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The Non Linear Static Pushover Analysis of RCC Frames

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Abstract - **As the Developing countries move towards the implementation of Performance Based engineering philosophies in seismic design of civil structures, new seismic design provisions will require structural engineers to perform nonlinear analyses of the structures they are designing. These analyses can take the form of a full nonlinear dynamic analysis, or static nonlinear Pushover Analysis. Because of the computational time required to perform a full nonlinear dynamic analysis, the Pushover Analysis, if deemed applicable to the structure at hand, For this reason, there is a need for easy to use and accurate, nonlinear Pushover Analysis. The loads are increased until the peak response of the structure is obtained on a base shear Vs. roof displacement plot. From this plot, and other parameters representing the expected or design earthquake the maximum deformations the structure is likely to undergo during the design seismic event can be estimated.**

Keywords: **Non-linear, Pushover, Dynamics, Base Shear, Earthquake, Performance Analysis & Lateral Displacement**

I. Introduction

As the developing country move towards the implementation of Performance Based Engineering philosophies in seismic design of civil structures, new seismic design provisions will require structural engineers to perform nonlinear analyses of the structures they are designing. These analyses can take the form of a full nonlinear dynamic analysis or a static nonlinear Pushover Analysis. Because of the computational time required to perform a full nonlinear dynamic analysis, the Pushover Analysis, for this reason, there is a need for easy to use and accurate, nonlinear Pushover Analysis tools which can easily be applied in a design office. In the US, the reference document for performing the Pushover Analysis is currently in FEMA 273. According to this procedure a vertical distribution of static, monotonically increasing, lateral loads is applied to a mathematical model of the structure. The loads are increased until the peak response of the structure is obtained on a base shear Vs. roof displacement plot. From this plot, and other parameters representing the expected, or design, earthquake, the maximum deformations the structure is expected to undergo during the design seismic event can be estimated. The performance-based design methodology requires the proper matching of two basic quantities, the seismic capacity and the seismic demand. Demand is a description of the earthquake ground motion effects on the building. Capacity is a representation of the ability of the building to resist the seismic effects. In a pushover procedure, the seismic capacity & demand are estimated explicitly in two separate steps.

1. Estimating seismic capacity.
2. Estimating seismic demand.

II. Theoretical Formulation

The Pushover Analysis is defined in FEMA 356 as a non – linear static approximation of the response a structure will undergo when subjected to dynamic EQ loading. The static approximation consists of applying a vertical distribution of lateral loads to a model which captures the material non-linearity of an existing or previously designed structure, and monotonically increasing those loads until the peak response of the structure is obtained on a base shear vs. roof displacement plot as shown in figure 1.

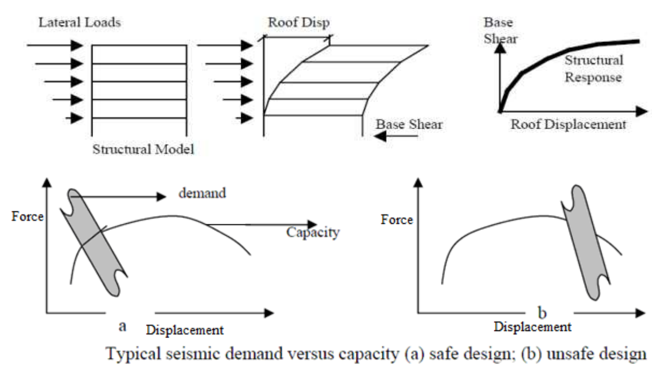

Fig. 1 Static Approximation Used In the Pushover Analysis

A. Pushover Analysis

Pushover analysis is a static non-linear procedure, in which the magnitude of the lateral load is incrementally increased maintaining a predefined distribution pattern along the height of the building. With the increase in the magnitude of loads, weak links and failure modes of the building can be found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. Local non linear effects are modeled and the structure is pushed until a collapse mechanism is developed. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve.

B. Method of Pushover Analysis

There are different methods followed for pushover analysis. Basically it has been classified into two ways are.

i) Force Control.

ii) Displacement Control.

C. Step in Performing the Non – Linear Static Procedure (Pushover Analysis)

1. ***Determine the Gravity Loading and the Vertical Distribution of the Lateral Loads:*** The loads acting on the structure are contributed from slabs, beams, columns, walls, ceilings and finishes. They are calculated by conventional methods according to IS 456-2000 and are applied as gravity loads along with live loads as per IS 875(Part II) in the structural model.

