

Evaluation of lateral stiffness of steel structures having different types of lateral load-resisting systems

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Abstract. In this paper, the evaluation of the elastic lateral stiffness factor (ELSF) of steel frames for different lateral load-resisting systems (LLRSs) is presented. First, 720 steel structural frame models have been analyzed and designed using the equivalent lateral force method. Then by using pushover analysis method, all models have been analyzed, compared and evaluated. Finally, the effects of a number of influenced parameters such as different types of LLRSs, span length, number of stories, number of spans as well as story height of the buildings on the lateral stiffness are assessed and by applying regression analysis some useful equations were submitted. Based on the results obtained for steel frames having different LLRSs, compared to ordinary moment-resisting frames (OMRFs) as a base (having ELSF of 1), the normalized average ELSFs of K-eccentrically braced-frames (K-EBFs), V-, Z-, inverted V-, X-braced-frames, shear walls with thickness of 25 cm (SW25) and shear walls with thickness of 30 cm (SW30) are about 2.2, 6, 7, 9, 11, 95, 155, respectively. Among the braced-frames, X-braced-frames have the maximum ELSF, about 10 times more than OMRF, while OMRFs provide the minimum ELSFs among all LLRSs, and the frames supported by shear walls have ELSFs about 100 to 150 times more than OMRFs.

Keywords: bracing; lateral load-resisting systems; lateral stiffness; pushover analysis; shear wall

1. Introduction

This paper deals with the analysis of the influence of lateral load-resisting systems (LLRSs) such as steel bracings and shear walls on structures. LLRSs include eccentrically braced-frames (EBFs), concentrically braced-frames (CBFs) and frames with shear walls (SWs). However, care must be given when choosing between different LLRSs and it is important to ensure that the desired mechanism possesses the required lateral stiffness, capable to withstand the seismic forces (Padmakar 2013). In this study, the pushover analysis is used to determine the ELSF of different LLRSs.

Some researches have been performed on different LLRSs to evaluate the seismic performance of new and existing buildings. Among them, Viswanath *et al.* (2010) performed a study on 4-story

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buildings. Their study aimed to evaluate the performance of structures in relation to the story and global drifts of Structure braced with steel X-braces. They concluded that the X-type bracings are more effective in enhancing the lateral stiffness of structures and are more economical compared to other types of bracings. Azam and Hosur (2013) examined how a combination of LLRSs can be used to improve the performance of a structure. Their examination was based on the use of concrete shear walls and special moment-resisting frames (MRF). They compared the performance of the structures based on their damping, stiffness, and strength by changing the location of the LLRSs. The observations were analyzed using static pushover and response spectrum analyses. They concluded that the location of the LLRSs has an important implication on a structure's damping, stiffness, and strength. They also supported the idea of combining different types of LLRSs. Tafheem and Khusru (2013) focused on analyzing how live, dead, wind and earthquake loads affect the structural performance of a building by examining a 6-story building model. The performance of the building was evaluated based on the structural responses when braced with V and cross (X) bracings are subjected to bending moment, axial and drift forces, as well as the story displacement. It was noted that structures with X-bracings were relatively stiffer and had a better capacity to resist lateral loading. Choudhari and Nagaraj (2015) applied a pushover analysis method to analyze the effects of knee, inverted V, V, and X bracings to model a 5-story steel frame using SAP2000. The obtained results were compared based on the performance points, story drift, roof displacement, and base shears. They concluded that the steel X-bracing systems are more effective in reducing maximum interstate drift and contributing towards enhancing a steel structure's lateral stiffness. Dharanya *et al.* (2017) examined the role of shear walls and bracings for a 5-story residential RC building using ETABS software. The aim of this study was to investigate the shear and axial forces, story drift, base shear as well as the lateral displacement variations when the structure is subjected to seismic loading. They outlined that such buildings tend to be highly responsive to oscillatory movements caused by torsional or lateral deflections. To make sure that all buildings have the required stiffness capacity enough to withstand seismic effects, using the cross (X) LLRSs is very helpful. Mohsenian and Nikkhoo (2019) studied the EBF structures equipped with dual vertical links. According to their obtained results, they concluded that the system has high ductility and due to desirable performance and significant advantages of the dual vertical links, this system can be used as a main LLRS.

Farghaly (2016) investigated the behavior of shear walls under a seismic event and studied the effect of height, location, and distribution of shear walls in slender high-rise buildings with and without boundary elements induced by the earthquake loading on a 12-story building applying SAP2000 software. The obtained results disclose that the behavior of the structure is definitely affected by the height and location of shear walls. Viet *et al.* (2017) presented an algorithm to determine the fuzzy critical loads of planar steel frame structures. The finite element method with linear elastic semi-rigid connection and response surface method (RSM) in mathematical statistics were applied to the problems with symmetric triangular fuzzy numbers. They concluded that using simple linear elastic semi-rigid connection models is suitable for the structural system having small displacements. Hassan *et al.* (2018) assessed the two design methods of elliptical clearance method and the conventional standard linear clearance method, by performing six cyclic pushover tests on full-scale models of steel CBF structures and a 3D finite element shell model was developed to replicate the response of gusset plate and bracing members under fully reversed cyclic axial loading. The study shows that the two design methods attain structural response as per the design intentions; however, the elliptical clearance method has a superiority over the standard linear method as a fact of improving detailing of the gusset plates, enhancing resisting capacity

and improving deformability of a CBF structure. Hashemi *et al.* (2019) applied the artificial neural network (ANN) method to predict the quantity of steel used in the steel MRFs. First, more than 1100 steel MRF structures were designed applying the variation of the influenced parameters, then the models were transferred to the ANN, and finally, the results of the performed parametric study were analyzed. The obtained results demonstrate that by using the ANN method, the weights of the structures can be estimated with an acceptable accuracy prior to the starting of the design process.

Some researchers have modeled the behavior of structures under lateral loading by applying a pushover analysis method. The buildings capable of withstanding the lateral load can be listed as MRFs, shear-walled frames, CBFs and EBFs (Thorat and Salunke 2014).

Members in the braced-frames are intended to work in compression and tension alike a truss. Braces assist in lowering shear force and reducing bending moment on beams and columns and decreasing the entire lateral displacement of buildings. The earthquake force is shifted as an axial force in the brace members. It is possible to use several kinds of EBFs like K-bracings including global bracing along the building height. It is also possible to use EBFs such as X, Z, V and IV shaped, (Baikerikar and Kanagali 2014).

