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Nonlinear Dynamic Analysis Method for Irregular Steel Moment Frame in 15-Story Structures

Fatemeh Abdollahpur[1]*, Elham Moadab[2], Narqes Isazadeh[2]

[1]M.A:Department of Earthquake Development, Faculty of Civil Engineering, Seraj Nonprofit Education Institute, Tabriz, Iran.
[2]PhD. Supervisor:Department of Earthquake Development, Faculty of Civil Engineering, Seraj Nonprofit Education Institute, Tabriz, Iran.

***Corresponding author**

Abstract: *The use of nonlinear static methods in estimating the performance of structures during earthquakes has been highly concerned by engineers. To further improve the results of nonlinear static methods, it is useful to concern the effect of all highest modes on the structure response. In this study, the results of previous studies on nonlinear static methods and considering the effect of highest modes on the irregular structures behavior in height will be reviewed. To estimate the seismic requirements in irregular buildings at height, the average maximum relative floor displacement and floor shear were obtained by MPA method and compared with the results of nonlinear time history analysis method. The study aims to estimate the correlation between MPA results and nonlinear dynamic analysis according to comparison with the US FEMA regulations and to examine the similarities and differences between each of them. In this study, the conditional mean spectrum will be used to estimate seismic parameters. Response and design spectrum are the basis of all earthquake load modeling in earthquake engineering. The target spectrum is used is one of the most important topics in earthquake engineering. Research in recent years has shown that the conditional mean spectrum can be a more appropriate target spectrum for selecting earthquakes which get the mean response spectrum in all frequencies with the condition of specific spectral acceleration in the desired frequencies. The results of nonlinear static analysis indicate that the models for capacity curve the is slightly different, but regular structures show more capacity. The yield displacements of the structure are almost identical.*

Keywords: *Time History Analysis, Nonlinear Equivalent Static Analysis, Irregular Steel Moment Frame, Pushover Model Analysis, Seismic Modeling, Conditional Mean Spectrum*

INTRODUCTION

Recognizing the earthquake phenomenon despite all complexities and ambiguities is increasing and building regulations are evolving following these advances. In previous years, only gravity loads were known to engineers, and these loads were considered as forces in calculations. Over time, during the course of evolution, the regulation of early seismic calculations moved toward considering forces as seismic forces. Over the past thirty years, there has been an increasing effort to assess the seismic resistance of a variety of buildings. However, due to the diversity of buildings and the complexity of the effect of various factors and parameters on the seismic vulnerability of buildings, preparation and development of standards (Kashkooli and Banan, 2013) .

A review on the performed work indicates that various methods have been used to assess the vulnerability of buildings and vital arteries against earthquakes (Rezvan Modab's dissertation, 2012).
The amount of damage caused by an earthquake in a building depends on its seismic performance. Pushover analysis has been widely used in recent years to estimate seismic needs and design structures. Non-linear static analysis method is a simple method that has become common to estimate the response due to nonlinear behavior of structures and to avoid nonlinear dynamic analysis. (Seismic Improvement Manual)
In most seismic codes, the uniform hazard spectrum obtained from probabilistic seismic hazard analysis is proposed as the target spectrum. Research in this area shows that the conditional mean spectrum can be more useful than the hazard spectrum. Be uniform as the target spectrum. This is because the uniform hazard spectrum considerably assumes that the spectrum of a particular earthquake has very high spectral values at all rotations. That the conditional mean spectrum meets this expectation. (Tarta and Pintea, 2012)
The purpose of these building letters is to provide simple rules and guidelines that make it possible to design and execute conventional buildings. Of course, these criteria are the minimum requirements to achieve an acceptable safety margin in structures. Experience has shown that following regulatory requirements for conventional structures has acceptable results and significantly reduces casualties and financial losses in critical loads such as the event of a severe earthquake. However, in the design of special structures such as high-rise buildings, nuclear power plants, oil refineries and the like, it is not possible to use only building codes. In order to design these structures, it is necessary to determine the seismic design criteria accurately and clearly by examining and studying all aspects of the problem. (Govind et al., 2014)
Performance-based design is very different from the one-level design process of regulations. In this way, in the design philosophy based on the performance level, it is possible to adjust different levels of structural performance for different ranges of seismic hazard intensity. The level of performance of the structure can be based on the state of component failure (cracks created, coating pour in concrete structures, local buckling, welding cracks in steel structures, etc.), based on the condition of the whole structure (Stability, total displacement, etc.), based on the amount of service of the building after the occurrence of the target earthquake or based on the amount of economic damage to the building after the occurrence of the target earthquake. By combining the desired level of performance and the severity of earthquake risk, a performance goal is set. (Himaja et al., 2015)
Also, one of the applications of seismic spectrum is to use it as a target spectrum to select accelerometers and their scale, which is used as input for dynamic analysis. (Abou-Elfath et al., 2017)
The selection of real accelerometers is based on the correspondence of the corresponding seismic response spectrum and the target spectrum, which is either proposed by seismic codes or obtained directly from seismic probability hazard analysis. Spectral matching is one of the most widely used accelerometer selection methods in seismic codes that can be used in both force-based design and performance-based design. As mentioned, the target spectrum in this case can be considered any spectrum. In most seismic codes, this spectrum is the uniform hazard spectrum obtained from probabilistic seismic hazard analysis. It has been shown that the conditional mean spectrum can be a more appropriate target spectrum than the uniform risk spectrum for this purpose. (Arvindreddy and Fernandes, 2015)
Many studies have been conducted in this field; Mr. G. Tarta and Mr. A. Pintea in (2012) investigated the seismic evaluation of multi-layer steel moment frames with rigid irregularities using standard and advanced pushover methods. Nonlinear static method based on pushover analysis is an important tool to describe the seismic demand and performance of structures. The standard pushover method is limited to single-state responses and the valid assumption is suitable for symmetric buildings. The standard pushover method is misleading when the response of the structures is affected by the higher vibration model.
This is the case for tall or asymmetrical buildings. Several pushover methods capable of describing the effects of higher vibration modes have recently been developed to overcome this problem. In this paper, a comparison between standard advanced pushover analysis and accurate results with the use of nonlinear time history

analysis has been obtained. The analysis has shown that a series of moment frames with rigid irregularities with a number of different reports are designed in accordance with EC8 and Romanian seismic design code for the seismic region of Verancia, Romania.

