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Pushover analysis of a reinforced concrete frame structure for seismic performance assessment using SAP 2000

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Abstract

The existing building can become seismically deficient since seismic code requirements are constantly upgraded and advancement in engineering knowledge. A seismic performance evaluation was conducted for a four-story reinforced concrete (RC) residential building. The structural response is evaluated using pushover analysis. The FEMA 356 and FEMA 440 criteria were used to evaluate the seismic performance of the case study building. The calculated values related to the performance of the buildings indicate whether the response of the existing building is sufficient and if rehabilitation is required.

Keywords: Performance assessment, Existing reinforced concrete building, Nonlinear static procedure, Pushover analysis, SAP2000.

1. Introduction

A large number of existing buildings in zone-III is need seismic evaluation due to various reasons such as noncompliance with the criterial requirements, updating of codes, design practice and change the use of the building.

In particular, the seismic rehabilitation of older concrete structures in high seismicity areas is a matter of growing concern, since structures venerable to damage must be identified and an acceptable level of safety must be determined. Before rehabilitation work, it is necessary to understand the capacity of the existing building to check if it meets the intended performance level. To make such assessment, simplified linear-elastic methods are not adequate. Thus, the structural

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engineering community has developed a new generation of design and seismic procedures that incorporate performance based structures and is moving away from simplified linear elastic methods and towards a more nonlinear technique. Recent interests in the development of performance based codes for the design or rehabilitation of buildings in seismic active areas show that an inelastic procedure commonly referred to as the pushover analysis is a viable method to assess damage vulnerability of buildings. Basically, a pushover analysis is a series of incremental static analysis carried out to develop a capacity curve for the building. Based on the capacity curve, a target displacement which is an estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the structure at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground shaking [1].

The Nonlinear static procedure in these documents is based on the capacity spectrum method, and assumes that the lateral force distribution for the pushover analysis and the conversion of the results of the capacity diagram is based only on the fundamental vibration mode of the elastic structure. This paper described SAP2000 is used in performing a pushover analysis of a simple three dimensional building [2]. SAP2000 has static pushover analysis capabilities which are fully integrated into the program; allow quick and easy implementation of the pushover procedures for both two and three dimensional buildings.

The main objective of this study is to evaluate the seismic performance of an existing RC building designed according to the Iranian code.

2. Pushover Methodology

A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements may yield sequentially. Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic non-linear force displacement relationship can be determined [3].

3. Pushover Analysis

After assigning all properties of the models, the displacement –controlled pushover analysis of the models are carried out. The models are pushed in monotonically increasing order until target displacement is reached or structure loses equilibrium; whichever occurs first. For this purpose, target displacement at roof level and number of steps in which this displacement must be defined. In this study, target displacement is taken 4% of building height. Pushover curve is a base shear force versus roof displacement curve. The peak of this curve represents maximum lateral load carrying capacity of the structure. The initial stiffness of the structure is obtained from the tangent at pushover curve at zero load level. The collapse is assumed when structure losses its 75% strength and corresponding roof displacement is called “maximum roof displacement”.

It is a plot drawn between base shear and roof displacement. Performance point and location of hinges in various stages can be obtained from pushover curve as shown in Fig.1. The range AB is elastic range, B to IO is the range of immediate occupancy IO to LS is the range of life safety and LS to CP is the range of collapse prevention. The Different Building performance levels are shown in table 1.

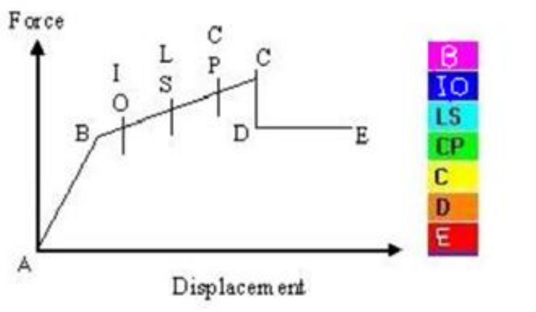

Fig.1 Different stages of plastic hinge

Table1. Different performance levels in building

	Collapse Prevention Level	**Life safety level**	***Immediate Occupancy Level***	***Operational Level***
Overall Damage	Severe	Moderate	light	Very light
General	Little residual stiffness and strength, but load bearing Columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced Parapets failed or at incipient failure. Building is near collapse	Some residual Strength and stiffness left in all stories. Gravity-load-bearing elements function. No Out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.	No permanent drift. Structure substantially retains original Strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable.	No permanent drift; structure substantially Retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All Systems important to normal operation are functional.
Non- structural Components	Extensive damage.	Falling hazards mitigated but many architectural, mechanical, and electrical systems	Equipment and contents are generally secure, but may not operate due to mechanical	Negligible damage occurs. Power and other utilities are available, possibly from

