Non-Linear Static Analysis of RCC Framed Structures with and Without Infill Walls

Khonaboina Sandeep Kumar, J.S.R. Prasad, Venu Malagavelli

Abstract: The concept of an earthquake is becoming an exceptional study in our use because no longer a particular area can be targeted as an earthquake-resistant area. So, the main motif of any structural engineer during the design is to design a structure that could cope with seismic pressure successfully. On this note, non-linear static pushover analysis has become a prominent tool for the structural design and evaluation of RC elements. In this project G + 5, G + 9, G + 5 with infill walls and G + 9 with infill walls RCC framed structures have been analyzed by the use of SAP 2000 v19. The structures are designed as in keeping with IS 1893(Part 1): 2002 for earthquake forces in seismic zone IV. The use of the equivalent strut approach for modeling the infill walls is adopted and strut is designed in accordance with FEMA-356. Non-linear Static pushover analysis is performed on the designed RCC framed structures with and without infill walls. And pushover results are used to evaluate structural performance under design earthquake load, and code requirements are discussed.

Keywords: Structural Elements, Pushover Analysis, Infill Walls and Failure Mechanism.

I. INTRODUCTION

Earthquake is the main cause for the ground motion in random fashion in both horizontally and also in vertically, which starts its origin at the epicentre. Generally structures present on the ground they start vibrating when they are subjected to earthquake by inducing inertial forces on them. There are some high seismic areas where structures located at that will face severe damages. In addition to the gravity load these structures should also capable of resisting lateral loads which develops a high stresses in the members. The main reason to use the Infill wall in the structures because the material is locally available in bulk and also it can be handled easily, also it has good heat insulating properties which makes it greater comfort for the occupants of the building. Pushover analysis, or also known as Nonlinear static analysis, was been urbanized above the past twenty five years and now it turn out the most successful analysis method for design and seismic performance examination purposes as this method is comparatively easy and follows post-elastic behavior. However, this method requires certain simplifications and is not accurate, because it is always expected that there will be some difference in seismic demand projected from the pushover analysis. However, pushover analysis also shows how to capture important structural response properties of the building exposed to seismic action, quality of pushover analysis in assessing overall structure and the accuracy, local seismic demands for all type of buildings that have remained a subject of controversy and advanced non-linear static methods have been developed to conquer some confines of old-style pushover procedures. Here walls with only masonry brick work are termed as walls without infill and walls with compressive struts placed diagonally in a frame are termed as infill walls. An infill wall is an economical and effective method to increase strength and reduce drift of existing frames. Strengthening of existing and also new reinforced concrete (RC) moment resisting frames often include the addition of Infill walls. But a relatively strong masonry infill brick walls will result in a failure of the columns of existing frame. With appropriate selection of the infill masonry strength along with the anticipation of its premature separation from the columns, a more appropriate failure mode can be achieved. But with proper anchorage, it may be possible to have a force failure in the masonry and avoid a premature shear/flexure column failure. With the help of the non-linear static technique in the use of structural analysis and layout program (SAP2000 v19) software by considering Indian Standard code 1893(2002), this assignment offers seismic evaluation of RC constructing buildings.

1. The superiority of Pushover analysis over elastic procedures in assessing the seismic characteristics of a structure is more advantageous
2. Linear analysis of the considered structures is carried out using SAP 2000 software. The general loads are considered for the building.
3. Then, pushover analysis is performed on the building using the SAP 2000 software.
4. The results of the non-linear static analysis are used to evaluate the design performance under the design earthquake load, and the code requirements are discussed.

II. METHODOLOGY

A. General

For the analysis of frame structures susceptible to earthquakes, we have various methods of structural analysis, which are generally divided into:

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- Gravity Analysis
- Equivalent Static analysis (Linear Static Method)
- Response Spectrum and Time History analysis (Linear Dynamic method)
- Pushover Analysis (Non-Linear Static Method).
- Non-linear Time History Analysis (Non-Linear Dynamic Method)

Of these methods, gravity analysis and Pushover analysis are considered for analysis of G + 5, G + 9, G + 5 with infill walls and G + 9 with infill walls of Structure.