In simple terms, stiffness is an indication of how rigid an object is. Hook's law considers it as an ability to displace an equally proportional force to the subjected force on solid objects. This entails that the stiffness of objectives has a significant effect on displacement. Thus, it is essential to determine how changes in stiffness influence the object's ability to displace a load to choose the best material or object to use in structures. The ability to solve structures analysis equations and problems relies on the ability to know the stiffness matrices and values (Rokhgar 2014).

The aim of this paper is to assess the ELSF of various types of shear walls and bracing systems of steel frames, to assess the impact of various parameters on the ELSF and to offer a database for determining the ELSFs of structures including braced-frames. Analyzing various kinds of bracings and shear wall LLRSs helps to explain the structural response of a building under seismic action. This can act as a guideline to view and examine the potential LLRSs throughout the design phase and choose the suitable LLRS based on the analyzed results.

2. Methodology

In this study, the equivalent lateral force (ELF) method of analysis was applied to analyze and design the structural models and then all the models were evaluated by applying the pushover analysis method as described in Section 3. ETABS software was used to build the models and to perform the ELF and pushover analysis methods.

3. Specifications of the assessed frames

3.1 Structural modeling

Distinctive kinds of steel frames having different LLRSs were analyzed and designed. Eight LLRSs were used including ordinary moment-resisting frames (OMRFs), ordinary concentrically braced-frames (OCBFs) with X-, Z-, V- and IV-shaped bracings, ordinary eccentrically braced-frames (OEBFs) with K-bracing and steel-concrete composite shear walls (SCCSWs) with two sets of concrete strengths. In the calculations of the above structural systems, the LLRSs are

Table 1 The range of variations of input parameters

Parameters	Ranges (720 data)
Number of stories (S) (low-, mid- and high-rise buildings)	1, 5 and 8
Story height (H)	3.2 and 3.4 m
Number of spans (N)	1, 3, and 5
Span length (L)	4.5, 5, 5.5, 6 and 6.5 m
Site class (S)	D
Concrete compressive strength (f'_c)	25 and 30 N/mm ²
Concrete modulus of elasticity	23500 and 25743 N/mm ²
Yield strength (F_y) of steel sections	240 N/mm ²
Ultimate strength (F_u) of steel sections	448 N/mm ²
Steel modulus of elasticity (E_s)	200000 N/mm ²
F_y of reinforcing steel bars	420 N/mm ²
Live load	25 kN/m
Super dead load	20 kN/m (excluding the self-weights)

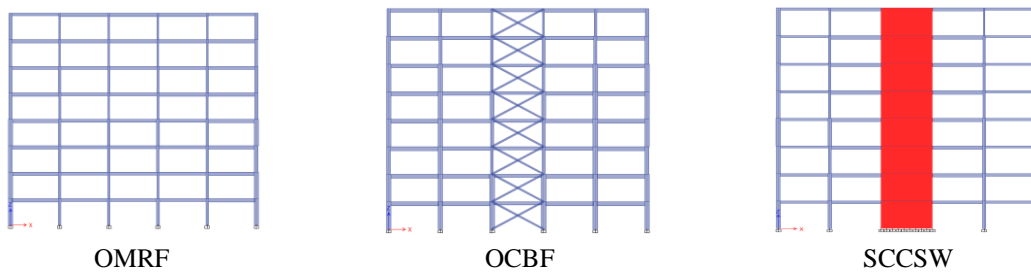


Fig. 1 Structural models of OMRF, OCBF, and SCCSW for high-rise buildings

placed at the middle spans of the frames and a number of 720 models of steel frames using different LLRSs have been analyzed. The specifications of the analyzed structural models and the properties of the employed materials are given in Table 1.

In all models, super dead loads and live loads are fixed to be the same for all models. The software automatically calculates the self-weight of the structure, but live loads and super dead loads are defined and assigned to the software.

3.2 Seismic analysis methods

The seismic loadings are determined according to ASCE 7-10 Code (2010) provisions. The seismic design category (SDC) of all the models is category C. After applying the SDC to all models, the ELF method is selected for the analysis and designing of all models based on ASCE code. Therefore, after designing the models, all the models are evaluated using nonlinear static analysis “NLSA” (pushover analysis method). All the models are analyzed and designed using ETABS software.

3.3 Some structural modeled samples

Some of the structural models of OMRF, OCBF, and SCCSW for high-rise buildings are shown in Fig. 1 for the illustration purpose.

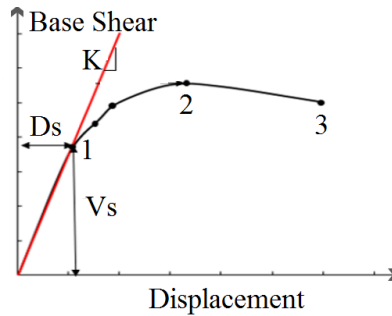


Fig. 2 Illustration of parameters related to ELSF on pushover curve

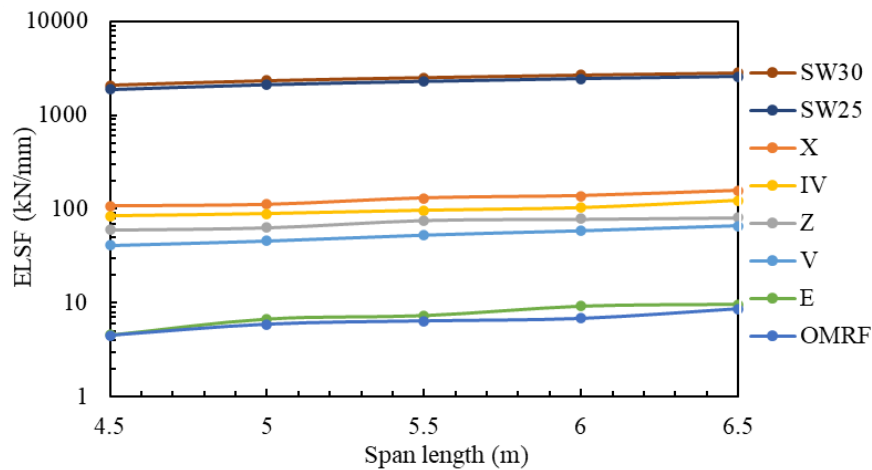


Fig. 3 ELSF versus span length for different types of LLRSs, $N = 1$, $S = L$, $H = 3.2$ m

3.4 Designed sections of steel frames

After loading, the structural models are designed according to AISC360-10 code by applying the LRFD method. The models containing shear walls are designed based on ACI-318-14 (2014). In the design processes of all models, the American standard profiles of type AISC W sections have been used. After designing the models, pushover analysis is performed for all the models to evaluate the ELSF of different types of LLRSs while changing the influenced parameters.

