ENERGY DISSIPATION OF ECCENTRICALLY-BRACED-FRAME (EBF) WITH DIFFERENT LEVEL OF ECCENTRICITY

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ABSTRACT

This research aimed at eliciting the form of relation that exists between level of eccentricity (e/L) and energy dissipation (E_d) of an Eccentrically Braced Frame (EBF). It continued a previous research that studied relative stiffness of an EBF. Three sets of EBF specimen were analysed by the merit of SAP2000 v9.0.1 computer-software to obtain range of inelastic drifts and its corresponding range of lateral loads. Specimens vary in level of eccentricity (e/L) and bay to height ration (h/L). Prior to it, a formula that calculates energy dissipation of a lateral resistant structure as product of lateral loads and the corresponding drifts was developed and used throughout the research for the purpose of quantifying E_d. Each specimen was alternatively loaded in direction confronting and concurring the bracing component. It was found that there was no significant difference in the form of relation between e/L and E_d, when lateral load applied confronting bracing component from when the same load applied concurring bracing component. Forms of each graph that relates e/L to E_d was presented and shown to consists of two parts, divided at e/L = 0.2; suggesting that e/L = 0.2 might be the point where level of eccentricity and relative stiffness of an EBF reach optimum. Mathematical equations for the relation between e/L and E_d of an EBF were then developed. In spite of this, an inconsistency with the prevalent theory was observed, hence the relations between e/L and E_d concluded so far were contested until further researches be made for clarification.

Key-Words: Ductility-Drifts; EBF; Energy Dissipation; Level of Eccentricity; Relative Stiffness.

Study into lateral-resistant steel structure has, in principle, yielded three types of frame structures: (1) Moment Resisting Frame (MRF); (2) Concentrically Braced Frame (CBF), and (3) Eccentrically Braced Frame (EBF). Each of this has enjoyed considerable wide use these days as structures for buildings, bridges, towers. etc, for the purpose of resisting lateral-seismically induced load.

In the sphere of designing a structure against seismic load, it has been customary to apply two prerequisites: (1) at normal lateral loading such as those which are induced by wind or minor-frequent earthquake, a structure should exhibit sufficient strength and stiffness as not to cause damages in the building, whereas (2) at extreme loading such as those induced by major-infrequent earthquake, a structure should not fail, while being allowed to deform inelastically; minor damages in the building as a results are permitted (Hadikusuma 1985) and (Park and Paulay 1974). The first entails that at normal loading, the structure should be such as to possess

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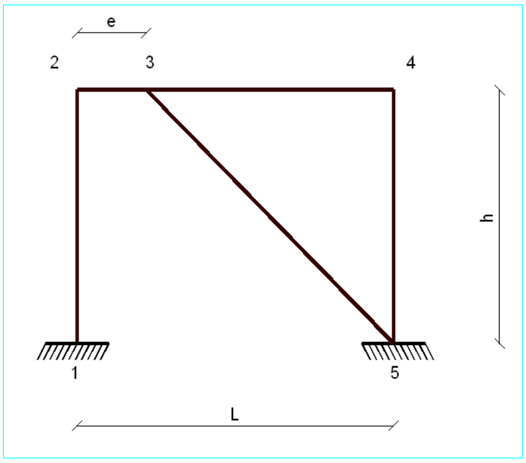

Figure 1. A Typical EBF

considerably sufficient stiffness and behave in elastic manner. Behaving in elastic manner, does not demand much capacity on the part of the structure to dissipate energy into the form of plastic deformation. The second demands that at extreme loading the same structure, while maintaining its stiffness, should be capable to behave in inelastic (ductile) manner to dissipate energy. Since a civil building in its service live undergoes normal as well as extreme loadings, its structure should be such as to comply with two prerequisites delineated above. In connection with it, it can be brought forward, that despite the wide use they have enjoyed and the single purpose for which they were invented, three types of structure mentioned above exhibit a principle difference in the way each of them resists lateral loading. Generally speaking, an MRF resists lateral loading by way of rotational capacity of its joint, a CBF by axial strength of its bracing component, and an EBF by dissipating energy through flexure and/or shear plastic capacity of its link (component 2-3 of the EBF shown in Figure 1). Since load is resisted by rotational capacity of its joints, an MRF proves to be ductile but possesses insufficient stiffness (too flexible), while on the other hand, a CBF, since utilizes axial strength of bracing component(s), proves to posses sufficient stiffness much over that of MRF, but is less in ductility to dissipate seismically induced energy. This dilemma has led to the invention of an intermediate form of lateral resistant structure known as Eccentrically Braced Frame (EBF) (Hadikusuma 1985).

A typical EBF is shown in Figure 1. In can be inferred from the figure that an EBF is a concentrically-braced-frame with one or both ends of the bracing component are positioned at a certain eccentricity (e in the figure) to the beam-column joint. Since bracing component is not absent, an EBF nevertheless possesses sufficient structural stiffness, whereas by having end(s) of bracing component eccentric to the beam-column joint, the frame can attain considerable ductility, either by way of plastic rotation of its joint or plastic deformation of its link. Thus an EBF is a steel frame that has considerable stiffness, and at once is sufficiently ductile to dissipate induced energy during an event of extreme loading. As such, EBF is the most suitable type of lateral resistant structure for high rise buildings in severe earthquake zone. EBF was first proposed by Roeder and Popov (1978), and due to its suitableness as earthquake resistant structure, has since enjoyed much research attention.

