Seismic Performance of IWF Flexural Link in Inverted-V Eccentrically Braced Frames With Different Stiffener Spaces

M. Fujii Hanafi¹,*, Muttaqin Hasan², Arief Panjaitan³, and Masaru Shimizu⁴

¹,²,³Civil Engineering Department, University of Syiah Kuala, Banda Aceh 23111 Indonesia
⁴Civil Engineering Department, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Japan 464-8601
Email: ¹muhammadfujihanafi@gmail.com
*corresponding author

Resistant structures, such as Eccentrically Braced Frames (EBFs), are required to be established in earthquake-hazard areas. In EBFs, an essential beam component, known as link, plays a crucial role in determining the performance of these structures. As the seismic energy dissipator, link experiences failure to prevent heavy damage to other EBFs members, such as beams and columns. Although several studies have been carried out to enhance the seismic performance of link, there is still limited regarding these elements. Therefore, this study aimed to investigate several IWF flexural links constructed in FE models of Inverted-V EBFs. A total of three flexural links with different stiffener spaces were considered namely non-spacing, 250 mm, and 100 mm stiffener spacing links. To assess their performance, cyclic loading with yield displacement control was used in EBFs models. Observations were mainly conducted on EBFs performances consisting of strength, stiffness, and dissipation energy. The results showed that the best seismic performance was specified on a 100 mm-stiffener spacing link by presenting the largest and most stable hysteresis curve. Based on these results, the configuration of the narrow space stiffener in the link element was recommended to improve the seismic performance of EBFs.

1 INTRODUCTION

High-level seismic-resistant structures, such as Eccentrically Braced Frames (EBFs) are required to be established in earthquake-hazard areas. In EBFs, link is an essential beam component that depends on stiffness and ductility, located between the ends of two diagonal braces or a diagonal brace and a column [1]. One type that is commonly used is Inverted-V EBFs, which has one link located in the middle of the span with 2 two-point connections from the bracing on the sides of each link.
Link in the EBFs function as dissipators of seismic energy through shear and flexural yielding mechanisms [3]. Initial, link melts through a bending or shear mechanism before buckling occurs in the compressed element. As a dissipator, it is damaged when subjected to seismic, safeguarding structural elements such as columns, beams, and braces from failure. Consequently, the presence of link and bracing can increase the stiffness of the structure.

In EBFs structural system, the three types of link that have been identified include short, intermediate, and long. This categorization is determined based on the length of the link with the ratio between moment capacity (Mp) and shear capacity (Vp). Specifically, intermediate link is characterized by a combination of shear and bending in the melting process [7]. Link is an element that behaves as short beams on both sides, where shear forces of the same magnitude act in opposite directions, accompanied by moments of the same magnitude and direction [4]. The selection of the length of EBFs link influences strength and stiffness.

**2 OBJECT AND RESEARCH METHODOLOGY**

The objects studied in this analysis are buildings and portals of Inverted-V EBFs. The portal served as an object from 3D modeling of the Inverted-V EBFs steel frame building using the IWF profile. The building area is 12 m x 12 m, comprises three floors, with a column spacing of 4 m and the height is 4 m. Furthermore, the building is located in Banda Aceh, which serves as a storage warehouse. The dimensions of the 3D EBFs were carried out using the trial and error method in the ETABS program.
Spectra Response Data were obtained based on the 2021 Indonesian seismic Map Spectra Response Program (Puskim-PusGeN-ESRC 2021) for the location in Banda Aceh with longitude coordinates 95.2027 Degrees and latitude 5.3412 Degrees, assuming a site class of SE (Soft Soil). The Inverted-V EBFs building was modeled using IWF steel profile material with BJ 37, incorporating a steel deck with concrete floor plate f'c 25 MPa. The loads included in the 3D modeling of Inverted-V EBFs buildings in the ETABS program. The loads were reviewed in structural planning in the form of dead loads, live loads, and seismic loads referring to SNI 1727-2020. The factors and loading combinations that must be reviewed refer to SNI 1726:2019. Subsequently, 3D modeling analysis of Inverted-V EBFs buildings produced economical and efficient steel profile dimensions of each structural element.