3.5 Pushover analysis method

In this study, the displacement-controlled method of pushover analysis is used, and all the models are pushed up to rupture displacement at the controlled joint. The procedure of applying the pushover analysis to find the ELSF of all the frames is illustrated below:

- a) The mathematical models of the steel frames are first created and designed using ELF method,
- b) 25% of live load, dead load, and super dead load are applied to the steel frames.
- c) Then pushover analysis is defined and the load patterns of pushover analysis are assigned. The lateral load pattern considered in this study is the acceleration pattern, in the

acceleration pattern, the lateral load is increased incrementally until the structure reaches the full capacity of the system which means drawing pushover curve up to the failure of the structure.

d) After pushover analysis, a pushover curve is drawn which represents base shear in function of lateral displacement of the structure.

e) The values of the ELSF are calculated using ASCE 41-13 (2013) in the software, with the help of a pushover curve, the procedure to calculate the ELSF's parameters is illustrated in Fig. 2.

In Fig. 2, the number (1) denotes the first plastic hinge formation of the structure where the ELSFs are found for all models, the number (2) represents the ultimate strength and the number (3) shows the maximum displacement that the structure can endure (displacement at rupture).

$$K = V_s/D_s \quad (1)$$

where:

V_s : Base shear at first hinge formation,

D_s : Displacement at first plastic hinge formation,

K : Elastic lateral stiffness factor (ELSF) (See Fig. 2).

4. Obtained results and discussion

In this Section, the results of the evaluation and comparison of the ELSFs of steel frames having different types of LLRSs, considering variations in different parameters, such as span length, number of spans, number of stories and story height are presented.

4.1 Notations used for influenced parameters

In order to know the effect of one parameter on the ELSF, other parameters are fixed. For better understanding, the symbols used in the graphs and Tables are explained as follows:

S: The type of the building according to its height, low-rise (1-story), medium-rise (5-story) and high-rise (8-story) buildings,

N: Number of spans,

L: Span length,

H: Height of the building,

SW30: Shear-walled frames with the compressive strength of concrete of 30 MPa,

SW25: Shear-walled frames with the compressive strength of concrete of 25 MPa.

4.2 Effects of different parameters on the ELSF

4.2.1 The effect of span length on the ELSF

Changes in span length could have an important effect on the weight and designed sections of the frames so that any variation in the span length affects the ELSFs of the steel frames. Figs. 3 to 11 show the ELSFs of the steel frames versus span length for different types of LLRSs considering different parameters. Note that in all figures, K-EBF (K-eccentrically braced-frame) is simply illustrated by E. From Fig. 3 and Table 2 it can be observed that by increasing the span lengths of all types of LLRSs, the ELSF value increases. From these figures and Table 2, it can be seen that after adding the LLRSs in steel frames, the stiffness of the frames increases and SW30 has the highest ELSF. Among the bracings, X-bracing has the maximum stiffness, which is much lesser the shear walls, and OMRF has the lowest value of ELSF.

Table 2 ELSF of different types of LLRSs versus span lengths, single-story single-span, H = 3.2 m

Span length (m)	ELSF (kN/m)							
	OMRF	E (K-EB)	V	Z	IV	X	SW25	SW30
4.5	4.509	4.539	40.987	60.304	84.524	107.401	1892.303	2071.39
5	5.921	6.718	45.676	63.656	89.136	111.417	2125.141	2326.591
5.5	6.410	7.298	52.734	76.081	96.623	130.597	2294.76	2512.52
6	6.807	9.184	58.552	78.334	102.953	138.043	2450.195	2682.858
6.5	8.639	9.621	66.132	81.111	122.631	156.603	2579.658	2824.643
Average K	6.457	7.472	52.8162	71.897	99.1734	128.812	2268.411	2483.6
Norm. ave. K	1	1.157	8.17943	11.134	15.3585	19.9486	351.2995	384.625

By applying the regression analysis, Eqs. (2) to (9) are found for ELSFs of the frames versus span length (L) for different types of LLRSs for the case of single-story single-span ($S = L$, $N = 1$) having $H = 3.2$ m with acceptable determination factors (R^2). In all equations, L is given in meters.

$$K = 2035.9\ln(L) - 970.06, \quad \text{with } R^2 = 0.9964 \quad (\text{for SW30}) \quad (2)$$

$$K = 1857.7\ln(L) - 883, \quad \text{with } R^2 = 0.9964 \quad (\text{for SW25}) \quad (3)$$

$$K = 134.95\ln(L) - 100.11, \quad \text{with } R^2 = 0.9486 \quad (\text{for X-bracing}) \quad (4)$$

$$K = 96.402\ln(L) - 64.36, \quad \text{with } R^2 = 0.8857 \quad (\text{for IV-bracing}) \quad (5)$$

$$K = 61.686\ln(L) - 32.744, \quad \text{with } R^2 = 0.9287 \quad (\text{for Z-bracing}) \quad (6)$$

$$K = 68.394\ln(L) - 63.205, \quad \text{with } R^2 = 0.9851 \quad (\text{for V-bracing}) \quad (7)$$

$$K = 13.831\ln(L) - 15.99, \quad \text{with } R^2 = 0.9648 \quad (\text{for E (K-EB)}) \quad (8)$$

$$K = 9.9071\ln(L) - 10.349, \quad \text{with } R^2 = 0.9246 \quad (\text{for OMRF}) \quad (9)$$

Table 2 presents the ELSFs of different types of LLRSs for the case of single-story single-span ($N = 1$, $S = L$) having $H = 3.2$ m for different span lengths.

As illustrated in Table 2, the comparison of the obtained results for the normalized average ELSFs of single-story single-span steel frames having different LLRSs relative to OMRF as a base (having ELSF of 1), the normalized average ELSFs of K-EBF (E), V-, Z-, inverted V-, X-braced frames, SW25, SW30 are about 1.2, 8, 11, 15, 20, 350, 385, respectively. Among the single-story single-span braced-frames, X-braces have the maximum ELSF, about 20 times more than OMRF, while OMRFs provide the minimum ELSF among all single-story single-span LLRSs, and the shear walls have ELSFs between 350-400 times more than OMRFs.

