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Research On Shear Links With Perforated Web Sections

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Keywords
Steel structures
Eccentrically braced frame
Link beam.

Abstract: In eccentirally-braced frames (EBFs), link-to-column connections and the structural elements outside of the links must resist the internal forces generated by fully yielded and strain-hardened links. Using slotted perforated web section concept in shear link may help to prevent difficulty in design of link-to-column connections and all other frame members by limiting the link capacity without loss of its stability. For this, a shear link beam with a section of W10×33 was selected and three different slot hole pattern were generated in its web to form three different specimens. Finite element models of these specimens were developed using ABAQUS software. Material of link beam was ASTM A992 steel. A series of analyses were performed under quasi-static cyclic loading to study the behavior of link beam with reduced web section. 10.6% of area reduction in the web section with different hole arrangements were investigated and the effect of slotted perforated web on shear links was examined. Finite element analyses have revealed that equally spaced 6×4mm slots in the web had stable hysteresis behavior whereas strength degredation was occured when equally spaced 3×8mm slots were used in the web. The results of this study indicate that using high number of slot holes may help to limit forces transmitting to the link-to-column connections and all other frame members.

Gövdesi Boşluklu Bağ Kirişleri Üzerine Bir Araştırma

Anahtar Kelimeler
Steel structures
Eccentrically braced frame
Shear link
Reduced web.

Özet: Dışmerkez çaprazlı çelik çerçeve sistemlerde, bağ kirişi-kolon birleşimleri, bağ kirişi dışında kalan kat kirişleri, kolonlar ve çaprazlar gibi çevre elemanlar bağ kirişinin plastikleşmesine karşı gelen iç kuvvetler altında boyutlandırılmaktadır. Özellikle bağ kirişlerinin kesme etkisi altında plastikleşmesi öngörülen sistemlerde, mekanizma durumunda çevre elemanlarda çok yüksek iç kuvvetler oluşmaktadır. Bağ kirişinin gövde enkesitinde stabilite kaybına yol açmayacak düzenleme ile boşluklar açılması bağ kirişinin plastikleşme kapasitesin düşürülmesini dolayısıyla çevre elamanların ve birleşimlerin tasarımında daha küçük iç kuvvetlerle çalışılmasını sağlayacaktır. Bu çalışmada, hazırlanan sonlu eleman modelinin doğrulanması amacıyla daha önce deneysel çalışması yapılmış ASTM A992 malzemeden imal edilmiş W10×33 enkesit profili bağ kirişi olarak seçilmiştir. ABAQUS sonlu eleman yazılımı ile gövde enkesit alanının 10.6% sına karşı gelecek şekilde üç farklı boşluk yerleşimi modellenmiştir. Çevrimsel yükleme altında boşluıklu bağ kirişi modellerinin analizleri gerçekleştirilerek davranışları incelenmiş, sonlu eleman analizlerinden elde edilen sonuçlar incelendiğinde gövde enkesitinde yerleştirilen boşluk sıklığının eleman davranışını önemli ölçüde etkilediği görülmüştür. Eşit aralıklı 3×8mm boşluk yerleşiminde elemanda yerel göçmeler meydana gelirken eşit aralıklı 6×4mm boşluk yerleşiminde kararlı bir çevrimsel davranış elde edilmiştir.

1. Introduction

Eccentrically Braced Frame (EBF) system is one of the most desirable structural system in seismic design of steel structures. Many researchers state that EBF systems provide the high level of stiffness, ductility and seismic energy dissipation capacity by combining benefits of moment frames and concentrically braced frames (Azad and Topkaya, 2017). In eccentirally braced frames, seismic energy is dissipated through shear, flexural or both shear and flexural yielding of link with large inelastic deformation in the link beam while columns, braces and beam outside of the link remain essentially elastic (Liao and Goel, 2006; Yiğitsoy et al., 2014). To facilitate the large inelastic link rotation demand, link-to-column connection is exposed to large moments and shear forces. Due to these forces, stress concentrations develop in connection area, resulting in fracture at low deformation level (Azad and Topkaya, 2017). In addition, depending on the overstrength ratio calculated by considering expected yield strength of the link, design of all other frame members is required to remain essentially elastic.

