Acta Technica 62 No. 4B/2017, 1–6

Assessment of geometry effect on cyclic behavior of eccientrically braced frames links

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Abstract. Eccentrically braced frames (EBFs) have good ductility if the links can accommodate the inelastic rotations imposed by severe seismic loading. These links are typically formed from eccentricities between two brace connections, or between a brace connection and column. Links in EBFs are designed to act as structural fuses, localizing frame damage within link regions during overloading. When links are properly designed, the columns, braces, and beam regions outside the links will remain essentially elastic. This study investigated methods for improving EBF link connection performance, and proposed an alternative ductile braced frame system for accommodating architectural features. Several EBF links with reduced web and flange sections were analytically investigated using validated finite element models in ABAQUS.

Key words. Eccentrically braced frames, cyclic, link, finite elements, Abaqus.

1. Introduction

Around 1970 in Japan, the term "eccentric systems" was first proposed by people such as [1–4]. In 2006, Chao adjusted structural computational models to study the web failure for judging the failure of ductile steel properties based on the test results in order to better determine the location of ductile failure. Under severe earthquake loading, eccentrically braced frames (EBFs) dissipate energy as stiffened beam segments, called links, rotate inelastically. These links are typically formed from eccentricities between two brace connections, or between a brace connection and column. Shorter links that rotate due to web shear yielding are more common than longer links which develop flexural hinges at each end. Links in EBFs are designed to act as structural fuses, localizing frame damage within link regions during overloading. When links are properly designed, the columns, braces, and beam regions outside the links will remain essentially elastic [5]. EBFs have an advantage over concentrically braced frames (CBFs), in that they can accommodate various architectural features. The eccentricity used to create links in EBFs, provides room

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for doors, windows, and hallways, allowing access through the frame. Okazaki et al. [6] tested link-to-column connections under cyclic loading and reported the inelastic rotation capacity of links with various link-to-column connection details. Of the twelve W18x40 links tested in [6], ten experienced fracture of the link flanges near the welds at rotations from 0.007 to 0.07 rad. One specimen with a connection that followed the modified welding recommendations outlined in FEMA-350 experienced fracture after 0.05 rad.

2. Finite element modeling

2.1. Verify model

In this article to have study on the behavior of EBF links, first it is necessary to verify an experimental model in software. A control model simulated the test setup and cyclic loading protocol used, allowing modeling techniques to be validated with existing experimental data. ABAQUS was used for the analyses. Displacement constraints simulated the boundary conditions and loading present in the experimental set-up. Non-linear material properties and large displacement effects were considered in the analyses. Material plasticity was based on the von Mises yield surface and an associated flow rule. Plastic hardening was defined using a nonlinear kinematic hardening law.

2.2. Control model validation

To evaluate the modeling techniques used in this study, the control model was subjected to cyclic loading and results were compared with the full-scale test performed by Okazaki et al. [1] The experimental setup used by Okazaki was re-created using the finite element program ABAQUS. The supports used in the experiment were simulated by roller supports on the ends of the beams, a pinned constraint at the column base, and out-of-plane constraints at the beam and column ends. Fig. 1 shows the ABAQUS model with applied boundary conditions.

After applying the cyclic load to the main model results will be compared with experimental one. Fig. 1 shows the plastic equivalent strain counter behavior for specimen and the ABAQUS models. From Fig. 1, the models in this study and Okazaki model have similar peeq counter. The numerical model which has been modelled in abaqus matched the closest with the experimental result. From Fig. 2 which shows load-displacement curves for both numerical and experimental models shows that similar stiffness, strength, and strength degradation behavior is evident between the experimental result and numerical model.

The good agreement between model and experiment confirms that modeling composite beams with reduced elastic-perfectly-plastic concrete properties can reasonably predict system-level frame behavior.

