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PUSHOVER ANALYSIS OF G+9 STOREYED RC BUILDINGS WITH INFILL WALLS AND USER DEFINED HINGES

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ABSTRACT

Presence of unreinforced masonry infill walls in the multi-storeyed RC buildings is advantageous for resisting the lateral forces to earthquake shaking.Openings in infill walls for windows and doors are unavoidable for functional or architectural reasons, thereby reduces the lateral force resistance of buildings. The present paper investigates the 3-D RC multi-storeyed building models with ten percentages of central openings in infill walls. The building models are considered as bare frame and 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. Pushover analysis performed using SAP2000v14.2.0. The results of ductility ratio, safety ratio, and hinge status are compared amongst the models.

Keywords: Ductility Ratio, Performance Levels, Pushover Analysis, Safety Ratio, User Defined Hinges

I. INTRODUCTION

Earthquake is a natural phenomenon can occur on land or sea, at any place on the surface of the earth where there is a major fault, which causes the random ground motions in all directions, radiating from epicentre. These ground motions make structure to vibrate and induces inertia forces in them [1]. In India majority of the existing reinforced concrete (RC) structures in this seismic region do not meet the current seismic code requirements such as stability, strength and serviceability with acceptable levels of safety under seismic effect. These are primarily designed for gravity loads only. However they can resist certain amount of lateral forces due to earthquake of small magnitude, due to the effects of stiffness of the masonry infill walls [2].

Reinforced concrete (RC) frame structures are built with brick masonry and/or concrete block as infill walls in all over the world. These infill walls significantly enhance the stiffness and strength of the infilled frame [3]. Generally infill walls are considered as non-structural elements during design. 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. Several buildings constructed in urban India and across the world have the ground storey frames without infill walls leading to soft open ground storey. Thus, upper storeys move almost together as a single block and most of the lateral displacement of the building occurs in the open ground storey due to earthquake excitation.

Door and window openings are inevitable parts of building frame structure. However, the presence of openings in infill walls affects the lateral stiffness of the frames considerably and hence needs investigation . Reduction of the lateral strength of the structure due to the presence of the openings in the infill walls depends upon the various factors such as percentage of opening, aspect ratio, and the location of the opening in the masonry wall. In Indian seismic code IS 1893 (Part 1):2002[4]. There is no provision regarding the stiffness and openings in the masonry infill wall. Whereas clause 7.10.2.2 and 7.10.2.3 of the "Proposed draft provision and commentary on Indian seismic code IS 1893 (Part 1): 2002" [4].Defines the provision for calculation of stiffness of the masonry infill and a reduction factor for the opening in infill walls [5].

II. BUILDING DESCRIPTION

In the present paper 3-D ten storeyed RC frame building models are considered. The plan and 3-D view of the building models are shown in Fig 1and Fig 2. The bottom storey height is 4.2 m, upper floors 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 as per IS 1893(Part-1)-2002[4]. 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 of concrete block is 25kN/m3. Young's modulus of concrete block is 25000 MPa. Poisson's ratio of concrete is0.25. Similarly for brick masonry infill density is 20 kN/m3 young's modulus of brick masonry infill 1067Mpa [7].Poisson's ratio of brick masonry infill is 0.18[7].10% of central openings are considered and three analytical models developed are,

Model 1- Building has no walls and modelled as bare frame, however masses of the walls are considered. Building has no walls in the first storey and walls in the upper floors and modelled as soft storey with 10% central opening of the total area, 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 10% 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 10% of the total area of infill. Stiffness and masses of the walls are considered.

