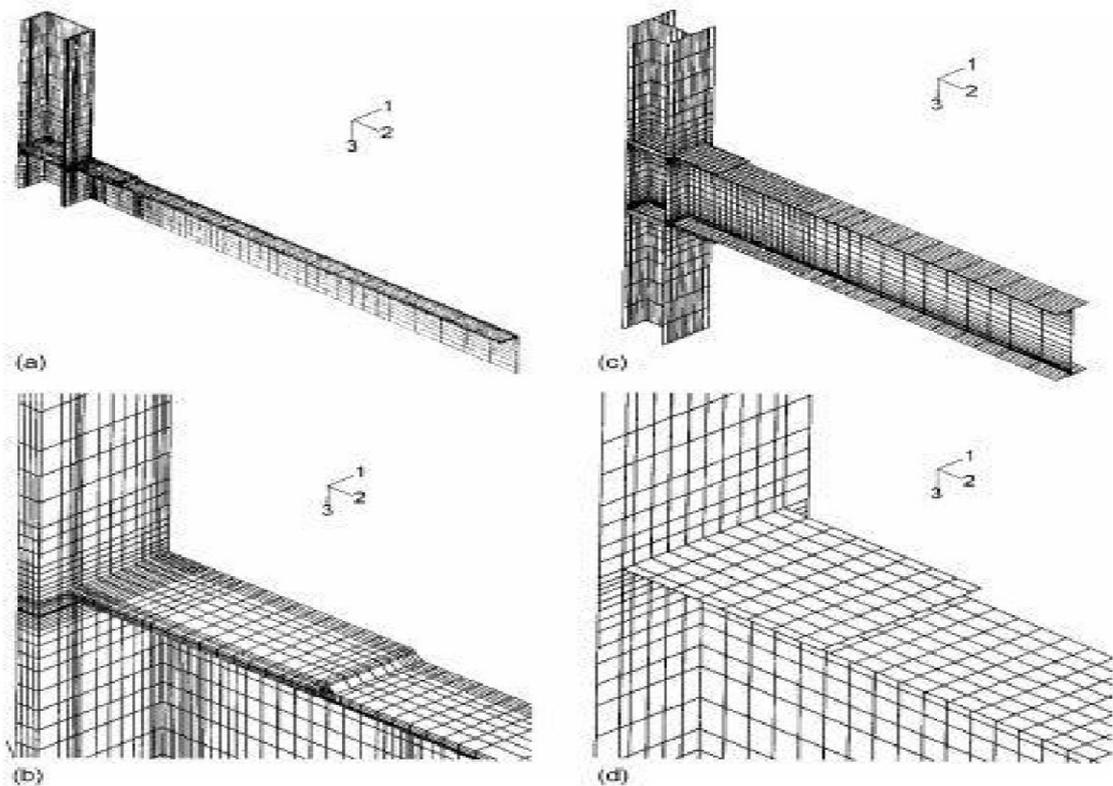


Figure 4. Finite element model of RCO3: (a) global view of SOL model; (b) local view of SOL model; (c) global view of SH model; (d) global view of SH model

This design allows for replacing slit dampers as bottom flange joint parts, allowing structures to be used after an earthquake. The suggested structural system uses the connection between the beam top flange and the column flange to transmit gravity loads from the beams to the columns because the major retrofit work after an earthquake is performed near the bottom flange. Because the center of rotation remains at the top flange of the beam, the Split-T at the top flange can be kept in an elastic range. When the structure deforms under earthquake load, the deformation is concentrated on the dampers at the bottom flange when utilizing these systems with a triangular and cubical shape. When considering the plastic hinge of beam-ends, the proposed structural system can be characterized as a "strong column weak beam" since the plastic deformation is concentrated on the dampers in the beam-ends.