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Many researches have been conducted to study the frame, especially to search for ways to enhance its stiffness and capacity to dissipate energy. To name but a view of those in this direction conducted in recent times are: Hines and Jacob (2012), Hasibuan (2010), Thene (2009) and Saritas and Filippou (2004). While Hines and Jacob (2012) and Saritas and Filippou (2004) focused on how to enhance an EBF's ductility performance, Hasibuan (2010) and Thene (2009) had moved more specifically to study the relation between level of eccentricity and relative fame stiffness of an EBF.

In connection with frame stiffness and energy dissipation, level of eccentricity of an EBF is of outmost important and therefore should be called into attention. As can be observed from Figure 1, reason for this lays in the fact that at zero eccentricity, i.e. when ratio of eccentricity to beam length is zero, an EBF resembles a CBF hence frame stiffness will be maximum and capacity to dissipate energy minimum; while at full eccentricity, i.e. when the same ratio reaches unity, an EBF resembles an MRF hence frame stiffness will be minimum and energy dissipation maximum. It is of outmost important therefore to elicit at what level of eccentricity both frame stiffness and energy dissipation of an EBF reach optimum. Thene (2009) who studied the relation between level of eccentricity and relative stiffness of an EBF came to conclusion that in term of relative stiffness, at level of eccentricity in the range of 0 to 0.2 an EBF shows affinity with CBF while at eccentricity beyond 0.2 to unity, the frame shows affinity with MRF. This indicates that eccentricity level of 0.2 could possibly be the critical value, in terms of relative frame stiffness, at which an EBF shifts character from resembling a CBF to that of an MRF.

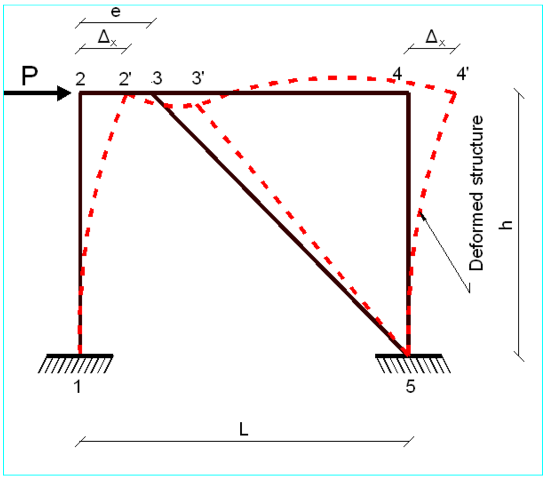

Figure 2. An EBF under Lateral Loading

Now question can be raised as to how the capacity of energy dissipation of an EBF varies, as level of its eccentricity moves from zero to unity. This paper seeks to answer that question. It reports a research conducted recently[1] on energy dissipation of EBFs. Objective of the research was to elicit relation between level of eccentricity of an EBF and its energy dissipating capacity,

[1] The research was conducted in 2010-2011, at the auspices of Civil Engineering Dept, Faculty of Science and Engineering, Nusa Cendana University – Kupang, in response to, and as continuation of that conducted previously by Thene (2009) at the same auspices.

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aiming at finding critical value of eccentricity at which frame stiffness and energy dissipating capacity of an EBF reach optimum. Knowledge that would be furnished by these studies will be of much help to a structure designer when selecting appropriate geometry for an EBF.

ANALYTIC EQUATIONS

Energy Dissipation

Since ductility of the frame is the interest of the research, energy dissipation was therein defined as the energy dissipated by the frame since the appearance of first plastic hinge until the occurrence of a plastic collapse mechanism in the frame. An EBF under the action of lateral load P is shown in Figure 2. As load P increases from zero to an ultimate value, the frame, either elastically or plastically, dissipates external energy induced into it by deforming to the right, resulting in drifts Δ_x. Drift will increase as P increases until a plastic mechanism occurs in the frame as P reaches the ultimate value. From the foregoing it can be construed that during the loading of P from incipient to the ultimate stage, there exist a corresponding value of Δ_x for every value of P. Moreover, since energy is dissipated by the deformation of material of the frame during loading, drifts of the frame (Δ_x) controls the value of P. Value of P therefore is a function of drifts (Δ_x). These can be depicted by the Lateral Load-Drifts Diagram shown in Figure 3a.