Mr. Arvindreddy, R.J. Fernandes in 2015 explained seismic analysis of the structure of regular and irregular frame RC that the multi-storey reinforced concrete building is exposed to the most dangerous earthquakes and it was found that the main reason for the failure of the RC building is irregular design dimensions and resistant system to lateral force. In this paper, an analytical study is made to find the response of various regular and irregular structures located in the dry zone V, which a 15-storey building was analyzed using static and dynamic methods through ETABS and IS code.

Dynamic analysis can take the form of dynamic time history analysis or linear response spectrum analysis. And the behavior of the structure is found by comparing the response in the form of floor displacement for regular and irregular structures. Different types of analysis methods such as static equivalent method and response spectrum method were accepted in order to study the displacement of classes. In this paper, two types of 15 regular and irregular reinforced concrete buildings that have been analyzed by static and dynamic methods have been considered and the behavior of regular structures has been compared with irregular structures.

Mr. Hamdy Abou-Elfath, Mostafa Ramadan, Mohamed Meshaly, Heba Alzobair Fdiel in (2016) examined the seismic performance of steel frames designed using different reports of drift limits, where strength of see frames is controlled by drift limits for their high flexibility. The purpose of this study is to evaluate the seismic performance of a 6-layer MRSF designed based on the Egyptian code with three different levels of 0.5, 0.75, 1.0%.

Seismic evaluation in this study was done by static pushover analysis and time history seismic analysis, where 10 earthquakes with different PGA levels are applied. The results show that the initial strength and stiffness of the design frames of floor drift limits is increased from the frame. Two of the designed frames show the maximum floor drift that is higher than the allowable limit set by the code. The maximum floor drift and the strain radius response of the frame under the earthquake are designed to increase the load by increasing the allowable floor limit.

This study aims to investigate the method (MPA) in the analysis of buildings with mass irregularities in height and important parameters in their seismic evaluation, which include the displacement of floors and the ratio of relative displacement of floors are extracted from the method (MPA). And shows that MPA estimation has good correlation results with respect to FEMA for all models under all earthquakes.

Materials and Methods

Structural Models

After introducing the loading compounds, the design results are presented. The design of the frames is done using sap2000 software.

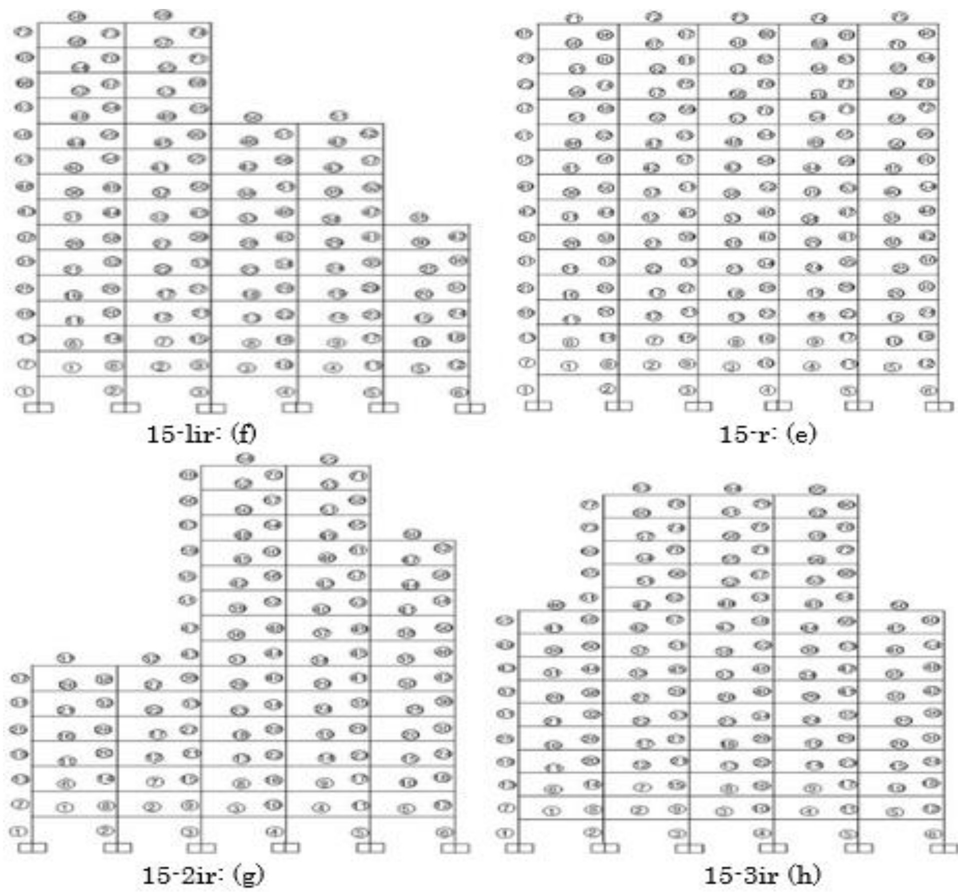
Table 1: Introduction of models

Name of Mode			Dead load	Live load	Earthquake coefficient
15 story	15-r	Regular 15- story	3t/m	1.8 t/m	0.05
	15-1ir	First Model irregular 15- story			
	15-2ir	Second Model irregular 15- story			
	15-3ir	Third Model irregular 15- story			

Combinations of dead loads (DL), live loads (LL) and earthquakes (EL) on which structural members and connections are designed or controlled according to model 2800 are:

COMB1: DL + LL
COMB2: DL + LL + EL
COMB3: DL + LL ± EL
COMB4: DL + EL
COMB5: DL ± EL

Shape of Models



Figuer 1: regular and irregular designed methods

Table 2: Specifications of structural sections
Beam and column design sections for 15-r model

Column No.	Section	Column No.	Section	Column No.	Section	Column No.	Section
1	w21x111	22	w24x162	43	w21x73	64	w24x76
2	w21x182	23	w24x146	44	w21x101	65	w24x76
3	w24x192	24	w21x101	45	w24x104	66	w24x62
4	w24x192	25	w24x94	46	w24x104	67	w24x55
5	w21x182	26	w24x146	47	w21x101	68	w21x62
6	w21x111	27	w24x146	48	w21x73	69	w21x68
7	w21x101	28	w24x146	49	w21x68	70	w21x68
8	w24x176	29	w24x146	50	w21x101	71	w21x62
9	w21x182	30	w24x94	51	w21x101	72	w24x55
10	w21x182	31	w21x93	52	w21x101	73	w21x44

