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TO STUDY THE EFFECT OF DIMENSIONS OF OPENERS ON QUAKE BEHAVIOR OF RESISTANT CORES OF REINFORCED CONCRETE IN TALL BUILDINGS

M. Nejati[1], A. K. Bandeh Lou[1,*], A. Geramifard[2] and H. Ghaleb[1]

[1]Faculty of Engineering, Civil Engineering Department, Urmia Branch, Islamic Azad University, Urmia, Iran

[2]Faculty of Engineering, Civil Engineering Department, Marand Branch, Islamic Azad University, Marand, Iran

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ABSTRACT

From engineering point of view, a construction can be named tall when its height leads to significant influence of lateral forces of wind and earthquake on its design. Also, contrary to gravity forces, the effect of lateral forces on constructions is so variable and increases along with height. Three fundamental factors should be considered in designing all tall buildings are resistance, rigidity and stability. In designing tall buildings, construction system should be consistent with these requirements. The need to resistance is the dominant factor in designing short buildings. But, increasing the height leads to more necessity of rigidity and stability. Therefore, in a tall building structure, the stable system against lateral and erect loads differs in terms of height of structure, kind of use and nature of forces.

Author Correspondence, e-mail: ashkan72@rambler.ru

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In this study, first, central concrete core system was introduced as the lateral carrier system. Then, some studies were reviewed focusing on the behavior of this specific system. Meanwhile, building models and implementing analytic analyses using ETABS were presented. Finally, data were compared to find ideal results.

Keywords: concrete center core; lateral resisting system; time history analysis; rms results; modal analysis.

1- INTRODUCTION

From the beginning of human history, tall towers and buildings have been under attention. Tall building first made for defense, but by passing the times, they were used for other purposes. Growth and development of tall buildings was started in 1980s for residential and commercial aims. Constructing commercial buildings was a response to trade unions. This led to much pressure over horizontal space of cities. Tall buildings, due to special facial features, are used by commercial companies as a kind of advertising device. On the other hand, tourist and commercial associations were interested in constructing tall hotels in downtowns.

Advanced methods of designing and technology contributed in increase in height of steel structures. In 1913, Wool Worth with 60 stories was constructed in New York. In 1931, 102 storey building of Empire state was made in New York. This structure with 381 meters height, consisted of steel frames and preventing components. Although using reinforced concrete was started in the late 19^{th} century and beginning of 20 century, but it wasn’t used in tall buildings before end of WWI. In this period, development of tall structures with reinforced concrete was so slow and the tallest building was 23 storey building of Exchange Building in Seattle, USA.

Economical recession in 1930s was an end to the first period of building skyscrapers. The second period started after WWII and finding modern architectures. In this period, experts tried to introduce new structure systems, improved materials and new methods of designing. This process faced its end with the construction of 110 storey towers of World Trade Center in New York in 1973 with 412 meters height using framed tubes system, and also, 442 meter building of Sears

Tower in Chicago in 1974 using bundled tubes system.

1-1- Definition of tall buildings

Defining the characteristics of buildings categorized as tall structures is hard. Also, height of structure is proportional to different factors. In an area with just one storey building, a five storey building is considered tall. In Europe, a 20 storey building may be considered tall, but citizens of small cities may consider 6 storey buildings as tall structures. In cities like Chicago and Manhattan with very different tall buildings, a tall building is a 70 or 100 storey building. There is no consensus regarding what factor or factors lead to tall buildings. Perhaps, division line can be drawn from the point where static design inclines to dynamic design.

From structure design view, it is simpler to consider a structure "tall" when analysis and design are influenced by lateral forces. Lateral transformation is the amount of lateral shift in the top side of building to the base of building. When the height of building increases, wind and quake forces are dominating on structure. In the last two decades, considerable advances have been occurred in developing proper structure systems. Architectures gained more detailed information regarding natural forces, especially wind.

1-2- Literature review

To have a resistant design in face of severe earthquake, it is necessary to consider malleability and energy saving of structures. Therefore, it is required to pay attention to details of different methods of buildings analysis and the process of choosing different coefficients of designs in Regulations. Considering earthquakes in different parts of the world and huge casualties, experts try to insert other parameters in designing structures. One of the parameters is the amount of energy absorption in a building.

In 1984, Park-Eng Won, using damage index of Park-Eng, introduced a method in the course of designing structures. In this method, the main parameters in designing are base cutting and the intensity of earthquake.

Aki Yama (1985) presented a method for designing tall buildings which was based on spectrum of entering energy in terms of equivalent spectrum speed and optimal distribution of damage.

Kravinkler and Naser considered malleability and cumulative damage. In 2000, Shen and Elbas introduced a new damage index in which entering energy, wasted energy and features of buildings were considered.

1-3- Introducing concrete core

Cores in tall buildings are among the most important elements of resistant structures against horizontal and vertical loads. Generally, bending behavior of cores is similar to cutting walls. The difference between one core and wall is high twisting resistance of core. The aim of this section is to present this feature and explaining its effects. Armed concrete cores are consisted of some connected cut walls and make a cylinder shape section. Inertia resistance of concrete cores is so high, therefore, are capable of bearing lateral loads. There are different methods to analyze cores. Cores are divided to two general categories, open and closed sections. A core system can show open or closed behavior.

If a building faces twisting, the twisting rigidity of core plays an important part in twisting resistance. Ratios of length, height and thickness of cutting walls of buildings are in a way that put them in the category of thin wall beams. So, when core twists, its surface sections would change (figure 1). Because in the base of building, it is prevented from twisting, tensions of twisting will be appeared.

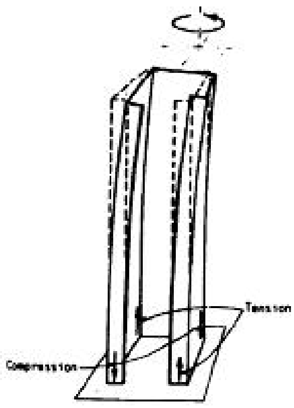


Fig.1. Twisted core

In this situation, it would be impossible to refuse tensions of twisting. Concrete of core openers leads to obstruction of sections and promotion of rigidity of twisting. The effect of cutting and bending should be considered in designing.

