Investigation the 3D-Pushover Analysis of Unsymmetrical Concrete Structures

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SUMMARY:
This research has been conducted for inspecting the accuracy of 3D-Pushover method in analysis of unsymmetrical concrete structures. In this study three multi-story moment resisting frames have been analyzed using 3D-pushover and non-linear dynamic time history method. The buildings considered have 4, 6, 8 stories with fixed plan in three cases. The results obtained from both methods are maximum lateral story displacement and maximum base shear. Studies show that 3D-pushover analysis is sensitive to loading pattern and its direction. Load patterns according to mode shapes and combination of mode shapes shows better results when building height increases. Also results of 3D-pushover in comparison with non-linear dynamic analysis are sensitive to intensity of earthquake and distance of building to causative fault. Results of 3D-Pushover analyses are sensitive to amount of eccentricity and structure's torsions and torsion increase will lead in lower accuracy of non-linear dynamic analysis results.

Keywords: Non linear dynamic analysis, 3D push-over analysis, Target displacement, Material nonlinearity

1. INTRODUCTION

Static non-linear analysis is known as a reliable method with a specific limitations and specific considerations. In most of the previous studies, this method was performed on the symmetric structures, and because of the symmetry, the structure was modeled in the form of two dimensions and then, Push over analysis was performed on the given structure. In this situation, the effects of eccentricity are not considered. But in 3-Dimensional un-symmetric structures, because of the existing eccentricity due to the un-symmetries in the mass distribution of the structure or stiffness of the resistant elements in the structure, there is a need to the application of the 3-dimensional analysis in asymmetric structures.
Although 3D-Pushover analysis is a quick and powerful method, it arises some questions such as appropriate loading pattern for analyzing as well as direction in which loading pattern should be applied. Anyway, assessment the accuracy of the push-over analysis method depends on many aspects which are solvable by comparison this method with the non linear dynamic analysis method. The main purpose of this research includes not only the investigation of the 3D pushover analysis method, but its application on the reinforced concrete structures. It is important to identify the features of the concrete structure which are modeled in three dimensions. For example these features are size of the columns, beams, and the number of the bars in any component. M.Lopez and R.Pinhoo (2003), in their model used a reinforced concrete building which was modeled three-dimensionally, and then, it was analyzed by three-dimensional push over method, with two loading types of triangular and fixed ones. In order to model the exact non linear behavior of concrete members, they used fiber elements method modeling. By this type of modeling the non linear behavior of concrete in the whole element is considered non-concentrated and spread.
Moghadam and Tso (2000) proposed a modified method for considering the effects of twists in the asymmetric structures. In this new method, the target displacement was obtained from the elastic spectrum analysis. For push over analysis, the loading which was on the basis of forces obtained from analyzing spectrum elastic was used, in fact by which the effects of higher modes also were

considered. The authors claim that this method shows good results about structures with sway intermediate moment frame system. Anyway, the results obtained from push over analysis method do not conform to the results obtained from dynamic analysis method. In addition, while the proposed method investigates the triangular shape loading, the shape of loading remains fixed during the whole time of analysis, and the changes of mode shapes resulted from the non elastic behavior of the structure have not been considered.
In current research, three reinforced concrete structures have been studied which are modeled using fiber elements. These structures are investigated by two analytical types. One of them is 3-D non-linear static analysis and the other, 3-D non-linear dynamic analysis. The results obtained from these two analyses, on the basis of the amount of the maximum base shear, have been compared.
In this study, in order to investigate the application of 3-dimensional pushover analysis in concrete structures, three structures with similar plans and different heights were used. Regarding that the results obtained from dynamic analyses shows the real behavior of the structure against the earthquake, the comparison is done in a way that after linear analyzing and the design of structures on each samples, 3-dimensional non linear dynamic analysis is done and the obtained results from this analysis are given in the form of displacement and maximum base shear.
Then in order to investigate 3-D push-over analysis, five types of lateral loading are used. After doing 3-D push-over analyses, the capacity curve is drawn for each of them. By the use of these graphs the amount of base shear corresponding to the maximum displacement obtained from push-over analysis is obtained. Then, this base shear is compared with the base shear obtained from dynamic analysis.
All of the three-dimensional non linear dynamic and static analyses are done with Seismostruct. This program is finite element software which has the capability of showing spatial structural behavior regarding the material nonlinearity and geometric nonlinearity. The non linear behavioral models of materials like concrete and steel are in it exactly and variously. Non elastic behavior is considered in the width of the area section and in the length of the element.

