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EFFECT OF LINK ON ECCENTRICALLY BRACED FRAMES

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The study deals with the eccentrically braced steel frames (EBF). EBF configuration is similar to traditional braced frames with the exception that at least one end of each brace must be eccentrically connected to the frame. The energy dissipation is achieved through the yielding of a beam segment called the link, while the other frame members, including outer beam segments, braces, and columns, should remain essentially elastic. The study incorporates applying lateral loading to several types of eccentrically loaded frames, in addition to a concentrically braced frame and a moment frames to compare the structural response. The paper includes analyzing the effect of link length on the ductility of the frame and the amount of drift.

KEYWORDS*: steel frames, eccentrically braced frames*

1. INTRODUCTION

Steel structures are widespread; they exhibit ductile behavior when subjected to transient lateral loading, caused by wind or earthquake action. There are three main types of frames. Moment frames, truss moment frames, and braced frames. There are two types of braced frames; concentrically braced frames (CBF), and eccentrically braced frames (EBF).

In EBF frames, a distance is either created between the two ends of the bracing members, or between the bracing member and the column, or between the bracing member and the beam as shown in figure 1. The created distance is called link (e). The main function of the link is to provide a weak section in the frame which provides plastic deformation capacity and dissipate the energy released by the earthquake.

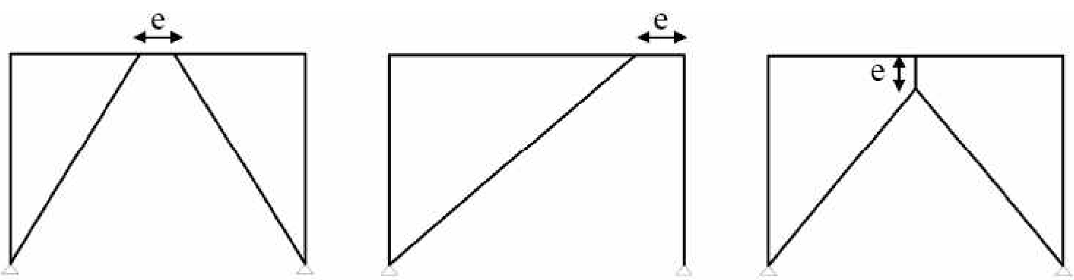


Figure 1: Link in eccentrically braced frame

This paper deals with eccentrically braced frames. EBFs exhibit lateral stiffness similar to that of Concentrically Braced Frames, and ductility similar to that of the Moment Frame [1].

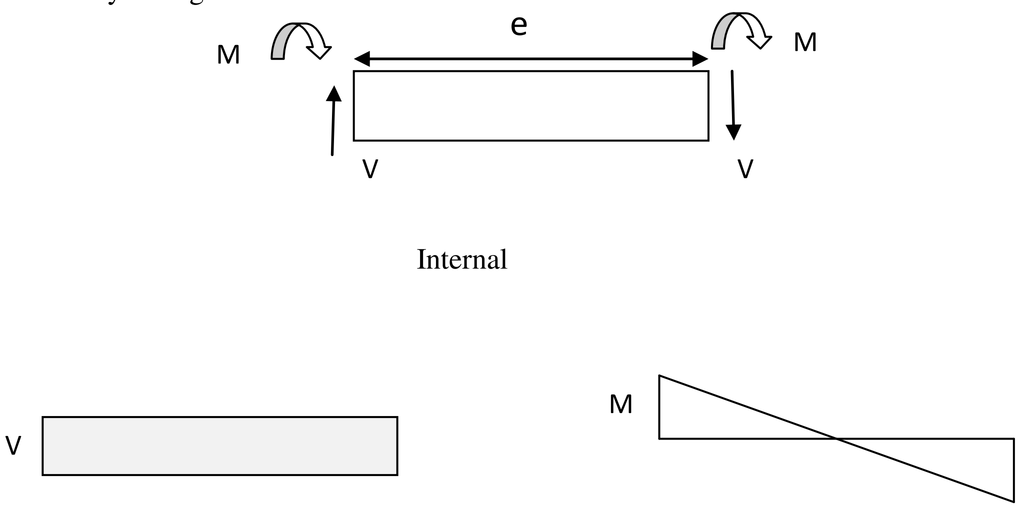
EBFs are desirable seismic load resisting systems as they combine the high elastic stiffness of concentrically braced frames with the ductility and stable energy dissipation of moment resisting frames [2].

