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Ali Köken
Mehmet Alpaslan Köroğlu
Selcuk University
akoken@selcuk.edu.tr
makoroglu@selcuk.edu.tr
Konya-Turkey

STEEL PLATE SLIT DAMPER USING ON STEEL FRAMES

ABSTRACT

In this study, a steel plate slit damper which was developed in order to avoid damages during an earthquake on steel frames was investigated. The goal of this system is to limit plastic deformation on the slit dampers which can be easily repaired or changed after a heavy earthquake. To investigate the performance of the proposed system, 3 full scale cyclic tests were investigated. The first specimen was a conventional extended end plate beam to column connection. The second one was the strengthened extended end plate beam to column connection and the last cyclic test was conducted on the specimen with a slit damper system. It is indicated from the test results that, proposed connections showed an excellent hysteretic behavior. In addition, the energy dissipation and plastic deformation in this system were concentrated only at the slit dampers.
Keywords: Metallic Damper, Slit Damper, Steel Frame, Energy Dissipation, Extended end Plate

ÇELİK ÇERÇEVELERDE YARIKLI ÇELİK PLAKALARIN SÖNÜMLEYİCİ OLARAK KULLANIMI

ÖZET

Bu çalışmada çelik çerçevelerde deprem sırasında oluşabilecek hasarların önlenebilmesi için yarıklı çelik sönümleyiciler çalışılmıştır. Bu sistemin amacı plastik deformasyonları ağır bir deprem sonrasında kolayca değiştirilebilen veya onarılabilen yarıklı çelik sönümleyiciler üzerinde sınırlandırmaktır. Bu sistemin davranışını izlemek için 3 adet tam tersinir tekrarlanır yükleme ile deney yapılmıştır. İlk numune alın levhalı birleşim, ikinci numune güçlendirilmiş alın levhalı birleşim ve son numune de yarıklı çelik sönümleyicili birleşim bölgeli elemanlardır. Deney sonuçlarından önerilen birleşimin iyi bir histeretik davranış sergilediği görülmüştür. Buna ek olarak, enerji sönümleme ve plastik deformasyonların sadece yarıklı metalik sönümleyicilerde yoğunlaştığı görülmüştür.
Anahtar Kelimeler: Metalik Sönümleyici, Yarikli Sönümleyici, Çelik Çerçeve, Enerji Sönümleme, Alin Levhasi

1. INTRODUCTION (GİRİŞ)

In steel structures Moment Frames (MF) are widely used as Lateral force resisting systems because of their superior ductility and energy dissipation capacity. Through the flexural yielding of the beam and shear yielding of the panel zone, MF behaves in a ductile manner. A large amount of plastic deformation is expected at each member and joint of a MF during an earthquake ground motion. MFs were believed to be one of the most effective lateral force resisting systems through many experimental tests of the 1960–1970s [1 and 2].

The typical welded steel moment frame connection used in seismically active zones in the United States failed to provide the expected ductile behavior in the 1994 Northridge earthquake in Los Angeles, California. And also During the Kobe (1995) earthquake, a large number of steel buildings suffered severe damage, which occurred at the beam-to-column joints and included fractures of full penetration welds, cracks in beam flanges ,and cracks through the column sections [3 and 4].

After the Northridge and Kobe earthquakes, many experimental programs on beam-to-column connections were developed to investigate the causes of the brittle failures. The research and development of structural control against earthquake excitation have achieved significant progress over the last three decades [5]. Structural control can generally be classified in to three categories as; Passive control systems, Active control systems and Semi-active control systems [6].

