Performance Based Design of Symmetrical Building

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***Abstract*—A reinforced concrete building is to be designed in such a way that it should remain safe and suffers no damage during an earthquake. It has been observed, that the main reason for the failure of a building is, columns do not possess sufficient strength carrying capacity. Therefore, it becomes necessary to provide vertical members strong to achieve proper design standards. In capacity design concept, the vertical members are designed stronger than horizontal members. A structure designed with capacity design method does not provide any suitable failure mechanism. In the capacity design of earthquake resisting structures, elements of primary lateral load resisting system are chosen suitably and designed and detailed for energy dissipation under severe inelastic deformation.**

***Index Terms*—Pushover Analysis, Plastic Hinges, Pushover Curve, Capacity Demand Curve, Formation of plastic hinges in two stages**

I. INTRODUCTION

"Capacity design is a concept or method of designing flexural capacities of critical member sections of a building structure based on the behavior of the structure in responding to seismic actions". This behavior is reflected in the assumptions that the seismic action is of a static equivalent nature increasing gradually until the structure reaches its state of near collapse and critical regions occur simultaneously at predetermined locations to form a collapse mechanism simulating ductile behavior.

During earthquakes, many of the buildings were collapsed due to improper strength hierarchy. Many of the buildings were collapsed in Ahmedabad during "2001 Bhuj earthquake, 2015 Nepal Earthquake" due to improper strength.

However, for specific situations, the applications of capacity design concept were already implied in some codes. In the capacity design of structures for earthquake resistance, distinct elements of the primary lateral force resisting system are chosen and suitably designed and detailed for energy dissipation under severely imposed deformations. The critical regions of these members, often termed as plastic hinges, are detailed for inelastic flexural action.

Ductility and energy dissipation of structure under an event of an earthquake depends on upon the vertical member (column) of the structure. As far as design is concerned, a key feature is to avoid undesirable modes of failure. Capacity design procedure which sets aside the results of analysis and aims at establishing a favorable hierarchy of strength in the structures by ensuring that strength of columns is higher than that of adjacent beams, with possible allowance for beam over strength. The area of greatest uncertainty of response of capacity design structures is the level of inelastic deformations that might occur under strong ground motions.

A capacity design approach is likely to assure predictable and satisfactorily inelastic response under conditions for which even sophisticated dynamic analysis techniques can yield no more than crude estimates.

II. ANALYSIS OF BUILDING

A G+10 Building is taken for analysis using ETABS

A. *Building Data:-*

1. Software Used – Etabs 2015
2. Type of Structure – Multi Storey RC Frame
3. No. of Stories – G+10
4. Storey Height – 3 mtr.
5. Bay Width – 4 mtr.
6. Grade of Concrete – 25 Kn/m^3

7. Grade of Steel – Fe 415
8. Beam Size – 230 mm X 350 mm
9. Column Size – 500mm X 500mm
10. Slab Thickness – 150 mm
11. Seismic Zone – 3
12. Type of Soil – medium soil (IS 1893-part 1)
13. Floor Finish – 1 Kn/m^2
14. Live Load – 2kn/m^2
15. Earthquake Load – As per IS 1893 – Part1
16. Wind Load – As per IS 875 – Part 3
17. Clear Clover to Beam – 25 mm
18. Clear Cover to Column – 40 mm
19. Unit Weight of Masonry – 20 kn/m^3
20. Unit Weight of Concrete – 25 Kn/m^3
21. Wall thickness – 230 mm

B. Load Calculation –

1. Load on Slab :
   a. Dead load – 0.150 x 25 = 3.75 kn/m^2
   b. Live load – 2 kn/m^2
   c. Floor Finish – 1 kn/m^2
2. Load on Beam : 0.23x(3-0.45)x20 = 11.73 kn/m^2

C. Load Combination –

a. 1.2 (DL+LL±EL)
b. 0.9 DL ± 1.5 EL
c. 1.5 (DL + LL)
d. 1.5 (DL ±EL)