When a hinge reaches point C on its force-displacement curve that hinge must begin to drop

load. The way load is dropped from a hinge that has reached point C is that the pushover force (base shear) is reduced until the force in that hinge is consistent with the force at point D. As the force is dropped, all elements unload, and the displacement is reduced. Once the yielded hinge reaches the Point D force level, the pushover force is again increased and the displacement begins to increase again.

If all the hinges are within the CP limit then the structure is said to be safe. However, depending upon the importance of structure the hinges after IO range may also need to be retrofitted.

4. Description of the Case Study Building

The four-story building is considered in this study. This structure is designed according to Iranian Code and is located in Zone III. The material Properties are 240 MPa concrete, AⅢ steel for the longitudinal and AⅡ transverse reinforcement. The plan layout is shown in fig 2. The typical floor height is 3.2 m and the details of beams and columns are shown in Table2. In the analysis, Young's modulus and unit weight of concrete are taken to be 28000- 30000 MPa and 25 KN/m3, respectively. The damping ratio is assumed as 5% in all modes.

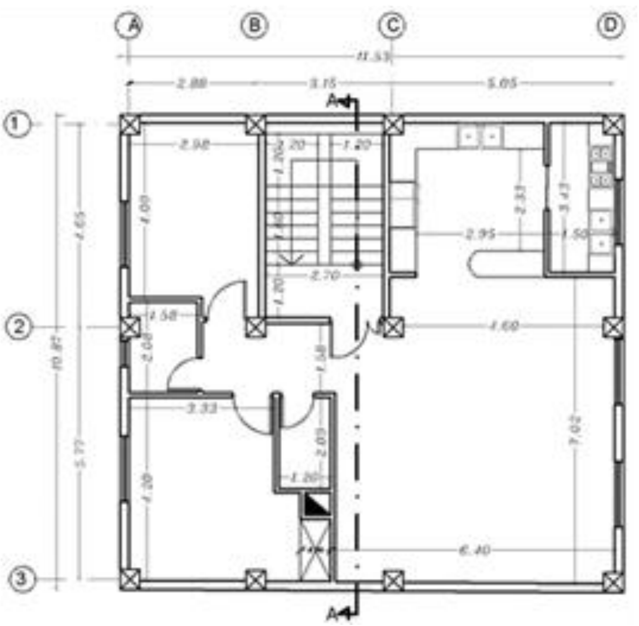

Fig.2 plan of building

Table 2. Details of beams and columns

Story	Beam	Column
1	0.45x0.45 m	0.45x0.45 m
2 & 3	0.4x0.4 m	0.4x0.4 m
4	0.35x0.35 m	0.35x0.35 m

5. Nonlinear Plastic Hinges Properties

The building has to be modeled to carry out nonlinear static pushover analysis. This requires the development of the force - deformation curve for the critical sections of beams and columns by using the guidelines [4]. The force deformation curves in flexure were obtained from the reinforcement details and were assigned for all the beams and columns. The Nonlinear properties of beams and columns have been evaluated using the section designer and have been assigned to the computer model in SAP2000. A three-dimensional model of each structure has been created to undertake the non-linear analysis. The loading structure shown in fig 3. The flexural default hinges (M3) were assigned to the beams at two ends. The interacting (P-M2-M3) frame hinges type a coupled hinge property was also assigned for all the columns at upper and lower ends [5]. Properties and recommends PMM hinges for columns and M3 hinges for beams as described in FEMA-356 and FEMA-440.

