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STUDY OF THE LATERAL LOAD RESISTING SYSTEM IN A REINFORCED CONCRETE FRAME BUILDING USING PARAMETRIC METHODS

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ABSTRACT

In earthquake-resistant design of Reinforced Concrete (RC) frame multistoreyed buildings, identification of lateral force resisting system presents a major challenge. Certain structural elements are identified to carry the lateral forces generated during strong earthquake shaking. The stiffness and configuration of those identified elements play a major role in determining the design force levels in the elements. A symmetric five-storied RC frame building is designed against the earthquake load combinations, specified as per Indian Earthquake Code, namely IS:1893 (Part 1)-2002. All the frames along both the directions are expected to share the lateral forces as per the stiffness and configuration. Next, certain frames, more specifically the outer ones, are identified to carry the lateral forces, and subsequently, the frames are made stiffer. The consequence on design is studied by obtaining the required amount of reinforcement for the two cases of varying column dimensions. Further, certain members are modeled to carry only the gravity forces by assigning release in moments along appropriate directions. Thus, the whole structure is not expected to get damaged during any strong earthquake. Consequently, the required amount of reinforcement in various frame members of different floor levels is compared for different cases.

Keywords: Gravity column, seismic design, nonductile column, drift capacity, moment release

1. INTRODUCTION

In many RC frame-type buildings, certain selected frame elements are assigned to participate in the lateral load resisting mechanism during strong earthquake shaking. Other frame members primarily participate in the gravity-resisting mechanism. This leads to ductile detailing of the members contributing to the lateral resistance and non-ductile detailing of the gravity members. The gravity members are known as gravity columns. The lateral force resisting system generally consists of moment-resisting frames and structural walls. The lateral displacements of the primary system, during strong earthquake shaking, are imposed on the gravity columns which may lead to possible collapse unless designed for adequate drift capacity. During 1994 Northridge earthquake, a number of gravity load systems collapsed due to excessive lateral deformations (EERI, 1994).

Nonlinear dynamic analyses on RC frame buildings with ductile and non-ductile frames have been carried out to assess collapse prevention during strong earthquake shaking In the present study, the influence of gravity columns on the required longitudinal and transverse reinforcement of lateral force-resisting members is investigated under design earthquake load combinations. The study is carried out for a symmetric plan building; however, the same can be carried out for an asymmetric plan building also.

2. INPUT DETAILS AND MODELING

A multistoreyed symmetric RC frame building of plan dimensions 15.52m×9.14m and height of 16.7m situated in Zone V as per the Seismic Zone map of India (IS:1893 (Part 1), 2002). The building is 5-storeyed and the typical floor-to-floor height is 3.04 m. The thickness of all floor slabs is 125 mm and the cross-sections of beams and columns are 225mm×300mm and 300mm×300mm respectively. The building is assumed to be founded on rocky stratum; thus, all the degrees of freedom (DOFs) are restrained at the bottom nodes of the building. The grade of concrete is M25 and steel used is Fe 415. The sizes of the footings required under the wind and earthquake load combinations are obtained while designing other components. The modulus of elasticity, Poisson's ratio and mass density of concrete have been considered as 25,000 MPa, 0.15 and 2,500 kg/m^3 respectively. The typical floor plan and elevation are shown in Figs. 1a and 1b respectively.

