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Eccentricity effect on the cyclic response of braced frame type-V

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Abstract. Eccentricity on the braced frames can sometimes not be avoided to facilitate some structural considerations, such as openings. V-type braced frames are among the most widely used bracing types because of their satisfying performance. The present study investigated the effect of eccentricity as 15 cm, and 25 cm on the reinforced concrete braced frames of 80 cm x 100 cm in dimension compared to V-type of Concentric Braced Frame (CBF). Results indicated that a frame with 15 cm of eccentricity has almost similar stress but higher strain compared to the CBF while the frame with 25 cm of eccentricity resulted in lowest stress but highest strain. As the eccentricity rises, a frame is likely to behave as a moment-resisting frame. Link beams are the most critical part of the Eccentric Braced Frame.

Keywords: Cyclic load, Eccentric Braced Frame (EBF), Lateral load, Strain, Stress.

1. Introduction

Lateral load on the structural frames is usually identified as a wind or a seismic load. It acts on the lateral axis, resulting in the flexure mechanism to the columns structure and axial or normal mechanism to the beams structure. Structural hysteresis behaviour can be investigated using this loading condition, and even dissipation energy can be identified. The cyclic load application on the frame structure can reduce the axial structural capacity by 50% of the actual capacity even with only one strong cyclic load [1].

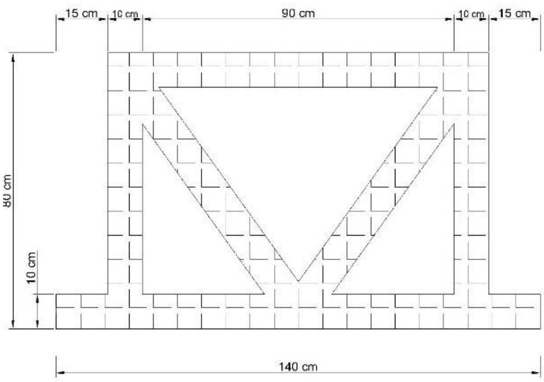
There are three types of frame structures that have been widely used worldwide so far. They are Moment Resisting Frame (MRF), Concentric Braced Frame (CBF) and Eccentric Braced Frame (EBF). CBF is the most rigid structure, resulting in small ductility. Discussing about lateral load, ductility has an important function. For example, the structures located in severe earthquake zones have to be designed in a fully ductile structure to maintain structural integrity against the external loads. Bracing is the most efficient and easiest choice to stiffen the frame. There is an only axial mechanism inside the bracing structure [2].

Some bracing types usually used as a stiffener on the frame structures are diagonal, V, inverted-V, K, X, Y and many more. Diagonal bracing is simple, while X-type results in the heaviest frame structure. CBF sometimes becomes over in structural rigidity, resulting in small ductility. For that reason, using EBF is a wise choice to get the satisfying structural rigidity and the fit ductility to carry the outside loads. EBF also offers flexibility for the frame structures to facilitate some architectural considerations because the bracing positions can be moved at a certain distance, such as placing the doors, windows, etc. Some studies regarding the bracing-frame performance are the experimental study on the diagonal EBF under lateral load by Setyowulan, Susanti and Wijaya [3], link beam on EBF by Musmar [4], a comparative analysis of various bracing systems related to the earthquake-resistant design by Islam, Mehandiratta and Yadav [5], the performance of EBF under seismic load by Prasad and Prasad [6] and also comparison study of bracing configuration on EBF structures by Wilson, Rafael and Lukas [7] and by Razak et al. [8].

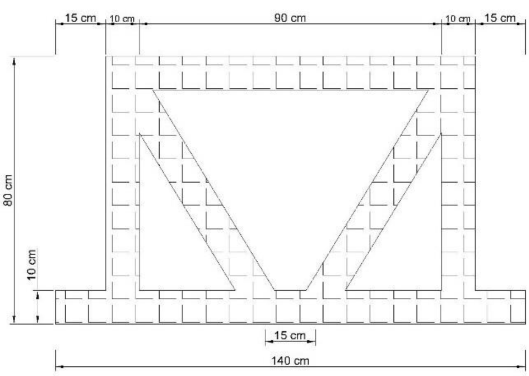
V-type of EBF structure is one of the most widely chosen structural bracing types other than the diagonal type because of its satisfying performance. V- bracing type provides an adequate rigidity compared to diagonal bracing but is not as high as X-type, which can sometimes be over rigid. Satisfying structural weight results in a balanced performance, not over rigid but also providing ductility to the frame structure. Performance of V-type EBF was investigated by Wijaya, Susanti and Syafirra [9] through the study on the shear stirrup space variation under cyclic load and analytical study on the cyclic response of EBF-V structure Bouwkamp, Vetr and Ghamari [10].

