PERFORMANCE BASED SEISMIC EVALUATION OF MULTI-STOREYED REINFORCED CONCRETE BUILDINGS USING PUSHOVER ANALYSIS

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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 SAP2000, a product of Computers and Structures International. 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).

Key Words: *Performance based seismic design, Static Pushover analysis*

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 minimise 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.

1.1 Performance Based Design

Performance-based seismic design can be used to design individual buildings to achieve higher performance and lower potential losses than proposed by present building codes, but with lower construction costs. The process takes into consideration the uncertainties inherent in quantifying the frequency and magnitude of potential events and assessing the actual responses of building systems and the potential effects of the performance of these systems on the functionality of buildings.

1.2 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.

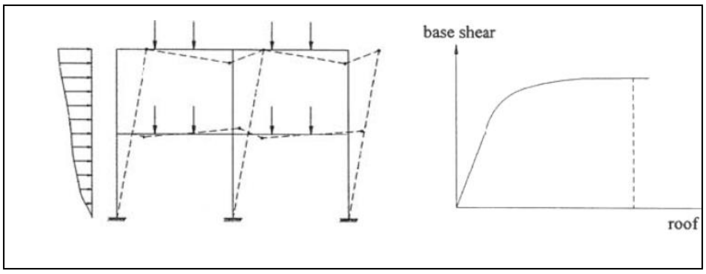

Fig -1: Illustration of Pushover Analysis

2. SEISMIC PERFORMANCE LEVELS

The design document – "Prestandard and Commentary for the Seismic Rehabilitation of Buildings, FEMA 356" defines four building performance levels namely collapse prevention (CP), life safety (LS), immediate occupancy (IO), and operational (O), as shown in Figure 2. These levels are discrete points on a continuous scale describing the building's expected performance, or alternatively, how much damage, economic loss, and disruption may occur. Each building performance level is made up of a structural performance level that describes the limiting damage state of the structural systems and a nonstructural performance level that describes the limiting damage state of the nonstructural systems.

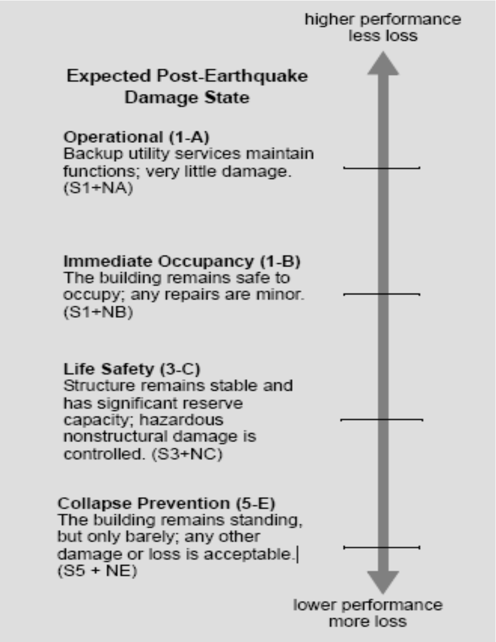

Fig -2: Building Performance Levels

3. CASE STUDY

The present case study is an example of a five storey residential building in zone III. It is an RC framed structure. The concrete slab is 150mm thick at every floor level. The beam layouts are shown in Figure 3.

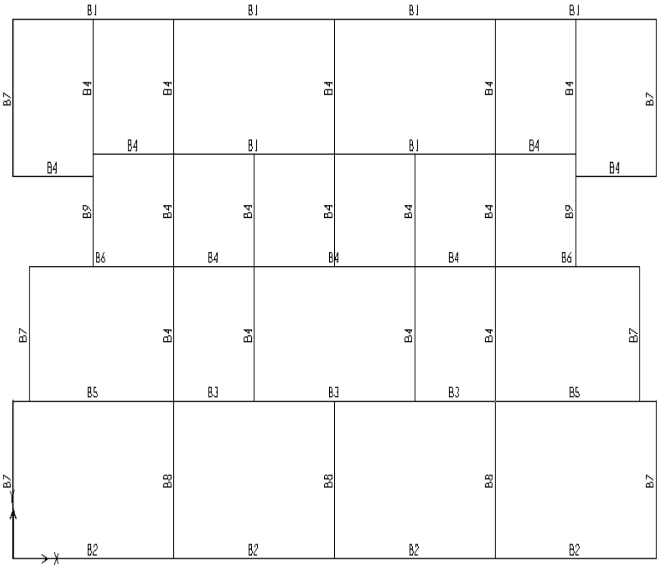

Fig -3: Building Floor Plan

The size and reinforcement details for beam and column sections are given in Tables 1 and 2 respectively.

