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Seismic Vulnerability of Open Ground Floor Columns in Multi Storey Buildings

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Abstract: ***Though multistoried buildings with open (soft) ground floor are inherently vulnerable to collapse due to earthquake load, their construction is still widespread in the developing nations. Social and functional need to provide car parking space at ground level far out-weighs the warning against such buildings from engineering community. An investigation has been performed to study the behavior of the columns at ground level of multistoried buildings with soft ground floor subjected to dynamic earthquake loading. The structural action of masonry infill panels of upper floors has been taken into account by modeling them as diagonal struts. Finite element models of six, nine and storied buildings are subjected to earthquake load in accordance with equivalent static force method as well as response spectrum method. It has been found that when infill is incorporated in the model, modal analysis shows different mode shapes indicating that dynamic behavior of buildings changes when infill is incorporated in the model. Natural period of the buildings obtained from modal analysis are close to values obtained from code equations when infill is present in the model. This indicates that for better dynamic analysis of RC frame buildings with masonry walls, infill should be present in the model as well. Equivalent static force method produces same magnitude of earthquake force regardless of the infill present in the model. However, when the same buildings are subjected to response spectrum method, significant increase in column shear and moment as well as total base shear has been observed in presence of infill. In general, a two fold increase in base shear has been observed when infill is present on upper floors with ground floor open when compared to the base shear given by equivalent static force method. The study suggests that the design of the columns of the open ground floor would be safer if these are design for shear and moment twice the magnitude obtained from conventional equivalent static force method. Study of the sway characteristics also reveals significantly high demand for ductility for columns at ground floor level. Presence of in filled wall on upper floors demands significant enhancement of column capacity or ductility to cope up with increased sway or drift.***

Keywords: concrete, earthquake, infill, multistory, response spectrum, soft story

1. Introduction

Many urban multi storey buildings in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first storeys. The upper storeys have brick infilled wall panels. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than *50%* of the storey above or below. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey." Whereas the total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with soft first storey, the upper storeys being stiff, undergo smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demands on the columns in the first storey for third buildings are also large, as the shear in the first storey is maximum. For the upper storeys, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiffnesses have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. The first storey columns in the parking area were badly damaged including spalling of concrete cover, snapping of lateral ties, buckling of longitudinal reinforcement bars crushing of core concrete Figure1a and Figure1b.

Figure 1a: Damage to columns in Himgiri apartment

The Indian seismic code requires members of the soft story (story stiffness less than 70% of that in the story above or less than 80% of the average lateral stiffness of the three stories above) to be designed for 2.5 times the seismic story shears and moments, obtained without considering the effects of masonry infill in any story. The factor of 2.5 is specified for all the buildings with soft stories irrespective of the extent of irregularities; and the method is quite empirical and may be too conservative and thus have further scope for improvement.

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Figure 1b: Soft story failure, Bhuj 2001

2. Literature Review

Samir Helou, & Abdul Razzaq Touqan (2008) The inclusion of a soft storey in multistory concrete buildings is a feature gaining popularity in urban areas where the cost of land is exorbitant. In earthquake prone zones, this feature has been observed in post earthquake investigations. Although engineers are prepared to accept the notion that a soft storey poses a weak link in Seismic Design, yet the idea demands better understanding. The following study illustrates the importance of the judicious distribution of shear walls. The selected building is analyzed through nine numerical models which address the behavior of framed structures. The parameters discussed include, inter alias, the fundamental period of vibration, lateral displacements and bending moment. It is noticed that an abrupt change in stiffness between the soft storey and the level above is responsible for increasing the strength demand on first storey columns. Extending the elevator shafts throughout the soft storey is strongly recommended.

F. Demir and M. Sivri (2002) In this study, effects of nonstructural masonry infills on the earthquake response of reinforced concrete structure are investigated by considering reinforced concrete structures with different configuration of masonry infills to examine the effects of irregular infill masonry structural performance. The diagonal strut model is adopted for modeling masonry infill. Numerical analysis is performed and results are presented in comparison with the experimental data and the effects of irregular configuration of masonry infill on the performance of the structure are studied.

