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

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***Abstract:** In past two decades earthquake disasters in the world have shown that significant damage occurred even when the buildings were designed as per the conventional earthquake-resistant design philosophy (force-based approach) exposing the inability of the codes to ensure minimum performance of the structures under design earthquake. The performance based seismic design (PBSD), evaluates how the buildings are likely to perform under a design earthquake. As compared to force-based approach, PBSD provides a methodology for assessing the seismic performance of a building, ensuring life safety and minimum economic losses. The non-linear static procedures also known as time history analysis are used to analyze the performance of structure . Plastic hinge formation patterns, plastic rotation, drift ratio and other parameters are selected as performance criterias to define different performance level. In this paper, a five-storey RC building is modelled and designed as per IS 456:2000 and analyzed for lmmediate occupancy performance level in ETABS2015 softwere. Analysis is carried out as per FEMA P58 PART 1 & 2. Plastic hinges as per FEMA273. From the analysis, it is checked that the performance level of the building is as per the assumption*

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

I. INTRODUCTION

As per the conventional earthquake-resistant design philosophy, the structures are designed for forces which are much less than the expected design earthquake forces. Hence, when a structure is struck with severe earthquake ground motion, it undergoes inelastic deformations. Even though the structure may not collapse, the damages can be beyond repairs. These methods usually don't consider the expected performance level and seismic risk levels of the structure after an earthquake event. Since, these methods give high base shear, high ductility demand and also don't give the actual performance of structure after an earthquake event so that need of new method comes which would give the actual performance of the structure after an earthquake event.

II. 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 (Farzad Naeim, 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, IS 1893:2000, FEMA 356 and the two design approaches were studied.

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III. SYSTEM DEVELOPMENT

A. 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.

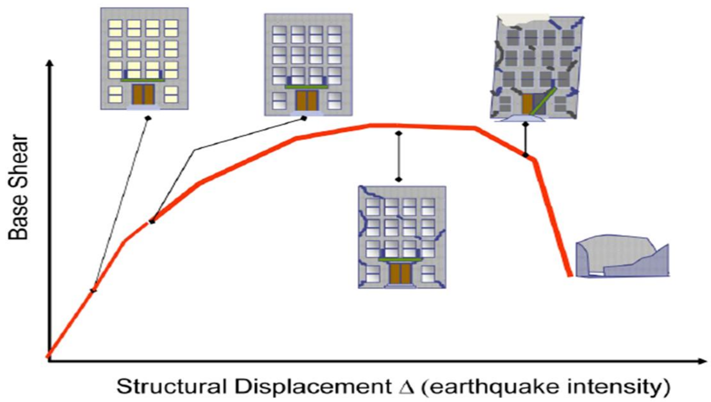

Fig.1 : Building Performance Levels

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.

