On Improved Performance Of Eccentrically Braced Frames With Replaceable Shear Link

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SUMMARY:
Previous experimental and numerical works have been carried out on bolt-connected shear links to improve its low performance as compared to the weld-connected link. The performance includes strength, stiffness, ductility, and energy dissipation. Cyclic tests were conducted in this study on half-scaled eccentrically braced steel frames with weld-connected shear link and with replaceable bolt-connected shear links. Higher grade of flange was used in the built-up link to prevent early failure in the shear link. The result shows that the frame with the replaceable shear link provides only slightly difference performance as compared to the frame with welded-link. Moreover, the frame with replaceable shear link showed a more effective web-yielding in entire length of shear link, while no yielding occured in other parts of the frame. Finally, the cyclic test was conducted on the previously tested frame with a new shear link. The result shows that the retrofitted frame could provide the similar level of performance as the original one.

Keywords: replaceable shear link, bolt-connected, cyclic test, energy dissipation

1. INTRODUCTION

More frequent occurrence of earthquake in seismic prone region needs a reliable and economical seismic resistant building. Eccentrically braced frame has shown its good performance as a seismic resistant structure due its sufficient stiffness, strength, ductility and energy dissipation. Its advantages are supported by both the diagonal braces that provide lateral structure stiffness, and the link that mobilizes the energy dissipation by its yielding mechanism. Early study by Kasai and Popov (1986) showed that the shear link or short link provided better energy dissipation than the flexural link or long link. The good performance of the shear link depends on the cyclic yielding mechanism on the web that should ensure a stable and 'fat' hysteretic curve. The compactness of the link web also contributes to this performance.

The connections between the link–end and adjacent beam or column are commonly provided by welded-connection due to its advantage over the bolted-connection. So far, the welded-connection provides more rigidity or stiffness and more capacity, i.e. strength, plastic rotation and energy dissipation. As shown by Ramadan-Gobarah (1995) and Stratan-Dubina (2002), the strong bolt-connected link could provide better energy dissipation due to cyclic load. Moestopo (2006) showed that the lack of stiffness and strength of the bolts as well as the lack of stiffness of end-plate contributed to the deficiencies of the bolt-connected link. Beside the less performance of a bolt-connected link as compared to a weld-connected link, the use of bolt-connection in a shear link has a potential for a more economical sesimic resistant structure by its good replaceability after more earthquake occurences.

Numerical and experimental works have been conducted by Moestopo et.all (2008,2009a) on link assemby to study the performance of bolt-connected shear link. Result showed that the thickness of end-plate as well as the diameter of bolts prevent the pinching of the hysteretic due to less rigidity of the connection in cyclic loading in the inelastic deformation of the link. Further work (2009b) showed the use wing plate at link-ends has effectively prevented early failure of the link by decreasing the stresses that are developed near link-ends due to higher bending moment and effect of welding at the end-plate of bolt-connected link. Recent study on the bolt-connected link (2012) showed the use of built-up section with higher grade flange has also improved the performance of the shear link by preventing early fracture of the flange. This enables the entire link-web to yield and to provide more energy dissipation as expected.

This paper reports the experimental work to study the performance of an eccentrically braced frame using shear link that was built up by higher grade flange and was bolt-connected for the purpose of replacement after the link has been effectively damaged.

2. EXPERIMENTAL WORK

Research was carried out on an eccentrically braced frame of three-story office-residential building that was designed for the most severe seismic region in Indonesia. The experimental work was conducted on two similar half-scaled (3000 mm by 2000 mm) K-split braced frames with shear link as shown in Figure.2.1. Column and beam out-side link are made of hot-rolled wide-flange section 100.100.6.8, while a built-up wide-flange section with the same dimension was used for the shear links. The first frame was built with a weld-connected link, while the second frame used a bolt-connected link. Figure.2.2. shows the dimension of the two shear links, where the bolt-connected link used 30-mm end-plate with four 19-mm high-strength bolt at each link end to prevent excessive yielding of its end connection. The data for each link specimen is shown in Table.2.1.

