

# Evaluation of Effective Parameters on Performance of Frames with Vertical Link Beam

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## تقييم فعالية المعلمات على أداء الإطارات مع شعاع الارتباط العمودي

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**Abstract:-**

passive control methods can be used to construct safe buildings against earthquake and increase resistance of these buildings. Braces are the most common method for controlling displacements in steel structures; braces are both concentric and eccentric. Concentric braces have high stiffness and low ductility, while eccentric braces have initial stiffness and proportional ductility. In eccentric braces, link beam is an area under plastic deformation which leads to earthquake energy absorption. These beams are either horizontal as a part of story beam or vertical located between story beam and two braces[1]. This study tends to evaluate effective parameters on seismic performance of eccentric braced frames (V-EBF) based on variations in performance point by using DRAIN-2DX. For this purpose, 72 frames with different link lengths, span lengths, and stories were considered.

**Keywords:** vertical link, nonlinear static analysis, target displacement, capacity spectrum method.

**المخلص:-**

يمكن استخدام طرق التحكم السلبي لبناء مباني آمنة ضد الزلازل وزيادة مقاومة هذه المباني. الطريقة الأكثر شيوعاً للتحكم في الإزاحة في الهياكل الفولاذية هي الأقواس، والتي تكون عموماً من النوع المحوري وغير المركزي. تتميز الأقواس المحورية بصلابة عالية وقوة ليونة منخفضة، بينما تتميز الأقواس اللامتراكزة بصلابة وليونة أولية جيدة. شعاع الرابطة في الأقواس غير المركزية هو منطقة تحت التشوه البلاستيكي تمتص الطاقة الزلزالية. تكون هذه الحزم إما أفقية، وهي جزء من شعاع الأرضية، أو يتم وضعها عمودياً بين عارضة الأرضية والقوسين. كان الهدف من هذه الدراسة هو تقييم المعلمات الفعالة في الأداء الزلزالي للإطارات المتباعدة (V-EBF) بناءً على دراسة التغيرات في نقطة الأداء باستخدام برنامج DRAIN-2DX. لتحقيق هذه الأهداف، تم النظر في 72 إطاراً بأطوال ارتباط مختلفة وأطوال امتدادات وعدد من الطبقات.

**الكلمات المفتاحية:** الربط العمودي، التحليل الساكن غير الخطي، إزاحة الهدف، طريقة طيف السعة.

## Introduction

In designing buildings in earthquake-prone areas, it is essential to consider two criteria:

- a) Sufficient stiffness and resistance in the structure to control lateral displacement and prevent destruction of structural and non-structural members under moderate to small earthquake
- b) Sufficient ductility and energy absorption capacity in the structure to prevent collapse of the structure under a severe earthquake

EBFs not only provide the considered stiffness, but also they have high ductility and energy absorption capability. There are two types of EBFs; frames with horizontal link (H-EBF) and frames with vertical link (V-EBF). Since total energy of these frames is absorbed by link beam, V-EBFs are preferred over H-EBFs, because link beam of H-EBF is a part of story beam which experiences plastic deformations during an earthquake; therefore, it is required to replace the story beam after an earthquake, which is difficult and impractical. In V-EBF systems, however, link beam is out of the story beam between story beam and two braces; therefore, it can be replaced easily after an earthquake. Figure 1 shows position of vertical link beam in EBFs.

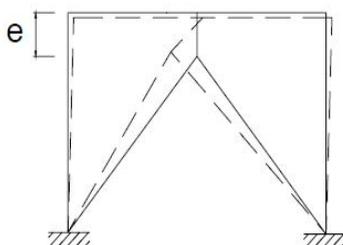


Figure 1: position of vertical link beam

Many studies have been conducted on vertical shear links. Vetr and Boukamp examined V-EBFs [2]. Bruneau and Zahrai improved seismic performance of bridges by using shear panel system (SPS). They modelled a single span bridge and a three-span bridge by using

ADINA and DRAIN-2DX and tended to improve these bridges by using TADAS, SPS and EBF systems [3].

