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Evaluation of Errors in Seismic Analysis Methods by Considering Lateral Stiffness Irregularities in Construction Projects

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Abstract. Basically, among the various stages that are considered when designing a building for earthquake resistance, the decision stage about building configuration is of fundamental importance. One of the important factors that has a significant impact on the seismic performance of the building is its regularity or irregularity in plan and height. Most of those with irregular configurations are more damaged by earthquakes. Therefore, it is important to set criteria for detecting irregularities in structures. In this study, in order to investigate the error rate of seismic analysis methods (static equivalent, spectral and time history) in intermediate structures with irregularity of hardness, 4 5-story steel samples with dual flexural frame system and bracing with different states of irregularity in height in soft SAP software has been modeled. The results showed that the equivalent static analysis method always provides conservative and somewhat uneconomical values compared to other methods, so it can be said that for static buildings, equivalent static analysis is reliable. Any analysis of time history better than spectral analysis better represents the behavior of the structure during an earthquake.

Keywords: *Hardness irregularity, error rate, seismic analysis, intermediate structure*

1. Introduction

Due to the occurrence of strong earthquakes in our country, the discussion of seismic design of buildings against earthquakes has always been an important challenge for structural and earthquake engineers. Meanwhile, the definition of different design methods in various regulations and articles always raises the question that which method is safer and more cost-effective for design. Meanwhile, linear and nonlinear analysis methods in static and dynamic mode can be used for calculation and design. Linear analysis refers to the analysis of a structure by considering the elastic behavior of its components. In general, linear analysis methods are suitable when during the earthquake the behavior of structural components is in the linear range or a small number of components are out of linear limit, including linear analysis methods can be static linear analysis (equivalent static), linear dynamic analysis , quasi-dynamic or spectral analysis pointed out that nonlinear analysis methods are more reliable for more accurate analysis of structural behavior and are more consistent with the behavior and nature of materials. And lateral strength on irregular structures in height, several researches have been done and the importance of these two parameters in controlling and designing structures has become more and more obvious [1]. They are responsible for seismic energy and providing the rigidity of the structure to control the movement of stories. Regarding the location of lateral load-bearing systems, regulations, architecture and engineering judgment, effective parameters are one of the reasons for geometric irregularities in height D, is an architectural requirement. A building may change its use on the upper stories for some reason, and on that story, in the mouth where the lateral bearing system is used in the lower story, it is not possible to install a brace (or shear wall), so the accounting engineer will have to Elimination of lateral bearing system in the mentioned class which may cause geometric irregularity. Another reason can be engineering judgment since the seismic force is distributed in proportion to the height of the stories and therefore the share of the lower stories is greater than the seismic force. The calculator can use fewer openings in the upper stories to install the lateral load-bearing system, which may also cause geometric irregularities. It is the same as the stiffness of the structure, but in fact the strength of a member or structure is different from its stiffness. Hardness percentage: The lateral story of the story itself or less than 80 percent of the average lateral stiffness of the three stories is called the soft story. Very soft story: if the lateral stiffness of each story is less than 60% or less than 70% of the average lateral stiffness of If the story is on itself, that story will be very soft [2]. When the hardness of one story is much less than the other stories, this story experiences more displacements during the earthquake, and during this displacement, many mechanisms and many damages in this The story is created and finally at the top and bottom of the columns of this story, a plastic joint is formed and leads to its collapse, in which case other stories may fall on this story. In this case, a large amount of seismic energy is consumed by the mechanisms created in the soft story. This philosophy (the existence of the soft class) has long been popular and even considered as a design method. By sacrificing one story, the other stories remain intact, although today this type of irregularity is completely rejected and according to the 2800 standard of the fourth edition, many restrictions are considered for these structures. In the following, the history of studies in the field of irregularity is presented by Tsu and Ying [3], suggested that in order to reduce the ductility of demand in the soft part of buildings with irregularly distributed hardness, it is better that the center of resistance be as close as possible to the center of mass. He also identified the eccentricity of resistance as an ineffective parameter in systems with irregular mass distribution. In contrast, two other researchers, by defining effective stiffness eccentricity, tried to introduce it as an influential parameter in both irregular mass and stiffness systems [4]. Di Stefano et al. [5] also examined the location of optimal strength of the center to control the ductility of demand in

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single-layer models with strong lateral elements in both main directions of the structure. These researchers concluded that the most suitable point for the center of resistance is between the other two centers. Different centers of mass, stiffness, and strength were dealt with in one-tier models. They argued that when a structure behaves in a linear region, the behavior of the structure depends on the position of the center of stiffness. The importance of the center of resistance becomes apparent. In addition, these researchers named the best arrangement that is the center of mass between the two centers of hardness and resistance the balance arrangement.

