SEISMIC EVALUATION OF A CONCRETE STRUCTURE WITH VARIOUS PERCENTAGE OF SYMETRY IN ACCORDANCE WITH PERFORMANCE-BASED DESIGN

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Abstract

Because of shortcoming in the current building codes with respect to predicting the performance of concrete structures to earthquakes, in recent years, performance-based design or capacity spectrum method has received attention by researches and new codes. The purpose is to design a structure with predictable performance for different types of earthquake, so that the performance of the structure can be chosen on the basis of its purpose. In seismic evaluation of a concrete structure, its behavior, particularly plastic behavior in the effect of earthquake, is studied. For this purpose, seismic requirement parameter is compared to the capacity parameter of the structure. In the capacity spectrum method, it is necessary to determine of performance purpose of the structure, the Capacity Curve of the structure, and the performance point of the structure. In this article, 3D analyzes, and nonlinear and push-over design and analysis is performed for a concrete building with various percentages of symmetry. The performance purposes of the structure will be studied by performing of these analyzes and drawing the capacity spectrum of the structure, together with capacity curves for individual members. In this article, five-storey concrete buildings with storey heights of 3 meters are designed, which have three spans in Y direction and five span in X direction, with a size of 5 m, in an area with highly earthquake risk with a type II soil, according to ABA and 2800 code (Iran codes), as a intermediate bending frame with shear walls. The design is performed for two cases: symmetrical and unsymmetrical. The eccentricity is applied by moving shear walls, and is defined with various models with type of eccentricity percentages. After that the models are designed and their structural details are obtained in accordance with ABA code (Iran code) (for structures with intermediate bending frames), the bending and shear joints, along with the interaction of bending and axial force diagrams must be extracted for various elements (beams, columns, walls) from ATC and FEMA codes, and applied to individual elements for nonlinear analyses were performed on the structure by using ETABS and SAP software, in order to obtain a seismic evaluation for nonlinear static and nonlinear dynamic analysis. In all models, whether symmetrical or nonsymmetrical, the nonlinear static analysis results are in good conformity with the nonlinear dynamic results. Nonlinear dynamic analyses show that selection of accelerometers and their scaling (calibration) has a considerable effect on the response of the structure.

KEYWORDS: Earthquake, Seismic Design, Vulnerability, Concrete structure, Capacity Spectrum

1. INTRODUCTION

In recent years, with perception of this subject that increasing of strength isn't the increasing of safety, behavior and performance was considered. For defect of current codes of building design, in respect of caution of performance of concrete structure, in recent years, design method on the basis of performance or capacity spectra was considered, to can design a structure that performance of it in contrary of different earthquake can be augury and request performance will be elected. In evaluation of concrete structures, state of structure behavior in particular in nonlinear condition is studied and for this purpose and comparison will be accomplished between demand seismic parameter and capacity of structure. With regard that a structure due to earthquake, enter in nonlinear form, static nonlinear and dynamic nonlinear method are used.
In performance methods, instead of the two previous requirements of serviceability and life security, there are four functional purposes: perfect performance, immediate settlement, life security, and limit of collapse. In new

codes, performance levels are defined for the individual structural and nonstructural elements, and the acceptable combinations of these two performance levels from the total performance level of the building. After the performance level of structure is determined, a performance purpose is defined by considering the performance level of the building and the level of earthquake risk; and also the importance of the building and the wishes of residents and employers.

