PERFORMANCE BASED ANALYSIS OF R.C.C. FRAMES

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Abstract- **Performance Based Seismic Engineering is the modern approach to earthquake resistant design. It is limit-states design extended to cover complex range of issues faced by earthquake engineers. Two typical new R.C.C. buildings were taken for analysis: G+4 and G+10 to cover the broader spectrum of low rise & high rise building construction. Different modeling issues were incorporated through nine model for G+4 building and G+10 building were; bare frame (without infill), having infill as membrane, replacing infill as a equivalent strut in previous model. All three conditions for 2×2, 3×3, 4×4 bays. Comparative study made for bare frame (without infill), having infill as membrane, replacing infill as a equivalent strut.**

Keywords- Capacity, Demand, Performance point, ATC 40, CSM, ETABS 9.7

I Introduction

The Buildings, which appeared to be strong enough, may crumble like houses of cards during earthquake and deficiencies may be exposed. Experience gained from the Bhuj earthquake of 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of the present day codes. Performance based seismic engineering is the modern approach to earthquake resistance design. The objective of performance-based analysis is to produce structures with predictable seismic performance. Performance based engineering is not new concept. Automobiles, Airplanes, and turbines have been designed and manufactured using this approach for many decades. But the applications of the same, to the buildings were limited. In order to utilize performance-based analysis effectively and intelligently, one need to be aware of the uncertainties involved in both structural performance and seismic hazard estimations. .A key requirement of any meaningful performance based analysis is the ability to assess seismic demands and capacities with a reasonable degree of certainty.

Capacity: The overall capacity of a structure depends on the strength and deformation capacity of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of nonlinear analysis, such as the pushover procedure, is required. This procedure uses a series of sequential elastic analysis, superimposed to approximate a force displacement capacity diagram of the overall structure. A lateral force distribution is again applied until additional components yield. This process is continued until the structure become unstable or until a predetermined limit is reached.

Demand: Ground motion during an earthquake produces complex horizontal displacement patterns in the structures. It is impractical to trace this lateral displacement at each time-step to determine the structural design parameters. The traditional design methods use equivalent lateral forces to represent the design condition. For nonlinear methods it is easier and more direct to use a set of lateral displacements as the design condition. For a given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the building during the ground motion.

Once, a capacity curve and demand displacement, are defined, a performance check can be done.

II Pushover Analysis Procedure

The ATC 40 [1] provides detailed guidelines about how to perform a nonlinear static pushover analysis. The following procedure is based on the ATC 40 procedure.

- Form the analytical model of the nonlinear structure.
- Set the performance criteria, like drift at specific floor levels, limiting plastic hinge rotation at specific plastic hinge points, etc.
- Apply the gravity load and analyze for the internal forces.
- Assign the equivalent static seismic lateral load to the structure incrementally.
- Select a control point to see the displacement.
- Apply the lateral load gradually using incremental iteration procedure.
- Draw the "Base Shear vs. Controlled Displacement" curve, which is called "pushover curve".
- Convert the pushover curve to the Acceleration-Displacement Response-Spectra (ADRS) format.
- Obtain the equivalent damping based on the expected performance level.

- Get the design Response Spectra for different levels of damping and adjust the spectra for the nonlinearity based on the damping in the Capacity Spectrum.
- The capacity spectrum and the design response spectra can be plotted together when they are expressed in the ADRS format.
- The intersection of the capacity spectrum and the response spectra defines the performance level.

III CAPACITY SPECTRUM METHOD

Capacity curve

The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of nonlinear analysis is required. This procedure uses sequential elastic analysis, superimposed to approximate force-displacement diagram of the overall structure. The mathematical model of the structure is modified to account for reduced resistance of yielding components. A lateral force distribution is again applied until additional components yield. A typical capacity curve is shown in **fig.1**

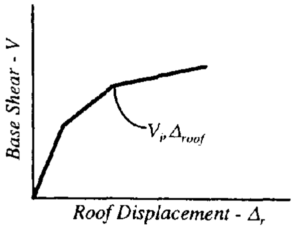

Fig.1 Capacity curve

a) Capacity spectrum

To convert the capacity curve, into the capacity spectrum, the required equation to make the transformation. (Refer ATC-40, Volume-1, p-8.9):

A typical capacity spectrum is as shown in **fig.2**.

