NONLINEAR STATIC ANALYSIS OF G+6 RC BUILDING WITH INFILL WALLS AND USER DEFINED HINGES

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Abstract – *The reinforced concrete (RC) frame structures with infill walls are commonly constructed in multi-storeyed buildings. Window and door openings are inevitable part of the infill walls. The presence of openings in infill walls considerably reduces the lateral strength and stiffness of RC frames. In the present study three-dimensional seven storeyed RC building models are considered with ten percentage of central opening. Bare frame and infill frame buildings are modelled considering special moment resisting frame (SMRF) for medium soil profile and zone III. Unreinforced brick masonry infill and concrete block infill walls are modelled as pin-jointed single equivalent diagonal strut. Pushover analysis is carried out for user defined hinge properties as per FEMA 440 guidelines using SAP2000v14.2.0 software. The results of ductility ratio, safety ratio, global stiffness and hinge status are compared amongst the models.*

Key words: User defined hinges, Pushover analysis, Performance levels, Ductility ratio, Safety ratio, Global stiffness.

1. INTRODUCTION

In India large numbers of buildings are constructed with brick/or concrete block infill walls. These infill walls significantly increase the stiffness and strength of the infilled frame [1]. In the current practice, masonry infill panels are treated as non-structural element during the design of the structure and their strength and stiffness contributions are ignored [2]. The RC frame action behaviour with masonry infill walls illustrates the truss action, where the infill wall behaves as the diagonal strut and absorbs the lateral load under compression [3]. Several buildings constructed in India and across the world have the ground storey frames without infill walls leading to soft open ground storey. Thus, upper floors move almost together as a single block and most of the lateral displacement of the buildings occurs in the open ground storey to earthquake excitation. Door and window openings are unavoidable parts of any structure. However, the presence of openings in infill walls reduces the stiffness and strength of the RC frame [1]. Indian seismic code recommends no provision regarding the stiffness and openings in the masonry infill wall.

2. DESCRIPTION OF THE BUILDING MODELS

In the present study three-dimensional seven storeyed RC frame buildings are considered. The plan and 3-d view of the building models are shown in Fig. 1, and Fig. 2. The bottom storey height is 4.2 m, upper storey height is 3.6 m, and bay width in both longitudinal and lateral direction is considered as 5 m. The building is assumed to be located in zone III. M25 grade of concrete and Fe415 grade of steel are considered. The stress-strain relationship is used as per IS 456:2000 [6]. The concrete block infill walls are modelled as pin-jointed equivalent diagonal struts. M3 (*Moment*), V3 (*Shear*), PM3 (*axial force with moment*), and P (*Axial force*) user defined hinge properties are assigned at rigid ends of beam, column, and strut elements. The density and Young's modulus of concrete block is 25 kN/m3 and 2500 MPa. Poison's ratio of concrete is 0.3. Ten percentage of central openings are considered and three analytical models are developed as mentioned below,

Model 1 - Building has no walls and the building is modelled as bare frame, however masses of the walls are considered. Building has no walls in the first storey and unreinforced masonry infill walls in the upper storeys, with central opening, however stiffness and masses of the walls are considered.

Model 2- Building has no walls in the first storey and one full unreinforced masonry infill wall in the upper storeys, with central opening of ten of the total area of infill. Stiffness and masses of the walls are considered.