2. ANALYTICAL MODELS

The used samples are three reinforced concrete structures with 4, 6, and 8 stories with space moment frame systems. In these samples the distance between frames are selected in a way that the eccentricity from the center of mass and centre of rigidity in every direction of the structure, is considered more than 0.05 dimension of the building in that direction in order to consider the effects of the un-symmetrical as well. In Fig.2.1 all of the characteristics of the plan like the direction of beams, the number of the bays, and the length of the bays are identified. The height of the stories is 3.20 meters. The weight of surrounding walls is considered for all of the stories.

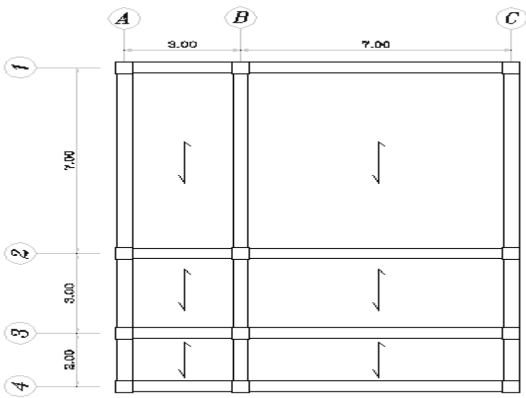

Figure 2.1.Typical plan of structures

3. STATIC ANALYSIS OF STRUCTURES

In order to linear analyze and design of the structures, the SAP2000 software has been used. This software is able to analyze three-dimensional static and dynamic easily. In modeling of the columns and beams, the existing triangular and square sections in the software are used. After modeling of structures and assigning the properties of beams and columns, dead load and live load of members applied. Spectrum analysis method has been used for seismic loading. For the given plan the amount of eccentricity between the center of mass and the centre of rigidity in the direction of x is 0.5 m and in the direction of y is 1.00 m. The information related to these analyses is shown in table 3.1.

Table 3.1. Information about analytical models.

	Seismic Coefficient & Base Shear				
Name	No. of stories	H(m)	T(sec)	W(KN)	Base Shear (KN)
Saze 4	4	12.80	0.47	6242	683
Saze 6	6	19.20	0.64	10343	1132
Saze 8	8	25.60	0.79	14462	1446

To design of structures the ACI-318 has been used. Design of the structures is done on the basis of sway intermediate regulations. The types of the sections used in these structures are shown in Fig.3.1.

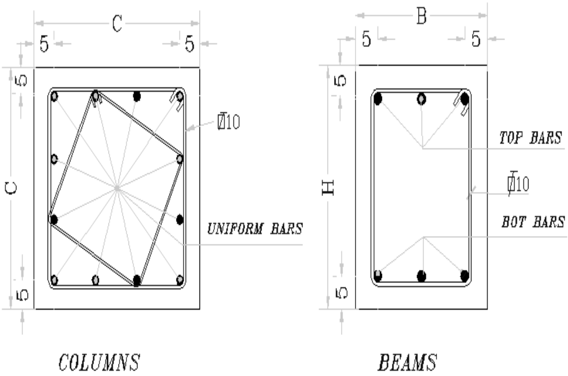

Figure 3.1. Cross sections of beams and columns

4. MDELING IN SEISMOSTRUCT SOFTWARE

The names of analytical models are, SAZE4, SAZE6 and SAZE8. These models have four, six and eight stories respectively, Fig.4.1 to Fig.4.3. In Seismostruct software there are significant possibilities in modeling for reinforced concrete structures, like modeling of the bars in the cross section and even modeling of the numbers and identifying the length of the reinforced bars. Therefore, in order to increase the exactness of the calculations, the modeling of the elements are done by considering the reinforced bars and observing the adequate length for them by following the regulations of sway intermediate, and the effect of the confinement of the elements by the surrounding rebar was solved by the proper selection of the materials. In each section of the element, three separate materials were used; core concrete, cover concrete, and bars. This software divides the elements into some fibers in order to consider well the non-elasticity feature of the materials in the section.