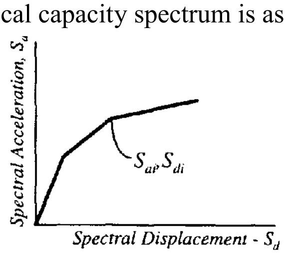

Fig.2 Capacity spectrum

b) Demand curve

Ground motion during an earthquake produces complex horizontal displacement patterns which may vary with time. Tracking this motion at every time step to determine structural design requirements is judge impractical. For a given structure and a ground motion, the displacement demands are estimate of the maximum expected response of the building during the ground motion. Demand curve is a representation of the earthquake ground motion. It is given by spectral acceleration (Sa) Vs. Time period (T) as shown in **fig.3**.

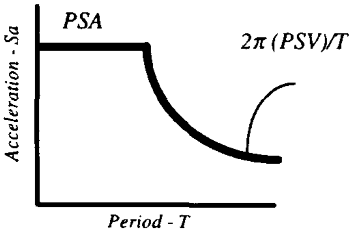

Fig.3 Demand curve (Traditional spectrum)

Fig.4. illustrates the construction of an elastic response spectrum (Demand curve) (Refer ATC-40, Volume-1, p-4-12).

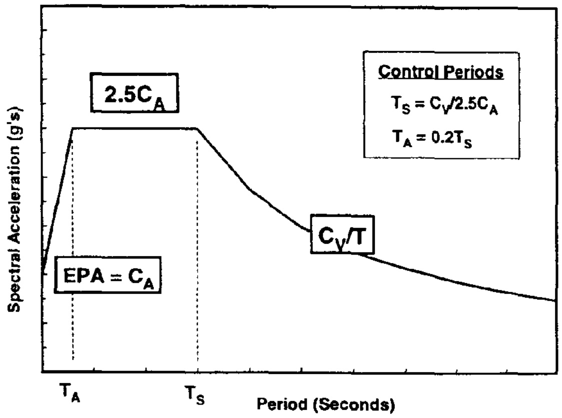

Fig.4 Construction of a 5% damped elastic response spectrum (Demand Curve)

As per provisions and commentary on Indian seismic code IS 1893(part-1), equivalent seismic coefficient Ca is given by,

Ca = Z*g*Sa/g

Cv = 2.5*Ca*Ts

c) Demand spectrum

To convert Demand curve (traditional spectrum-Sa Vs T format) into demand spectrum (acceleration displacement response spectrum-Sa Vs Sd format). (Refer ATC-40, Volume-1, p-8-10).

A typical demand spectrum is as shown in **fig.5.**

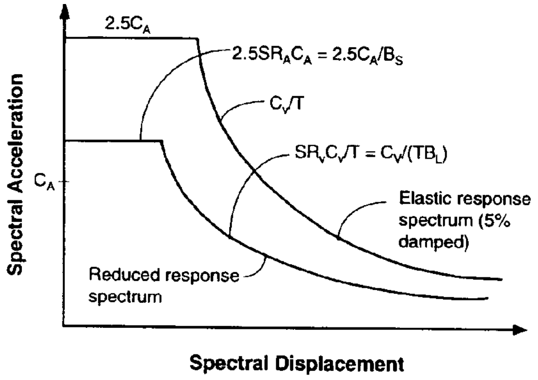

Fig.5 Reduced response spectrum

d) Performance point

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curve is performance point. **Fig.6.** shows superimposing demand spectrum and capacity spectrum.