2. PROBLEM DEFINITION AND MODELING

In this article, five-storey concrete buildings with storey heights of 3 meters with various percentages of symmetry are considered and this models are designed and their structural details are obtained in accordance with ABA code (Iran code) (for structures with intermediate bending frames), the bending and shear joints, along with the interaction of bending and axial force diagrams must be extracted for various elements (beams, columns, walls) from ATC and FEMA codes. It applied to individual elements for nonlinear analyses were performed on the structure by using ETABS and SAP software, in order to obtain a seismic evaluation for nonlinear static and nonlinear dynamic analysis. In nonlinear static analysis, according to output of SAP software which performs on the basis on four type load pattern, a program written that calculate the performance point of the structure by the capacity spectrum method which introduced in ATC-40 code (the requirements of 2800 code have been considered in this program). Following assumption are considered in models:

1. With replacing of shear walls, various percentages of symmetry are obtained that A,B,C,D and E are explanatory of 0% , 8.1% , 16.2% , 24.3% and 32.4% out of axial.
2. Structures have three spans in Y direction and five spans in X direction, with a size of 5 m and height of them is 3m.
3. Resistance system of these structures is intermediate bending frame with shear walls.
4. P-Δ effects weren't considered and the story floors were assumed to be rigid and the dead load and effective live load were 800 and 200 (Kg/m^2), respectively.
5. These structures are assumed in an area with highly earthquake risk with a type II soil, according to ABA and 2800 code (Iran codes).
6. Other characteristics of structure are shown in table (1) (which F_y , F'_c , I, R, A are yield stress, compressive strength ,important factor, plasticity factor and basic acceleration, respectively).

Table1. Characteristics of concrete frames

F_y	4000	(kg_f/cm^2)
F'_c	250	(kg_f/cm^2)
I	1	-
R	9	-
A	0.35	-

2.1. Loading Pattern in Push-Over Static Analysis

Nonlinear static analysis is very sensitive to the pattern used for lateral loading on the structure. Lateral loading on the structure model should be as similar to the loading which really occurs at the time of earthquake as possible. Only in this way critical cases of deformation and internal forces can be created in the model. For this reason, the FEMA code suggests at least two types of lateral load distribution be applied to the structure. In the nonlinear static analysis, four types of loading have been used: ELF, SRSS, UNIFORM, and MODE 1. Loading type ELF is the same as the loading introduced in the 2800 code, where the shear in the base of the structure(V) is made to act at the centers of gravity of the storey, and lateral force due to earthquake (F_i) is proportional to the mass and height of the storey(according to Eq. 1).

$$F_i = \frac{W_i h_i^k}{\sum_{j=1}^{n} W_j h_j^k} V \tag{1}$$

Which F_i, W_i, h_i are applied lateral load, weight and height of storey i ,respectively and

$$K = 0.5T + 0.75 \tag{2}$$

Loading type SRSS applied the base shear resulting from semi-dynamic analysis to the center of mass of the storey, while considering the number of modes with a model mass share of more than 90%. Loading type UNIFORM, as its name suggests, applies uniformly the base shear to the centers of mass of the storey. In loading type MODE 1, which is done automatically by SAP2000, loading is applied to the storey on the basis of the mode1 shape. In symmetrical models, the base shear, based on the model shape, is applied to the center of mass of the structure, but in unsymmetrical models, the shear is applied to a point at a distance from the center of mass. The more unsymmetrical the building is equal to the more distance of the shear application point from the center of mass.

2.2. Definition of Plastic Hinges in Models

The method of defining plastic hinges was explained in code for retrofitting of the present structures that introduced in Fig. (1).