Table -1: Details of beam sections

Beam No.	Size (mm)	Longitudinal reinforcement		Transverse reinforcement
		Top	Bottom	
B1	300*500	6Y20, 1Y16	4Y20	2Y8@75c/c
B2	200*450	6Y20	4Y20	2Y8@75c/c
B3	250*500	4Y20, 2Y16	4Y20	2Y8@75c/c
B4	250*500	4Y16	2Y16	2Y8@75c/c
B5	250*500	4Y20, 2Y16	3Y20	2Y8@75c/c
B6	250*500	2Y16	3Y16	2Y8@75c/c
B7	150*500	3Y16	4Y16	2Y8@75c/c
B8	250*500	7Y20	3Y20	2Y8@75c/c
B9	300*500	4Y20, 2Y12	4Y20	2Y8@75c/c

Table -2: Details of column sections

Column No.	Size (mm)	Longitudinal reinforcement	Transverse reinforcement
C1	400*450	8Y20	6Φ@100c/c
C2	400*450	6Y20, 2Y16	6Φ@100c/c
C3	400*450	4Y20, 4Y16	6Φ@100c/c
C4	400*500	8Y20	6Φ@100c/c
C5	400*500	6Y20, 2Y16	6Φ@100c/c
C6	400*500	4Y20, 4Y16	6Φ@100c/c
C7	400*450	10Y20	6Φ@100c/c

The infill walls are modelled as equivalent struts. The 3D model of the building is shown in Figure 4.

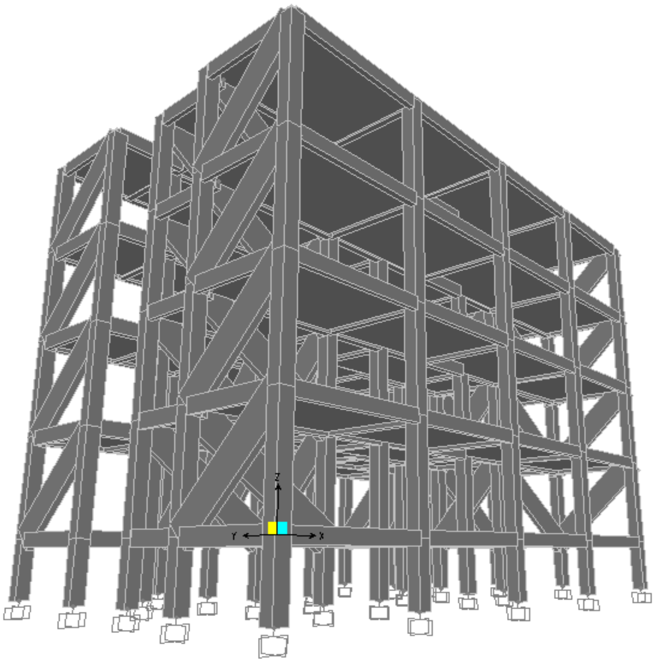

Fig -4: 3Dimensional Model of Building

3.1 Calculation of Base Shear (Using IS 1893 – 2002 : Part-1)

The fundamental periods of the building are calculated below:

$T_{ax} = 0.09x16/\sqrt{20} = 0.32s$

$T_{ay} = 0.09x16/\sqrt{12} = 0.42s$

The spectral acceleration coefficient (Sa/g) corresponding to each of the periods is 2.5. Zone factor, Z = 0.16 (zone III). For an ordinary moment resisting frame, response reduction factor, R = 3. For residential building, importance factor, I = 1.0

Horizontal seismic coefficient, $A_h = ZISa/2Rg = 0.16\times1\times2.5 / 2\times3 = 0.067$ for DBE

Horizontal seismic coefficient, $A_h = ZISa/Rg = 0.16\times1\times2.5 / 3 = 0.134$ for MCE

Seismic weight of the building is calculated as W = 10524kN

Thus, design seismic base shear, $V_b = A_h \times W = 706kN$ for DBE

Thus, design seismic base shear, $V_b = A_h \times W = 1412kN$ for MCE

The design base shear Vb computed is distributed along the height as per the following expression:

$$F_i = \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} V_b$$

$$Q_{ix} = F_{ix} + 0.3F_{iy}$$

$$Q_{iy} = F_{iy} + 0.3F_{ix}$$

Table 3 shows the distribution of the base shear along the height of the building.