11	w24x176	32	w21x122	53	w21x101	74	w24x62
12	w21x101	33	w24x131	54	w21x68	75	w24x62
13	w21x101	34	w24x131	55	w21x62	76	w24x62
14	w24x162	35	w21x122	56	w21x93	77	w24x62
15	w21x166	36	w21x93	57	w21x93	78	w21x44
16	w21x166	37	w21x83	58	w21x93	79	w21x44
17	w24x162	38	w21x111	59	w21x93	80	w21x50
18	w21x101	39	w24x117	60	w21x62	81	w21x50
19	w21x101	40	w24x117	61	w24x62	82	w21x50
20	w24x146	41	w21x111	62	w24x76	83	w21x50
21	w24x162	42	w21x83	63	w24x76	84-90	w21x44

Bean number	Section
1-75	w14x53

Beam and column section design for 15-1 ir model

Column No.	Section	Column No.	Section	Column No.	Section
1	w21x68	21	w21x68	41	w24x62
2	w24x76	22	w21x68	42	w21x44
3	w24x84	23	w21x62	43	w21x44
4	w24x84	24	w24x55	44	w24x55
5	w24x76	25	w24x55	45	w21x57
6	w21x68	26	w21x62	46	w21x57
7	w21x62	27	w21x62	47	w24x55
8	w24x68	28	w21x62	48	w21x44
9	w24x76	29	w21x62	49	w21x50
10	w24x76	30	w24x55	50	w24x55
11	w24x68	31	w21x50	51	w24x55
12	w21x62	32	w21x62	52	w21x50
13	w24x62	33	w21x62	53	w21x44
14	w21x68	34	w21x62	54	w21x50
15	w24x68	35	w21x62	55	w21x50
16	w24x68	36	w21x50	56	w21x50
17	w21x68	37	w21x44	57	w21x50
18	w24x62	38	w24x62	58-74	w21x44
19	w24x55	39	w24x62		
20	w21x62	40	w24x62		

Beam No.	Section	Beam No.	Section
1-5	w14x34	18	w18x40
6	w16x36	19	w16x36
7	w14x34	20	w18x40
8	w18x40	21	w16x36
9	w14x34	22	w14x34
10	w16x36	23	w16x36
11	w18x40	24	w14x34

12	w14x34	25-32	w16x36
13	w18x40	33	w14x34
14	w14x34	34	w16x36
15	w18x40	35	w16x36
16	w18x40	36-55	w14x34
17	w16x36		

Beam and column section design for 15-2 ir model

Column No.	Section	Column No.	Section	Column No.	Section
1	w21x68	21	w21x68	41	w24x62
2	w24x76	22	w21x68	42	w21x44
3	w24x84	23	w21x62	43	w21x57
4	w24x84	24	w24x55	44	w21x57
5	w24x76	25	w24x55	45	w24x55
6	w21x68	26	w21x62	46	w21x44
7	w21x62	27	w21x62	47	w24x55
8	w24x68	28	w21x62	48	w24x55
9	w24x76	29	w21x62	49	w21x50
10	w24x76	30	w24x55	50	w21x44
11	w24x68	31	w21x50	51	w21x50
12	w21x62	32	w21x62	52	w21x50
13	w24x62	33	w21x62	53	w21x50
14	w21x68	34	w21x62	54-71	w21x44
15	w24x68	35	w21x62		
16	w24x68	36	w21x50		
17	w21x68	37	w21x44		
18	w24x62	38	w24x62		
19	w24x55	39	w24x62		
20	w21x62	40	w24x62		

Bean No.	Section	Beam No.	Section
5 تا1	w14x34	18	w18x40
6	w16x36	19	w16x36
7	w14x34	20	w18x40
8	w18x40	21	w16x36
9	w14x34	22	w14x34
10	w16x36	23	w16x36
11	w18x40	24	w14x34
12	w14x34	25-32	w16x36
13	w18x40	33	w14x34
14	w14x34	34	w16x36
15	w18x40	35	w16x36
16	w18x40	36	w16x36

17	w16x36	37-59	w14x34

Beam and column section design for 15-2 ir model

Column No.	Section	Column No.	Section	Column No.	Section
1	w21x68	21	w21x68	41	w24x62
2	w24x76	22	w21x68	42	w21x44
3	w24x84	23	w21x62	43	w21x44
4	w24x84	24	w24x55	44	w24x55
5	w24x76	25	w24x55	45	w24x57
6	w21x68	26	w21x62	46	w24x57
7	w21x62	27	w21x62	47	w24x55
8	w24x68	28	w21x62	48	w21x44
9	w24x76	29	w21x62	49	w21x44
10	w24x76	30	w24x55	50	w21x50
11	w24x68	31	w21x50	51	w24x55
12	w21x62	32	w21x62	52	w24x55
13	w24x62	33	w21x62	53	w21x50
14	w21x68	34	w21x62	54	w21x44
15	w24x68	35	w21x62	55	w21x44
16	w24x68	36	w21x50	56	w21x50
17	w21x68	37	w21x44	57	w21x50
18	w24x62	38	w24x62	58	w21x50
19	w24x55	39	w24x62	59	w21x50
20	w21x62	40	w24x62	60-80	w21x44

Beam No.	Section	Beam No.	Section
1-5	w14x34	18	w18x40
6	w16x36	19	w16x36
7	w14x34	20	w18x40
8	w18x40	21	w16x36
9	w14x34	22	w14x34
10	w16x36	23	w16x36
11	w18x40	24	w14x34
12	w14x34	25-32	w16x36
13	w18x40	33	w14x34
14	w14x34	34-36	w16x36
15	w18x40	37-39	w14x34
16	w18x40	40	w16x36
17	w16x36	41-65	w14x34

Method of performing pushover analysis

Although the nonlinear dynamic analysis method is a comprehensive method for analyzing structures and gives more accurate answers than other existing methods, but this method is relatively complex and difficult to model, so the pushover nonlinear static analysis method is used. To predict the performance of a structure under earthquake forces, it is necessary to analyze a nonlinear time history with reliable earthquake records (indicating different seismic properties including amplitude, frequency content, duration, etc.) which in most cases is complex, time consuming and impractical.