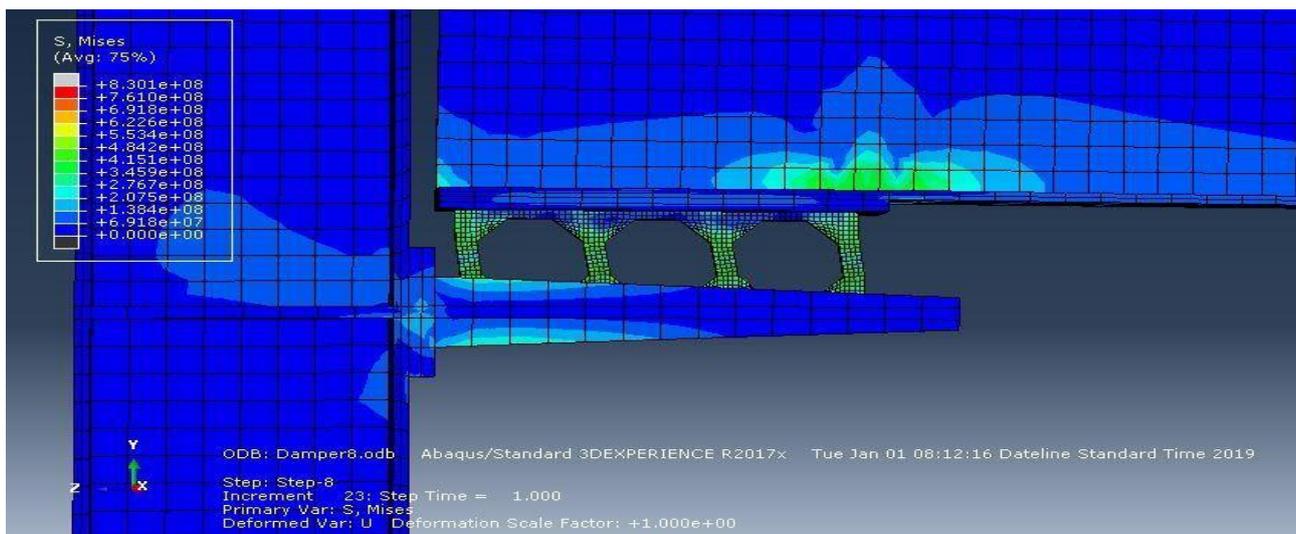


Figure 5. The shape of cubical slit damper after applied load in Abaqus software

Energy exhausted capacity at the end flange can deform compatibility with repeated loads, such as tensile and compressive forces on the bottom flange. To restrict the damage to the connection element without causing damage to the main structural components, and as shown in Figure5, energy dissipation through the vertical struts of a triangle shape damper with varied data of moment against rotation studied using the (ABAQUS) program.

