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EFFECT OF STRUCTURE LATERAL SYSTEM AND IRREGULARITY ON THE FUNDAMENTAL TIME PERIOD OF STEEL STRUCTURE

M. O. ABOELMAGED[1], N. Z. AHMED[2], M. N. ABDELMOOTY[3]
AND W. A. ATTIA[4]

ABSTRACT

The time period of structures has a significant effect on seismic forces calculations. However, most of the design code use an approximate empirical formula that depends mainly on building height, for time period estimation. The aim of this study is to investigate the effect of lateral load resisting systems and irregularities of building configuration on the fundamental period of vibration for steel structures. For this purpose, steel buildings with different lateral systems and irregularities were selected. 36-Moment Resisting Frames (MRFs), 108-Concentric Braced Frames (CBFs) and 68-Eccentric Braced Frames (EBFs) were studied using ETABS software. Three heights were considered; 5, 8, and 12 story and three types of irregularity were investigated; vertical, horizontal and combined irregularities. After full analysis and optimum design for buildings, the results of the fundamental periods of vibration of this study were compared with the time period recommended by different international design codes and standards. The comparison showed that the lateral system and building irregularity have a significant effect on the fundamental period of vibration for the buildings with the same height. It is recommended that the code equation for irregular steel buildings be investigated further.

KEYWORDS: Fundamental time period, Irregularity; EBF, CBF, and MRF, Modal analysis, Lateral system.

1. INTRODUCTION

In design codes, calculation of the seismic loads requires the estimation of the fundamental period of the structure. There are various methods that can be used to estimate the fundamental period. The most accurate way of determining the natural

[1] Ph.D. Candidate, Structural Engineering Department, Faculty of Engineering, Cairo University, Egypt
mohanad.aboelmaged92@eng1.cu.edu.eg
[2] Assistant Professor, Structural Engineering Department, Faculty of Engineering, Beni Suef University, Egypt.
[3] Professor, Structural Engineering Department, Faculty of Engineering, The American University in Cairo, Egypt.
[4] Professor, Structural Engineering Department, Faculty of Engineering, Cairo University, Egypt.

period is to perform an eigenvalue analysis. However, design codes recommend the use of empirical formulas to estimate the time period. Time period expressions were derived or verified from time periods measured during earthquakes [1].

Any empirical formula should be based on the periods of buildings measured from their motions recorded during earthquakes and the structures should be tested by strongly shaking and no significant deformation recorded in the inelastic range. Thus, the measured time period should reflect the undamaged stage of the building [2]. Furthermore, most of the design codes recommend lower bound expressions for the time period. These expressions are usually based on the geometrical properties such as height and width and can be very useful in the preliminary design stage before the member sizes are determined. However, these design codes do not consider building irregularity and the variation in structural systems into consideration. In Euro Code 8 [3], for buildings with heights of up to 40 m, the value of fundamental period *T* in seconds may be approximated by as shown in Eq. (1).

$$T = C_t . H^{3/4} \tag{1}$$

Where C_t is a factor depending on the lateral system and it is taken as 0.085 for Moment Resisting Frames (MRF) and 0.075 for Eccentric Braced Frames (EBF) and 0.05 for all other systems. *H* is the height of the building, in meter, measured from the top of the foundation. Egyptian Code for loads [4] uses the same approximate fundamental period (*T*) recommended by Euro Code 8, but the Egyptian Code for loads also proposes Eq. (2) to estimate the time period based on Rayleigh formula.

$$T = 2\pi\sqrt{\sum_{i=1}^{n} W_i\, U_i^2 / g \sum_{i=1}^{n} F_i\, U_i} \tag{2}$$

Where W_i is the portion of the total weight of the structure assigned to level *i*, F_i is the lateral force at level *i*, U_i is the deflection at level *i* relative to the base due to lateral forces, *g* is acceleration due to gravity, and *n* is the total number of stories in the building. The American Society of Civil Engineers [5] suggests the approximate fundamental period (T), in seconds, as given by Eq. (3).

$$T = C_t H^x \tag{3}$$

Where *x* depends on the lateral system and C_t = 0.0724, *x* = 0.8 for MRFs and C_t = 0.0731, *x* = 0.75 for EBFs. The Uniform Building Code [6] adopted a similar equation to that used in Euro Code 8 but with C_t 0.0853 for MRF and 0.0731 for EBF and 0.0488 for all other systems.

The investigation of the effect of structural system on the time period has been the subject of much previous research work. The fundamental period of steel moment-resisting frames, as well as braced steel frames, has been studied. The influence of the plan and bay dimensions, normalized stiffness and height of stories and various cross-sections as columns and beams on the fundamental natural frequency has been studied and, it is found that the fundamental natural frequency decreases with the increase in height and normalized stiffness of the building irrespective of the building's plan dimensions [7]. The structural performance and arrangement of bracing configurations under earthquake ground motions have been investigated [8-11]. The behaviour of vertically irregular moment resisting building frames have been studied and the reliability of the irregularity criteria provided by different codes [14].

In the review of the current researches and the empirical code equations, it became necessary to develop a better understanding of the response of steel structures with different systems during earthquakes and the effect of their behaviour on the time period of structures. The main objectives of this research are thus to:

- Study the effect of building structural systems on the time period
- Highlight the importance of the variations of horizontal and vertical irregularities of the time period

1.1 Code Provisions

The fundamental period of vibration for steel structures must be determined during the design stage in order to calculate the value of earthquake base shear.

According to the Egyptian code for loads [4], the empirical formula to calculate the fundamental period for moment resistant space frames is the same as Eq. (1). The formula considers only the building height. The above formula is applied to steel MRFs with height 15 m and 3×5 bays width. Furthermore, the optimized design was performed for the building and the time period results are displayed in Table 1 for the Code equation, modal analyses, and Rayleigh formula.

Table 1. Time period comparison.

Building type	ECP 201 2012, Eq. (1)	Rayleigh Eq., (2)	T_{Modal}
MRF1-5-3bay	0.648	1.554	1.551

Table 1 shows a significant variation between the values obtained from the code empirical formula and other results. This variation is due to nonstructural elements such as walls, which were not considered in the analysis model. In this paper using the Rayleigh formula Eq. (2) will be considered as the reference to compare the model result with the code equation to overcome the gap between the empirical code formula and the analysis result.

2. METHODOLOGY

2.1 Loads

The structures considered in the research are designed according to the Egyptian Code for Loads and Forces on Structures [4], Egyptian Code of Practice for Steel Construction and Bridges allowable stress design [12], and American Institute of Steel Construction [13]. Seismic design is based on the equivalent lateral force procedure of ECP 201. Table 2 shows the design parameters and loads.