Also, Azimi Nejad and Sarvoghd Moghaddam [7] modeled one-story instruments with different permutations of mass centers, hardness and resistance and studied its behavior at different levels of earthquakes under single and two-component mappings. Among their main results, some can be mentioned. Among other things, the location of the center of mass between the other two centers does not necessarily reduce the rotation or displacement of the story, but it is better that the center of resistance is closer to the center of mass, and that the effect of two-way earthquake in nonlinear chronological analyzes in most cases And this increase is less in the exit of smaller resistance centers. Regarding the effect of torsion phenomenon in models with strong elements in both main directions under the influence of two-component maps, Pfeiffer et al. [8 and 9] presented articles and concluded that in rigid torsional structures, the maximum deformation of the structure is almost similar to linear mode. Kumar [10] and Lucini et al. [11] in separate studies have studied the torsion and the effect of eccentricity on the performance of buildings and the effect of the stiffness of the filler walls. By defining the eccentricity of mass and stiffness, a maximum of 10% of the story dimensions are considered and if it enters the nonlinear area, the center of resistance has a more important effect. The dependence of stiffness behavior and strength of wall-type structural elements as an irregular system in the plan by Zinc in his study has emphasized that the general pinching effect is defined by defining the eccentricity of mass and stiffness, up to 10% of the story dimensions. The forms of entry into the nonlinear region, the center of resistance, have a more important effect. The dependence of the stiffness behavior and the strength of the structural elements of the wall type were examined as an irregular system in the plan by Roy [13] and two strategies were proposed for balancing the centers of hardness and resistance. The considered models were subjected to one- and two-way seismic demands and examined the relative performance of these two criteria. One of the results was that the strategy of focusing the centers of mass and resistance for structures in areas with high seismicity at levels Life safety performance and collapse threshold performed better. A new method for designing irregular buildings by [14] was proposed. In this method, instead of using the usual static equations, it distributes the resistance among the lateral bearing members, then the resistance of some modified elements to the center of mass is obtained. In this way, the designer can more appropriately control the effects of torsional and irregular anchors and predict a more appropriate form to minimize interclass displacement. In [15] stated that safety margin collapse of reinforced concrete buildings with 5 to 10 stories is considered with a special bending frame system under 5, 10 and 20% mass center exits by examining the two indices of collapse probability and the relative margin of collapse. The results show that the increase of mass center deviation in the studied building models that the amount they have a small torsional irregularity ratio, which reduces the likelihood of their collapse. Improving the safety margin of collapse of these buildings by increasing the eccentricity of the mass is due to more rigid torsional behavior in them. Safety has not changed significantly. Surgery and dignity [16], using nonlinear static analysis and nonlinear dynamic analysis, first the formation of plastic joints and performance levels provided by reinforced concrete structures were determined, then, these structures were reinforced using steel braces and steel surface reinforcement. Their rejection was re-determined and compared with the first case. The models were selected from two different plans in two modes of 10 and 15 stories. In addition, the structures studied in this article, in addition to being tall, were selected from irregular type in the plan. Irregularities can also be investigated in the results. The results show that the use of steel bracing has significantly improved the performance level and seismic capacity of the structure. In this research, as an innovation, the error rate of seismic analysis methods (static equivalent, spectral dynamics and time history dynamics) in intermediate structures with irregular lateral stiffness has been investigated.

2- Research method

The structure is a 5-story steel frame with a dual system of bending and bracing frames in Tehran. 4 models are examined in this research. The first sample is a regular frame, the second sample is a very soft story irregularity on the first story, the third sample is a very soft story irregularity on the third story and the fourth sample is a very soft story irregularity on the roof, 3 openings of 5 meters. The building is built on the soil of Tabap 3 and the importance of the building is considered equal to 1. SAP2000 software [17] has been used for modeling and analysis. SeismoSignal software [18] has been used to extract seismic parameters. IPE240 has been used for beams, IPB300 columns and braces have been used. The general geometry of the models according to Figure (1) is presented and the specifications of the materials used are also used according to Table (1).