2. ***Building Performance Level Determination:*** The next thing that may be determined is the Building Performance Level. The Building Performance Level is the desired condition of the building after the design earthquake decided expertise structural engineer, & is a combination of the Structural Performance Level & the Non–Structural Performance Level. The Structural Performance Level is defined as the post event conditions of the structural building components. This is divided into three levels & two ranges. The levels are S – 1: Immediate Occupancy, S –3: Life Safety, and S – 5: Collapse Prevention. The ranges are S – 2: which is a range between S – 1 and S – 3, and S – 4: which is a range between S –3 and S – 5. The ranges are included to describe any building performance level which may be decided upon by the expertise engineer. The Non Structural Performance Level is defined as the post – event conditions of the non - structural components. This is divided into five levels. They are N – A: Operational, N –B: Immediate Occupancy, N – C: Life Safety, N – D: Hazards Reduced, and N – E: Non – Structural Damage Not Limited. By combining the number from the Structural Performance Level with the second letter from the Non – Structural Performance Level, one can attain the total Building Performance Level. The combinations to achieve the most common Building Performance Levels, 1 – A: Operational, 1 – B: Immediate Occupancy, 3 – C: Life Safety, and 5 – E.

The Building performance levels can be classified as follow:

1. Immediate Occupancy Structural Performance Level (S-1)
2. Damage Control Structural Performance Range (S-2)
3. Life Safety Structural Performance Level (S-3)
4. Limited Safety Structural Performance Range (S-4)
5. Collapse Prevention Structural Performance Level (S-5)
6. Structural Performance Not Considered (S-6)

TABLE 1 TARGET BUILDING PERFORMANCE LEVELS AND RANGES

Non Structural performance Levels	S-1 Immediate Occupancy	S-2 Damage Control Range	S-3 Life Safety	S-4 Limited Safety Range	S-5 Collapse Prevention	S-6 Not Considered
N-A Operational	Operational 1-A	2-A	Not recommended	Not recommended	Not recommended	Not recommended
N-B Immediate Occupancy	Immediate Occupancy 1-B	2-B	3-B	Not recommended	Not recommended	Not recommended
N-C Life Safety	Not recommended	2-D	Life Safety 3-C	4-C	5-C	6-C
N-D Hazards Reduced	Not recommended	2-C	3-D	4-D	5-D	6-D
N-E Not Considered	Not recommended	Not recommended	Not recommended	4-E	Collapse Prevention	No Rehabilitation

TABLE II EARTHQUAKE LEVELS (FEMA 356)

Earthquake levels	p	t (years)	N (years	Approximate N (years)	Remarks
Serviceability earthquake -1	50%	50	72	75	Frequent
Serviceability earthquake -2	20%	50	224	225	Occasional
Design basis earthquakes	10%	50	475	500	Rare
Maximum considered earthquake 1	5% 10%	50 100	975 949	1000	Very rare
Maximum considered earthquake 1	2% 10%	50 250	2475 2373	2500	Extremely rare

III. PERFORMANCE ANALYSIS OF RCC FRAME USING "SAP 2000"

A. Model of Typical RCC Structure

Modeling of frame structure consists of several steps. In first step, geometry of all members of the structure is modeled. Then, materials and its properties such as compressive strength, Poisson's ratio and shear strength of materials are defined. Frame sections such as Beams and columns and its dimensions are defined. In next step, applied loads and load combinations for the whole structure is defined. Flexural hinge properties are defined: in terms of moment rotation and axial force moment interaction relations for columns, and moment rotation relations for beams. Shear hinge property of beams and columns are defined in terms of shear force-shear deformation relation. The potential location of hinges in the member needs to be specified it depends on hinge length.

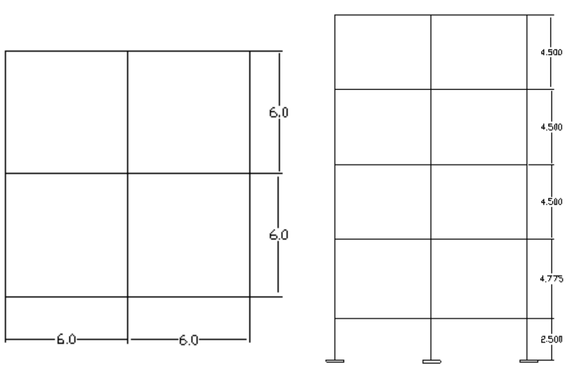

Fig. 2 Typical Plan & Elevation Of Rc Building

B. Building Description

The building selected to carry out seismic analysis is an Office building located in seismic zone IV. RC building designed only for Gravity load as per IS 456:2000 and SP 16-1980. The floor plan and elevation of a typical building is as shown in Fig. 2. The plan is regular in nature in the sense that it has all beams and column equally placed in both X & Y directions. The Beams and Columns are modeled as frame elements with moment transferring rigid joints and infill panels as pin joined diagonal strut members so that the ends of strut coincide with the joints between beams & columns. The frame shown in Figure 2 is considered for Pushover and Time History analyses and is carried out using SAP-2000 software package.