Jaswant N. Arlekar, Sudhir K. Jain and C.V.R. Murty (1997) Open first storey is a typical feature in the modern multistorey constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. This paper highlights the importance of explicitly recognizing the presence of the open first storey in the analysis of the building. The error involved in modeling such buildings as complete bare frames, neglecting the presence of infills in the upper storeys, is brought out through the study of an example building with different analytical models. This paper argues for immediate measures to prevent the indiscriminate use of soft first storeys in buildings, which are designed without regard to the increased displacement, ductility and force demands in the first storey columns. Alternate measures, involving stiffness balance of the open first storey and the storey above, are proposed to reduce the irregularity introduced by the open first storey. The effect of soil flexibility on the above is also discussed in this paper.

M. N. Fardis and T. B. Panagiotakos (1997) The effects of masonry infills on the global seismic response of reinforced concrete structures is studied through numerical analyses. Response spectra of elastic SDOF frames with nonlinear infills show that, despite their apparent stiffening effect on the system, infills reduce spectral displacements and forces mainly through their high damping in the first large post-cracking excursion. Parametric analyses on a large variety of multi-storey infilled reinforced concrete structures show that, due to the hysteretic energy dissipation in the infills, if the infilling is uniform in dl storeys, drifts and structural damage are dramatically reduced, without an increase in the seismic force demands. Soft-storey effects due to the absence of infills in the bottom storey are not so important for seismic motions at the design intensity, but may be very large at higher motion intensities, if the ultimate strength of the infills amounts to a large percentage of the building weight. The Euro code 8 provisions for designing the weak storey elements against the effects of infill irregularity are found to be quite effective, in general, for the columns, but unnecessary and often counterproductive for the beams.

3. Analytical Modeling – ETABS

For the modeling of the six and nine storey structure, line element was used for beams and columns and concrete element was used for slabs. The base of structure was fully fixed by constraining all the degrees of freedom. A six storey RC building in Zone III on medium soil was analyzed and the shear forces, bending moment’s axial forces, mode shapes around the structure due to different load combinations were obtained. Seismic analysis was performed using Equivalent lateral force method and response spectrum method given in IS 1893:2002. The structural model and the building plan shown in figure 3.1 and 3.2.