A 2D portal analysis of Inverted-V EBFs with a length of 1.000 mm and different stiffener spaces was carried out using the ABAQUS program, and the three models are shown in Fig. 5.
### Table 1. Modeling Name

<table>
<thead>
<tr>
<th>Model</th>
<th>Link Length (mm)</th>
<th>Stiffener Spaces (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRBE 1,0 TP</td>
<td>1.000</td>
<td>0</td>
</tr>
<tr>
<td>SRBE 1,0 P100</td>
<td>1.000</td>
<td>100</td>
</tr>
<tr>
<td>SRBE 1,0 P250</td>
<td>1.000</td>
<td>250</td>
</tr>
</tbody>
</table>

**Fig. 4.** Link Length 1.000 mm with Stiffener Spaces 250 mm and 100 mm

**Fig. 5.** 2D Modeling of Portal Inverted-V EBFs with Stiffener Spaces 250 mm and 100 mm and non-spacing link

Pushover analysis was carried out to obtain the yield deformation ($\Delta y$), which was used for cyclic loading. Subsequently, cyclic loading with yield deformation units ($\Delta y$) was applied to observe the inelastic behavior of the Inverted-V EBFs portal. This is crucial to
understand how the deformation due to seismic loads surpasses yield deformation of the Inverted-V EBFs portal.

Analysis of 2D portal Inverted-V EBFs modeling produced yield deformation obtained from pushover analysis in the form of a load-displacement relationship curve. The yield deformation value was obtained from the yield point on the curve and the structure performance was measured by three parameters, namely strength, stiffness, and energy dissipation.

3 RESEARCH AND DISCUSSIONS

The results of the structural analysis of the 3D modeling of the Inverted-V EBFs building in the form of cross-sections of IWF steel profiles for each element are presented in Table 2.

<table>
<thead>
<tr>
<th>Component</th>
<th>Dimension</th>
<th>Weight (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>IWF 450 x 300 x 18 x 11</td>
<td>124</td>
</tr>
<tr>
<td>Beam/Link</td>
<td>IWF 400 x 300 x 16 x 10</td>
<td>107</td>
</tr>
<tr>
<td>Brace</td>
<td>IWF 400 x 300 x 14 x 9</td>
<td>94.3</td>
</tr>
</tbody>
</table>

The results of the structural analysis of the 2D portal Inverted-V EBFs model from the pushover analysis showed a yield deformation value ($\Delta y$) = 7 mm, as presented in Fig. 6.

![Pushover Analysis](image)

*Fig. 6. Results Pushover Analysis*

Cyclic loading with yield deformation units ($\Delta y$) gave inelastic behavior to the Inverted-V EBFs, which was applied in stages to 22 cycles until it was deemed sufficient to reciprocate. Simulation per cycle was carried out to achieve melting deformation for three 2D portal Inverted-V EBFs models, as shown in Fig. 7.
Controlled deformation that exceeds the yield deformation leads to the formation of a hysteresis area, which is defined as the amount of energy absorbed during a seismic event. A comparison of the hysteresis curves for each model is shown in Figure 9, indicating that closer stiffener spaces result in high portal performance. Furthermore, the maximum load out for each model including SRBE 1.0 TP, SRBE 1.0 P100, and SRBE 1.0 P250 is 1.442 kN, 1.788 kN, and 1.559 kN, respectively, with a maximum displacement of 140 mm.
Fig. 9. Comparison of Hysteresis Curves

Fig. 10. Strength Comparison (Strain/Stress)
The results of the structural performance assessment, including strength, stiffness, and energy dissipation show that the maximum value is located in the portal model SRBE 1,0 P100. Furthermore, the maximum force strength is found in cycle 22 or 140 mm displacement of 1,789 kN (strain) and 1.794 kN (stress). The configuration with a 100 mm spacing of stiffeners on the link results in a significant decrease in stiffness, indicating superior energy dissipation of the input energy.

4 CONCLUSION

In conclusion, this study showed the structural performance behavior in the form of strength, stiffness, and energy dissipation to configure the narrow space stiffener in the link. Among the portal models analyzed, SRBE 1,0 P100, characterized by link length of 1,000 mm and stiffener spaces of 100 mm, has the best performance compared to others. The effectiveness of adding stiffeners resulted in a significant increase of 19.51% (strength),

Fig. 11. Stiffness Comparison (Strain/Stress)

Fig. 12. Comparison of Energy Dissipation and Energy Input
19.53% (stiffness), and 6.19% (energy dissipation) with spaces 100 mm. At 250 mm spaces, the improvement was 7.54% (strength), 7.45% (stiffness), and 2.29% (energy dissipation) with spaces 250 mm.

REFERENCES

2. Moestopo, M., Kusumastuti, D., Novan, A., Improved Performance of Bolt-Connected Link Due to Cyclic Load, Jakarta: International Conference on Seismic Engineering and Disaster Mitigation (2008)
10. SNI-03-1726-2019
11. SNI-03-1729-2020