Table 1: Characteristics of materials

0.8 TON/M^3	Mass unit
7.85 TON/M^3	Weight unit
2.1x107 TON/M^2	Elasticity model
24000 TON/M^2	Steel tension, Fv
37000 TON/M^2	Final resistance of steel, Fv

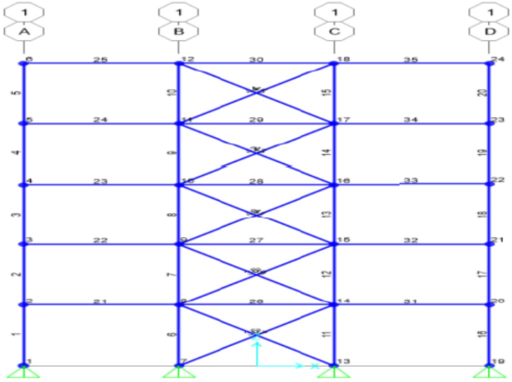


Figure 1: General geometry of studied models

3. Seismic analysis methods

According to the existing seismic regulations, in general, three types of analysis are introduced for structures (static, spectral dynamics, time history dynamics), each of which is specific to specific conditions when a single structure under these three types of analysis They give different answers. In Regulation 2800, dynamic analysis is done in two ways: spectral analysis and time history analysis. Dynamic analysis should be done according to the movement of the earth. The effects of ground motion can be determined by the reflection spectra of the design or the time history of acceleration changes [19].

3-1- Introducing the equivalent static analysis method

After the 1908 earthquake in Italy, a team of experienced civil engineers was sent to study the buildings destroyed in the earthquake and to investigate the cause of their damage. Examining the overturned buildings, the team concluded that the earthquake had created a horizontal force in the structures that caused them to overturn, and finally suggested that this force be equal to one-twelfth of the building's weight. The amount of seismic force was expressed in the form of CW = V relation. Static equivalent method, despite having weakness in modeling the dynamic and nonlinear behavior of structures, is considered as one of the most widely used methods for estimating seismic force on structures.

3-2 Introduction of time history analysis method

Dynamic temporal analysis (or time history) is used to determine the instantaneous response of a structure under acceleration (accelerometer). The accelerometer should reflect as much as possible the actual movement of the ground at the construction site during an earthquake. The regulations are mentioned to be used. Reflections are obtained based on the maximum value obtained from these three pairs of accelerometers. If seven pairs of accelerometers are considered, the average reflection of accelerometers can be used. [19] Time history has been used to perform dynamic analyzes.

3-3. Introduction of spectral analysis method

In the history method, we practically try to obtain the answers of the structure at any point in time during the loading period, and to have a history of the results for each parameter we want. But the problem is that time history analysis is usually a long and time consuming process and therefore they are often used to design special and very important structures in civil engineering, given that in practice the design process of members of a structure requires, we have maximum values of force and displacement. If, instead of obtaining the total history of the answers over time, we obtain a good estimate of the maximum values, the analysis of the structure against the seismic force will be much easier. It is also called quasi-dynamic method, exactly such an approach is done with a careful look, it should be said that the word dynamic means that the forces acting on the structure and the structural responses to these forces change over time. Some of these issues are fully covered in the analysis of time history, but the fact is that spectral analysis is not dependent on time and therefore it is also called quasi-dynamic analysis [19].

4- Results

The results of static analysis, dynamic spectral analysis method and time history analysis method are given. It is a method for calculating the amount of deformation, internal forces and abutment reactions of a structure. The information required for these calculations is the characteristics of structural sections and loads on the structure. After analyzing the structures and determining the internal forces (shear, axial, bending anchor and torsional anchor), they design the structure according to them. The purpose of design is to determine the necessary sections for different members. The basic assumptions of linear static analysis method are: 1- The behavior of materials is linear 2- Earthquake loads are fixed (static) 3- The total force on the structure is equal to a coefficient of building weight. The resulting base shear is equal to the base shear force according to the regulations. Next, the values of displacement and shear base of the structure in different irregular states of hardness according to Figures (2) to (7) and Tables (3) to (6) are presented.