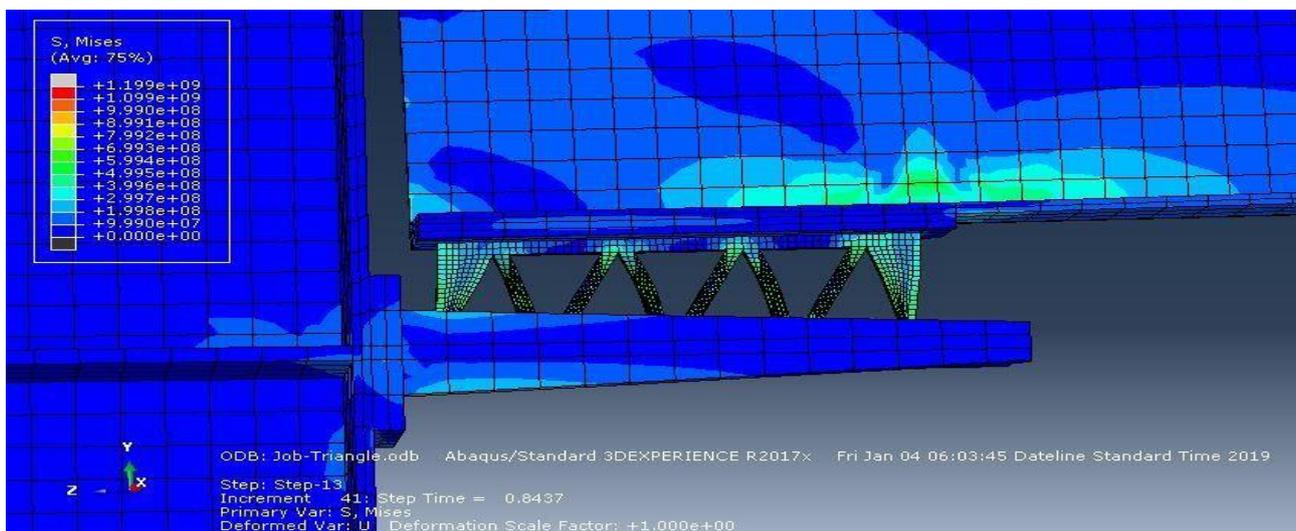


Figure 6. The shape of the triangular slit damper after applied load in Abaqus software

Plastic deformation on the vertical struts of the slit dampers dissipates the energy, as illustrated in Fig 6. with different fill-up data of moment versus rotation for two distinct shapes of slit dampers with the same area of roundness. It has been shown that changing the shape of the slit damper from cubic to

triangular, which was analyzed by the (ABAQUS) program, has a very good energy dissipative ability, as well as having a high stiffness compared to other shapes, and is thought fit to use as a connection element in the system offered in this study [25]. The struts of the dampers were idealized, as shown in Figure 2. and Figure 3, where the triangular and cubical shapes have been created for dissipate energy. Figure 7 obtained by ABAQUS shows the difference stiffness and strength of the two forms according to the applied load. The ultimate load for the cubical shape is 38.8401KN, and the maximum displacement is 7.71876, and for the Triangular shape, the ultimate load is 38.8401.

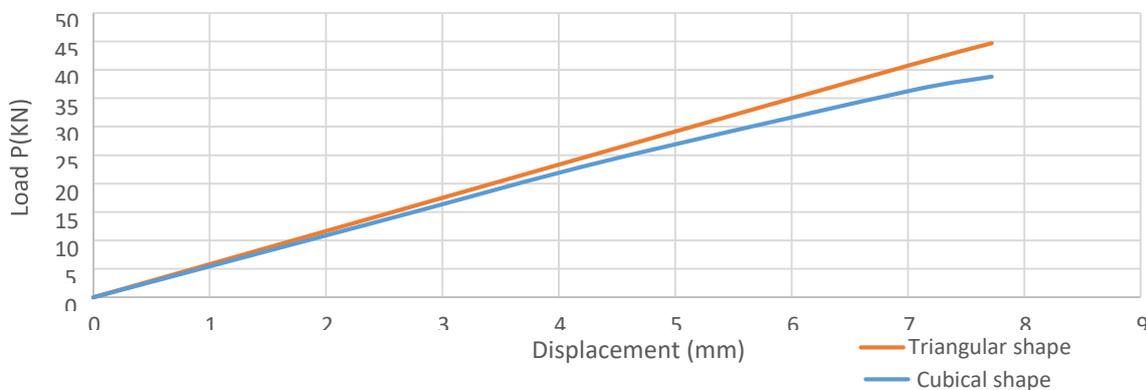


Figure 7. shows displacement vs applied load for cubical and Triangular shape of dampers

3. Test Results and Discussion

The ABAQUS symmetric boundary circumstance approximately the aircraft 2-3 constrains displacement alongside the 1 axis in addition to rotations` first derivative! The 2 and 3 axes have to be zero. The ABAQUS uneven boundary circumstance approximately the 1-2 aircraft constraints displacements alongside the 1 and a pair of axes to zero, in addition to rotations across the three-axis. The length of the finite-detail mesh modified relies on the period and peak of the specimen, as proven in Figure 8. and Figure 9. Right-attitude prisms made up the bulk of the strong elements. Using the displacement-manipulate characteristic, a vertical become ordered on the beam's unfastened cease (ABAQUS). Using the danger method, the matching records of the implemented load become 1KN. For the Type SOL fashions, figuring out lateral motion of the beam and column webs and flanges becomes feasible using a distinctive feature of the truth tall displacement record that displacements of the beam net centerline in the 1 path had been set to zero. The first eigenvector of the loaded connection association become matched with Type SH fashions, and

most disorder becomes set at 2% of the flange thickness. At the unfastened cease of the beam, lateral motion path of the flanges of Type SH fashions become inhibited. Three situations of lateral restraint of the beam flanges were selected for the Type SH version of Specimen to observe the impact on lateral-torsional buckling at the response of bolstered metallic moment-resisting connections.