Bruneau and Sarraf performed tests for improving resistance of bridges by using vertical shear links. In designing SPS, they tended to have lower SPS yield resistance than capacity of other structural elements in order to dissipate energy by yielding the element. Stiffness of elements should not be too low, because this leads to large lateral displacement in the structure and may cause damages to non-ductile elements. Moreover, very highly stiff SPS increases the need for ductility [4]. Ghobarah and Abou Elfath (2001) studied seismic performance of non-ductile concrete structures reinforced by divergent steel bracing with vertical link [5]. Shayanfar, Rezaeian and Taherkhani studied seismic behavior of divergent braced frames with vertical link pairs [6].

### Link Length

Link beam length is one of the important parameters in design of vertical shear links (VSLs). To cause hinge rupture in shear before bending, hinge length is limited to [6]:

$$e \leq 1.6 \frac{M_{PL}}{V_{PL}} \quad (1)$$

where,  $M_{PL}$  is plastic moment capacity of the beam section and  $V_{PL}$  is plastic shear capacity of the beam section. However, Vetr and Baukamp suggested following relation as a conservative relation for the case where moment is equal at two ends of the link beam [2].

$$e \leq 1.4 \frac{M_{PL}}{V_{PL}} \quad (2)$$

Angle of rotation for link beams shorter than equation (1) is suggested at 0.08 radian [7].

Energy dissipation capacity, yield mechanism and collapse all greatly depend on link length. For short link beams, shear yield is the governing behavior, while bending yield is deterministic in long link beams.

Link beam is generally under high shear force along and considerable bending moment at the end. As shown by shear and bending distribution in vertical shear hinge (Figure 2), moment is not

equal at two ends; proportional to rotational stiffness of the beam or braces, upper moment is more than lower moment.

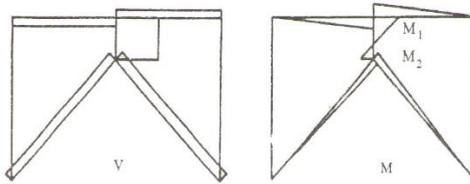


Figure 2: shear and bending distribution in V-EBF [1]

Plastic shear force ( $V_p$ ) and plastic bending moment ( $M_p$ ) of link beam can be calculated by [7]:

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

$$M_p = Z.F_y \quad (3)$$

where,  $t_f$  denotes flange thickness,  $t_w$  denotes web thickness,  $Z$  denotes plastic link section,  $d$  represents total height of the section and  $F_y$  is the link yield stress.

Stiffness, resistance and energy dissipation capacity of long link beams under severe periodic loads are not comparable to short link beams.

### The Studied Models and Their Modeling

A regular plan, as shown in Figure 3, was chosen for the considered frames. Four spans were braced in each direction. The selected frames were side frames. In these frames, the stories were 3 m in height. The frames had 3, 6, 9 and 12 stories. There were 3 spans (3, 4 and 5 m in width). For better understanding of results, behavior of the frames used in models was completely shear or bending. For this purpose, 6 link lengths were used of which four (20, 40, 30 and 50 cm) had shear behavior and two others (160 and 170 cm) had bending behavior. ETABS V9.5 was used to design frames. Simple column-beam connections were considered for the frames. Structures were loaded based on the Iran National Building Regulations [8]. Earthquake force was based on equivalent static method of the Iran Seismic Design Code (the Standard2800) [9]. The studied structures were residential and located in a relatively high-

risk area. The ground was type II. Three numbers were used for naming the frames. The first number from the left indicates the number of stories. The second number from the left indicates length of frame span. The last number indicates link length in meter. For example, 6-3-0.4 is a 6-story frame with a 3-m span and 0.4 m link length.

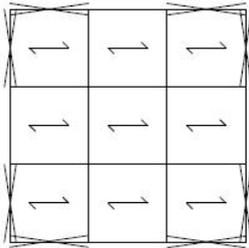


Figure 3: the plan used in calculations

For example, seismic calculations of a 3-story structure are presented below.

$$W = 62402kg$$

$$H = 9m$$

$$T = 0.08H^{3/4} \rightarrow T = 0.415, T_0 = 0.1, T_s = 0.5, S = 1.5$$

$$T_0 \leq T \leq T_s, B = S + 1 \rightarrow B = 2.5$$

$$C = \frac{ABI}{R} \rightarrow C = 0.125$$

$$V = CW \rightarrow V = 7800$$

Then, DRAIN-2DX was used for nonlinear analysis. Type 02 beam-column element was selected for elements of beam, column and braces [10]. DRAIN-2DX lacks shear element; thus, many efforts have been made to model link beam so that this member can have shear behavior. To model link beam in V-EBFs, this study used the method suggested by Ghobarah and Ramadan [11]. Ghobarah and Ramadan tended to model link beam by an elastic beam with a series of transitional springs at both ends using bilinear material curve. These shear springs are located along the shear imposed on the beam at two ends of the link beam which are bound to horizontal

degree of freedom of primary and secondary nodes. Vertical degree of freedom of primary and secondary nodes are assumed equal.