B. Pushover Analysis

Pushover analysis is the type of analysis in which a model undergoes monotonically increasing horizontal forces with an increase in height-wise distribution until the target deformation is achieved. To analyze the seismic characteristics of existing structures according to the basic guidelines and standards for rehabilitation, an intermediate analysis method will be adopted, since it is conceptual and the calculations are simple. This type of rough analysis consists of a series of sequential elastic analysis, which is superimposed to approximate a force-displacement curve of entire structure. This helps to complete the yielding stages, as well as failure modes at each member and structural levels, and also the growth of the overall global capacity curve for a given structure.

III. MODELLING OF G + 5, G + 9, G + 5 WITH INFILL WALLS AND G + 9 WITH INFILL WALLS OF RCC BUILDINGS

A. Plan of RC Frame

Plan of RC Frame is exactly same for every model in this project.

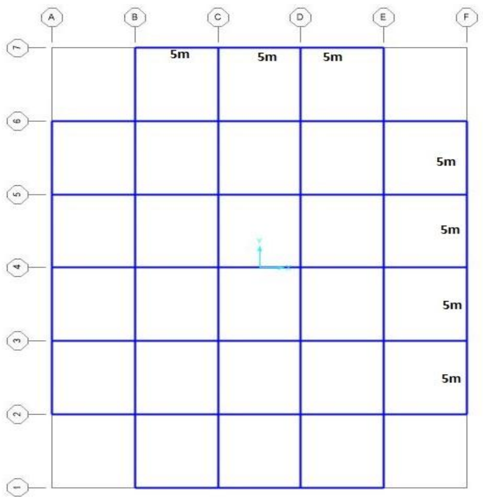

Fig.1. Plan

B. Design Considerations

To carry out the analysis the following considerations are made.

- There are no slabs on ground floor, and the floor will lie directly on the ground.
- Seismic loads will not be acting along the vertical direction, as this is not considered significant. As seismic loads will be considered horizontally (along any of two main directions)
- The floor diaphragms are assumed to be rigid.

C. Material Properties

The following table shows the material properties considered in this work.

Table-I: Material Properties

Name of the property	Specification
Grade of concrete	M 25 (fck = 25 MPa)
Modulus of Elasticity	5000√fck = 25000 MPa
Grade of Steel	(fy = 500MPa)
Density of concrete	25kN/m3

D. Load Calculation

In this project, G + 5, G + 9, G + 5 with infill walls and G + 9 with infill walls building in Zone 4 is taken into consideration and load calculation is done according to the IS code. In SAP2000 we do not need to calculate the self-weight of the structural elements. This automatically includes the self -weight of the structural elements in the analysis based on existing specific weights, data depending on the type of material.

For the sake of simplicity all the Column sizes are assumed to be same as 230mm x 450mm and all floor Beams for G + 9 and G + 5 with and without infill walls are as 230mm x 495mm and 230mm x 420mm respectively as shown in below table.

Table-II: Structural Elements

Model	Element Sizes of Buildings (mm)	
	Beams	*Columns*
G + 5 RCC structure	230 x 420	230 x 450
G + 9 RCC structure	230 x 495	230 x 450
G + 5 RCC structure (infill)	230 x 420	230 x 450
G + 9 RCC structure (infill)	230 x 495	230 x 450

E. Design Data

Table-III: Structure Details

Structure details		
No.of Storeys with infill walls	5, 9	
No.of Storeys without infill walls	5, 9	
Dimension in X Direction	25	m
Dimension in Y Direction	30	m
Storey Height	3	m
Live Load (Typical)	2	KN/sq.m
Type of soil	Medium (Type II)	
Zone	IV	
Z: Zone Factor	0.24	
I: Importance Factor	1.0	
Slab Thickness	125	mm
Wall Thickness external	230	mm
Wall Thickness internal	150	mm
Wall Load External (2.7 m Height)	12.42	KN/m
Wall Load internal (2.7 m Height)	8.1	KN/m

IV. GENERAL DESCRIPTION OF STRUCTURE

All the models in this project were designed in accordance with the design considerations and general descriptions which were clearly mentioned in the above and below tabular columns. Initially the structure is designed for Gravity loads and then Pushover analysis is carried out under Pushover load in PUSH-X direction. Hinges assigned for Beams and Columns as per FEMA 356. After assigning all the load cases we perform the analysis to get the Pushover curve for each and every model in this project.