EBFs are characterized by a favorable combination of high ductility, stiffness, and strength. The energy dissipation is achieved through the yielding of a beam segment called the link, while the other frame members, including outer beam segments, braces, and columns, should remain essentially elastic [3].

Eccentrically braced frames are a seismic load resisting system in which inelastic action is restricted primarily to ductile links [4].

If the link is long enough the energy dissipation is attained from flexural yielding, otherwise the link experiences shear yielding.

According to Bruneau [5], shear yielding allows for the development of large plastic deformations without the development of excessive local strains that occurs in flexural yielding.



Shear Force diagram

Bending Moment

Figure 2: Internal forces along the link

According to Kasai [6], shear yielding provides a larger energy dissipation capacity than flexural yielding.

Thus there are three important parameters in the design of an EBF frame:

- The bracing configuration.
- The link length.
- The link section properties.

When an EBF frame is subjected to lateral forces at the beam level, internal shear forces and bending moments are created within the beam (Fig.2).

The equilibrium of internal forces yield: $e = \frac{2M}{V}$. Shear force is constant along the beam length. Large bending moments occur at the end, of opposite sign, with reverse curvature bending.

Also figures (2,4) show that links generally exhibit very high shear, which is constant along the link length, and very large bending moments at the link ends. The other members of the frame show high axial forces, smaller shear and smaller moment relative to internal link forces.

As shown in figure 2, in the case of existence of lateral force on the frame at the beam level, the internal shear is constant along the link. Thus in the case of the short links or the shear yielding links the inelastic deformations take place due to the yielding that occurs along the entire length of the link. Furthermore, web yielding takes place along the entire web depth since shear stress is relatively uniform over the web depth in the inelastic range.

For long links or the flexural links, yielding only takes place at the link ends where plastic hinges form.

Thus EBF systems with shear yielding links are stable and exhibit more ductility than in the case of EBF systems with flexural yielding links.

According to AISC code, links are categorized as:

- Short links, shear links, $e < \frac{1.6\,M_p}{V_p}$
- Long links, flexural links, $e > \frac{1.6\,M_p}{V_p}$
- Intermediate links, $\frac{1.6\,M_p}{V_p} < e < \frac{2.6\,M_p}{V_p}$

Where:

M_p = nominal plastic moment capacity, N.mm.

V_p = nominal plastic shear capacity, N.

e = Link length, mm

The plastic shear capacity is expressed as: $V_p = 0.6F_y(d - 2t_f)t_w$

Where

F_y: is the specified minimum yield strength.

d : the overall beam depth

t_w : the web thickness

At $e > \frac{2M_p}{V_p}$ flexural yielding occur at the link ends where fully plastic moment $M_p$occurs. The section plastic moment capacity $M_p = ZF_y$

Where:

Z : is the plastic section modulus.

2. RESEARCH SIGNIFICANCE

- Studying the effect of the link length on the behavior of several types of EBF systems by selecting links of different lengths (shear and moment links) for the V type bracing, D type bracing, K type bracing, K bracing with vertical shear link.
- Studying the effect of link location on the behavior of several types of EBF systems.
- Studying the effect of reduced link section on the behavior of the EBF systems.

3. MODEL ANALYSIS

Computer package program SAP2000 is used to analyze the frames.

Plane model frames for four types of eccentrically braced frames, a concentrically braced frame, and a moment frame (Fig.3) are generated. Each is composed of two stories, and of 12m total height. The model span is 10m. Sections are listed in Table 1.

Table 1: Section Property of the Structural Members

Member Type	Section Property
Column	W16x36
Beam	W16x36
Links	W16x36 W10x19
Bracing	Tube 8x8x0.5

In all cases, frames are subjected to a unit concentrated load of 1 KN as shown in figure (2).

As illustrated in figure (4), for K-braced frames, and also all adopted eccentrically braced frames, links generally experience very high internal shear of constant value along the link length. Links also show very large bending moment of opposite sign at link ends, with the reverse curvature bending.

The axial forces in the links are generally very small, the other parts of the frame exhibit higher axial forces, smaller shear forces and smaller bending moments (Fig.4).

Considering the link in Fig (2), equilibrium of internal forces yields $e = \frac{2M}{V}$. At $e = \frac{2M_p}{V_p}$, both flexural and shear hinges form simultaneously, at $e \leq \frac{2M_p}{V_p}$ the link shear will reach V_p before the end moments would reach M_p, and the link will yield in shear, otherwise when $e > \frac{2M_p}{V_p}$ the link will yield in flexure.

