Performance Based Seismic Design of Reinforced Concrete Building by Non-linear Static Analysis

Mr. Prashant G. Ingle[1]* Prof. Vijaykumar P. Bhusare[2]

[1,2] Department of Civil Engineering, Imperial College of Engineering and Research, Wagholi, Pune, Savitribai Phule Pune University, Pune

Abstract – Recent earthquake disasters in the world have shown that significant damage can occur even when the buildings are designed to satisfy the codal provisions, thus exposing the inability of the codes to ensure minimum safety of the structures under an earthquake. The displacement-based approach known as the performance-based seismic design (PBSD), which evaluates how building systems are likely to perform under a variety of conditions associated with potential hazard events, is becoming very popular now. In contrast to force-based approaches, PBSD provides a systematic methodology for assessing the seismic performance of a building, thus ensuring life safety and minimum economic losses. PBSD demands the use of non-linear analysis procedures to evaluate the response of structures under lateral loads. The non-linear time history analysis is the most accurate, but requires much computational effort, time and cost. Thus, the use of nonlinear static analysis procedure known as the pushover analysis has been proposed. In pushover analysis, the magnitude of the lateral loads is incrementally increased, maintaining a predefined distribution pattern along the height of the building. It gives an insight on the progressive mode of failure of the structure, thus making it more performance-based. The scope of the present study aims at evaluation of RC buildings designed according to IS 456:2000. The non-linear static pushover analysis procedure has been used in this regard. The non-linear methods can give an Idea regarding the pattern of the plastic hinge formations and thus aid in the performance based seismic design of the structure. The pushover analysis has been carried out using ETABS Softwere. The results of analysis have been compared in terms of base shear, storey drift, storey displacements and plastic hinge rotations. An existing five storeyed residential building was analysed for seismic performance using the dual requirement of life safety under design basis earthquake (DBE) and collapse prevention under maximum considered earthquake (MCE).

Keywords: PBSD, Performance Level, Non-Linear Static Analysis, Performance Level, Plastic Hinge

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1. INTRODUCTION

Amongst the natural hazards, earthquakes have the potential for causing greatest damages. Seismic design of structures should be done with the approach of designing them explicitly for life safety, thus not attempting to reduce damage in a structure, and minimize economic losses. Thus, in contrast to force-based approaches, the displacement-based approach known as the performance based seismic design provides a systematic methodology for assessing the seismic performance of a building. Non-linear static methods have recently gained wide acceptancy, and offer the advantage of giving direct information on the magnitude and distribution of plastic strains within a structure, based on the ground motions represented by the design response spectrum, without the difficulties inherent in a non-linear time-history analysis, and the associated requirement to choose suitable ground motion time histories. The static pushover analysis not only provides information on strength capacity of the structure but also provides vital information on ductility as well as an insight on the progressive mode of failure of the structure. Thus the method is more performance-based than being conventional strength-based approach.

2. LITERATURE SURVEY

The literature shows considerable research in PBSD. This research is reviewed keeping in view the methodology, principles and various aspects of PBSD. Some of related works are discussed below. Seismic evaluation and retrofitting of concrete buildings are studied considering seismic safety and re-strengthening. Also pre-standard and commentary for the Seismic Rehabilitation of Buildings are provided by ASCE FEMA repost where provisions are given for the same. This paper outline and compares the three methods along with discussion in the context of traditional force based seismic design and earlier design approaches of performance based design. Factors defining different performance states were discussed including the need to include residual displacement as a key performance limit. Sashi K. Kunnath (2006), conducted study on seismic design and evaluation of building structures using PBSD. Deterministic approach and probabilistic approach is discussed in which capacity spectrum method from ATC-40 and standard pushover analysis from FEMA 356 is in brief. Comparative study of ATC-40 and FEMA 356 is done (FarzadNaeim, Hussain Bhatia, 2008). This paper provides a basic understanding of the promises and limitations of performance based seismic engineering. The state-of-the-art methodologies and techniques embodied in the two leading guidelines on this subject ATC-40 and FEMA 273/274 are introduced and discussed. Numerical examples are provided to illustrate the practical applications of the methods discussed (Vivinkumar, R.V., 2013). This study explains about two major seismic design methods (*i.e.*) Force based design and direct displacement based design in which former is a conventional method while later one is a performance approach of design. Design and analysis were done on two dimensional bare frames of four, eight and twelve stories based on following codes IS 456, IS1893:2000, FEMA 356 and the two design approaches were studied.

3. SYSTEM DEVELOPMENT

3.1. Performance Based Seismic Design

Performance based seismic design is a process of designing new buildings or seismic up-gradation of existing buildings, which includes a specific intent to achieve defined performance objectives in future earthquakes. Performance objectives relate to expectations regarding the amount of damage a building may experience in response to earthquake shaking and the consequences of that damage. Performance objectives are operational (O),immediate occupancy (IO), life safety (LS), collapse prevention (CP), in which Life safety is the major focus to reduce the threats to the life safety of the structure in Figure 1.