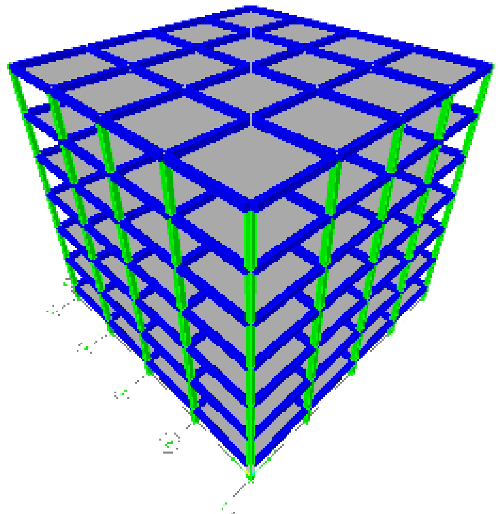

Figure 3.1: Structural Model

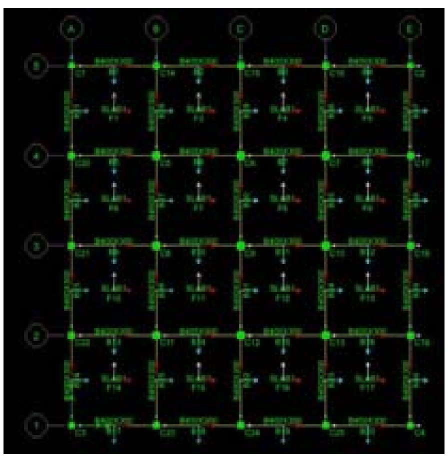

Figure 3.2: The Building in Plan

3.1 Properties of Reference Rc Frame Model

Number of span and bays = 4× 4
Thickness of slab = 125 mm
Width of each bay = 5000 mm
Story height = 3.0 m
Size of corner column (mm × mm) = 0.30 m x 0.30 m, 0.325 mx0.325 m
Size of interior column (mm × mm = 0.425 m x 0.425 m, 0.475 mx0.475 m
Size of edge column (mm × mm) = 0.35 m x 0.35 m, 0.375 m x 0.375 m
Beam size = 0.3 m x 0.4m
Density of concrete = 25 kN/m3
Grade of concrete: M30, Grade of steel = Fe 415
Live load on roof = 1.5 kN/m2
Live load on floors = 3 kN/m 2
Thickness of Brick wall = 230 mm
Density of brick wall including plaster = 20 kN/m3
Amount of infill = with infill, 50% infill, without infill

Model I: Building has to no wall in the first storey and one full brick infill masonary wall (230 mm thick) in the upper storeys.
Model II: Building has no wall in the first storey and half brick infill masonary wall (115 mm thick) in the upper storeys.
Model III: Building has no wall in all storeys.

4. Results and Discussion

4.1 Forces and Moment in Column

The distribution of shear force in columns of a central frame is shown in Figure 4.1 for no infill condition (orequivalent static condition) while the same for 50 percent infilled panels shown in Figure 4.2 It can be inferred from these figures that when infill present, column shear near ground floor (soft floor) has a sharp increase compared to the shear force of the frame without infill.

The increase in shear is about twofold compared to the no infill condition or equivalent static condition. Thus the building frame behaves in a flexible manner causing distribution of horizontal shear across floors. In presence of infill, the relative drift between adjacent floors is restricted causing mass of the upper floors to act together as a single mass.

In such a case, the total inertia of the all upper floors causes a significant increase in the horizontal shear at base or in the ground floor columns. Similar increase in column bending moment is observed as shown in Figure 4.3 and Figure 4.4 due to similar reason. The axial force of some inner columns increases when infill is present in adjacent panels as can be seen in Figure 4.5 and Figure 4.6 In the present study, infill is modeled as diagonal struts which develop axial force while resisting the relative lateral drift across floors. The vertical component of this axial force gives rise to axial force in interior columns.

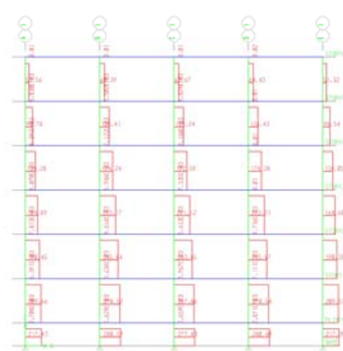

Figure 4.1: Distribution of shear force in column due to response spectrum earthquake load for no infill condition

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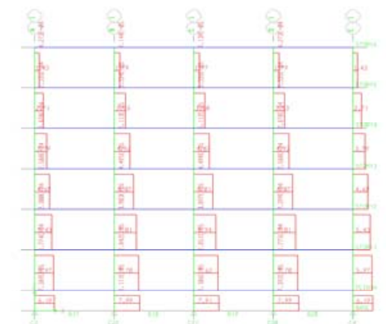

Figure 4.2: Distribution of shear force in column due to response spectrum earthquake load for 50 percent infill condition

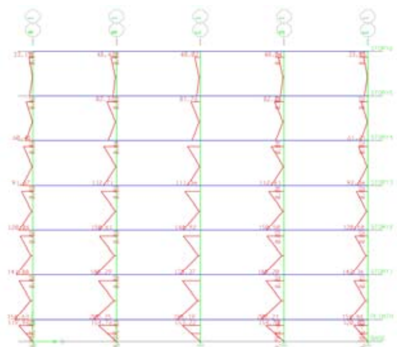

Figure 4.3: Distribution of bending moment in column due to response spectrum earthquake load for no infill condition