Link beams attached to the columns have less inelastic rotation capacity due to the tendency of fracture in the flange at connection area (Prinz and Richards, 2009). In bolted web connection, bolt slippage was occurred because of the large shear force. The bolt slippage lead to flange fractures (Malley and Popov, 1984; Okazaki, 2004; Popov, 1983). Extensive analytical and experimental researches on link beam with link-to-column connection have shown that promising connection details very limited and researches are on-going (Okazaki 2004; Okazaki et al., 2015; Okazaki and Engelhardt, 2006). Also there is no any prequalified link-to-column connection according to the AISC 341-16 (2016).

In order to prevent brittle failure of eccentrically braced frames, link-to-column connections and all other frame members must be proportioned following the capacity design principles considering the forces developed by the fully yielded and strain hardened link, nominal forces must be amplified by overstrength factor. In previous study on overstrength, overstrength value of 1.5 has been suggested (Popov, 1989). Ji at. al. (Ji et al., 2016) stated that this value underestimate the maximum forces for short links, especially links with link length ratio lower than unity. Capacity design concept in EBFs may lead to overdesign in some cases (Hauksdottir, 2008). If link beam capacities are reduced as much as possible, this may allow link-to-column connections and all other frame members to be designed in way that is more economical.

The present research investigates the effects of removing some portion of web area in link beam on cyclic behavior of link. Several finite element analyses were done to reveal that the behavior of link beam with reduced sections. The next section describes the finite element modelling, model verification study and analyses considering investigated parameters. The third section presents the results of the analyses. In the last section, results were discussed.

2. Material and Method

2.1. Reference model

W10×33 wide-flange American profile with length of 584 mm was considered as a reference model based on (Okazaki et al. 2004). The depth, flange width, web and flange thicknesses of the W10×33 section were 247mm, 202mm, 7.4mm and 11mm, respectively. Material of the profile was ASTM A992 steel, the yield stress and tensile strength values that determined by coupon testing are given in Table 1 (Okazaki et al., 2004).

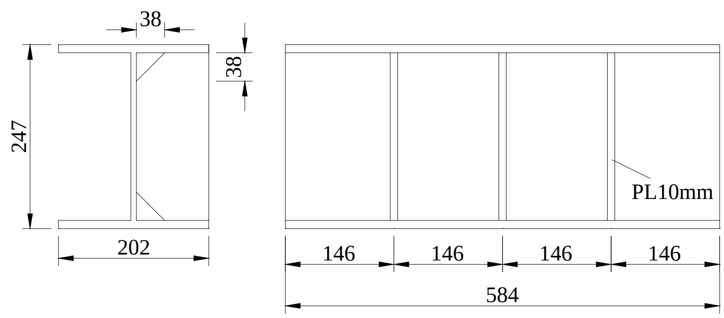

Figure 1: Reference model (Okazaki et al., 2004).

Table 1: The measured yield stress and tensile strength values.

Yield Stress F_y [MPa]		Tensile Strength F_u [MPa]	
Flange	Web	Flange	Web
356	382	507	503

2.2. Shear link prototypes

Three slot hole arrangements with 10.6% of area reduction in web section were implemented on reference profile. Fig 2. summarize the details of the investigated slot hole patterns and properties of slotted perforated links are given in Table 2. The prototypes are classified into three groups according to the slot hole geometry. For example, tag of 3×8 defines the slot hole pattern which have three slots placed along the depth with the height of 8mm. In the longitudinal direction of the web, each row has two slot-shaped perforations.

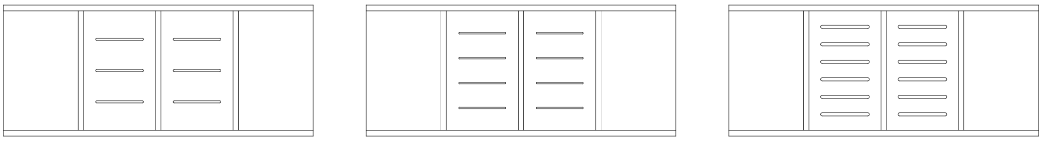

Figure 2: Slot hole patterns.

