Push Over Analysis with Vertical Irregularities for Medium Rise RCC Structure

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***Abstract* — The performance of a stuctural sytem can be evaluated resorting to non- linear static analysis. This involves the estimation of the structural strength capacities at desired performance level. This study aims at evaluating and comparing the response of five reinforced concrete building systems by the use of different methodologies namely the ones described by the ATC 40 and the FEMA 273 using nonlinear static procedures , with described acceptance criteria. Some results are also compared with the nonlinerar dynamic analysis. The methodologies are appllied to 3 storey frames sysytem with and without vertical irregularity, both designed as per the IS 456-2000 and IS 1893- 2002 (Part II) in the context of Performance Based Seismic Design procedures. Present study aims towards doing Nonlinear Static Pushover Analysis of G +3 medium rise RCC residential building frame which is to be designed by Convential Designe Methodology. However before exploring actual RCC residential building , a fundamental understanding of a Capacity Design Method has been obtained through the solution of G+3 RCC building by conventional method. A Nonlinear Static Anlysis (Pushover Anlysis) has been used to obatin the inelastic deformation capabilities of frame. It is found that irregularity in elevation of the building reduces the performance level of stucture and there is also decrease in deformation or displacement of the building.**

***Keywords*— Performance based design, Static Pushover Analysis, Lateral displacement, Storey shear, Base shear, Storey drift.**

I. INTRODUCTION

A. General

Over the past decades and more it has been recognized that damage control must become a more explicit design consideration which can be achieved only by introducing some kind of nonlinear analysis into the seismic design methodology. Following this pushover analysis has been developed during past decades and has become the preferred method of analysis for performance-based seismic design, (PBSD) and evaluation purposes. It is the method by which the ultimate strength and the limit state can be effectively investigated after yielding, which has been researched and applied in practice for earthquake engineering and seismic design. Nonlinear response history analysis is a possible method to calculate structural response under a strong seismic event. However, due to the large amount of data generated in such analysis, it is not considered practical and PBS Evaluation usually involves nonlinear static analysis, also known as pushover analysis. Moreover, the calculated inelastic dynamic response is quite sensitive to the characteristics of the input motions, thus the selection of a suitable representative acceleration time–histories is mandatory. This increases the computational effort significantly. The simplified approaches for the seismic evaluation of structures, which account for the inelastic behavior, generally use the results of static collapse analysis to define the inelastic performance of the structure. Currently, for this purpose, the nonlinear static procedures (NSP) or pushover analysis described in FEMA-273/356/440, ATC-40/55 documents are used. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Various simplified nonlinear analysis procedures and approximate methods to estimate maximum inelastic displacement demand of structures are proposed by researchers.

II. PUSHOVER ANALYSIS

Nonlinear Static (Pushover) Analysis is a procedure where a building model is subjected to increasing load in one direction. The Pushover Analysis consists of the application of gravity loads and a respective lateral load pattern until the building collapses or a specified displacement is reached. The frames are subjected to gravity analysis and simultaneous lateral loading. In all cases, lateral forces are applied monotonically in a step-by-step manner. The applied lateral forces are proportional to the product of mass and the first mode shape amplitude at each story level under consideration. Pushover analysis procedure explicitly addresses the nonlinear behaviour of the structure. Pushover analysis provides information about failure mechanism, failure modes, ductility demand, displacement capacity and stability of the structure. However Pushover Analysis gives a reasonably, accurate estimate for strength of the structural frame, assuming that its element do not fail due to secondary effect before the inelastic mechanism occurs. In more frequent cases of sequential yielding the estimates of displacements corresponding to the base shear near the formation of inelastic mechanism are not typically accurate. Nevertheless, in most cases the simple bilinear force displacement (moment-curvature) relationship represents an acceptable approximation considering all the uncertainties involved in seismic design.

This method is one of the simplest possible analytical tools for determining the main characteristics of non-linear structural behaviour under monotonically increasing static load. It is based on several simplified assumptions and does not pretend to be very accurate. Comprehensive nonlinear analysis will be more accurate but computationally very time consuming and not suitable for design purpose as compared to simple pushover analysis. Nevertheless this method can provide fair estimates of several parameters that cannot be predicted by elastic analysis and which represent a basis for the evaluation of structural behaviour during strong earthquakes. Three dimensional static analyses are performed in a step by step fashion in which the possibility of formation of inelastic hinges in a member is checked in each step. If no element reaches its inelastic moment capacity, then load applied is incremented and analysis is performed for new load case. Whenever, any element reaches its inelastic moment capacity, inelastic hinge is introduced in that element. Now, new analysis is performed on this structure with new earthquake load distribution, as earthquake load distribution will depend on the structural properties. Checking is done for inelastic moment capacity of other elements and plastic hinge is introduced when element reaches its inelastic moment capacity. Load required for formation of plastic hinge in elements are considered as the event. This procedure is repeated until inelastic mechanism is formed in the entire structure that leads to collapse of structure. The collapse load corresponds to the load required for final event to occur.