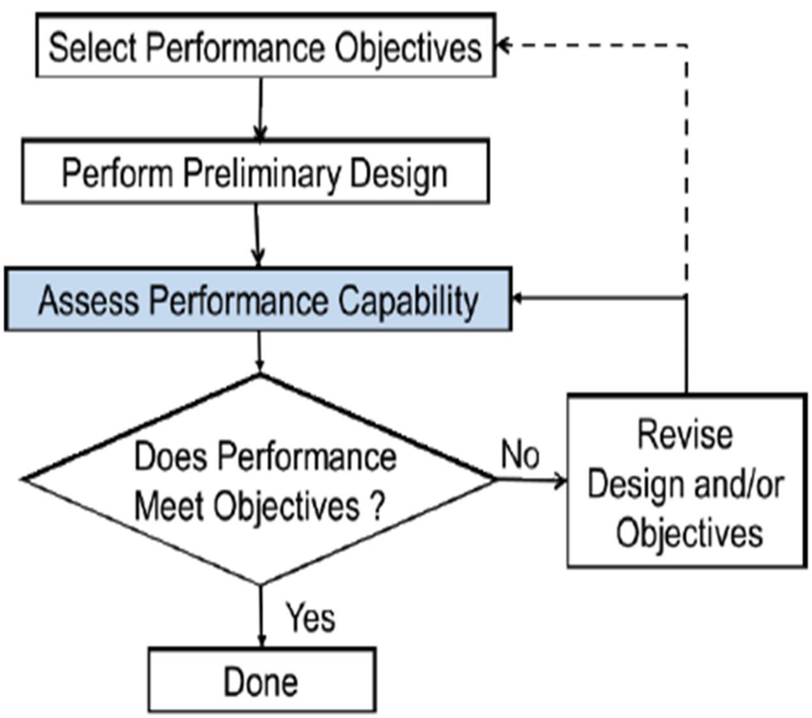

Fig.2 : Flowchart of the performance-based design process

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B. 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. Time histories which are required for static analysis are taken from PEER ground motion data. Total seven time histories are taken for analysis. Criteria for selection of histories are magnitude, shear velocity at 30 meter depth.

1) Material Properties

Grade of Concrete: M 25
Grade of Reinforcing Steel: Fe-415

2) Sectional Properties

Size of Beam = 230 mm × 380 mm
Size of Column = 500 mm × 500 mm
Thickness of Slab = 125 mm

3) Loading Considered

Dead Load:
a) Roof Level:
Weight of wall on beam = 18.5 kN/m
Weight of F.F. = 2 kN/m^2
Live Load :
Live Load at floor levels = 4 kN/m^2

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

5) Assumptions

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

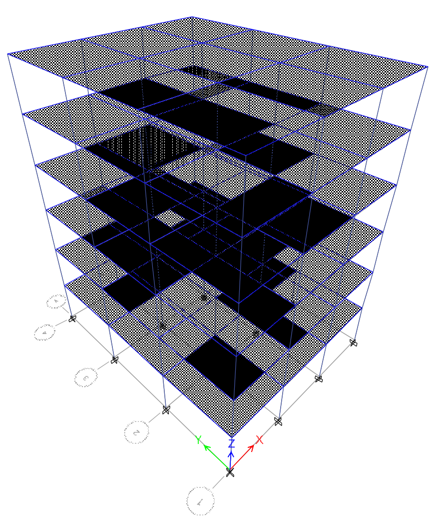

Fig.4 Elevation

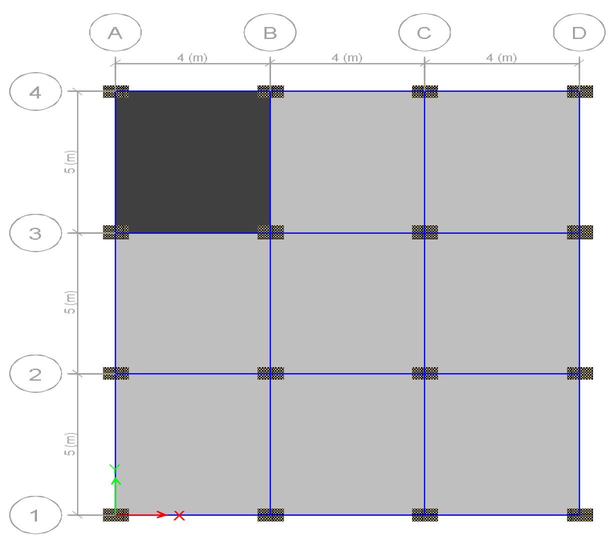

Fig.5 Plan

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IV. PERFORMANCE ANALYSIS

Performance of the building is analysed 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,

TABLE 1 : Storey Drift

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

Acceptance Criteria for Plastic rotation as per FEMA 273,

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

The drift of given building is as per following table,

TABLE 3 : Storey Response

TABLE: Story Response				
Story	Elevation m	Location	X-Dir	Y-Dir
Story6	18	Top	0.000382	0.000581
Story5	15	Top	0.000726	0.001015
Story4	12	Top	0.000776	0.001027
Story3	9	Top	0.000806	0.000958
Story2	6	Top	0.000662	0.000731
Story1	3	Top	0.000321	0.000344
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 static analysis is given in following table.