2. Material and Methods

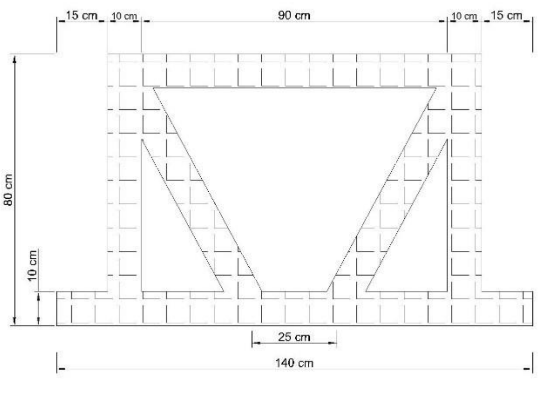
The present experimental study was conducted at the Structure and Construction Material Laboratory of Brawijaya University. Three total models were investigated, consisting of one CBF and two EBF structures using 15 and 25 cm of eccentricity span. Detailed dimensions of the present models are shown in Figure 1. The mix design procedure uses the concrete grade K-175 (f'c = 14,525 MPa). To verify the suitability of the concrete grade, the experimental study used three standard concrete cylinders for each model that were compressively tested using Compression Testing Machine to get the actual concrete compressive strength. The present research also conducted a tensile test using Universal Testing Machine to obtain the actual steel grade for the used steel reinforcement.



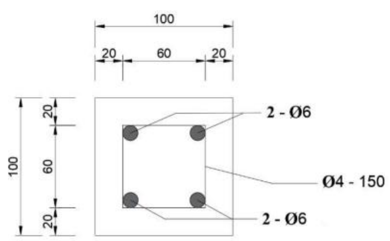
CBF model



EBF – 15 cm model



EBF – 25 cm model



Model's cross-section

Figure 1. Detailed dimensions of CBF and EBF models

The cyclic load was set using two load cells on the loading frame, placed at the lateral direction on the top of each left and right column. The bottom beam was set fixedly to the loading frame, so there was no axial and shear displacement on the bottom of both columns. To eliminate the vertical displacement at the top of column structures and the top beam, the present experiment used a steel plate with the steel bars placed between the plate and the top beam, so only lateral displacement exists. Figure 2 shows the model's setting on the loading frame.

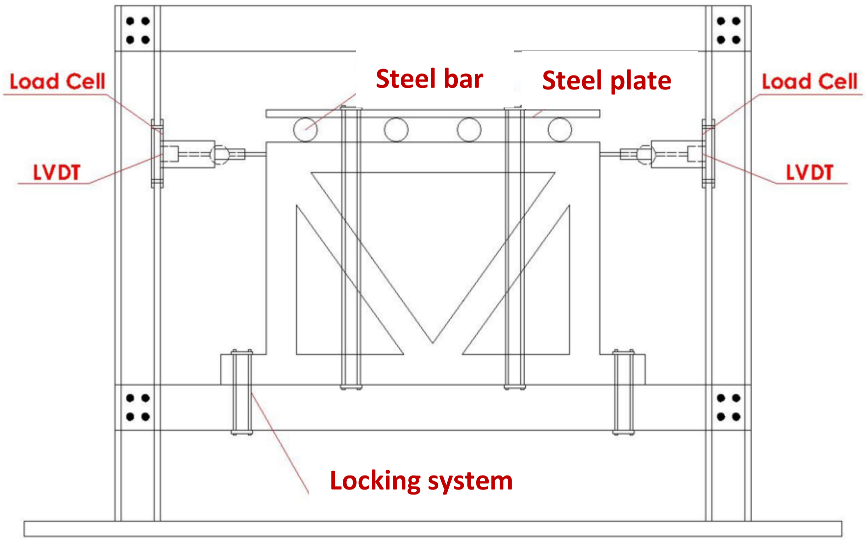


Figure 2. Model's setting on the loading frame

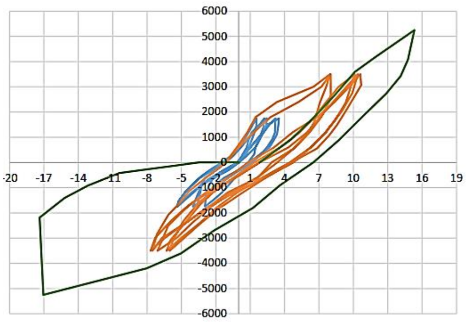
Left and right load cells consecutively gave the lateral loads to illustrate the cyclic load. The load increment was gradually increased from 25, 50, 75 and 100% of the maximum load. The maximum load was determined using the previous experimental result of 7000 kg. Each load increment was applied five times consecutively from the left and right load cells. The recorded output is the load coming from the load cell, the displacement from LVDT and the strain from the steel and concrete strain gage. Two LVDT were used at the same place with the load cell. Strain gages were placed at the critical parts of the frame structures.