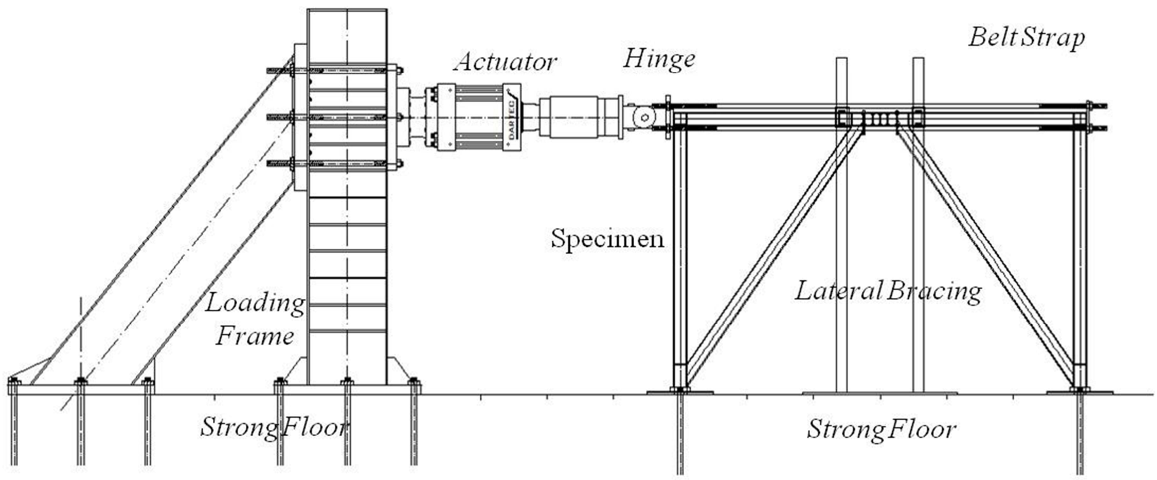
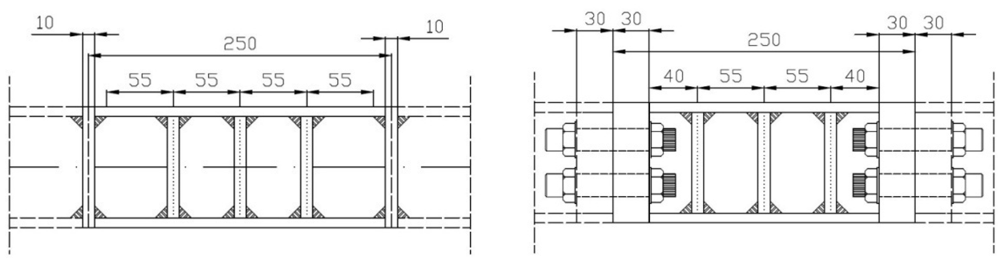


Figure 2.1 Testing Set Up



(a) (b)

Figure 2.2 Shear Links
(a) Weld-connected link (b) Bolt-connected Link

Table 2. 1 Shear Link Specimen

	Weld-connected link	Bolt-connected link
Section	Wide-flange built-up section 100.100.6.8 (in mm)	
Yield-strength	307 MPa (web) 360 MPa (flange)	
Tensile-strength	455 MPa (web) 500 MPa (flange)	
Length	250 mm	250 mm, including 30 mm-thick end-plates
Stiffener	3 of each side	2 of each side

A quasi-static cyclic loading was applied on each frame by displacement control using a horizontal actuator. The loading pattern was applied as shown in Figure.2.3, until failure occurs in the link. A lateral support was provided in the link area, to prevent the out-of plane frame buckling. The lateral displacement of the frame and the applied loading was recorded by data logger. Strain gauges were mounted to monitor the shear strain at the link-web as well as the normal strain at the other components (column, beam outside link, and diagonal brace) that are expected to remain elastic.