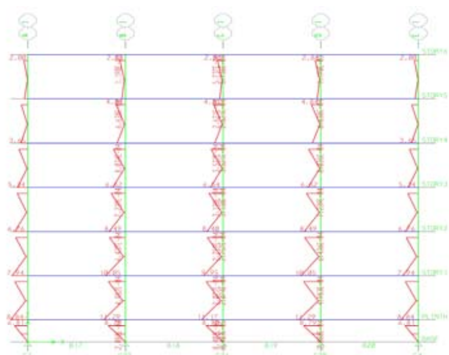

Figure 4.4: Distribution of bending moment in column due to response spectrum earthquake load for 50 percent infill condition

Figure 4.5: Distribution of axial force in column due to response spectrum earthquake load for no infill condition

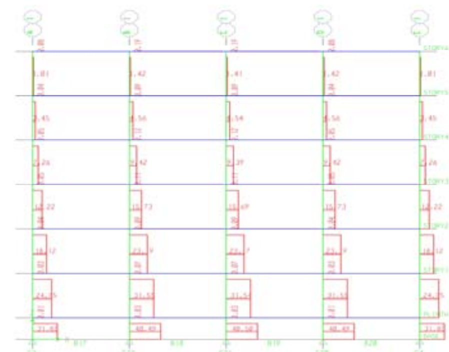

Figure 4.6: Distribution of axial force in column due to response spectrum earthquake load for 50 percent infill condition

4.2 Mode Shapes

As a part of the study mode shapes of different modes of vibration of the building are determined. Though higher mode shapes are more of a theoretical topic, these do indicate the dynamic characteristics of a building. Mode 1st, 5th and 12th mode of the building are visually compared in Figure 4.7 through Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12 It can be observed that when infill is present in the building, the mode shape changes significantly. Vibration frequency gets almost double when infill is present in the model. Since frequency is significantly increased, it is quite natural that earthquake force on the building would also significantly increase. Thus it can be said that presence of infill significantly changes the dynamic characteristics of a building.