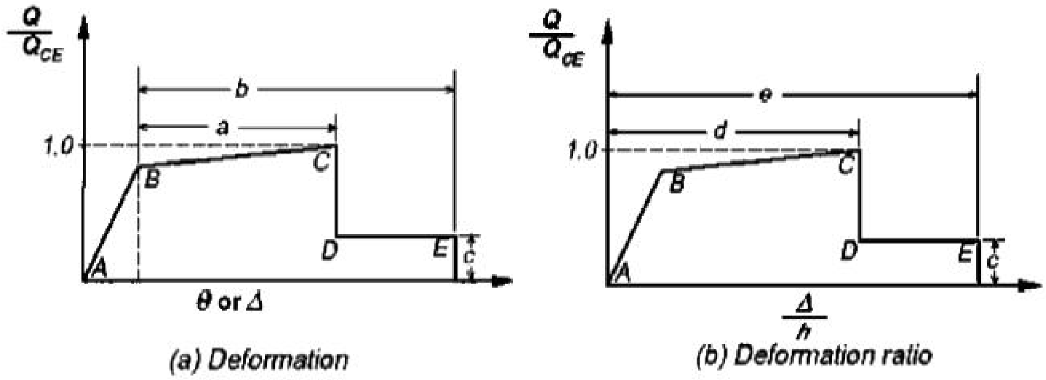

Fig. 1. Plastic hinges introduced

It should be mentioned, from A (Zero loading) to an effective yield point (B), the behavior of the element is linear. There is reducing stiffness linearly between B and C. At C there is a sharp reduction in resistance to D, which remains constant until E, where resistance becomes Zero. The vertical axe of C represents the member resistance, and the horizontal axe presented the deforming at which the sharp reduction in resistance occurs. If it is known the response value does not pass through point C, the force-displacement relation can be plotted with points A, B, and C only, omitting D and E.
The analyses were done in the Y-direction. The modeling of inelastic elements was performed by defining plastic hinges in them. After that the modal linear analysis was performed for the structures, their dynamic characteristics were obtained. Tables (2) and (3) show the modal characteristics and the shear center for the storey of structure A.

Table 2. Modal characteristics of

mode	Period (sec)	Partnership (x)%	Partnership (Y)%
1	0.372	0.00	72.66
2	0.371	72.69	0.00
3	0.242	0.00	0.00
4	0.086	0.00	20.66
5	0.086	20.64	0.00
6	0.055	0.00	0.00
7	0.041	0.00	4.93

Table 3. Shear and mass center for storey of

floor	1	2	3	4	5
Center of mass Y (m)	7.5	7.5	7.5	7.5	7.5
Center of mass X (m)	12.5	12.5	12.5	12.5	125
Base shear x (ton)	9.34	18.69	28.02	37.37	46.75
base shear Y (ton)	9.34	18.69	28.02	37.37	46.75

2.3. Design of elements of the structure and considerations of intermediate formability

To satisfy the geometrical limitations imposed in ABA on dimensions, the column dimensions and the beam dimensions were taken as 30×30 and 35×30 centimeter (in cross section) respectively, and the shear wall thickness was considered 15 cm.
We can option the detail of column, beams, and the state of width and lengthwise bars of frame member by the width and lengthwise bars and state of formation and calculation of shear bars.
Considering geometrical limitations, and the requirements for width and lengthwise bars of bending and compressive frame members, the detailed drawings for members were selected. (Other factors considered were special requirements for shear and for load-carrying vertical and lateral walls, and also for diaphragms.).

3. NONLINEAR DYNAMIC ANALYSIS

Earthquake characteristics are one of the factors that influence the structures dynamic response. In this article three types of accelerograph (Chichi, North, and Palm) have been used. The scaling of each accelerograph, according to the Regulatory Guideline, has been done between 0.2T and 1.5T (T is the period of the structure). After calculating the maximum displacement of the structure from the three acceleroghaphs, the displacements for other storey at that time are calculated, and also their drifts obtained. This work has been done for structures A, B, C, D, and E. For controlling the performance point of the structures, the drift criteria have been used for the storey. This criterion is in agreement with the (FEMA273) code criteria.
Considering the codes for rehabilitation of existing structures (Iran), storey drift criteria for transient and sustained state must be considered for shear walls. In the related table, the following drifts have been given for different situations: for performance level of "uninterrupted usability" the transient drift of 0.5%; for performance level of' "life security", the transient drift of 1% and sustained drift of 0.5%; and finally for performance level of "collapse threshold", the transient drift of 2% and the sustained drift equal to 2%.
Considering nonlinear static analyses and loading patterns, for controlling the performance of structures, SRSS and UNIFORM loading patterns should be used. But for a better comparison, maximum drift of the storey for both all loading pattern and for all state of structure obtained.