D. Geometry of G+10 Building –

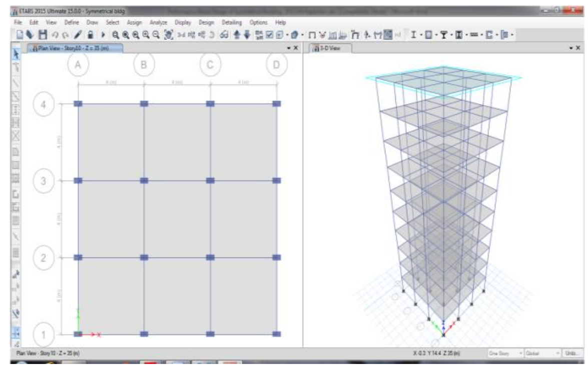

Fig. 1 Geometry of G+10 Building

E. Pushover Analysis

In the pushover analysis, the structure is represented by a 2-D or 3-D analytical model. The structure is subjected to a lateral load that represents approximately the relative inertia forces generated at locations of substantial masses such as floor levels. The static load pattern is increased in steps and the lateral load-roof displacement response of the structure is determined by a specific target displacement level or collapse is reached. A typical lateral load roof displacement performance relationship for a structure obtained from the pushover analysis in Fig.1. The internal forces and deformations computed at the target displacement levels are estimates of strength and deformation capacities which are to be compared with the expected performance objectives and demands. The sequence of component cracking, yielding and failure as well as the history of deformation of the structure can be traced as the lateral loads (or displacements) are monotonically increased.

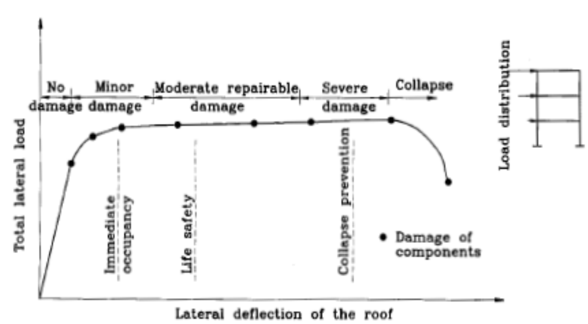

Fig. 2 Typical Performance Curve from Pushover Curve

A. Performance levels of elements

An idealized Load - Deformation curve is a piece wise linear curve defined by five points given below.

1. Point “A” – unloaded condition or starting point.

2. Point “B” – yield condition.

3. Point “C” – ultimate condition – 25% more than yield strength.

4. Point “D” – moment degradation. Residual strength can be assumed to be 20% of the yield strength.

5. Point “E” – final deformation.

The structural performance states are as follows:

TABLE I

Structural Performance States

Structural Performance States			
From yield Point	Immediate Occupancy	Life Safety	Collapse Prevention
B	0.2 Δ	0.5 Δ	0.9 Δ

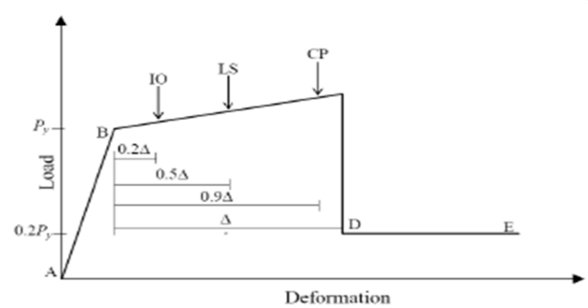

Fig. 3 – Load Deformation Curve

F. Plastic Hinges

Lateral load analysis systems of the structures, dissipate energy under severely imposed deformations through critical regions of the members, often termed as "plastic hinges". Location of plastic hinges in the structures is important because plastic hinges cause excessive deformation. In plastic hinge regions, rotations of the member are very high which leads to failure. In the capacity design of structures for earthquake resistance, a distinct element of primary lateral force resisting systems are chosen and suitably designed and detailed for energy dissipation under several imposed deformations. So these critical regions are well detailed. In capacity design concept, potential plastic hinge regions within the structure are clearly defined. These are designed to have dependable flexural strengths as close as practicable to the required strength. The plastic rotation capacity (ϴp) in a reinforced concrete member depends on the ultimate curvature (Ø/u) and the yield curvature (Ø/y) of the section and the length of the plastic hinge region (Lp). Park and Paulay reported that various researchers had proposed different empirical models to predict the length of a plastic hinge. One of the most widely used models for Lp is that proposed by Priestley.