Energy dissipation can be achieved by a number of mechanisms like; friction, sliding, yielding of metals, phases transformation of metals and deformation of visco elastic solid or fluid [6]. Exclusively, one of the most popular mechanisms for dissipation of energy in put to a structure is through the yielding of metallic materials which are popular nowadays. Numerous metallic dampers which make use of flexural deformation of metals have been proposed such as: the patented added damping and stiffness damper (ADAS) [7], triangular added stiffness and damping damper (TADAS) [8], the honeycomb damper [9], the buckling-restrained brace (BRB) [10 and 11],and the slit damper [4, 6, 12 and 13]. On the other hand, some Researchers have made use of alternative materials devices to be installed between beams and columns in a frame structure [4]

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

During an earthquake, a large amount of energy is imparted to the structure. It is important to reduce such permanent damage to the structure. Therefore, the studies on passive energy dissipation in earthquake risk mitigation of civil structures have greatly increased in the last three decades [1 and 5]. The concept of passive energy dissipation is to limit such permanent damage to the structure. A portion of the input seismic energy could be diverted into these devices when designated energy dissipative devices installed within the structure. So, damage of the structure can be effectively reduced. In addition, repair and/or replacement of the devices after earthquakes can be carried out with minimal interruption to occupancy, a crucial benefit to building owners and occupants if these devices which are called dampers are located at convenient positions [14]. Many kinds of dampers, including friction dampers, viscoelastic dampers, viscous fluid dampers, lead dampers and metallic dampers have been developed.

This present study aims to develop a new steel structure that achieves structural performance and is easily repairable after a heavy earthquake. The principal feature of this system is to limit plastic deformation on the metallic dampers at the bottom flange of the beam-ends. In this innovate structural system, the mechanical joint is adopted that is equipped with a metallic damper as the beam-to-column connection. The goal of this study is not only to limit the earthquake energy but also to repair the structure easily and quickly.

Metallic dampers dissipate energy input to a structure from an earthquake through inelastic deformation of metals and dissipate energy through the nonlinear property of steel plate after yielding out of plane. Generally, a good metallic device for seismic applications must exhibit:

- Adequate elastic stiffness to withstand in-service lateral load (e.g. wind)
- A yield strength of the damper exceeding the expected in-service lateral loads
- Large energy dissipative capability
- A stable hysteretic force-displacement response which can be modeled numerically.

Lots of metallic dampers have been proposed and installed which the popular are; added damping and stiffness damper (ADAS) [7], triangular added stiffness and damping damper (TADAS) [8], the honeycomb damper [9], the buckling-restrained brace (BRB) [10 and 11], and the slit damper [4, 6, 12 and 13]. On the other hand, some researchers have made alternative materials such as; lead and shape-memory alloys, Low Yield Steel Shear Panel (LYSSP) [15], Bell-shaped Steel Dampers, Lead Joint Dampers, Lead Extrusion Dampers and pi damper [16].

3. EXPERIMENTAL VERIFICATION (DENEYSEL ÇALIŞMA)

The objective of the experiments is to verify the structural characteristics as well as the cyclic performance of the proposed devices. Therefore, large-scale structural testing was performed to investigate a comparison of the cyclic performance between the proposed steel structures that have dampers and that of a conventional extended end plate resisting frame.

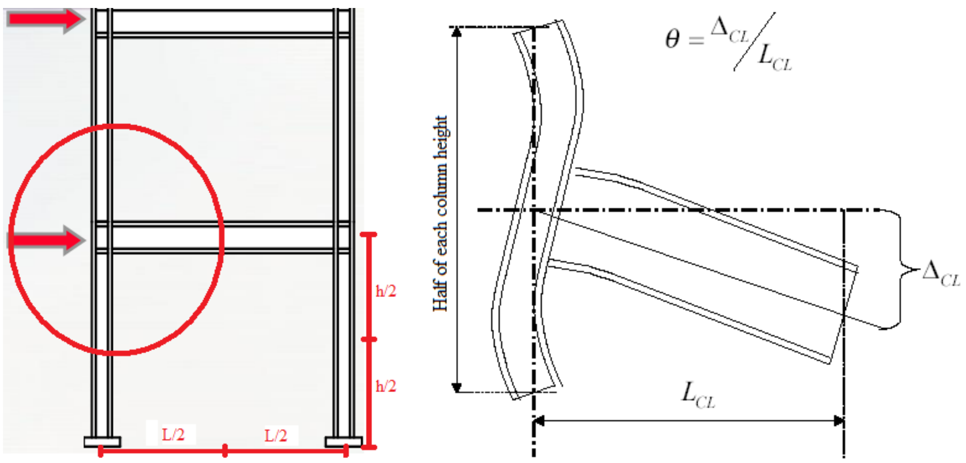


Figure 1. Idealization of beam to column connection
(Şekil 1. Kolon kiriş birleşiminin modellenmesi)

In the test beam to column connection were idealized as in Figure 1. Before the seismic load damages the superstructure, the damper must be able to yield and absorb the seismic energy. So, the design yield points of these test specimens were determined to be allowable strength and allowable deformation angle of the beam and column in the study.