4. STRUCTURE CAPACITY CURVES

Performance point shows a state which the structure capacity and the seismic requirement are equal. Therefore, the best method for determining the performance point is the intersection of these curves. Capacity curve shows the variation of lateral load applies to the structure vs. lateral displacement of a point on the structure (like the roof). Nonlinear static analysis is used for obtaining this curve. Figure (2-4) show the capacity curve of structure A. The load patterns used were (SRSS, ELF, UNIFORM, and MODE1). As seen in the figures, for structure A, the capacity curve is different for each loading conditions. Therefore, for every curve a different performance point is obtained. That is why choosing the suitable loading pattern which shows the actual displacement of each structure is so important.

In structure A, because of the high modal participation in the first mode, the curves obtained for ELF, SRSS, and MODE 1 are close, but as eccentricity increases, this participation is reduced, and therefore, the difference between capacity curve and ELF and SRSS curve increases. In order to examine the better curve, for different loading conditions, they have been plotted in the same graph, so that the effect of eccentricity on the push over curve and consequently on the performance point could be observed, Figures 8 to 11.

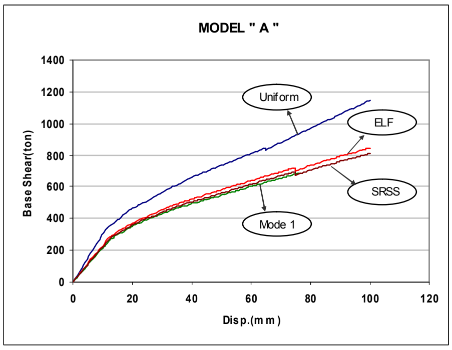

Fig. 2. Capacity curve for structure A under different loading conditions

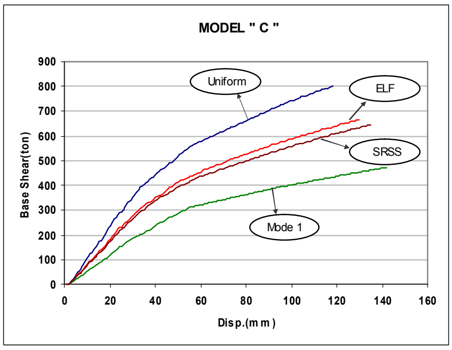

Fig. 3. Capacity curve for structure C under different loading conditions

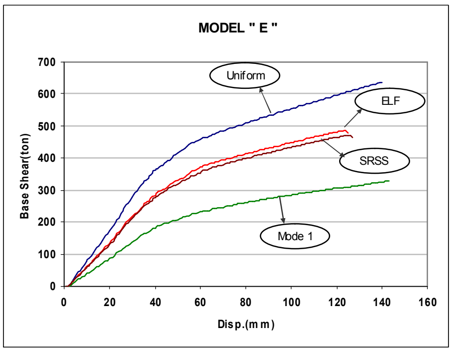

Fig. 4. Capacity curve for structure E under different loading conditions

After the capacity curve is obtained, the performance point should be calculated. For example, the displacement at the performance point of the symmetrical structure (A) under loading conditions of SRSS is shown in Fig. (5). In this figure, the requirement spectrum (2800 code) and the reduced requirement spectrum (2800 code) diagrams and also, Banana - shaped curves have been presented for performance point damping and the structure's capacity spectrum.

