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Effect of Lateral Load Patterns in MPA in Shift and Drift Moment Resisting Concrete Frames with Irregularity of Mass in the Height

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Abstract

Today, using non-linear static analysis of the seismic vulnerability of structures and improvements is quite common. Guidelines for the seismic rehabilitation of structures ranging from (FEMA273) in increasingly non-linear static analysis, different lateral load patterns suggest the use of any of the conditions and requirements that choice leads to a different results in this pattern to structures, Both lateral shift and the shift is relative. The aim of this study is to investigate the effect of selecting the patterns of lateral loading on the structural response analysis method (MPA) and compare them with analytical method (NLTH). In order to achieve the overall results and the effect of parameters on the seismic vulnerability of reinforced concrete buildings in the study, several structures based on nonlinear dynamical behavior have been used. To prevent the spread of the results, but different in the number of layers (floors) (8, 12 and 15 floors) with different mass irregularities in elevation, in concrete moment resisting frames were designed to handle. Because of the nonlinear behavior of buildings during an earthquake, IDARC Analysis computer program that can model the nonlinear behavior of reinforced concrete members is used. Lateral load patterns used are: (A: Reverse Triangular, (b) uniform c: Moody SRSS). For nonlinear analyses of 10 acceleration, as the history of 10 strong ground motion is used as theoretical.

1. Introduction

In reinforced concrete structures, the damages occur when the structure enters a non-linear range and the structures responses such as displacement and the relative drift or lateral displacement of storeys exceeds a certain limit. Among different analytical methods, using nonlinear static methods in seismic upgrading and investigating the vulnerability of buildings are very common and lead to reduced computation volume and thus, saving time and money; meanwhile, it provides a better and more palpable understanding of the structure performance during loading for the designing engineer.

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But in practice, the earthquake is dynamic in nature and static methods only simulate it statically and are far from the actual nature of

earthquake. However, MPA is a combination of non-linear static and dynamic methods. Another key issue in the MPA procedure is to find the target displacement, for which different methods are provided in various in different instructions (such as the capacity spectrum method and displacement coefficients). In this study, the nonlinear dynamic time history analysis equivalent of a single degree of freedom structure was used to calculate the point performance of the structure [1].

2. Ground Motions

Seismic excitation was done by 10 earthquake records given in Table 1. To obtain the results mean, the selected records need to belong to the same area with identical conditions. Accordingly, all of the selected records are from California region, which have obtained for hard soil (Site NEHRP, class D). The soil type of the experiment place is consistent with the soil type of the selected area.

Table 1. Characteristics of earthquake records

No	Earthquake Name	Station	PGA
1	Imperial 1979	Chihuahua	0.254
2	Imperial 1979	Chihuahua	0.27
3	Northridg 1994	Hollywood Storage	0.231
4	San Fernando1971	Lake Hughes#1	0.145
5	San Fernando1971	Hollywood Storage	0.21
6	Super Stition Hills 1987	Wildlife Liquefaction Arrey	0.134
7	Super Stition Hills 1987	Wildlife Liquefaction Arrey	0.134
8	Super Stition Hills 1987	Salton Sea Wildlife Refuge	0.119
9	Super Stition Hills 1987	Plaster City	0.186
10	Super Stition Hills 1987	Calipatria Fire Station	0.247

3. Loading

To perform the structures analysis operation and evaluation and comparing their results, several hypotheses in loading were considered as following

1. We assumed that the roofs of all storeys are solid.
2. The dead and alive loads of storeys are as 600kg/m2 and 200kg/m2, respectively.
3. The spans are 5 meters long with the number of 4, and the frames are placed at the distance of 5 m from each other.
4. The mass of all storeys from the dead load was achieved as + 20% of living load, which were divided according to the ratio of nodes loading surface between medial and lateral nodes of the storeys.
5. The lateral resistant system was a concrete moment frame system.

6. Since the results was to examine the MPA results with NLTH in frames with mass irregularity in the height, this objective was achieved by applying mass irregularity with differences of 50%, 150% and 300% than to the next storey respectively in levels of lower, middle and upper storeys.