The test set up was designed to simulate the boundary conditions of a beam-to-column connection subassembly in a moment resisting frame under typical lateral loading. Thus, it was created by using pin connections to support both ends of the vertical column, and by connecting the actuator to the loading point of the beam, as shown in Figure 2. The distance between the column center and the loading point was 2000 mm, and the column was supported with pins on both points which the distance between points was 3000 mm. The cycling load was applied by hydraulic jack. During loading, lateral supports were installed on the beam to prevent an out-of-plane deformation of the beam.

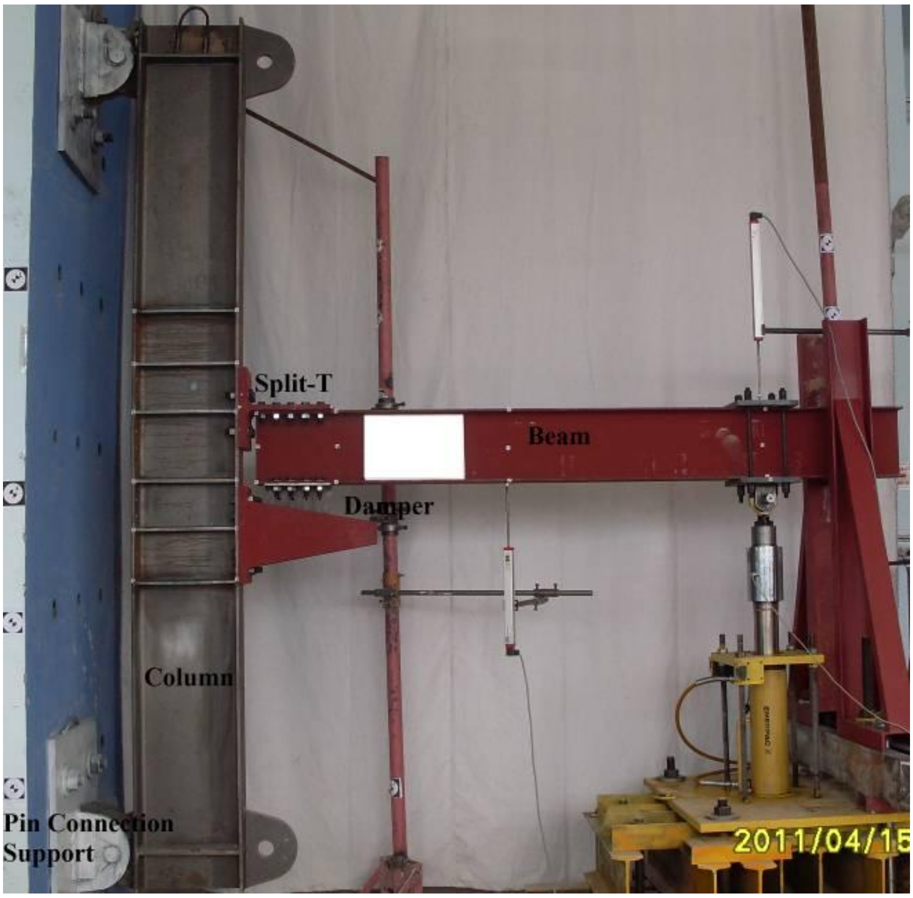
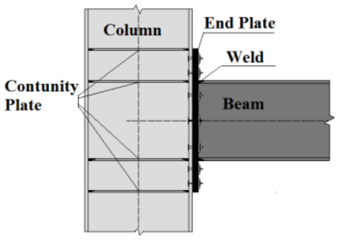
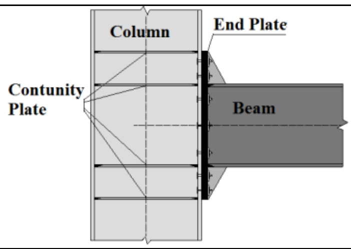
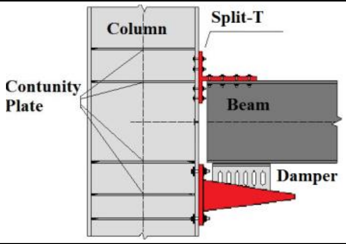