Pushover Analysis:

Response characteristics that can be obtained by Pushover Analysis include;

1. Estimates of the deformation demands on elements that have to deform inelastically, in order to dissipate energy.
2. Identification of the critical regions, where the inelastic deformations are expected to be high.
3. Consequences of strength deterioration of particular elements on the overall structural stability.
4. Identification of the strength irregularities in plan or elevation that causes changes in the dynamic characteristics in the inelastic range.
5. Estimates of inter-storey drifts, accounting for strength and stiffness discontinuities. In this way, damage on nonstructural elements can be controlled
6. Sequence of members yielding and failure and the progress of the overall capacity curve of the structure.
7. Verification of the adequacy of the load path, considering all the elements of the system, both structural and nonstructural.
8. To provide approximate evaluation of deformation demands in critical elements.
9. Expose undesirable strength and stiffness discontinuities in structure.
10. Expose potentially brittle elements
11. Expose regions of large deformation demands requiring proper detailing.
12. Assess stability of structural system

2. MODELING

2.1 GENERAL

The Pushover Analysis is defined as non-linear static approximation of the response that a structure will undergo when subjected to dynamic earthquake loading. Because we are approximating the complex dynamic loading characteristic of ground motion with a much simpler monotonically increasing static load, there are bound to be limitations to the procedure. The objective is to quantify these limitations. This will be reinforced concrete bare frames of three stories with and without vertical irregularities

2.1.1 Base Model (Model M01) :

This is the basic and the vertically irregular structure of the building having 6 bays in both the directions and three storeys above the ground storey, the dimension of the storey is as shown in the fig 01. The typical storey height and ground storey height is same i.e. 3.0m. The Bay width is 3.5 m. The detail basic specifications of the building are:

Table 1: Preliminary Assumed data for G+3 RCC Frame

Sr. No.	Content	Description
1	Type of structure	Multi-storey medium rise rigid jointed plane frame (RC moment resisting frame)
2	Seismic Zone	V
3	Zone factor	0.36
4	Number of Story	G+3
5	Floor height	3.00m
6	Base floor height	3.00m
7	Infill wall	230mm thick wall
8	Imposed load	3KN/m^2
9	Materials	Concrete (M25) and Reinforcement Fe415
10	Size of column	C_1=250 mm x 250 mm Outer column
		C2=280 mm x 280 mm Interior column for 1st Floor
		C3=280 mm x 280 mm Interior column for 2nd Floor
		C4=250 mm x 250 mm Interior column for 3rd Floor
		C5=280 mm x 250 mm All columns for soft story/G.F.
11	Size of Beam	B01=230mm x 280 mm Longitudinal direction
		B02=230mm x 280 mm Transverse direction
12	Depth of slab	150mm
13	Sp.Wt. of RCC	25 KN/m^3
14	Sp.Wt. of infill	20 KN/m^3
15	Type of soil	Medium soil

16	Response spectra	As per IS 1893 (part 1):2002 for 5% Damping
17	Importance factor	1

With respect to the above structural and seismic data for modeling the plan, elevation and 3-D view of the base model as shown below. All dimensions are in mm.

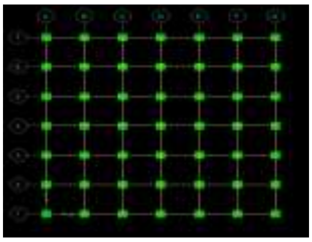


Fig 1: BASE PLAN

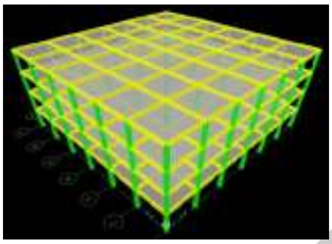


Fig 2: 3D view of Base Bare Frame Model (M-01)

2.3 Base Model with Geometric Irregularity (Model – M02 to M05)

The base model having the shape irregularity to know the effect of mass irregularity on the shape (vertical geometric) irregular building the geometry is changed by reducing the no. of bays in X- direction vertically downword, as per the IS 1893:2002 (part-1). The structural data is same. Depending on this change of structural configuration the elevation and 3 – D view of the model are as shown below

Table 2 – Percentage of vertical irregularity.

