SEISMIC PERFORMANCE OF STEEL TALLBUILDINGS WITH OUTRIGGER SYSTEMIN NEAR FAULT ZONES

Mehrdad ABDI MOGHADAM
MSc Graduate, Kharazmi University, Faculty of Engineering, Tehran, Iran
mehrdad_brb@yahoo.com

Afshin MESHKAT-DINI
AssistantProfessor,Kharazmi University, Tehran, Iran
meshkat@khu.ac.ir

Abdol-Reza S.MOGHADAM
Associate Professor, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
mogadam@iiees.ac.ir

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ABSTRACT

As much as a building becomes taller, the stiffness of the structure plays a more important role than the other structural parameters of building. To reach the desirable stability for tall towers, it is necessary to increase the stiffness of structure. One of the best available ways to maintain the lack of stiffness is to use outrigger belt trusses between external columns. For high-rise buildings, particularly in the seismic active zones, this bracing system can be added to the structure. The main objective of this paper is to study the performance of a continuous three-story outrigger system which is used in a tall braced frame steel skeleton. For this purpose, three 30-story buildings with different configurations of outrigger systems have been selected and designed. The structural models have been designed according to the Iranian seismic code 2800 (3rd edition). For performing the non-linear time history analyses, the particular criterion for the selected strong earthquake records is the appearance of a coherent pulse or multiple pulse features in the velocity time history concerning with high amplitude factors and long period. The illustrated results of this research show that the response parameters of the studied structures subjected to near-field earthquake records are greater than those of far-field ones.Furthermore, the outrigger systems increase the base shear but decrease the drift and lateral deflection significantly. The reduction values in the lateral deflection are about 40% and 50% respectivelyfor the model with single top outrigger and the model with mid and top outriggers,respect to the model without any outrigger under influencing of strong records. Furthermore, the other response parameters would remain in the acceptable performance domain. Yet, an intensive concentration of the axial stress resultants were resulted in the perimeter column elements which would be caused by the action of outrigger systems.

INTRODUCTION

This research deals with the seismic response parameters of nonlinear dynamic behavior of steel tall buildings with outrigger frameworks. When a building becomes taller in height, the demand for general increase of structural stiffness will be an important design factor. The application of outriggers and belt trusses in tall buildings provides both goals of the enough stiffness and the reduction of seismicdrift. The magnitude of reduction in seismic drift depends on the flexural rigidity of the perimeter wide columns and stiffness of the belt truss system as well as locations of the outriggers. The usage of outriggers and belt trusses in structural skeleton of tall buildings is notaed as an effecient lateral resisting system, especially in zones near to active faults. Yet, It needs still to extended furtherstudiesonthe seismic response parameters of this type of resistant structures (Stafford smith, 1983. Seng Kian and Torany Siahaan, 2001. Kamgar and saadatpor, 2012).Nair 1987 proposed the idea of virtual outrigger system which entitled abelt truss anddescribes the composite structural action of floors and the truss lattices.

The existence of an overall robust flexural behavior for the outrigger braced high-rise buildings causes that effects of dynamic instability in seismic response of the perimeter wide columns and the diagonal bracing elements of the outrigger panels, would be decreased considerably. When subjected to strong earthquake events, the aforementioned effects are very importantto be notified in the structural design process. It was denoted several times that during the strong ground shakingsdue to powerful earthquakes, the overall seismic behavior of most of basic column elements and panel zones of moment resisting frames would strongly be influenced by both of the progressive effects of the stiffness deterioration and the strength degradation. The intensive appearance of these effects was also reported for the total seismic behavior of bracing elements of both of concentric and eccentric braced frames (Rutenberg and Tal, 1987.Nicoreac and Honderkamp, 2012. Lee and Tovar, 2014).

