COMPARING NONLINEAR TIME HYSTORY AND NONLINEAR STATIC ANALYSIS OF RC STRUCTURES WITH VERTICAL MASS IRRIGULARITY

Mohammad MehdiERFANI
MSc. Graduated in structural engineering, University of Zanajn, Zanajn, Iran
s.m.m.erfani@gmail.com

MahdiGORZIN
MSc. Graduated in structural engineering, University of Zanajn, Zanajn, Iran
mahdigorzin@yahoo.com

Hossein TAJMIR RIAHI
Assistant professor, University of Isfahan, Isfahan, Iran
tajmir@eng.ui.ac.ir

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ABSTRACT

Investigations on the past earthquakes proved that irregular buildings are vulnerable in accordance with regular ones. This paper investigates seismic behaviour of reinforced concrete buildings with mass irregularity. These irregularities are considered as three irregular regions in bottom, middle and upper levels along the frame height of the frames. It also discusses nonlinear static analysis results with different load patterns. Nonlinear time history analyses for these types of structures are also performed in this paper. This method is used for verifying the results obtained by nonlinear static analysis. In order to extend the results to cover more types of structural systems, both moment resisting frames and moment frames with shear walls are studied. Results of the present investigation have been shown that mass growth in a story which is subjected to mass irregularity leads to increase differences between the results obtained by nonlinear static pushover and nonlinear time history analysis. Also results show that uniform loading pattern in nonlinear static analysis method is not recommended for concrete buildings with vertical mass irregularity. Generally, differences between the two methods are less in frames equipped with shear walls in accordance with moment resisting frames.

INTRODUCTION

Earthquakes happened in the past years demonstrated that irregular buildings have been damaged more severely than regular ones. (Valmundsson and Nau (1997)), (Al-Ali et al, (1998)). The main reason is the concentration of permanent deformation in the irregularparts. Analysis of irregular buildings for design purpose using elastic methods leads to underestimate results in irregular regions (Chintanapakdee and Chopra (2004)). Therefore, some limitations are considered in seismic standards for such buildings. Different applications of stories in a building results in mass change in each level and if these changes are significant, they lead to mass irregularity thorough height. Nowadays a number of buildings with different application are built in most countries. Using different applications in stories causes to create different dead load and live load in them. Consequently effective mass in earthquake is differed in building stories. Earthquake design codes express that if mass differential among stories pass a specified limit, vertical mass irregularity arises.

Past studies show that studying on irregular buildings only by static and linear analysis cannot give acceptable and reliable results. For these types of buildings, dynamic and nonlinear methods have been recommended. One of the prevalent methods in seismic evaluation of structural behavior is nonlinear static analysis. In this method, ground motion is simulated by lateral loads that are applied to structures as static loads. Nonlinear behavior of structural elements isconsidered with simulating material and geometrical nonlinearity. On the other side, nonlinear time history analysis method is the most accurate method. In this method, applied loads have dynamic characteristic and nonlinearitycan beconsidered similar to nonlinear static method. It sounds logical that before using every structural analysis methods, results obtained from those methods should be verified by more accurate methods and compare them for structures with various dimensions and number of stories. It is better to verify these methods by time history analysis which is the most accurate one. This verification determines limitations, deficiency and advantages of the method.

There are many buildings with the same structural systems which have different performance because of their number of story and their height. Therefore, in this paper, in order to expand the results to extensive spectrum of buildings, short, medium height and tall buildings have been studied. Also, two prevalent and applicable lateral resisting systems in concrete buildings are modeled and investigated. Moment resisting frames and a dual system consists of moment resisting frames equipped with shear walls are these systems. In the present study, vertical mass irregularity effects on the mentioned lateral resisting system are studied. In addition, nonlinear static pushover analysis and time history analysis results obtained from analyzing the buildings are compared.