Model 3 - Building has no walls in the first storey and one full concrete infill wall in the upper storeys, with central opening of ten of the total area of infill. Stiffness and masses of the walls are considered.
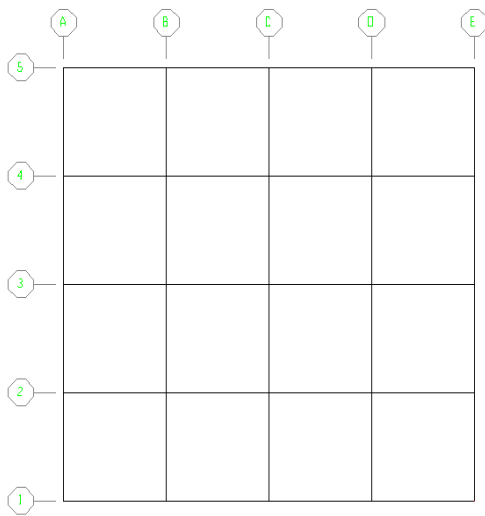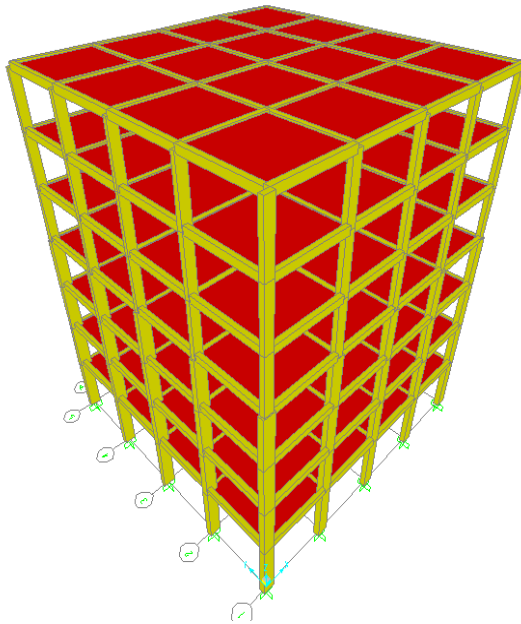
Fig.1: Plan of the Building

Fig.2: 3-D view of G+6 building model

3. METHODOLOGY

3.1 User Defined Hinges

The definition of user-defined hinge properties requires moment–curvature analysis of beam and column elements. Similarly load deformation curve is used for strut element. For the problem defined, building deformation is assumed to take place only due to moment under the action of laterally applied earthquake loads. Thus user-defined M3 and V3 hinges for beams, PM3 hinges for columns and P hinges for struts are assigned. The calculated moment-curvature values for

beam (M3 and V3), column (PM3), and load deformation curve values for strut (P) are substituted instead of default hinge values in SAP2000v14.2.0.

3.1.1 Moment curvature for beam section

Following procedure is adopted for the determination of moment–curvature relationship considering unconfined concrete model given stress-strain block as per IS 456:2000.
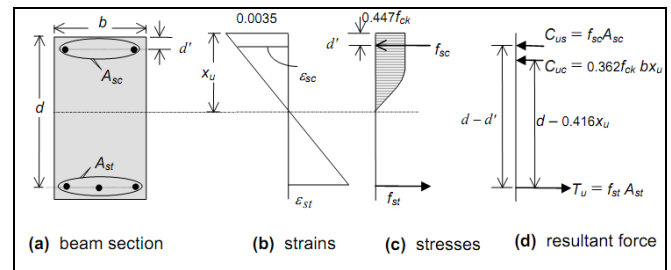

Fig.3 Stress-Strain block for beam [9]

1. Calculate the neutral axis depth by equating compressive and tensile forces.

2. Calculate the maximum neutral axis depth $x_{u\,max}$ from equation 1.

$$\frac{0.0035}{x_u} = \frac{\left(\dfrac{f_y}{E_s} + 0.002\right)}{(d - x_u)} \quad \text{……………… (1)}$$

3. Divide the x_{umax} in to equal laminae.

4. For each value of x_u get the strain in fibers.

5. Calculate the compressive force in fibers corresponding to neutral axis depth.

6. Then calculate the moment from compressive force and lever arm (C×Z).

7. Now calculate the curvature from equation 2.

$$(\phi) = \frac{\varepsilon_s}{d - x_u} \quad \text{……………………… (2)}$$

8. Plot moment curvature curve. The curve is shown in Fig.4.

Assumption made in obtaining Moment Curvature Curve for beam and column

[1] The strain is linear across the depth of the section ('Plane sections remain plane').

[2] The tensile strength of the concrete is ignored.

[3] The concrete spalls off at a strain of 0.0035.

[4] The point 'D' is usually limited to 20% of the yield strength, and ultimate curvature,θ_u with that.

[5] The point 'E' defines the maximum deformation capacity and is taken as $15\theta_y$ whichever is greater.