A. Stiffness of Infill Walls (FEMA-356)

The elastic stiffness in the plane of the continuous non RC masonry panel before cracking should be symbolized by the equivalent width of the diagonal compression strut, indicated by "a". Elastic modulus and thickness of equivalent strut need to be same as infill panel.

$$a = 0.175\,(\lambda_1 h_{col})^{-0.4} r_{inf}$$

Where,

$$\lambda_1 = \left[\frac{E_{me} t_{inf} \sin 2\Theta}{4 E_{fe} I_{col} h_{inf}}\right]^{\frac{1}{4}}$$

Table-IV: Strut Details

Details of Strut	
Name	Strut
Material type	Masonry
Density of Material	19KN/m3
Depth of the strut	230mm
Width of the strut (a)	1350mm
Assign moment releases at	M22 & M33

Fig. 1 shows concentrically placed compression struts along the diagonals of the frame. These struts provide infill stiffness to solid infill panels. Although loads acted upon columns by the infill are not shown in this arrangement. To overcome this, we may place the struts eccentrically inside the frames as shown in Fig. 2. Results yielded by this type of analytical model should display the infill effect acting directly on columns.

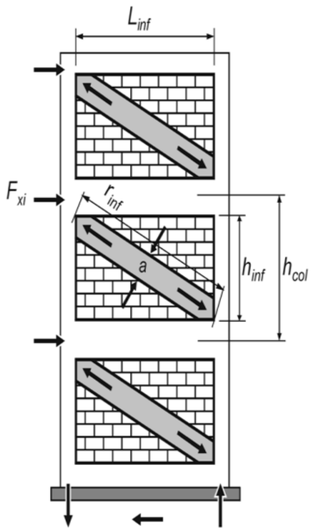

Fig.2. Concentric struts

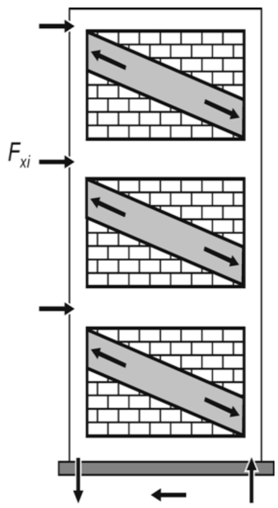

Fig.3. Eccentric struts

V. RESULTS AND DISCUSSIONS

Total 7 steps were performed in SAP 2000 software, and for all the corresponding steps the Base force applied is given in KN and corresponding Displacement is given in m. Where all A to B, B to IO, IO to LS, CP to C, C to D and D to E represents the structural components acceptance criteria as mentioned in ATC -40.

A. An Isometric View of G + 5 Structure without Strut and its Hinge Formation for Base Shear is given below.

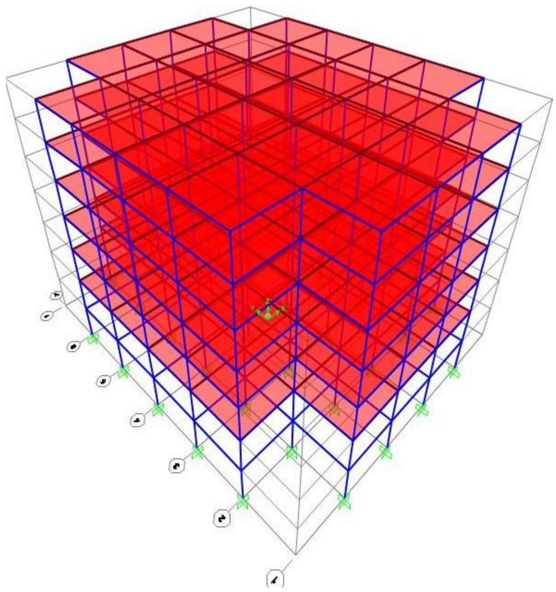

Fig.4. G + 5 Structure without strut

- Load Resisting Mechanism for a typical frame of Building G + 5 for Bare frame is shown in below Fig.5.
- Hinge formation for base shear is at 2758 KN.
- Hinges are spread over the elevation of the frame