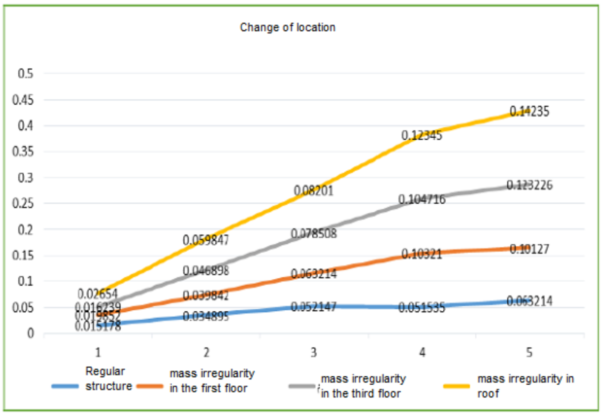


Figure 2: change in location from static analysis in terms of meter

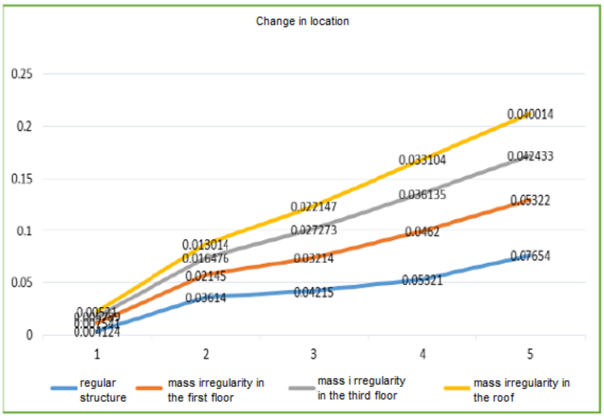


Figure 3: change in location from dynamic analysis in terms of meter

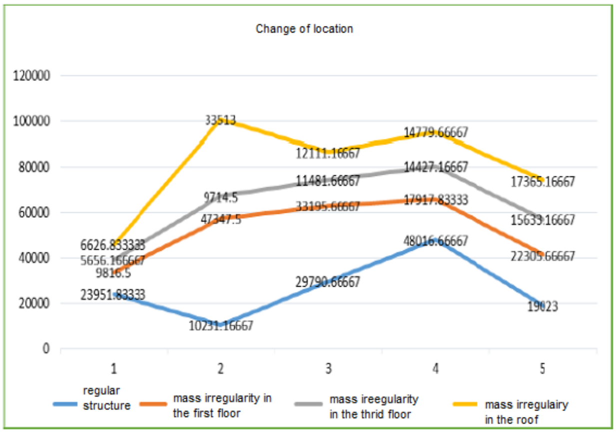


Figure 4: change in location from dynamic analysis of time history in terms of meter

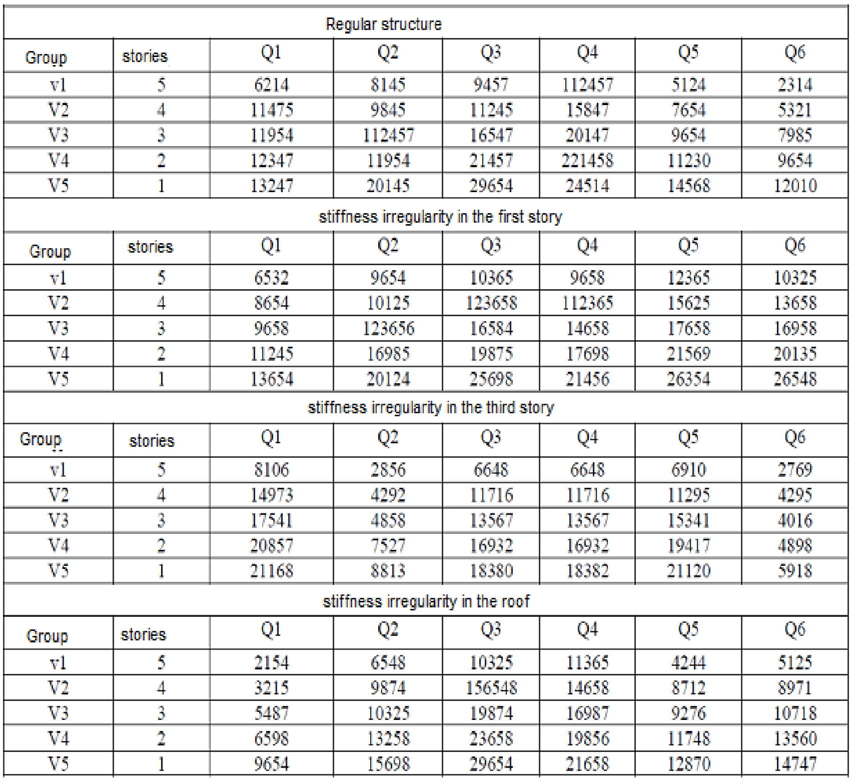
Table 2: change in location from static analysis in terms of meter