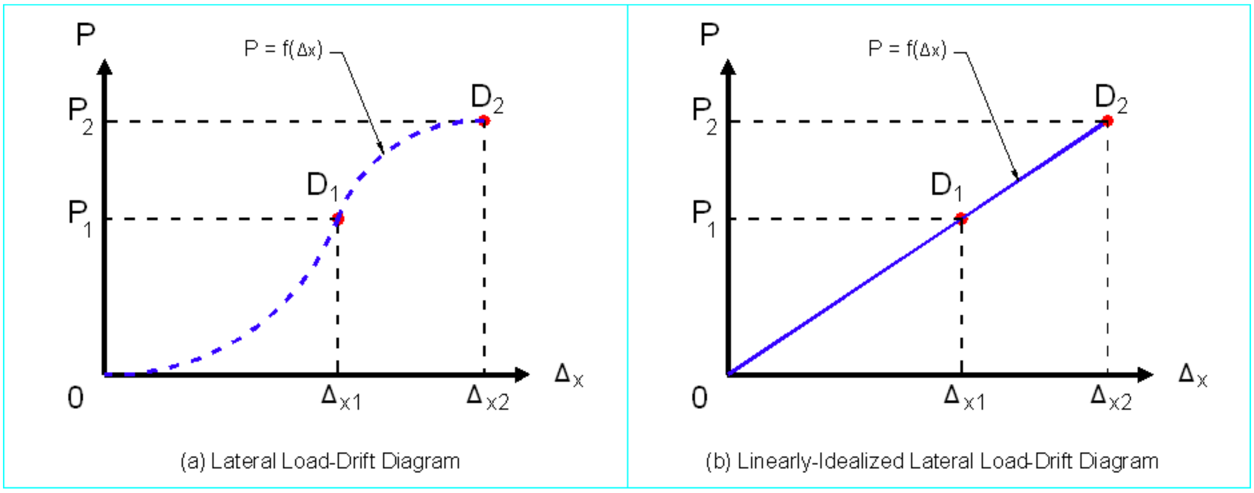

Figure 3.Lateral Load-Drifts Diagram of an EBF

The diagram depicts a function that maps drifts to values of load P. Shown also in the diagram are point D1 and D2 that respectively denotes the stage of the appearance of first plastic hinge, and of plastic mechanism in the frame. It can be deduced from the diagram that energy dissipated by the frame during first plastic hinge until plastic mechanism is:

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$$E_d = \int_{\Delta_{x1}}^{\Delta_{x2}} f(\Delta_x)d(\Delta_x) \quad (1)$$

where E_d is energy dissipated by the frame and $f(\Delta_x)$ is the drifts function that maps drifts to load P. Depending on geometry of the frame and mechanical characters of material that makes it, drifts function can take any forms. Eliciting exact form of drifts function of an EBF is beyond the scope of the research and therefore was not done. Since at most cases, load-drifts diagram tends to flatten after first yielding (plastic hinge) occurs in the frame, the function, especially between first plastic hinge and plastic mechanism, can be safely assumed as linear without sacrificing much accuracy, and had been so assumed as that shown in Figure 3b throughout the research. In such a case, the energy dissipated by the frame during first plastic hinge until a plastic mechanism can be expressed as:

$$E_d = \frac{1}{2}(P_1 + P_2)(\Delta_{x2} - \Delta_{x1}) \quad (2)$$

Equation (2) was used throughout the research for the purpose of quantifying energy dissipation of an EBF.

Level of Eccentricity and Bay to Height Ratio

Level of eccentricity of an EBF had been defined as the ratio of link length (e) to the beam length (L), hence was expressed as dimensionless e/L. Another geometric feature of an EBF that may affect energy dissipation is bay to height ratio. Bay to height ratio was expressed as dimensionless h/L, of which h is the height and L is the bay length of the frame.

DESIGN AND RESULTS OF THE EXPERIMENT

Three sets of EBF specimens were analyzed in the research. Specimens in the first set has h/L = 0.5, in the second 0.75 and in the third 1.00. Each set consists of 6 specimens which vary in level of eccentricity from zero to unity with an increment of 0.2. First and second columns of tables in Appendix 4 explain the design of the specimens while figures in Appendix 1 portray them. Unto beam component including the link was assigned steel profile of WF 300x200x9x14, unto column WF 400x200.8.13 and unto bracing component][260x90x9x14, each is of f_y = 300 MPa steel.

Each specimen was modeled into SAP2000 v9.0.1 computer-software, and was analyzed for response to lateral loading using the same software. A constant vertically downward concentrated-load that represented live load was applied on each of the beam-column joint, while an increasing concentrated horizontal load P was applied at the left beam-column joint. Each specimen underwent two events of loading. First, the load P was rightward in direction

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confronting the bracing component; while secondly, it was leftward in direction concurring the same component. At each event and for each specimen, value of load P and its corresponding drifts were recorded at two occasions: (1) when first plastic hinge occurs in the frame and (2) when plastic mechanism occurs in the same. Appendix 4 registers results of the experiment.

DISUCSSION

Formulation of the Relation between Level of Eccentricity and Energy Dissipation of an EBF

For the purpose of studying the relation between energy dissipation and level of eccentricity, amount of energy dissipated by each specimen was calculated by way of Eq. (2) based on the result of the experiment, and was plotted against level of eccentricity. Figure 4 and Figure 5 show the graphs that portray the result, each respectively for load P confronting, and concurring bracing component.