[6] The ultimate strain in the concrete for the column is calculated as 0.0035-0.75 times the strain at the least compressed edge (IS 456 : 2000) [6].
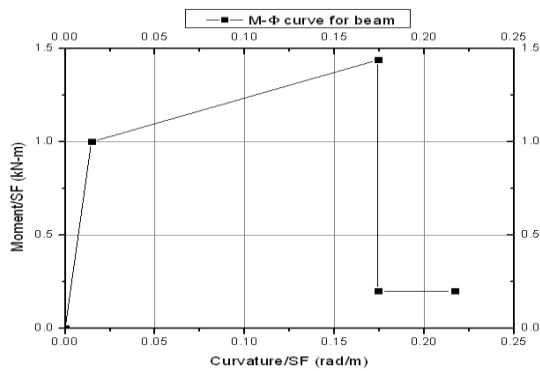

Fig. 4 Moment curvature curve for beam

3.1.2 Moment curvature for column section

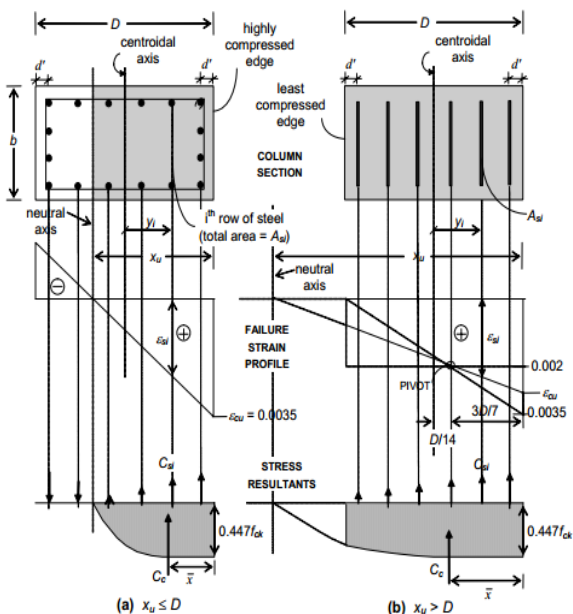Following procedure is adopted for the determination of moment-curvature relationship for column.

Fig.5 Analysis of design strength of a rectangular section under compression

1.0 Calculate the maximum neutral axis depth xumax from equation 3.

$$\frac{0.0035}{x_u} = \frac{\left(\dfrac{f_y}{E_s} + 0.002 \right)}{(d - x_u)}$$ ……………(3)

2. NA depth is calculated by assuming the neutral axis lies within the section.

3. The value of xu is varied until the value of load (P) tends to zero. At P = 0 kN the value of xu obtained is the initial depth of NA.

4. Similarly, NA depth is varied until the value of moment tends to zero. At M = 0 kN-m the value of xu obtained will be the final depth of NA.

5. For the different values of xu, the strain in concrete is calculated by using the similar triangle rule.

6. The curvature values are calculated using equation 4
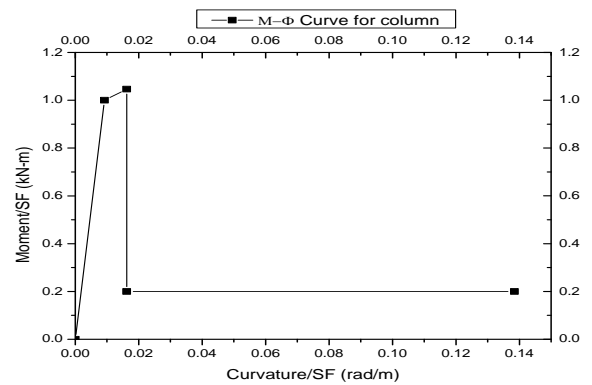
7. Plot the moment curvature curve as shown in Fig 6.

Fig.6 Moment-curvature for column section

3.2 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. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve for that structure. Pushover analysis as per FEMA 440 [11] guide lines is adopted.

The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. 4% of height of building [10] as maximum displacement is taken at roof level and the same is defined in to several steps. The global response of structure at each displacement level is obtained in terms of the base shear, which is presented by pushover curve. Pushover curve is a base shear versus roof displacement curve. The peak of this curve represents the maximum base shear, i.e. maximum load carrying capacity of the structure; the initial stiffness of the structure is obtained from the tangent at pushover curve at the load level of 10% [12] that of the ultimate load and the maximum roof displacement of the structure is taken that deflection beyond which the collapse of structure takes place.