Table 2: The details of the investigated slot hole patterns.

Tag	n	h_h [mm]	h_s [mm]	l_s [mm]	Ratio of reduced area [%]	Width-to-thickness ratio of portions between two slits
3×8	3	8	51	86	10.6	6.89
4×6	4	6	41	86	10.6	5.54
6×4	6	4	29.5	86	10.6	3.99

n : quantity of the removed portions in vertical direction, h_h: height of the removed portions, h_s : height of the portions between slot holes , l_s : length of the slits.

2.3. Finite element modeling

Finite element models of W10×33 shear link beam with three different slot hole patterns were developed by using ABAQUS/CAE 2017 (HKS, 2017) software. Four-node shell element (S4R) was utilized to define the link beam and stiffeners. Material nonlinearites was taken into consideration through Von-Mises yield criterion with combined hardening. To capture second order effects, geometric nonlinearities were accounted for by employing the “nlgeom” option in ABAQUS. Finite element model of typical link beam is shown in Fig. 3.

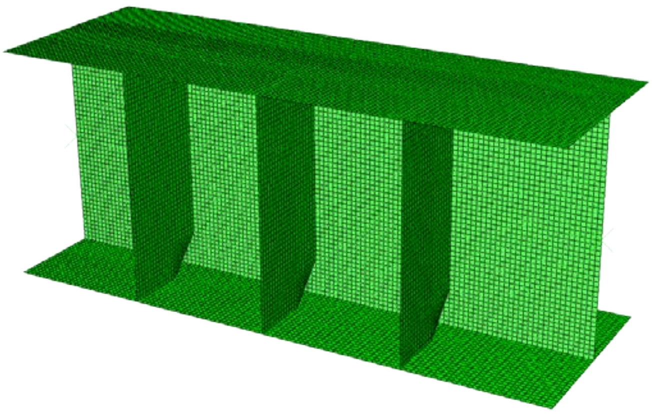

Figure 3: Finite element model of typical link beam.

Rigid body constraint was employed at both ends of the link. Motions of the end surfaces were constrained to the motion of a single reference point in the middle of the web at each end. As illustrated in Fig. 4, node on left end was constrained against all three rotations and translation except for horizontal translation. On the other hand, node on right end was free to vertical translation, but all other rotations and translations were fixed at this node.

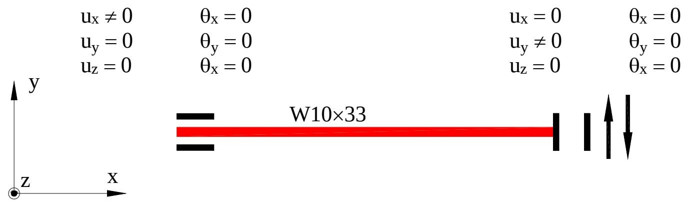

Figure 4: Boundary conditions.

Cyclic displacement history was applied on the right end reference node which is vertically free end of the shear link. Revised loading protocol for shear links, which developed by Richards and Uang (Richards and Uang, 2003), was followed (see Fig. 5). Displacement was determined by trigonometric tangent rule (link length times link end rotation angle) for each step. Maximum link rotation was 0.13 rad (76mm in drift). The expected link rotation was 0.08 rad without any strength and stiffness degradation.

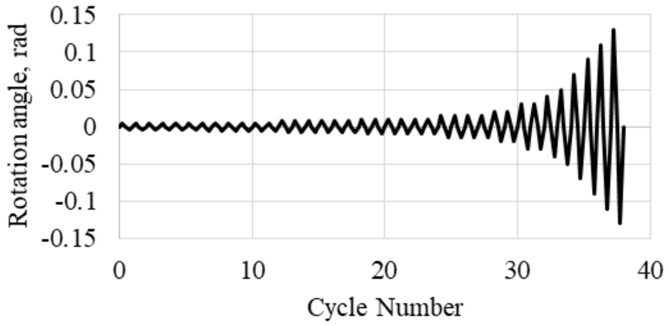

Figure 5: Loading protocol.