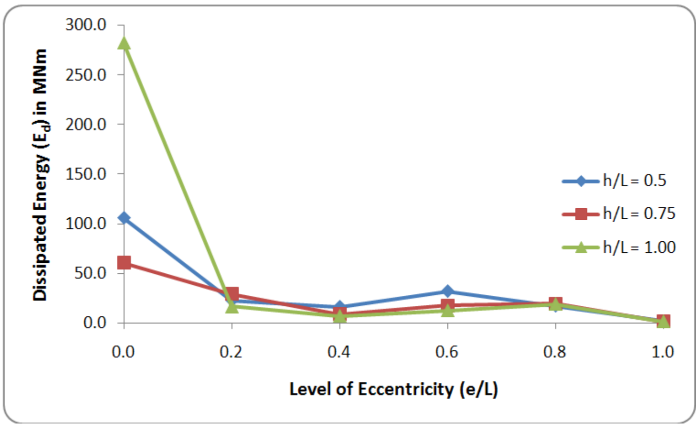

Figure 4. Energy Dissipation vs. Level of Eccentricity when Load P Confronting the Bracing Component

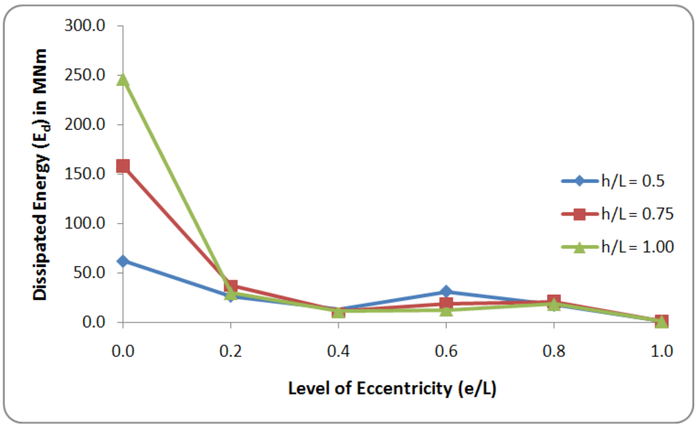

Figure 5. Energy Dissipation vs. Level of Eccentricity when Load P Concurring the Bracing Component

Both figures show graphs of remarkably similar traits. There is no difference when load was applied confronting the bracing component from when it was applied concurring the same component. Energy dissipation reached maximum at zero level of eccentricity, and dropped significantly as the level of eccentricity increased from 0 to 0.2. Beyond 0.2 there is no significant change in energy dissipation. There was however, an increase, at level of eccentricity in the range of 0.4 to 0.6, but of small significance. Beyond that it kept decreasing toward zero as level of eccentricity approached unity.

Engaging inferential statistic tools of Microsoft Excel 2007 and applied it on coordinates of the graphs produced mathematical equation for each of them. Polynomials of order 5 had been selected as the type of trend line by which equation for each of the graph was assessed. Coefficient of correlation (R^2) for each of the equation is unity. Registered in the following are those mathematical equations, for loading

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confronting the bracing component, and for loading concurring the same component of the EBF specimens.

Lateral loading confronting the bracing component:

1. For h/L = 0.5

$$E_d = 2x10^9(e/L)^5 - 4x10^9(e/L)^4 + 2x10^9(e/L)^3 + 8x10^8(e/L)^2 + 6x10^8(e/L) + 1x10^8;$$

2. For h/L = 0.75

$$E_d = -2x10^9(e/L)^5 + 6x10^9(e/L)^4 - 8x10^9(e/L)^3 + 6x10^9(e/L)^2 - 2x10^9(e/L) + 2x10^8;$$

3. For h/L = 1.00

$$E_d = -6x10^9(e/L)^5 + 2x10^{10}(e/L)^4 - 2x10^{10}(e/L)^3 + 1x10^{10}(e/L)^2 - 3x10^9(e/L) + 3x10^8$$

Lateral loading concurring the bracing component:

1. For h/L = 0.5

$$E_d = 4x10^9(e/L)^5 - 1x10^{10}(e/L)^4 + 8x10^9(e/L)^3 - 2x10^9(e/L)^2 + 3x10^7(e/L) + 6x10^7;$$

2. For h/L = 0.75

$$E_d = -2x10^8(e/L)^5 + 1x10^9(e/L)^4 - 2x10^9(e/L)^3 + 2x10^9(e/L)^2 + 1x10^9(e/L) + 2x10^8;$$

3. For h/L = 1.00

$$E_d = 2x10^9(e/L)^4 - 5x10^9(e/L)^3 + 5x10^9(e/L)^2 - 2x10^9(e/L) + 2x10^8.$$

In each of the equation, E_d is quantity of energy dissipation [in kNmm] and dimensionless e/L is level of eccentricity of an EBF.

Value of Eccentricity for the Optimum Energy Dissipation and Relative Stiffness of an EBF

From Figure 4 and Figure 5, and that which was discussed in the preceding, it is evident that each graph can be perceived as consists of two parts: (1) for $0 \le e/L < 0.2$ and (2) for $0.2 \le e/L \le 1.0$, divided at e/L = 0.2. Comparing this with that of Thene (2009) suggests that first part might be the range of level of eccentricity where energy dissipation and relative frame stiffness of an EBF is maximum; and that level of eccentricity 0.2 could possibly be the point where energy dissipation and relative stiffness of an EBF reaches optimum. However, for reason that will be expressed in the following, these notions should be postponed until further studies are conducted.