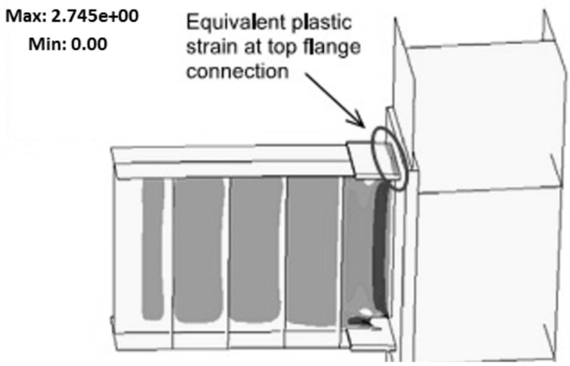


Fig. 1. ABAQUS model simulating Okazaki et al. test

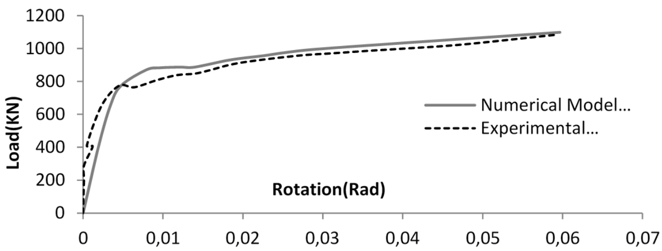


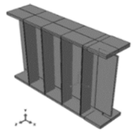
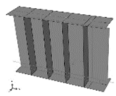
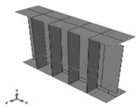
Fig. 2. Load-displacement curve for numerical and experimental models

3. Models to investigate different thickness

Seventeen additional models were analyzed, representing shear yielding links with different thickness. The same modeling techniques were used as described for the control model. The cross-section (nominal W18_40) and length (635 mm) of the models matched those of the control model. The seventeen link models will be considered as three groups, with each group designed to investigate specific aspects of link performance. The first group consisted of six links designed to investigate the effects of various stiffner thickness. The response parameters were the link rotational stiffness, ultimate strength, and rotation when the failure index reached 1.0 (hereafter referred to as 1) at any location. The second group consisted of six links that had the same parameters; the only variation for these models was the thickness of the web. The third group consisted of five links with different thickness of flange. Table 1 describes and illustrates each of the links in the groups and gives values for the response parameters. Results will be discussed in the following section.

After applying rotation to the models, the reaction forces of models have been gotten from Abaqus software and it is shown in the Fig. 4. Results in Fig. 5 are only for first group models. All models have the same diagrams. As the results show the maximum reaction force is for model FI1 which has the thickest stiffner in web, and the minimum reaction force is for model FI6 which has no stiffner. Assessment of

Table 1. Description of group 1 link models

Flange Stiffner Thickness	Stiffner Thickness	Web Thickness	Flange Thickness	Variable Section	Models	
5	10	8	15	 Web Stiffner Thickness	FI1	1
5	8	8	15		FI2	2
5	6	8	15		FI3	3
5	4	8	15		FI4	4
5	2	8	15		FI5	5
5	0	8	15		FI6	6
5	8	7	15	 Web Thickness	W0	7
5	8	8	15		W1	8
5	8	9	15		W2	9
5	8	10	15		W3	10
5	8	11	15		W4	11
5	8	12	15		W5	12
5	8	8	13	 Flange Thickness	F1	13
5	8	8	15		F2	14
5	8	8	17		F3	15
5	8	8	19		F4	16
5	8	8	20		F5	17

steel frame components have used a low cycle fatigue failure index based on a stress modified critical strain criterion. The failure index is computed as the accumulated equivalent plastic strain (PEEQ in ABAQUS) divided by a critical plastic strain.

Table 2 describes and illustrates each of the links in the all group and gives values for the response parameters.