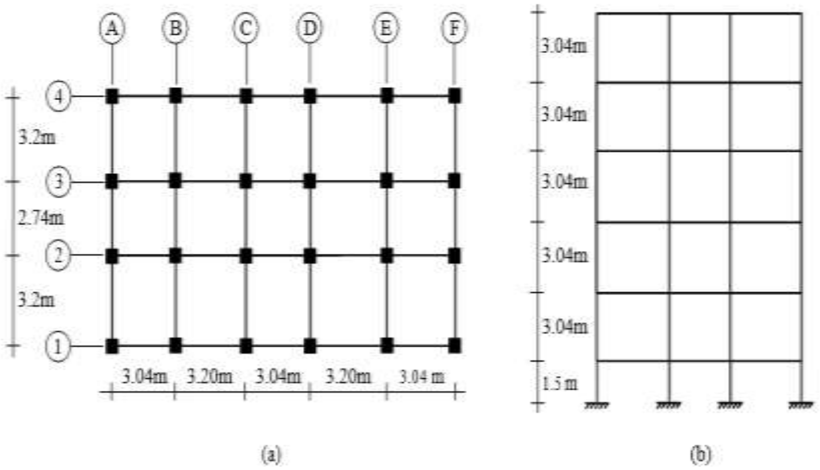

Fig.1 (a) Typical floor plan and (b) elevation of the building along gridline A

The beams and columns are modelled using two-noded frame element option of the computer program SAP2000 (CSI, 2010). Each node of this frame element has six DOFs including three translational and three rotational DOFs. The slabs are modelled using four-noded thin shell elements, each having six DOFs similar to those of the frame element. To maintain compatibility of deformations along the edges of slab and the corresponding beams, each beam is discretised in six segments, along with the slab into sub-area elements, at nodes common to both the beam and slab (Dhar, 2011). The loads on the structure are Dead Load (DL) (IS:875 (Part 1), 2003), Live Load (LL) (IS:875 (Part 2), 2003) and Earthquake Load along X (ELX) and Y (ELY) directions (IS:1893 (Part 1), 2002) respectively. ELX and ELY represent equivalent static lateral forces, due to earthquake shaking, along X and Y directions respectively. The various load combinations are considered as per IS:1893 (Part 1) respectively.

3. INITIAL DESIGN

The building is analysed under the specified load combinations and the reinforcement in slabs, beams and columns obtained from the limit state design principles of the Indian Concrete Code IS:456-2000 (IS:456, 2005; SP:16, 1999). Conventionally, slabs are divided into middle and edge strips and moments are evaluated due to vertical loads only. In this study, the bending moments are evaluated from the output of the shell elements under the prescribed load combinations. Among all the floors and roof of the building, the reinforcement provided in the middle and edge strips of the panels are Y10@250c/c and Y10@175c/c respectively.

For the beams, the design forces and moments were grouped into two categories, namely (a) for ground, first and second floors and (b) third and fourth floors and roof. However, the same reinforcement has been provided for both the categories with the longitudinal steel being 2nos. Y16 bars both at supports and mid-span along with transverse steel of 2 legged Y8 stirrups @ 300mm center-to-center distance. Similarly, for columns, the design forces and moments were grouped into two categories, namely (a) for ground, first and second stories and (b) third, fourth and fifth stories. However, the same reinforcement has been provided for both the categories with the longitudinal steel being 4nos. Y16 bars throughout the height along with transverse steel of 2 legged Y8 stirrups @ 250mm center-to-center distance.

4. PARAMETRIC STUDY

- **Stiffening of Exterior Frames**

  The lateral force attracted by a particular frame of a multistoreyed building depends on its lateral stiffness. In the present study, the effect of selective frame stiffening along the two principal directions on design aspects is investigated through a parametric analysis. Two cases have been considered as follows:

(a) **Case 1**: In the first case the depth of the columns was changed from 300mm to 500mm along global X direction only at the two outer frame lines (1) and (4) (Fig. 2a). The width of column remains the same as 300mm.

(b) **Case 2**: The depth of the columns was increased from 300mm to 500mm along global Y direction only at the exterior frames (A) and (F) along Y direction (Fig. 2b). The width of column remains the same 300mm.