3. Result and Discussion

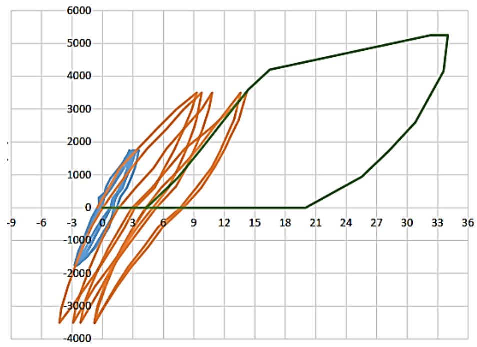
Compression and tensile tests were conducted for concrete and steel bar samples applied for the mainframe models. The tensile test result showed that the steel bar samples for diameters 4 mm and 6 mm had yield stress of 422,301 MPa and 453,886 MPa while the ultimate strength reached 688,615 MPa 613,041 MPa, respectively. According to the slump test result of the concrete samples, the average slump value was 13,67 cm, which means that the concrete mixture has good workability. Finally, the concrete compressive test result found that the average compressive strength of 19,52 MPa goes beyond the designed mixture is 14,525 MPa.

Figure 3 shows the application of cyclic loading on the frame, while Figure 4 shows the load versus displacement history of the present frame models where the blue colour indicates the first phase (25% of the maximum load), orange colour shows the second phase (50% of the maximum load) and green colour indicates the third phase (75% of the maximum load). Each phase consists of five times loading steps consecutively from the right, and in Figure 4, it can be seen that the CBF model reached the maximum cyclic load (phase 3 – step 2/5250 kg) while EBF – 25 cm resulted in a minimum load (phase 2 – step 2/3500 kg). EBF – 15 cm is on between phase 3 – step 1/5250 kg. The highest displacement was recorded at 15 cm. Hence, from the previous explanation, it can be summarized that EBF – 15 cm provides a suitable strength and ductility compared to the CBF model, which is too stiff and EBF – 15 cm, which is too weak.

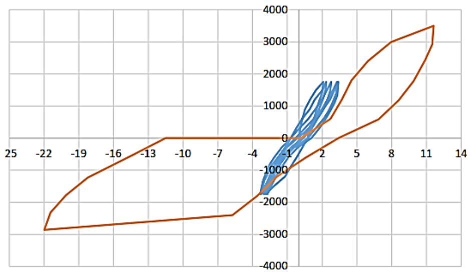
Figure 3. Cyclic loading test on the loading frame