3.1. Hysteretic Behaviour

Figure 11. indicates the instant as opposed to rotation dating of every specimen. The dashed line in Figure 8 represents the basic second of the beam (1260 kN m) calculated through the usage of the fabric. As located in Figure 8, the proposed specimens exhibited solid hysteretic conduct till the closing nation turned into reached for the duration of 0.04 rad tale waft cycles. During loading, D1, D2 sustained plastic deformation most effective on the slit dampers with no symptoms and symptoms of harm to different components of the structures, as proven in Figures 5 and 6. The plots also confirmed that the slit dampers had maintained a massive wide variety of cycles below vast plastic deformations. Strength degradation commenced seeing the mightiest cracks slowly fashioned on the ends of the struts because of strain concentration. Commonly, this passed off rapidly after 0.04 rad tale waft cycles of loading.

The exams had been stopped after nearly all of the struts withinside the dampers had been fractured and whilst the sustained load turned into drastically reduced. The most energy of specimen D1 did now no longer arrive on the plastic beam second, whilst the most energy of specimen D2 turned into nearly similar to the beam plastic second, even though the ratio of the most energy to the beam plastic second is identical to 0.63. This result shows that the hysteretic conduct of slit dampers is largely ruled through the pressure hardening below load reversals. The most energy multiplied withinside the high-quality path through about 40% over than that of the metallic specimen D2. However, the wrong direction confirmed certainly equal strengths, whereby, no matter the presence of slabs, nearly identical energy and deformation ability had been located in specimen D2. In phrases of the failure after check, it turned into showed that deformation turned into targeting the slit damper.

Similarly, to the proposed specimens, the traditional welded specimen W additionally exhibited solid hysteretic conduct till the closing nation turned into reached. As expected, the panel quarter nearly remained in the elastic variety because of the robust panel quarter. It is thought that the info provided

through FEMA 350 displays the proper connection technique that permits for ductile conduct. Nevertheless, the neighborhood buckling of the beam as a first-rate structural member does now no longer facilitates the restoration of the connection. Conversely, the damper connection is considered extraordinarily powerful in phrases of economy and permits restore paintings to be carried out without difficulty through really changing dampers. Figure 11 shows that the plastic rotation of all connections exceeds 0.03 rad.