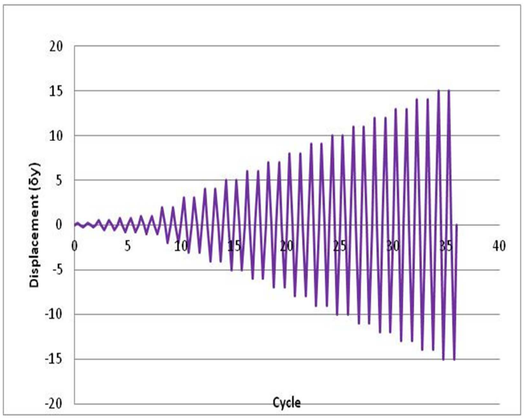


Figure 2.3. Cyclic Loading Pattern

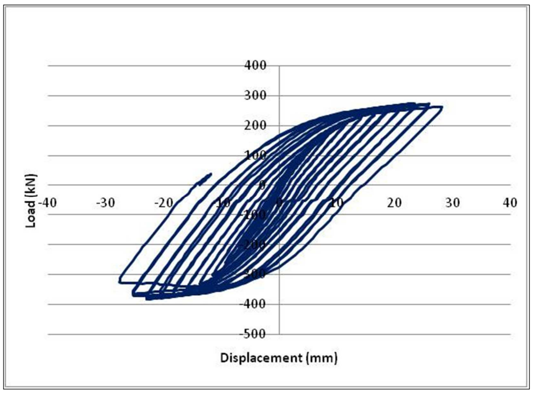
Figure 2.4. Laboratory Testing Set Up

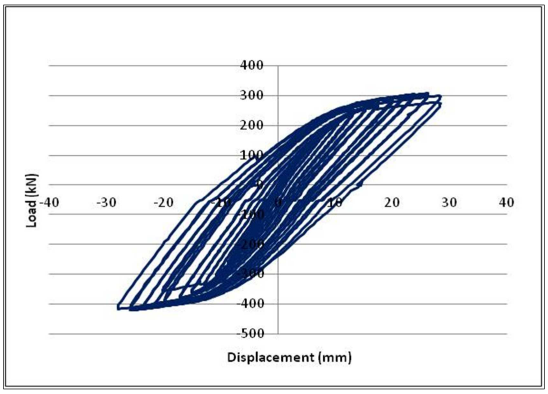
The damaged shear link of the second frame was then replaced by the same bolt-connected link. The same cyclic loading was applied to observe the performance of the retrofitted frame.

3. DATA ANALYSIS

Figure 3.1. shows the load-displacement of the two eccentrically braced frames: frame with weld-connected link (Frame 1) and frame with bolt-connected link (Frame 2). The failure of Frame 1 was observed as fractures occured at the connecting weld in the flange, while loading was completed in Frame 2 as the fractures occured at the web of shear link (Figure 3.2). Meanwhile, the data of strains at other structural components, i.e. column, beam outside link, and diagonal braces, showed that no yielding occured in those elements.

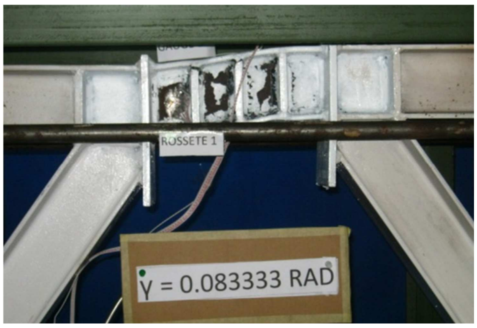
The test results also show that due to the cyclic loading, the maximum load of Frame 2 (P = 306 kN) was slightly higher than the maximum load of Frame 1 (P = 270 kN), and the maximum displacement of Frame 2 (D = 26 mm) is slightly higher than Frame 1. The early failure of link in Frame 1 contributed to this result.

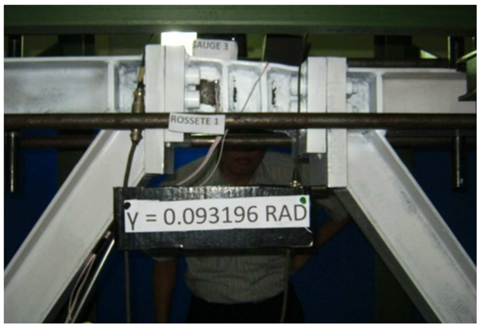




(a) (b)

Figure 3.1. Hysteretic Load-Displacement
(a) Weld-connected Link (b) Bolt-connected Link





(a) (b)

Figure 3.2. Damaged Link After Loading
(a) Weld-connected Link (b) Bolt-connected Link

In the first cycles of the loading history, the Frame 2 showed slightly less lateral stiffness than the Frame 1. However, as the loading increased, the Frame 2 experienced slower stiffness degradation than Frame 1. (Figure3.3). This better performance of bolt-connected link in this frame is clearly supported by the use of thicker end plates and shorter length of the link, that provides more resistant to the shear deformation of the link. This result would be different for larger dimension of shear link.