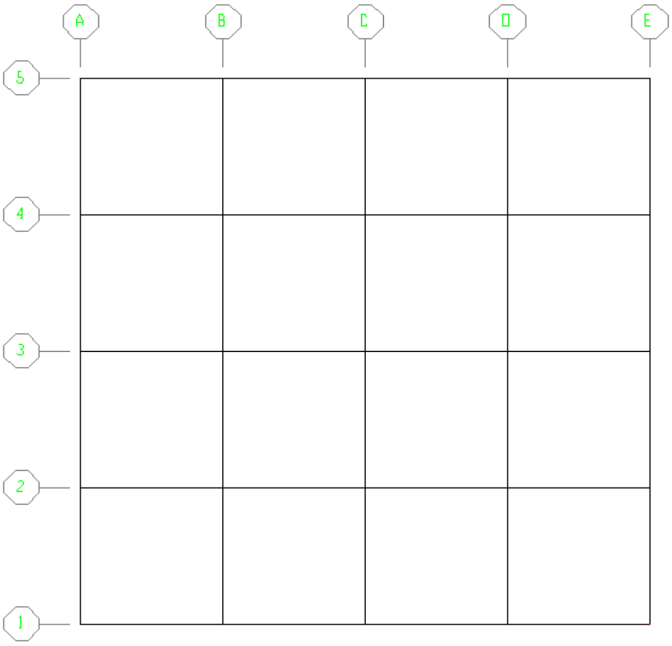

Fig.1 Plan of building model.