By applying the regression analysis, Eqs. (10) to (17) are extracted for ELSFs of the frames versus span length (L) for different types of LLRSs for a 5-span 5-story mid-rise building having $H = 3.2$ m with acceptable determination factors. In all equations, L is given in meters.

$$K = 314.52\ln(L) - 393.07 \quad \text{with } R^2 = 0.9871 \quad (\text{for SW30}) \quad (10)$$

$$K = 286.23\ln(L) - 356.46 \quad \text{with } R^2 = 0.9909 \quad (\text{for SW25}) \quad (11)$$

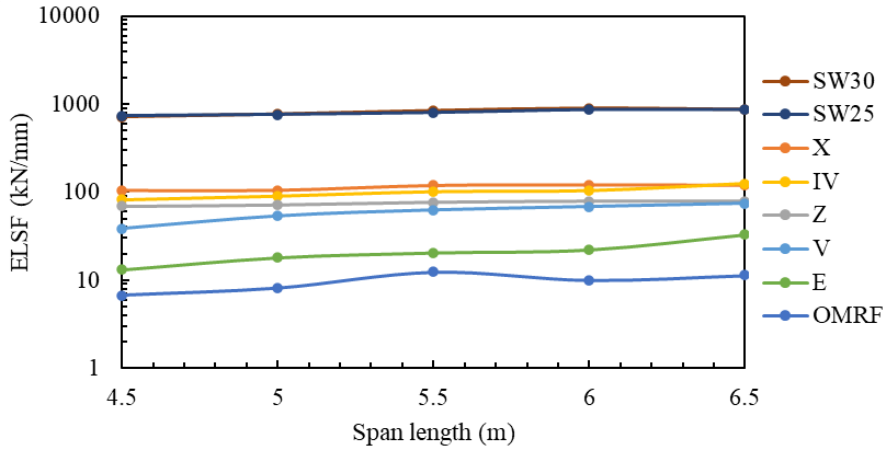


Fig. 4 ELSF versus span length for different types of LLRSs, N = 3, S = L, H = 3.2 m

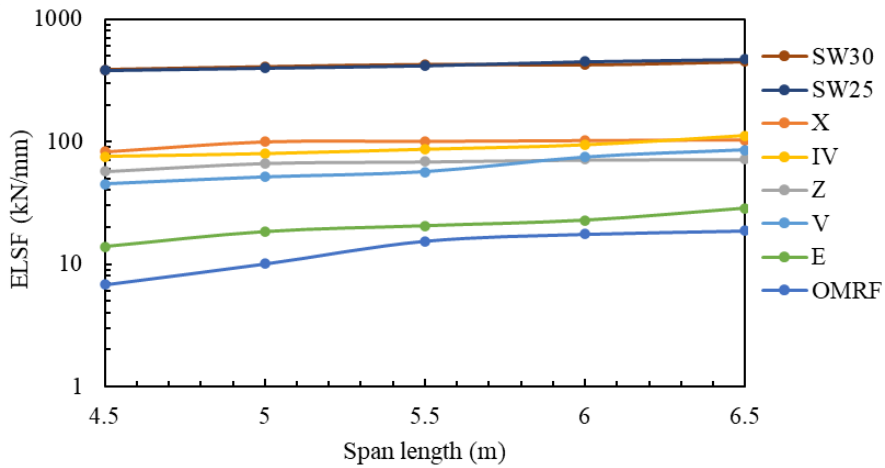


Fig. 5 ELSF versus span length for different types of LLRSs, N = 5, S = L, H = 3.2 m

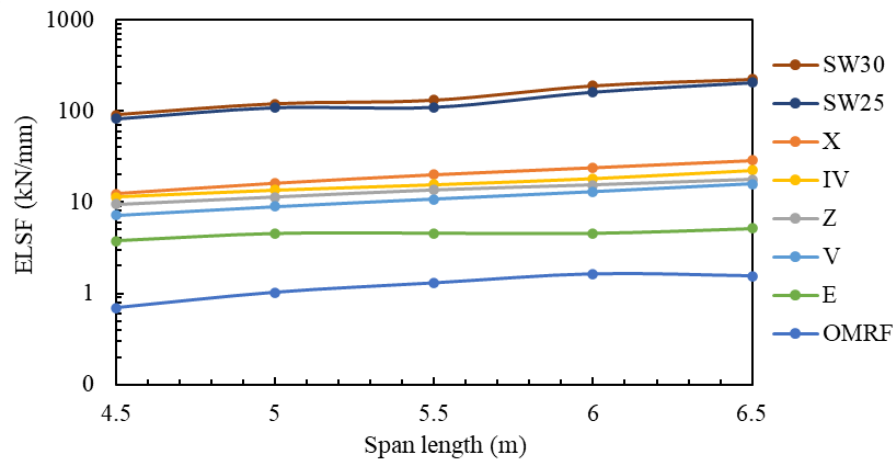


Fig. 6 ELSF versus span length for different types of LLRSs, N = 1, S = M, H = 3.2 m

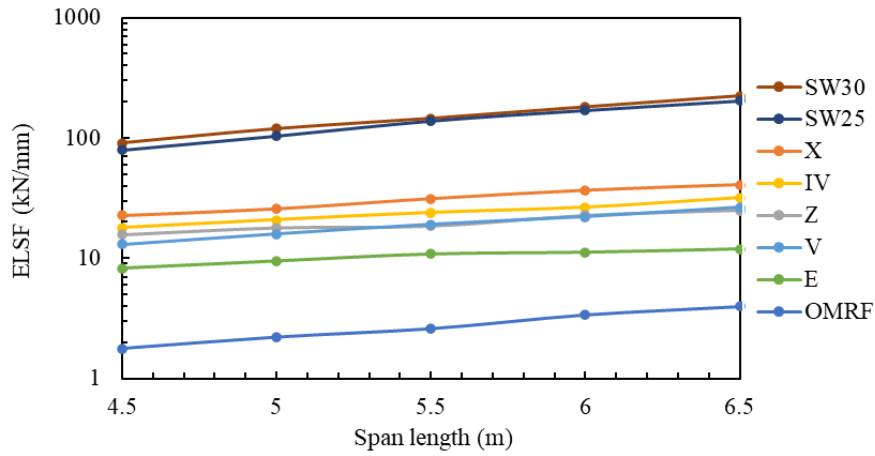


Fig. 7 ELSF versus span length for different types of LLRSs, $N = 3$, $S = M$, $H = 3.2$ m