Inconsistency with Prevalent Theory

An unexpected feature that demands explanation is obviously shown by the results of the experiment (as portrayed by the graphs). The graphs showed that capacity of an EBF to dissipate energy decreases as level of eccentricity increases; that is, an EBF that resembles a CBF possesses much more capacity to dissipate energy than the one which resembles an MRF. This goes contrary to the prevalent theory, which states that a CBF due to the presence of the bracing component will be highly stiff, possessing narrow range of ductile deformation to fuse energy, hence of least capacity to dissipate energy; while an MRF due to the lack of the bracing component is considerably flexible, possessing wide range of ductile deformation, hence of greater capacity to dissipate energy. Results of this research showed the reverse, were inconsistent with the prevalent theory, and hence call for explanation.

The inconsistency, as was brought forward in the preceding, can be explained on the basis of: (1) location where the first plastic hinge forms in the frame, and (2) inadequacy of Eq. (2)[1] to explain the relation between energy dissipation and level of eccentricity. To understand the inconsistency, it should be emphasized that the theory, as stated in the preceding, works only at the condition when first plastic hinge due to lateral loading forms in the link-beam of an EBF. Since a properly designed link-beam is capable of wide range of ductile deformation, an EBF with first plastic hinge forming in the link can undergo longer ductile drifts before a plastic mechanism occurs, hence dissipate energy in a much more quantity. Presence and functionality of a link in a lateral resistant frame therefore adds to its capacity to dissipate energy while the absence or non-function of the same will reduce it. Since such a link is absent, a full CBF will show least energy dissipation capacity, and conversely an EBF, with the presence of functional link, will show much more energy dissipation capacity. However, if first plastic hinge does not form in the link but in other stronger components, much greater load P is required to form both plastic hinges and the subsequent plastic mechanism in the frame, hence calculation by way of Eq. (2) will nevertheless result in higher energy dissipation, irrespective of the presence or absence, and hence functional or nonfunctional of the link. Observation upon plasticity status of each specimen used in this study (figures in Appendix 2 and 3) shows that a great number of them had the first plastic hinge forming not in the link but in other stronger components. This explains why each graph above does not vary in accordance with the degree of presence and/or functionality of the link-beam, that is the energy dissipation as specimens transform from being a full CBF to an EBF and then to a full MRF, but is inconsistent with it. Moreover, when first plastic hinge forms not in the link but in other stronger components, drifts of the frame, and consequently values of load P, are controlled more by the presence or functionality of bracing component rather than by the presence or functionality of link-beam. If a bracing is functionally presence, greater load P is required to drift the frame until plastic mechanism, hence calculation

[1] as far as specimens used in the research are concerned,

by way of Eq. (2) gives greater energy dissipation irrespective of the link-beam; while non-functional or absence of the bracing component will result in lesser load P to drift the frame until plastic mechanism, hence calculation by way of Eq. (2) gives lesser energy dissipation, all these again are irrespective of the functionality of link-beam. Therefore load P and hence impression of energy dissipation as furnished by Eq. (2), will not vary in accordance with ductility of the frame but with the degree of presence or functionality of the bracing component. This is accurately depicted by the graphs shown above. As specimens transform from a full CBF (with a full functional and presence of bracing component) to a full MRF (full non-functional and absence of bracing component) energy dissipation, as calculated by the merit of Eq. (2), decreases. From the foregoing, it can be concluded that since at most of the specimens, first plastic hinge did not form in the link but in other stronger component, calculation by Eq. (2) did not describe the energy dissipation as it may relate to the level of eccentricity of an EBF, but energy dissipation as it may relate to the presence and/or functionality of bracing component. Adding it to the fact that presence of bracing component adds to stiffness of the frame, the equation, while intended to describe relation between energy dissipation and level of eccentricity, had ended up describing, though not in a very precise way, the relation between frame stiffness and level of eccentricity of an EBF. This explains why the graphs produced by the research under consideration exhibits similar trend as those produced by Thene (2009) (Figure 6), and not the reverse or otherwise as was supposed to. Results so far presented by the experiment therefore should justifiably be contested.

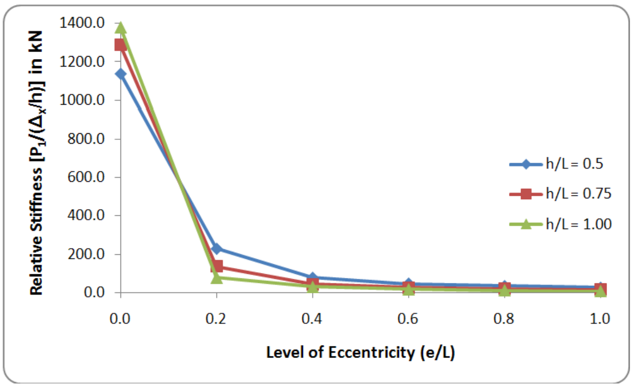

Figure 6. Relation between Level of Eccentricity and Relative Stiffness of EBFs (Thene 2009)