MODELLING

In this paper, concrete moment resisting frames and concrete frames equipped with shear wall are studied. Intermediate ductility has been considered for both models. In order to cover more range of buildings, studied frames consist of two dimensional frames with 6, 10 and 15 stories. Because of diversity of irregularity location in buildings, 3 alternative irregularity locations which are in bottom, middle and upper levels along height have been considered. The frames have 5 bays and beams which are 4 meters length. Load bearing width of each beam is 4 meters and story heights are 3.2 meters. The plan and elevation of the buildings are identical for all structures. Generic geometric properties of the frames are depicted in Figure 1.

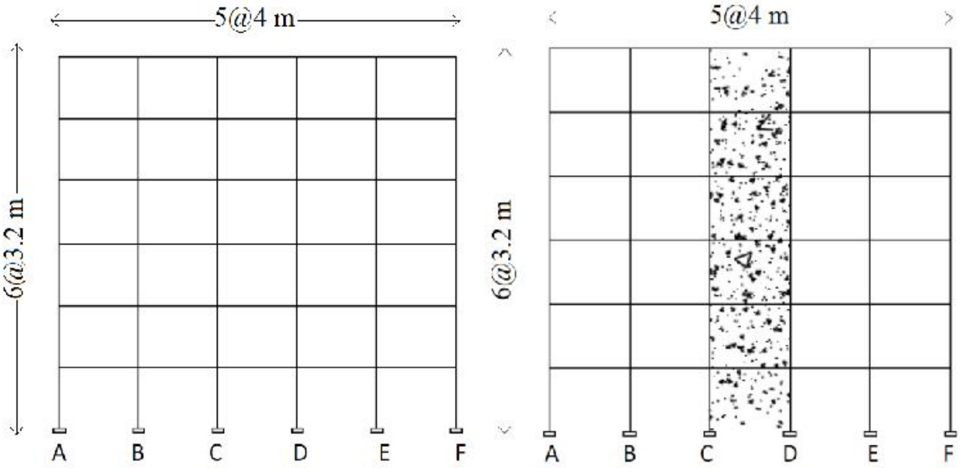

Figure 1. General dimensional properties of the Frames

In order to prevent complexity of expression, the frames are called with short indications. mrfstands for the moment resisting frames and SWF stands for the frames equipped with shear walls. A number that shows the number of stories is perched after that. R and IR are used for defining regular and irregular frames, respectively. For mass irregularity locations, T is used to indicate that irregularity has been located at the top of building. Similarly, M and B have been selected for middle and bottom, respectively. For example, mrf-6-IR-M-3 defines a 6-story moment resisting frame with mass irregularity which has been located at the third story.

Masses of all stories are the same except the story which bears mass irregularity. For considering mass irregularity, loads which produce 50 percent additional mass in comparison with the other stories, are applied to irregular stories. Story loading values is tabulated in Table 1. According to this table, dead loads are 650, 610 and 975 kg/m^2 for typical stories, roof stories and irregular stories, respectively, in all frames. Similarly, live loads are 200, 150 and 300 kg/m^2 for typical stories, roof stories and irregular stories, respectively.

Table 1. Loading properties on floors

Floor	Dead load (kg/m^2)	Live load (kg/m^2)
Irregular story	975	300
Roof	610	150
Other floors	650	200

The studied frames have been loaded according to the Iranian National Building Code (INBC) section 6 for gravity and earthquake loading. The frames have been designed according to the Iranian National Building Code (INBC) section 9.

In this paper, for modelling of nonlinear behaviour of the frames and also considering and controlling acceptance criteria, FEMA356 has been used. PERFORM-3D software has been used for analysing the frames. Beams are ductile members and are controlled by displacement. In fact, these members dissipate earthquake energy with their deformation. In the PERFORM-3D software, most elements consist of a number of components. So, FEMA beam, concrete type has been used for modelling of the beams. This component is exerted to model inelasticbending in concrete beams, based on the FEMA 356 model. Modelling of the columns is more complicated than the beams. For modelling of the columns, FEMA concrete column component has been employed in the software. This component is used to model inelastic bending in concrete columns, based on an interpretation of the FEMA-356 model. Vertical fibermodel has been used for shear wall modelling in the software.