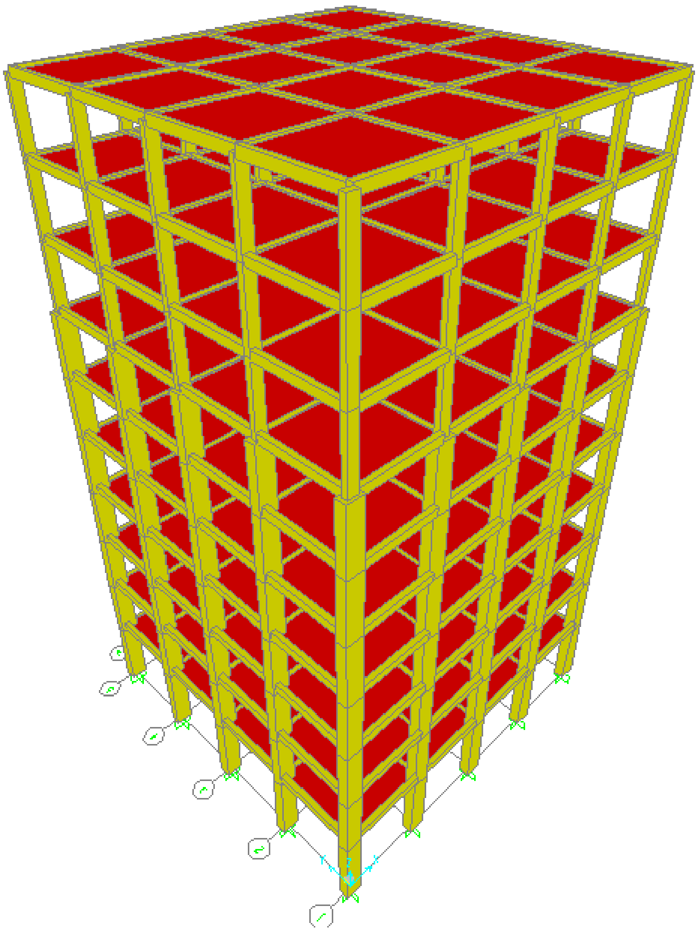

Fig.2 3-D view of ten storeyed building model

III. 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

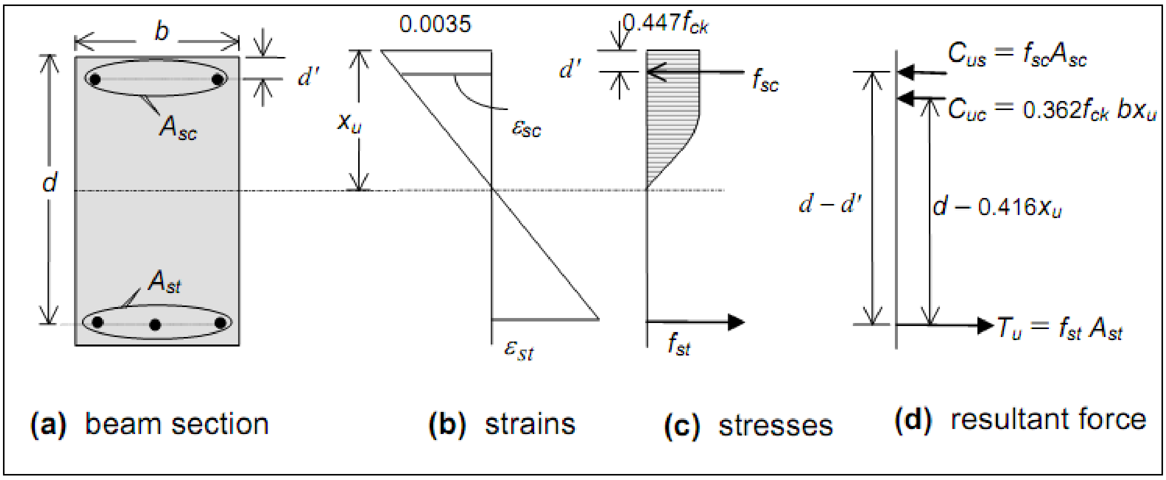

Fig.3 Stress-Strain block for beam [9]

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.

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

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.

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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]

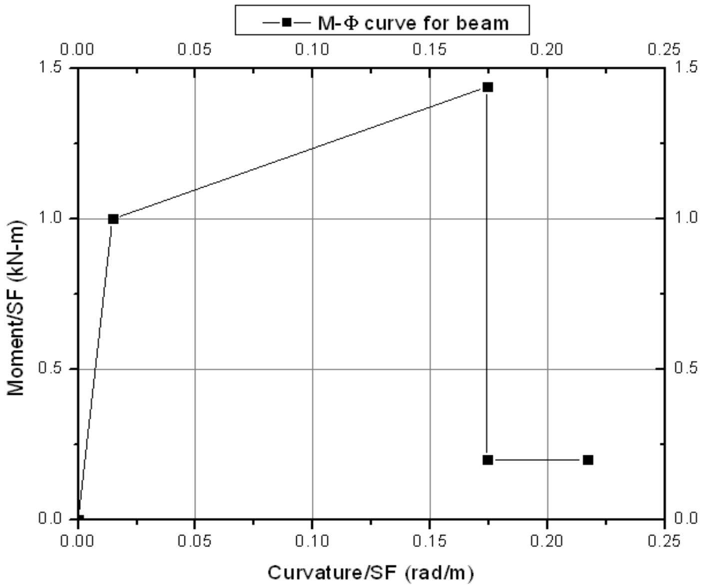

Fig. 4 Moment curvature curve for beam

3.1.2 Moment curvature for column section

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

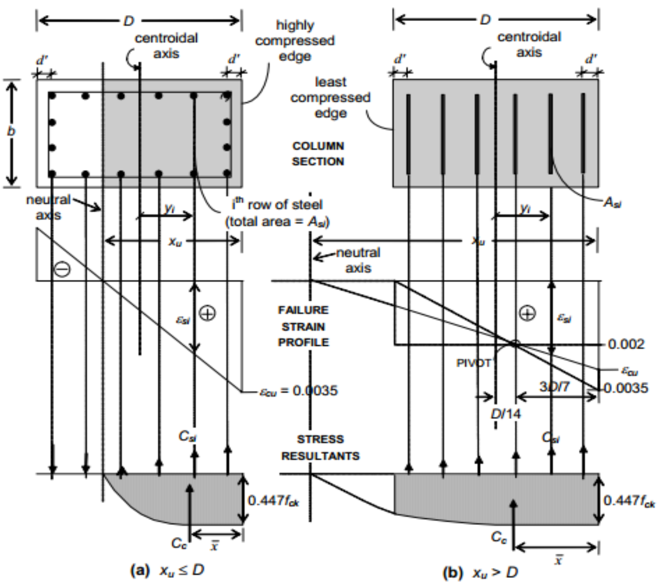

Fig.5 Analysis of design strength of a rectangular section under compression

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

$$\frac{0.0035}{x_u} = \frac{\left(\frac{f_y}{E_s} + 0.002\right)}{(d - x_u)} \quad \text{.............................(3)}$$

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.