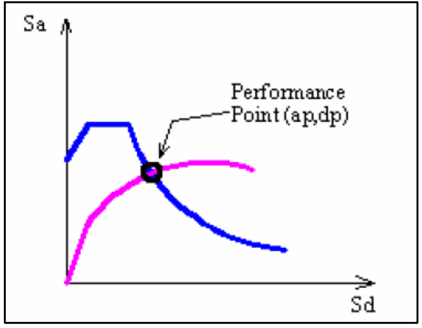

Fig.6 Performance point

Check performance level of the structure and plastic hinge formation at performance point. A performance check verifies that structural and non-structural components are not damaged beyond the acceptable limits of the performance objective for the force and displacement implied by the displacement demand.

IV PUSHOVER ANALYSIS IN ETABS 9.7

The nonlinear analysis of a structure is an iterative procedure. It depends on the final displacement, as the effective damping depends on the hysteretic energy loss due to inelastic deformations, which in turn depends on the final displacement. This makes the analysis procedure iterative. Difficulty in the solution is faced near the ultimate load, as the stiffness matrix at this point becomes negative definite due to instability of the structure becoming a mechanism.

Extended Three Dimensional Buildings Systems (ETABS) and Structural Analysis Program finite element program that works with complex geometry and monitors deformation at all hinges to determine ultimate deformation. It has built-in defaults for ACI 318 material properties and ATC-40 and FEMA 273 hinge properties.

The analysis in ETABS 9.7 involves the following four steps.1) Modeling, 2) Static analysis, 3) Designing, 4) Pushover analysis.

Steps used in performing a pushover analysis of a simple three-dimensional building. ETABS 9.7 general purpose, three-dimensional structural analysis program, is used as a tool for performing the pushover. The following steps are included in the pushover analysis.

1. Creating the basic computer model in the usual manner.

2. Define properties and acceptance criteria for the pushover hinges. The program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members. These built in properties can be useful for preliminary analyses, but user defined properties are recommended for final analyses.

3. Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations.

4. Define the pushover load cases. In ETABS 9.7 more than one pushover load case can be run in the same analysis. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled.

5. Run the basic static analysis and, if desired, dynamic analysis. Then run the static nonlinear pushover analysis.

6. Display the pushover curve and the table.

7. Review the pushover displaced shape and sequence of hinge formation on a step-by-step basis.

Plastic Deformation curve:

For each degree of freedom, one can define a force-displacement (moment-rotation) curve that gives the yield value and the plastic deformation following yield. This is done in terms of a curve with values at five point A-B-C-D-E as shown in **fig 7.**

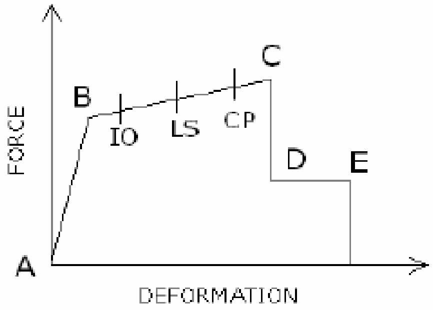

Fig.7 Force V/s Deformation curve

The shape of this curve as shown in **fig.7.**is intended for pushover analysis. The following points should be noted:

Point A is always the origin.

Point B represents yielding. No deformation occurs in the hinge up to point B, regardless of the deformation value specified for point B. The displacement at point B will be subtracted from the deformation at point C, D, and E.

Only plastic deformation beyond point B will be exhibited by the hinge.

Point C represents the ultimate capacity for pushover analysis.

Point D represents a residual strength for pushover analysis. However, you may specify a positive slope from C to D or D to E for other purposes.

Point E represents total failure. Beyond point E the hinge will drop load down to point F (not shown).

V Analysis of new R.C.C. building

Two kind of R.C.C. buildings were taken for analysis: G+4 and G+10. Eighteen different types of model to simulate real field problem were developed. In all the models, the support condition was assumed to be fixed and soil condition was assumed as medium soil.