A shear wall compoundcomponent has been assigned for each shear wall element. Shear properties and axial-bending properties must bespecified for each shearwall compound component. Shear properties are considered as elastic material. However, axial-bending properties of shear walls defined as inelastic material. Defining nonlinear materials for axial-flexural properties results in considering concrete cracking effects and moving the neutral axis. The Mandel model has been used for modelling of concrete shear walls and the Park model has been used for modelling of steel bars.

ANALYSES

PUSHOVER ANALYSIS

In seismic assessment of structures, pushover analysis is the most popular method because of its simplicity and applicability. Pushover curves show the relationship between a deformation parameter and a strength parameter. In this research, roof displacement and base shear are selected as deformation parameter and strength parameter, respectively. These parameters are obtained from analysis in which lateral load patterns applied to structures. Lateral loads in nonlinear static pushover analysis are applied to centre of mass of stories as nodal loads.In order to perform nonlinear static pushover analysis, two lateral load patterns have been considered. One of them is uniform lateral load pattern and the other one is a load pattern obtained by spectrum analysis.In the nonlinear static pushover analysis, the centre of mass of roof has been defined as a controlling point. Also ASCE41-06 has been used for calculating the target displacement. Target displacements for each frame have been calculated and listed in Table 2.

Table 2. Target displacement calculated for pushover analysis

frame	Target displacement (mm)	frame	Target displacement (mm)	frame	Target displacement (mm)
mrf-6-R	176	mrf-15-R	473	swf-10-R	178
mrf-6-IR-B-01	177	mrf-15-IR-B-01	456	swf-10-IR-B-01	178
mrf-6-IR-M-03	178	mrf-15-IR-M-08	460	swf-10-IR-M-05	181
mrf-6-IR-T-05	184	mrf-15-IR-T-14	475	swf-10-IR-T-09	188
mrf-10-R	306	swf-6-R	80	swf-15-R	374
mrf-10-IR-B-01	306	swf-6-IR-B-01	80	swf-15-IR-B-01	374
mrf-10-IR-M-05	312	swf-6-IR-M-03	81	swf-15-IR-M-08	377
mrf-10-IR-T-09	315	swf-6-IR-T-05	88	swf-15-IR-T-14	387

TIME HISTORY ANALYSIS

In this research, the frames are subjected to a set of 7 ground motions. This set of ground motions has been called GM. The ground motions and their general properties are shown in Table 3.

Table 3. Ground motions used in this paper

No.	Earthquake name	magnitude	Station name	Station number	component	PGA (g)
1	Cape Mendocino	Ms(7.1)	Eureka – Mytle& West	89509	90	0.178
2	Imperial Valley	Ms(6.9)	Parachute Test Site	5051	225	0.111
3	Landers	Ms(7.4)	North Palm Springs	5070	90	0.134
4	Duzce	Ms(7.3)	Sakarya	------	90	0.023
5	Northridge	Ms(6.7)	Castaic – Old Ridge Route	24278	90	0.568
6	Loma Prieta	Ms(7.1)	Saratoga – Aloha Ave	58065	90	0.324
7	Kocaeli	Ms(7.8)	Mecidiyekoy	------	0	0.054

To be consistent with the seismic codes, the ground motions have been scaled. This ground motions were scaled according to the method explained in the ASCE41-06. The records were scaled individually rather than scaling them as pair because the structures are planar. The records were scaled such that their mean of 5%-damped linear response spectrumto be kept up to the ASCE41-06 response spectrum modified for stiff soil and high risk regions. The scaling has been executed for the period range 0.2Ti to 1.5Ti, where Ti is the fundamentals period of vibration of each frame modeled as a linear system. Therefore, scale factors are gained and applied to the modified GM records which have been scaled such that their peak points of their intensity (PGA) fitted to the acceleration of gravity (g). After mentioned procedures, records have been provided to apply to the frames. For example, scale factor obtained from the procedure for 10 stories moment resisting frame is 0.63. Response spectrum of the code, mean of the ground motions fixed their PGA to the acceleration of gravity and their modified response spectraare shown in Figure 2. Also response spectra of the ground motions that scaled to the acceleration of gravity (g) and their mean are plotted in Figure 3.