2- MODELING

This part considers introduction of structure models with or without opener in cores. Generally there are five different configurations. To study the effects of height; three different buildings were selected, i.e. 16, 18 and 20 stories. As a whole, 15 models were prepared. Structures were concrete made and every story had 3 meters. Openings were 6 meters to avoid effects of exit from center.

Buildings were residential. Dead load and live load were 700 and 200 kg/m2. The roof was double edges with 17 cm thickness. The general characteristics of used materials are presented in table 1. The building is in Urumieh, and the land is in category of 2.

Table 1. Characteristics of used materials

analytical features of materials		features of material design	
M mass of concrete	245 kg/m^3	(fc) 28 days of pressure resistance	250 kg/cm^2
W weight of concrete	2400 kg/m^3	(fy) concrete resistance	4000 kg/cm^2
(Ec) elasticity of concrete	2.5 x 10^{10} kg/m^2	(fys) concrete resistance	4000 kg/cm^2
v povason coeffcient	0.2		

To study opening effects and comparability of results, first, the main components of structure were designed based on 2800 standard about coefficient of static analysis and using ACI318 Regulations. Features of the implemented earthquake are presented in the next section.

2-1- Features of the implemented earthquake

Based on the building and the supposed area of construction and its soil, Elsentro earthquake was applied. This earthquake (1940) occurred in The USA.

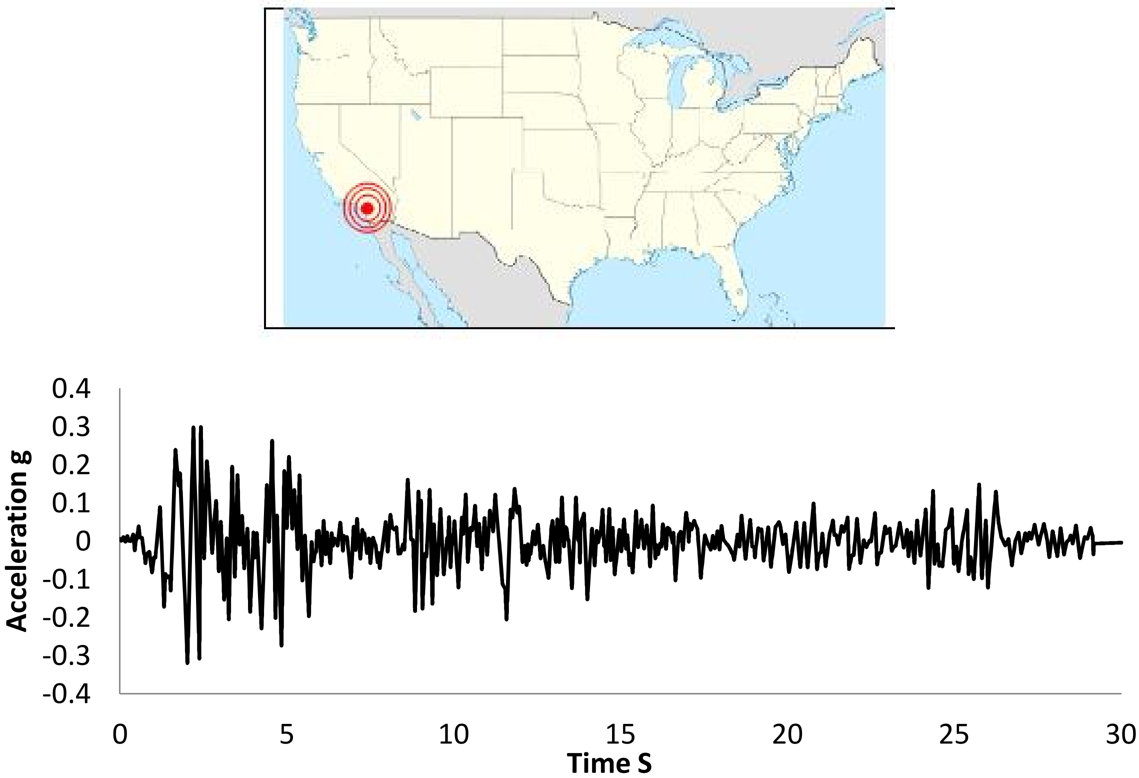


Fig.2. History of acceleration of Elsentro earthquake

2-2- Introducing Models

In this part, different models used in the analysis of results will be introduced. As a whole, 15 kinds of models were chosen based on the features of table 2. In table 3, earthquake and k coefficients in terms of 2800 standard were presented.

Table 2. Characteristics of models

Opening Area percent in each story %	Opening Area in each story m^2	Core Area in each story m^2	Total Height m	No. Of stories	Model name
0	0	72	48	16	16F-Full
0.427	0.308	71.692	48	16	16F-M1
3.846	2.769	69.231	48	16	16F-M2
10.684	7.692	64.308	48	16	16F-M3
20.940	15.077	56.923	48	16	16F-M4
0	0	72	54	18	18F-Full
0.427	0.308	71.692	54	18	18F-M1
3.846	2.769	69.231	54	18	18F-M2
10.684	7.692	64.308	54	18	18F-M3
20.940	15.077	56.923	54	18	18F-M4
0	0	72	60	20	20F-Full
0.427	0.308	71.692	60	20	20F-M1
3.846	2.769	69.231	60	20	20F-M2
10.684	7.692	64.308	60	20	20F-M3
20.940	15.077	56.923	60	20	20F-M4

Table 3. Earthquake coefficient of C and K coefficient

coefficient K	coefficient C	
1.21	0.07419	16 stories
1.25	0.06898	18 stories
1.29	0.06468	20 stories

In figure 3, plan of models are presented.