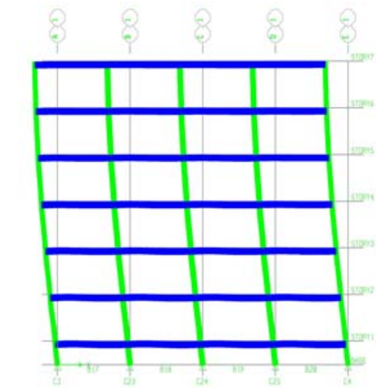

Figure 4.7: Mode 1 period 1.0526 sec frequency 0.950

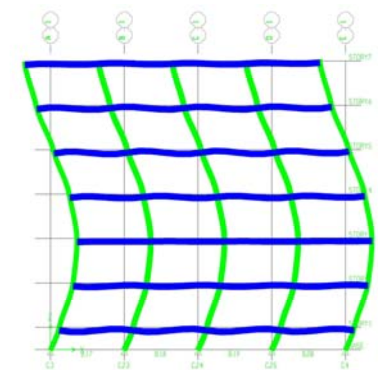

Figure 4.8: Mode 5 period 0.3381 sec frequency 2.957

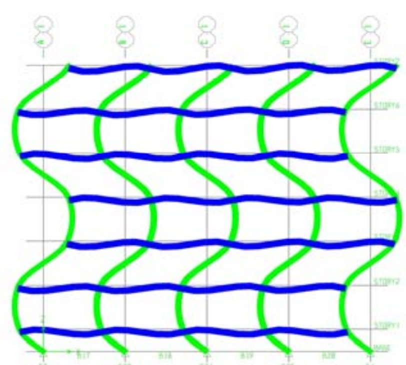

Figure 4.9: Mode 12 period 0.1240 sec frequency 8.064

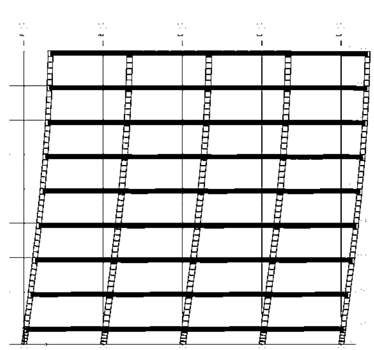

Figure 4.10: Mode 1 period 1.3089 sec frequency 0.8674

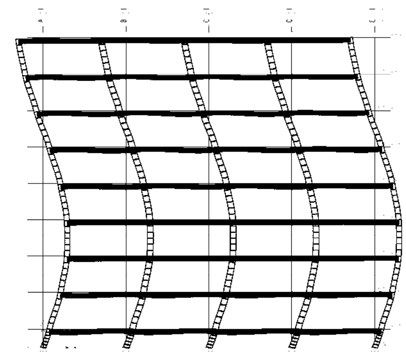

Figure 4.11: Mode 5 period 0.4217 sec frequency 2.056

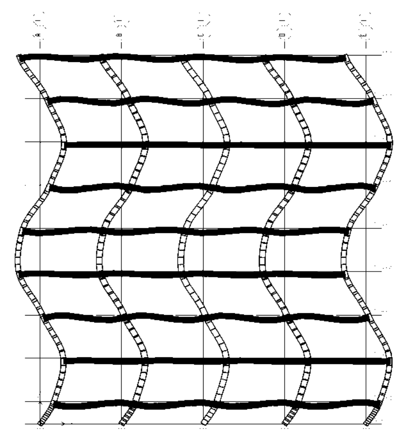

Figure 4.12: Mode 12 period 0.1522 sec frequency 7.320

4.3 Comparison of Base Shear

Base shear is a very important parameter for earthquake resistant design of buildings. In the present study, shear developed at the base of the building due to response spectrum load for no infill condition and 50% infill condition has been evaluated and compared for six and nine storied building. The results are shown in Figure 4.13.

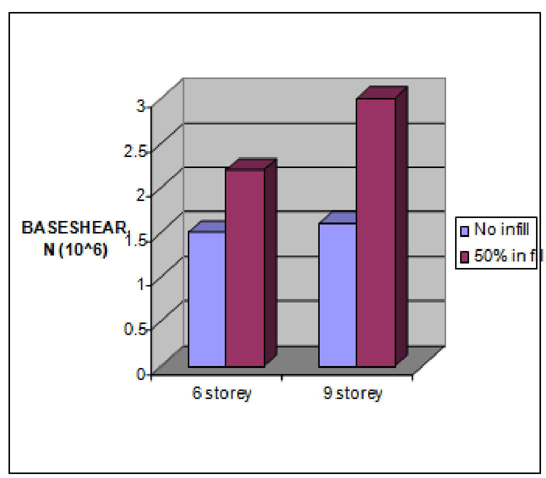

Figure 4.13 comparison of base shear for different height of buildings

4.4 Effect of Variation of Infill Amount on Storey Sway

Sway is plotted for the buildings for different percentage of infill (0% and 50%) of both equivalent static force method and response spectrum method in Figure 4.14 and Figure4.15 The infill act as equivalent diagonal strut which is responsible to increases the story stiffness. Both for equivalent static force method and response spectrum method lateral sway is the highest for frame with 0% infill and it reduces with the increase of infill due to increased stiffness of the story for the presence of infill.