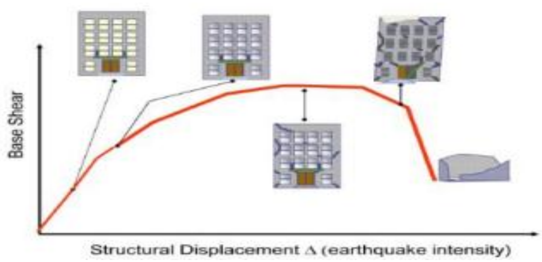

Fig.1 : Building Performance Levels

Performance based design approach in which performance levels are described in terms of displacement as damage is better correlated to displacements rather than forces. The fundamental goal of PSBD is to obtain a structure which will reach a target displacement profile when subjected to earthquakes consistent with a given reference response spectrum. The performance levels of the structure are governed through the selection of suitable values of the maximum displacement and maximum inter storey drift. Figure 2 shows the typical process of design is to be followed.

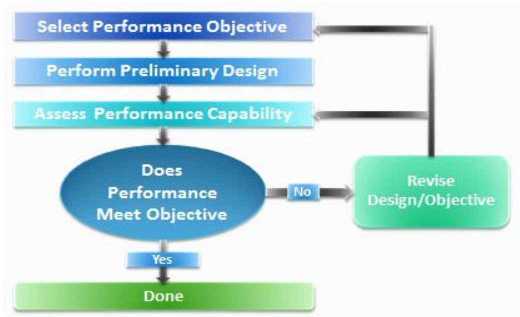

Fig.2: Flowchart of the performance-based design process

3.2 Non-linear Static Analysis Procedure

The non-linear static analysis procedure normally called pushover analysis, POA, is a technique in which a computer model of a structure is subjected to a predetermined lateral load pattern, which approximately represents the relative inertia forces generated at locations of substantial mass. The intensity of the load is increased, i.e. the structure is ‘pushed’, and the total force is plotted against a reference displacement. The resulting plot of base shear - roof displacement, shown in Figure 1, is called the 'capacity curve', which can then be combined with a demand curve (in the form of acceleration-displacement response spectrum). This reduces the problem to a SDOF system. The internal forces and deformations computed at the target displacement levels are estimates of the strength and deformation demands, which need to be compared to available capacities.

3.3 Capacity Response Spectra

The conventional response spectrum is represented by the acceleration versus period relationship for different damping levels. In the capacity response spectrum format, the period axis is converted in the displacement axis. The structure period T is represented by radial lines, instead of being the horizontal axis. The advantage of this representation is that both strength and displacement demands are evident in a single graph. The elastic displacement demand and the structure period may be determined for elastic forces. Considering the inelastic behaviour, the inelastic displacement at the reduced

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force is obtained in the horizontal branch of the capacity curve corresponding to the intersection with inelastic reduced spectra. At the same time, the reduced period due to inelastic deformation may be determined. Another advantage of this representation is that both earthquake demands and structure capacity may be compared directly from the same figure.

3.3. Structural Model Development

In the present work, a six storey RC frame building situated in zone V is taken for the purpose of study. It consists of 3 bays of 4 m each in X-direction and 3 bays of 5 m each in Y-direction. The total height of the building is 18 m. The building is modelled and designed as per IS 456:2000 in ETABS2015.

3.3.1 Material Properties:

Grade of Concrete: M 25

Grade of Reinforcing Steel: Fe-415

3.3.2 Sectional Properties:

Size of Beam = 230 mm × 450 mm

Size of Column = 500 mm × 500 mm

Thickness of Slab = 125 mm

3.3.3 Loading Considered:

Dead Load:

a) Roof Level:

Weight of wall on beam = 18.5kN/m

Weight of F.F. = 2 kN/m^2

Live Load :

Live Load at floor levels = 4kN/m^2

3.3.4 Seismic Properties

(as per IS 1893:2002 part 1):

Zone Factor = 0.36

Response Reduction Factor = 5

Soil Profile Type = II

Importance Factor = 1

3.3.5 Assumptions:

1) All columns supports are considered as fixed at the foundation.

2) Plastic hinges are assigned to all the member ends. In case of columns PM_2M_3 hinges (*i.e.* Axial Force and Biaxial Moment Hinge) are provided at both the ends, while in case of beams M_3 hinges (*i.e.* Bending Moment Hinge) are provided at both ends.