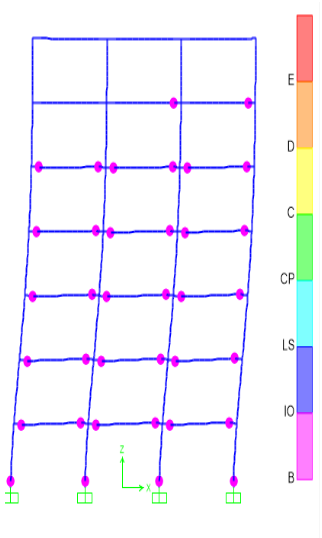

Fig.5. Hinge formation due to base shear

B. An Isometric view of G + 5 Structure with Strut and its Hinge Formation for Base Shear is given below.

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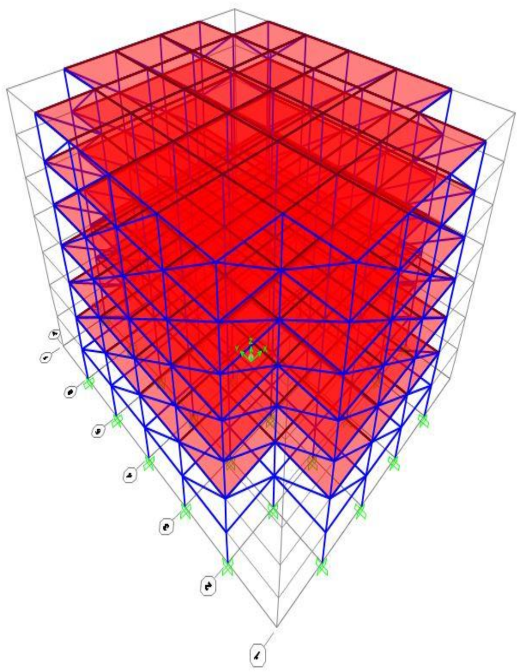

Fig.6. G + 5 Structure with strut

- Load Resisting Mechanism for a typical frame of Building with Infill panels is shown in below Fig.7.
- Hinge formation for base shear at 5231 KN.
- Hinge formation is concentrated in the plinth and ground levels.

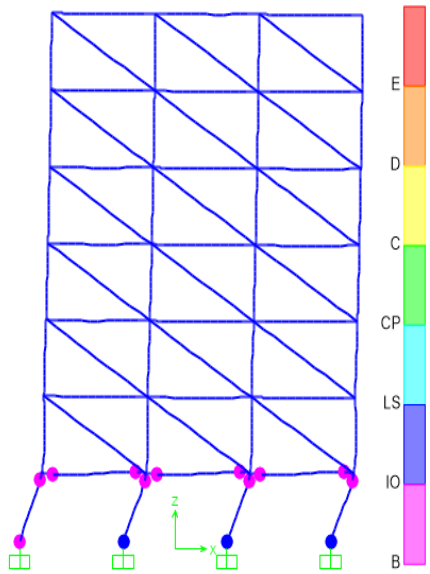

Fig.7. Hinge formation due to base shear

C. Pushover Curve for both Buildings G + 5 with and without Strut in PUSH-X Direction

- When Infill wall is considered roof displacements are very less for the joint and for bare frame roof displacements are seen to be relatively higher values.
- This is due to Increase in stiffness with the presence of Infill and bare frame structure is less stiff.
- It is also seen that bending moment in the ground floor columns are enhanced by almost cent percent when the soft storey effect is considered.