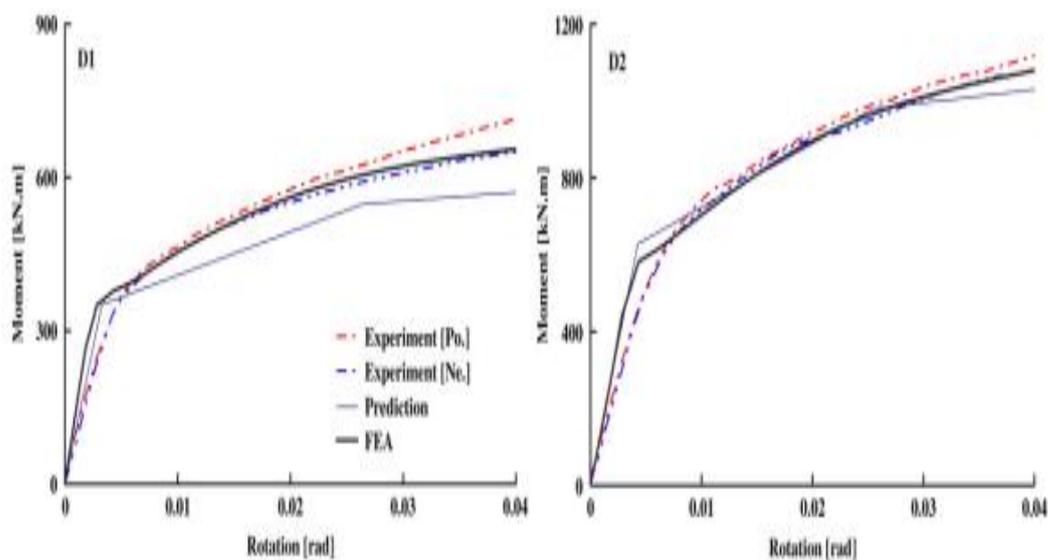


Figure 8. Comparison of experiment vs finite element in skeleton curve

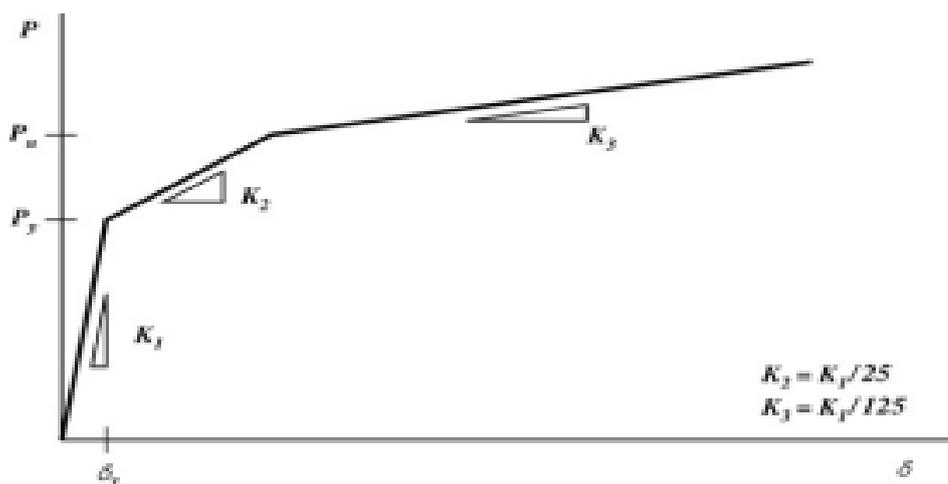


Figure 9. Trilinear skeleton curve of slit damper

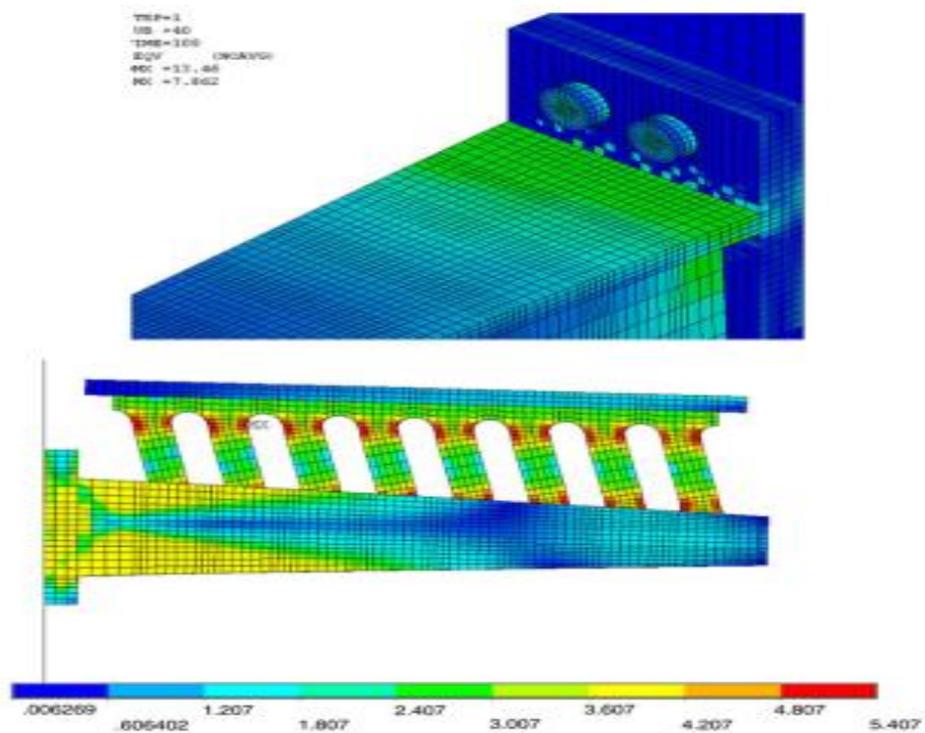


Figure 10. von mises stress contour specimen D2

3.2. Prediction of The Moment Versus Rotation Curve

The skeleton curves have been anticipated primarily based totally on the theoretical formulation furnished in 2. three. For comparison, the preliminary theoretical stiffness and the absorbed energy have been shown in the figure below.