	Regular structure	stiffness irregularity in the first story	stiffness irregularity in the third stories	stiffness irregularity in the roof
Storeys	Change of location under EX	change of location under EX	change of location under EX	Change of location under EX
STORY1	0/015178	0/019852	0/016239	0/02654
STORY2	0/034895	0/039842	0/046898	0/059847
STORY3	0/052147	0/063214	0/078508	0/08201
STORY4	0/021535	0/010321	0/104716	0/012345
STORY5	0/063214	0/010127	0/123226	0/014235

Table 3: change in location from dynamic analysis in terms of meter

	Regular structure	stiffness irregularity in the first story	stiffness irregularity in the third story	stiffness irregularity in the roof
Stories	Change of location under RSP	Change of location under RSP	Change of location under RSP	Change of location under RSP
STORY1	0/004124	0/007541	0/005789	0/00521
STORY2	0/03614	0/02145	0/016476	0/013014
STORY3	0/04215	0/03214	0/027273	0/022147
STORY4	0/05321	0/04620	0/036135	0/033104
STORY5	0/07654	0/05322	0/042433	0/040014

Table 4: change in location from dynamic analysis of time history in terms of meter



Regular structure

Group	stories	Q1	Q2	Q3	Q4	Q5	Q6
v1	5	6214	8145	9457	112457	5124	2314
V2	4	11475	9845	11245	15847	7654	5321
V3	3	11954	112457	16547	20147	9654	7985
V4	2	12347	11954	21457	221458	11230	9654
V5	1	13247	20145	29654	24514	14568	12010

stiffness irregularity in the first story

Group	stories	Q1	Q2	Q3	Q4	Q5	Q6
v1	5	6532	9654	10365	9658	12365	10325
V2	4	8654	10125	123658	112365	15625	13658
V3	3	9658	123656	16584	14658	17658	16958
V4	2	11245	16985	19875	17698	21569	20135
V5	1	13654	20124	25698	21456	26354	26548

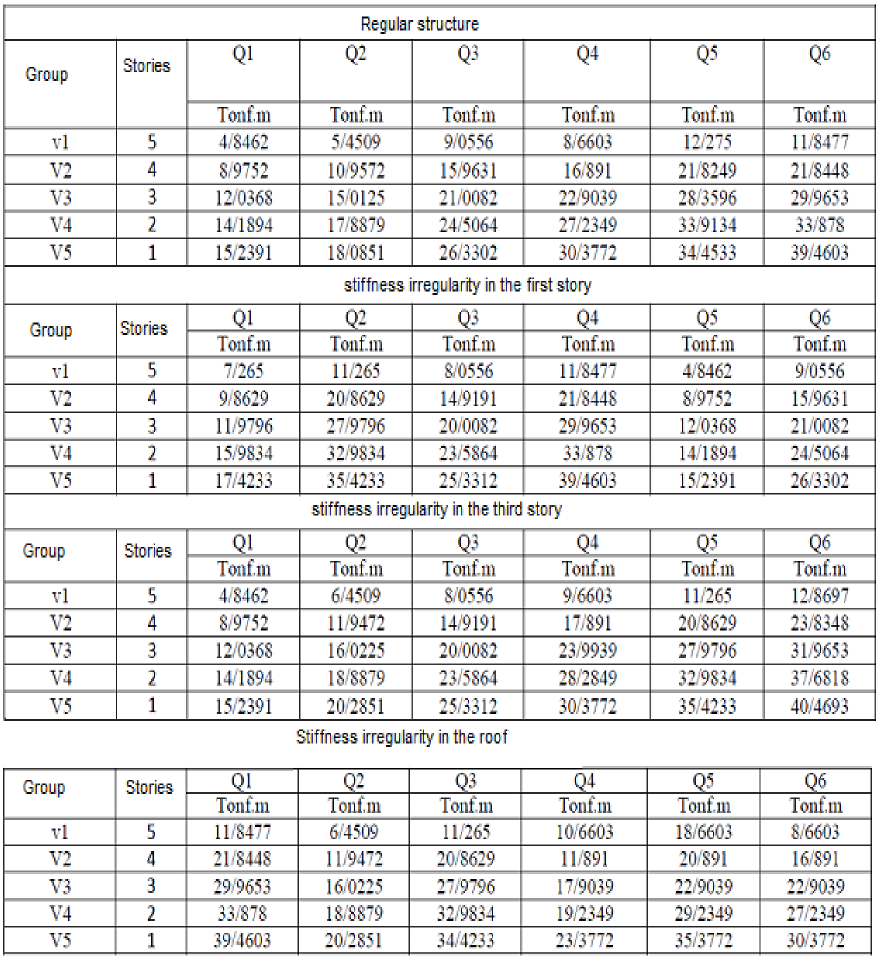
stiffness irregularity in the third story