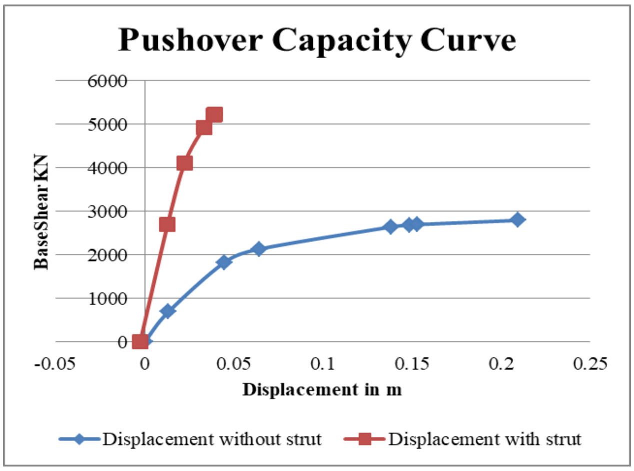

Fig.8. Base shear v/s Roof displacement curve for Buildings in X direction.

D. An Isometric view of G + 9 Structure without Strut and its Hinge Formation for Base Shear is given below.

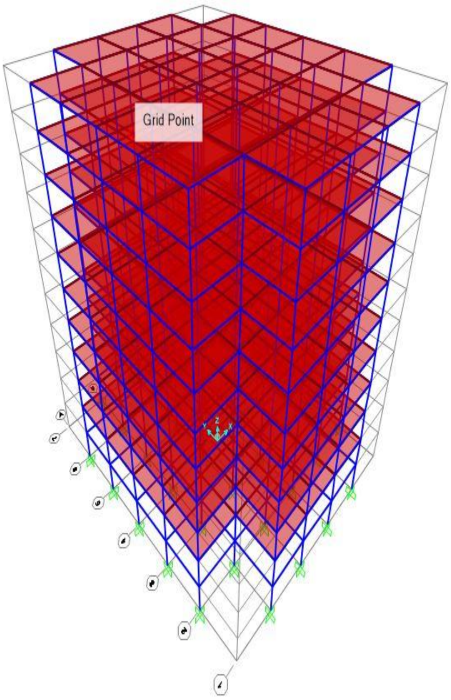

Fig.9. G + 9 Structure without strut

- Load Resisting Mechanism for a typical frame of Building for Bare frame as shown in below Fig.10.
- Hinge formation for base shear at 2545 KN
- Hinges are spread over the elevation of the frame