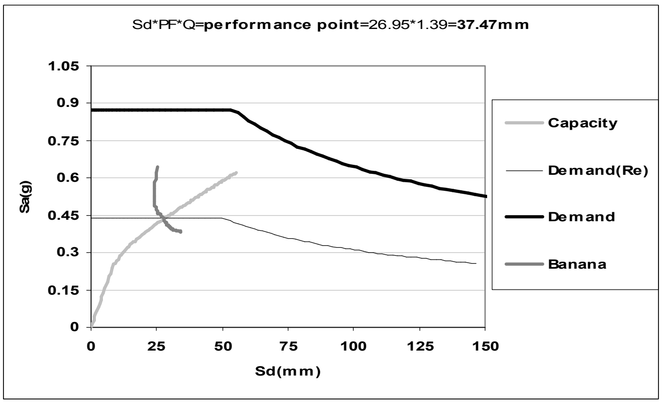

Fig. 5. Determination of performance point for structures A in (SRSS) load pattern

5. COMPARISION OF MAXIMUM DRIFT OF STOREY IN NONLINEAR STATIC AND DYNAMIC ANALYSES

The philosophy of performing dynamic analyses is studying unsymmetrical structures and controlling the response obtained from nonlinear static analyses with responses obtained from nonlinear dynamic analyses.
After that the displacement of a point on the roof at the performance point of the structure, is calculated, the corresponding displacement of the similar points on other storey should be obtained. This was done for different loading conditions for structures A, C and E. Fig (6-8) shows the drift of the storey for different loading conditions of structure A, C and E.

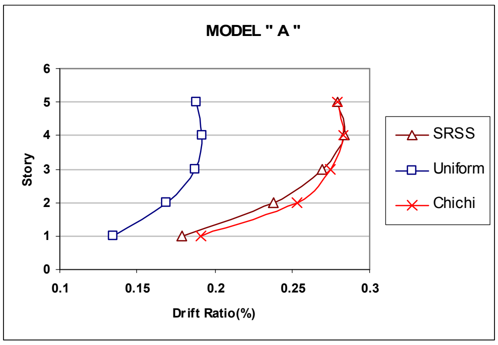

Fig. 6. Drift of the storey in structure (A) under different loading conditions

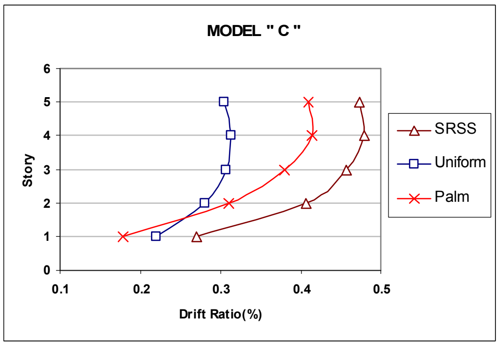

Fig. 7. Drift of the storey in structure (C) under different loading conditions

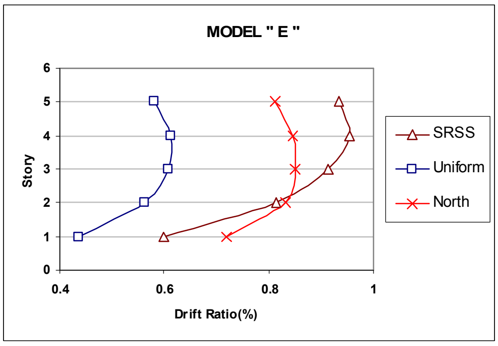

Fig. 8. Drift of the storey in structure (E) under different loading conditions

Tables (4-9) shows the maximum drift of the storey for different loading conditions of structure A,B,C,D and E.

Fig. 4. Maximum drift of the storey in structure(A) under nonlinear static loading

structure	A			
Load distribution	ELF	SRSS	Mode1	Uniform
Maximum drift	0.27	0.29	0.29	0.19

Fig..5. Maximum drift of the storey in structure(B) under nonlinear static loading

structure	B			
Load distribution	ELF	SRSS	Mode1	Uniform
Maximum drift	0.32	0.35	0.42	0.24

Fig. 6. Maximum drift of the storey in structure(C) under nonlinear static loading

structure	C			
Load distribution	ELF	SRSS	Mode1	Uniform
Maximum drift	0.45	0.48	0.85	0.31