In recent destructive major earthquakes such as the Tabas 1978 and the Bam 2003 in Iran as well as the Northridge 1994 in California, the recorded strong near field ground motions caused many huge damages to buildingstructural skeletons (Alavi and Krawinkler,2000). The occurrence of the most structural damages was corresponding to the relatively short duration of impulsive motions which expose large amounts of kinetic energy to low, mid and high rise building structures. Furthermore, the destructive capabilitiesof powerful earthquake records have direct relationship with the emergence of coherent high amplitude velocity pulses in the time history. It was observed that great acceleration spikes and distinct feature of multi velocity pulse configurations are simultaneously displayed in time history of near field records, especially those ones which contain powerful forward directivity effects. As shown in Figure 1, the mentioned wave-like features can be viewed in the first temporal domain of the velocity time history of various strong earthquake records, (MovahedH. et al., 2014).

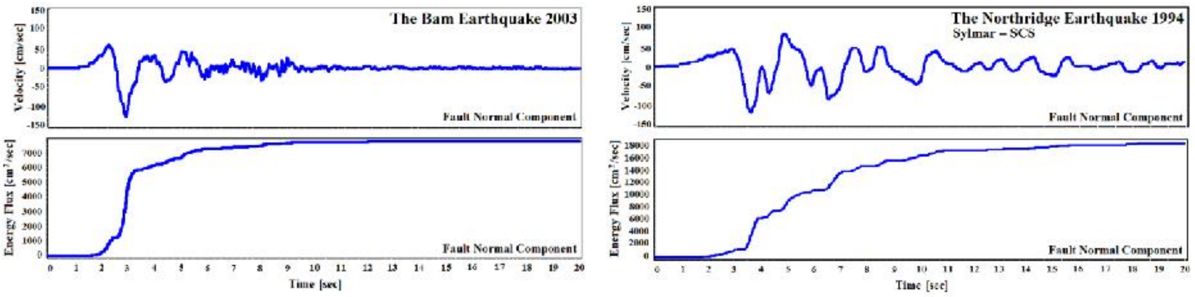


Figure 1: The velocity time history and input energy spectra for the Bam 2003 and SCS 1994 records

DESCRIPTION OF STUDIED MODELS

As shown in Figure 2, the studied models are three 30 story structures with different configurations of belt trusses. The outrigger panels have the height of three stories and a typical plan with six equal bays in both of x and y directions, was considered for the selected studied models. The floor to floor height is 3.5m which making total height of the structures as 105m. The applied dead load is considered as 500kg/m^2 and the supposed values for the live load are 200 kg/m^2 for all stories and 150 kg/m^2 for the roof respectively. The complete seismic designation process has been performed according to the Iranian seismic design code 2800. All of the sections of members and the connection zones of the studied models have been designed and controlled based on the Iranian national building code (steel structures - part 10). The shape and dimensions of all sections are shown in Tables 1 to 3 as well as Figure 3.The consideration of the principle of strong column and weak beam in all connection assemblages as well as the assessment of the adequate strength of panel zones have been adjusted and approved remarkably. All of the slab floors are 15 cm thick and the analytical definition of the probable nonlinear hinges for all three studied models was assigned based on Fema 356.