Sr.No	Designation	Type of Frame	Percentage of irregularity
1	Model 01	Regular	-
2	Model 02	Irregular	200%
3	Model 03	Irregular	300%
4	Model 04	Irregular	200%
5	Model 05	Irregular	300%

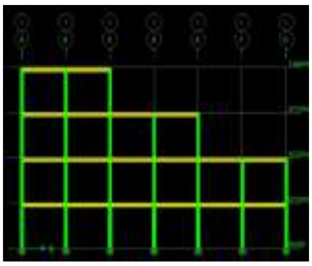


Fig 3: ELEVATION OF M02

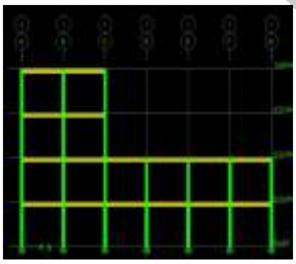


Fig 4: ELEVATION OF M03

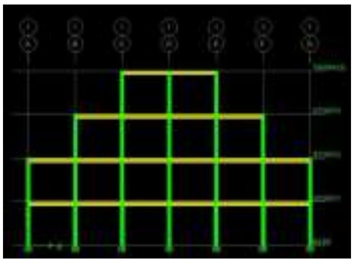


Fig 5: ELEVATION FOR MODEL M04

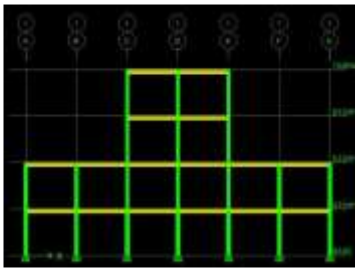


Fig 6: ELEVATION FOR MODEL M05

III. RESULTS AND DISCUSSION

Analysis of G 3+ storied bare frame model, with and without vertical irregularity is done using E-tabs. From the analysis results obtained, bare frame models with and without irregularities are compared. The comparison of these results to find effect of vertical irregularity is given below.

3.1 LINEAR ANALYSIS

3.1.1 LATERAL DISPLACEMENT

As the percentage of vertical irregularity changes the lateral displacement changes widely i.e. its reduces.

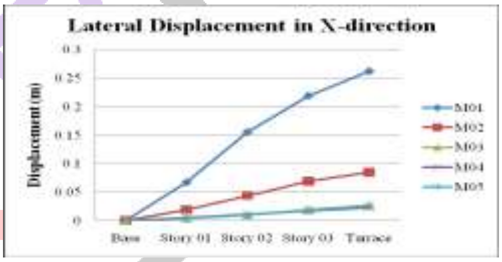


Fig 7: Lateral Displacement in X direction

The regular frame shows the displacement of 0.265m, but due to change in vertical irregularity it reduces to 0.08m for 200% irregularity and which goes down up to 0.02m for 300% reduction in vertical geometry.

3.1.2 Inter Storey Drift

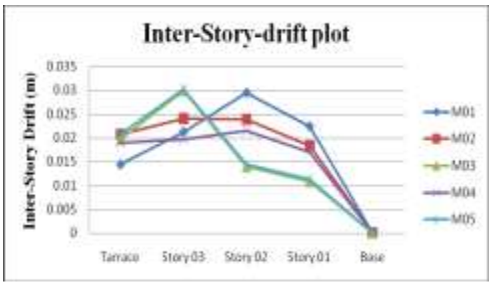
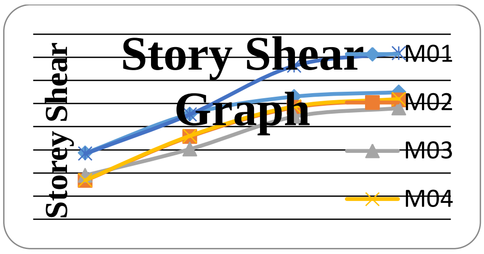


Fig. 8: Lateral Displacement in X direction

The change in percentage of vertical irregularity causes change in storey drift, as the percentage increases with reduction in storey drift.