To overcome these limitations, it is necessary to provide an analysis method that is relatively simple but reflects the main characteristics of earthquakes and structures and also reflects changes in forces and distribution of deformations resulting from nonlinear behaviors. Pushover analysis is one of the methods that can help to achieve this goal. (Shahri et al.; Nourizadeh et al., 2013)

Topics related to the spectrum used

In this study, time history analysis was analyzed based on the standard spectrum and the conditional mean spectrum. The shape of the spectra and how to obtain the scale coefficient of the spectra and their value are shown in Figure 2.

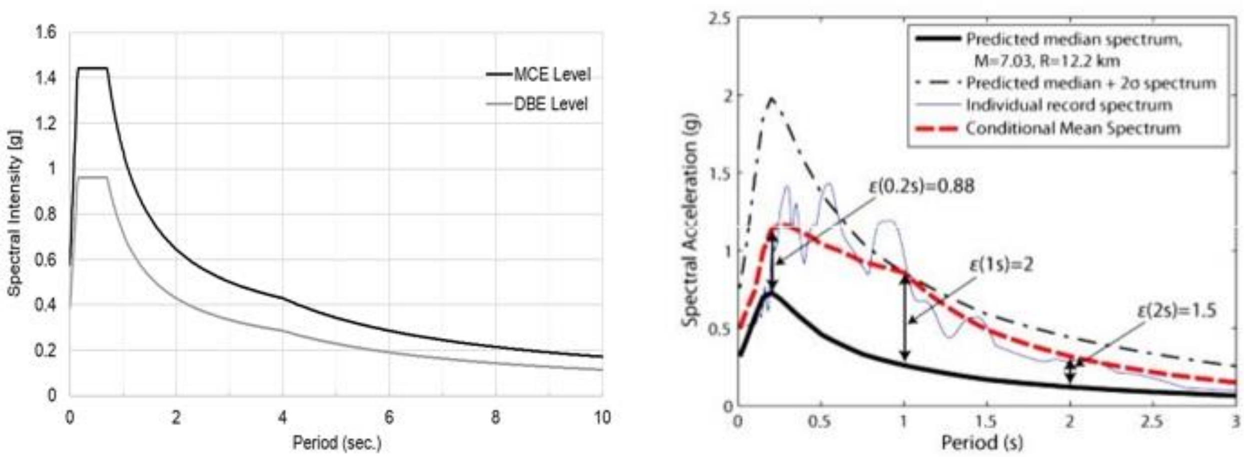


Figure 2: a) Standard design spectrum diagram- [Regulation 2800], b) Conditional average spectrum diagram- (Seismic Improvement Manual)

Scale method and scale coefficient

To obtain the scale coefficient used in the analysis, considering the height of 3 meters for the 9-story and 15-story models, the value of T is calculated using the following equation:

Equation (1) $T=0.08(H)^{0.75}$

Tehran with soil type II is at highly seismic risk, according to the spectrum used in Figure 1, we obtain spectral acceleration and divide it for each of the earthquake records used. And we get the minimum value in the intervals of 0.2T and 1.5T for 15-story building, which scale factor or scale factor is obtained by dividing 1.

Table 3: Scale coefficients used in this research

Name of Earthquake	15-story	Name of Earthquake	15-story
68	50.71	68	38.89
125	47.57	125	45.33
169	46.2	169	24.07

174	39.14	174	21.77
721	29.13	721	16.64
725	34.92	725	23.34
752	22.46	752	19.8
767	53.26	767	38.42
829	22.07	829	21.15
848	57.68	848	45.55
900	29.13	900	23.24
953	18.05	953	14.52
960	35.02	960	17.37
1111	40.22	1111	24.62
1116	39.14	1116	26.48
1148	94.76	1148	81.03
1158	29.72	1158	15.69
1244	29.13	1244	20.97
1485	44.43	1485	28.89
1602	20.11	1602	11.18
1633	52.97	1633	26.29
1787	33.64	1787	29.13

The Properties of Earthquakes Applied

One of the basic steps in determining seismic responses and fragility curves based on time history analysis is the selection and scale of earthquake records. Different issues such as soil conditions, distance to the earthquake source, type of fault, spectrum shape (frequency content of the record), etc. should be considered in the selection of records. In addition, the number of records selected should be such as to minimize the average of the results of time history analysis and changes in the record-to-record response.

In this section, 22 earthquake records (22 earthquakes with two components) proposed by FEMA P-695 [Error! Bookmark not defined.] was used to compare structures responses. Applying a large number of records allows for statistical comparison and evaluation. In Error! Reference source not found.) Selected records are provided. The records are taken from large-scale events provided to researchers in the PEER database for soil types C and D. Also, the type of faults that produce earthquakes are of the type of strike-slip or reverse.

As mentioned earlier, to reduce variables and uncertainties between records due to their inherent differences in magnitude, distance to source, source type, and soil type, FEMA P-695 requires that all selected records be normalized to maximum speed. Normalization with this value (PGV) is a relatively safe way to delete unspecified variables. The scale coefficient is calculated based on the maximum speed in FEMA P-695 and is presented in the last row for each record. This coefficient is multiplied by the record before being applied to the structure.

Table 4: Records used to analyze time history

ID No.	Record ID	Components IDs according toPEER NGA Database(PEER, 2012)		$PGA_{component-1}$ (g)	$PGA_{component-2}$ (g)	Normalization factor
		Component 1	Component 2			
1	953	NORTHR/MUL009	NORTHR/MUL279	0.52	0.42	0.65
2	960	NORTHR/LOS000	NORTHR/LOS270	0.48	0.41	0.83
3	1602	DUZCE/BOL000	DUZCE/BOL090	0.82	0.73	0.63
4	1787	HECTOR/HEC000	HECTOR/HEC090	0.34	0.27	1.09