300mm □ 500mm columns

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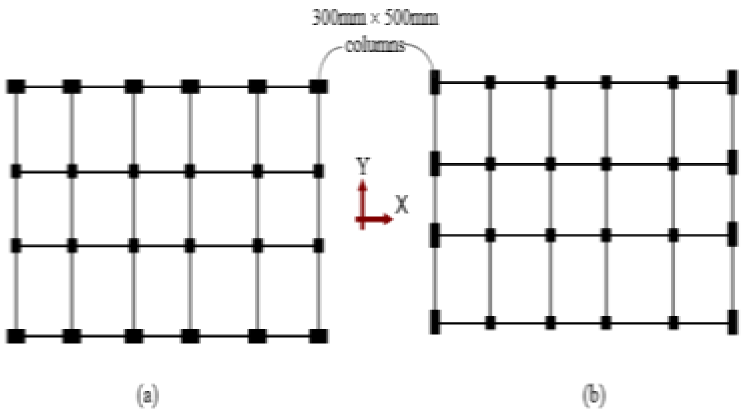

Fig.2 Stiffening of exterior frame along global (a) X-direction and (b) Y-direction

With increase in depth of particular vertical members (namely exterior columns), the columns are expected to attract more forces and moments due to enhanced stiffness. Particularly, during strong earthquake shaking, significantly increased force demand will be imposed on these columns whereas the interior columns can be designed for lesser force capacities. Thus, the interior columns are expected to be designed with less vertical reinforcement as compared to the columns with increased depth.

Case 1: The bending moments on the beams are found to be less than the moment obtained for the initial design case; thus, beam reinforcement remains the same. Unlike beams, the columns with enhanced sizes (300mm×500mm) show increased flexural demand and the reinforcement is redesigned to 4 nos. Y20 bars. The transverse reinforcement remains the same as obtained for the initial design case. The design flexural demand corresponds to the bending moments obtained under the load combination 0.9DL+1.5ELX.

Case 2: Due to the increased depth 500mm along global Y-direction (width of the building), both columns and beams in those two exterior frames are subjected to higher forces and moments as compared to the initial design case. In Case 1, more members (beams and columns) were available for framing action and this did not increase flexural demand in the beams. Between the two categories, reinforcement was increased to 3 nos. Y16 bars at the support locations of the beams in ground, first and second floors; there was no change in beam reinforcement in the upper floors. The governing design moments were obtained from the load combinations 0.9DL+1.5ELY and 1.2(DL+LL+ ELY) for the midspan and support moments respectively. However, the reinforcement in columns remains the same as obtained for initial design case.

- **Release of Moments**

  In a moment resisting frame of a building, if the ends of a few columns are completely released against bending moments, there will not be any bending moment transfer in those columns. At the support sections, they will be subjected to only shear and axial forces depending on the loading along its height. Thus, the columns without the end releases will be subjected to higher bending moments and more predominant framing action. If the selective moment release is carried out for columns located along certain frames, the columns along other frames will form the lateral load resisting system of that building during strong earthquake shaking. The columns for which the bending moments are released are known as gravity columns. These gravity columns are expected to have less longitudinal reinforcement as compared to the columns carrying higher bending moments.

- **Square Columns**

  In the second level parametric study, both ends of the all the columns of size 300mm×300mm are released against transfer of bending moments for both Cases 1 and 2. The predominant frame action of the exterior columns (with increased size) is investigated by applying the two-design earthquake lateral loads ELX and ELY for the Cases 1 and 2 respectively (Figs. 3a and 3b). The resulting longitudinal reinforcement is compared with the previous cases.

In Case 1, when the building is analysed against load combinations involving lateral force along Global X-direction (ELX), the beams along gridlines (1) and (4) tend to carry more bending moments. This results in increase of longitudinal reinforcement. As compared to the previous selective stiffening case, for ground, first and second floors, 2 nos. of bars at midspan and 3 nos. of bars at supports are provided. Also, for the upper floors, 2 nos. of bars are provided both at midspan and support sections. In the selective stiffening case, the bar diameter was 16mm; for selective release, the required diameter of bar is 20mm. Thus, there is an increase in reinforcement of 57% in the beam

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sections. However, the increased longitudinal steel in columns for selective stiffening case is sufficient to cater for the selective release case also. The design bending moments are obtained for the load combination 0.9DL+1.5ELX in second floor beams. For Case 2, when the building is analysed against load combinations involving lateral force along Global Y-direction (ELY), the beams along gridlines (A), and (F) tend to carry more bending moments. The previously assumed beam section 225mm×300mm is found to be inadequate in resisting the increased flexural demand with the required beam section as 300mm×500mm. Thus, the beams now tend to attract more forces and moments. For all the floors 2 nos. of bars of 20mm diameter are provided at midspan and at the supports. Also, for the upper floors, 2 nos. of bars are provided both at midspan and support sections. The transverse steel remains the same, i.e., 2 legged