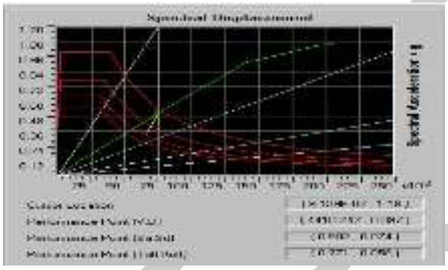
3.1.3 Storey Shear:



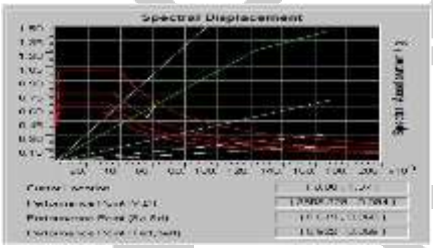
Fig, 9: Storey Shear Graph

The change in percentage of vertical irregularity also cause in storey as the percentage increases with reduced in storey drift i.e. as shown in Fig. 9. The regular frame shows the storey shear of 1097.85kN at base, but due to change in vertical irregularity it reduces to 1030kN for 200% irregularity and which goes down up to 960kN for 300% reduction in vertical geometry.

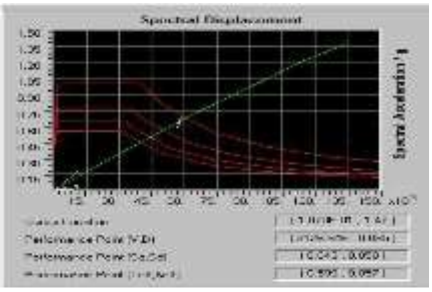
3.2 Push over results



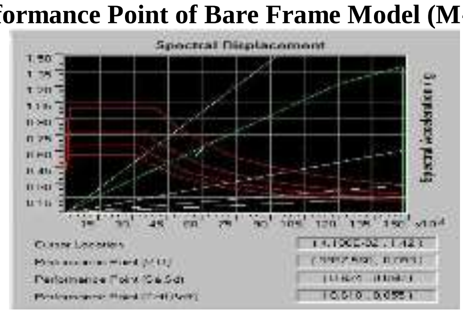
a) Performance Point of Bare Frame Model (M-01)



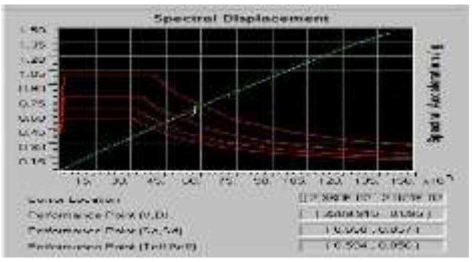
b) Performance Point of Bare Frame Model (M-02)



c) Performance Point of Bare Frame Model (M-03)



d) Performance Point of Bare Frame Model (M-04)



e) **Performance Point of Bare Frame Model (M-05)**

Fig. 10: Demand Spectrum curves showing Performance point for different Models

Table 3- Push over Result

Frame Type	**G +3 Storey**	**G +3 Storey**
	Performance point X (kN)	Displacement X (m)
Bare frame (6×6)(M-01)	4410.242	0.097
Bare frame (6×6)(M-02)	3859.229	0.094
Bare frame (6×6)(M-03)	3126.646	0.095
Bare frame (6×6)(M-04)	3937.560	0.093
Bare frame (6×6)(M-05)	3209.915	0.095

From the results for G +3 storeys, bare frame without vertical irregularity have more lateral load capacity (Performance point value) as compared to bare frames with vertical irregularity.

It can also be concluded that as the no of bays reduces vertically the lateral load carrying capacity increases with reduction in lateral displacement.

IV. CONCLUSIONS

G +3 bare frame model and G +3 bare frame with vertical irregularity Models are analysed using Standard Software, and the following conclusions are drawn based on the present study.

1. Bare frame without vertical irregularity has more lateral load capacity (Performance point value) compared to bare frames with vertical irregularity. (i.e. the vertical irregularity reduces the flexure and shear demands)
2. The lateral displacement of the building is reduced as the percentage of irregularity increases.
3. As the percentage of vertical irregularity increases, the storey drift reduces and goes on within permissible limit as clause no 7.11.1 of IS 1893-20002 (Part I)
4. There is no effect of geometric irregularity on storey shear, but there is 2 to 5 % differences in lateral displacement.

5. As the no of bays reduces vertically the lateral load carrying capacity increases with reduction with reduction in lateral displacement.

From above discussion, the seismic performance of irregular building is reduced by 11 to 12.5 % for 200% vertical irregularity and 28 to 30 % for 300% vertical irregularity as compared to symmetric base.

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