2.3. Model verification

Reference model adopted from Okazaki et. Al. (Okazaki et al., 2004) was subjected to quasi-static cyclic loading, to verify the accuracy of the finite element modeling assumptions in this study, then results were compared to those from experimental research (Okazaki et al., 2004). Specimen denoted as 4A-RLP was examined out of 24 specimens. Link geometry, material properties and loading protocol were explained above sections. The inelastic rotation versus link shear force curves from the experimental test and finite element analysis are illustrated in Fig. 6. The results of the test and model analysis demonstrated a good agreement. Similar behavior was observed both experimental and model study.

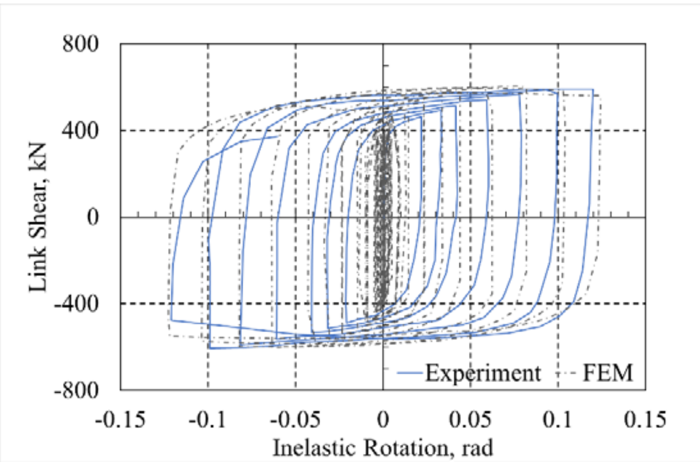

Figure 6: Link shear versus inelastic rotation hysteresis curves from experimental and model study.

3. Results

As shown in Fig.7, for 3×8 slot hole arrangement, the graph reveals that inelastic web buckling has started at rotation 0.04 rad, after that there has been a gradual strength degradation in link shear. Plastic rotation capacity was defined by which the link shear force was equivalent to 80% of maximum shear force value. According to this approach, plastic link rotation capacity for 3×8 slot hole arrangement was 0.06 rad. which was less than the required plastic link rotation specified as a 0.08 rad. for shear links. The reduced capacity of model 3×8 can be explained by which the inelastic buckling of web plate around slots occur. The curve of model 4×6 in Fig. 8 exhibits a slight decrease in link shear capacity after the rotation level of 0.08 rad. In this case, plastic rotation capacity was achieved at a link rotation of 0.10 rad. As can be seen from the Fig. 9, when 6 slot holes were incorporated into the web, strength degredation was not observed. All cycles were successfully completed and stable hysteresis were achieved.

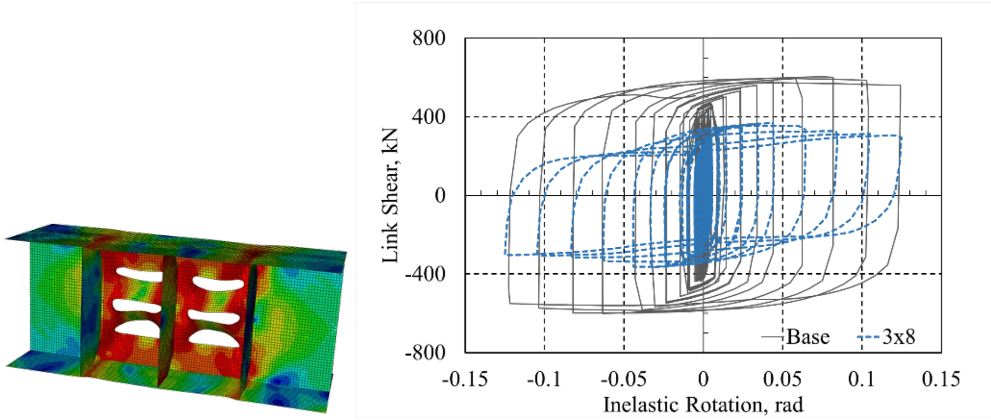

Figure 7: Deformed shape and link shear versus inelastic rotation hystereses loops for 3×8.