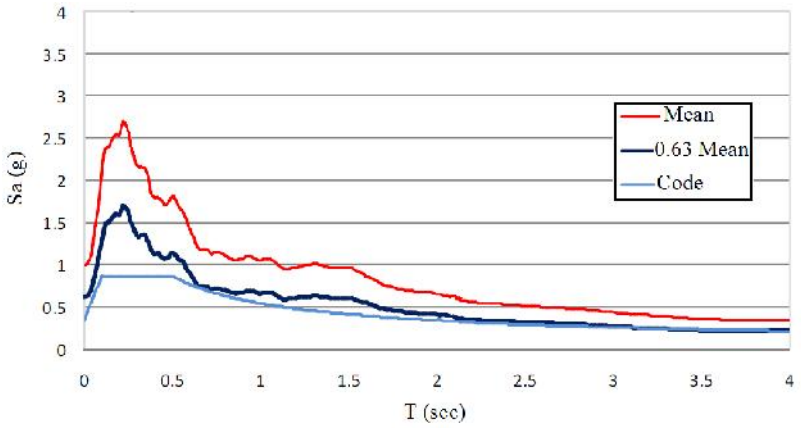

Figure 2.Response spectrum of the code and mean of the ground motions

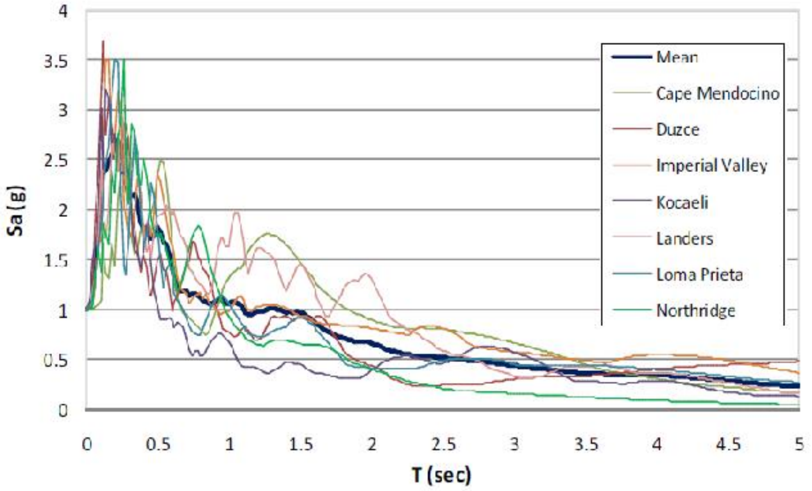

Figure 3.Response spectra of the ground motions and the mean of them

Table 4shows the obtained scale factors according to the mentioned procedure. Scale factors of moment resisting frames are more than the factors for frames with shear walls. This factor is increased due to increasing in number of stories.

Table 4. Scale factors obtained and are used for time history analysis

Scales factors for scaling the GM set					
Moment resisting frames			Frames with shear walls		
6 stories	10 stories	15 stories	6 stories	10 stories	15 stories
0.61	0.63	0.66	0.61	0.62	0.63

COMPARATIVE STUDY

Figure 4compares distribution of the maximum interstory drift ratio at each story level for the 10-storymoment resisting framewhich irregularity located in the eighth story (mrf-10-IR-M-05).Comparison of maximum interstory drift ratio distribution for a frame with shear wall which irregularity located in eighth story (swf-15-IR-M-08). The curves are gained from time history analysis and pushover with the two load pattern mentioned before. The results of time history analysis are the average of the GM set. The maximum interstory drift ratios of the pushover are gained from deformed shape of the frame when it reaches to the target displacement. As can be seen in these figures, interstory drift ratios achieved by pushover analysis with uniform lateral load pattern differ from the other curves. Results show that nonlinear static analysis method with uniform lateral loading pattern is not suitable for irregular structures especially in moment resisting frames. There is a significant difference between this loading pattern for drift response and results of nonlinear time history analysis. This difference is due to inability of this loading pattern for consideration of higher modes. Yet, the difference in frames with dual system is less than moment resisting frames. Therefore, the other analysed loading pattern is in accordance with lateral force which is obtained from spectral analysis. As can be seen in these figures, Drift ratios of the two methods for the moment resisting frame are mostly close together in the stories of 6 and 7. Maximum difference which is approximately 30 percent occurs in the third story. Deference between the two methods for the frame with shear wall in middle stories is more than the other stories. In general, pushover analysis predicts form of drift ratio distribution in height.