Plastic rotation capacity (ϴp) = (Ø/u - Ø/y) L

Length of Plastic Hinge (Lp) = 0:08L + 0:022$f_{ya}d_{bl}$

Where,

L – Distance from the critical section to point of contraflexure

f_{ya} – Yield strength (Mpa) of a longitudinal bar

d_{bl} – diameter of the bar

III. RESULTS

A. Pushover Curve

1. Pushover curve obtained for G+10 building model with push in X – direction is as shown in Fig. 4 The ultimate base shear the building can take before failure is around 2657kN and the corresponding roof displacement is 262mm.

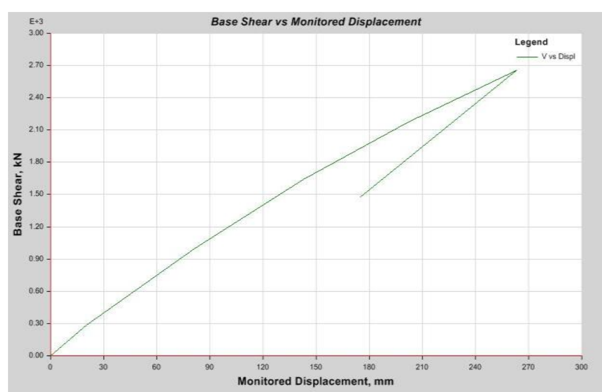

Fig. 4 – Pushover Curve of G+10 building with Push in X direction

Pushover curve obtained for G+10 building model with push in Y – direction is as shown in Fig. 5. The ultimate base shear the building can take before failure is around 2017kN and the corresponding roof displacement is 255mm.

Fig. 5 – Pushover Curve of G+10 building with Push in Y direction

B. Capacity Demand Curve for Immediate Occupancy

Capacity Spectrum curve is shown in the green colour. The Pink colour curve in the figure shows Response Spectrum Curve for various damping values. It is governed by the coefficient of acceleration and coefficient of velocity, mentioned as per IS 1893-2002, (Part 1). The Red colour curve is the Single Demand Spectra and cyan colour lines are the constant period lines. The intersection of capacity curve and demand curve is called performance point. The base shear at performance point is 2486kn and displacement is 241 mm. ductility ratio is 3.74 and damping ratio is 0.19.