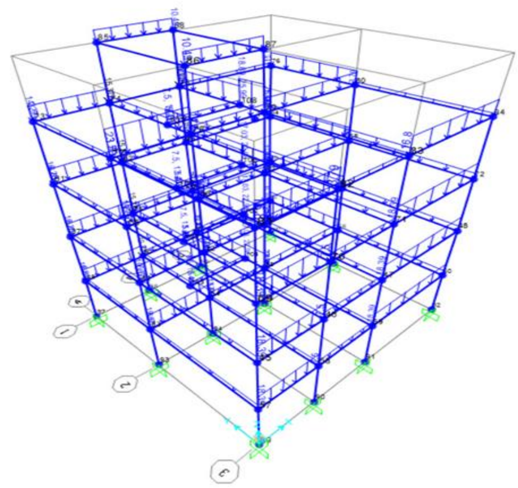

Fig.3 The loading structure

6. Result and Discussion

6.1. General

A four storied reinforced concrete frame was taken for the investigation. The frame was subjected to design earthquake forces as specified in the Iranian code for zone III along X and Y directions. The responses of the frames are discussed in the below.

6.2. Pushover curve

The resulting pushover curve for the four-story building from FEMA-356 and FEMA-440 are shown in fig 4 and 5 respectly. Curves are initially linear but start to deviate from linearity as the beams and columns undergo inelastic actions. When the building is pushed well into the inelastic range, the curve become linear again but with a smaller slope. The curve could be approximated by a bilinear relationship. From FEMA-356 a target displacement of 0.184 m, the base shear of the structure was 1216.654 KN. From FEMA-440 a target displacement of 0.196 m, the base shear of the structure was 1234.906 KN.

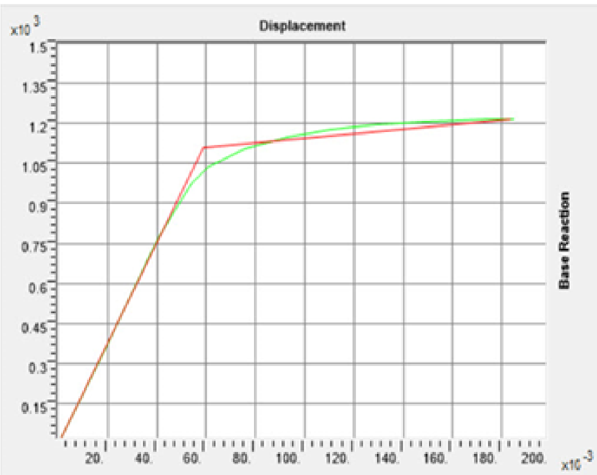

Fig4. Capacity curve FEMA-356

6.3. Plastic hinges mechanisms

Plastic hinges formation for the building mechanisms have been obtained at different displacement levels. The hinging patterns are plotted at different levels in figures 6 to11. Plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories. But since yielding occurs at events B, IO and LS respectively, the amount of damage in the building will be limited.