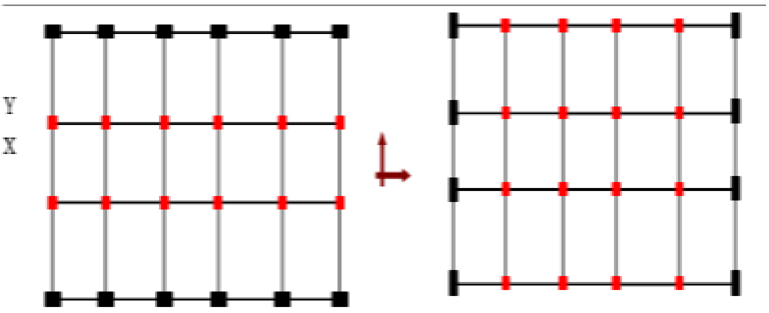

Fig. 3 Selective release of bending moments in columns for design earthquake force along global (a) X-direction and (b) Y-direction (columns with moment release are marked red)

Y8 stirrups @ 300mm center-to-center distance throughout the length of the beam. For the columns, the longitudinal reinforcement was increased to 4 nos. 22mm diameter bars. The design bending moments are obtained for the load combination 0.9DL+1.5ELY in second floor beams.

- **Directional Release of Moments**

  In another variation, the ends of the interior columns (size: 300mm□300mm) are not released against transfer of bending moments; only the ends of the peripheral edge columns are released corresponding to particular directions (Figs. 4a and 4b). The directions of release of bending moments in the peripheral columns correspond to the directions of applied design earthquake lateral loads ELX and ELY for the Cases 1 and 2 respectively. The ends of the interior columns are not released against transfer of bending moments along any direction.

For design earthquake loads applied along X-direction, there is no significant increase in bending moments for the exterior columns. Like Case 1 of the previous study, in which only the ends of the interior columns were released, 2 and 3 nos. of 20 mm diameter bars were provided at midspan and supports in ground, first and second floors respectively. For the upper floors, the beam reinforcement remained the same at midspan and support sections. The longitudinal and transverse steel in columns of all the stories also remains the same as in the previous case.

For design earthquake forces applied along Y-direction, the beams along gridlines (A), and

(F) tend to carry more bending moments. Like Case 2 in the previous study, the required beam cross section was increased to 300mm×500mm. The required longitudinal and transverse reinforcement in the beams of all the floors remained the same as obtained in the previous study. However, the required longitudinal reinforcement in the columns for all the stories was 4 nos. 22mm diameter bars, unlike the previous study in which less reinforcement was required in the columns of upper 3 stories. The forces and bending moments are obtained for the combination 0.9DL+1.5ELY in second floorbeams.

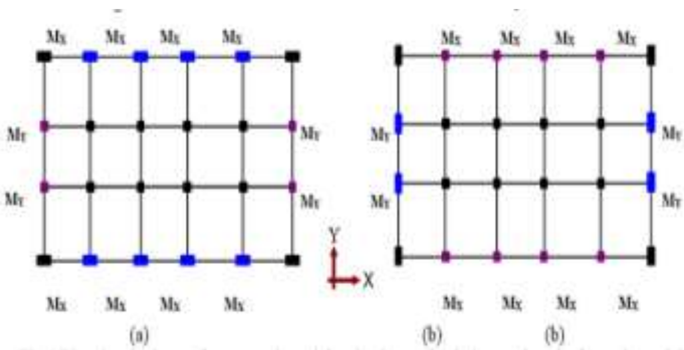

Fig.4 Directional release of moments in peripheral columns for design earthquake force along global (a) X-direction and (b) Y-direction

- **Combined Study**

  In this analysis, the results of the previous two studies were combined and analysis carried out for design earthquake load combinations along appropriate directions. At both the ends of the columns on the peripheral edges (barring the corner columns), the bending moments were released along the appropriate directions of applied forces. In the interior columns, the moments were released along both the directions. The sizes of the corner columns were increased to 500mm□500mm.