Table - 3: Distribution of lateral force

Floor level	Seismic weight, W_i (kN)	Ht, hi (m)	Lateral Force, Q_{ix} (kN)		Lateral Force, Q_{iy} (kN)	
			DBE	MCE	DBE	MCE
Rf	1615	16	370.3	740.6	370.3	740.6
3	2253	12.5	315.3	630.6	315.3	630.6
2	2253	9	163.4	326.9	163.4	326.9
1	2253	5.5	61.0	122.1	61.0	122.1
Grnd	2150	2	7.7	15.4	7.7	15.4

3.2 Pushover Analysis

Pushover analysis is performed in order to study the performance of the building. There are two pushover cases for evaluating the building:

1. Gravity push, which is used to apply gravity load.
2. Lateral push, which is used to apply the lateral load, starting at the end of gravity push.

Initially, the gravity loads are applied in a force controlled manner. Next, the lateral loads are applied, in a displacement controlled manner. A gravity load combination of DL+0.5LL has been used. The direction of monitoring the behaviour of the building is same as the push direction. The effect of torsion is ignored. In case of columns, user defined PMM hinges are provided at both the ends, while in case of beams, user defined M3 hinges are provided. The maximum target displacement of the structure is kept at 4% of the height of the building = 0.64m. The pushover curve obtained is shown in Figure 5.

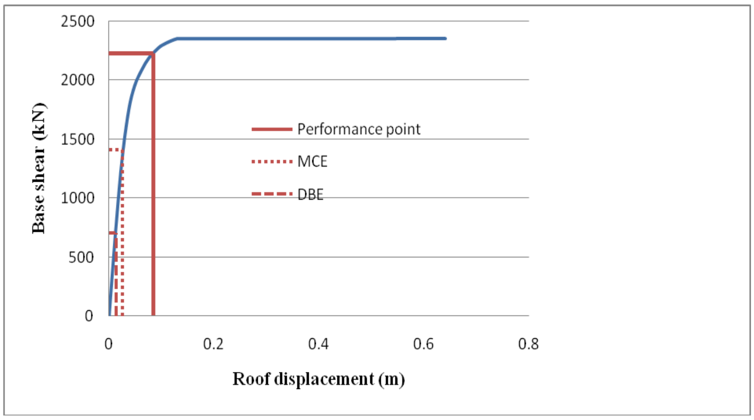

Fig -5: Pushover Curve of the Building

From Figure 5, it is seen that the following performance requirements are satisfied by the building:

Strength requirements at target displacement:

- Base shear demand at DBE is exceeded
- Base shear demand at MCE is exceeded

Displacement requirements at target displacement:

- Drift ratio at DBE is exceeded
- Drift ratio at MCE is exceeded

The status of plastic hinges at a nearest point on the curve beyond the displacement corresponding to DBE and MCE are shown in Figures 6 and 7 respectively.