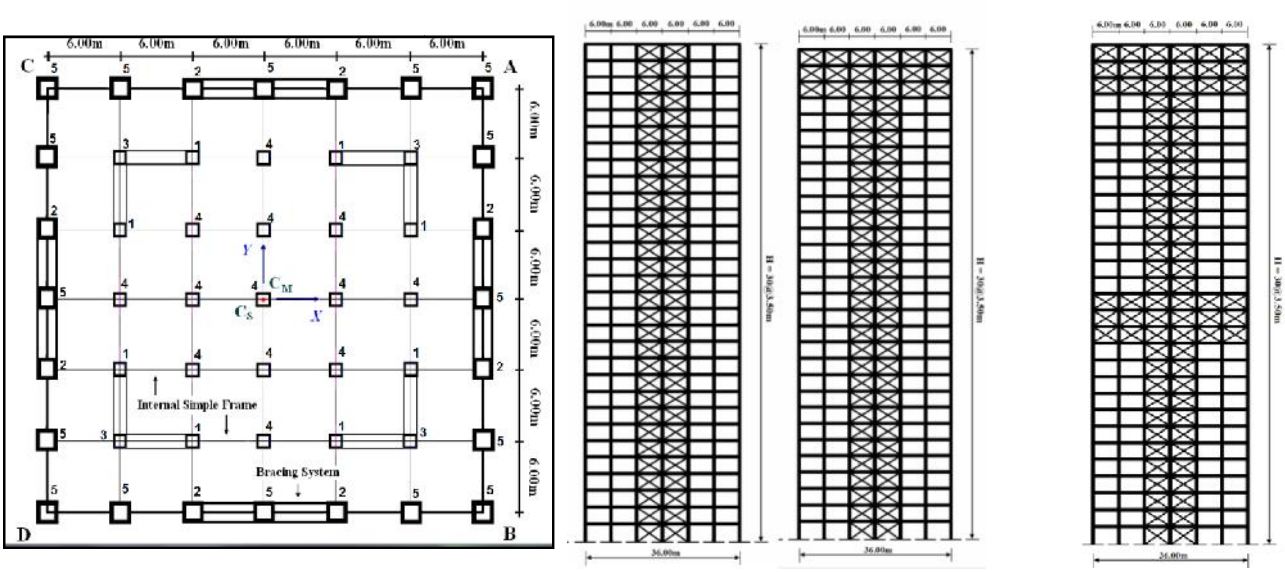


Figure 2.The plan and elevation of the studied structures, C_M: mass center, C_S: shear center

Table1. The beamsdesigned sections

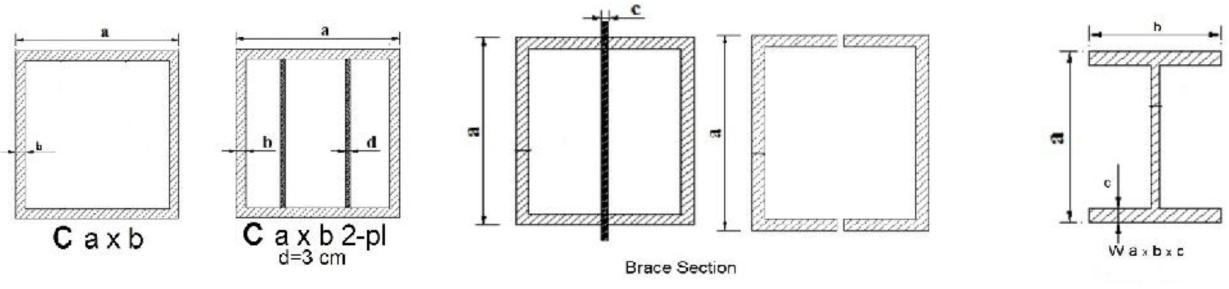
Story	Beam section
1_30	W40x20x1.5

Table2. The brace elements designed sections of all outrigger bents

story	1_5	5_10	10_15	15_20	20_25	25_30	MID OUTRIGGER	TOP OUTRIGGER
section	2UNP400	2UNP380	2UNP350	2UNP300	2UNP260	2UNP260	2UNP400+PL	2UNP350

Table 3. The column elements designed section (cm)

1	2	3	4	5
C100 x 3.5-2PLY	C90 x 3.5-2PLY	C80 x 3.5-2PLY	C70 x 3	C65 x 2
C80 x 3.5-2PLY	C80 x 3.5-2PLY	C70 x 3-2PLY	C65 x 2	C60 x 2
C70 x 3-2PLY	C70 x 3-2PLY	C70 x 2.5	C60 x 2	C50 x 1.5
C70 x 2.5	C70 x 2.5	C65 x 2.5	C50 x 1.5	C45 x 1.5
C60 x 2	C60 x 2	C60 x 2	C45 x 1.5	C40 x 1.5
C55 x 1.5	C60 x 2	C55 x 1.5	C40 x 1.5	C35 x 1.5



(a) (b) (c)

Figure 3.(a) Columns section, (b) Braces section, (c) Beams section

THE ENSMBLE OF CHOOSEN EARTHQUAKE RECORDS

A great number of nonlinear dynamic time history analyses were conducted for the studied models subjected to an ensemble of free field recorded pulse type ground motions.The particular criterion for selected strong earthquake records was appearance of pulse or a multiple pulse features in the velocity time history concerning with high amplitude factors and long period.It is worth noting that there are surpassing forward directivity effects in the time history of the selected earthquake records, with the exception of the MRP event in Table 4. These effects are along with the appearance of pulse type features in the velocity time history. Hence, a various types of long period and high amplitude velocity pulses as well as large acceleration spikes can be observed in the time histories of the selected records. The records and feature of them are noted in Table 4.