A. Modeling of G+4 building

The nine model for G+4 building were; bare frame, having infill as membrane, replacing infill as a equivalent strut in previous model. All three condition for 2×2, 3×3, 4×4. It was X-direction and Y-direction, each of 4m in length. All the slabs were considered as shell element of 150mm thickness.

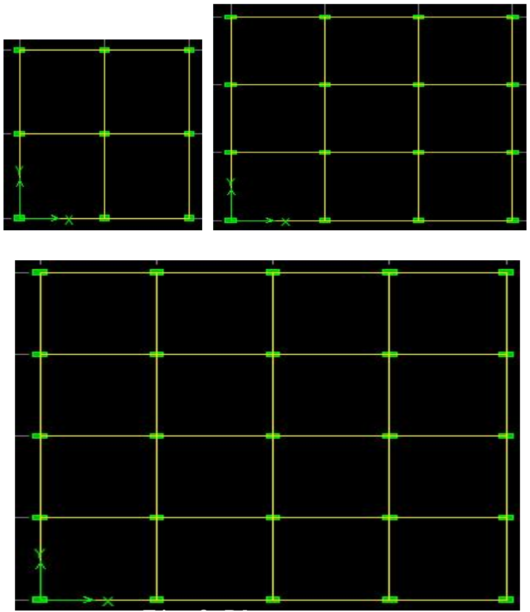

Fig.8 Plan

The model was the bare frame having beams, columns and slabs. All structural members were of M25 grade concrete and Fe415 steel. The slabs were considered as rigid floor diaphragm.

The geometrical properties are listed in Table.1.

Table 1.Geometrical properties for G+4 Storey

Floor	**Column Size (mm×mm)**	**Beam size(mm×mm)**	**Live Load KN/ m2**
GF	230x600	230×500	2
1st floor	230x600	230x500	2
2nd floor	230x500	230x450	1.5
3rd floor	230x500	230x450	1.5
4th floor	230x500	230x450	1.5

Fig.9. shows the elevation of the building model for 4×4 bays. The storey height was 3m and the support condition at base was assumed to be fixed.

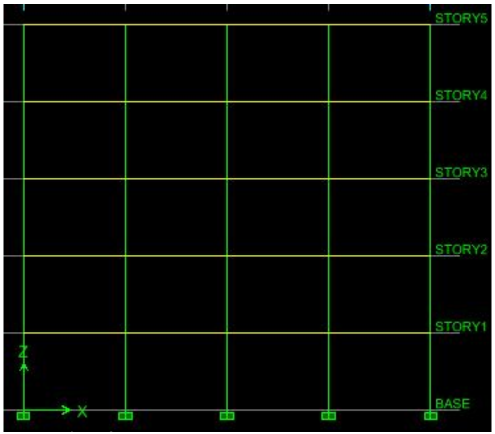

Fig.9 elevation for 4×4 bays bare frame

G+4 with infill membrane wall

The model incorporates infill wall as a membrane element. The property of membrane element is such that it has only inplane stiffness and outplane stiffness is voids. The infill walls were provided below all the beams except the first floor beams. The thickness of wall was 115mm. The material properties of masonry infill wall are Modulus of Elasticity: 3500 kN/m2, Density: 20 kN/m3, Poisons ratio: 0.17.

The geometrical properties of beams and columns and loading were same as considered in bare frame.

G+4 with infill as equivalent strut

In the case of an infill wall located in a lateral load-resisting frame the stiffness and strength contribution of the infill has to be considered. Non-integral infill frame subjected to lateral load behaves like diagonally braced frame. In this model, the equivalent compression strut was modeled in place of membrane wall having material property same as membrane wall. **Fig.10** shows the elevation of the model with strut. The ends of diagonal struts were released for moments and shears in all the directions, to make it as a pinned joint.