Figure 2. Test setup
(Şekil 2. Deney düzeneği)

In the connection between the beam and column, a split-T connection element was used on the top of the beam, and the energy absorption elements constructed by welding the steel damper to the split-T was used at the bottom of the beam. To facilitate installation and removal high strength bolts were used. Three full-scale specimens that had metallic dampers are shown in Table 1. Large-scale structural testing was performed to investigate a comparison of the cyclic performance between the proposed steel structures that have steel slit damper and that of a conventional extended end plate connection and strengthened extended end plate connection.

Table 1. Beam-to-column connection of three full-scale specimens
(Tablo 1. Üç adet tam ölçek kolon kiriş birleşimi deneyi)

<table>
<tr><td>Extended end plate connection</td><td>Strengthened extended end plate connection</td><td>Steel slit damper connection</td></tr>
<tr><td>
</td><td>
</td><td>
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The test specimen was an external T-shaped model composed of a IPE 270 beam and IPE 400 column. Although Steel grade St 44 was selected for the beams and columns, slit plate was manufactured of steel grade St 37. Since yielding on dampers must be earlier than beams and columns to accomplish the goal of the system. The material properties for the beams and columns were as follows: Young's modulus E = 209000 N/mm^2, yield stress f_{yd}= 282 N/mm^2 and ultimate stress f_{ud} = 443 N/mm^2. The cyclic displacement amplitude followed the loading protocol in the AISC Seismic Provisions [17], which is the same as the SAC loading protocol 1997 [18]. The loading protocol is shown in Table 2.

Table 2. Details of the cyclic loading according to SAC standard
(Tablo 2. SAC standartına gore tersinir tekrarlanır yük yükleme detayları)

Load Step	Peak Deformation,θ (rad.)	Number of Cycles	Beam End Displacement (cm)
1	0.00375	2	0.75
2	0.005	2	1.00
3	0.0075	2	1.50
4	0.01	4	2.00
5	0.015	2	3.00
6	0.02	2	4.00
7	0.03	2	6.00
8	0.04	2	8.00
9	0.05	2	10.00
10	0.06	2	12.00

In order to evaluate the relative rotation of connection, some points at four side- edges of beam flange and column flange were measured by using photogrammetry. Points on the beam and column can be seen in Figure 2. On the other hand, the connection moment M is represented as follows:

$$M = P \times h \quad (1)$$

where P = lateral load applied to beam end; h = a distance from the column face to load application point on beam (h=2000 mm).

Steel slit damper which was manufactured of steel grade St 37 folded as U section and slit as in Figure. Dimensions are given in mm for the damper. 180 mm. height U section was slit with steel plasma cutting system (Figure 3.).