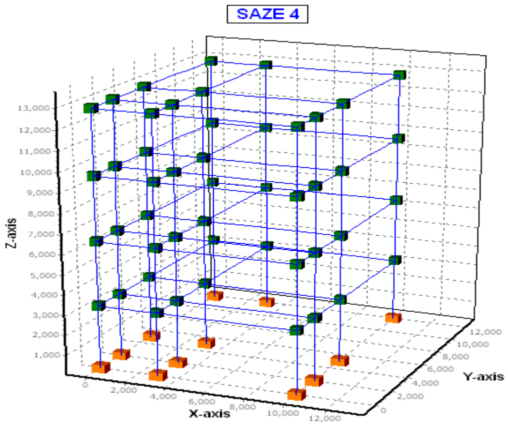

Figure 4.1. Analytical model of 4 stories, SAZE4

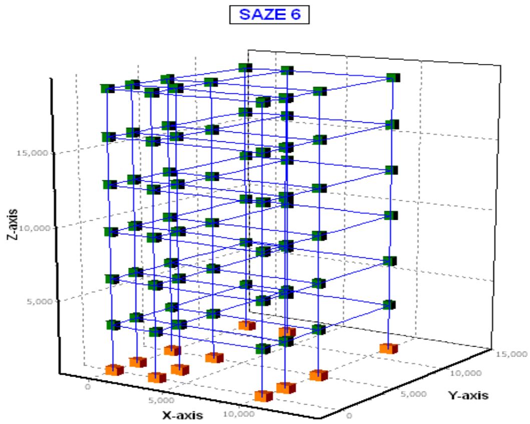

Figure 4.2. Analytical model of 6 stories, SAZE6

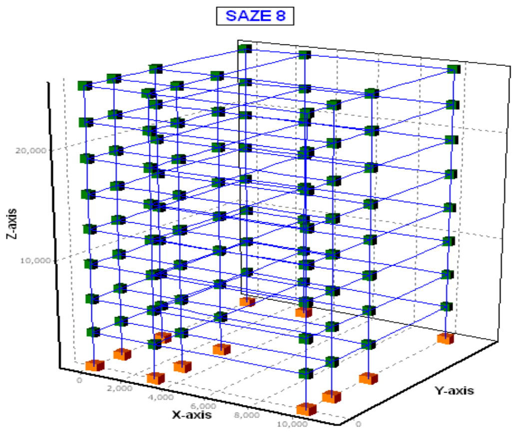

Figure 4.3. Analytical model of 8 stories, SAZE8

The concrete is modeled by a model which was proposed by Mander in 1988 and modified by Martinez. In this model the confinement effects of the concrete which are resulted by the horizontal bars, are considered by the concrete with a fixed pressure. This model is defined by four parameters: maximum amount of compressive strength of the non confined concrete ($f'c$=2.10 kN/cm^2) and the tension strength of the concrete (f_t= 0.21 kN/cm^2), the strain of the concrete in the maximum stress (ε_{co}), and the confinement ratio of the concrete (k). In the case of K ratio, its amount for the confined concrete has been considered 1.2 while this amount for the unconfined concrete has been considered as 1.0. These quantities are suitable for observing the sway intermediate behavior of structures. The bars which are existed in the elements are proposed by Menegoto and Pinto model. The modules of elasticity (E_s=20600 kN/cm^2) has been considered and F_y= 40 kN/cm^2.

4.1. The Records Used For Analyzing

In order to analyze the non linear dynamic, four seismic records have been used. For providing these records, those earthquakes which have 10% probability of occurring in the 50 years have been used. As the linear static analysis and design of the samples have been done on the basis of area with a relatively higher risk of earthquake, the given records have been coordinated with the base acceleration of PGA = 0.35g. The features related to these records have been shown in table 4.1.

Table 4.1. Features of the records.

Record	PGA $(\frac{cm}{s^2})$	Duration(sec)	DT (sec)	Number of Points	Distance(km)	Earthquake Magnitude
Imperial Valley,1979 Array#05	386.04	39.38	0.01	3939	4.1	6.5
Imperial Valley,1979 Array#06	295.69	39.08	0.01	3909	1.2	6.5
Landers,1992 Barstow	417.49	80	0.02	4000	36	7.3
Landers,1992 Yermo	509.70	80	0.02	4000	25	7.3

It should be noted that the record of ≠05, ≠06 were related to the earthquake of Imperial Valley that occurred in 1979 and they were near fault records while the records of Yermo, Barstow were related to the earthquake that happened in Lander, in 1992 which was far from the fault.

5. ANALYSIS OF MODELS

5.1. Three-Dimensional Non Linear Dynamic Analysis of Models

The important issue in the analyses of 3-dimensional dynamic analysis is the introduction of mass elements to the structure. These elements are single and appear in the basic nodes of the given structure. The allocated mass for each node is determined on the basis amount of load-receiving and includes the whole dead load plus 20 percent of live load of floor. The unit for measuring these masses is ton. This type of distribution in the mass element of floor can model the irregularity results from the mass distribution in the structure as well, and consider the twisted effects. Of course, in addition to the introduction of mass elements for the dynamic analysis, the permanent static loads including dead loads and live loads are considered on the structure so as to add these loads effects during the earthquake. To find the amount of the maximum displacement in the control point and also maximum base shear of the structure in the X and Y directions, results of dynamic analysis are used. These results will be arranged using Excel software, and then, the maximum quantities will be obtained.