C. Analysis and Design of RCC Building

The basic analyses i.e. determination of forces and moments are carried out for structure in "SAP-2000". These analyses results are taken for the design for of building by using IS 13920:1993, IS- 4*56:2000* and SP 16:1980.

D. Preliminary Data for RC Frame Building

The salient features of the frame are given below,

1. Type of structure - Multi-storey rigid jointed frame
2. Zone: IV
3. Number of stories: G + 3, G + 5, G + 8 with & without Soft storey and G + 10 with & without soft storey
4. Floor to floor height - 4.5m
5. Grand storey & Soft Storey Height: *4.775m & 3.0 m*
6. Walls: 250mm thickness including plaster
7. Live load: 5kN/m^2 on floor and 3kN/m^2 on the roof
8. Materials: M *20* and Fe415
9. Lateral load calculation - Static method (IS 1893 (Part): 2002) and ATC-40
10. Size of exterior columns: - 300x 750mm, 300x 550 mm.400 x 750 mm
11. Size of interior columns:- 300x 750mm, 300x 550mm, 550 X 800 mm
12. Size of beams in both directions: 230 X 600mm 13. Total depth of slab: 175mm.

E. Earth Quake Load Analysis

TABLE III DETERMINATION OF TOTAL BASE SHEA BY IS-1893 OF DIFFERENT STOREY'S

Sl. No.	No. of Storey	Total Dead load (W1) kN	Total Live load (W2) kN	Total Load(W) = W1 + W2	Ah	Base shear VB = Ah W
1	G + 3	9222.154	1080	10302.154	0.04932	508.172
2	G + 5	14857.90	1800	16657.90	0.037657	627.296
3	G + 8	24283.45	2800	27083.45	0.025793	770.490
4	G + 8 (Soft Storey)	22884.25	2800	25684.25	0.021957	754.00
5	G + 10	29848.90	3600	33448.90	0.024689	825.853
6	G + 10 (soft storey)	28451.54	3600	32051.54	0.025338	812.12

IV. RESULTS AND DISCUSSION

The type of nonlinear analysis carried out to evaluate the seismic performance of frame namely, pushover analysis. The pushover analysis consists of the application of gravity loads and a representative lateral load pattern. Lateral forces calculated according to IS 1893-2002 were applied monotonically in a step-by-step nonlinear static analysis. In pushover analysis, the behavior of the structure is characterized by a capacity curve that represents the relationship between the base shear force and the displacement of the roof.

A. Model of Typical 4-Storey Building

1. Base Shear & Performance Point: The pushover curve is shown in Figure 4. In pushover curve we get the graph of applied lateral load vs lateral displacement. The performance point of frame is obtained from the intersection of capacity and demand spectra from SAP analysis. The base shear, roof displacement, spectral acceleration, spectral displacement, effective time period and effective damping corresponding to the performance point is shown in same figures. The displacement at performance point by FEMA 440 Equivalent Linearization is lesser than ATC- 40 (fig5).

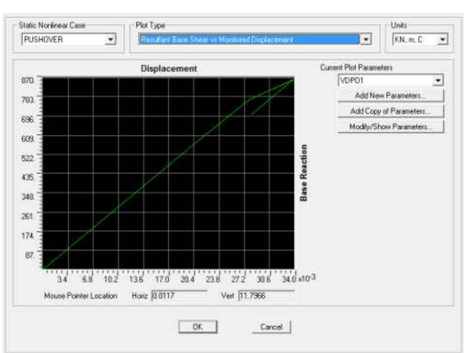

Fig. 4. Typical Pushover Curve of 4 Storey Frame

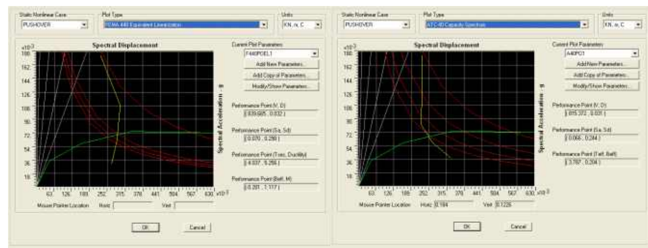

Fig. 5 Pushover Curve of 4-Storey Frame by FEMA 440 Equivalent Linearization & ATC-40 Capacity Spectrum

