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SEISMIC EVALUATION OF 3-DFOUR STOREYED RC MULTISTOREYED BUILDINGS BY PUSHOVER ANALYSIS

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ABSTRACT

The RC frame structures with infill walls are frequently used in multi-storeyed buildings in recent past. 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 four storeyed reinforced concrete (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 under 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 and hinge status are compared amongst the models

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

I. 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.

II. DESCRIPTION OF THE BUILDING MODELS

In the present study three-dimensional four 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 ofcentral 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 varying 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 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.

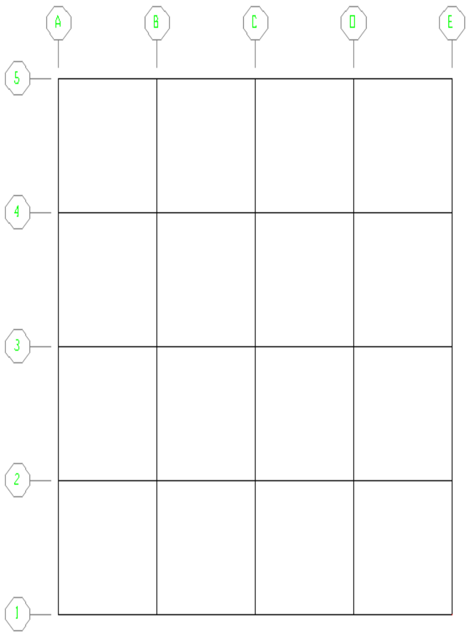

Fig.1 Plan of Building Model

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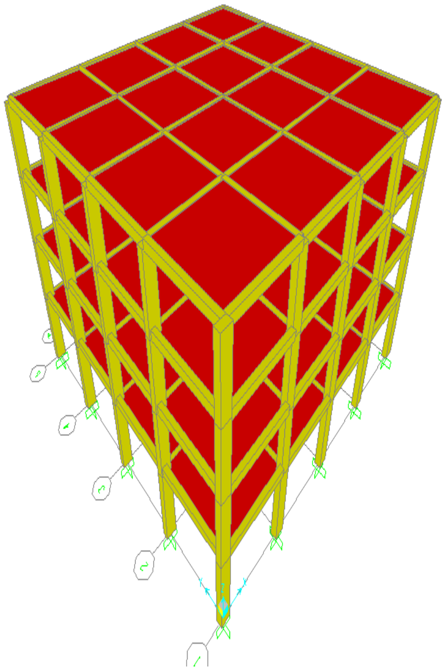

Fig: 2 3-D view of building model

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

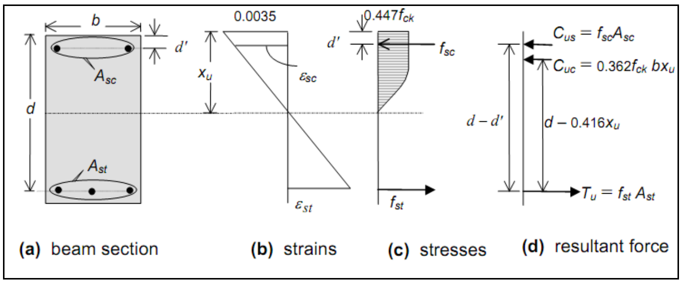

Fig.3 Stress-Strain block for beam [9]

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.

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

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.

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

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]