5	169	IMPVALL/H-DLT262	IMPVALL/H-DLT352	0.35	0.24	1.31
6	174	IMPVALL/H-E11140	IMPVALL/H-E11230	0.38	0.36	1.01
7	1111	KOBE/NIS000	KOBE/NIS090	0.51	0.50	1.03
8	1116	KOBE/SHI000	KOBE/SHI090	0.24	0.21	1.10
9	1158	KOCAELI/DZC180	KOCAELI/DZC270	0.36	0.31	0.69
10	1148	KOCAELI/ARC000	KOCAELI/ARC090	0.22	0.15	1.36
11	900	LANDERS/YER270	LANDERS/YER360	0.24	0.15	0.99
12	848	LANDERS/CLW-LN	LANDERS/CLW-TR	0.42	0.18	1.15
13	752	LOMAP/CAP000	LOMAP/CAP090	0.53	0.44	1.09
14	767	LOMAP/G03000	LOMAP/G03090	0.56	0.37	0.88
15	1633	MANJIL/ABBAR--L	MANJIL/ABBAR--T	0.51	0.50	0.79
16	721	SUPERST/B-ICC000	SUPERST/B-ICC090	0.36	0.26	0.87
17	725	SUPERST/B-POE270	SUPERST/B-POE270	0.45	0.44	1.17
18	829	CAPEMEND/RIO270	CAPEMEND/RIO360	0.55	0.39	0.82
19	1244	CHICHI/CHY101-E	CHICHI/CHY101-N	0.44	0.35	0.41
20	1485	CHICHI/TCU045-E	CHICHI/TCU045-N	0.51	0.47	0.96
21	68	SFERN/PEL090	SFERN/PEL180	0.21	0.17	2.10
22	125	FRIULI/A-TMZ000	FRIULI/A-TMZ270	0.35	0.31	1.44

Findings

Results of Pushover Analysis

For the initial evaluation of the modeled structures, nonlinear static analysis was performed by applying the target displacement at the control point on two-dimensional models. The diagrams shown in Figure 3 show the results of nonlinear static analysis. As can be seen in these diagrams, the capacity curve of the models is slightly different from each other, but regular structures show more capacity. The yield displacement of structure is almost identical.

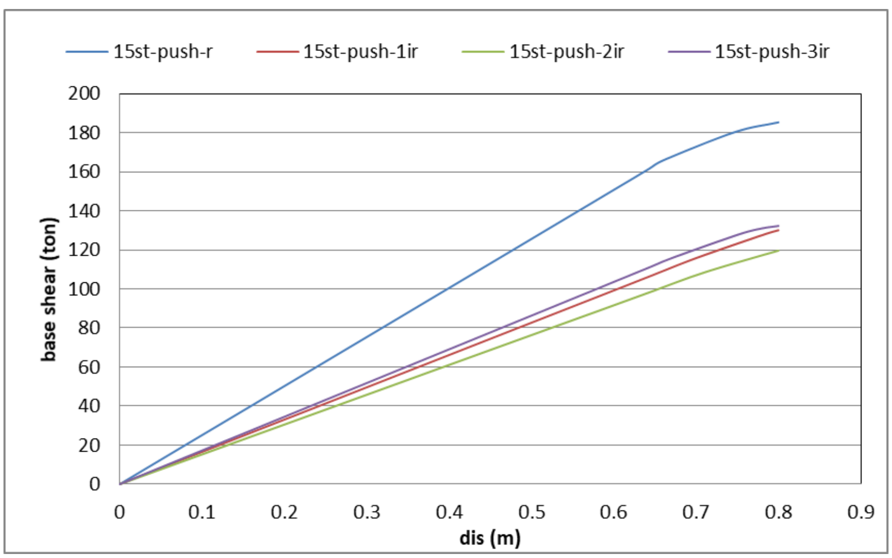


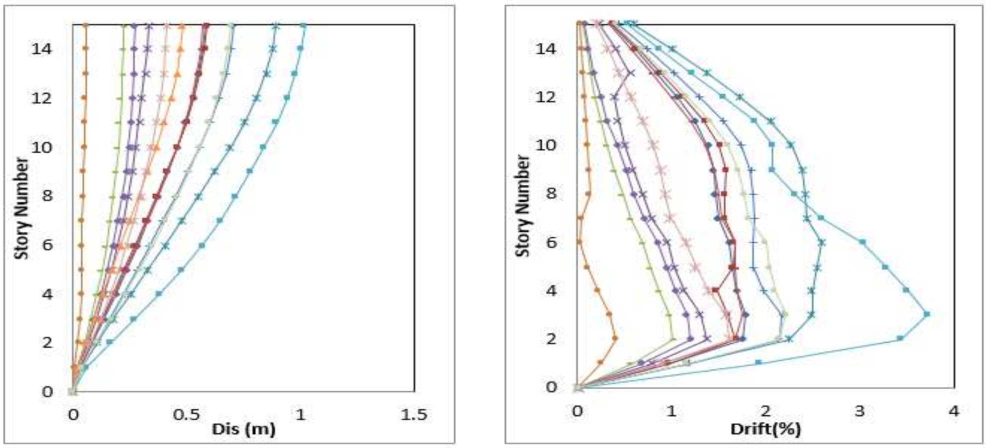
Figure 3: Pushover diagram for 15-story models

Time History Analysis

Time history analysis for regular and irregular structures have been performed to investigate the differences between the responses of the two studied spectrum. The results of these analysis are summarized in the displacement and base shear diagrams.

Results of Time History Analysis Based On Standard Spectrum

The records used are scaled according to the standard spectrum. The selected structures are classified into two regular and irregular groups. Figure 4 shows the displacements and relative displacements between story. The difference between the model shown for relative displacement in the regular and irregular groups indicates that the demand for relative displacement in the middle story is very high compared to the upper story. So, this value has reached 4% a 3rd and 4th story of a 15-story structure.