The shear force V is constant along the link length. The plastic shear capacity is expressed as

$$V_p = 0.6F_y(d - 2t_f)t_w$$

Where

F_y: is the specified minimum yield strength.

d : the overall beam depth

At $e > \frac{2M_p}{V_p}$ flexural yielding occur at the link ends where fully plastic moment $M_p$occurs.

The section plastic moment capacity $M_p = ZF_y$

where Z is the plastic section modulus.

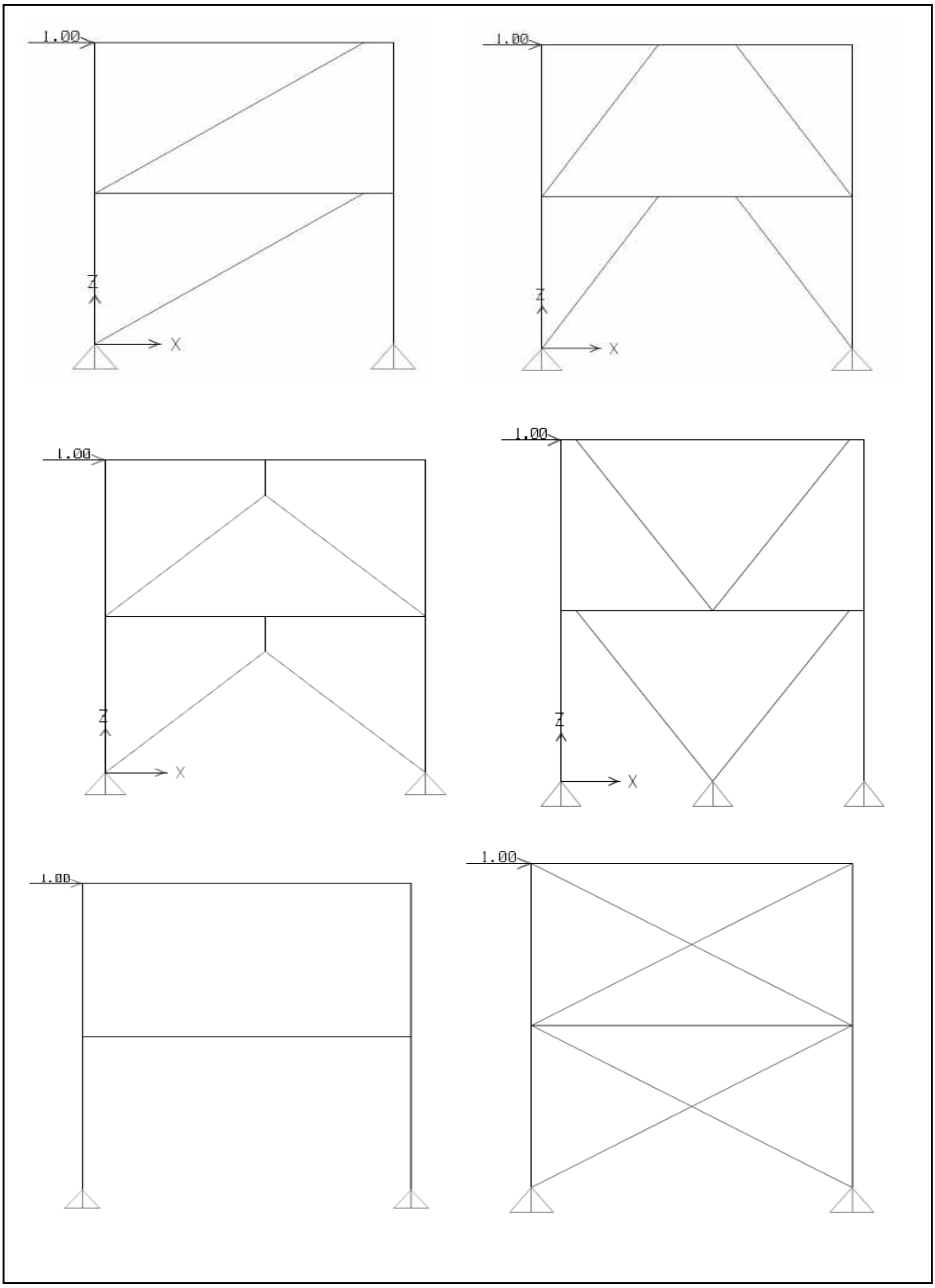
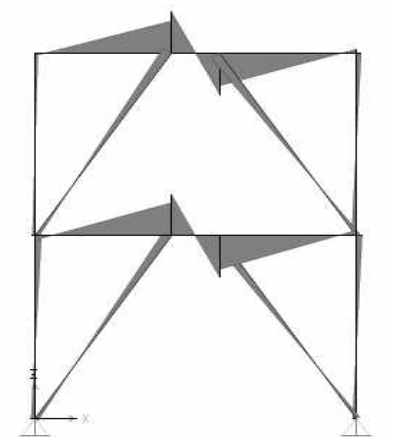
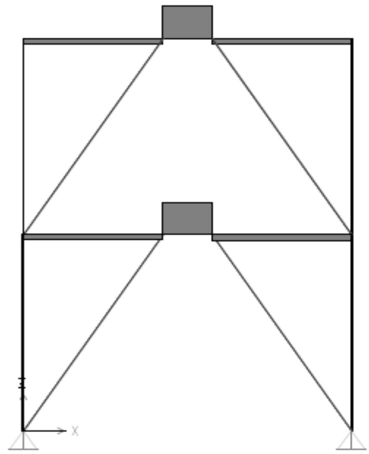