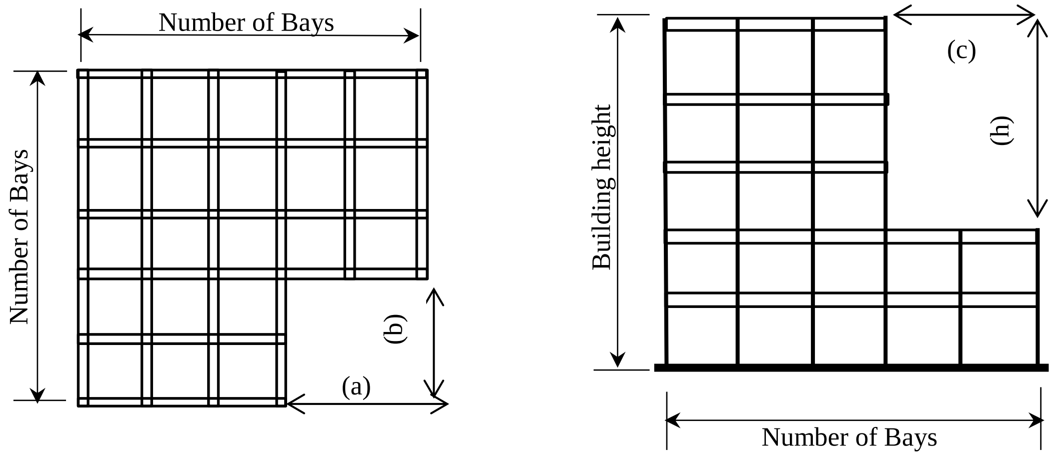
Table 2. Design parameters and loads.

Importance Factor	1
Soil class	C
Response spectrum type	1
live load (kN/m^2)	3
Dead load	100 mm concrete deck
Wall load (kN/m^2)	3
Ducts and ceiling load (kN/m^2)	1.5
Wind speed (m/s)	42

Steel members are designed using ST37 with 240 N/mm^2 minimum yield stress and 360 N/mm^2 tensile strength. European steel catalogue and some built-up sections are used in the design. A rigid diaphragm is assumed at each floor. ETABS software is used to perform analysis and design, with many iterations to reach the optimum design.

2.2 Model Geometry

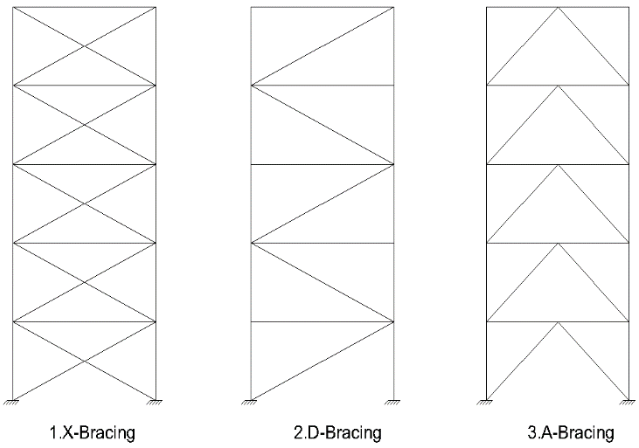
All considered structure frames are modelled in 3 heights 5, 8 and 12 stories, with typical story height of 3m. The model consists of 5 bays in the x-direction and 3, 6 and 8 bays in the y-direction with 6 m span of the bay. The bay is divided by secondary beams at 2 m in the y-direction. Three types of irregularity according to the Egyptian Code for Loads [4] are defined. Vertical, horizontal and combined irregularity are achieved in this research by removing bays from the horizontal and vertical projection for each building to comply with code requirements. Figure 1 shows the vertical and horizontal irregularity concept. The number of bays removed to achieve horizontal irregularity are marked as (a) and (b) while (h) and (c) are the number of stories and bays removed to achieve vertical irregularity.



a) Horizontal irregularities b) Vertical irregularities

Fig. 1. Horizontal and vertical irregularity concept.

The naming of each structure starts with frame type MRF, CBF or EBF followed by the number of stories, then the number of bays and type of irregularity (Ver) for vertical irregularity, (Hor) for horizontal irregularity and (Com) for combined irregularity. For example, MRF-8-6bay-Hor means moment resisting frame with 8 stories height, 6 bays in the y-direction and horizontal irregularity. An additional number is added for CBF and EBF, which refers to the bracing configuration, one for X bracing, two for A bracing and three for D bracing in CBF and Z bracing in EBF, number one is excluded from EBF. Figures 2 and 3 show the bracing configuration.



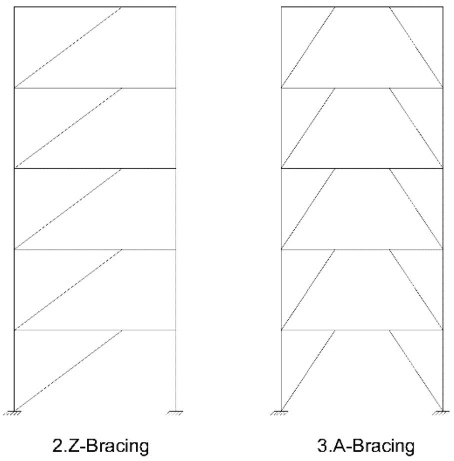
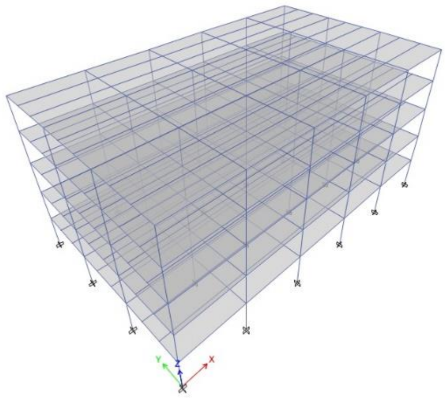
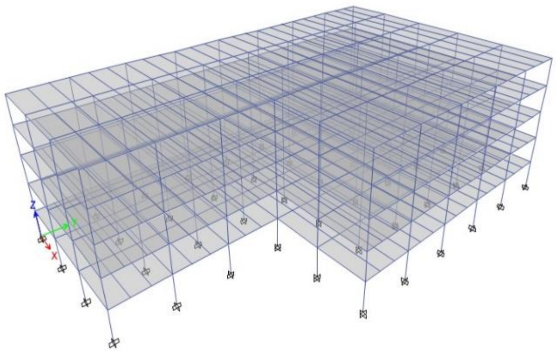


Fig. 2. CBF Bracing configuration Fig. 3. EBF Bracing configurations

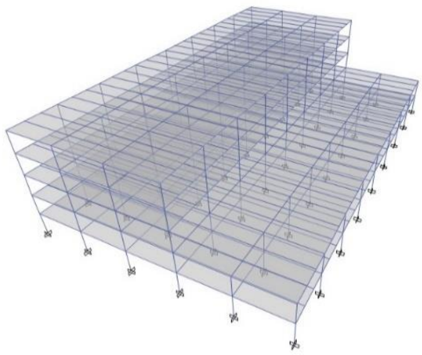
Figures 4, 5, and 6 show the configuration sample for 36 MRF models, 108 CBF models, and 68 EBF models.