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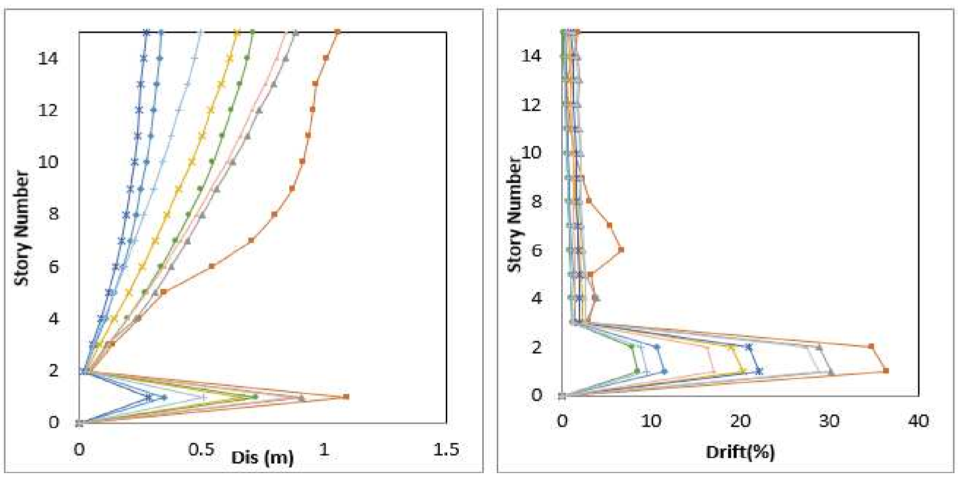

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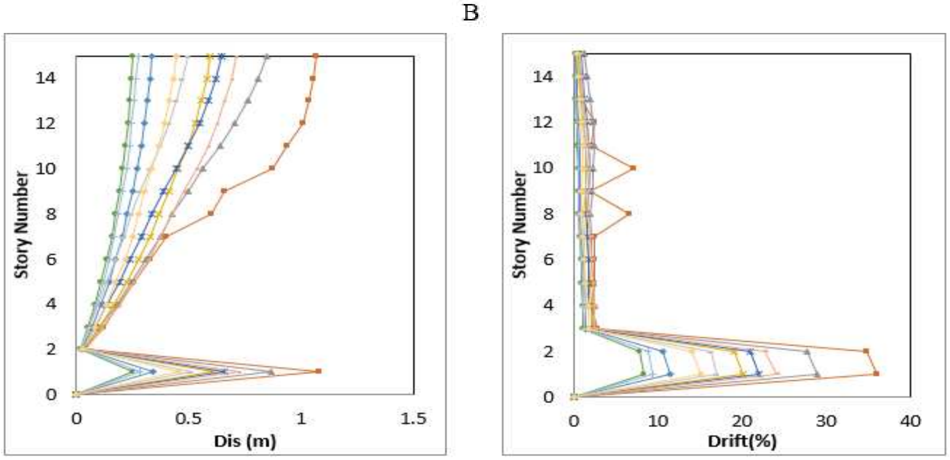

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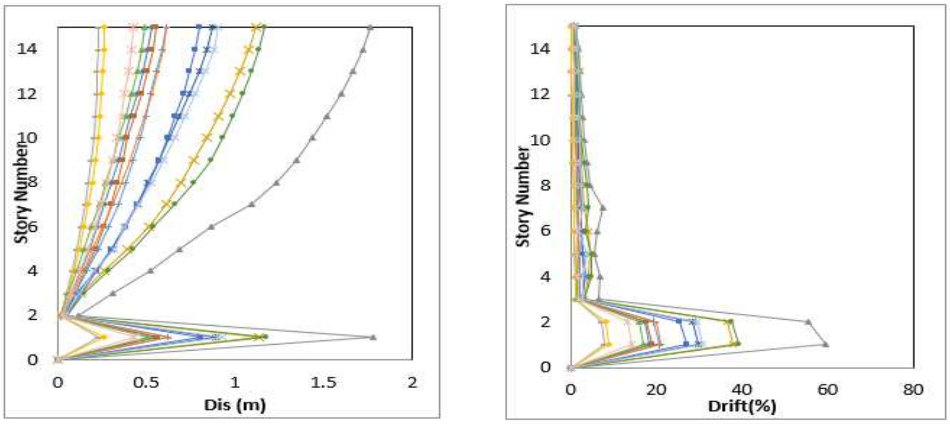
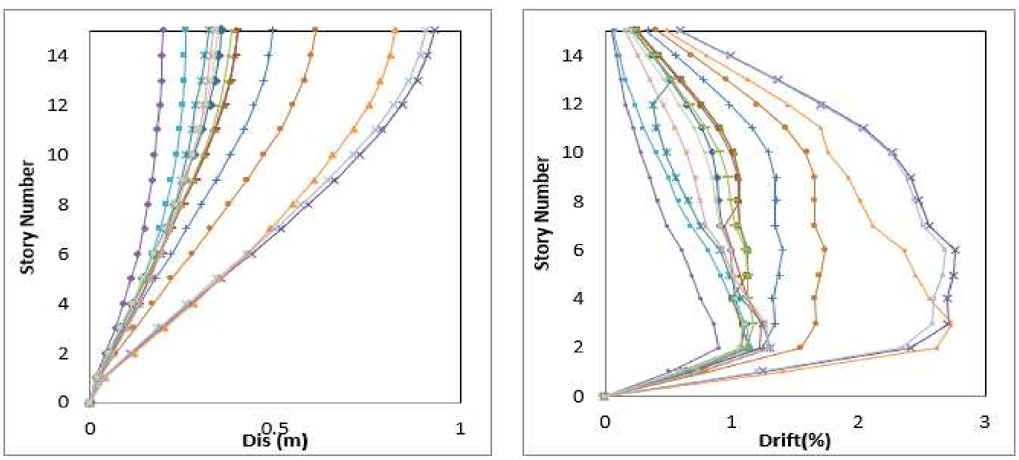


D

Figure 4: a) Displacement and drift for 15-r model, b) Displacement and drift for 15-1ir model, c) Displacement and drift for 15-2ir model, d) Displacement and drift for 15-3ir model

Results of time history analysis based on conditional mean spectrum

Time history analysis were performed based on based on conditional spectrum method. In this section, 22 records from the FEMAP695 record set have been used, which have been scaled using the conditional mean spectrum. This scaling was selected based on the method provided in Regulation 2800 and the scale coefficients were presented (Figure 5).