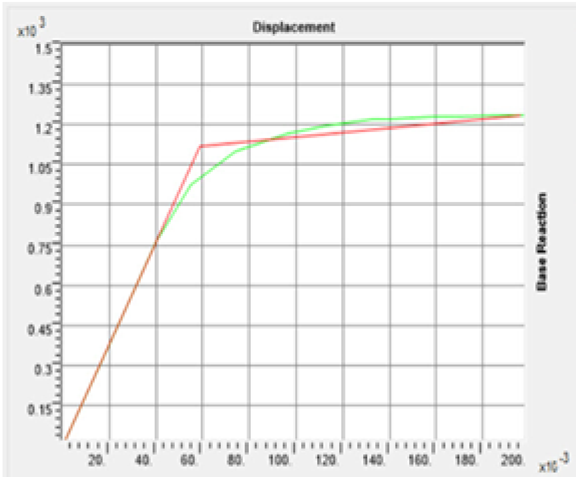

Fig5. Capacity curve FEMA-440

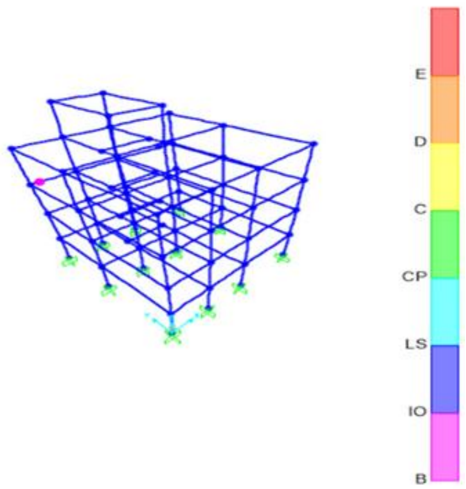

Fig6. Deformed shape of the frame at Step3

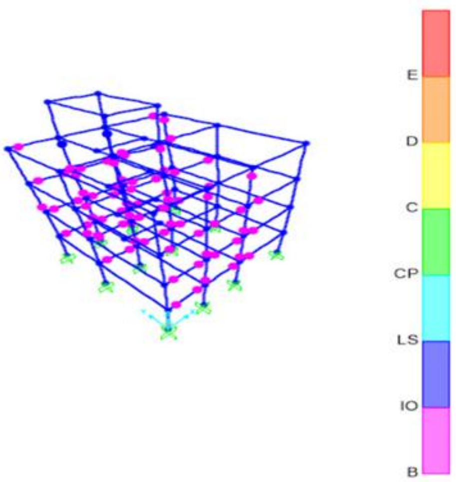

Fig7. Deformed shape of the frame at Step5

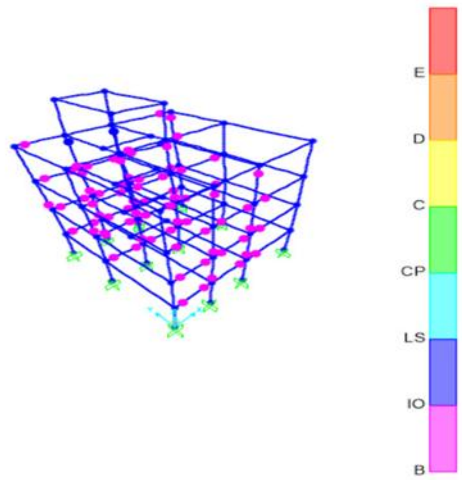

Fig8. Deformed shape of the frame at Step9

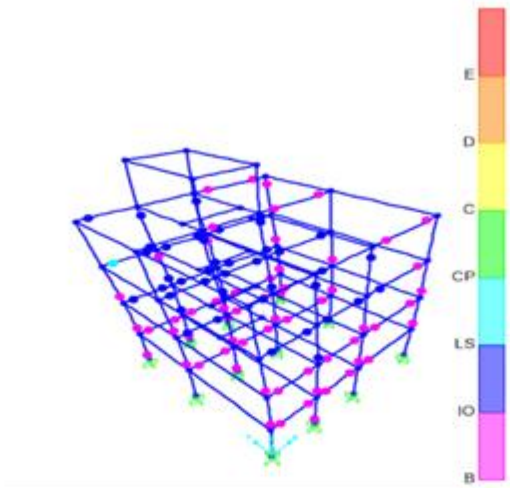

Fig9. Deformed shape of the frame at Step15

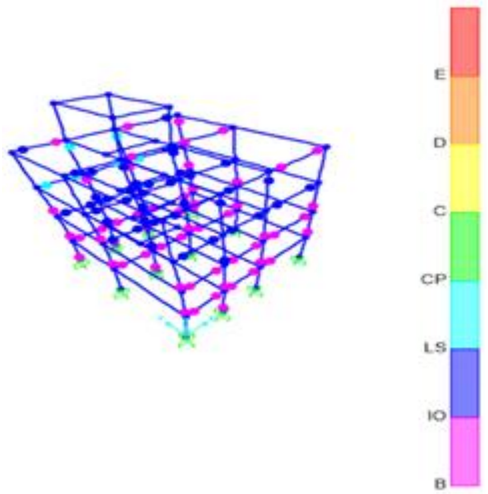

Fig10. Deformed shape of the frame at Step18

7. CONCLUSIONS

The performance of reinforced concrete frames was investigated using the pushover Analysis. These are the conclusions drawn from the analyses:

1. The pushover analysis is a relatively simple way to explore the non-linear behaviour of Buildings
2. The behaviour of properly detailed reinforced concrete frame building is adequate as Indicated by the intersection of the demand and capacity curves and the distribution of Hinges in the beams and the columns. Most of the hinges developed in the beams
3. The causes of failure of reinforced concrete during the earthquake may be attributed to the quality of the materials
4. The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behaviour of structures
5. It must be emphasized that the pushover analysis is approximate in nature and is based on static loading. As such it cannot represent dynamic phenomena with a large degree of accuracy. It may not detect some important deformation modes that may occur in a structure subjected to severe earthquakes, and it may exaggerate others. Inelastic dynamic response may differ significantly from predictions based on invariant or adaptive static load patterns, particularly if higher mode effects become important.
6. Thus performance of pushover analysis primarily depends upon choice of material models included in the study.
7. It would be desirable to study more cases before reaching definite conclusions about the behaviour of reinforced concrete frame buildings.

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