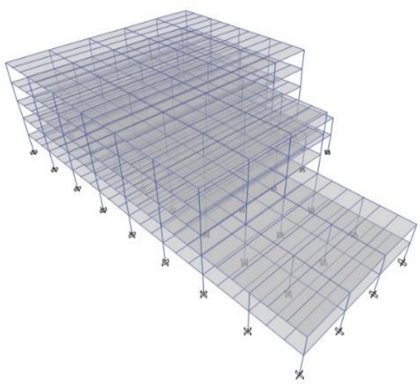
(a) MRF-5-3bay



(b) MRF-5-8bay-Hor

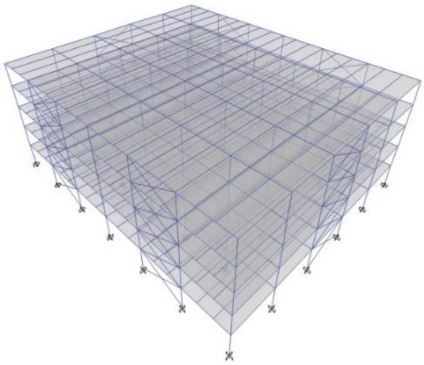


(c) MRF-5-8bay-Ver

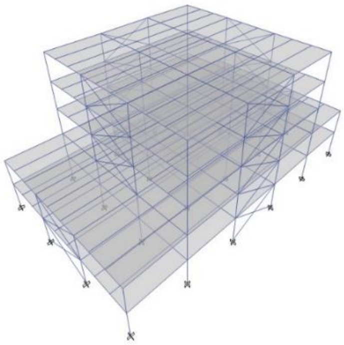


(d) MRF-5-8bay-Com

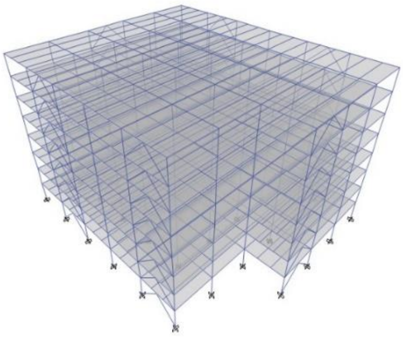
Fig. 4. MRF configuration.



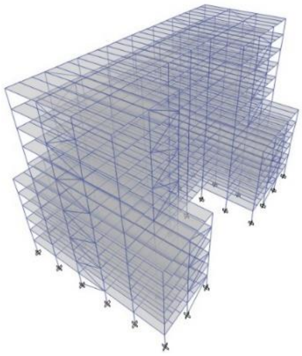
(a) CBF-1-5-6bay



(b) CBF-1-5-3bay-Ver

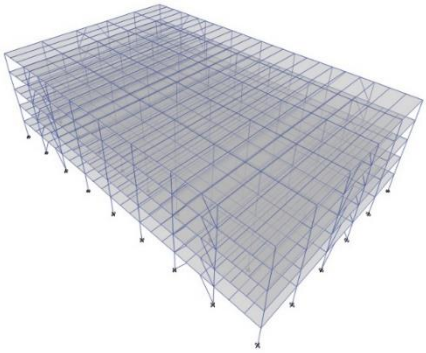


(c) CBF-2-8-8bay-Hor

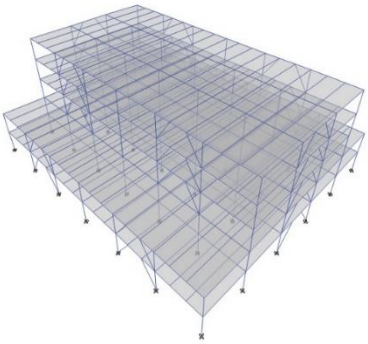


(d) CBF-3-12-8bay-Com

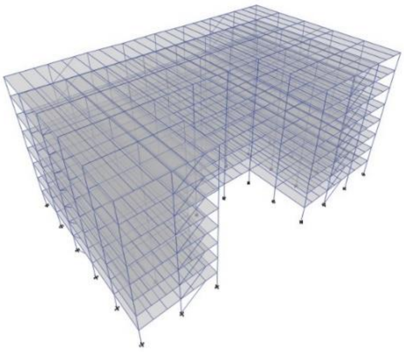
Fig. 5. CBF configuration.



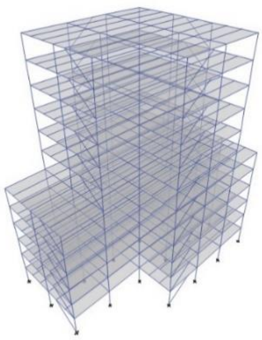
(a) EBF-2-5-8bay



(b) EBF-2-5-6bay-Ver



(c) EBF-3-8-8bay-Hor



(d) EBF-3-12-3bay-Com

Fig. 6. EBF configuration

3. RESULTS AND DISCUSSIONS

3.1 MRF Results

The fundamental periods for all MRFs sorted by the height of the structure, Rayleigh equation (Eq. (2)), and ETABS generated period, are summarized in Table 3. The effect of the irregularity on time period represented in the ratio between the time period for irregular building T_i and the time period for regular building T_{basic}.

Table 3. MRF comparison table.

Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}
MRF-5-3bay	1.554	1.551	1
MRF-5-3bay-Hor	1.523	1.520	0.98
MRF-5-3bay-Ver	1.450	1.448	0.934
MRF-5-3bay-Com	1.372	1.371	0.884
MRF-5-6bay	1.602	1.559	1
MRF-5-6bay-Hor	1.591	1.589	1.019
MRF-5-6bay-Ver	1.498	1.496	0.96
MRF-5-6bay-Com	1.493	1.497	0.96
MRF-5-8bay	1.616	1.614	1
MRF-5-8bay-Hor	1.606	1.603	0.993
MRF-5-8bay-Ver	1.513	1.512	0.937
MRF-5-8bay-Com	1.548	1.551	0.961
MRF-8-3bay	2.487	2.484	1
MRF-8-3bay-Hor	2.373	2.370	0.954
MRF-8-3bay-Ver	2.134	2.131	0.858
MRF-8-3bay-Com	2.209	2.207	0.888
MRF-8-6bay	2.577	2.574	1
MRF-8-6bay-Hor	2.537	2.534	0.984
MRF-8-6bay-Ver	2.237	2.235	0.868
MRF-8-6bay-Com	2.444	2.445	0.95
MRF-8-8bay	2.591	2.588	1
MRF-8-8bay-Hor	2.571	2.568	0.992
MRF-8-8bay-Ver	2.251	2.249	0.869
MRF-8-8bay-Com	2.489	2.490	0.962
MRF-12-3bay	3.226	3.222	1
MRF-12 -3bay-Hor	3.071	3.068	0.952
MRF-12 -3bay-Ver	2.684	2.681	0.832
MRF-12 -3bay-Com	2.746	2.746	0.852
MRF-12-6bay	3.392	3.388	1
MRF-12 -6bay-Hor	3.304	3.302	0.975
MRF-12 -6bay-Ver	2.722	2.718	0.802

Table 3. MRF comparison table, (Cont.)

Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}
MRF-12 -6bay-Com	3.017	3.026	0.893
MRF-12-8bay	3.468	3.464	1
MRF-12 -8bay-Hor	3.324	3.327	0.96
MRF-12 -8bay-Ver	2.720	2.717	0.784
MRF-12 -8bay-Com	3.244	3.246	0.937

The MRF buildings with horizontal irregularity present results that are close to the regular building even with bays and height change. However, the vertical and combined irregularity present results that are lower than the regular building. This variation increases with height increase as shown in the results of Figs. 7, 8, and 9.

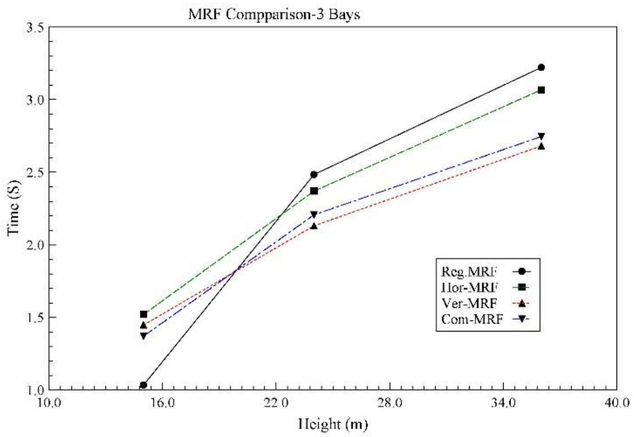


Fig. 7. MRF 3 bays comparison.

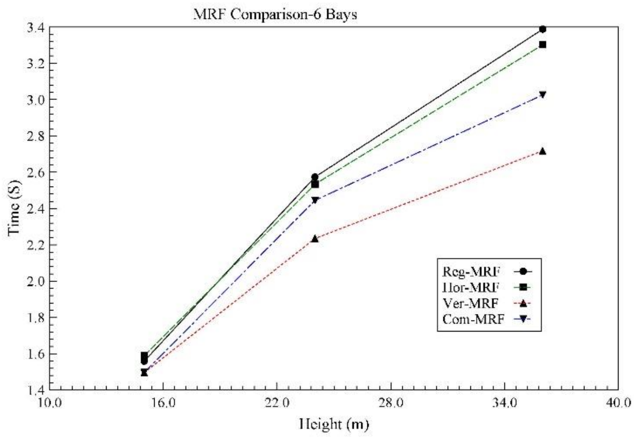


Fig. 8. MRF 6 bays comparison.

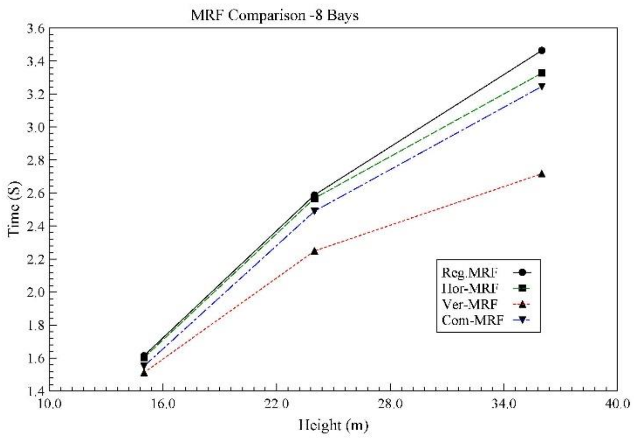


Fig. 9. MRF 8 bays comparison.

3.2 CBF Results

The fundamental periods for all CBFs sorted by the height of the structure, Rayleigh equation (Eq. (2)), and ETABS generated period, are summarized in Table 4. The effect of the irregularity on time period represented in the ratio between the time period for irregular building T_i and the time period for regular building T_{basic}.

Table 4. CBF comparison table.

Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}	Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}
CBF1-5-3bay	0.9066	0.906	1	CBF1-8-3bay	1.5502	1.549	1
CBF1-5-3bay-Com	0.7128	0.712	0.786	CBF1-8-3bay-Com	1.2817	1.281	0.827
CBF1-5-3bay-Hor	0.8665	0.866	0.956	CBF1-8-3bay-Hor	1.5039	1.503	0.97
CBF1-5-3bay-Ver	0.7313	0.73	0.806	CBF1-8-3bay-Ver	1.2873	1.286	0.83
CBF1-5-6bay	1.1434	1.142	1	CBF1-8-6bay	1.8603	1.86	1
CBF1-5-6bay-Com	0.9617	0.961	0.842	CBF1-8-6bay-Com	1.6081	1.608	0.865
CBF1-5-6bay-Hor	1.1468	1.146	1.004	CBF1-8-6bay-Hor	1.8494	1.849	0.994
CBF1-5-6bay-Ver	0.9650	0.964	0.844	CBF1-8-6bay-Ver	1.5841	1.584	0.852
CBF1-5-8bay	1.2689	1.268	1	CBF1-8-8bay	1.9641	1.964	1
CBF1-5-8bay-Com	1.0050	1.004	0.792	CBF1-8-8bay-Com	1.6326	1.633	0.831
CBF1-5-8bay-Hor	1.1815	1.181	0.931	CBF1-8-8bay-Hor	1.9135	1.913	0.974
CBF1-5-8bay-Ver	1.0649	1.064	0.839	CBF1-8-8bay-Ver	1.7073	1.708	0.87
CBF2-5-3bay	0.8268	0.826	1	CBF2-8-3bay	1.4154	1.415	1
CBF2-5-3bay-Com	0.6345	0.634	0.768	CBF2-8-3bay-Com	1.1715	1.172	0.828
CBF2-5-3bay-Hor	0.8168	0.816	0.988	CBF2-8-3bay-Hor	1.3021	1.301	0.919
CBF2-5-3bay-Ver	0.6658	0.665	0.805	CBF2-8-3bay-Ver	1.1734	1.174	0.83
CBF2-5-6bay	1.0804	1.08	1	CBF2-8-6bay	1.7379	1.738	1
CBF2-5-6bay-Com	0.8493	0.849	0.786	CBF2-8-6bay-Com	1.4809	1.482	0.853
CBF2-5-6bay-Hor	1.0077	1.007	0.932	CBF2-8-6bay-Hor	1.7391	1.739	1.001
CBF2-5-6bay-Ver	0.8486	0.848	0.785	CBF2-8-6bay-Ver	1.4751	1.476	0.849
CBF2-5-8bay	1.1792	1.179	1	CBF2-8-8bay	1.7908	1.797	1
CBF2-5-8bay-Com	0.8495	0.849	0.72	CBF2-8-8bay-Com	1.4446	1.453	0.809
CBF2-5-8bay-Hor	1.0794	1.079	0.915	CBF2-8-8bay-Hor	1.7073	1.716	0.955
CBF2-5-8bay-Ver	0.9203	0.92	0.78	CBF2-8-8bay-Ver	1.5195	1.525	0.849
CBF3-5-3bay	1.0348	1.034	1	CBF3-8-3bay	1.6563	1.655	1
CBF3-5-3bay-Com	0.8218	0.821	0.794	CBF3-8-3bay-Com	1.3526	1.352	0.817
CBF3-5-3bay-Hor	0.9921	0.991	0.958	CBF3-8-3bay-Hor	1.6277	1.627	0.983
CBF3-5-3bay-Ver	0.8422	0.841	0.813	CBF3-8-3bay-Ver	1.3913	1.39	0.84
CBF3-5-6bay	1.2580	1.257	1	CBF3-8-6bay	2.0291	2.107	1
CBF3-5-6bay-Com	1.0746	1.074	0.854	CBF3-8-6bay-Com	1.7410	1.817	0.862
CBF3-5-6bay-Hor	1.2600	1.259	1.002	CBF3-8-6bay-Hor	2.0381	2.117	1.005
CBF3-5-6bay-Ver	1.0596	1.058	0.842	CBF3-8-6bay-Ver	1.7503	1.827	0.867
CBF3-5-8bay	1.3840	1.383	1	CBF3-8-8bay	2.3999	2.663	1

Table 4. CBF comparison table, (Cont.)

Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}	Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}
CBF3-5-8bay-Com	1.1125	1.112	0.804	CBF3-8-8bay-Com	2.0987	2.387	0.896
CBF3-5-8bay-Hor	1.3828	1.382	0.999	CBF3-8-8bay-Hor	2.3813	2.666	1.001
CBF3-5-8bay-Ver	1.1852	1.184	0.856	CBF3-8-8bay-Ver	2.1172	2.387	0.896
CBF1-12-3bay	2.3351	2.334	1	CBF2-12-6bay-Ver	2.2979	2.3	0.862
CBF1-12-3bay-Com	1.9497	1.949	0.835	CBF2-12-8bay	2.7234	2.725	1
CBF1-12-3bay-Hor	2.3089	2.307	0.988	CBF2-12-8bay-Com	2.2703	2.273	0.834
CBF1-12-3bay-Ver	1.9431	1.942	0.832	CBF2-12-8bay-Hor	2.7576	2.759	1.012
CBF1-12-6bay	2.7268	2.726	1	CBF2-12-8bay-Ver	2.4128	2.416	0.887
CBF1-12-6bay-Com	2.2972	2.298	0.843	CBF3-12-3bay	2.3231	2.323	1
CBF1-12-6bay-Hor	2.7312	2.731	1	CBF3-12-3bay-Com	1.9950	1.995	0.859
CBF1-12-6bay-Ver	2.5907	2.59	0.95	CBF3-12-3bay-Hor	2.5080	2.507	1.079
CBF1-12-8bay	2.9854	2.986	1	CBF3-12-3bay-Ver	2.0033	2.003	0.862
CBF1-12-8bay-Com	2.4255	2.426	0.812	CBF3-12-6bay	2.9360	2.936	1
CBF1-12-8bay-Hor	2.9349	2.935	0.983	CBF3-12-6bay-Com	2.4949	2.496	0.85
CBF1-12-8bay-Ver	2.9696	2.969	0.994	CBF3-12-6bay-Hor	2.9889	2.989	1.018
CBF2-12-3bay	2.3146	2.315	1	CBF3-12-6bay-Ver	2.5348	2.536	0.864
CBF2-12-3bay-Com	1.9041	1.905	0.823	CBF3-12-8bay	3.0716	3.072	1
CBF2-12-3bay-Hor	2.2740	2.274	0.982	CBF3-12-8bay-Com	2.4152	2.418	0.787
CBF2-12-3bay-Ver	1.9139	1.915	0.827	CBF3-12-8bay-Hor	2.9845	2.985	0.972
CBF2-12-6bay	2.6676	2.669	1				
CBF2-12-6bay-Com	2.2732	2.276	0.853	CBF3-12-8bay-Ver	2.6131	2.616	0.852
CBF2-12-6bay-Hor	2.7238	2.725	1.021				

The CBF buildings with horizontal irregularity present results that are close to the regular building even with bays change but when the height increases the time period change slightly higher than the basic building. The vertical and the combined irregularity present results that are lower than the regular building. This variation increases with height increase as shown in Figs. 10, 11, and 12.

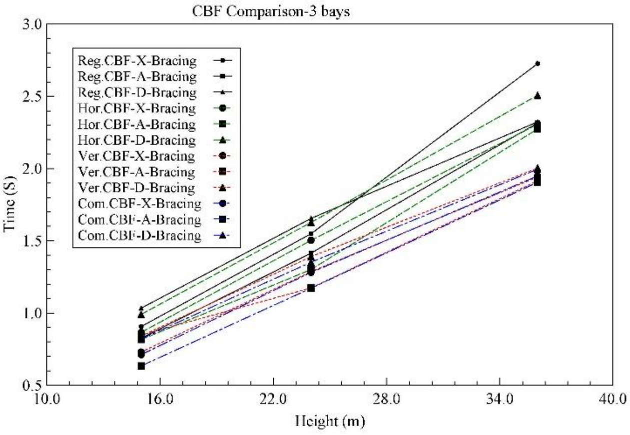


Fig. 10. CBF comparison 3 bays.