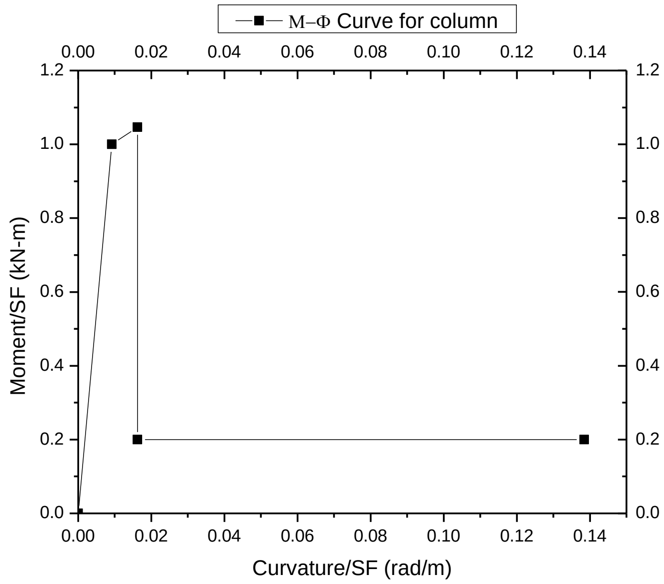

Fig.6 Moment-curvature for column section

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 loadand 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.

IV. 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 seismicdesigned building models along bothlongitudinal and lateral direction.

4.1.1 Location of hinges

The location of the hinges for user defined hinges and performance levels for all building models are presented in the below Table 1.

Table: 1 Location of hinges for ten storeyed building models

Model No	Displacement		Base force(kN)	Location of hinges								
				AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
1	Yield	29.30	2109.17	2100	0	0	0	0	0	0	0	2100
	Ultimate	146.42	8232.08	1815	278	3	0	4	0	0	0	2100
2	Yield	26.88743	4795.03	2460	3	0	0	0	0	0	0	2460
	Ultimate	144.00	17263.38	2207	208	20	25	0	0	0	0	2460
3	Yield	21.62	9496.30	2274	340	0	20	0	0	0	0	2460
	Ultimate	104.65	29714.24	2252	190	0	18	0	0	0	0	2460

For ten storeyed building models, the base force is found more in infill frame building compare to bare frame building by 54.4% at the ultimate state for brick masonry and 26.89% for concrete block infill. In ten storeyed bare frame building model hinges are formed 86.42%, 13.24%, 0%, 0%, 0.19% and 0% between A to B, B to IO, IO to LS, LS to CP and C to D respectively and most of the hinges are formed in the beams and columns of bottom storey in both X and Y direction at ultimate state. 89.71%, 8.45%, 0%, 0%, 0%, 0% and 91.54%, 7.7%, 0%, 0%, 0%, 0% between A to B, B to IO, IO to LS, LS to CP and C to D respectively for brick infill wall and concrete block infill wall respectively. Hinges are formed in the beams and columns of open ground storey in both X and Y direction at ultimate state.

From the above results it can be concluded that, as the stiffness of infill wall is considered in the building model, base force is more than the bare frame building. The stiffness of the building decreases with the increase in percentage of central openings. The performance of all the building models is within the life safety range at the ultimate state These results reveal that, seismically designed multi-storeyed RC buildings are safe to earthquakes.

4.2 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 for ten storeyed building models

Model No	Initial yield	Collapse yield	DR
1	29.30	146.42	5.00
2	26.89	144.01	5.36
3	7.62	104.65	13.73

For ten storeyed building models, the reduced ductility ratio are found in bare frame building compare to infill frame building by 6.74% for brick masonry and 63.58% for solid concrete block infill For ten storeyed building models DR for brick masonry and solid concrete block infill are crossed the targeted value From the above results it can be concluded that, the solid concrete block buildings are more ductile as compare to the brick infill buildings.

4.3 Safety Ratio

The ratio of base force at the performance point 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 for Ten Storey Building Model

Model No	Base force (kN)	Base shear (kN)	SF
1	1711.932	1439.722	1.19
2	3075.666	2416.282	1.27
3	4704.967	2300.824	2.04

In ten storeyed building models, for brick masonry infill model is found to be1.06 times safer and for solid concrete block infill 1.71 times safer compared to the bare frame building model by equivalent static method. From the above results it can be concluded that, the safety ratio values are more than 1, the building models considered are safer.

V. CONCLUSIONS

Based on the results obtained by analyses 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 ultimate state 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.

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