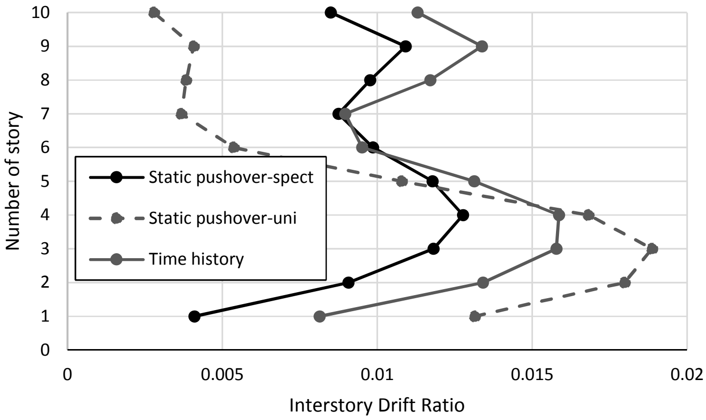

Figure 4.Comparing the methods for drift ratio distribution for mrf-10-IR-M-05

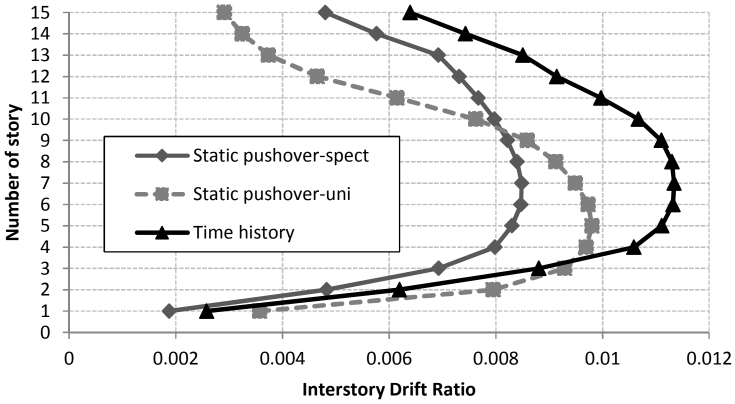

Figure 5.Comparing the methods for drift ratio distribution for swf-15-IR-M-08

Figure 6 shows drift ratios distribution of mrf-15-IR-M-8 happened in stories for time history and pushover analysis. Also Figure 7 shows the same parameter for swf-15-IR-M-8. As can be seen in these figures, drift ratios of the frame with shear walls are regularly less than the moment resisting frame one in all the stories because of their stiffness. Drift ratios in the middle stories are more than the other stories in the swf-15-IR-M-8. In addition, difference between the two methods is increased in middle stories because of irregularity location which is placed in the eighth story. This difference is decreased in bottom and upper stories. The two methods predict the story that endures the maximum drift ratio. The pushover analysis predicts a maximum value of mrf-15-IR-M-8 for the sixth story but time history results show that the maximum drift ratio is happened in the 13th story. Drift ratio distribution in the stories in the swf-15-IR-M-8 has smooth curves but the mrf-15-IR-M-8 has wavy carves.

In all frames equipped with shear walls with varies irregularity locations, drift ratios in the middle stories are more than the other stories as depicted in figure 7. Also, in these frames, pushover analysis gives less value in accordance with the time history method. Drift ratio distribution obtained from pushover analysis for these frames are compatible with the results of ground motion analysis.