2. Plastic Hinge Patterns

The plastic hinge patterns of frame at Different Steps from pushover analysis are shown in Figure 6 & 7 in the analyses. It is observed that more number of columns underwent yielding than beams at the displacement levels corresponding to Final Steps. It is also seen that more number of beam ends showed hinges at yielding level in model of pushover analysis at each step of pushover. Plastic hinging pattern at step no 1 indicates that bottom storey Beams yielded, whereas there was no hinge formation in the middle columns. The plastic hinge pattern from pushover analysis at last step Figure 7. But since yielding occurs at events B, IO, LS, CP, C, D & F.

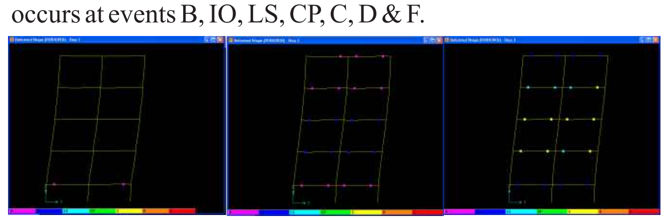

Fig. 6 Typical Hinges pattern 4 storey building at Step No. 1, 2 & 3

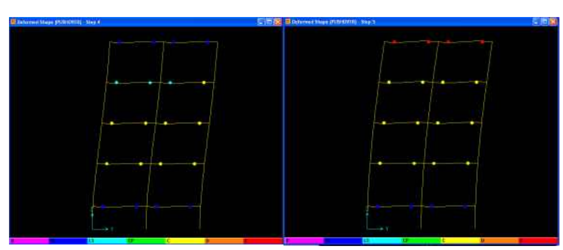

Fig. 7 Hinges pattern 4 storey building at Step No. 4 & 5

TABLE III THE COMPARATIVE STATEMENT BETWEEN BASE SHEAR & DISPLACEMENT BY IS-1893, PERFORMANCE POINT BY FEMA 440 EL AND ATC-40 & MAXIMUM LATERAL DISPLACEMENT BY IS-1893.

No. of Storey	Capacity of frame by Static Analysis		Capacity of frame by Pushover Analysis					Maximum Lateral Displacement by IS 1893-2002	
	IS 1893-2002		FEMA 440 EL		ATC-40		Maximum Base Shear (KN)	δ =0.004H	
	Base Shear (kN)	δ (mm)	Base Shear (kN)	δ (mm)	Base Shear (kN)	δ (mm)		δ (mm)	Base Shear by Pushover curve (kN)
G+ 3	508.173	18.261	839.665	32.00	815.37	31.00	862.134	83.1	______
G+ 5	627.295	46.832	1014.598	64.40	989.36	61.00	1016.236	119.1	_____
G+ 8	770.491	64.584	1495.211	269.00	1464.69	240.00	1577.297	173.1	1377.966
G+ 8 Soft Storey	754.002	59.119	1482.138	224.00	1429.65	187.00	1567.102	166.6	1401.414
G+ 10	825.853	87.759	1680.51	325.00	1637.58	274.00	1740.826	209.1	1513.022
G+ 10 Soft Storey	812.123	82.056	1670.387	263.00	1616.13	231.00	1710.806	202.0	1544.984

V. CONCLUSION

The performance of reinforced concrete frames was investigated using pushover analysis. These are the conclusions drawn from the analyses:

1. The pushover analysis is a relatively simple way to explore the non linear behavior of building, accurate and easiest method in comparison with the complete dynamic analysis.
2. The behavior of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the beams and columns. Most of the hinges developed in the beams and very few in the columns but with limited damages.
3. The results obtained in terms of demand, capacity and plastic hinges gave an insight into real behavior of structure mention in Plastic Hinges Pattern Figures.
4. The Result obtained from Base Shear by IS 1983 is in Elastic State & more conservative than Pushover analysis which is in plastic state.
5. The Performance point given by ATC-40 is more conservative as comparison with the FEMA 440 EL.
6. The Displacement obtained from FEMA 440 EL & ATC 40 are nearly double of Displacement obtain by IS-1893-2002. So IS-1893-2002 results are more Conservative.
7. The Displacement obtained for G + 8, G + 8 with Soft Storey & G + 10, G + 10 with Soft Storey due the soft storey performance point reduces so it represents that soft storey structure fails earlier than other regular storey.
8. The performance point displacement obtain from pushover analysis are exceeding the maximum lateral displaceme by IS-1893-2002.

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