CBF



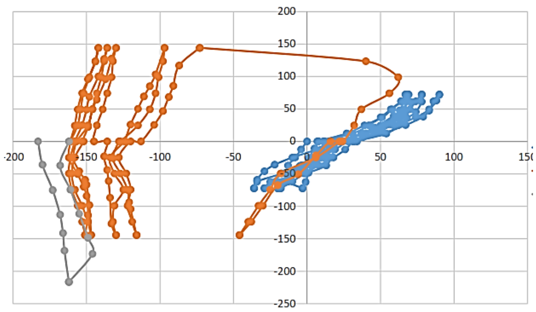
EBF – 15 cm



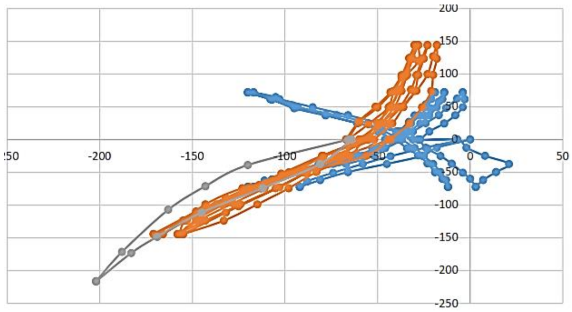
EBF – 25 cm

Figure 4. Load-displacement behaviour

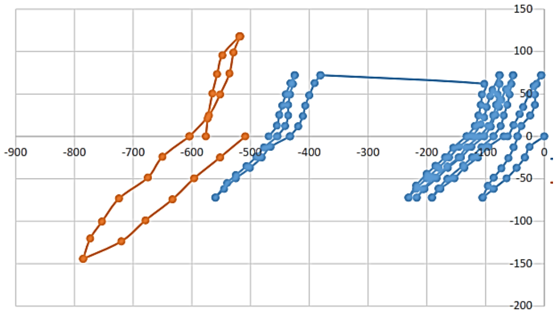
Compression stress and strain history can be seen in Figure 5**.** The compressive strains were recorded from the strain gage placed inside the bottom of each frame model's right concrete column structure. Blue for phase 1, orange for phase 2 and grey colour for phase 3. The strain values shown in the figure have to be multiplied by 10^{-6}. The lowest compressive strain resulted from the CBF model (183 x 10-6) but the highest compressive stress simultaneously (216.337 MPa). EBF – 15 cm showed almost similar performance to CBF (compressive strain as 183 x 10^{-6} and stress as 216.257 MPa), and EBF – 25 cm resulted in a much higher compressive strain (785 x 10^{-6}) but lowest stress as 144 MPa. From all models' compressive stress and strain history, some deviated strains result due to over high sensitivity of the strain gages. But generally, as an eccentricity increases, the compression strain increases but the stress decreases.



CBF



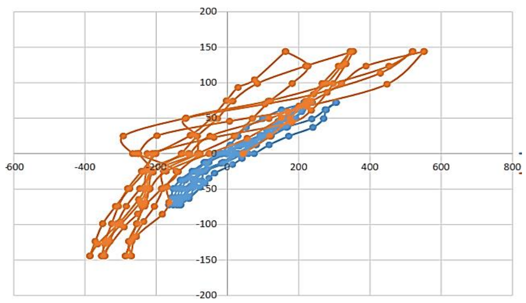
EBF – 15 cm



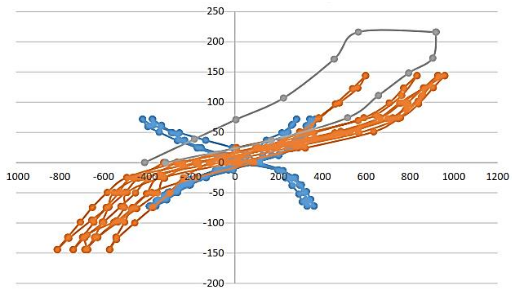
EBF – 25 cm

Figure 5. Compression stress-strain behavior

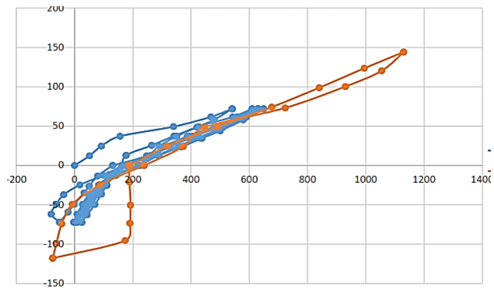
A steel strain gage placed on the steel reinforcement at the bottom of the left column structure from each model was used to record the tensile strain parameter. Figure 6 shows the tensile stress versus strain behavior of each frame. The tensile behavior can be seen compared to the compression strain result. The lowest to biggest maximum strains have resulted from CBF (552 x 10^{-6}), EBF – 15 cm (959 x 10^{-6}) and EBF – 25 cm (1130 x 10^{-6}), respectively. It confirms the previous conclusion that the most rigid frame was CBF (tensile stress as 144.18 MPa), then followed by EBF – 15 cm (tensile stress as 216.283 MPa) and EBF – 25 cm (tensile stress as 144.18 MPa).



CBF



EBF – 15 cm



EBF – 25 cm

Figure 6. Tensile stress-strain behavior

CBF, EBF – 15 cm and EBF – 25 cm models have collapsed due to failures in the different locations of the frames. ECF model could reach a higher cyclic load if the bottom beam does not collapse. The bracing and mainframe structure still has a capacity against the load. EBF – 15 cm collapsed on its link beam and column's bottom parts which means that for EBF structures, the link beam is the most critical part. It was proved by EBF – 25 cm model, where the structure was also extremely damaged on its link beam (Figure 7). Hence, future research should strengthen the bottom columns, beam, and link beam parts.

CBF

EBF – 15 cm

EBF – 25 cm

Figure 7. Frame model's failures

4. Conclusions

The experimental result indicated that the maximum cyclic load decreased as the eccentricity increased. EBF with an eccentricity of 15 cm showed almost similar strength to CBF. On EBF with the eccentricity of 25 cm, the maximum load decreased by 33% compared to CBF. On the other hand, strain increases as eccentricity increases. For EBF-15 cm and EBF-25 cm, the tensile strain improved by 73% and 100%, respectively, compared to CBF. Compressive strain also increases by 10% and 300% for each EBF-15 cm and EBF-25 cm compared to CBF. It proved that as the eccentricity increases, the longer the link beam, the structural stiffness decreases but the ductility increases.

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