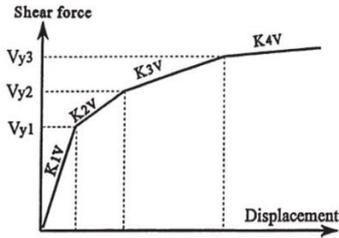


Figure 4: shear force-displacement curve for steel links

$$K_{1V} = \frac{GA_{web}}{e} \quad (4)$$

$$K_{2V} = 0.03K_{1V} \quad (5)$$

$$K_{3V} = 0.015K_{1V} \quad (6)$$

$$K_{4V} = 0.002K_{1V} \quad (7)$$

where, G denotes shear module of the section, e denotes link length, and  $A_{web}$  denotes web cross-section of vertical link.

### Determining Performance Point

#### Performance Point

Performance point indicates a case where structural capacity and seismic requirement are equal. Therefore, position of performance point needs to meet two conditions. First, the point should fall on the capacity curve to represent position of the structure in displacement; second, this point should fall on the spectral requirement curve in which nonlinear effects are shown and indicate nonlinear requirement in identical structural displacement. Accordingly, the best method to determine performance point is to intersect capacity curve and requirement curve in which nonlinear effects are shown.

#### Capacity Curve

Capacity curve is obtained by pushover curve of the structure.

#### Displacement (Requirement) Curve

The required displacement of the structure under the design risk-level earthquake is obtained by using nonlinear time-history analysis. Figure 5 shows capacity curve, bilinear capacity curve and the reduced 2800 curve for the 6-story frame with 3 m span length and 0.4 m link length.

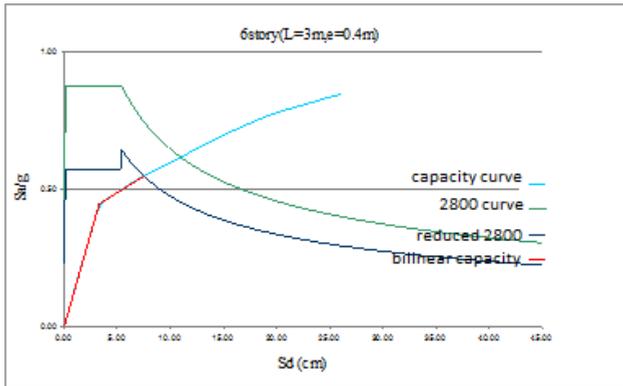


Figure 5: performance point calculation

### Performance Level

FEMA356 suggests three performance levels [13].

#### Immediate Occupancy

Immediate occupancy refers to a very limited structural damage caused by earthquake.

#### Life Safety

Life safety refers to a major damage caused by earthquake to the structure; however, this damage does not lead to fatality.

#### Collapse Prevention

Collapse prevention refers to a performance level in which it is predicted that earthquake causes extensive damages to the structure, while the building does not collapse and fatality is minimized.

Since a certain performance level was not intended in this study, various performance levels were considered for different parameters.

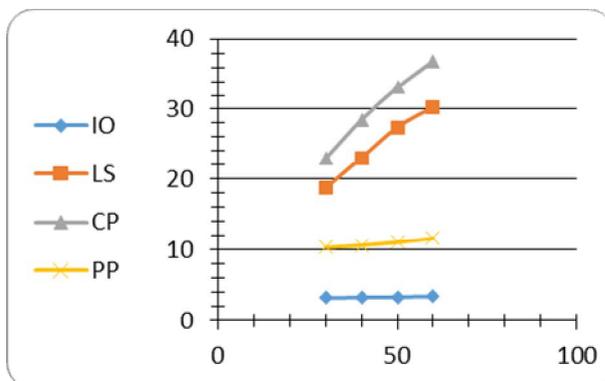
**Table 1: modeling parameters and acceptance criteria for nonlinear procedures [13]**