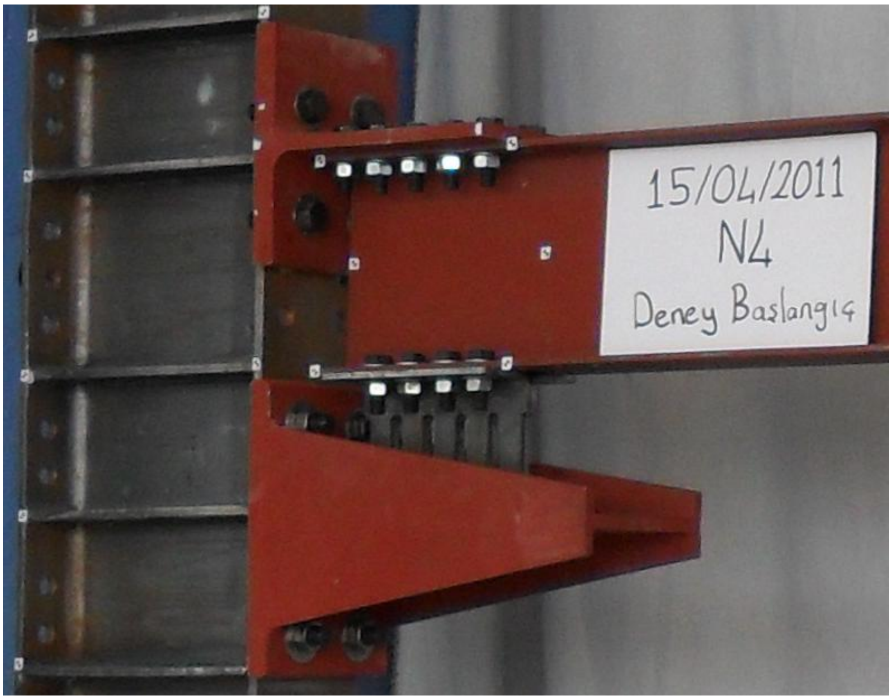

Figure 3. Detail of connection
(Şekil 3. Bağlantı detayı)

4. FINDINGS AND DISCUSSIONS (BULGULAR VE TARTIŞMALAR)

The beam moment rotation hysteretic behavior resulting from the experimental study is shown in Figure 4. The dashed line in Figure 4 represents the yield point of the beam (120 kN m) calculated by using the material properties of IPE 270 beam. As observed in Figure 4 reinforced extended end plate connection had not only higher moment capacity than extended end plate connection but also had more rigidity. As observed in Figure 4, the proposed specimens exhibited stable hysteretic behavior until the ultimate state was reached during 0.04 rad story drift cycles. Strengthened extended end plate connection had better energy absorption capacity. Also the energy absorption capacity of connection with slit damper was evaluated quite less than the connection with strengthened extended end plate and extended end plate the scope of the study was achieved. The damage occurred before reaching the yield point of beam. The maximum moment capacity of specimen connection with strengthened extended end plate connection was obtained 202 kNm, specimen connection with extended end plate connection was 185 kNm and specimen connection with slit damper was 128 kNm.

It is observed that the plastic rotation of all connections exceeds 0.03 rad. The plastic rotation exceeded 0.03 rad even for the test specimen with steel slit damper.