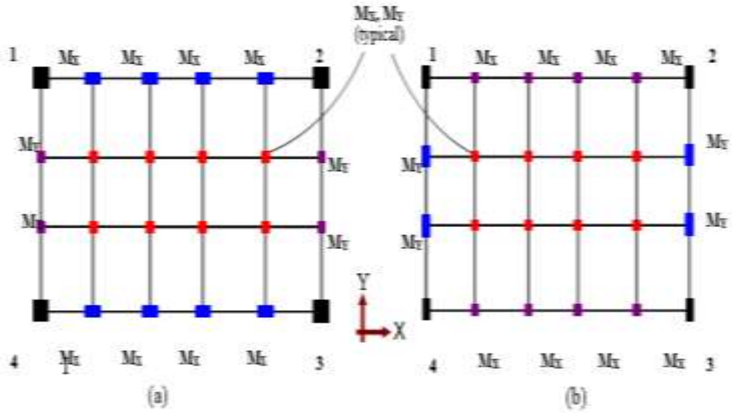

Fig.5 Combined study of release of bending moments in columns: directional release in columns on peripheral edges along global (a) X-direction and (b) Y-direction, and release of bending moments in all the interior columns.

For design earthquake loads applied along X and Y-directions, the maximum bending moments in the corner columns are compared as obtained from the previous studies (Table 1). For the combined analysis case, the maximum bending moments among the four corner columns (1, 2, 3 and 4) are obtained as 121kNm and 183kNm for Cases 1 and 2 respectively. Thus, the corner columns are attracting significantly higher forces than the previous cases due to the effect of moment release in other columns and increase in cross-section to 500mm□500mm. However, due to the increased sizes of the columns, the required longitudinal reinforcement is less than the previous moment release cases; 4 nos. of 20mm diameter bars are required in the cross-section. The required transverse reinforcement remains the same as in the previous cases. The maximum bending moments are obtained for load combinations 0.9DL+1.5ELX and 0.9DL+1.5ELY.

Table 1: Comparison of maximum bending moments (kNm) in corner columns for the different analysis cases

Column Labels	Initial Design	Selective Stiffening		Moments released in interior columns		Directional release of moments	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	21.0	50.6	60.0	80.1	128.3	91.3	128.3
2	21.0	52.1	60.0	81.8	128.3	91.3	128.3
3	19.2	52.1	58.3	81.8	126.4	88.9	126.3
4	19.2	50.6	58.3	80.1	126.4	88.9	126.3

In the present study, the building was subjected to linear elastic analysis under the code- specified design load combinations to obtain the influence of gravity columns on the required reinforcement of the columns. To obtain the actual seismic behaviour, the building should be subjected to nonlinear analysis with geometric and material nonlinearities for the sections and reinforcement obtained as per the current design.

The inelasticity in the beams and columns may be modeled using lumped or distributed plastic models. For lumped plasticity, shear and flexural hinges need to be modeled in the frame members of the lateral load resisting system. Thus, the inelasticity in these members at large lateral deformations will be possibly captured after the collapse of gravity columns.

3 CONCLUSIONS

The following salient conclusions were drawn on the basis of the sequential studies as mentioned earlier:

- The stiffening of corner columns and columns supported along peripheral edges attracted more forces and moments on the members than release of selective columns against bending moments.

- As compared to the longitudinal direction, the framing members along the transverse direction attracted more forces and moments for almost the same base shear values.
- Moment release of the interior columns and directional moment release of the peripheral edge columns had similar influence on longitudinal reinforcement of the columns.
- The moment release of internal and peripheral edge columns had almost insignificant influence on the transverse reinforcement of the corner columns.
- The actual inelastic behaviour of the entire building needs to be investigated by modeling nonlinearities in members.

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