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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

V. CONCLUSIONS

A. 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.

B. 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.

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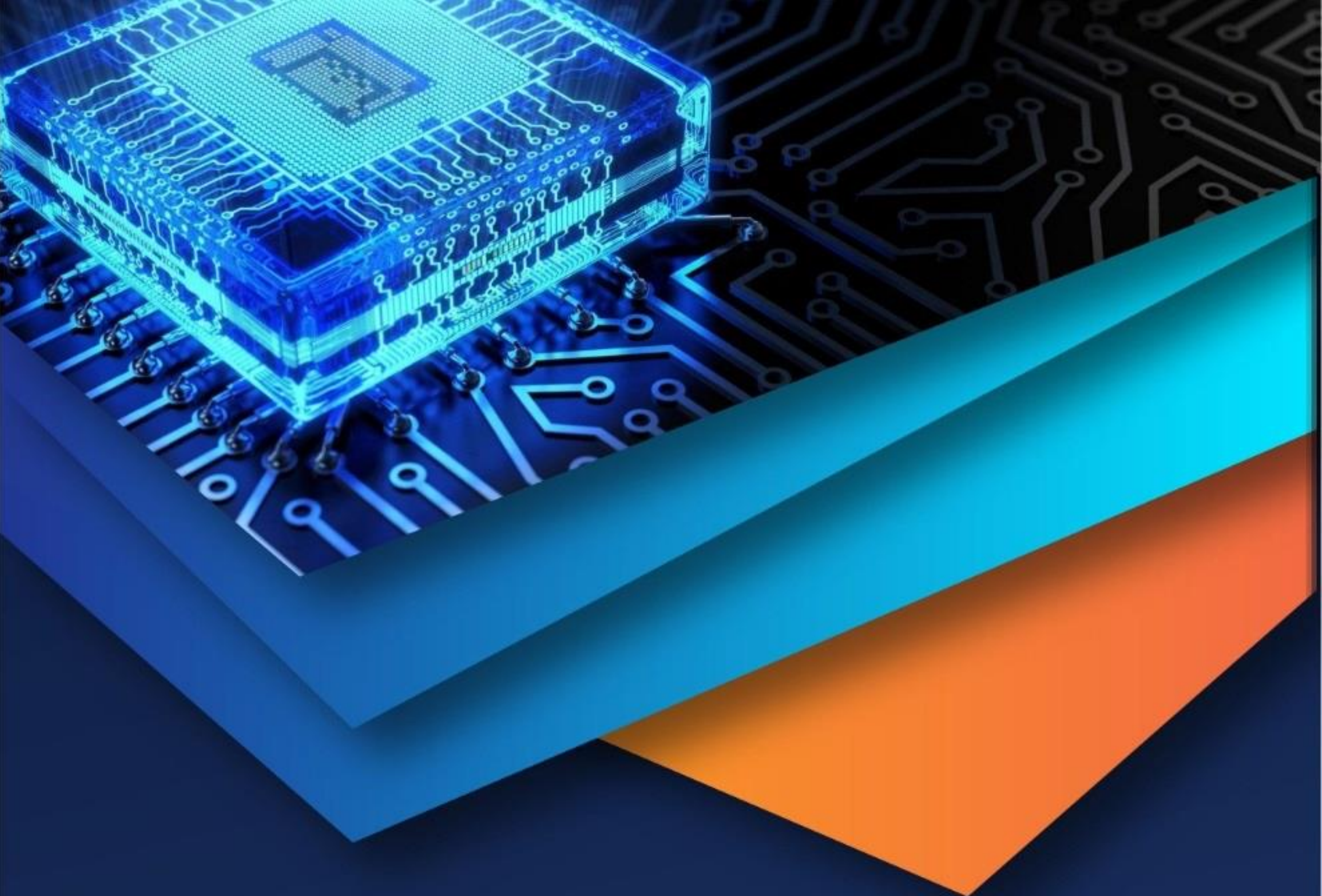

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