Table 2. All models result

Joint failure percentage	Strength (kN)	Weight (kg)	Variable tickness (mm)	Models
0	1298	55/024	18	FI1
0	1332	54/412	16	FI2
5	1299	53/812	14	FI3
10	1300	53/188	12	FI4
20	1298	52/576	10	FI5
60	1230	51/963	8	FI6
100	1212	49/443	13	F1
100	1230	51/963	15	F2
100	1234	54/483	17	F3
100	1243	57/003	19	F4
100	1246	58/263	20	F5

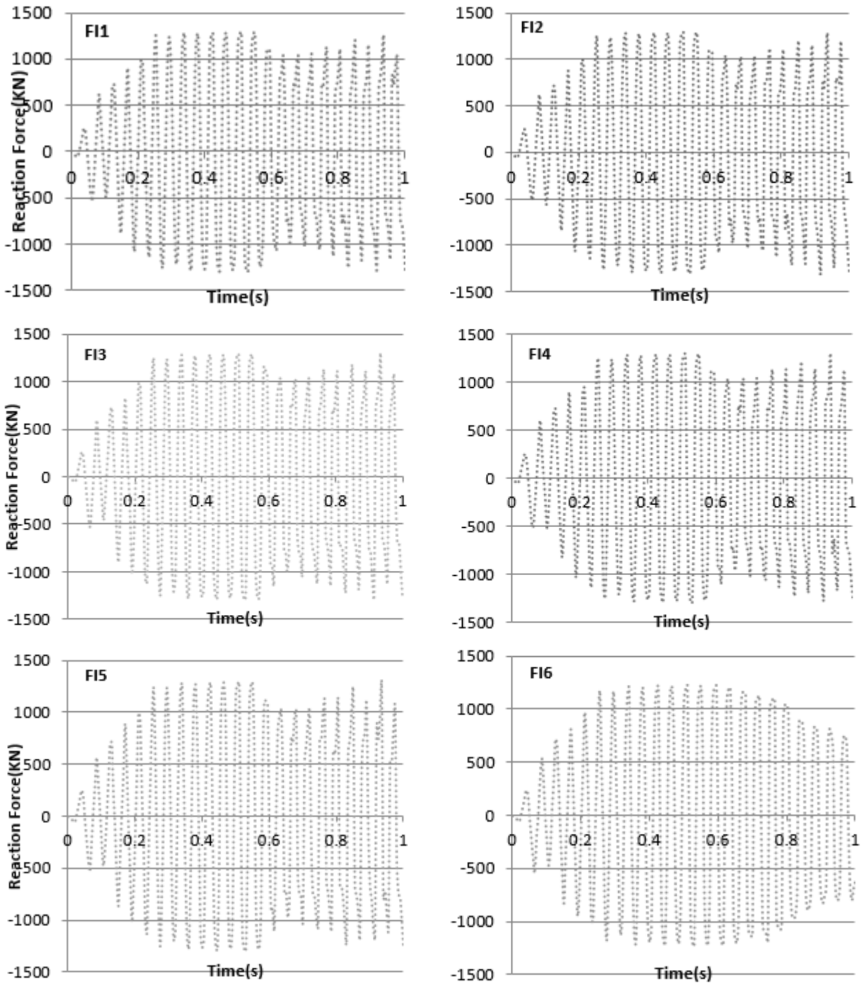


Fig. 3. Reaction force of first group EBF links

4. Conclusion

In this study, the cyclic behavior of EBF links with reduced web sections was investigated using nonlinear finite element analysis. Finite element models were developed to simulate typical experimental testing of EBF links. Validation of modeling techniques was performed using existing experimental data. Low-cycle material fatigue was estimated using a failure index. The following conclusions regarding EBF links with reduced web sections are based on the cyclic analysis of seventeen W18×40 links with link-to-column connections. Recent research highlights the limited ductility of EBF link-to-column connections, indicating reductions in link rotation capacity due to connection fractures. The current seismic provisions warn engineers of the issues with EBF link-to-column connections, and suggest avoiding the connections altogether until a practical solution is found. In EBFs, flange-to-column stress concentrations lead to early connection failure through material fatigue; however, unlike EBF beams, the stubs of the first models did not yield, eliminating the possibility for material fatigue.

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Received October 31, 2017