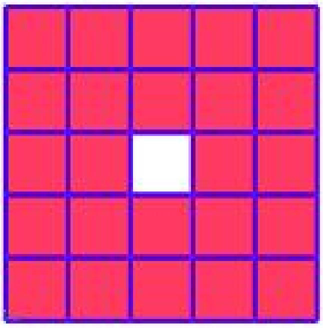


Fig.3. The whole plan of models

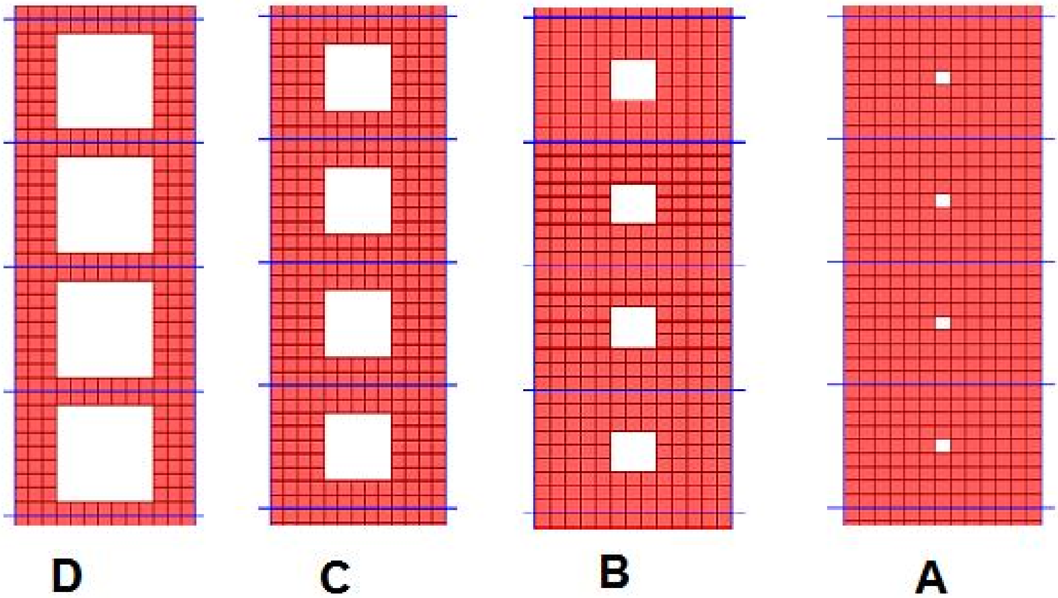


Fig.4. Open faces of a) M, b) M2, c) M3 and d) M4

2-3- Semi-static analysis and design of components

In this part, 16, 18 and 20 stories buildings were analyzed based on coefficients presented in table 3. Then, based on ACI318 Regulations, the main components of structures, including beams and columns, were designed. In tables 4 to 6, sections of designing beams and columns in 16, 18 and 20 stories buildings were presented.

Table 4. Sections of the main components of 16 stories building

Trans. rebar	Longi. rebar	Column dim. cm	Beam dim. cm	stories
Φ12@15	24Φ22	90x90	75x100	1 , 2 , 3 , 4
Φ12@15	20Φ22	80x80	65x90	5 , 6 , 7 , 8
Φ12@15	16Φ22	70x70	55x75	9 , 10 , 11 , 12
Φ12@20	16Φ22	60x60	45x65	13 , 14 , 15 , 16

Table 5. Sections of the main components of 18 stories building

Trans. rebar	Longi. rebar	Column dim. cm	Beam dim. cm	stories
Φ12@15	24Φ22	90x90	75x100	1 , 2 , 3 , 4
Φ12@15	20Φ22	80x80	65x90	5 , 6 , 7 , 8
Φ12@15	16Φ22	70x70	55x75	9 , 10 , 11 , 12
Φ12@20	16Φ22	60x60	45x65	13 , 14 , 15 , 16
Φ10@20	12Φ20	50x50	35x55	17 , 18

Table 6. Sections of the main components of 20 stories building

Trans. rebar	Longi. rebar	Column dim. cm	Beam dim. cm	stories
Φ12@15	28Φ22	100x100	90x120	1 , 2 , 3 , 4
Φ12@15	24Φ22	90x90	75x100	5 , 6 , 7 , 8
Φ12@15	20Φ22	80x80	65x90	9 , 10 , 11 , 12
Φ12@15	16Φ22	70x70	55x75	13 , 14 , 15 , 16
Φ12@20	16Φ22	60x60	45x65	17 , 18 , 19 , 20

3- ANALYSIS OF MODELS AND RESULTS

In this part, after performing semi-static analysis and time history, results were derived. These results include periods of each building in every status, rigidity of stories, history of cutting in terms of earthquake and history of moving one of the nodes of roof.

Table 7. Measures of 12 first periods of 16 stories building

mode no.	16F-FULL	16F-M1	16F-M2	16F-M3	16F-M4
mode 1	1.049	1.458	1.485	1.608	2.075
mode 2	0.317	0.363	0.386	0.471	0.699
mode 3	0.155	0.168	0.184	0.238	0.377
mode 4	0.099	0.106	0.118	0.157	0.247
mode 5	0.071	0.075	0.085	0.113	0.171
mode 6	0.056	0.059	0.067	0.088	0.129
mode 7	0.047	0.049	0.055	0.071	0.1
mode 8	0.04	0.042	0.047	0.06	0.08
mode 9	0.035	0.037	0.041	0.051	0.066
mode 10	0.032	0.033	0.037	0.044	0.056
mode 11	0.029	0.03	0.033	0.039	0.048
mode 12	0.027	0.028	0.031	0.036	0.043