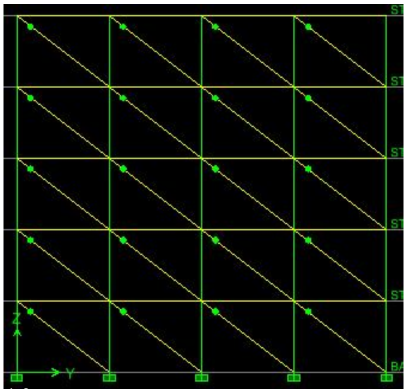

Fig.10 elevation for 4×4 bays infill as diagonal strut

The dot at the end of strut as shown in Fig. represents the end releases. In ETABS 9.7 this released hinges are provided at one end only.

B. Modeling of G+10 building

Three models of G+10 R.C.C. Buildings were created in ETABS, addressing modeling issues. One was bare frame, second model was having infills as membrane wall and third model was having infill as equivalent diagonal strut.

G+10 model without infill

Fig. shows the elevation of G+10 model without infill for 4×4 bays. The storey height was kept constant as 3m.

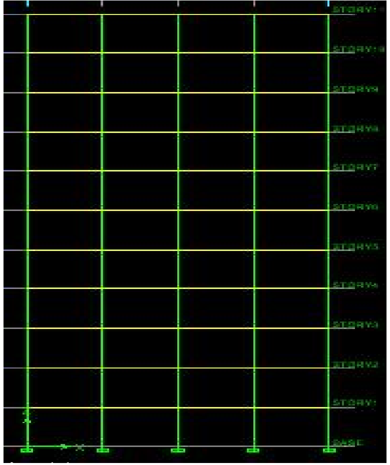

Fig.11 elevation for 4×4 bays bare frame

The geometrical properties are listed in Table.2.

Table 2.Geometrical properties for G+10 Storey

Floor	Column Size (mm×mm)	Beam size(mm×mm)	Live Load KN/ m2
GF	230x900	230×650	2
1st floor	230x900	230x650	2
2nd floor	230x900	230x650	2
3rd floor	230x750	230x650	2
4th floor	230x750	230x650	2
5th floor	230x750	230x650	2
6th floor	230x550	230x650	2
7th floor	230x450	230x450	2
8th floor	230x450	230x450	1.5
9th floor	230x450	230x450	1.5
10th floor	230x450	230x450	1.5

G+10 building with infill as membrane wall and G+10 with infill as equivalent strut are similarly model as G+4 building with infill as membrane wall and G+4 with infill as equivalent strut respectively.

Similar modeling for 2×2, 3×3 is carried out for G+4 and G+10.

VI Results

Frame Type	**G+4 storey**	**G+4 storey**	**G+10storey**	**G+10storey**
	Performance point X (KN)	Displacement X (meter)	Performance point X (KN)	Displacement X (meter)
Bare frame (2×2)	1115. 33	0. 077	1156. 34	0.145
Infill as membrane wall(2×2)	1465. 31	0. 103	1423. 76	0. 191
Infill as diagonal strut(2×2)	1699. 43	0. 120	1800. 49	0. 265
Bare frame (3×3)	2370. 58	0. 081	2419. 50	0. 144
Infill as membrane wall(3×3)	2973. 87	0. 104	2973. 13	0. 188
Infill as diagonal strut(3×3)	3499. 74	0. 129	3778 .94	0. 264
Bare frame (4×4)	4050. 97	0. 082	4163. 49	0. 146
Infill as membrane wall(4×4)	5154. 53	0. 105	5079. 91	0. 186
Infill as diagonal strut(4×4)	5932. 90	0. 125	6500. 80	0. 265

VII Conclusion

From the results for G+4 and G+ 10 storeys in bare frame without infill having lesser lateral load capacity (Performance point value) compare to bare frame with infill as membrane and bare frame with infill having lesser lateral load capacity compare to bar frame with equivalent strut.

Also conclude that as the no of bays increases lateral load carrying capacity increases but with the increase in bays corresponding displacement is not increases.

Also conclude that as the no of storey increases lateral load carrying capacity does not increase but corresponding displacement increases.

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