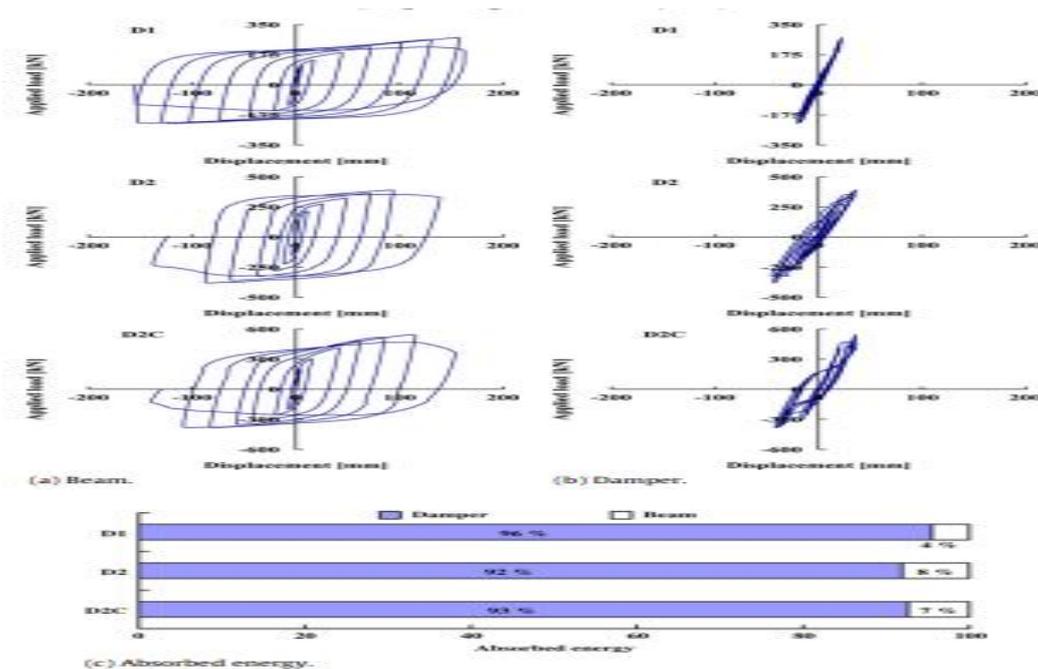


Figure 11. Loops of a damper of the beam and dissipate of absorbed energy.

Were placed side by side those got from the experimental data. Furthermore, the predicted skeleton curve for the slit damper was obtained from preceding research, which was idealized with trilinear models, the predicted initial slope of the moment relationship virtually aligns with the experimental curve and the curves obtained by finite element analysis (FEA) for the proposed specimens. The accuracy of the expected connection strength is also significant. Referring to Table 2, the discrepancy between the predicted yield point result and the test yield point result is approximately $\pm 10\%$. Where $P_y =$ anticipated yield moment. Any P and $eMy_N =$ experimental yield moments of positive and negative deflection, respectively. This result shows that a theoretical model comparing the relationship between moment and rotation properly describes the behavior of the sample. In addition, we compared the FEA results of the proposed support system. A non-linear FEM was performed, and the pretend connection was represented by a slotted damper and bolt volume element and a beam and column shell element, the results of which were compared to the experimental skeleton curve. The elastic and plastic properties of the material were obtained directly from the coupon test. Figure 10 shows the von Mises stress contour of sample D2, the FEA model provided a very accurate prediction of the elastoplastic response.