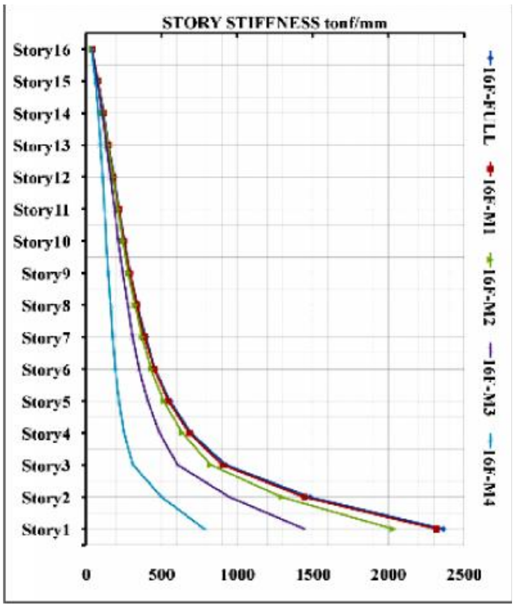
Table 8. Measures of 12 first periods of 18 stories building

mode no.	16F-FULL	16F-M1	16F-M2	16F-M3	16F-M4
mode 1	1.243	1.243	1.256	1.313	1.487
mode 2	0.377	0.378	0.394	0.45	0.571
mode 3	0.184	0.184	0.198	0.241	0.331
mode 4	0.117	0.117	0.128	0.162	0.227
mode 5	0.086	0.087	0.096	0.123	0.173
mode 6	0.067	0.067	0.075	0.095	0.13
mode 7	0.058	0.058	0.064	0.079	0.105
mode 8	0.051	0.052	0.056	0.067	0.087

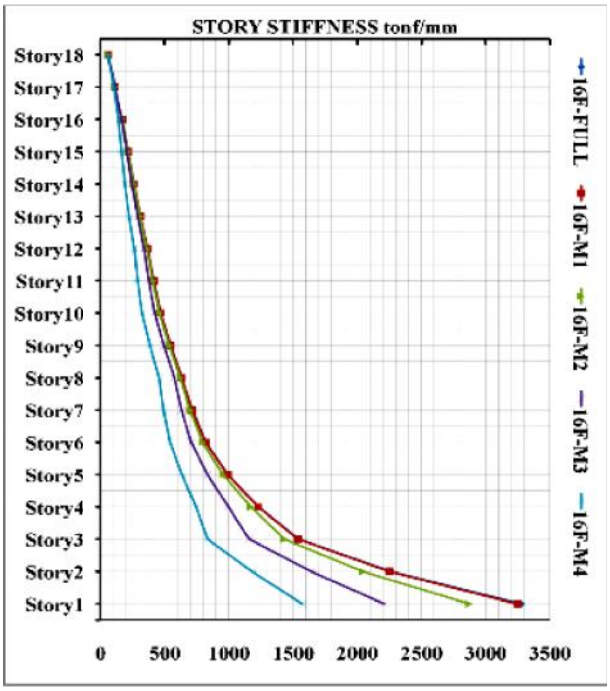
mode 9	0.045	0.045	0.05	0.059	0.074
mode 10	0.045	0.045	0.045	0.053	0.065
mode 11	0.042	0.042	0.044	0.046	0.056
mode 12	0.039	0.04	0.042	0.045	0.05

Table 9. Measures of 12 first periods of 20 stories building

	periods sec				
mode no.	16F-FULL	16F-M1	16F-M2	16F-M3	16F-M4
mode 1	1.297	1.297	1.308	1.353	1.485
mode 2	0.412	0.413	0.427	0.473	0.572
mode 3	0.204	0.205	0.217	0.256	0.333
mode 4	0.131	0.131	0.142	0.175	0.233
mode 5	0.095	0.096	0.105	0.131	0.172
mode 6	0.076	0.076	0.083	0.103	0.137
mode 7	0.063	0.063	0.069	0.085	0.109
mode 8	0.056	0.057	0.061	0.072	0.091
mode 9	0.051	0.051	0.055	0.064	0.078
mode 10	0.048	0.048	0.049	0.057	0.068
mode 11	0.047	0.047	0.048	0.051	0.06
mode 12	0.046	0.046	0.047	0.048	0.054


STORY STIFFNESS tonf/mm
Story16
Story15
Story14
Story13
Story12
Story11
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
0
500
1000
1500
2000
2500
16F-FULL
16F-M1
16F-M2
16F-M3
16F-M4

A.


STORY STIFFNESS tonf/mm
Story18
Story17
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Story14
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Story12
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Story5
Story4
Story3
Story2
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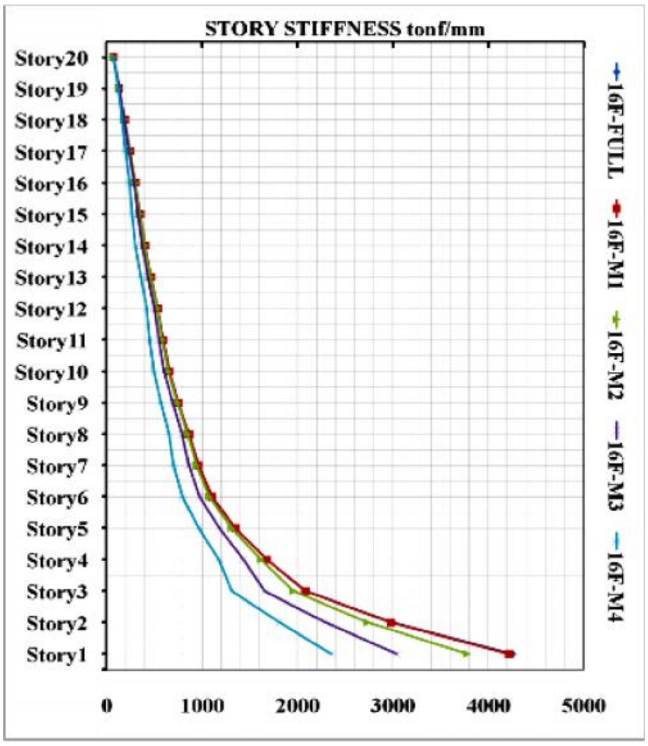
16F-M2
16F-M3
16F-M4