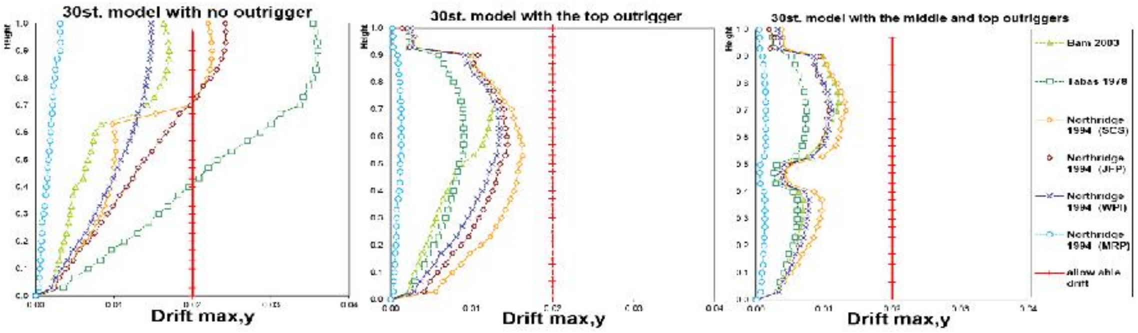
Table4. Seismological features of the selective records

Ground Motion	Component	Duration (sec)	PGA (g)	PGV (cm/s)	PGD (cm)	Magnitude	PGV/PGA (sec)	PGD/PGV (sec)
						M_W		
Bam 2003 (Bam - 1.0 km)	LN	30	0.635	59.6	20.7	6.6	0.09	0.34
	TR		0.793	123.7	37.4		0.16	0.3
	UP		0.999	37.66	10.11		0.03	0.26
Tabas 1978 (Tabas – 3.00km)	LN	30	0.836	97.7	39.9	7.4	0.12	0.4
	TR		0.851	121.3	94.5		0.14	0.78
	UP		0.688	45.5	17		0.06	0.37
Northridge 1994 (SCS -6.20km)	LN	30	0.897	102.23	45.28	6.7	0.12	0.44
	TR		0.612	117.47	54.16		0.19	0.46
	UP		0.586	34.59	25.63		0.06	0.74
Northridge 1994 (JFP -6.10km)	LN	30	0.593	99.1	23.96	6.7	0.17	0.24
	TR		0.424	105.95	50.69		0.25	0.48
	UP		0.399	33.91	8.89		0.08	0.26
Northridge 1994 (WPI-7.10km)	LN	30	0.325	67.4	16.1	6.7	0.21	0.24
	TR		0.455	92.8	56.7		0.21	0.61
	UP		0.29	37.2	13.3		0.13	0.36
Northridge 1994 (MRP - 28.00 km)	LN	30	0.19	20.2	4.79	6.7	0.11	0.24
	TR		0.29	20.7	4.24		0.07	0.2
	UP		0.16	7.9	0.9		0.05	0.11

RESPONSE PARAMETERS OF THE STUDIED MODELS

One of the mostimportant response parameters which controls the design process of tall building is the seismic drift which the corresponding curves are illustrated in Figure 4. The cures are plotted for the point A of the plan.It is denoted that for the studied model with no outrigger, the maximum drift was happened at the top zone of the structure in relatively upper numerical domain respect to the allowable limit. Furthermore, the minimum values obtained for the drift in other two models were occurred almost in the outriggers locations as well as significant decreases respect to those ones corresponding to other floor levels. Yet, the computed structural response parameters due to powerful records entitled SCS and JFP due to the Northridge 1994 earthquake, would take place in the highest analytical limits. Obviously, this is because of the existence a continuous configuration of long period multiple pulses in the velocity time history of the record.