Figure 3.4 and Table 3.1 showed that for all loading cycles, the cummulative input energy in both Frame 1 and Frame 2 are almost the same, however the dissipation energy in the Frame 1 is consistently higher than in the Frame 2.

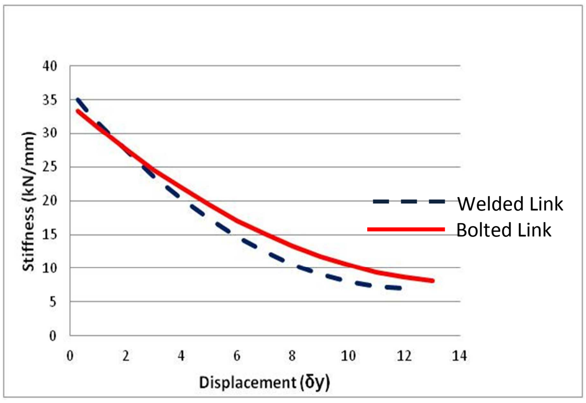


Figure 3.3. Stiffness Degradation of Frames

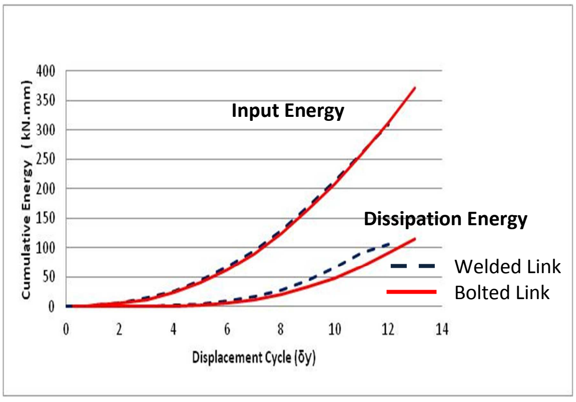


Figure 3.4. Cummulative Energy

Table 3.1 shows the cummulative energy that was observed in each frame during the inelastic loading until the 12th cycle, i.e. when the Frame 1 failed. At each loading cycle, the Frame 1 consistently showed higher performance than Frame 2. The cummulative dissipation energy of Frame 1 is 105,73 kNm or 15% higher than Frame 2, and the ratio Ed/Ei of Frame 1 at 12th cycle is 34,03%, or 17% more effective than Frame 2.

Table 3.1 Cummulative Energy

(a) Frame 1 - Weld-connected Link

Cycle (δy)	Rotation (Rad)	Dissipation Energy,Ed (kNm)	Input Energi,Ei (kNm)	Ratio Ed/Ei (%)
1	0.0023	0.01	2.53	0.68
2	0.0058	0.13	6.56	2.01
3	0.0092	0.56	14.5	3.86
4	0.0153	1.7	27.05	6.31
5	0.0227	4.23	44.75	9.46
6	0.0316	9.08	67.64	13.44
7	0.0393	16.8	95.93	17.52
8	0.048	28.41	129.98	21.86
9	0.0609	44.46	169.35	26.25
10	0.0714	65.86	213.65	30.83
11	0.077	91.79	261.59	35.09
12	0.0833	105.73	310.77	34.03

(b) Frame 2 - Bolt-connected Link

Cycle (δy)	Rotation (Rad)	Dissipation Energy,Ed (kNm)	Input Energi,Ei (kNm)	Ratio Ed/Ei (%)
1	0.0016	0.01	1.83	0.72
2	0.0063	0.09	5.35	1.75
3	0.0124	0.37	12.48	2.99
4	0.0174	1.12	24.14	4.66
5	0.0257	2.81	40.99	6.86
6	0.0374	6.21	63.16	9.85
7	0.0486	11.9	90.65	13.14
8	0.0586	20.22	123.62	16.36
9	0.0605	33.4	163.82	20.39
10	0.0698	48.86	208.37	23.45
11	0.0717	67.69	258.29	26.21
12	0.0887	91.12	313.25	29.09

The same observation is presented in Figure 3.5. The envelope of load-displacement hysteretic diagram of Frame 1 with weld-connected link is slightly thicker than the envelope of frame with bolt-connected link (Frame 2). This also indicates a slightly better energy dissipation in weld-connected link than in bolt-connected link.