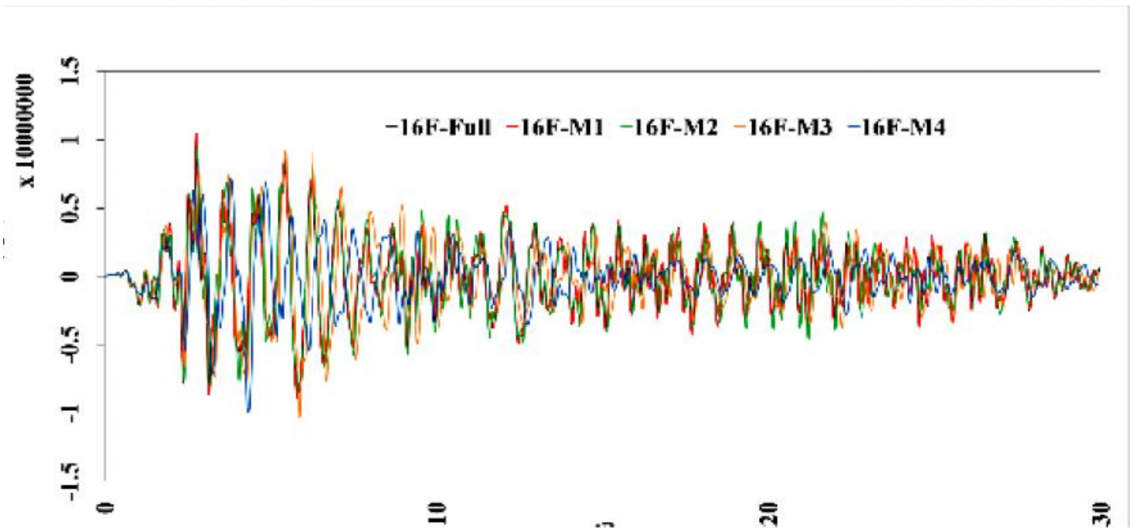
B.

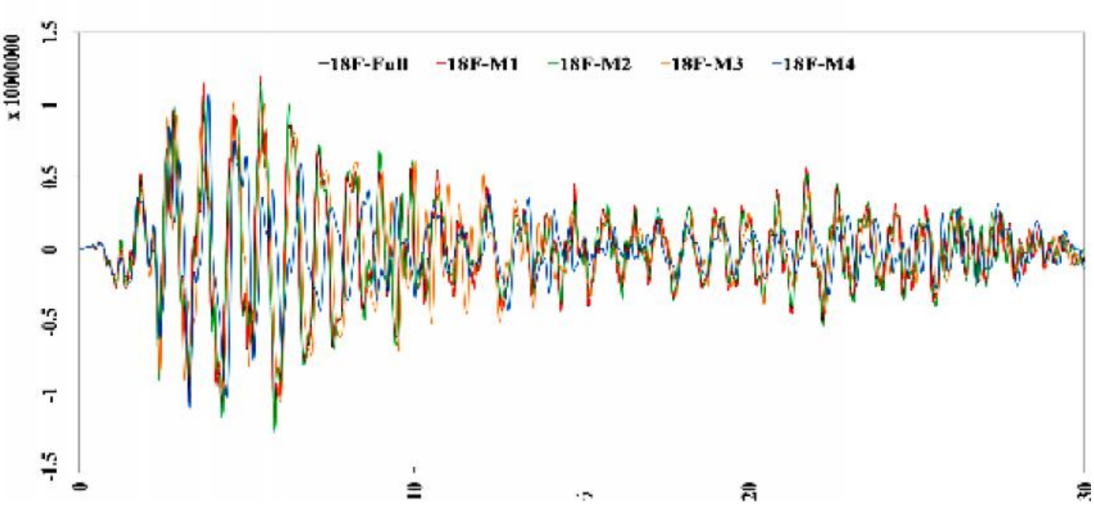


C.

Fig.5. Measures of rigidity of stories in different models of a) 16, b) 18 and c) 20 stories buildings

A:





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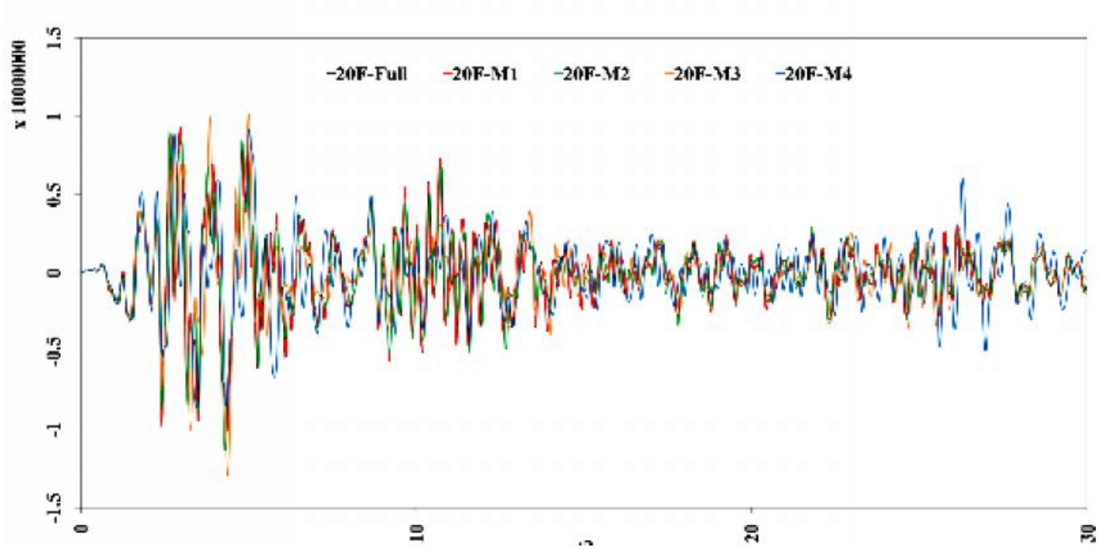


C:

Fig.6. Measures of cutting history under Elsentro`s earthquake in different models of a) 16, b) 18 and c) 20 stories buildings