Now, two ways can be offered as solution to this problem. First, specimens are redesigned in such as way as to ensure that first plastic hinge will form in the link. If that can be attained, Eq. (2) will faithfully describe quantity of energy dissipation of a lateral resistant frame, and can be applied on so designed specimens for the purpose of eliciting relation that exists between energy dissipation of an EBF and its level of eccentricity. Second, by proposing an equation in place of Eq. (2) that calculates energy dissipation strictly in terms of ductility, that is by only considering range of drifts of the frame in inelastic domain. If such an equation can be presented, EBF specimens of the research presently considered can nevertheless be used to study the relation between energy dissipation and level of eccentricity of an EBF. This paper recommends that further researches

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be made, employing one of the solutions offered, for the purpose of assessing actual relation between energy dissipation and level of eccentricity of an EBF, before conclusion on the matter of optimum value of eccentricity can be accurately drawn.

CONCLUSION

1. For the purpose to increase knowledge about lateral resistant frame structures, and as continuation of research into relative stiffness of an EBF, this paper studied the relation between level of eccentricity of an EBF and its capacity to dissipate energy.
2. Amount of energy dissipation of an EBF can be calculated as product of lateral loads and the corresponding lateral drifts of a frame, that occurs since the appearance of first plastic hinge until the occurrence of a plastic collapse mechanism in the frame (Equation (1) and (2)).
3. Capacity to dissipate energy of an EBF, calculated by the way expressed in conclusion 2 was found to vary with its level of eccentricity in polynomial way in the order of 5, reaching maximum when level of eccentricity is zero and minimum when level of eccentricity is unity.
4. There was no significant difference in the relation between level of eccentricity and energy dissipation of an EBF, when the lateral load applies confronting the bracing component from when the lateral load applies concurring the bracing component.
5. Form of graphs that relates level of eccentricity (e/L) to the energy dissipation (E_d) of an EBF was shown to consist of two parts: (1) for $0 \leq e/L < 0.2$ and (2) for $0.2 \leq e/L \leq 1.0$, divided at e/L = 0.2.
6. This suggests that level of eccentricity 0.2 might be the point where energy dissipation and relative stiffness of an EBF reaches optimum.
7. However, since most of the EBF specimens in the research did not have their first plastic hinge form in link-beam but in other stronger components, conclusion 3 to 6 above are contested.
8. In response to it, this paper recommends that a further research be made, either by employing EBF specimens which are designed in such a way as to ensure that first plastic hinge will form in the link-beam, or by using other equation in place of Equation (2), that calculates energy dissipation of an EBF strictly in terms of frame ductility.
9. Only after such a research has been made, can the relation between level of eccentricity and energy dissipation; and value of level of eccentricity for the optimum frame stiffness and energy dissipation of an EBF, be drawn.

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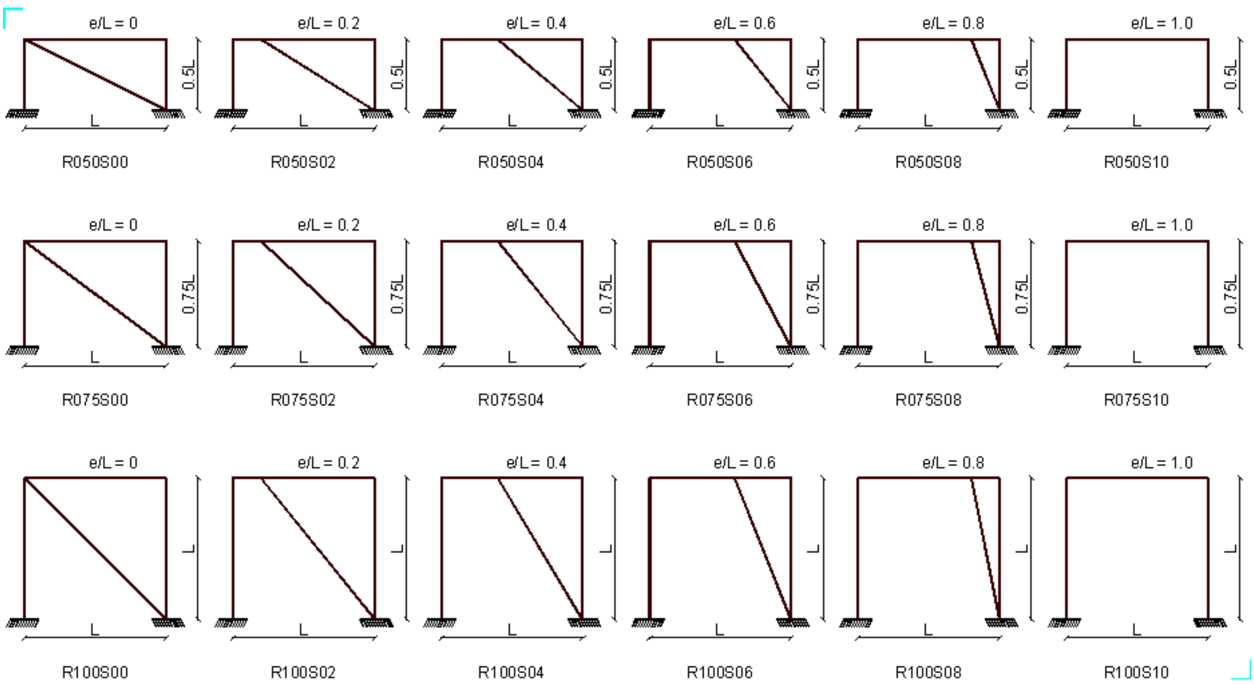
APPENDIX 1. Specimens of the Research