Figure 3: D Bracing, K Bracing, K-Bracing with vertical shear links, V Braced, Non braced, Concentrically braced frames.



Bending Moment Diagram EBF



Shear Force Diagram

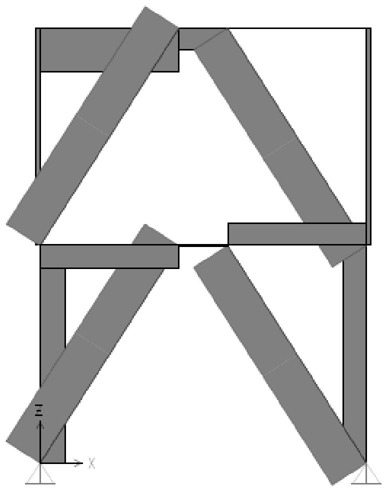


Figure 4: Internal forces in K Braced frame

1. Analysis of Results and Discussion:

The stiffness k, of a structure is its resistance to elastic deformation. The variations of the lateral stiffness of EBF with respect to the link length for different types of bracing are shown in Figure (5). The figure shows that the shorter "shear" links exhibit more stiffness than the longer "flexural" links. Furthermore using short links is more beneficial in terms of enhancing the frame stiffness and drift control. At about (e/L) > 0.38, the frame stiffness starts to decrease in a larger scale.

Also figure (5) demonstrate the variations of the lateral stiffness of EBFs with respect to reduced link sections. The solid line curve represents the case where the link section is W16x36, the dotted line represents the case when the reduced link section W10x19. It can be noticed that the reduced link sections decrease the structural stiffness of the frame, allowing the larger beam section, outside the link to easily satisfy the capacity design requirement, that it remains elastic, as the link yields, while maintaining acceptable inter story drift angle. Thus EBF frames present an efficient laterally stiff framing system with significant energy dissipation capability to accommodate large seismic forces, through shear links, while the remained frame maintains elastic response.

Longer links should be avoided in EBF systems; despite that the AISC seismic provisions permit EBF systems to be designed with any link length provided the proper rotation limits exist.