**Table 5-6 Modeling Parameters and Acceptance Criteria for Nonlinear Procedures—Structural Steel Components (continued)**

Component/Action	Modeling Parameters			Acceptance Criteria				
	Plastic Rotation Angle, Radians		Residual Strength Ratio	Plastic Rotation Angle, Radians				
	a	b		IO	Primary		Secondary	
					LS	CP	LS	CP
EBF Link Beam <sup>10, 11</sup>								
a. $e \leq \frac{1.6 M_{CE}}{V_{CE}}$	0.15	0.17	0.8	0.005	0.11	0.14	0.14	0.16
b. $e \geq \frac{2.6 M_{CE}}{V_{CE}}$	Same as for beams.							
c. $\frac{.6 M_{CE}}{V_{CE}} < e < \frac{2.6 M_{CE}}{V_{CE}}$	Linear interpolation shall be used.							

**Curves**

Figures 6 and 7 show diagrams related to variations in target displacement (p.p) versus increase in link length for 6-story frames with constant span length. In these figures, horizontal axis indicates link length (cm) and vertical axis indicates displacement at different performance levels and target displacement (cm). Figures 8 and 9 show effect of story height on target displacement (p.p) for frames with constant link and span length. Figures 10 and 11 show effect of increase in span length on target displacement of 6-story frames with constant link length. It is noteworthy that only several diagrams are presented in this section.



**Figure 6: 6-story frames with shear links**

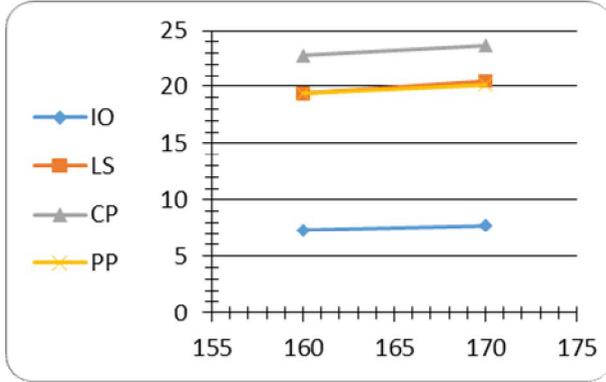


Figure 7: 6-story frames with bending links

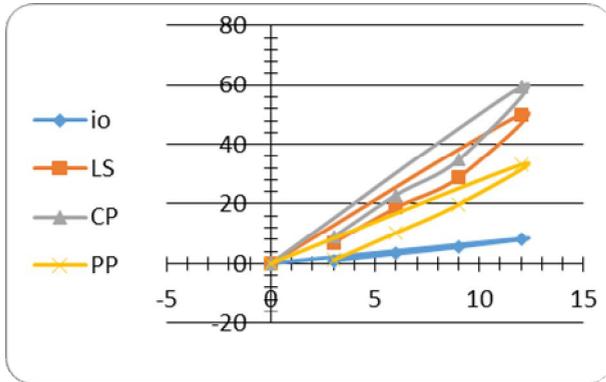


Figure 8: frames with different stories and shear link and constant span length

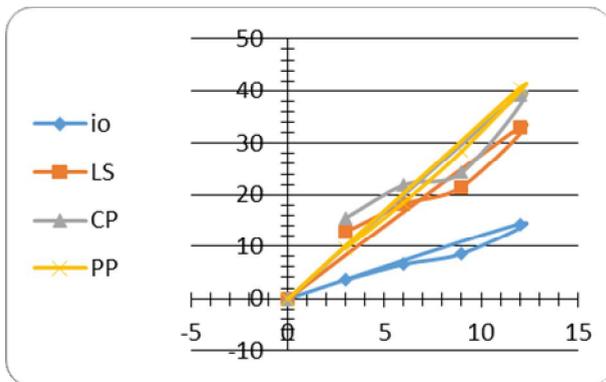


Figure 9: frames with different stories and bending link and constant span length