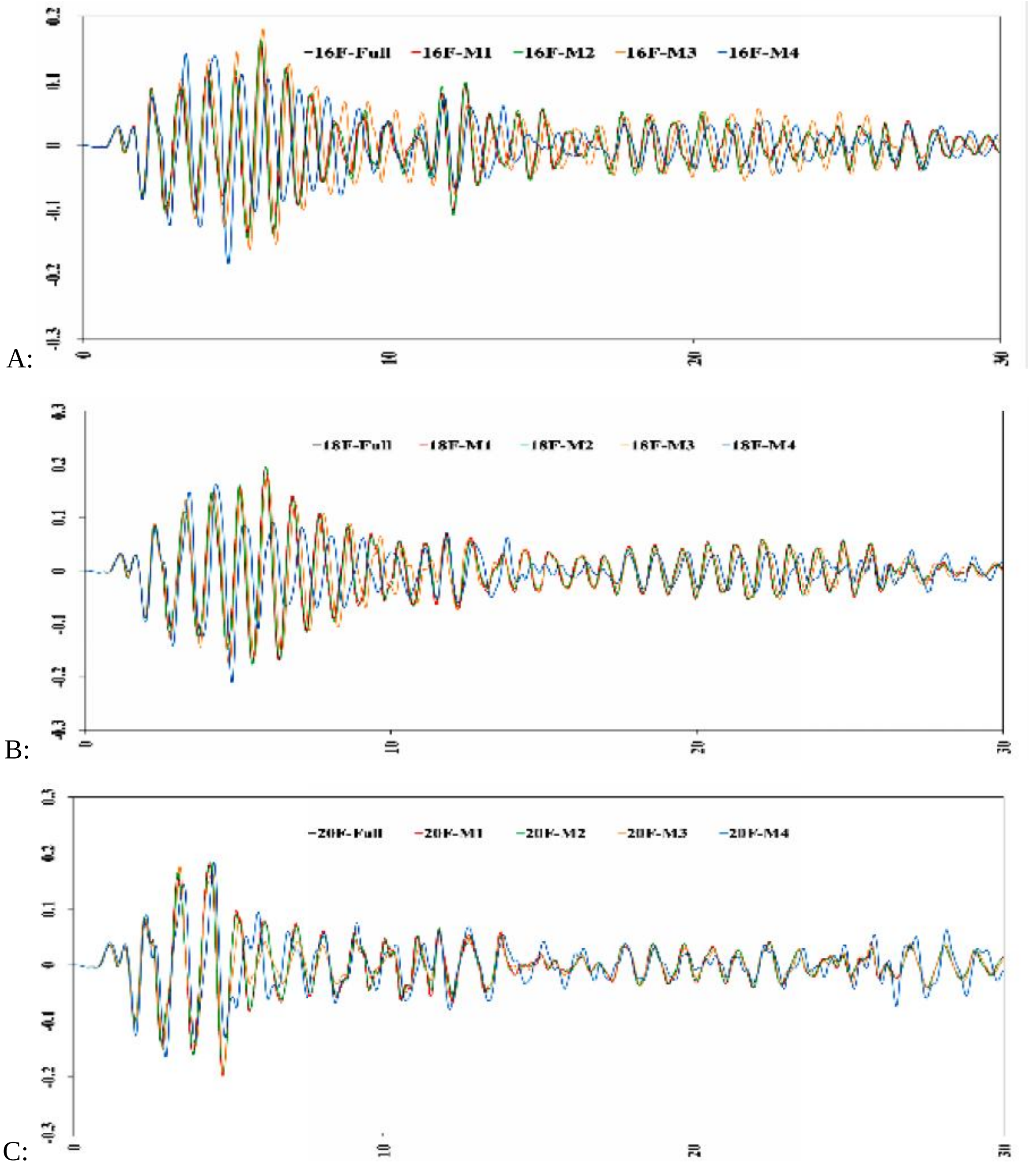
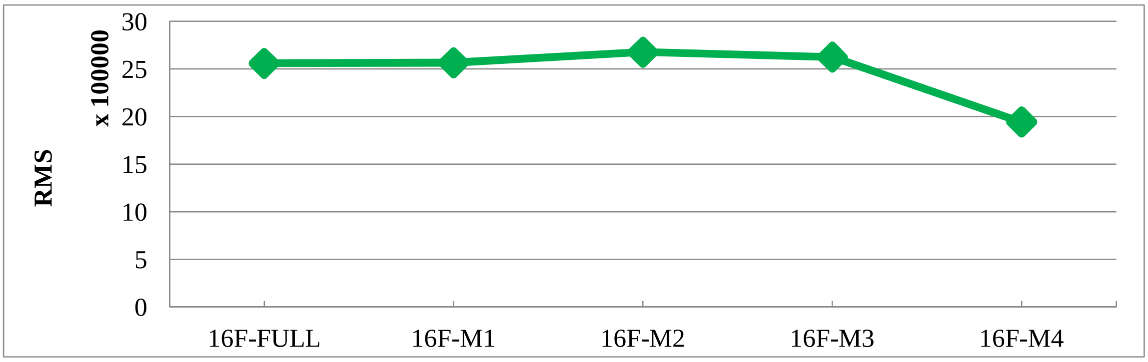
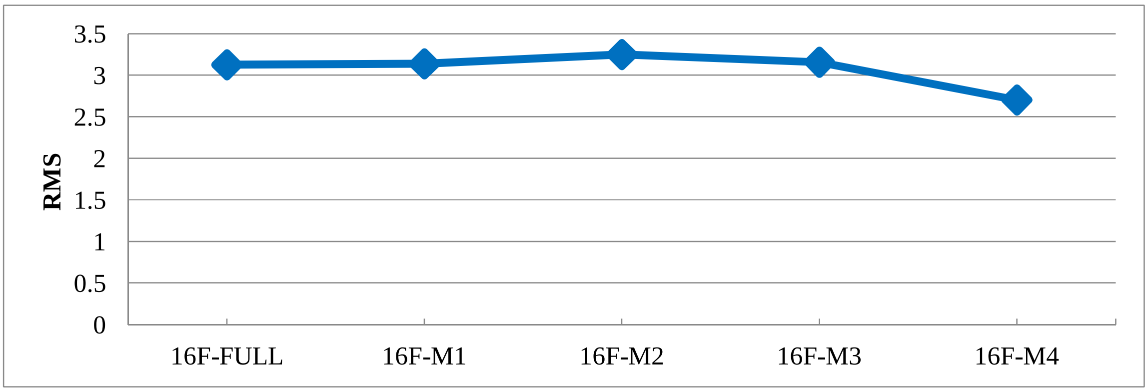