To demonstrate the effect of belt truss in the maximum drift reduction, this parameter was evaluated for JFP record. In the model without belt truss the maximum response of drift is about 0.024 which the permissible limit was not fulfilled.According to assess the seismic response parameters of the more stiffenedstructural model by adding a belt truss at the top of the building skeleton, the mentioned value is reduced to 0.014.The placed belt truss at the top of the structure would cause 42 percent reduction in the maximum drift parameter. For the studied model with two belt trusses placed at both of the mid and top levels, the maximum calculated drift which the structure has experienced is equal to 0.011. In this case, 54 percent reduction has been achieved numericallyas compared to the model with no belt truss.



(a) (b) (c)

Figure 4. Maximum drift parameter related to seismic response of the studied models at point A, (a) The model without any outrigger; (b) The model with the top outrigger; (c) The model with both middle and top outriggers.

In Figure 5 the response velocity spectrums corresponding to the ensemble of selective records are plotted. Vertical lines indicate the first mode of the studied structures. As can be seen in Figure 4, for the model with no belt truss, the maximum response drift has occurred under the Tabasrecord.By checking the velocity response spectrums in the Figure 5respect to the natural period of the structure without belt truss, itis observed that the highest component isdue to the Tabasrecord.Yet, thecorresponding maximum components obtained for the two other studied models are due to the SCS record.Generally, the existence of anessential relationship between the probable maximum response parametersubjected to an earthquake record and the location of the natural period axis of the structure which identified in the response velocity spectra, can be noted as the ability of the mentioned record which to cause the most damages in the resistant skeleton.

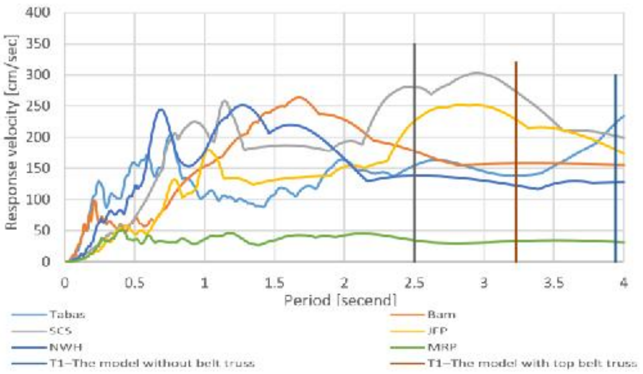
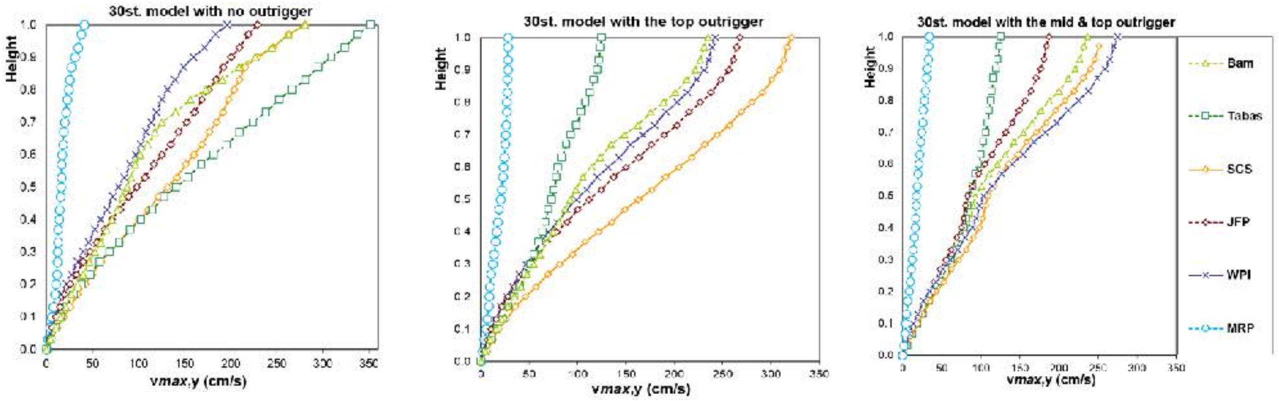