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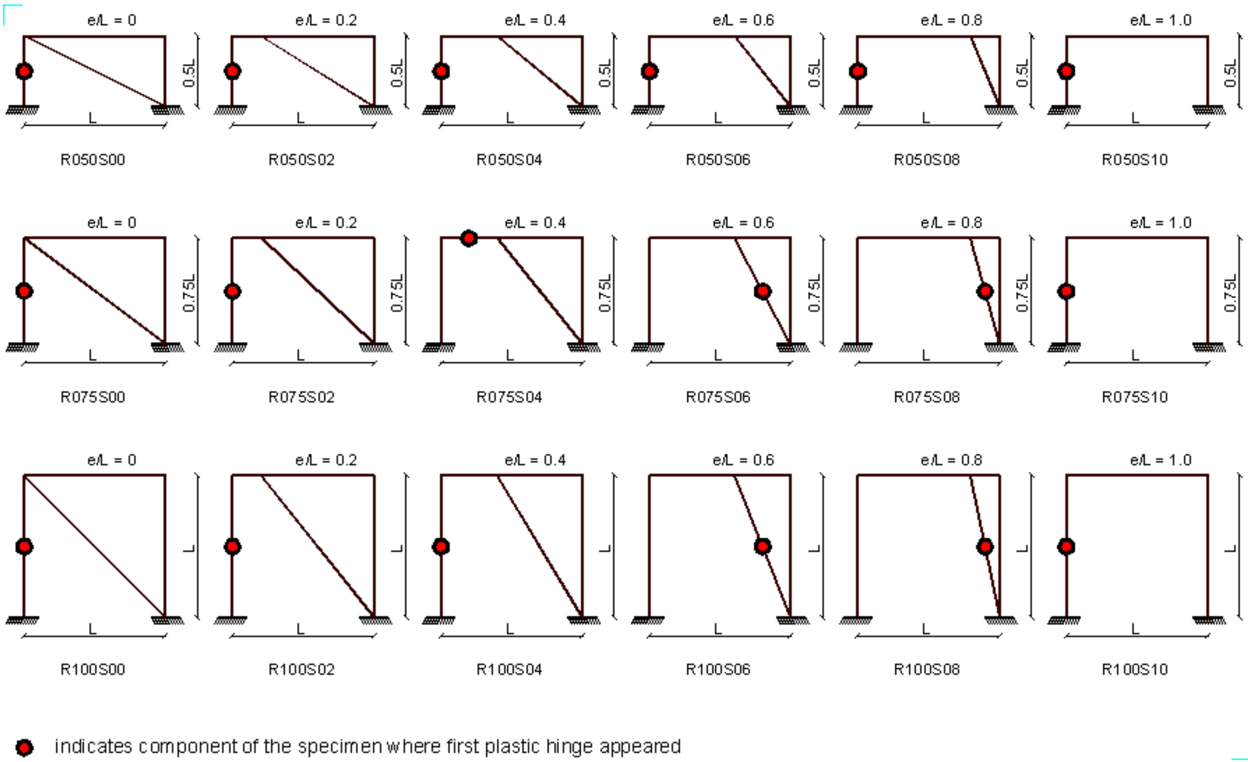
APPENDIX 2. Location of First Plastic Hinge in the Specimens when Load P Confronted Bracing Component