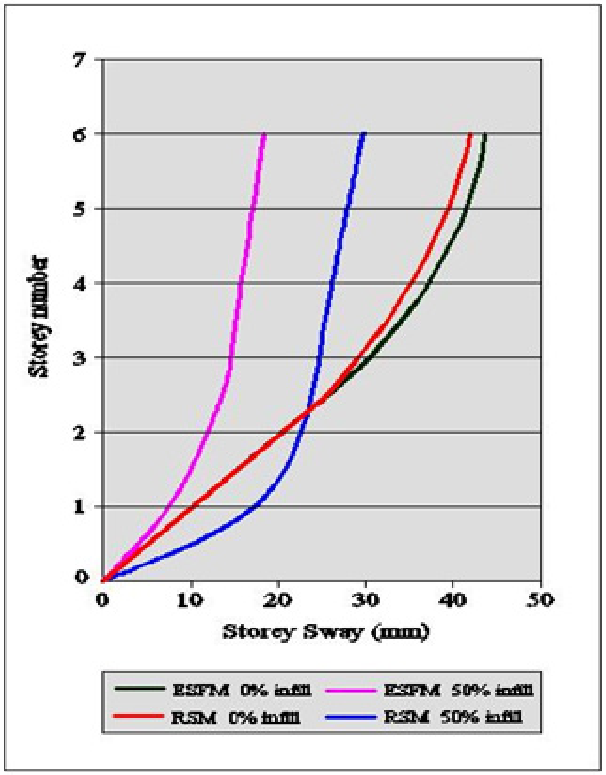

Figure 4.14: Storey sway for 6 storied Building for 50% infill and for No infill condition

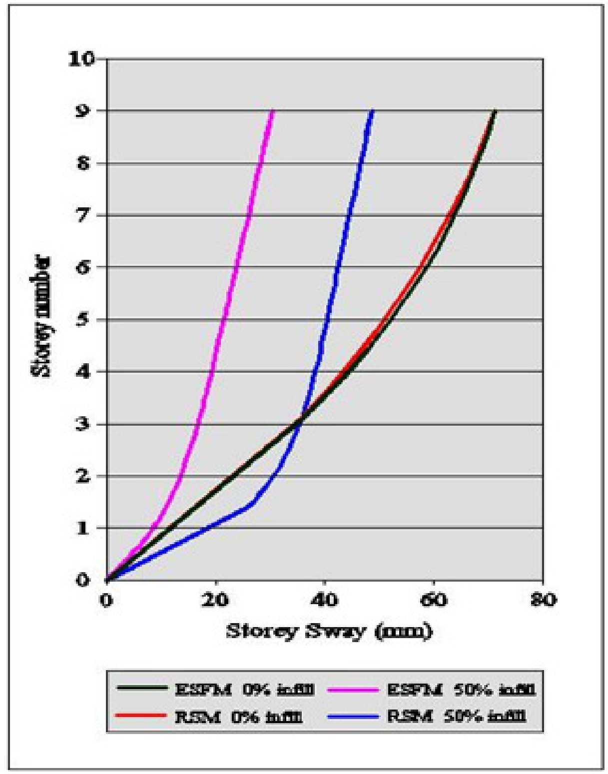

Figure 4.15: Storey sway for 9 storied Building for 50% infill and for No infill condition

5. Conclusions

Earthquake vulnerability of buildings with open ground floors is well known around the world. In such a situation, an investigation has been performed to study the behavior of such buildings subjected to earthquake load so that some guideline could be developed to minimize the risk involved in such type of buildings. It has been found that calculation of earthquake forces by treating them as ordinary frames results in an underestimation of base shear.

Calculation shows that, when RC framed buildings having brick masonry infill on upper floor with soft ground floor is subjected to earthquake loading, base shear can be more than twice to that predicted by equivalent earthquake force method with or without infill or even by response spectrum method when no infill in the analysis model.

The possible schemes to achieve the above are

(i) Provision of stiffer columns in the first storey, and
(ii) Provision of a concrete service core in the building.

The former is effective only in reducing the lateral drift demand on the first storey columns. However the latter is effective in reducing the drift as well as the strength demands on the first storey columns.

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6. Scope of Study

Earthquake vulnerability of buildings with open ground floor is well known around the world. In such a situation, an investigation has been performed to study the behavior of such buildings subjected to earthquake load so that some guideline could be developed to minimize the risk involved in such type of buildings. It has been found that code provisions do not provide any guideline in this regard. Present study reveals that such types of buildings should not be treated as ordinary RC framed buildings. It has been found that calculation of earthquake forces by treating them as ordinary frames results in an underestimation of base shear.

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