Group	stories	Q1	Q2	Q3	Q4	Q5	Q6
v1	5	8106	2856	6648	6648	6910	2769
V2	4	14973	4292	11716	11716	11295	4295
V3	3	17541	4858	13567	13567	15341	4016
V4	2	20857	7527	16932	16932	19417	4898
V5	1	21168	8813	18380	18382	21120	5918

stiffness irregularity in the roof

Group	stories	Q1	Q2	Q3	Q4	Q5	Q6
v1	5	2154	6548	10325	11365	4244	5125
V2	4	3215	9874	156548	14658	8712	8971
V3	3	5487	10325	19874	16987	9276	10718
V4	2	6598	13258	23658	19856	11748	13560
V5	1	9654	15698	29654	21658	12870	14747

Table 5: basic cut from dynamic analysis of time history in terms of ton



Regular structure

Group	Stories	Q1	Q2	Q3	Q4	Q5	Q6
		Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m
v1	5	4/8462	5/4509	9/0556	8/6603	12/275	11/8477
V2	4	8/9752	10/9572	15/9631	16/891	21/8249	21/8448
V3	3	12/0368	15/0125	21/0082	22/9039	28/3596	29/9653
V4	2	14/1894	17/8879	24/5064	27/2349	33/9134	33/878
V5	1	15/2391	18/0851	26/3302	30/3772	34/4533	39/4603

stiffness irregularity in the first story

Group	Stories	Q1	Q2	Q3	Q4	Q5	Q6
		Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m
v1	5	7/265	11/265	8/0556	11/8477	4/8462	9/0556
V2	4	9/8629	20/8629	14/9191	21/8448	8/9752	15/9631
V3	3	11/9796	27/9796	20/0082	29/9653	12/0368	21/0082
V4	2	15/9834	32/9834	23/5864	33/878	14/1894	24/5064
V5	1	17/4233	35/4233	25/3312	39/4603	15/2391	26/3302

stiffness irregularity in the third story

Group	Stories	Q1	Q2	Q3	Q4	Q5	Q6
		Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m
v1	5	4/8462	6/4509	8/0556	9/6603	11/265	12/8697
V2	4	8/9752	11/9472	14/9191	17/891	20/8629	23/8348
V3	3	12/0368	16/0225	20/0082	23/9939	27/9796	31/9653
V4	2	14/1894	18/8879	23/5864	28/2849	32/9834	37/6818
V5	1	15/2391	20/2851	25/3312	30/3772	35/4233	40/4693

Stiffness irregularity in the roof

Group	Stories	Q1	Q2	Q3	Q4	Q5	Q6
		Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m	Tonf.m
v1	5	11/8477	6/4509	11/265	10/6603	18/6603	8/6603
V2	4	21/8448	11/9472	20/8629	11/891	20/891	16/891
V3	3	29/9653	16/0225	27/9796	17/9039	22/9039	22/9039
V4	2	33/878	18/8879	32/9834	19/2349	29/2349	27/2349
V5	1	39/4603	20/2851	34/4233	23/3772	35/3772	30/3772