4. Results and Discussions

4.1 Performance Evaluation of Building Models

Performance based seismic evaluation of all the models is carried out by nonlinear static pushover analysis. User defined hinges are assigned for the seismic designed building models along the both longitudinal and lateral direction.

4.1.1 Location of hinges

The location of hinges for user defined hinges and performance levels along both longitudinal and lateral direction for building models are presented in Table 1

Table: 1 Location of hinges of building models

Model No	Displacement		Base force(kN)	Location of hinges					
				AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	Total
1	Yield	20.65	1741.38	1470	0	0	0	0	1470
	Ultimate	103.22	6956.46	1293	177	0	6	0	1470
2	Yield	8.72	1681.36	1704	6	0	0	0	1710
	Ultimate	101.61	14465.08	1524	153	26	7	0	1710
3	Yield	7.60	5999.84	1704	6	0	0	0	1710
	Ultimate	103.96	25532.45	1635	52	8	15	0	1710

For building models, the base force is found more in infill frame building compare to bare frame building by 51.90% at the ultimate state for brick masonry and 72.75% for concrete block infill. In bare frame building model hinges are formed 87.96%, 1.20%, 0%, 0.41% and 0% between A to B, B to IO, IO to LS, and LS to CP and CP to C respectively and most of the hinges are formed in the beams and columns of open ground storey in both X and Y direction at ultimate state. 89.12%, 8.95%, 1.52%, 0.41%, 0%, and 95.61%, 3.04%, 0.47%, 0.08%, 0% between A to B, B to IO, IO to LS, LS to CP and CP to C respectively for brick infill wall and concrete block infill

wall respectively and most of the hinges are formed within the collapse prevention in the beams and columns of open ground storey in both X and Y direction at ultimate state.

4.20 Ductility Ratio

The ratio of collapse yield (CY) to the initial yield (IY) is called as ductility ratio [13]. Ductility ratio (DR) for building models are tabulated in the Table 2.

Table: 2 Ductility ratios of building models

Model No	Initial yield	Collapse yield	Ductility ratio
1	20.65	103.22	5.00
2	8.72	101.61	11.65
3	7.60	103.96	13.68

For building models, reduced ductility ratio are found in bare frame building compare to brick infill frame building by 57.08% and 63.45% for solid concrete block infill.

4.30 Safety Ratio

The ratio of base force to base shear by ESM is defined as safety ratio (SR). The buildings are safe when SR is equal to one, safer when SR is more than one, and unsafe when SR is less than one [14].

Table: 3 Safety ratios of building models

Model No	Base force (kN)	Base shear (kN)	Scale factor
1	1648.646	1257.086	1.31
2	3278.025	2168.894	1.51
3	4390.988	2153.457	2.04

In building models, for brick masonry infill model is found to be 1.15 times safer and for solid concrete block infill 1.55 times safer compared to the bare frame building model.

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure.

4.4 Global stiffness

The ratio of performance base force and performance displacement is known as global stiffness of the structure. The global stiffness of buildings is computed to study the deformations in the building models. The global stiffness of building models tabulated in Table 4.

Table: 4 Global stiffness of building models

Model no	Performance base force(kN)	Performance displacement(mm)	Scale factor
1	1648.646	19.56	84.29
2	3278.025	14.847	220.79
3	4390.988	6.282	698.98

For building models, the global stiffness increases 2.72 times for brick masonry infill and 8.29 times for the solid concrete block infill compared to bare frame building. The results reveal that, the presence of infill walls in building models contributes to the increase in global stiffness.

5. Conclusions

Based on the results obtained for the building models, the following conclusions are drawn,

1. RC framed multi-storeyed buildings must be designed considering methods mentioned in earthquake codes to reduce vulnerability to earthquake shaking.

2. Flexural hinges are found within the life safety range at the displacement controlled and plastic hinges formation takes place in beams and columns of open ground storey of building model.

3. Ductility ratio for brick masonry infill and for solid concrete block infill are more than the target value equal to 5 and the solid concrete block buildings are more ductile as compare to the brick infill buildings.

4. The models considered in this paper are safer and ductile.

5. RC multi storeyed buildings designed considering earthquake load prescribed in earthquake codes are stiffer to sustain earthquakes.

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