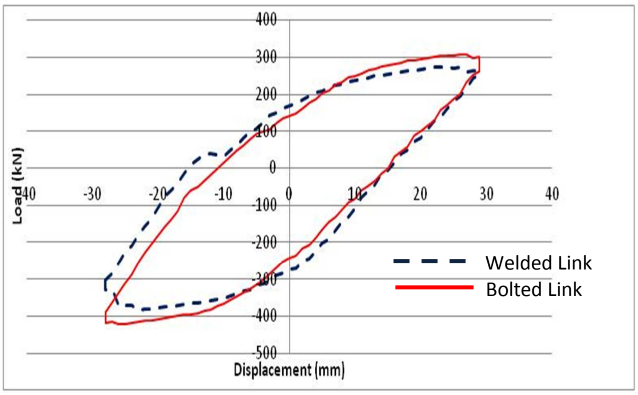


Figure 3.5. Load-Displacement Envelope

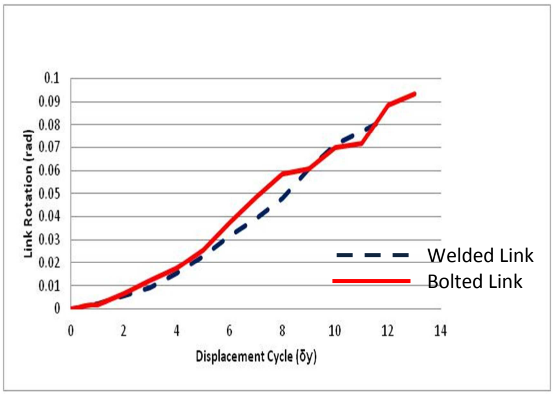


Figure 3.6. Link Rotation

Besides the better performace of Frame 1, the link rotation that was developed during the loading history (Table 3.1 and Figure.3.6.) showed the similar results on both frames. However, higher rotation capacity was provided by Frame 2 before its failure at 13th loading cycle.

The damaged bolt-connected link was then replaced by a new bolt-connected link, that was made by same material and same dimension. The new link was assembled to the same elastic frame using the same bolted-connection. Figure 3.7 shows the hysteretic diagram of the retrofitted frame due the same cyclic loading pattern. No significant change was observed in the performance of the link and the frame. The results show that beside its slightly less performance in energy dissipation, the bolt-connected link with higher grade of its flanges could be used as an effective replaceable link.

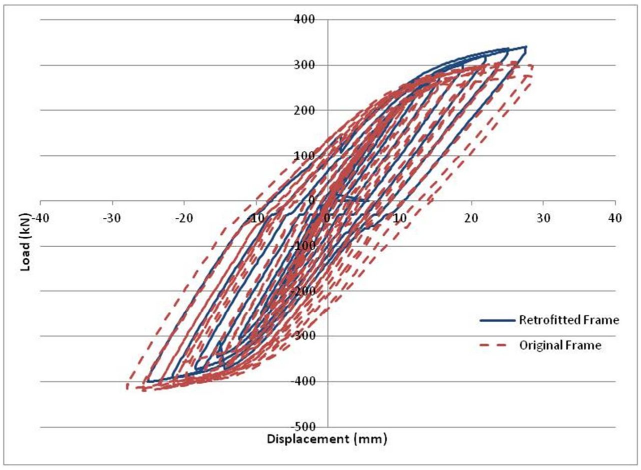


Figure 3.7. Load-displacement of Retrofitted Frame

4. CONCLUSION

The results indicates that the use of bolt-connected shear links with higher grade of its flange in an eccentrically braced frames, provide only slightly less performance than the weld-connected links, especially in energy dissipation. However, the use of the bolt-connected shear links will provide more economical solution as replaceable links for eccentrically braced frames, particularly for its application in the more prone seismic zones.

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