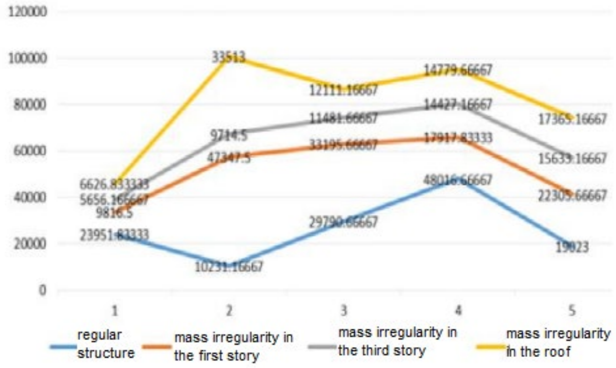


Figure 5: basic cut from dynamic analysis of time history

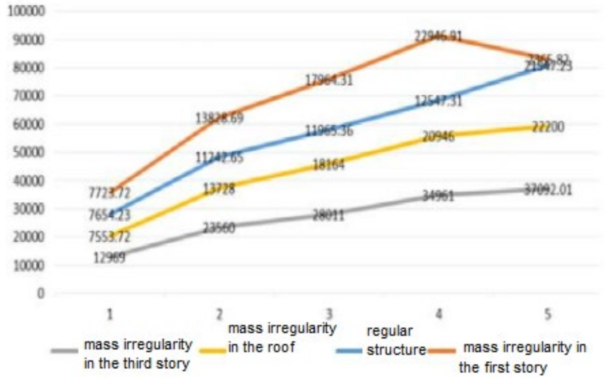


Figure 6: basic cut from corresponding static analysis

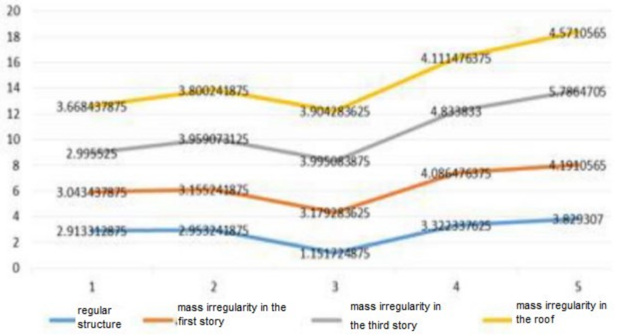


Figure 7: basic cut from spectral dynamic analysis

5. Conclusion

Estimation of seismic requirements of structures using conventional nonlinear static analysis methods is based on the assumption that the response of the structure is controlled only by its main mode. This assumption is not valid for irregular and tall structures due to the participation of higher vibrational modes in seismic responses of the structure. Prior to base shear matching, it is clear that the equivalent static analysis method always provides conservative and somewhat uneconomical values compared to other methods, but if the comparison criterion is considered after base shear matching, which causes a specific distribution of seismic force. In classes, especially in dynamic versus static analysis: according to the graphs drawn above to compare the results of analysis of this frame under static, spectral dynamic (quasi-dynamic) and dynamic time history (moment to moment) in the study of classes is evident. The shear distribution in the frame is similar in static and spectral analysis modes, but to some extent the shear distribution values due to dynamic analysis are moment by moment. The mass irregularity in the first story was 55% higher than in the other classes and the irregularity. In the third story, it was 20% less than the regular sample. Comparison of class displacement shows that the form of deformation (displacement) of classes in spectral analysis is close to static, but spectral analysis shows less than static values for maximum class displacement, and in dynamic analysis this value decreases if the criteria Regulation 2800 to be used to design a frame. Comparing the displacement of stories, it has been determined that the form of deformation (displacement) of stories in spectral analysis is close to static, but spectral analysis shows less values for static displacement than in static analysis. The value decreases if the rules of Regulation 2800 are used to design a frame. Spectral and relative to static represent the better behavior of the structure during an earthquake because in the analysis of time history, unlike the static analysis used in the first mode, the effect of higher modes is seen and in this analysis the condition of acceleration pairs of regulations is considered. First of all, the number of accelerometers used should be sufficient. Secondly, the intended accelerometers should also meet the rules of the regulations.

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