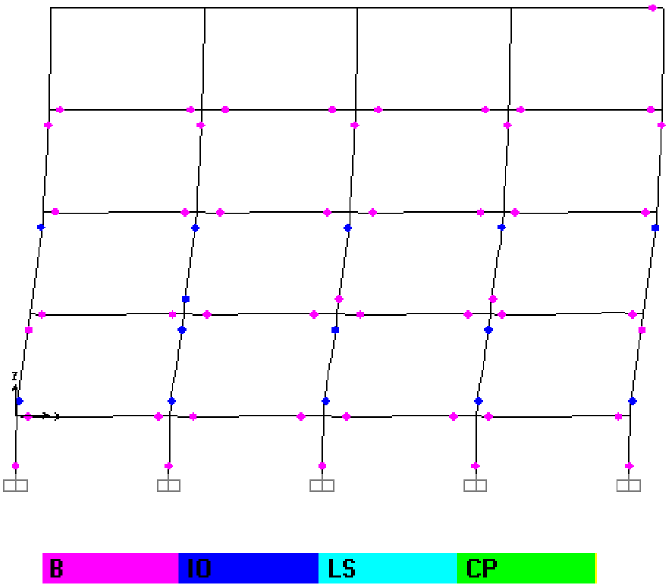

Fig -6: Status of hinges at DBE

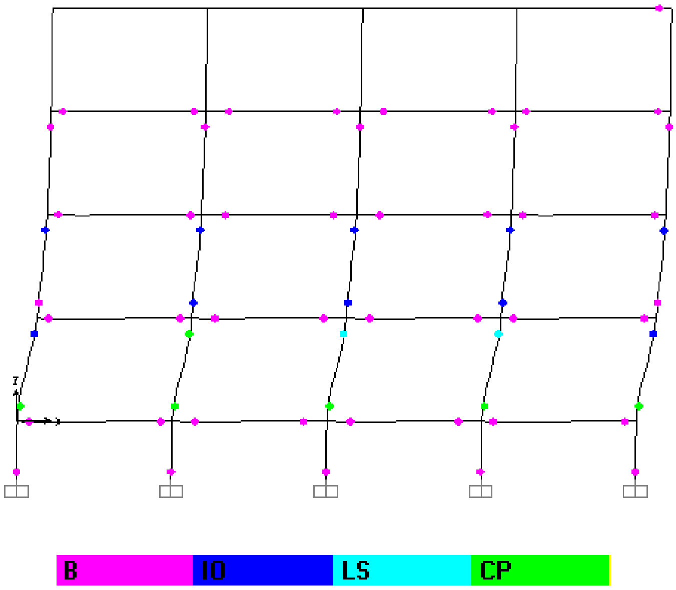

Fig -7: Status of hinges at MCE

Though the status of plastic hinges at DBE does not exceed life safety, at MCE, few hinges are at collapse prevention state.

3.3 Inter Storey Drift

The inter storey drift Δ is calculated as $\Delta = \frac{\delta}{h}$ where δ is the inter storey displacement and h is the storey height. The inter storey drifts corresponding to the displacement profiles are shown in Figure 8. The limiting value of inter storey drift is 0.4% as per IS 1893:2002. For some storeys, the drift is more than 0.4%.

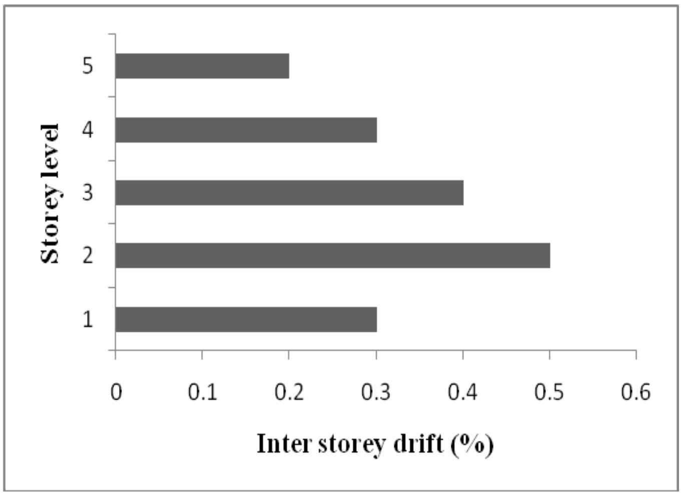

Fig-8: Inter storey drifts

Thus, the building satisfies the strength requirements but fails to satisfy one of the displacement requirements. Also for some of the storeys, the storey drift exceeds the limiting value of 0.4% specified in IS 1893:2000. Hence, the performance of the building is not satisfactory.

4. CONCLUSIONS

4.1 Performance Based Seismic Design

The need for performance based seismic engineering in contrast to force-based design approaches was studied and the four building performance levels namely operational, immediate occupancy, life safety and collapse prevention were studied in detail using FEMA 356. 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.

4.2 Seismic Evaluation using Pushover Analysis

Pushover analysis was studied in detail. An existing five storeyed residential building located in zone III was modelled using SAP2000 and analysed. Pushover analysis was performed and it was found to satisfy the strength requirements but failed to satisfy one of the displacement requirements at MCE. Also storey drift requirement specified by IS 1893:2000 is not satisfied. Thus the global performance of the building was considered unsatisfactory and the building needs to be retrofitted for seismic stability.

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