Fig. 7. Maximum drift of the storey in structure(D) under nonlinear static loading

structure	D			
Load distribution	ELF	SRSS	Mode1	Uniform
Maximum drift	0.60	0.68	1.17	0.45

Fig. 8. Maximum drift of the storey in structure(E) under nonlinear static loading

structure	E			
Load distribution	ELF	SRSS	Mode1	Uniform
Maximum drift	0.92	0.95	1.51	0.61

Fig. 9. Maximum drift of the storey in structures under nonlinear dynamic loading

structure	A	B	C	D	E
Load distribution	**Chichi**	**Palm**	**Palm**	**North**	**North**
Maximum drift	0.283	0.36	0.41	0.69	0.65

By comparing the results obtained for drift, we can conclude that the results of nonlinear static analysis with SRSS loading pattern, are very close to the nonlinear dynamic results. On the other hand, according to the code for rehabilitation of existing structures, loading patterns SRSS and uniform must be used for determining the performance point in nonlinear static analysis. There fore, loading pattern SRSS has been selected for determining the performance point of structures. With regard to the criteria for controlling the performance point in structures (related of the rehabilitation of existing structures code), the maximum drift of storey is 0.29% which is between of the sum of the maximum transient drift and sustained drift, 0.5 and 1.5. Therefore, the structure is classified as "Immediate Occupancy" (IO) category. Similar results for other structures are summarized in Table (10).

From the above, it could be concluded that symmetrical and unsymmetrical structures designed (on the basis of ABA and 2800 codes) for a specific level of risk, do not have identical performances.

Table 10. Performance of different models

Structure	A		B		C		D		E	
Load distribution	SRSS	UNIFORM	SRSS	UNIFORM	SRSS	UNIFORM	SRSS	UNIFORM	SRSS	UNIFORM
Max drift	29.0	19.0	35.0	24.0	0.48	0.31	0.68	0.45	0.95	0.61
control	0.29<0.5		0.35<0.5		0.48<0.5		0.5<0.68<1.5		0.5<0.98<1.5	
Performance level	IO		IO		IO		LS		LS	

In the most unsymmetrical (greatest eccentricity), the level of performance is life security (LS) (which is the purpose defined in 2800 code), but in symmetrical cases (in the " Immediate Occupancy" (IO)), higher levels are obtained for performance. In other word, structure A, B and C have IO level and structures D and E have LS level.

6. CONCLUSION

2800 code defines the purpose of designing residential buildings with importance factor 1 for withstanding earthquakes with a risk level 1, as "life security". In view of this, designing structures symmetrically according to ABA and 2800 codes has a higher performance level. The symmetrical 5-storey concrete structures with intermediate concrete frame plus shear walls, which are designed in accordance with ABA and 2800 codes, have a level of performance defined as " Immediate Occupancy" against earthquakes with the Risk level of 1. With the increasing eccentricity, the performance level goes from " Immediate Occupancy" to "life security". In spite of different percentages used for eccentricity, and considering the height of 15m for the structure, results obtained from nonlinear static analyses are in good conformity with those obtained from nonlinear dynamic analyses. In other words, although the structure is unsymmetrical, nonlinear analyses can still be used. In nonlinear static analyses, increasing eccentricity causes a fall in the slope of the capacity diagrams. In symmetrical models, results obtained from loading patterns SRSS, ELF, and MODE 1 is very close. In nonlinear static analyses, in creasing eccentricity results in a considerable nonconformity between MODE 1 results and results obtained from SRSS and ELF. That's reason is the special deformation produced in eccentric structures in MODE 1. in all models, whether symmetrical or nonsymmetrical, the nonlinear static analysis results are in good conformity with the nonlinear dynamic results. Nonlinear dynamic analyses show that selection of accelerometers and their scaling (calibration) has a considerable effect on the response of the structure.

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