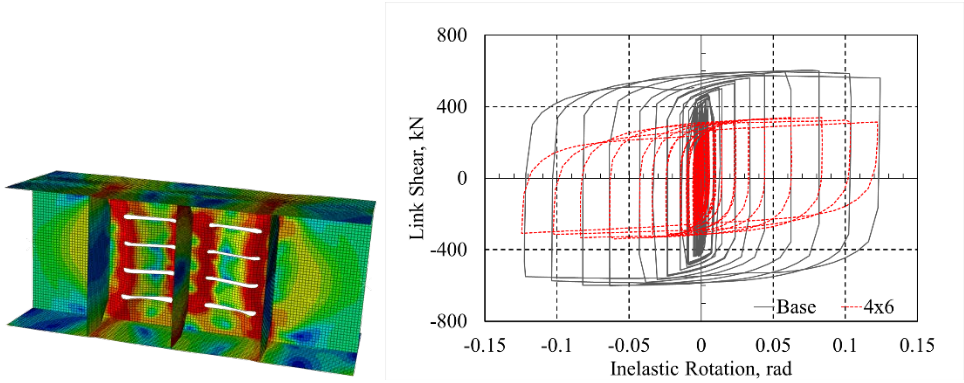

Figure 8: Deformed shape and link shear versus inelastic rotation hystereses loops for 4×6.

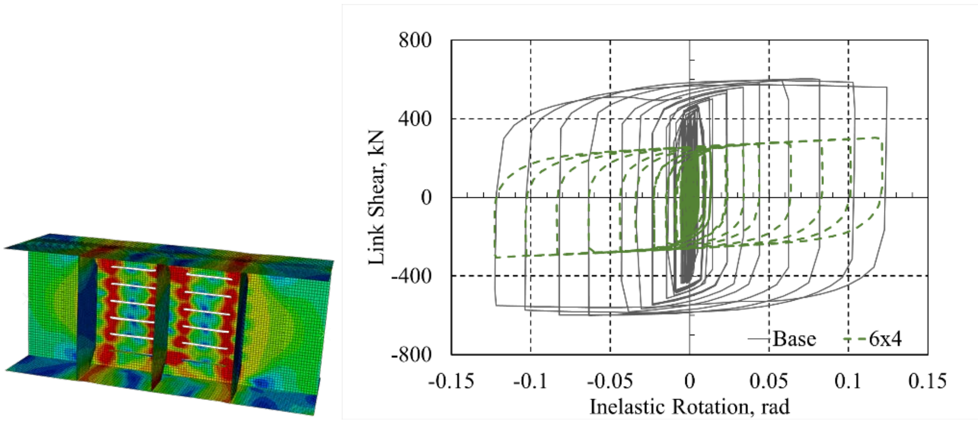

Figure 9: Deformed shape and link shear versus inelastic rotation hystereses loops for 6×4.

4. Discussion and Conclusions

An objective of this research was to investigate the effectiveness of the slotted perforated web section on shear links. In this study, three different slot hole patterns were taken into account with 10.6% of total area reduction. Shear force versus inelastic rotation curves show that increasing number of slots in the web with the same reduced area has contributed to the reduction in shear force capacity at yielding point while inelastic link rotation capacity was increased. A comparison of the results reveals that width-to-thickness ratio of the portions had a significant influence on the inelastic link rotation. As width-to-thickness ratio of the portions between slot holes increases, the portions reach their strength because they lose their stability.

The research has also shown that stress concentration was moved closer to the edges of the holes. If there is no buckling failure was observed, shear yielding dominated plastic mechanism transforms into the flexural yielding at the two sides of the strips.

Further research is continuing by the authors to develop exact correlation between the slot hole dimensions and link behavior to provide design basis for shear links with reduced web section.

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