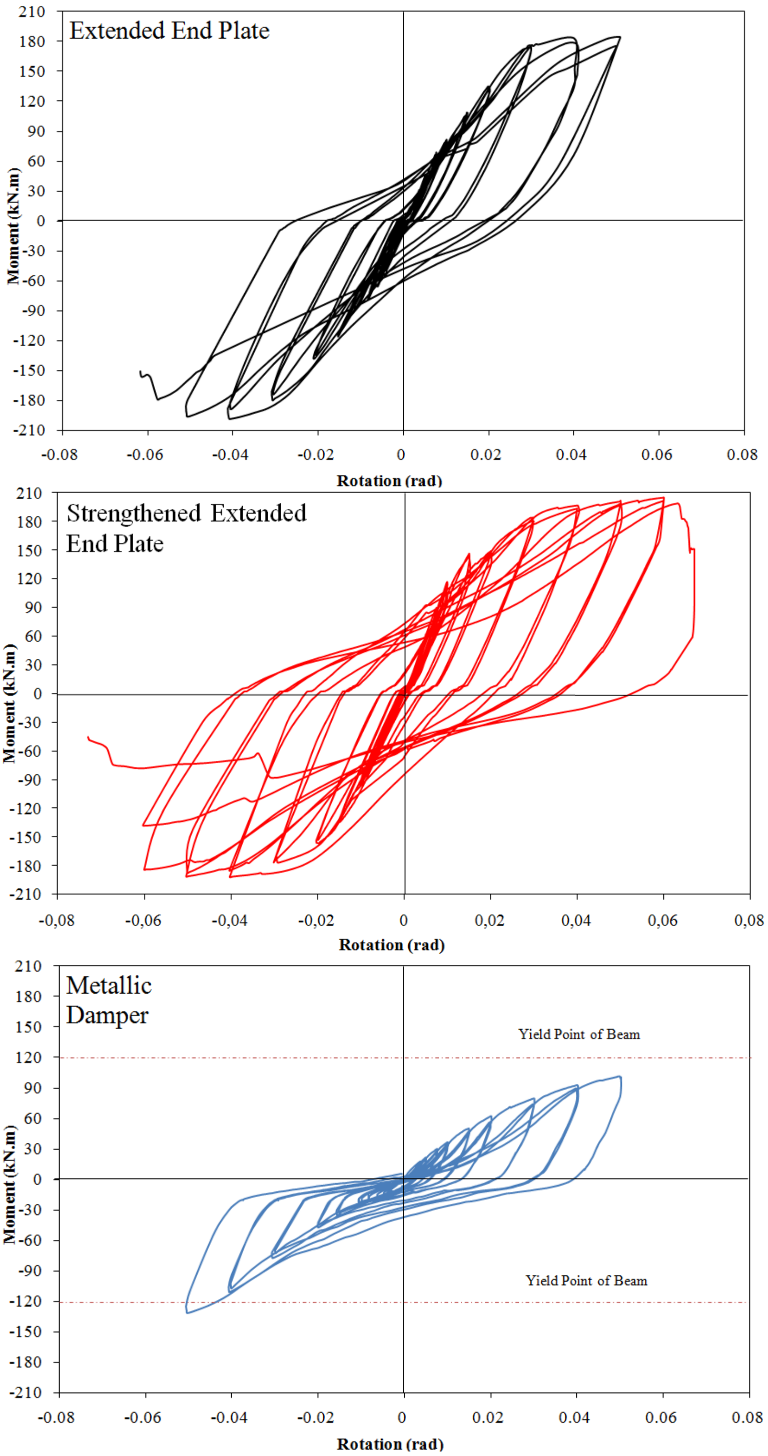

Figure 4. Moment-rotation curve of specimens
(Şekil 4. Deney numunelerinin moment-dönme eğrileri)

5. CONCLUSION AND RECOMMEDATIONS (SONUÇ VE ÖNERİLER)

In this study, a steel slit damper on beam to column connection is proposed because of high deformation capacity and ease of repair after a heavy earthquake. This connection is connected to the bottom flange of the beam using high-strength bolts. To verify the performance of the proposed system cyclic tests were conducted on three full-scale specimens that one had slit dampers and on one specimen that had a conventional extended end plate connection and the other had strengthened extended end plate connection. The key conclusions are noted below.

- The system with reinforced extended end plate connection exhibited stable hysteretic behavior under large story drift. The system had more moment carrying capacity than the system with conventional extended end plate.
- The system with slit damper was designed so that the yield point of the beam was not exceeding before the damage occurred on dampers. Consequently, the plastic deformation was concentrated at the slit dampers while the beams and columns remained almost elastic.
- The conventional system with reinforced extended end plate connection specimen and also reinforced specimen also showed good plastic deformation capacity. However, the entire plastic deformation originated from the local buckling of the beam. After local buckling stage failure on the weld between the bottom of beam and face of column. Therefore, it is ineffective to repair these connections after an earthquake.
- It is seen from the tests that the energy absorption is concentrated at the steel slit dampers rather than at the beams. Thus, the steel slit dampers can be replaced quickly after an earthquake instead of beams and columns.
- Connection of damper changes the behavior of system. Further research is necessary to investigate the behavior of a structural system equipped with slit damper. So more research on seismic capacity of the proposed system is recommended.

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NOT (NOTICE)

Bu makale, 28-30 Eylül 2011 tarihleri arasında Elazig Fırat Üniversitesinde "Inetnational Participated Construction Congress" IPCC11'de sözlü sunum olarak sunulmuştur.

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