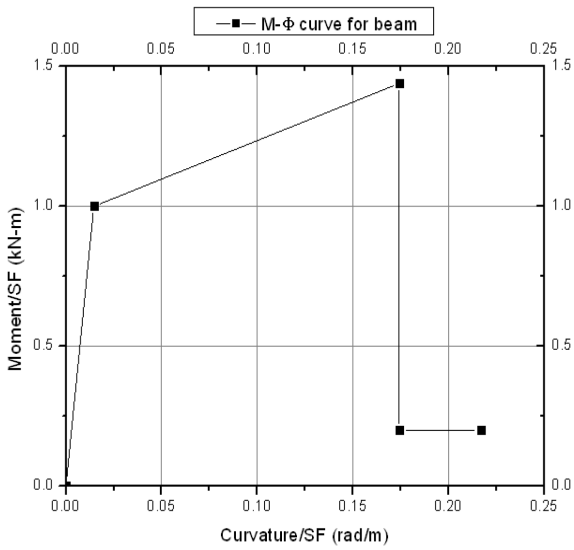

Fig. 4 Moment curvature curve for beam

3.1.2 Moment Curvature for Column Section

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

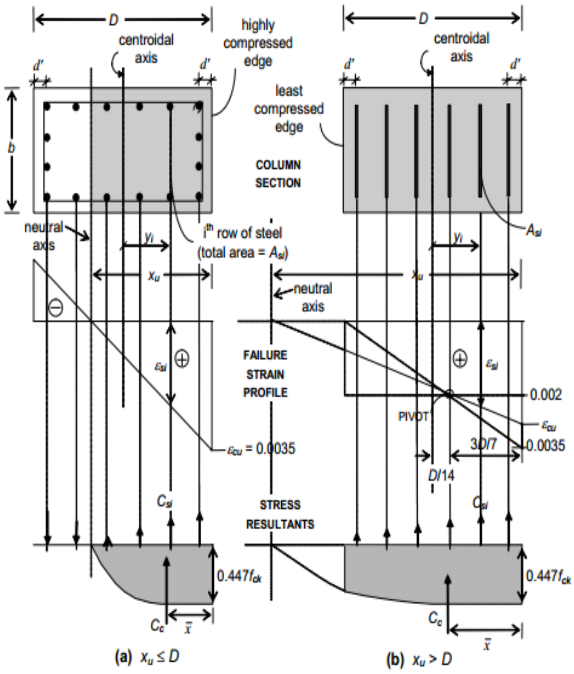

Fig.5 Analysis of design strength of a rectangular section under compression

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

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

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.

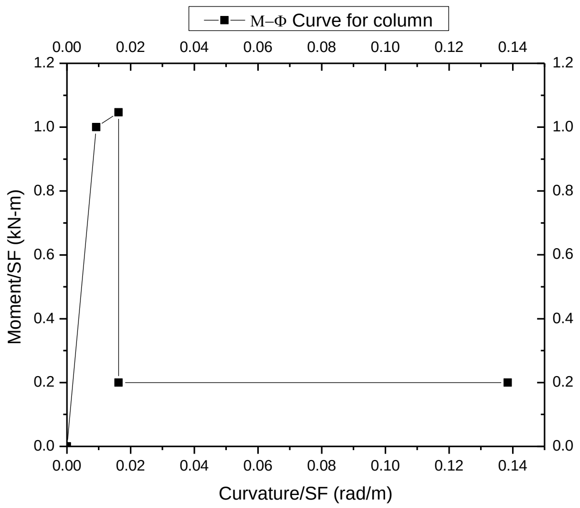

Fig.6 Moment-curvature for column section

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 seismic designed building models along the both longitudinal and lateral direction.

4.1.1 Location of Hinges

The location of the hinges for user defined hinges and performance levels along longitudinal direction for all building models are presented in the below table 1

Table: 1 Location of hinges for four storeyed building models

Model No	Displacement(mm)		Base force(kN)	Location of hinges				
				AtoB	BtoIO	IOtoLS	LStoCP	Total
1	Yield	12.01	1599.59	840	0	0	0	840
	Ultimate	60.01	6443.85	720	120	0	0	840
2	Yield	11.42	2984.84	900	0	0	0	900
	Ultimate	59.42	9661.13	894	6	0	0	900
3	Yield	5.01	4498.12	898	2	0	0	900
	Ultimate	59.01	13806.72	862	22	16	0	900

For building models, the base force is found more in infill frame building compare to bare frame building by 33.33% at the ultimate state for brick masonry and 53.32% for concrete block infill. In four storeyed bare frame building model hinges are formed 85.71% 14.29% between A to B, B to IOrespectively and most of the hinges are formed in the beams and columns of bottom storey in both X and Y direction at ultimate state. Similarly for brick infill wall model 99.33%, 6.7% between A to B, B to IO respectively at ultimate state and for concrete block infill wall 95.78%, 2.44%, 1.77% between A to B, B to IO, IO to LS respectively and most hinges are formed in the beams andcolumns of bottom storey in both X and Y direction at ultimate state.

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 of Building Models

Model No	Initial yield	Collapse yield	Ductility ratio
1	12.01	60.01	5.00
2	11.42	59.42	5.20
3	5.01	59.01	11.78

For building models, reduced ductility ratio are found in bare frame building compare to brick infill frame building by 3.846% and 57.55% for solid concrete block infill. From the above results it can be concluded that, the solid concrete block buildings are more ductile as compare to the brick infill building.

4.3 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 for four storeyed building models

Model No	Base force (kN)	Base shear (kN)	Scale factor
1	1345.603	996.969	1.35
2	1685.225	1072.733	1.57
3	2623.765	1069.051	2.45

In building models, for brick masonry infill model is found to be 1.16 times safer and for solid concrete block infill 1.81 times safer compared to the bare frame building model by equivalent static method. Thus the safety ratios for all building models considered are safe.

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 collapse prevention level 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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