3.3. Plastic deformation and energy

In a damage-restricted structure, most of the seismic input energy is absorbed by specific bars. Therefore, the damage is limited to specific members. Figure 12 shows the relationship between the shear force of the proposed sample and the displacement of the damper and beam. Where "shift" indicates.

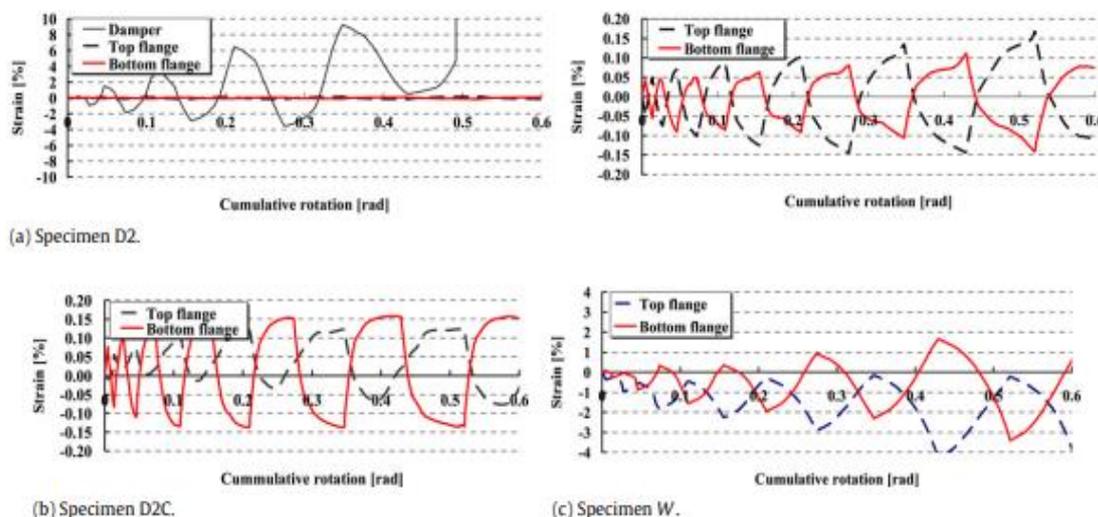


Figure 12. Strain profile of beam flange and damper

The counseled metal structures with wonderful shapes of slit dampers had been subjected to large-scale structural trying out to evaluate their cyclic performance. A general of slit damper specimens had been created. D1 and D2 are natural metal specimens with slit dampers. The distinction among specimens Figure three and fig .four is the intricacy of the slit dampers, which changed into the design to reap various ratios of the beam`s second call for its flexural strength, with a most second potential of 488. Seventy-five Kn.m for slit damper D1 (cubical shape) and a complete quantity of rotational perspective of 0.047261 rad, and a most second potential of 449.34 KN.m for slit damper D2 (triangular shape) and a most angular rotation of 0.03796 rad and a percent of distinction second ratio of 2.047, it means that the instant potential of triangular An outside T-formed version with a huge flange beam and column serves because of the check specimen.