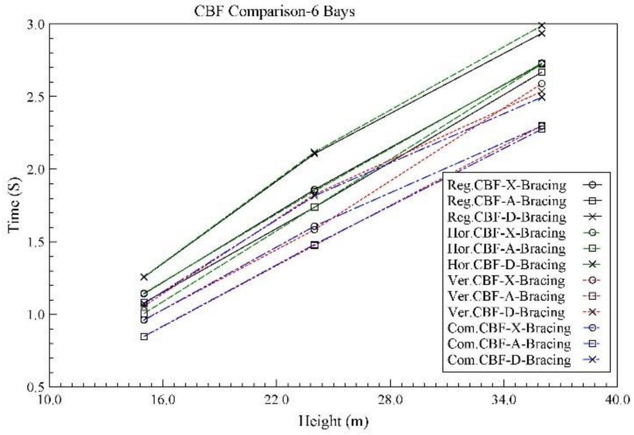


Fig. 11. CBF comparison 6 bays.

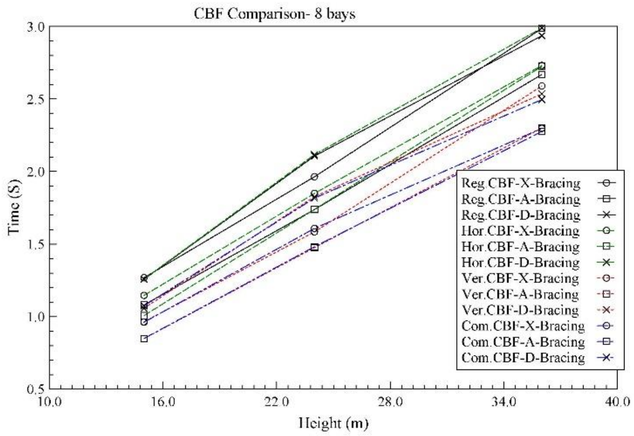


Fig. 12. CBF comparison 8 bays.

3.3 EBF Results

The fundamental periods for all EBFs sorted by the height of the structure, Rayleigh equation (Eq. (2)), and ETABS generated period, are summarized in Table 5. The effect of the irregularity on time period represented in the ratio between the time period for irregular building T_i and the time period for regular building T_{basic}.

Table 5. EBF comparison table.

Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}	Building type	Rayleigh Eq. (2)	T_{ETABS}	T_i/T_{basic}
EBF2-5-3bay	1.2366	1.234	1	EBF2-8-8bay-Hor	1.5164	1.514	1
EBF2-5-3bay-Com	1.1839	1.181	0.957	EBF2-8-8bay-Ver	1.4178	1.416	0.935
EBF2-5-3bay-Hor	1.2361	1.234	1	EBF3-8-3bay	1.5086	1.505	1
EBF2-5-3bay-Ver	1.1799	1.178	0.955	EBF3-8-3bay-Com	1.4420	1.448	0.962
EBF2-5-6bay	1.2047	1.203	1	EBF3-8-3bay-Hor	1.5472	1.544	1.026
EBF2-5-6bay-Com	1.1529	1.151	0.957	EBF3-8-3bay-Ver	1.4332	1.443	0.959

Table 5. EBF comparison table. (Cont.)

EBF2-5-6bay-Hor	1.1954	1.193	0.992
EBF2-5-6bay-Ver	1.1596	1.158	0.963
EBF2-5-8bay	1.1737	1.172	1
EBF2-5-8bay-Com	1.1985	1.196	1.02
EBF2-5-8bay-Hor	1.1727	1.171	0.999
EBF2-5-8bay-Ver	1.1297	1.128	0.962
EBF3-5-3bay	1.2731	1.27	1
EBF3-5-3bay-Com	1.1526	1.15	0.906
EBF3-5-3bay-Hor	1.2155	1.213	0.955
EBF3-5-3bay-Ver	1.1335	1.131	0.891
EBF3-5-6bay	1.2349	1.232	1
EBF3-5-6bay-Com	1.1376	1.136	0.922
EBF3-5-6bay-Hor	1.2288	1.227	0.996
EBF3-5-6bay-Ver	1.1473	1.145	0.929
EBF3-5-8bay	1.1808	1.179	1
EBF3-5-8bay-Com	1.1407	1.138	0.965
EBF3-5-8bay-Hor	1.2433	1.241	1.053
EBF3-5-8bay-Ver	1.1712	1.169	0.992
EBF2-8-3bay	1.4874	1.485	1
EBF2-8-3bay-Com	1.4319	1.428	0.962
EBF2-8-3bay-Hor	1.5209	1.518	1.022
EBF2-8-3bay-Ver	1.4043	1.402	0.944
EBF2-8-6bay	1.5187	1.518	1
EBF2-8-6bay-Com	1.4292	1.428	0.941
EBF2-8-6bay-Hor	1.5340	1.533	1.01
EBF2-8-6bay-Ver	1.4373	1.436	0.946
EBF2-8-8bay	1.5156	1.514	1
EBF2-8-8bay-Com	1.4320	1.429	0.944
EBF3-8-6bay	1.4408	1.439	1
EBF3-8-6bay-Com	1.3893	1.382	0.96
EBF3-8-6bay-Hor	1.4482	1.446	1.005
EBF3-8-6bay-Ver	1.3434	1.337	0.929
EBF3-8-8bay	1.4336	1.432	1
EBF3-8-8bay-Com	1.3802	1.371	0.957
EBF3-8-8bay-Hor	1.4406	1.432	1
EBF3-8-8bay-Ver	1.3647	1.359	0.949
EBF2-12-3bay	1.9116	1.908	1
EBF2-12-3bay-Com	1.7890	1.782	0.934
EBF2-12-3bay-Hor	1.8924	1.889	0.99
EBF2-12-3bay-Ver	1.7823	1.778	0.932
EBF2-12-6bay	1.9221	1.918	1
EBF2-12-6bay-Com	1.8239	1.817	0.947
EBF2-12-6bay-Hor	1.9286	1.922	1.002
EBF2-12-6bay-Ver	1.8102	1.805	0.941
EBF2-12-8bay	1.9162	1.913	1
EBF2-12-8bay-Com	1.8176	1.805	0.944
EBF2-12-8bay-Hor	1.8998	1.891	0.988
EBF2-12-8bay-Ver	1.7742	1.766	0.923
EBF3-12-3bay	1.8704	1.867	1
EBF3-12-3bay-Com	1.7426	1.736	0.93
EBF3-12-3bay-Hor	1.8828	1.88	1.007
EBF3-12-3bay-Ver	1.7186	1.764	0.945
EBF3-12-6bay	1.9294	1.926	1
EBF3-12-6bay-Com	1.7503	1.715	0.89
EBF3-12-6bay-Hor	1.8573	1.851	0.961
EBF3-12-6bay-Ver	1.7221	1.715	0.89

The EBF buildings with horizontal irregularity present results closer to the regular building even with bays change and sometimes have the same result. The vertical and combined irregularity present results lower than the regular building this variation increases with height increase as shown in Figs. 13, 14, and 15.