5.2 Three-Dimensional Pushover Analysis of Models

In order to analyze the three-dimensional pushover analysis, Seismostruct software has also been used. To analyze of each sample in different directions, five types of lateral loading have been used. The results obtained from analysis of structures is done on the basis of the control point, as its displacement is more than of other points which is called flexible corner.

5.3 Lateral Loadings

1. Lateral loading which is on the basis of equivalent static loads, (push load 1).
2. Loading which is on the basis of the loads obtained from the structural spectrum analysis, and is done by SPA2000 software. For loading in Seismostruct software, the outputs will be obtained from SPA2000 software, and will be considered separately as the nodal loads in all of the basic nodes of the structure in two directions of X and Y. It should be noted that this loading is done simultaneously in two directions and by so doing, the eccentricity effect is also added in the structure (push load 2).
3. Uniform loading, in this loading the total shear of the structure is divided equally among the given floors, and then, the amount of shear for each floor is distributed among the nodes on the basis of each node's load-receiving level (push load3).
4. The loading which is on the basis of deformation resulted from the first and second structural mode. For this type of loading, the facilities of the given program have been used so that for the structures, first the eigenvalues analysis quantities is done and the structural loading is done on the basis of deformation obtained from the first and second structural mode. In this process, instead of force in the nodes, the displacements which are resulted from the eigenvalues analysis for each node is used (push load 4).
5. Loading which is on the basis of the combination of the dominant modes. In this case the facilities of the given program have been used, and the combination of the modes has been done on the basis of using combining method of SRSS total square root.

6. The results obtained from the analysis

6.1. Non linear dynamic analyses

In this part, the results obtained from the three-dimensional dynamic analyses in two directions of X and Y has been shown in tables 6.1 to table 6.3. The non linear dynamic analysis has been done using four records. The aim from these analyses is to obtain the target displacement and maximum base shear. In this research the target displacement is the maximum displacement of the control point which is obtained by the non linear dynamic analyses. Control point is the point that has the maximum displacement in structures. The target displacement is used as a criterion in the analyses of push-over analysis for controlling of the structure. The results obtained from dynamic analyses are investigated in determining the target displacement.

Table 6.1. The results of the nonlinear dynamic analysis of 4-story structure

SAZE 4				
RECORDS	X DIRECTION		Y DIRECTION	
	DISPLACEMENT (m)	BASE SHEAR (KN)	DISPLACEMENT (m)	BASE SHEAR (KN)
Imperial Valley 1979,Array#05	0.48	2340	0.36	2350
Imperial Valley 1979,Array#06	0.41	2575	0.34	2530
Landers,1992, Barstow	0.22	2210	0.20	2290
Landers,1992, Yermo	0.33	2152	0.24	2140

Table 6.2. The results of the nonlinear dynamic analysis of 6-story structure

SAZE 6				
RECORDS	X DIRECTION		Y DIRECTION	
	DISPLACEMENT (m)	BASE SHEAR (KN)	DISPLACEMENT (m)	BASE SHEAR (KN)
Imperial Valley 1979,Array#05	0.37	3900	0.42	3890
Imperial Valley 1979,Array#06	0.55	4112	0.45	4110
Landers,1992, Barstow	0.33	2830	0.23	3230
Landers,1992, Yermo	0.44	3630	0.29	3510

Table 6.3. The results of the nonlinear dynamic analysis of 8-story structure

SAZE 8				
RECORDS	X DIRECTION		Y DIRECTION	
	DISPLACEMENT (m)	BASE SHEAR (KN)	DISPLACEMENT (m)	BASE SHEAR (KN)
Imperial Valley 1979,Array#05	0.93	4855	0.71	4450
Imperial Valley 1979,Array#06	0.69	4461	0.59	4520
Landers,1992, Barstow	0.34	3460	0.21	3490
Landers,1992, Yermo	0.82	3630	0.71	3660

6.1.1. The summary of the results obtained from the Dynamic analyses

1. In all of the given structures the displacement of the x direction is more than that of the y direction.
2. The amount of base shear resulted from the records of Imperial Valley's earthquake, due to the fault, were more than those of Landers' in all of the samples. In other words, the impact of the records (≠06 and ≠05) on the structures were more and these records caused ever-lasting deformations in the given structures.