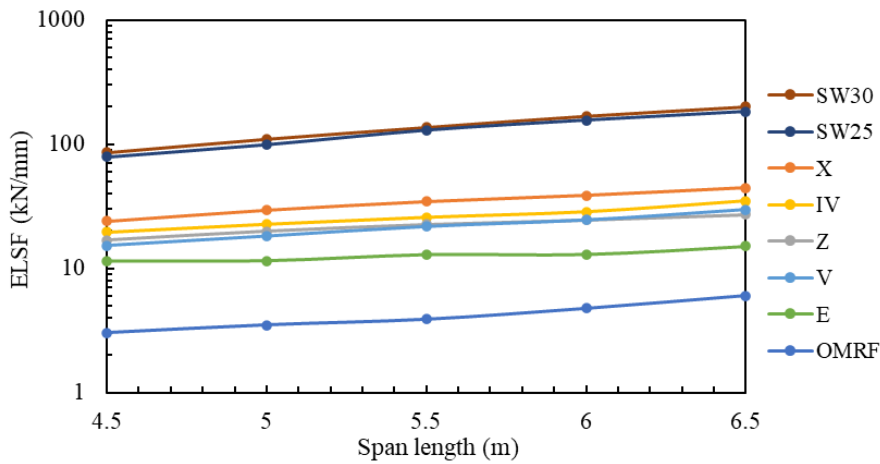


Fig. 8 ELSF versus span length for different types of LLRSs, $N = 5$, $S = M$, $H = 3.2$ m

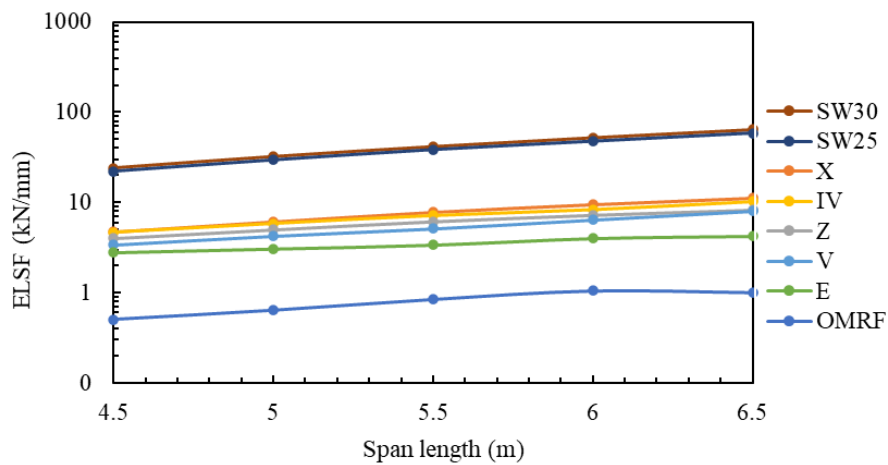


Fig. 9 ELSF versus span length for different types of LLRSs, $N = 1$, $S = H$, $H = 3.2$ m

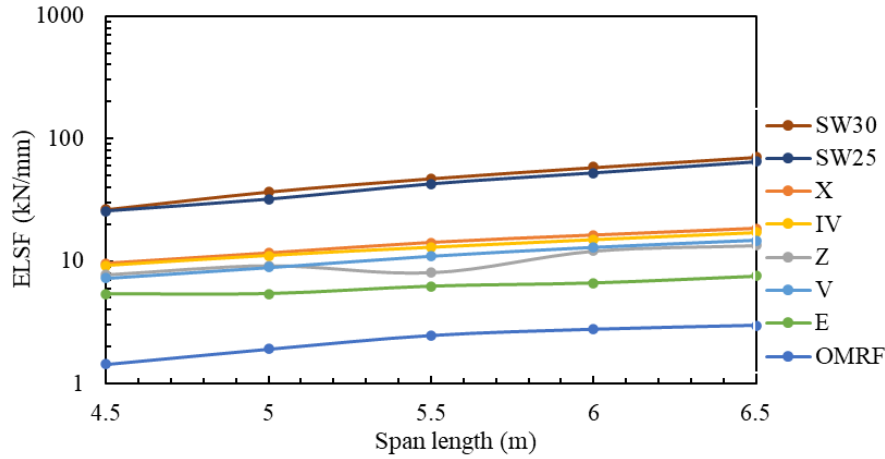


Fig. 10 ELSF versus span length for different types of LLRSs, $N = 3$, $S = H$, $H = 3.2$ m

$$K = 54.737\ln(L) - 58.656 \quad \text{with } R^2 = 0.9952 \quad (\text{for X-bracing}) \quad (12)$$

$$K = 39.001\ln(L) - 39.881 \quad \text{with } R^2 = 0.9523 \quad (\text{for IV-bracing}) \quad (13)$$

$$K = 27.395\ln(L) - 24.322 \quad \text{with } R^2 = 0.9981 \quad (\text{for Z-bracing}) \quad (14)$$

$$K = 37.609\ln(L) - 41.985 \quad \text{with } R^2 = 0.9743 \quad (\text{for V-bracing}) \quad (15)$$

$$K = 9.3954\ln(L) - 3.1944 \quad \text{with } R^2 = 0.8359 \quad (\text{for E (K-EB)}) \quad (16)$$

$$K = 7.8168\ln(L) - 9.0229 \quad \text{with } R^2 = 0.9115 \quad (\text{for OMRF}) \quad (17)$$

By applying the regression analysis, Eqs. (18) to (25) are extracted for ELSFs of the frames versus span length (L) for different types of LLRSs for a 5-span 8-story high-rise building having $H = 3.2$ m with acceptable determination factors. In all equations, L is given in meters.