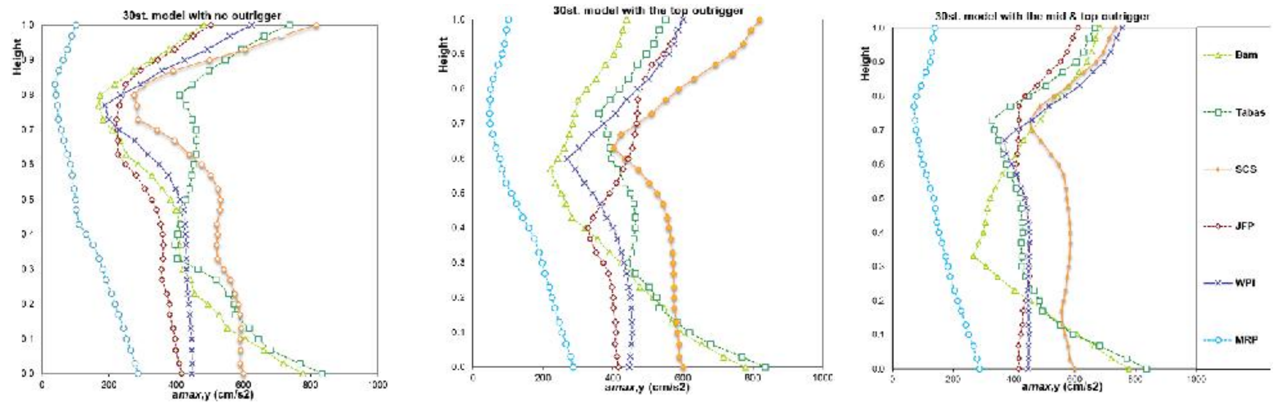
Figure 5.Response velocity spectra of the selected records



(a) (b) (c)

Figure 6. The normalized maximum relative velocityof the studied models at C_M,(a) The model without any outrigger; (b) The model with the top outrigger; (c) The model with both middle and top outriggers.

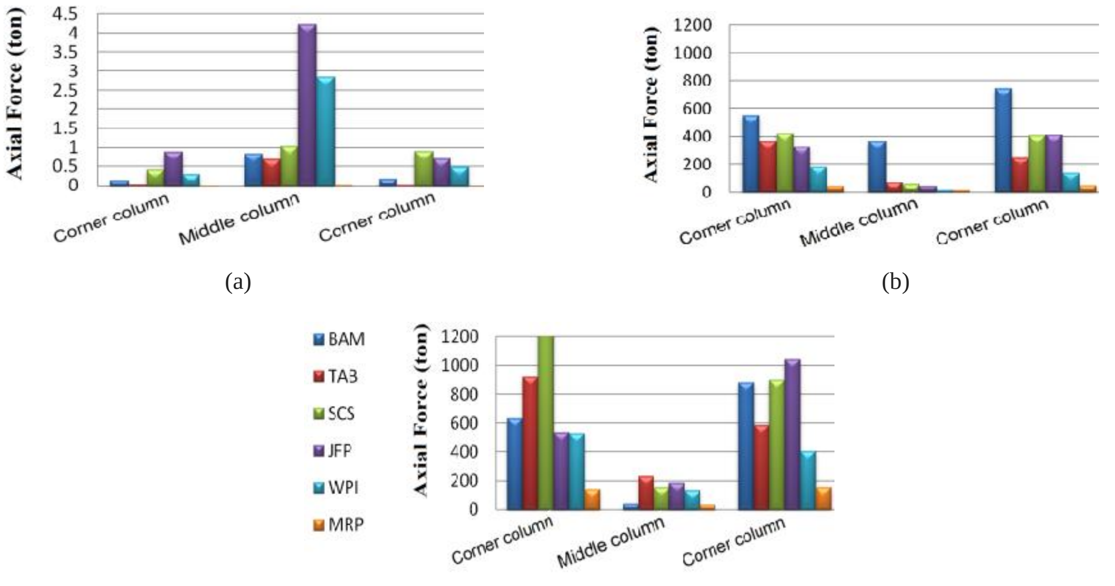
Figure 6 shows the evaluation of thenormalized maximum relative velocity of the studied structuresatC_M and in Y directionof the plan (Figure 1). The fault normal component i.e. TR component of each earthquake record was imposed in Y direction. Reviewing of the cures plotted in Figure 6indicates an uprising trend with height, which the highest values of relative velocity occur at the top levels of the structures. Besides, the mentioned increasing trend is found to be prevented using belt trusses. In the places where the belt trusses exist, the increasing velocity rate is decreased considerably.