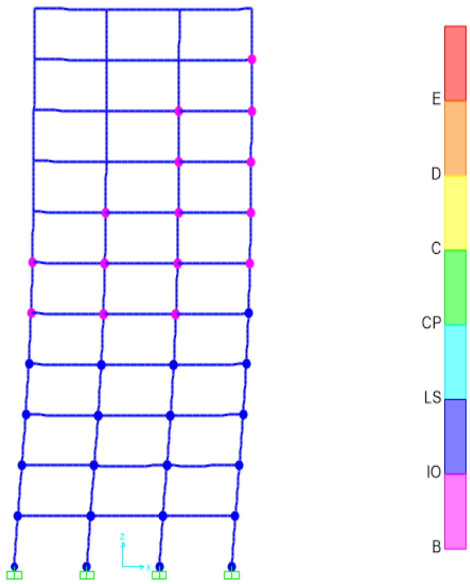

Fig.10. Hinge formation due to base shear

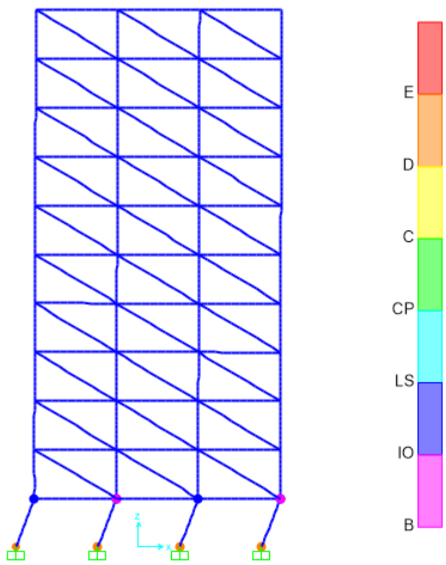

Fig.12. Hinge formation due to base shear

E. An Isometric view of G + 9 Structure with Strut and its Hinge Formation for Base Shear is given below.

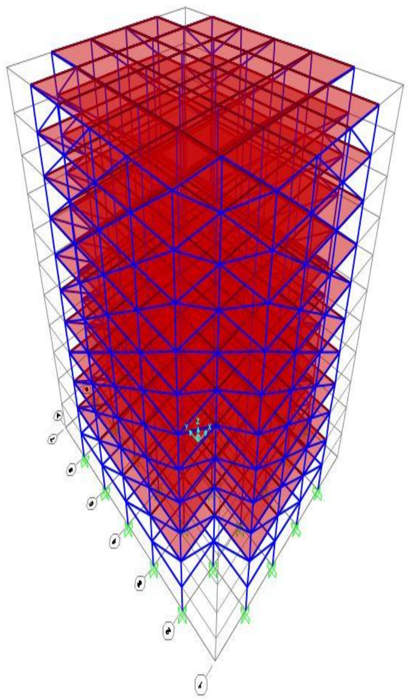

Fig.11. G + 9 Structure with strut

- Load Resisting Mechanism for a typical frame of Building with Infill panels as shown in below Fig.12.
- Hinge formation for base shear at 3617 KN.
- Hinge formation is concentrated in the plinth and ground levels.

F. Pushover curve for both Buildings G + 9 with and without strut in PUSH-X direction

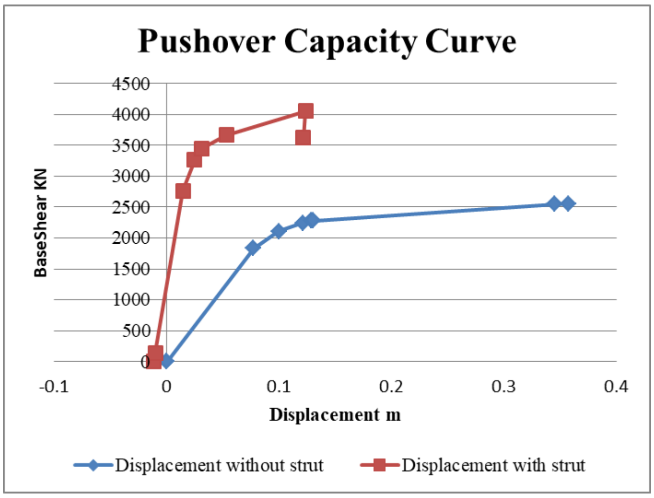

Fig.13. Base shear v/s Roof displacement curve for Buildings in X direction.

Fig.8 and 13 shows the base shear v/s roof displacement curves for the Buildings with and without strut in Push-X direction is obtained from pushover analyses. These curves show that consideration of infill stiffness gives more base shear capacity along X direction; It also increases the ductility by an amount of 47% of same direction.

The above figures 5, 7, 10 &12 describes the failure mechanism at a typical frame of Buildings. When the infill stiffness is considered for both heights i.e., Fig.7 & 12, it shows that the hinge formation is concentrated in the plinth and ground levels. Whereas when the infill stiffness is neglected i.e., Fig.5 & 10, it shows better performance as the hinges are spread over the elevation of the frame.

It is also seen that bending moment in the ground floor columns are enhanced by almost 100 percent when the soft storey effect is considered, indicating that the existing buildings are vulnerable.

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VI. CONCLUSIONS

The existence of masonry infill panels significantly changes the distribution of structural forces. The total shear strength of the floor increases considerably with increasing stiffness of the building in the presence of masonry infill. In addition, bending moments in the columns of the ground floor increase, and the destruction mode is the mechanism of the soft storey (the formation of hinges in the columns of ground floor).

1. The mechanism of masonry infill frame for resisting the lateral load is unlike bare frame. Initially at the joints, during lateral force, bare frame behaves like a rigid frame by the development of plastic hinges. On other side, the infill frame acts like a braced frame counterattacked by a truss mechanism made by tension in the column and by the compression in the masonry infill panel. The plastic hinges are enclosed with the joint in contact with the infill panel. It's clear that buildings with open ground storey are underprovided. So, Retrofit is needed.
2. There are no major differences in hinge formation found from G + 5 to G + 9. This accounts no limitation on building heights.
3. For a model with Infill wall the displacement at top floor is less than that of a bare frame with same height.

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