$$K = 125.92\ln(L) - 163.13 \quad \text{with } R^2 = 0.9961 \quad (\text{for SW30}) \quad (18)$$

$$K = 107.75\ln(L) - 136.57 \quad \text{with } R^2 = 0.9971 \quad (\text{for SW25}) \quad (19)$$

$$K = 30.88\ln(L) - 35.604 \quad \text{with } R^2 = 0.9686 \quad (\text{for X-bracing}) \quad (20)$$

$$K = 24.51\ln(L) - 26.435 \quad \text{with } R^2 = 0.9973 \quad (\text{for IV-bracing}) \quad (21)$$

$$K = 23.342\ln(L) - 26.475 \quad \text{with } R^2 = 0.9581 \quad (\text{for Z-bracing}) \quad (22)$$

$$K = 26.361\ln(L) - 31.248 \quad \text{with } R^2 = 0.9777 \quad (\text{for V-bracing}) \quad (23)$$

$$K = 7.3018\ln(L) - 3.4278 \quad \text{with } R^2 = 0.9702 \quad (\text{for E (K-EB)}) \quad (24)$$

$$K = 6.8098\ln(L) - 8.1909 \quad \text{with } R^2 = 0.9769 \quad (\text{for OMRF}) \quad (25)$$

As Figs. 3 to 11 illustrate, the ELSFs of the steel frames versus span length for different types of LLRSs with different story heights and numbers of stories indicate that by increasing the span

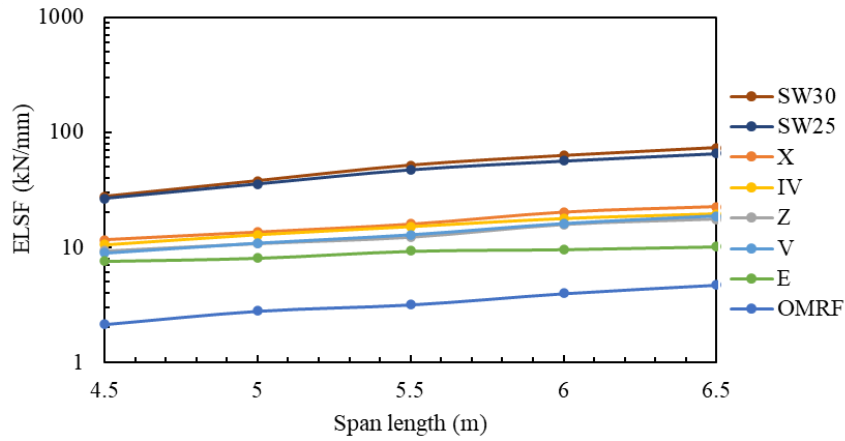


Fig. 11 ELSF versus span length for different types of LLRSs, $N = 5$, $S = H$, $H = 3.2$ m

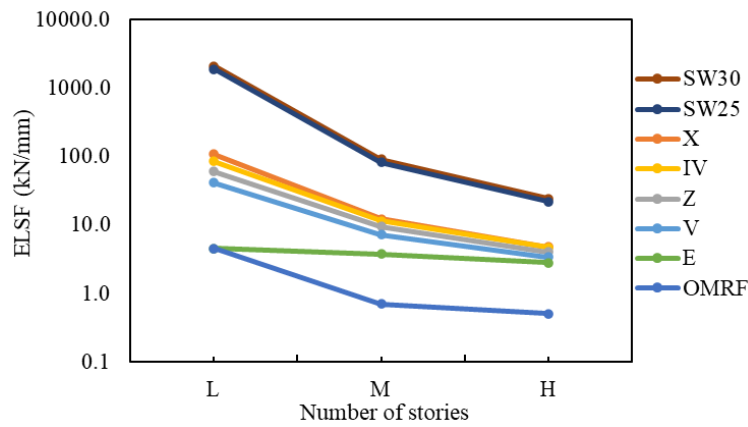


Fig. 12 ELSF versus the number of stories for different types of LLRSs, $N = 1$, $L = 4.5$ m and $H = 3.2$ m

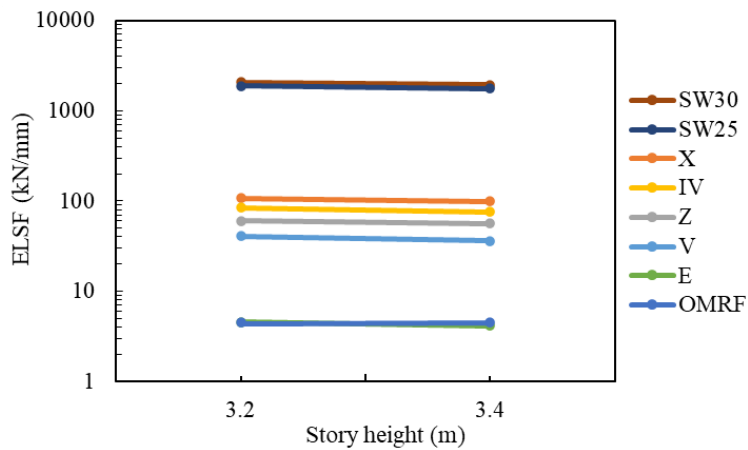


Fig. 13 ELSF versus the story height variation for different types of LLRSs, $S = L$, $L = 4.5$ m and $N = 1$

Table 3 ELSF of different forms of LLRS versus the number of stories, $N = 1$, $L = 4.5$ m and $H = 3.2$ m

Number of stories	ELSF (kN/m)							
	OMRF	E (K-EB)	V	Z	IV	X	SW25	SW30
L	4.509	4.539	40.987	60.304	84.524	107.401	1892.3	2071.39
M	0.694	3.742	7.187	9.408	11.400	12.292	82.147	89.841
H	0.507	2.804	3.381	4.002	4.669	4.725	22.043	24.151

Table 4 ELSF of different forms of LLRS versus story height variation, $S = L$, $L = 4.5$ m and $N = 1$

Story height (m, %)	ELSF (kN/m)							
	OMRF	E (K-EB)	V	Z	IV	X	SW25	SW30
3.2	4.509	4.539	40.987	60.304	84.524	107.401	1892.3	2071.39
3.4	4.091	4.123	35.940	56.604	76.163	99.561	1770.28	1937.786
+6.25%	-9.27%	-9.20%	-12.3%	-6.10%	-9.90%	-7.30%	-6.50%	-6.50%

length for all types of LLRSs, the ELSFs of the steel frames increase. From these figures, it can be seen that for all cases, SW30 has the highest ELSF and among the bracings, X-bracing has the maximum stiffness, which is much lesser than the shear walls, while OMRF has the lowest value of ELSFs.