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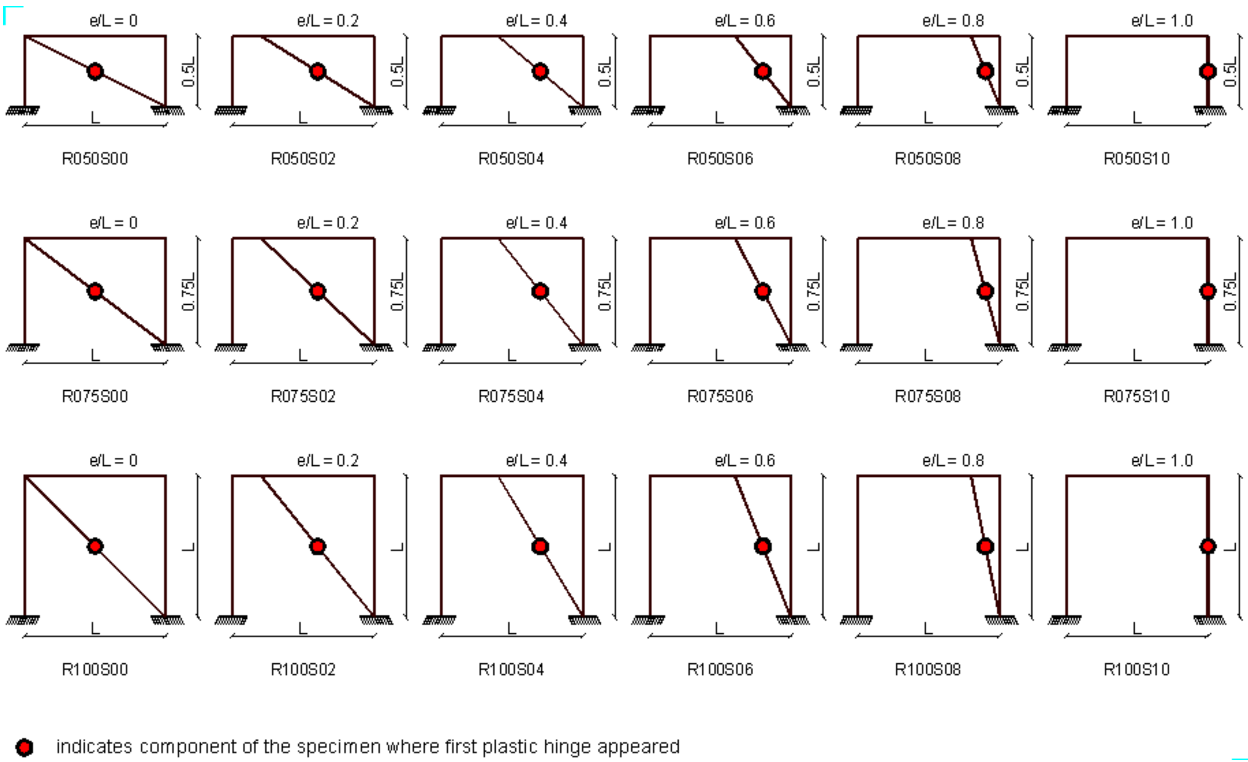

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APPENDIX 4. Results of the Experiment

h/L = 0.5		Lateral load confronting the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R050S00	0.0	1007000	4.92	6680000	32.42	105.7	27.50
R050S02	0.2	381500	4.84	1960000	24.12	22.6	19.28
R050S04	0.4	190000	10.73	921000	39.47	16.0	28.74
R050S06	0.6	202500	13.76	1001000	66.96	32.0	53.20
R050S08	0.8	174000	15.44	648000	57.09	17.1	41.65
R050S10	1.0	124500	16.57	203400	27.09	1.7	10.52

h/L = 0.75		Lateral load confronting the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R075S00	0.0	479000	3.97	1738000	58.55	60.5	54.58
R075S02	0.2	219000	8.15	1302000	46.62	29.3	38.47
R075S04	0.4	168300	17.75	450000	46.47	8.9	28.72
R075S06	0.6	129500	23.93	459000	83.33	17.5	59.40
R075S08	0.8	108800	27.32	410000	101.91	19.3	74.59
R075S10	1.0	86600	32.79	121400	45.97	1.4	13.18

h/L = 1.00		Lateral load confronting the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R100S00	0.0	196800	2.94	6350000	89.18	282.3	86.24
R100S02	0.2	121500	9.18	701000	49.79	16.7	40.61
R100S04	0.4	99600	21.68	280000	59.07	7.1	37.39
R100S06	0.6	32400	13.17	261000	98.53	12.5	85.36
R100S08	0.8	65800	35.17	277000	145.75	19.0	110.58
R100S10	1.0	61800	49.85	85500	68.76	1.4	18.91

h/L = 0.5		Lateral load concuring the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R050S00	0.0	30700	0.11	5058000	24.48	62.0	24.37
R050S02	0.2	52800	0.45	2075000	25.14	26.3	24.69
R050S04	0.4	84100	3.02	822000	32.03	13.1	29.01
R050S06	0.6	125700	8.11	972000	64.50	30.9	56.39
R050S08	0.8	182000	15.83	656000	57.48	17.5	41.65
R050S10	1.0	126600	16.86	166000	22.10	0.8	5.24

h/L = 0.75		Lateral load concuring the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R075S00	0.0	19900	0.06	6250000	50.38	157.8	50.32
R075S02	0.2	32400	0.77	1452000	51.18	37.4	50.41
R075S04	0.4	44000	3.89	482000	48.55	11.7	44.66
R075S06	0.6	56200	9.54	454000	81.25	18.3	71.71
R075S08	0.8	72500	17.39	418000	103.15	21.0	85.76
R075S10	1.0	87000	32.95	111200	42.11	0.9	9.16

h/L = 1.00		Lateral load concuring the bracing component					
Specimen	**e/L**	**First Plastic Hinge**		**Plastic Mechanism**		**Dissipated Energy (MNm)**	**Δ_{x2}-Δ_{x1} (mm)**
		P_1 (kN)	Δ_{x1} (mm)	P_2 (kN)	Δ_{x2} (mm)		
R100S00	0.0	11980	-0.01	5925000	82.86	246.0	82.87
R100S02	0.2	17500	0.56	920000	63.82	29.7	63.26
R100S04	0.4	23300	3.78	330000	67.34	11.2	63.56
R100S06	0.6	20580	6.61	260800	96.34	12.6	89.73
R100S08	0.8	30650	15.33	268500	139.87	18.6	124.54
R100S10	1.0	61980	50.00	80500	64.83	1.1	14.83

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