(a) (b) (c)

Figure7.The normalized maximum absolute acceleration of analyzed structural models, (a) The model without any outrigger; (b) The model with the top outrigger; (c) The model with both middle and top outriggers.

It is noticeable that the differences in the physical characteristics of the recorded strong ground motions can lead to have remarkable differences in the structural response parameters. Figure 7illustrates the normalized absolute acceleration of floors during the time domain of the selected records. The curves are corresponding to the Y direction of the plan at C_M (Figure 1). As illustrated in Figure 7, theeffects of energized propagation of vertical componenthave an obvious emergenceespecially at the top floor levels which are caused by the analytical characteristics of higher modes of vibrations of tall buildings. This concept can be considered as a more accurate definition of lashing forces according to the Iranian seismic design code 2800. In addition, it can be noted that the story absolute acceleration is generally reduced when the outrigger beltsshould be added to the middle levels of the structure. However, for the studied model with two outriggers, the maximum absolute acceleration is decreased a few subjected to the most of the records in Table 4. For instance, this response parameter for the basic model with no outrigger has a total decrease of 9 percentages in comparison with the one obtained for the model with two outrigger belts. Yet, there is appropriate increase for the maximum absolute acceleration of the floors subjected to the SCS near-field record.



(a) (b)

(c)

Figure 8. Distribution of the axial force in perimeter columns of the studied models in Figure 2, (a) The model with no outrigger; (b) The model with the top outrigger; (c) The model with both middle and top outriggers

To investigate the effect of dynamic shear lag phenomena, the maximum axial forces in the corner and central columns of the four perimeter frames under influencing of the selected earthquake records of Table 4 have been evaluated.Beside Figure 8(a) which is related to the basic studied model, both Figure 8(b) and (c) display the maximum axial force distribution caused by the two supposed configurations of outrigger belts in the peripheral columns of the plan. Obviously, the use of belt truss system increases the overall stiffness of the lateral load resistant skeleton of tall buildings. Furthermoreit converts the external overturning moment caused by wind and earthquakes to reversal axial forces in the peripheral columns. Evaluating the seismic behavior of three 30-story studied models of Figure 2indicates that the existence of the quasi-rigid action of outriggers as well as the appearance of strong dynamic shear lag effects, increase the axial force resultants in the corner columns considerably. It was also observed that the both dynamic effects of seismic wave propagation and modal behavior, are affected by thethree-component powerful near-field records which would lead to increase in asymmetric distribution of axial forces in the columns of four perimeter frames surrounding the plan.

CONCLUSION

In this research, the seismic response parameters of steel tall buildings with the structural composition of peripheral braced framesas well as stiffenedbelt trusses have been evaluated.Conceptual assessment of the analytical results denotes that ignoring the use of belt trusses would lead to bigger drift amounts especially at the upper floor levels. In this case, the seismic performance level of main structural elements may hit the life safety limit. Belt trusses significantly diminish drift amounts. Yet, the other structural response parameters which obtained subjected to powerful records which contain forward directivity effects, would take place in the highest analytical limits as well as upper seismic performance levels too. Obviously, this is because of the existence a continuous configuration of long period and high amplitude coherent velocity pulses and energized acceleration spikes in the time history or the record. Having a general assessment on this research results, it is denoted that the application of outrigger belts in the lateral load resistant structure of tall buildings causes a considerable increase in the lateral stiffness and control the drift response parameter efficiently. Furthermore, the other response parameters would remain in the acceptable performance domain.

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