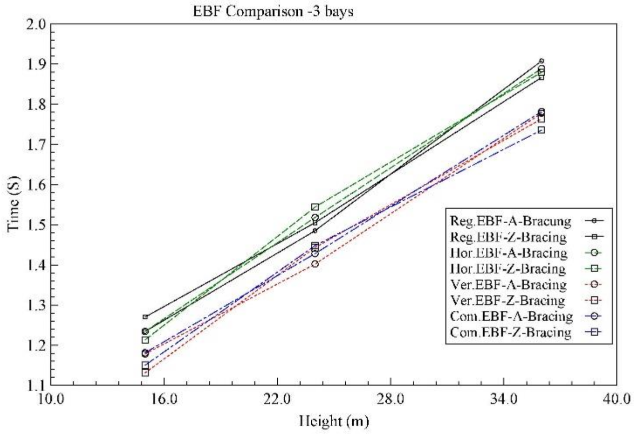


Fig. 13. EBF comparison 3 bays.

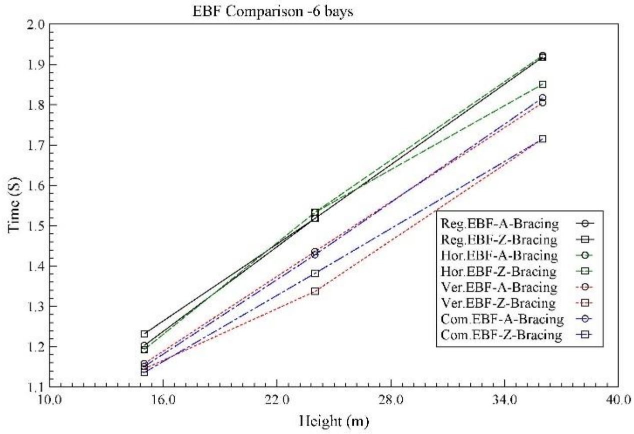


Fig. 14. EBF comparison 6 bays.

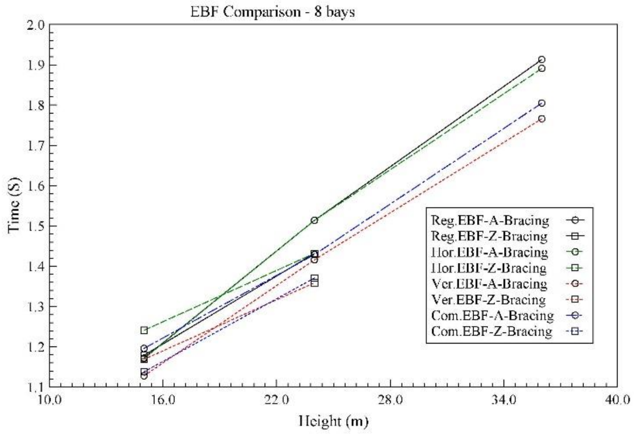


Fig. 15. EBF comparison 8 bays.

3.4 Lateral Systems Result Analysis

Other factors like buildings height, number of bays and irregularity are considered a common factor to illustrate the effect of the lateral system and bracing type on the fundamental time period. For buildings with 5-story height, the MRFs present a higher time period than other lateral systems. CBFs with D-bracing present the lower time period with 35.5% lower than MRFs. EBFs with Z-bracing present time period lower than MRFs by 24.2% but higher than CBFs. The A-shape bracing present the higher time period in CBFs. Figure 16 shows the previews result for the 5-story buildings.

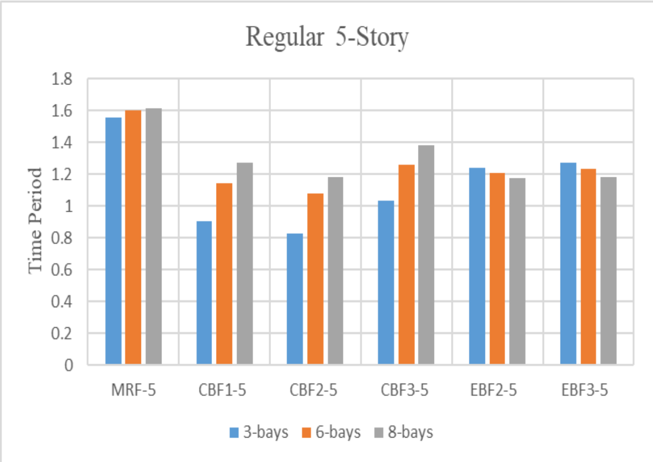


Fig. 16. Lateral systems comparison for 5 story buildings.

For buildings with an 8-story height, the MRFs present the higher time period than other lateral systems. EBFs with A-bracing present the lower time period with 42.7% lower than MRFs. CBFs with D-bracing present time period lower than MRFs by 35.5% but higher than EBFs. The A -shape bracing present the higher time period in CBFs. Figure 17 shows the previews result for 8 story buildings.

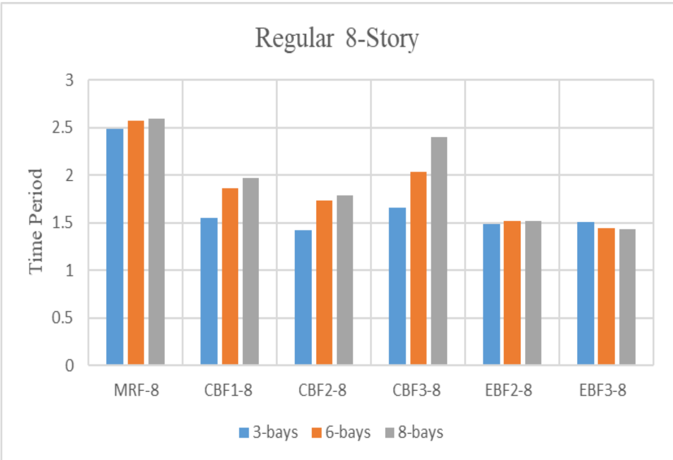


Fig. 17. Lateral systems comparison for 8 story buildings.