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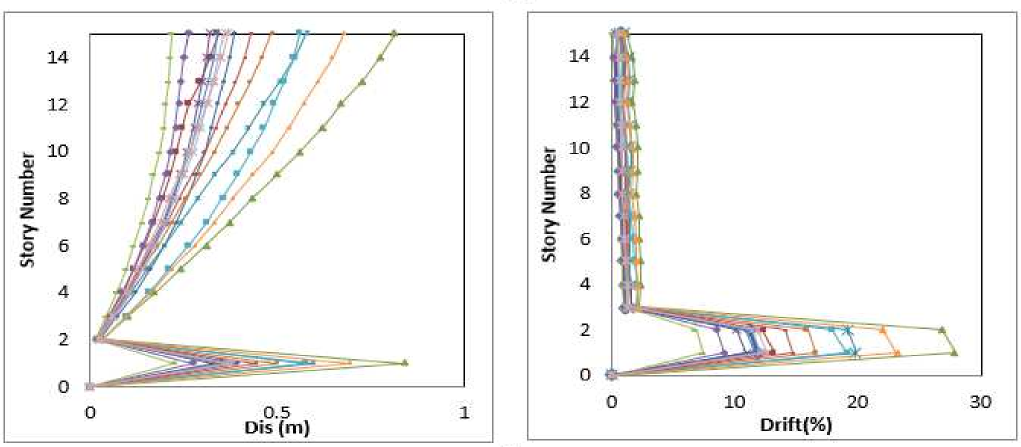
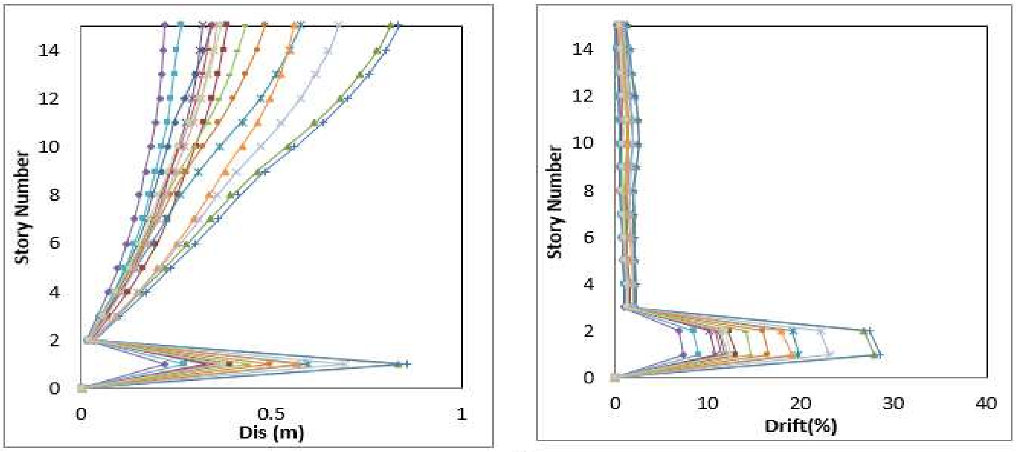
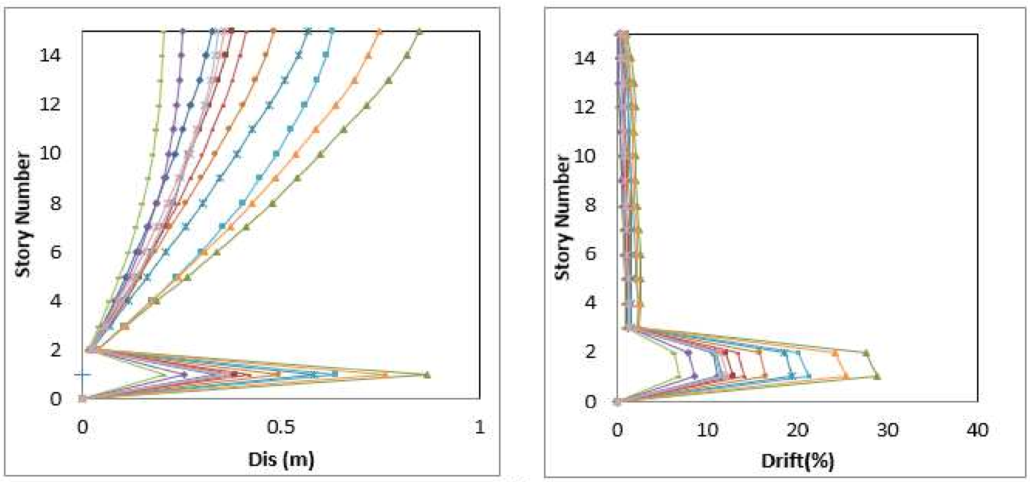