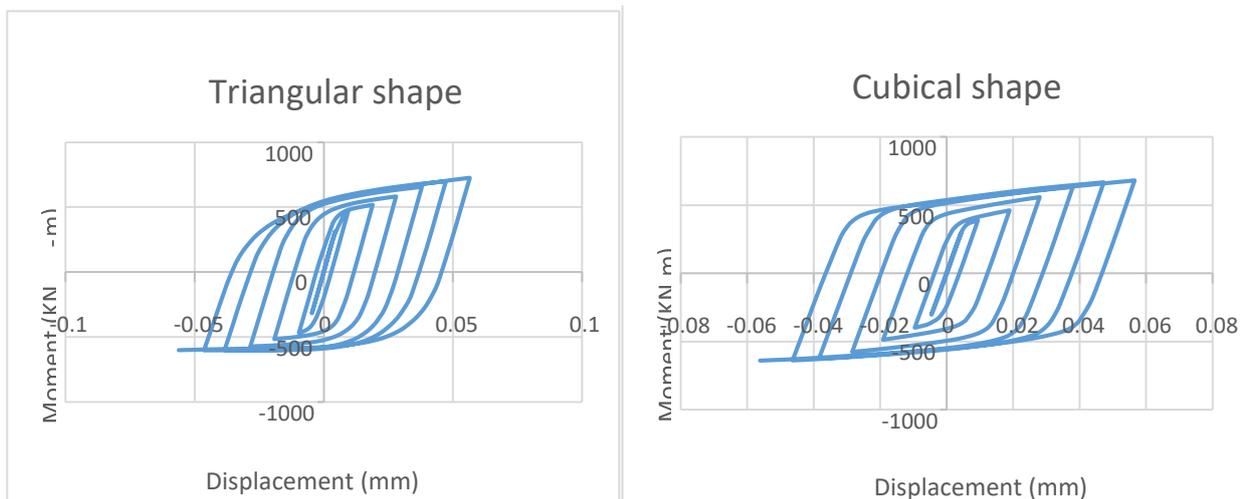


Figure 13. Shows the result of moment-displacement of triangular and cubical damper shapes

Table 2. Comparison between experimental results and analytical results

Specimens	Type of dampers	My	Myp	Rotational angle(rad)
1-W	Slender slit damper	351	385	0.027
2- D1	Triangular damper	387.3	449	0.03796
3- D2	Cubical damper	430	488	0.047261

The columns were H400x400x21x21, and the beams were H582x302x12x17. According to the planned connection between the beam and the column, a split connector was used at the top of the beam,

and an energy-absorbing element created by two differently shaped slotted steel dampers was used at the bottom of the beam. The friction and tensile connections on the specimens were strong enough to prevent the connections from loosening or slipping until the slotted dampers on each specimen reached maximum strength. The girders and columns were made of steel grades KSSS400 and SM490. Figures 2 and 3 show slot dampers with two types of slot dampers installed. As already mentioned, the basic feature of the proposed system is that the plastic deformation is limited to the slotted damper on the lower flange at the beam end. As a result, the sample beams in Figures 5 and 6 were designed to remain elastic until the final state was reached. This means that the maximum bending moment (BM) of the slotted damper of the beam is determined below the plastic moment (M_p) of the beam. For samples D1 and D2, the maximum ratio of beam bending moment to plastic moment is 0.41 and 0.56, respectively. D1 or D2. The column was supported with pins on both ends, and the distance between the column center and the loading point was 3500 mm. The points were separated by 3000 mm. Lateral supports were added to the beam to avoid out-of-plane distortion during loading. A quasistatic cyclic pattern defined in terms of connection rotation was specified in the loading protocol.

4. Conclusion

This research proposes a new structural structure with good deformation capability and ease of repair after an earthquake. The suggested connection is a beam-to-column joint system in which three types of slit dampers are used to link the slit damper to the bottom flange of the beam (slender, triangular, and cubical shape). Three full-scale specimens with slit dampers and three specimens were subjected to quasi-static cycle testing to evaluate the proposed system's performance. The most important conclusions are: Under substantial tale drift, the suggested structural system demonstrates stable hysteretic behavior. Given that the results are greater than the welded test specimen, the proposed connection can be considered a rigid connection at first. And plastic moment of the beam section in the suggested structural systems was not less than the maximum beam moment. Furthermore, the plastic deformation was limited to the slit dampers, while the beams and columns remained elastic. varieties of slit dampers (cubical, triangular, and thin) have distinct theoretical solutions, proving that the cubical shape is the best moment resist and deformation capacity. And Test results revealed that specimens D1(cubical) had stronger plastic deformation capacities than specimens D2 (triangular). Even though the two specimens exhibited different plastic rotations, this

finding shows that the impacts of the composite beam should be addressed while developing the suggested connections. So the energy absorption is thought to be centered only at the slit dampers and not at the beams. After an earthquake, the slit dampers can be replaced., structural system's load-carrying mechanism is governed by bending moment rather than shear force, unlike the bracing system. This mechanism demonstrates that the recommended approach is well suited to tall structures when moment-resisting structures outperform brace frames.

Declaration of Competing Interest: The authors declare that they have no conflict of interest.

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