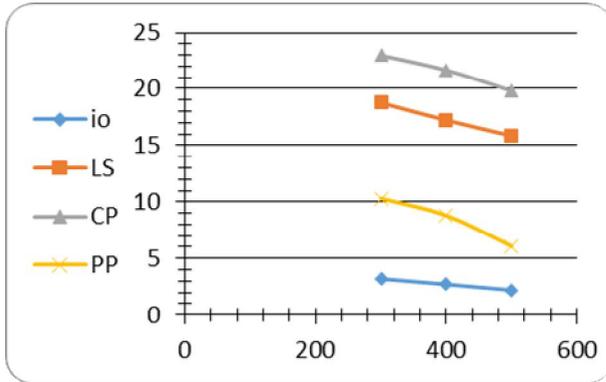


Figure 10: 6-story frames with shear link and different span lengths

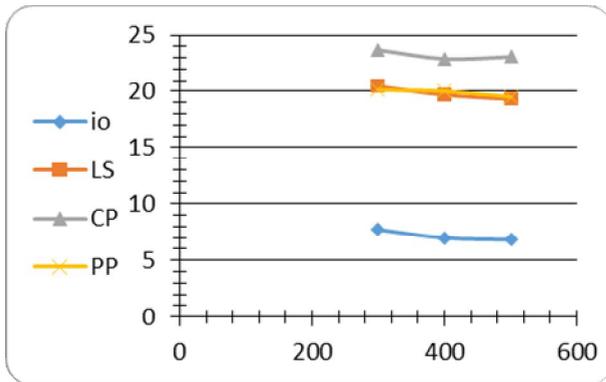


Figure 11: 6-story frames with bending link and different span length

### Conclusion

1. The increase in length of shear links increases target displacement and performance point shifts to life safety. The increase in length of bending links also increases target displacement and weakens frame performance;
2. Shear link beams have stronger performance level than bending link beams;
3. For shear links, the increase in the number of stories increases target displacement and performance point shifts to life safety. For bending links, this increases target displacement and performance shifts to collapse prevention;

4. The increase in the number of stories increases variations in performance point of bending links compared to bending links to the extent to which they do not show any performance;
5. The increase in span length reduces target displacement of shear and bending links and performance point shifts to immediate occupancy.

### **Reference:**

- [1] Vetr, M. G. & Ghamari, A, 2018. Experimentally and analytically study on eccentrically braced frame with vertical shear links.seismic.
- [2] Vetr, M. G. & Bauwkamp, W. G., 2000. seismic behavior, design and analysis of eccentric braced frames with vertical shear hinges. *Seismology and Earthquake Engineering*.
- [3] S.M.Zahrai, M.Bruneau. Cyclic Testing of Ductile End Diaphragms For Slab-on-Girder Steel Bridges, Journal of Structural Engineering, Vol.125, No.9, September, 1999.
- [4] M.Sarraf, M.Bruneau. Ductile seismic retrofit of deck-truss bridges, J Struct Engng, ASCE, 124(2), 1998.
- [5] A.Ghobarah, H.Abou Elfath. Rehabilitation of a reinforced concrete frame using eccentric steel, Engineering Structures, 23, 745-755, 2001.
- [6] M.Shayanfar, A. Rezaeian ,S.Taherkhani, Assessment of the seismic behavior of eccentrically braced frame with double vertical link (DV-EBF), 14th World Conference on Earthquake Engineering, 2008, Beijing, China.
- [7] AISC"American Institute of Steel Construction". Seismic provision for structural steel buildings, Chicago, 1997.
- [8] Anon., 2005. Minimum loads on buildings regulations. In: iran national building regulation. s.l.:s.n.
- [9] building and housing research center, 2006. Regulations for design of buildings against earthquakes (the standard 2800). 3rd ed. s.l.:s.n.
- [10] G.H.POWELL. Drain-2dx element description and user guide, Department of civil engineering the University of California, 1993
- [11] T.Ramadan, A.Ghobarah. Analytical model for shear-link behavior, J Struct Engng, ASCE, 121(11), 1574-80, 1995.
- [12] ATC. Seismic evaluation and retrofit of concrete buildings. *ATC-40*. applied technology council, Redwood; 1996
- [13] FEMA 273/274/356. NEHRP Guidelines for the seismic Rehabilitation of Buildings Ballot version. Federal Emergency Management Agency (FEMA), Washington D.C; 1996.