Fig.7. Measures of cutting history under Elnestro`s earthquake in different models of a) 16, b) 18 and c) 20 stories buildings

Table 10. Measures of mean of squares every history components of 16 stories building

Model name	Base shear kg	Roof Acc. m/s^2	Roof Disp. m
16F-FULL	2559481	3.126187	0.041076
16F-M1	2566369	3.136903	0.041164
16F-M2	2676701	3.249012	0.043565
16F-M3	2625326	3.157503	0.047907
16F-M4	1943965	2.703518	0.042830





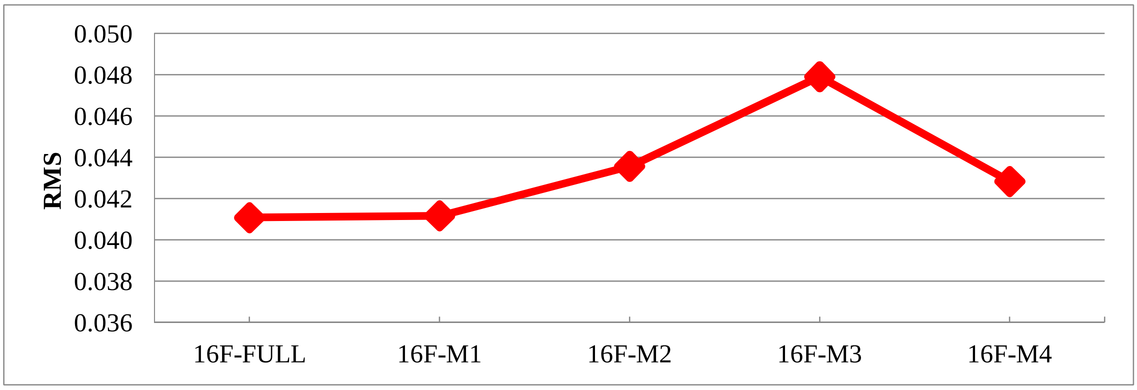
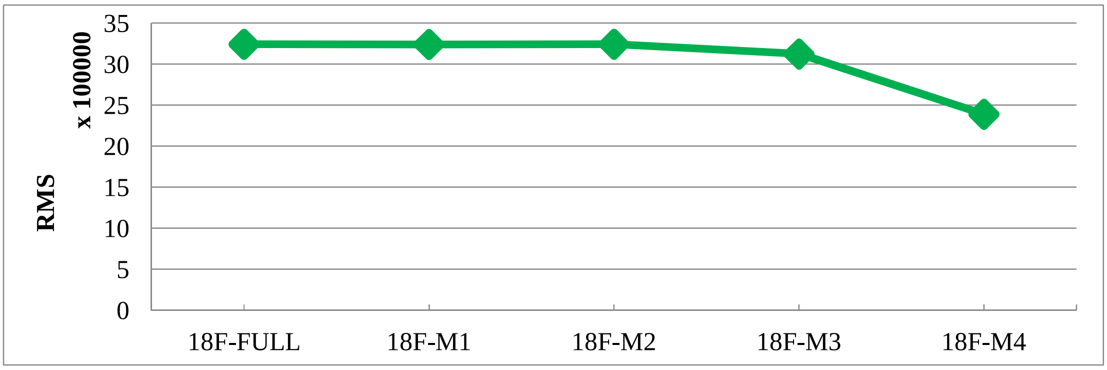
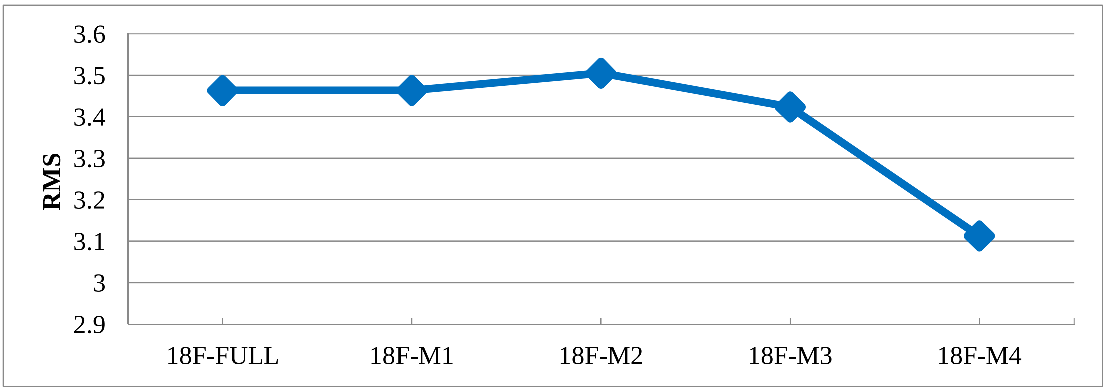


Fig.8. Measures of rms of base cutting and slope of roof and shift of roof in 16 stories buildings

Table 11. Measures of mean of squares every history components of 18 stories building

Model name	Base shear kg	Roof Acc. m/s^2	Roof Disp. m
18F-FULL	3241801	3.463119	0.051730
18F-M1	3240089	3.463306	0.051720
18F-M2	3241600	3.505123	0.051487
18F-M3	3122553	3.423377	0.050971
18F-M4	2388377	3.112768	0.043676





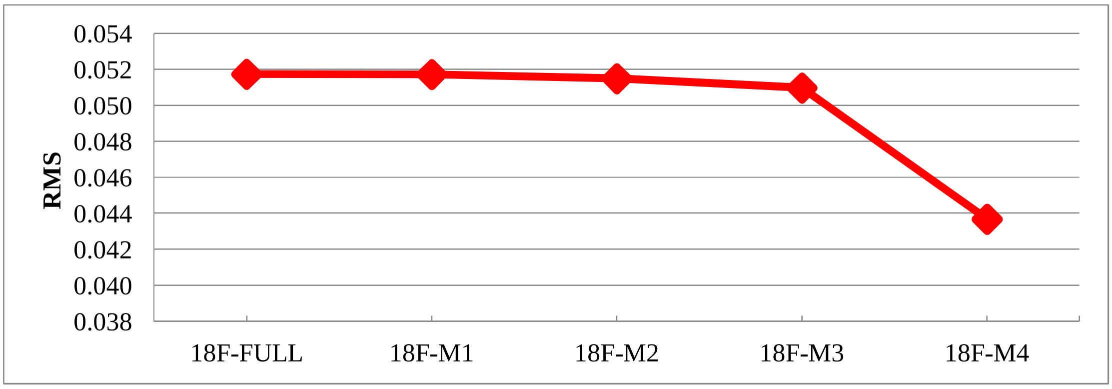


Fig.9. Measures of rms of base cutting and slope of roof and shift of roof in 18 stories buildings