4. Lateral Load Patterns

Selecting the type of lateral loading patterns in MPA method is so important. Thus, the aim of this study, which was to investigate the displacement and the drift of concrete flexural frames with mass irregularity in height, was achieved by selecting different lateral loading patterns and applying them to the studied frames along with examining and comparing the results with the results of nonlinear time history method [2]. The mentioned models were applied to the structures as follows:

a. Uniform distribution

In this case, the lateral load on each storey is distributed in the ratio of the structure mass in that storey according to Eq. (1)

$$S_j^* = \frac{m_j}{\sum_i m_i} \quad (1)$$

b. Inverted triangular distribution

c. In this case, the lateral load is applied to the structure similar to the distribution of earthquake loads regulations, meaning as linear, according to Eq. (2)

$$S_j^* = \frac{w_j h_j}{\sum_{i=1}^{n} wi\ hi} \quad (2)$$

d. SRSS modal distribution

e. In this case, the load distribution is achieved by multiplying the storeys mass in the structure modal mass vector form according to Eq. (3)

$$S_j^* = m_j \Phi_{jn} \quad (3)$$

5. Designed and Analysis Frames

Models used in this article included 3, 8, 12 and 15 storeys flexible concrete frames, which were analyzed after loading as mentioned mass irregularities and considering the Δ-P effect [3] and designed according to the Iran’s Concrete Regulations (ICR). Due to the numerous examples, the specifications of beams and columns sections and their armature-making are given as sample for a 12-storey frame with mass irregularity in the lower level (first storey) and with 300% difference rate than to other storeys [4].

Table 2. Specifications of sections and shear and flexural armatures of a 12 storeys frame with mass irregularity mass in lower, middle and upper storeys with 300% difference rate than to the adjacent storey

7.5

	Storey	Positive Armature	Negative Armature	Cutting Armature	Beams Dimensions		Storey	longitudinalArmature	Cutting Armature	Columns Dimensions
Beams Armatures	12	3φ16	3φ20	φ8@10cm	50*45	Columns Armatures	12	8φ20	φ8@10cm	50*50
	11	3φ18	4φ20	φ10@10cm	50*45		11	8φ20	φ8@10cm	50*50
	10	3φ20	3φ25	φ10@10cm	50*45		10	8φ20	φ8@10cm	50*50
	9	4φ20	4φ25	φ12@10cm	50*45		9	10φ20	φ8@10cm	50*50
	8	5φ20	5φ25	φ12@10cm	50*45		8	10φ20	φ8@10cm	55*55
	7	6φ20	5φ25	φ12@10cm	50*45		7	10φ20	φ8@10cm	55*55
	6	6φ20	6φ25	φ14@10cm	50*45		6	12φ20	Φ10@10cm	55*55
	5	4φ25	6φ25	φ14@10cm	50*45		5	12φ20	Φ10@10cm	55*55
	4	5φ25	7φ25	φ14@10cm	50*45		4	12φ20	Φ10@10cm	60*60
	3	5φ25	7φ25	φ14@10cm	50*45		3	12φ20	Φ10@10cm	60*60
	2	5φ25	7φ25	φ14@10cm	50*45		2	20φ20	Φ12@10cm	60*60
	1	5φ25	7φ25	φ14@10cm	50*45		1	20φ25	Φ12@10cm	60*60

Irregularities in the middle storey (300%)

	Storey	Positive Armature	Negative Armature	Cutting Armature	Beams Dimensions		Storey	longitudinalArmature	Cutting Armature	Columns Dimensions
Beams Armatures	12	3φ14	5φ14	φ8@10cm	50*45	Columns Armatures	12	8φ20	φ10@10cm	50*50
	11	4φ14	5φ16	φ10@10cm	50*45		11	8φ20	φ8@10cm	50*50
	10	3φ18	6φ18	φ10@10cm	50*45		10	8φ20	φ10@10cm	50*50
	9	4φ18	6φ20	φ12@10cm	50*45		9	10φ20	φ10@10cm	50*50
	8	5φ20	4φ25	φ12@10cm	50*45		8	10φ20	φ10@10cm	55*55
	7	5φ20	5φ25	φ12@10cm	50*45		7	12φ20	φ10@10cm	55*55
	6	6φ20	7φ25	φ16@10cm	50*45		6	14φ20	φ8@10cm	55*55
	5	5φ25	6φ25	φ14@10cm	50*45		5	16φ20	φ8@10cm	55*55
	4	6φ25	7φ25	φ14@10cm	50*45		4	16φ20	φ8@10cm	60*60
	3	6φ25	7φ25	φ14@10cm	50*45		3	16φ20	φ8@10cm	60*60
	2	6φ25	7φ25	φ14@10cm	50*45		2	20φ20	φ8@10cm	60*60
	1	4φ25	5φ25	φ14@10cm	50*45		1	20φ25	φ8@10cm	60*60

Irregularities in the upper storey (300%)