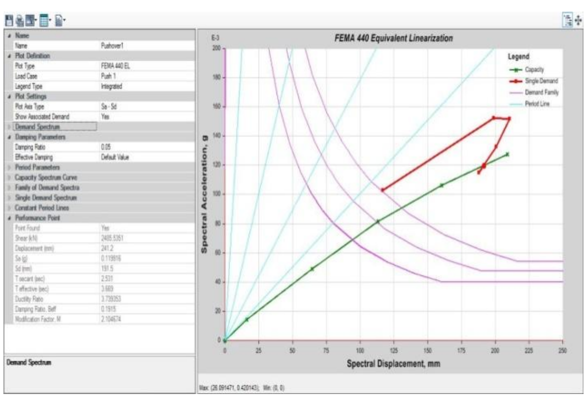

Fig. 6 – Capacity Demand curve

C. Formation of Plastic Hinges

D. Plastic Hinge states are distributed in two different types –

1. B, C, D, E points
2. IO, LS, CP acceptance points

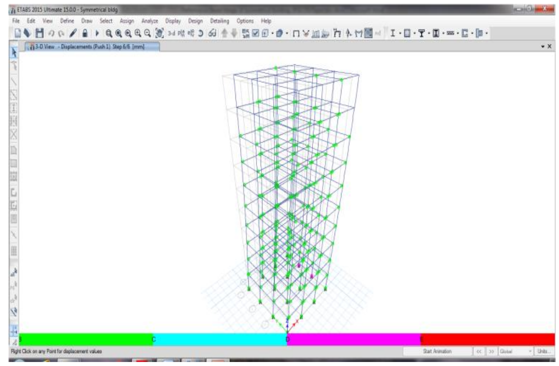

Fig. 7 Formation of Plastic Hinges: A, B, C, D, E type

In this type of formation, hinges started forming in the beams of second floor with the displacement of 20.6 mm. Further with the increase in load and the displacement, hinges started forming in only beam till the displacement of 81 mm. with the increased displacement of 142.5 mm, column started forming hinges and the maximum displacement is found to be 263 mm and maximum force of 2658 Kn with the ultimate strength of the structure. Finally, the residual strength forms with the force of 1475 Kn at 175 mm displacement. Detailed properties of formation of hinges are shown in Table 2 and 3.

TABLE II

FORMATION OF PLASTIC HINGES

Step	Base Force (Kn)	Displacement (mm)	A - B	B - C	C - D	D - E	> E	Total
0	0	0	800	0	0	0	0	800
1	285.8	20.5	798	2	0	0	0	800
2	994.7	81	646	154	0	0	0	800
3	1642	142.5	612	188	0	0	0	800
4	2175	203	582	218	0	0	0	800
5	2658	263	562	236	2	0	0	800
6	1474	175	562	236	0	2	0	800

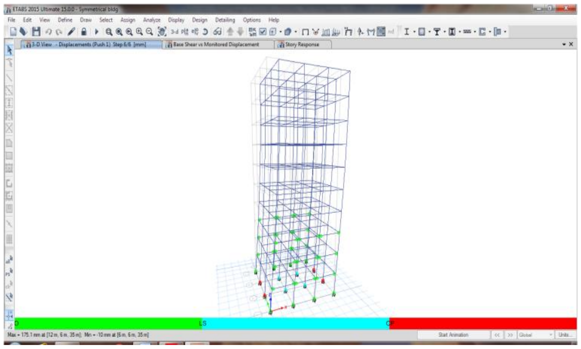

Fig. 8 Formation of Plastic Hinges: IO, LS, CP Acceptance Point

In this stage, the hinges are firstly formed in the column of ground floor with the force of 1642 Kn at the displacement of 143 mm. The column formed hinges first because of the soft Storey phenomenon. Further increasing the force the structure formed hinges up to thefourth floor. Detailed properties of formation of hinges are shown in Table 2 and 3.

TABLE III

FORMATION OF PLASTIC HINGES IN ACCEPTANCE STAGES

Step	Base Force (Kn)	Displacement (mm)	A - IO	IO - LS	LS - CP	> CP	Total
0	0	0	800	0	0	0	800
1	285.8	20.5	800	0	0	0	800
2	994.7	81	800	0	0	0	800
3	1642	142.5	798	0	0	2	800
4	2175	203	798	0	0	2	800
5	2658	263	748	44	6	2	800
6	1474	175	748	44	4	4	800

E. Reinforcement Provided

Reinforcement provided in the beams and columns are as per the ductile detailing IS: 13920

Member	Size	Reinforcement
Beam	230x350	[2-16 Ø] (top) + [2-20 Ø] (extra at end supports) [3-20 Ø] (bottom)
Column	500x500	[4-32 Ø] (corner) + [12-25 Ø]

IV. CONCLUSION

1. G+10 building has overall performance point in severe damage range i.e. > collapse Prevention.
2. The nature and characteristics of pushover curve and capacity spectrum curve obtained for all building models were comparable to the literature.
3. The Plot of displacement vs storey level promptly indicates effect of stiffness on displacement control.

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