Table 12. Measures of mean of squares every history components of 20 stories building

Model name	Base shear kg	Roof Acc. m/s^2	Roof Disp. m
20F-FULL	2405292	3.225988	0.043953
20F-M1	2401174	3.218777	0.043944
20F-M2	2333630	3.097116	0.043179
20F-M3	2177819	3.003171	0.040381
20F-M4	2298276	3.402250	0.042748

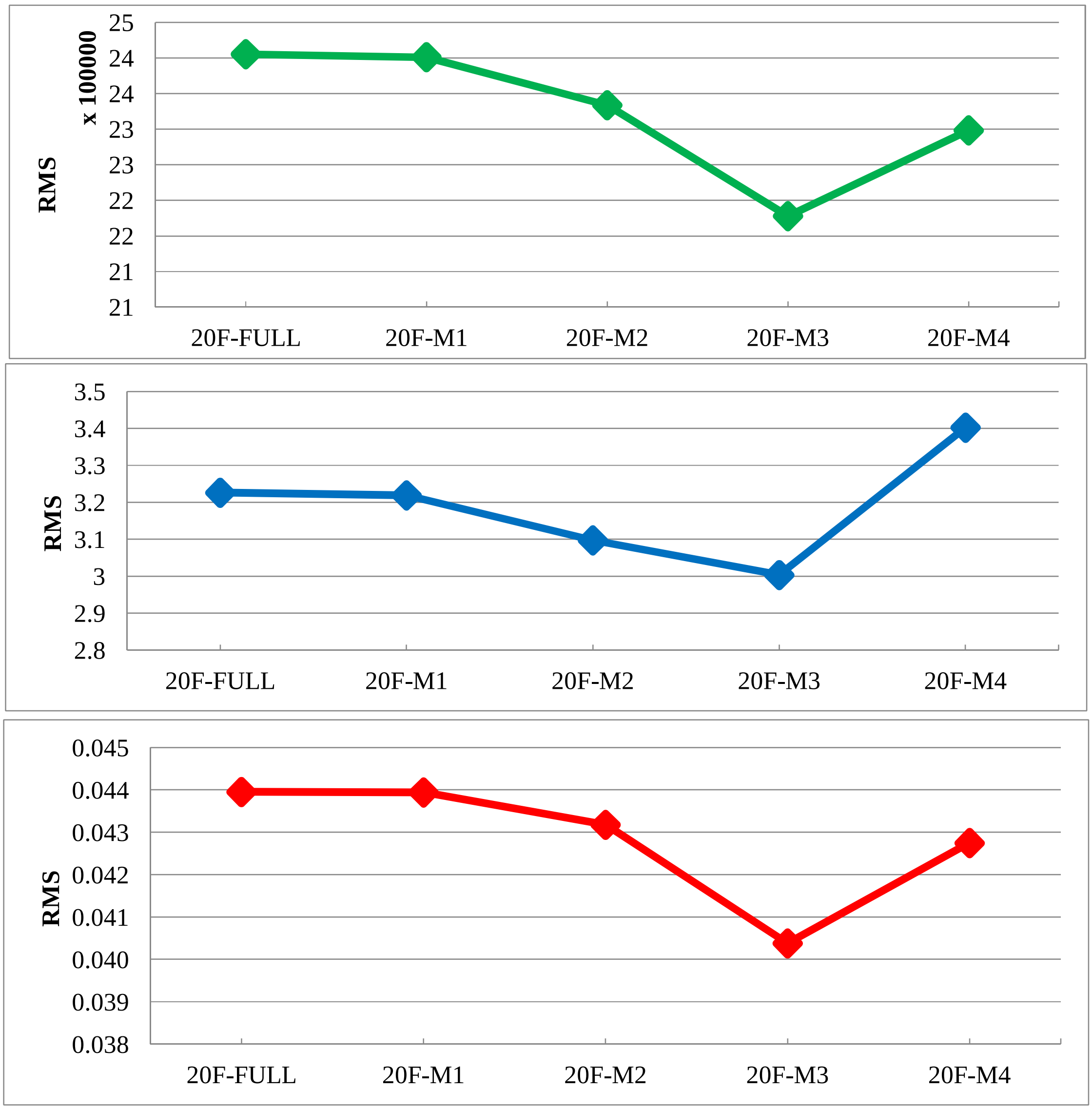


Fig.10. Measures of rms of base cutting and slope of roof and shift of roof in 20 stories buildings

4- CONCLUSION

After considering results of software analyses of 16, 18 and 20 stories buildings with concrete core system, some findings were observed. For simplicity, every component was studies separately.

In 16 stories building

It can be conferred that presence of bender contributes in less amount of base cut in building. But, this reduction is clearer in maximum numbers of base cut. Results indicate that opener changes the frequency of history of base cut. This change in M4 made some improvement but in M3 faced with increase. Comparing history of shift of roof node makes it clarify that increasing opener level leads to promotion in the amount of shift. This can be observed by RMS results being more evident M3.

In 18 stories building

In all positions of opener, it can be observed that presence of opener leads to increase in the amount of base cut and shift in the roof. But in M3 model, opener reduces this amount. Considering RMS results, except in M4, no change was observed in other models.

In 20 stories building

The presence of opener in this building leads to increase in maximum and minimum amounts of base cut, shift and acceleration of roof. This increase was more in M3. Concerning RMS results, all models faced decrease, especially in M3 with 50%. In M4, except in base cut, other measures faced increase.

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