For buildings with 12-story height, the MRFs present the higher time period than other lateral systems. EBFs with A-bracing present the lower time period with 42.6% lower than MRFs. CBFs with D-bracing present time period lower than MRFs by 24.8% but higher than EBFs. The A -shape bracing present the higher time period in CBFs. The Z-shape bracing present a higher value in EBFs with slight variation than the A-shape bracing. Figure 18 shows the previews result for 12 story buildings.

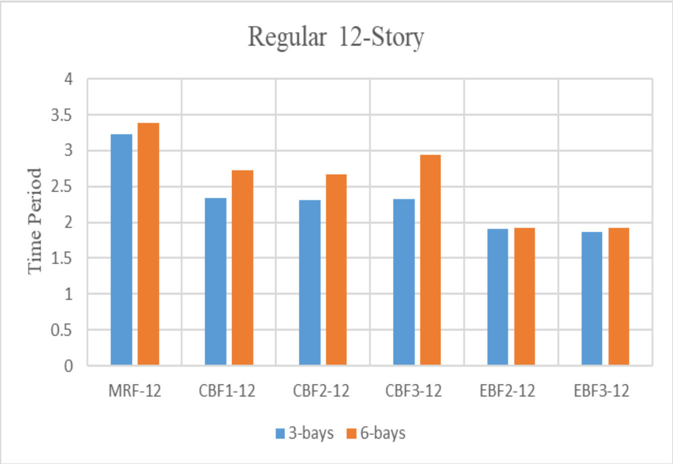


Fig. 18. Lateral systems comparison for 12 story buildings.

4. CONCLUSIONS

Based on the analysis and the optimum design of 36 MRFs, 108 CBFs, and 68 EBFs, the following conclusions can be drawn:

(1) The horizontal irregularity in buildings presents results closer to regular buildings with MRF and EBF but are slightly higher in CBF when the number of stories increases.

(2) The vertical irregularity in buildings presents result lower than regular buildings even when the number of stories and bays increase for all lateral systems.

(3) The combined irregularity in buildings present result lower than regular buildings, this difference appears in MRF and CBF more than EBF.

(4) MRFs present a higher time period for all heights.

(5) CBFs present time period lower than MRFs with 35.5% in buildings with 5 and 8 stories height and 24.8% in buildings with 12-story height, the D-shape bracing present the lower time period and A-shape the higher.

(6) EBFs present time period lower than MRFs with 24.2% for 5-story buildings, 42.6% for 8-story buildings and 42.7% for 12-story buildings, the Z-shape bracing present the lower time period.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

REFERENCES

1. Tremblay, R., "Fundamental Periods of Vibration of Braced Steel Frames for Seismic Design", Earthquake Spectra, Vol. 21, pp. 833-860, 2005
2. Goel, R.K., and Chopra, A.K., "Period Formulas for Moment-Resisting Frame Buildings", Journal of Structural Engineering, Vol.123, pp. 1454-1461, 1997.
3. Euro Code 8, "Design of Structures for Earthquake Resistance", European Committee for Standardization, 1998.
4. ECP 201, "The Egyptian Code for Loads and Forces in Construction and Buildings", Housing and Building National Research Center, Cairo, Egypt, 2012.
5. ASCE/SEI 7-10., "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, Virginia, 2010.
6. UBC, "Uniform Building Code", International Conference of Building Officials, 1997.
7. Cinitha, A., "A Rational Approach for Fundamental Period of Low and Medium Rise Steel Building Frames", International Journal of Modern Engineering Research, Vol. 2, pp. 3340-3346, 2012.
8. Sheikh, H., and A. Massumi "Effects of Bracing Configuration on Seismic Behavior of Tall Steel Structures Subjected to Earthquake Ground Motions", Proceedings of the 10th US National Conference on Earthquake Engineering, Anchorage, Alaska. 2014.
9. Amini, A., M. Majd, and M. Hosseini, "A Study on the Effect of Bracing Arrangement in the Seismic Behavior Buildings with Various Concentric Bracings by Nonlinear Static and Dynamic Analyses", Fifteenth World Conference on Earthquake Engineering, Lisbon, Portugal, 2012.
10. Pandit, L., and Shinde, R., "Study of Effect of Bracing on Critical Story of High-Rise Frame Structure", International Journal of Engineering Research and General Science, Vol. 3, 2015.
11. Hemmati, A., Kheyroddin, A., "Behavior of Large-Scale Bracing System in Tall Buildings Subjected to Earthquake Loads", Journal of Civil Engineering and Management, Vol. 2, pp. 206-216, 2013.
12. ECP 205, "Egyptian Code of Practice for Steel Construction and Bridges Allowable Stress Design", Housing and Building National Research Centre, Cairo, Egypt, 2001.
13. ANSI/AISC 360-10, "An American National Standard - Specification for Structural Steel Building", Chicago, Illinois, 2010.
14. Yousef, A. M., El-Metwally, S. E., and El-Mandouh., M. A., "Seismic Response of Vertically Irregular HSC Moment-Resisting Building Frames", Journal of Engineering and Applied Science, Vol. 57, No. 5, pp. 409-430, 2010.

تأثير النظام الإنشائي الجانبي وعدم الانتظام على زمن التردد الأساسي للمنشآت المعدنية

يدرس البحث تأثير النظام الجانبي وعدم الانتظام على زمن التردد الطبيعي للمنشـــآت المعدنية حيث تمت نمذجة ودراســة ٣٦ إطاراً مقاوماً العزوم (MRF) و١٠٨ شـكالات مركزيه التكتيف (CBF) و٦٨ شكالات لا مركزيه التكتيف (EBF) باستخدام برنامج اللإتابس، هذا وتم اعتبار ثلاثة ارتفاعات ٥ و ٨ و١٢ دور بالإضــافة الى ثلاثة انواع من عدم الانتظام وهى عدم الانتظام الرأســي والأفقي والمجمع، وبعد الانتهاء من التحليل والتصــميم الأمثل للمباني تمت مقارنة نتائج زمن التردد الطبيعي للمنشــآت مع نظائرها المســتخدمة بالأكواد والتي يعتمد معظمها على ارتفاع المبنى فقط واثبتت نتيجة البحث أن النظام الإنشائي الجانبي للمباني وعدم انتظام المبنى لهما تأثير كبير على زمن التردد الطبيعي للمباني ذات نفس الارتفاع.