4.2.2 The effect of the number of stories on the ELSF

Fig. 12 demonstrates the variation of the ELSF of steel frames versus the number of stories (low-, mid- and high-rise structures) for different types of LLRSs. From Fig. 12 and Table 3, it can be seen that adding LLRSs to steel frames, causes an increase in the ELS of the frames, SW30 has the highest ELSF. Among the bracings, X-bracing has the maximum stiffness, which is much lesser than the shear walls, and OMRF has the lowest value of ELSF. Fig. 12 and Table 3 also demonstrate that with increasing the number of stories, the ELSF decreases for all types of LLRSs. From Fig. 12 it is observed that when the number of spans varies from 1 (L for low-rise) to 5 (M for mid-rise) and then to 8 (H for high-rise), the percentage of decreasing in ELSF decreases when the number of stories increases.

4.2.3 The effect of story height variation on the ELSF

Fig. 13 and Table 4 demonstrate the variation of the ELSF of steel frames versus story height for different types of LLRSs. From this figure and Table 4, it can be seen that the ELSF of steel frames for all types of bracing and shear walls is decreased with increasing the height of the stories from 3.2 m to 3.4 m.

As illustrated in Table 4, the comparison of the obtained results for the ELSFs of steel single-story single-span frames having different LLRSs shows that an increase of 6.25% in height makes decrease about 9.27%, 9.20%, 12.30%, 6.10%, 9.90%, 7.30%, 6.50% and 6.50% in ELSFs of OMRF, K-EB (E), V-bracing, Z-bracing, inverted V-bracing, X-bracing, SW25, and SW30, respectively. Among the single-story single-span braced-frames, z-bracings and X-bracings have less reduction in ELSF, and the shear walls have a minimum reduction in the values of ELSFs.

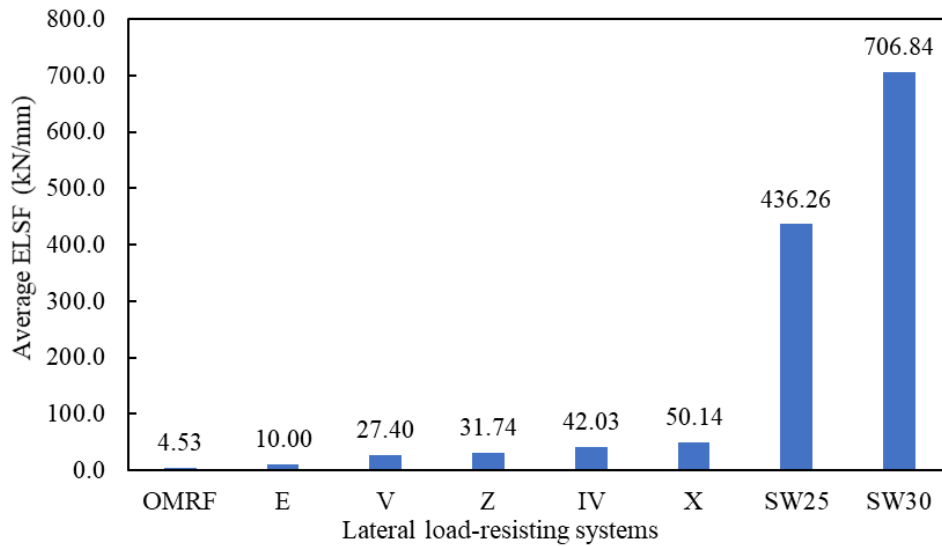


Fig. 14 Average ELSF of the frames having different LLRSs

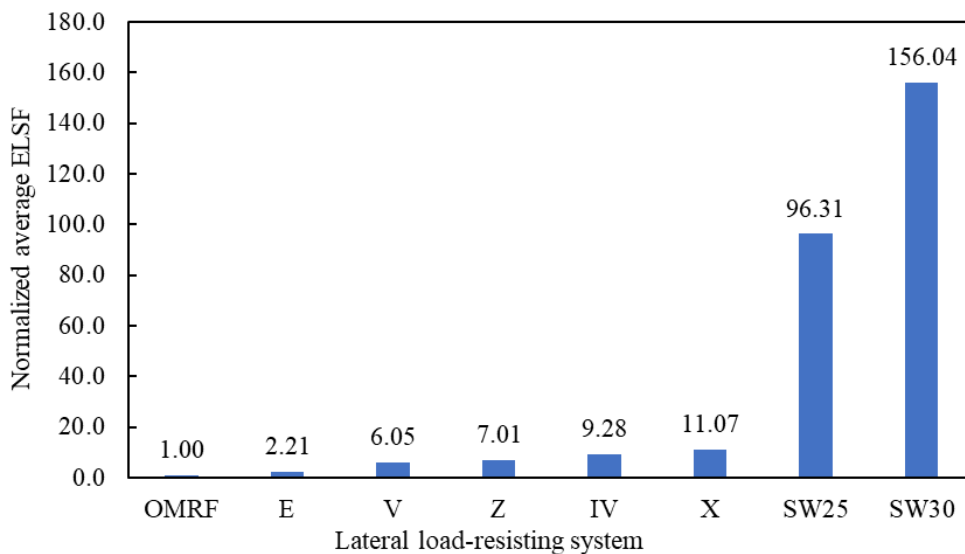


Fig. 15 Normalized average ELSFs of the frames having different LLRSs compared to OMRF

5. Proposition of ELSF values for the structures having different LLRSs

The ELSFs of steel frames having different LLRSs have been found using pushover analysis. The average values of ELSFs calculated for 720 models (8 LLRS types, each type is analyzed applying 90 cases considering different influenced variables) are shown in Fig. 14 and the values of the normalized average ELSFs normalized to ELSF values of OMRFs ($K = 1$) are shown in Fig. 15. As can be seen, the frames having shear walls with a thickness of 30 cm (SW30) are stiffer than braced-frames and then SW25. Among the bracings, X-type CBFs are stiffer than others are.