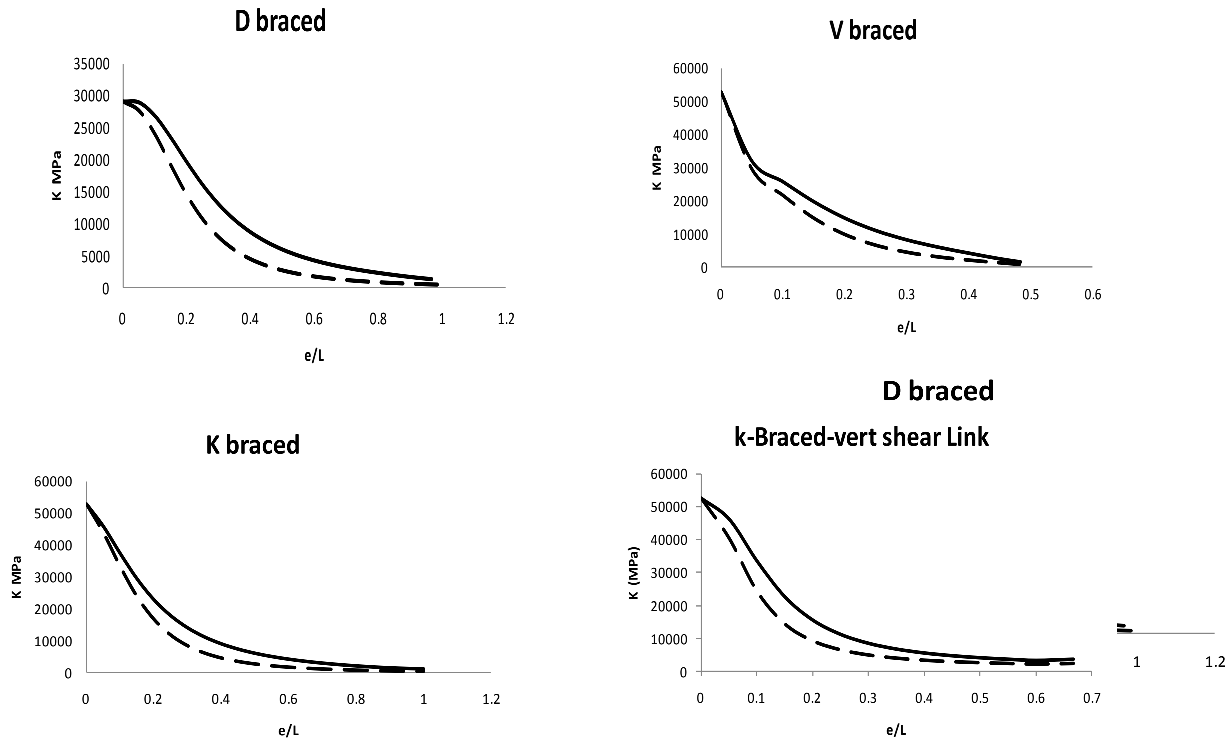


Figure 5: The variations of the lateral stiffness with respect to the link length

Finally, when the link element is properly designed, the inelastic action of the system is confined to the link element. The strength and ductility of the frame are then directly related to the strength and ductility of the shear link.

The analysis also shows that the vertical shear element is subjected to a large shear force, when compared to internal forces within the frame. Thus large amount of the energy would be dissipated by the inelastic shear strain of the vertical shear-link element under severe lateral loading conditions. If damaged such vertical element may be replaced with minimal damage, with the slab zone.

4. CONCLUSIONS AND RECOMMENDATIONS

- EBF systems with shear yielding links are stable and exhibit more ductility than in the case of EBF systems with flexural yielding links, since internal shear force is constant along the length of the link, and web yielding takes place along the entire web depth.
- All EBF systems adopted in this study with shorter links or shear links exhibit more stiffness than in case of flexural links, this behavior is beneficial in terms of drift control.
- The reduced link sections decrease the structural stiffness of the frame, allowing the larger beam section, outside the link to easily satisfy the capacity design requirement, that it remains elastic, as the link yields, while maintaining acceptable inter story drift angle.
- All EBF systems almost exhibit similar behavior; the vertical shear links in eccentrically K braced frames have the advantage of being replaced with minimal damage upon subjected to lateral deformation.
- All eccentric frames in this study exhibit lateral stiffness close to that of concentrically braced frames and demonstrate ductility similar to that of the Moment Frame, hence EBFs are efficient laterally stiff framing systems with significant energy dissipation capability to accommodate large seismic and wind forces.
- All eccentric frames in this study almost exhibit similar behavior; the vertical shear links in eccentrically K braced frames have the advantage of being replaced with minimal damage upon subjected to lateral deformation.

Further research ought to be done to obtain an optimized eccentrically braced structure with reduced section link having the proper section and length which would satisfy the capacity design requirement that the link yields while the larger beam section remains elastic.

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تأثير الجائز الرابط علي الهياكل المعدنية اللامركزية التكتيف

تتناول الدراسة الهياكل المعدنية اللامركزية التكتيف. و تختلف هده الهياكل عن الهياكل مركزية التكتيف في أن أحد نهايات دعامات التكتيف تتصل بالهيكل بشكل لا مركزي. و أن فقدان الطاقة يتأتى من التشوه اللدن لجائز يسمى الرابط بينما تبقى باقي أجزاء الهيكل ضمن حالة المرونة. و تتضمن الدراسة التأثير بحمل أفقية على عدة أشكال من الهياكل المعدنية اللامركزية التكتيف و هيكل معدني مركزي التكتيف و إجراء دراسة مقارنة. و تشمل الدراسة أيضا على تحليل أثر طول و مقطع الرابط على ممطولية الهيكل و كذلك مقدار الإزاحة.