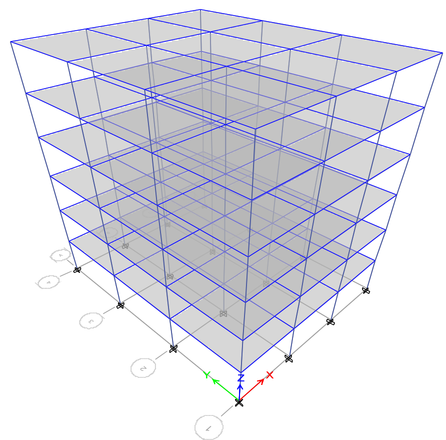

Fig.4 Elevation

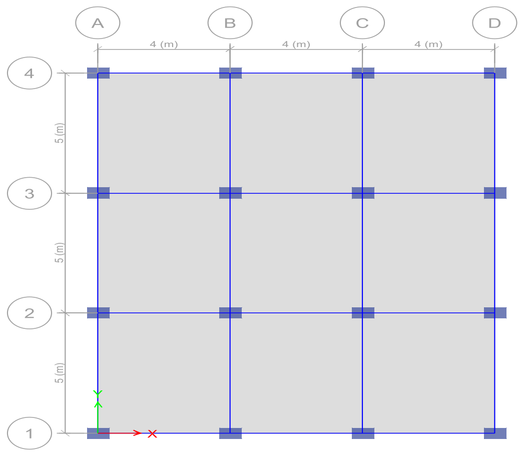

Fig.5 Plan

4. PERFORMANCE ANALYSIS

Performance of the building is analyzed as per FEMA 273 by which we will know whether building falls in desired performance level or not.

Acceptance Criteria for storey drift as per FEMA273,Acceptance Criteria for Plastic rotation as per FEMA 273,The drift of given building is as per following table.

Table 1: Storey Drift

Performance Level	Operational	Immediate Occupancy	Life Safety	Collapse Prevention
Storey Drift	<0.2%	<0.5%	<1.5%	<2.5%

Table 2: Plastic Rotation

Structural System	Immediate Occupancy	Life Safety	Collapse Prevention
Beam	0.01	0.02	0.025
Column	0.005	0.015	0.02

Table 3: Storey Response

TABLE: Story Response				
Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story6	18	Top	0.000386	0.000575
Story5	15	Top	0.000724	0.001011
Story4	12	Top	0.000775	0.001020
Story3	9	Top	0.000801	0.000945
Story2	6	Top	0.000666	0.000728
Story1	3	Top	0.000318	0.00031
Base	0	Top	0	0

Thus, by this design building lies in immediate occupancy performance level. So, the required performance objective of design is achieved. Final design of given building after non-linear dynamic analysis is given in following table.

Table 4: Final Design of Building

Storey	Section	Section Size	Area of Steel
3,4,5	Beam	380*600	1350(top) 1350(bottom)
1,2,3	Beam	380*680	1600(top) 1600(bottom)
5	Column	600*600	2500
3,4	Column	830*830	3100
2	Column	980*980	3700
1-Middle	Column	980*980	6100
1-Corner	Column	980*980	8000

5. CONCLUSIONS

1) The need for performance based seismic engineering in contrast to force-based design approaches as studied and the four building performance levels namely operation, immediate occupancy, life safety and collapse prevention were studied. In performance based design, multi-level seismic hazards are considered with an emphasis on the transparency of performance objectives, thus ensuring better performance and minimum life-cycle cost.

2) It has been recognized that the story drift performance of a multi-story building is an important measure of structural and non-structural damage of the building under various levels of earthquake motion. Storey drift requirement specified by FEMA 273 is satisfied for building under consideration. Thus the global performance of the building was considered as satisfactory for design objective.

6. REFERENCES

Applied Technology Council (1996). Seismic Evaluation and Retrofitting of concrete Buildings, ATC-40.Volume 1 and 2, SeismicSafety Commission, Redwood City, 1-346.

ASCE (2000). Pre-standers and Commentary for theSeismic Rehabilitation of Buildings. FEMA 356 Report, American Society of Civil Engineers for the Federal Emergency Management Agency, Washington DC.

Federal Emergency Management Agency (1997). NEHRP Guidelines for theSeismic Rehabilitation of Buildings. Report FEMA-273, Federal Emergency Management Agency, Washington DC.

FEMA P-58-1/2 Seismic Performance Assessment of Buildings,/ September 2012

Khan, R.A. (2014). Performance Based Seismic Design of Reinforced Concrete Building. International Journal of Innovative Research in Science, Engineering and Technology, 3, 13495-13506.

Kunnath, S.K. (2006). Study on Seismic Design and Evaluation of Building Structures Using PBSD.CRC Press, Taylor & Francis Group, Boca Raton.

Naeim, F. and Bhatia, H. (2008). The seismic design handbook 2nd edition Springer Publication, Berlin, pp. 757-792.

Priestley, M.J.N. (2003). Performance BasedSeismic Design of Concrete Buildings. Bull. NZSEE. (In Press)

Corresponding Author

Mr. Prashant G. Ingle*

Department of Civil Engineering, Imperial College of Engineering and Research, Wagholi, Pune, Savitribai Phule Pune University, Pune

E-Mail – er.prashantingle2018@gmail.com