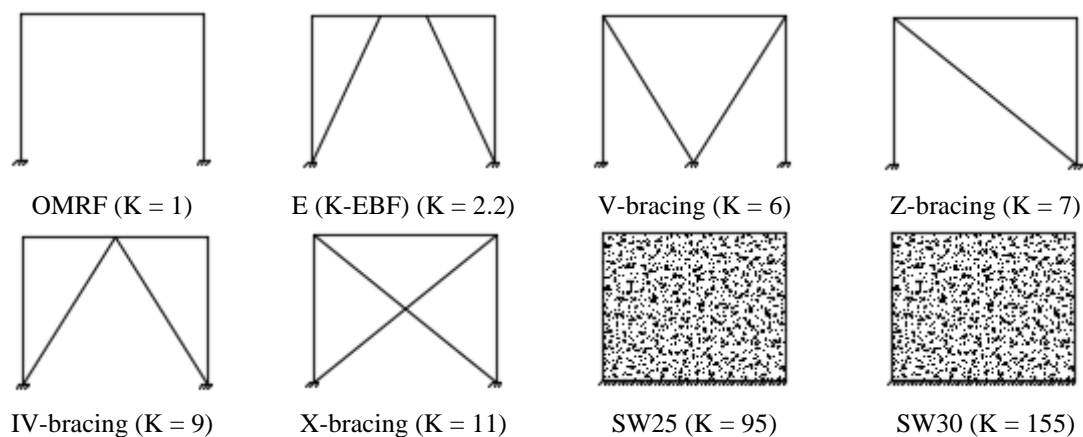


Fig. 16 Normalized average ELSFs for the examined frames having different LLRSs

In addition, OMRF has the minimum value of the ELSF. Fig. 15 demonstrates the comparison of ELSFs of frames having different LLRSs normalized to ELSF of OMRF. The obtained results show that the ELSF of SW30 is about 155 times, and SW25 is about 95 times larger than ELSF of OMRF.

As compared in Figs. 15 and 16, the obtained results for the normalized average ELSFs of steel frames having different LLRSs normalized to that of OMRF as a base (1) are about 2.2, 6, 7, 9, 11, 95, 155 for K-EBF (E), V-bracing, Z-bracing, inverted V-bracing, X-bracing, shear wall with thickness of 25 cm (SW25) and shear wall with thickness of 30 cm (SW30), respectively. Among the braced-frames, X-braced-frames have the maximum ELSF, about 10 times more than OMRF, while OMRFs provide the minimum ELSF among all LLRSs, and the frames supported by shear walls have ELSFs between 100 to 150 times more than OMRFs. Note that these values have been extracted for 720 frames having different LLRSs with different numbers of high, numbers of spans, story heights, and span lengths. For the case of the single-story single-span case, the ELSF values are given in Table 2.

6. Conclusions

To assess the elastic lateral stiffness factors (ELSFs) of the steel structure frames having different lateral load-resisting systems (LLRSs), first, 720 steel frame models were analyzed and designed using equivalent lateral force (ELF) method, then by applying the pushover analysis method, the results of all models have been analyzed, compared and evaluated, finally the effects of a number of parameters influencing on the ELSF including different LLRSs, span length, number of stories, number of spans and story height are investigated.

The calculations and analyses indicate that:

- The shear walls are stiffer than concentrically and eccentrically bracings (as it was expected), and among the bracings, X-bracing has the maximum ELSF. OMRF provides the minimum ELS among all LLRSs.
- By increasing the span length of the structure, the ELSs of all types of LLRSs increase.
- Increasing the number of stories causes a decrease in the ELSFs of all types of LLRSs.

- The ELSFs of the steel braced-frames and OMRFs increase when the number of spans is increased.
- As the story heights of structures increase, the ELSFs decrease.

References

- ACI-318-14 (2014), "Building code requirements for structural concrete and commentary", American Concrete Institute, U.S.A.
- ASCE 7-10 Code, (2010), "Minimum design loads for buildings and other structures", American Society of Civil Engineers/SEI, Structural Engineering Institute, Standard ASCE/SEI 7-10, Reston, Virginia, U.S.A.
- ASCE 41-13, (2013) "Seismic evaluation and retrofit of existing buildings", American Society of Civil Engineers, Standard ASCE/SEI 41-13, Reston, Virginia, U.S.A.
- Azam, S.K.M. and Hosur, V. (2013), "Seismic performance evaluation of multistoried RC framed buildings with shear wall", *Int. J. Sci. Eng. Res.*, **4**(1), 1-6.
- Baikerikar, A. and Kanagali, K. (2014), "Study of lateral load resisting systems of variable heights in all soil types of high seismic zone", *Int. J. Res. Eng. Technol.*, **3**(10), 109-119.
- Dharanya A., Gayathri S. and Deepika M. (2017), "Comparison study of shear wall and bracings under seismic loading in multi-storey residential building", *Int. J. ChemTech Res.*, **10**(8), 417-424.
- Hassan, M.S., Salawdeh, S., Hunt, A., Broderick, B.M. and Goggins J. (2018), "A study on detailing gusset plate and bracing members in concentrically braced-frame structures", *Adv. Comput. Des.*, **3**(3), 233-267. <http://doi.org/10.12989/acd.2018.3.3.233>.
- Farghaly A.A. (2016), "Seismic assessment of slender high rise buildings with different shear walls configurations", *Adv. Comput. Des.*, **1**(3), 221-234. <http://doi.org/10.12989/acd.2016.1.3.221>.
- Hashemi, S.S., Sadeghi, K., Fazeli, A. and Zarei, M. (2019), "Predicting the weight of the steel moment-resisting frame structures using artificial neural networks", *Int. J. Steel Struct.*, **19**(1), 168-180. <https://doi.org/10.1007/s13296-018-0105-z>.
- Mohsenian, V. and Ali Nikkhoo, A. (2019), "Evaluation of performance and seismic parameters of eccentrically braced-frames equipped with dual vertical links", *Struct. Eng. Mech.*, **69**(6), 591-605. <http://doi.org/10.12989/sem.2019.69.6.591>.
- Rokhgar, N. (2014), "A comprehensive study on parameters affecting stiffness of shear wall-frame buildings under lateral loads", Ph.D. Dissertation, Rutgers University-Graduate School-New Brunswick, U.S.A.
- Tafheem, Z. and Khusru, S. (2013), "Structural behavior of steel building with concentric and eccentric bracing: A comparative study", *Int. J. Civil Struct. Eng.*, **4**(1), 12-19. 10.6088/ijcsr.201304010002.
- Thorat, S.R. and Salunke, P.J. (2014), "Seismic behaviour of multistorey shear wall frame versus braced-concrete frames", *Int. J. Adv. Mech. Eng.*, **4**(3), 323-330.
- Viet, T.T., Anh, V.Q. and Huynh, L.X. (2017), "Fuzzy analysis for stability of steel frame with fixity factor modeled as triangular fuzzy number", *Adv. Comput. Des.*, **2**(1), 29-42. <http://doi.org/10.12989/acd.2017.2.1.029>.
- Viswanath, K.G., Prakash, K.B. and Desai, A. (2010), "Seismic analysis of steel braced-reinforced concrete frames", *Int. J. Civil Struct. Eng.*, **1**(1), 114-122.