B



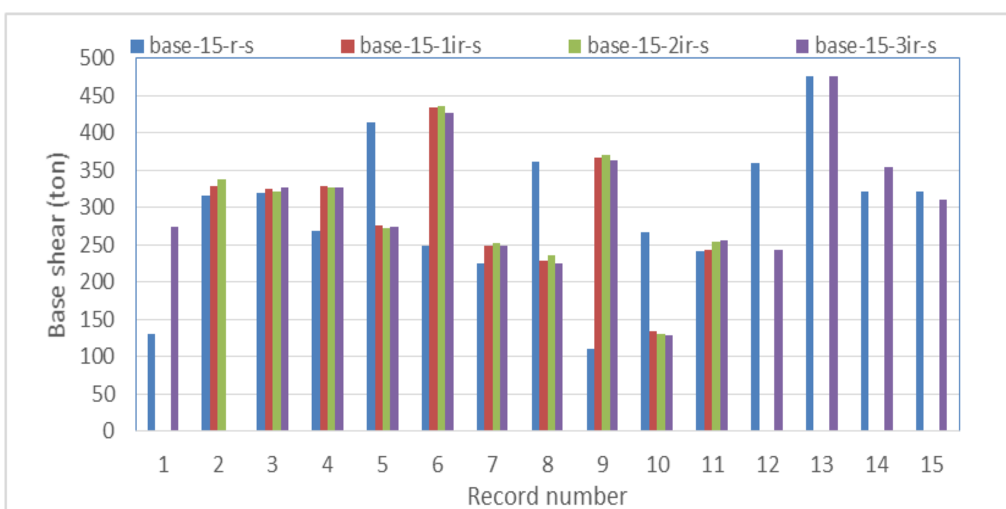
C



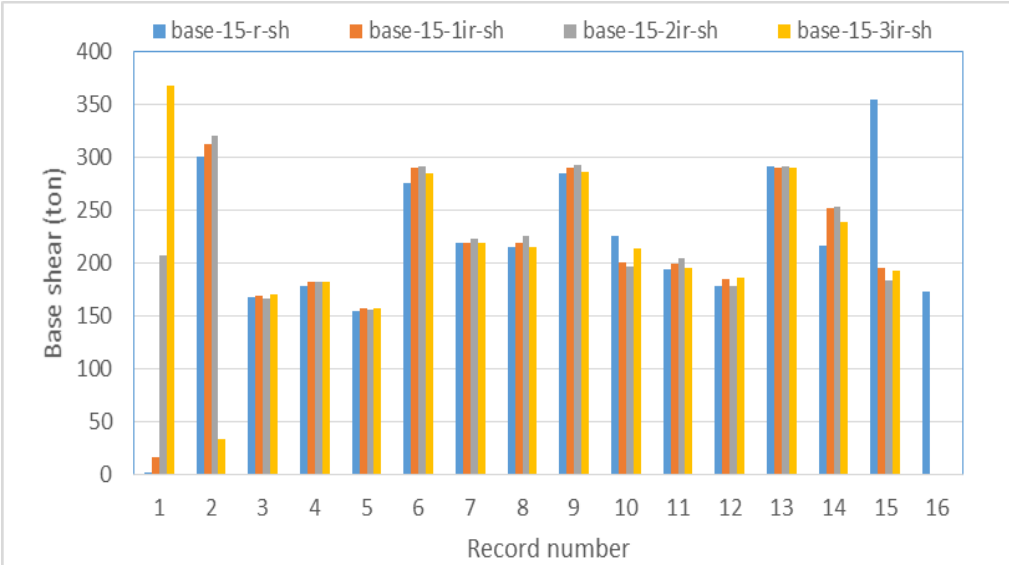
D

Figure 5: a) Displacement and drift diagram for 15-r model, b) Displacement and drift for 15-1ir model, c) Displacement and drift for 15-2ir model, d) Displacement and drift for 15-3ir model

Results of Base Shear



A



B

Figure 6: a) 15-storey structures of basic shear of standard spectrum, b) 15-storey structures of basic shear of standard spectrum of conditional average spectrum

Displacements Median of model

The results of time history analysis in the form of displacement median and drift diagrams for structures are shown in Figure 7. In all cases, the displacements created in the structures by the conditional and standard spectrum scale method are different. The displacement demand created in standard-scale structures is higher than the conditional spectrum, which indicates that the standard spectrum applies higher and more conservative values to the structure than the conditional mean spectrum. However, the conditional mean spectrum applies smaller values to the structure.

this difference in irregular structures is less than regular structures. In such structures, the dominant mode period is not the first mode, and the difference between the periods of the first mode and the dominant mode indicates this reason.

This difference is also more evident in the base shear. The median of the base shear for the conditional mean spectrum is less than the values obtained from the standard spectrum, indicating less demand on the structure with this scaling method there.

Conditional mean spectrum can be used for designing, even in irregular structures to reduce structure response in higher modes.

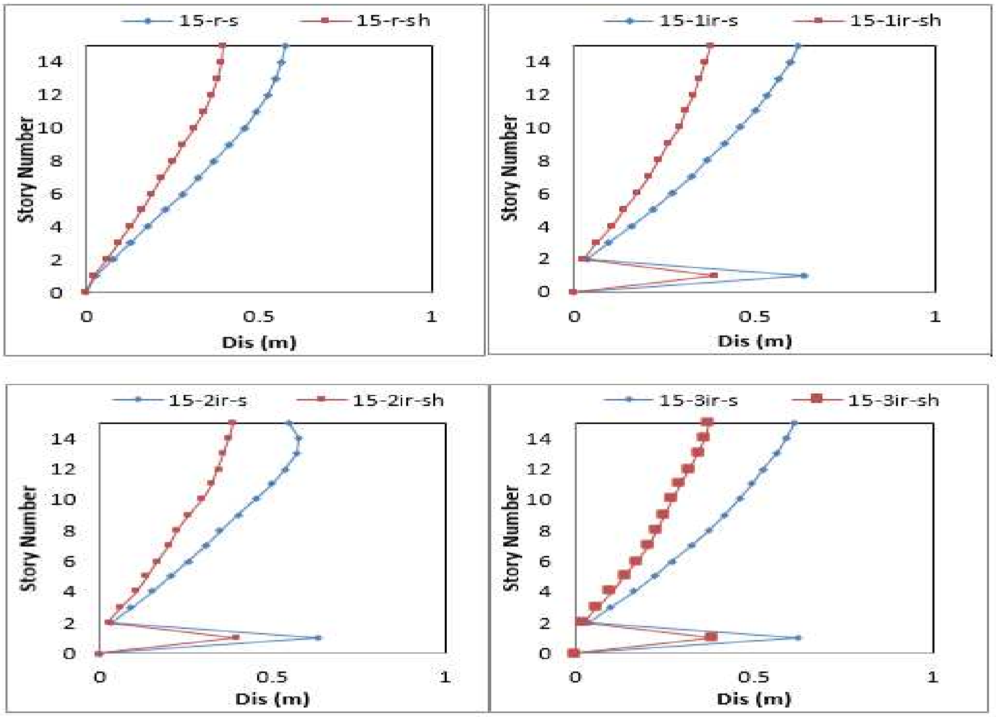


Figure 7: Comparison of median displacement for a 15-story structure

Conclusion

In the present study, first, an irregular pattern was defined in structures with different heights in terms of stiffness and mass. Steel moment frame structures were designed using the methods defined in the regulations and applying the existing restrictions. These elements were modeled in SAP200 software. Using the definitions and acceptance criteria introduced in FEMA 356, concentrated plastic joints are assigned to structural members. Then, using the introduced method to analyze the modal time history in this regulation, the displacement force curve for the structures was obtained. Different spectrums can be used for the studied accelerometers scale. In this study, the conditional mean spectrum was used due to the high accuracy of this type of spectrum.

The results of nonlinear static analysis indicate that the capacity curve of the models is slightly different, but regular structures show more capacity. The yield displacement of structure is almost identical.

The results of time history analysis in the form of intermediate displacement and drift diagrams for structures showed that in all cases the displacements created in the structures by the conditional and standard scale scales are different. The displacement demand created in standard-scale structures is higher than the conditional spectrum, which indicates that the standard spectrum applies higher and more conservative values to the structure than the conditional mean spectrum. However, the conditional mean spectrum applies smaller values to the structure.

This difference is also more evident in the base sections. The median of the base shear for the conditional mean spectrum is less than the values obtained from the standard spectrum, indicating less demand on the structure using this scaling method.

By using the conditional mean spectrum for design, even in irregular structures, the structure response can be reduced in higher modes.

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