3. Having a maximum base shear which is resulted from the seismic record, does not mean having a maximum displacement, i.e. it is possible to have a maximum displacement because of a record but at the same time do not have a maximum base shear.

6.2. Three Dimensional Pushover Analysis

After doing three-dimensional dynamic analysis on the samples, and obtaining the target displacement quantity in the control point. Control point is obtained from the static analysis, and it is a node that in any structure has the greatest amount of relative displacement. For each of the structures, the analysis of the pushover analysis is done. To do three dimensional pushover analyses, five patterns of lateral loading are used. To investigate the capacity of the structures, the pushover analysis is done for x, -x, y, and (–y) directions for each of structures. Using these analyses, the capacity of the structure due to its loading pattern in different directions will be investigated. The results of 3D-pushover analysis of structures have been shown in tables 6.4 to table 6.6.

Table 6.4. The results of the pushover analysis of 4-story structure

SAZE 4				
PUSH LOADS	MAX BASE SHEAR(KN)		MAX BASE SHEAR(KN)	
	X DIR	(-X)DIR	Y DIR	(-Y) DIR
1	2404	2225	2343	2351
2	2816	2678	2803	2879
3	2663	2500	2620	2665
4	2147	2161	2402	2447
5	1830	1797	2106	2133

Table 6.5. The results of the pushover analysis of 6-story structure

SAZE 6				
PUSH LOADS	MAX BASE SHEAR(KN)		MAX BASE SHEAR(KN)	
	X DIR	(-X)DIR	Y DIR	(-Y) DIR
1	3700	3200	3597	3564
2	4488	4200	4513	4208
3	4185	3684	4178	4640
4	3752	3817	4193	4250
5	3280	3280	3667	3668

Table 6.6. The results of the pushover analysis of 8-story structure

SAZE 8				
PUSH LOADS	MAX BASE SHEAR(KN)		MAX BASE SHEAR(KN)	
	X DIR	(-X)DIR	Y DIR	(-Y) DIR
1	4281	3832	3830	3830
2	5289	5014	4909	5102
3	4904	4520	4494	4563
4	4770	4739	5364	5726
5	4348	4256	4804	4775

6.2.1. Results obtained from 3-dimensional push over analyses

1. With respect to results of pushover analysis, it can be concluded that the maximum base shear in two directions of positive x and negative x are not equal, and it differ from each other due to the existence of the eccentricity. So that on the basis of the done push over analyses, it can be concluded that the structures are weak in the –x direction and reach to the critical state with lower base shears.
2. Comparing the results about the structures in two directions of –y and y showed that the lowness of the eccentricity quantity, the maximum base shears are nearly equal, and according to the obtained results, the sample structures are critical in the y directions. The results showed that Y and (–x) directions are critical for the structures.

7. RESULTS

Regarding the obtained results from the 4 story building, in x direction, it can be said that the uniform loading patter has better results when compared with those of other loadings. Also, in y direction, the same loading pattern has shown better results when compared with those of other loading patterns. The results from the 6-story building showed that the loading pattern which is on the basis of the results obtained from the spectrum analysis, in X direction has better results when compared with the other loadings. In y direction, also the load distribution on the basis of spectrum analysis and the loading obtained from the first mode have better results when compared with other loading patterns.
Regarding the results obtained from the analyses about the 8-story structure in x direction, it can be concluded that the loading pattern on the basis of deformation resulted from the mode in the structure, has better results compared with those obtained from other loading patterns. Also, in y direction, the loading pattern, on the basis of mode combination shows better results compared with the other loading patterns.

8. CONCLUSIONS

- Three-dimensional push-over analysis is very sensitive to the type of the given loading so it is possible to get unreal results by a wrong loading pattern.
- The direction of the loading in this method is very important in order to determine the critical case. In other words, to determine the critical direction of the structure, three-dimensional push-over analysis should be done for all of the directions.
- The amount of eccentricity existing in the structure is efficient in the obtained results. As it was obvious in the results, in the direction that the stiffness of the structure was greater and the amount of twist was lower, the obtained results from the push-over analysis were greater than with compared to dynamic analysis.
- As the height of the structure increases, the need to the push-over analysis, on the basis of the displacements resulted from higher modes increases significantly.
- In the case of determining a proper loading pattern on the basis of obtained results from three samples, it can be stated that for the 4-story building, a uniform loading is suitable. For the 6-story building a loading pattern which is on the basis of spectrum analysis and first mode of the structure, show the best response, and also in the case of the 8-story building, spectrum analysis and combination of mode responses have shown the best responses.

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