	Storey	Positive Armature	Negative Armature	Cutting Armature	Beams Dimensions		Storey	longitudinalArmature	Cutting Armature	Columns Dimensions
Beams Armatures	12	3φ18	6φ18	φ10@10cm	50*45	Columns Armatures	12	10φ20	φ12@10cm	50*50
	11	3φ20	6φ18	φ10@10cm	50*45		11	10φ20	φ10@10cm	50*50
	10	4φ20	6φ20	φ12@10cm	50*45		10	10φ20	φ8@10cm	50*50
	9	5φ20	5φ25	φ12@10cm	50*45		9	12φ20	φ8@10cm	50*50
	8	4φ25	5φ25	φ12@10cm	50*45		8	12φ20	φ8@10cm	55*55
	7	5φ25	6φ25	φ14@10cm	50*45		7	14φ20	φ10@10cm	55*55
	6	5φ25	6φ25	φ14@10cm	50*45		6	14φ20	φ10@10cm	55*55
	5	6φ25	7φ25	φ14@10cm	50*45		5	16φ20	φ10@10cm	55*55
	4	6φ25	7φ25	φ14@10cm	50*45		4	16φ20	φ10@10cm	60*60
	3	6φ25	7φ25	φ14@10cm	50*45		3	18φ20	φ10@10cm	60*60
	2	6φ25	7φ25	φ14@10cm	50*45		2	22φ20	φ10@10cm	60*60
	1	4φ25	5φ25	φ14@10cm	50*45		1	22φ25	φ10@10cm	60*60

6. Conclusions

1. MPA procedure was examined under all three loading patterns; all irregularity cases have error compared to the accurate method, and change in the proportions of mass irregularity has little effect on the results of the MPA method.
2. Irregularity in the lower storeys causes the creation of more plastic joints near the irregularity, and thus, increases the ratio of relative displacement of the storey near the irregularity (not only

in the irregular storey but also near it); also, the error rate of MPA method becomes more than the accurate method.

3. Irregularity in middle storeys causes the creation of more plastic joints near the irregularity as well as in lower storeys, and thus, in general, increases the ratio of relative displacement in the lower half; the error rate of MPA method increases compared to the accurate method.
4. Irregularity in upper storeys causes the creation of more plastic joints near the irregularity as well as in lower storeys; it increases the ratio of relative displacement in all storeys. The error rate of MPA method increases compared to the accurate method.
5. In many cases, in middle and lower irregularities and by using the uniform loading pattern, the error rate of MPA method compared to the accurate method for the storeys drift in upper storeys is close to the values of the accurate method.
6. In structures with high participation of the first mode, or in other words, the first mode is prevailing, we can reach to acceptable solutions by using only the same single mode. Also, the effect of higher modes tends to reduced error that such an error reduction usually occurs in places with the largest error rates.
7. Approximating the cutting curve of base- roof displacement with a two-linear or three-linear model causes error generation. This case is very noticeable especially in the conversion region of initial part to the scope of sold work. In cases that the single –degree structure response occurs in this range, a sudden increase in error rate is observed. By distancing from this range, the errors rate reduces.
8. Using a fixed value for the parameter γ (the conversion coefficient of single degree of freedom structure displacement to multiple degrees of freedom) in modal method is associated with errors. By changing the displacement pattern, this value will also change.
9. Converting the multi-degree structure to single-degree structure, and reversely, is true for the linear mode, but using these relationships for nonlinear mode will create errors.
10. In modal method (uniform and inverted triangular distributions), the impact of modes other than the first modes is not considered in the structure response, since only the first mode is used in these loading patterns.
11. Modal method is a convenient method for rapid analysis of structures and can be also used to design as well as assessment of existing buildings.
12. The accuracy of nonlinear increasing static modal analysis method (uniform and inverted triangular) is better for short buildings, while the accuracy of SRSS modal method is more desirable in case of tall buildings since the impact of second and higher modes is more in these buildings.

13. With regard to the loading patterns used for analyses, the most appropriate pattern to examine the displacement and drift in different storeys and also with lower standard error than to the accurate method are as the following under different irregularities.

Table 3. Appropriate loading patterns for MPA analysis for frames with mass irregularities in height

More appropriate loading pattern and with fewer errors compared to the accurate			Examined Parameter	Storey
Upper Irregularity	Middle Irregularity	Lower Irregularity		
Inverted triangular	Modal(SRSS)	Inverted triangular	Displacement	Lower Storeys
Modal(SRSS)	Modal(SRSS)	Inverted triangular	Drift	
Uniform	Modal(SRSS)	Modal(SRSS)	Displacement	Middle Storeys
Inverted triangular	Uniform	Modal(SRSS)	Drift	
Modal(SRSS)	Uniform	Modal(SRSS)	Displacement	Upper Storeys
Modal(SRSS)	Modal(SRSS)	Uniform	Drift	

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