Drift ratio curves of moment resisting frames with different irregularity location are wavy. Drift ratios of moment resisting frames resulted from pushover analysis in some stories have acceptable accuracy according to time history analysis but for the other stories have much value. Values of pushover are regularly less than the other method.

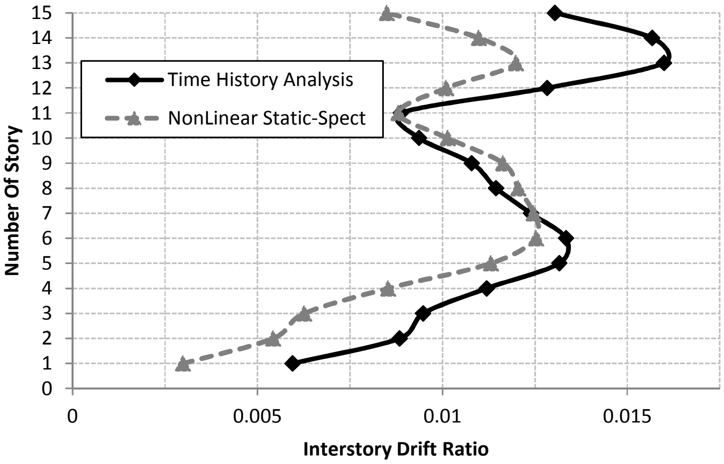

Figure 6.Drift ratio distribution for 15-story moment resisting frame(mrf-15-IR-M-8)

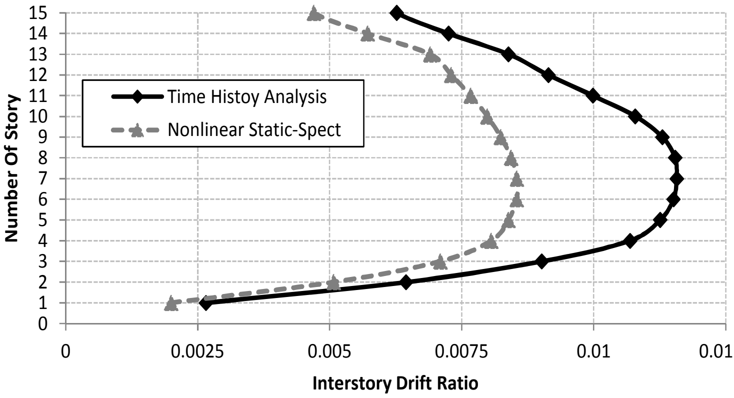

Figure 7.Drift ratio distribution for a 15-story frame with shear wall(swf-15-IR-M-8)

Results obtained from analysing the other frames show that when the number of buildings increases, the difference between the results of pushover and time history methods are increased specially in moment resisting frames. It proves the effects of higher modes on seismic behaviour of moment resisting frames. Effects of higher modes are less for the frames with shear walls. Of course using advanced procedures such as modal pushover analysis will increase the results accuracy of the nonlinear static analysis.

With respect to the results of the analysis, it can be inferred that the differences between results of the two methods which are concerned in this paper are more for irregular buildings in accordance with regular ones. It proves the importance of dynamic analysis in irregular structures.

CONCLUSIONS

It can be inferred from the results that using uniform lateral load pattern in nonlinear static pushover is not recommended for irregular concrete frames. The difference of results of nonlinear time history analysis and nonlinear static analysis in irregular frames is more than regular ones. This difference indicates the necessity of dynamic analysis in irregular structures. Interstory drift ratios obtained from nonlinear time history analysis are mostly higher than the results of nonlinear static analysis even in regular frames. Distribution of relative drift of stories in structure height resulted from nonlinear time history analysis is predicted to be in an acceptable range by nonlinear static analysis with loading distribution according to lateral force based on spectral analysis. Moreover, differences between the results of the two analysis increases by raising the mass irregularity position in structure height. In moment resisting frame, uniform lateral loading predicts lower values in higher stories in comparison with lateral loading distribution based on spectral analysis. It also predicts higher value of relative drift in lower stories.

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