

Seismic Analysis of Reinforced Concrete Building with Soft First Storey

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Abstract

Open first storey is now a days unavoidable feature for most of the multistorey buildings in urban areas for vehicle parking, shops etc. Many earthquakes in the past, have demonstrated the potential hazard associated with soft first storey buildings. The first storey become soft and weak relative to the upper stories, since the first storey is composed of only columns while the upper stories are divided by unreinforced masonry infills. Structurally those unbalances are unhealthy and the soft first storey buildings are well known for being susceptible to collapse through past big earthquakes.

In the present paper, an investigation has been performed to examine the behavior of various alternative models of same reinforced concrete moment resisting frame building with an open first storey & unreinforced masonry infills in the upper stories. The structural action of masonry infill panels of upper stories has been taken into account by modeling them as equivalent diagonal struts. The parameters discussed include fundamental natural periods, stiffness of open first storey in relation to the upper storey, lateral displacements, inter-storey drift by linear elastic analysis using ETABS analysis package. It is noticed that significant change in stiffness between the soft storey and upper storey is responsible for increasing the strength demand on first storey columns.

The objective of this paper is to promote safety without too much changing the constructional practice of reinforced concrete structures.

Keywords: Seismic Analysis, Soft Storey, Infill, ETABS.

INTRODUCTION

Earthquakes are natural hazards under which disasters are mainly caused by damage or collapse of buildings. Objective of seismic analysis is stated as the structure should be able to endure minor shaking intensity without sustaining any damage, thus leaving the structure serviceable after the event. The structure should withstand moderate level of earthquake ground motion without structural damage, but possibly with some non-structural damage. The structure should sustain sever earthquake ground motion without collapse of structural framework, but possibly with some structural as well as non-structural damage. Structures need to

have suitable earthquake resistant features to safely resist large lateral forces which are imposed on them during earthquakes. Ordinary structures are usually built to safely carry their own weights and therefore perform poorly under large lateral forces caused by even moderate size earthquake. These lateral forces can produce the critical stresses in a structure and in addition cause lateral sway of the structure.

Soft Storey

Now a days construction of multistoried Reinforced Concrete (RC) frame buildings is becoming common in India. The most common type of vertical irregularity occurs in buildings that have an open ground story. Many buildings constructed in recent times

have a special feature that the ground stories are left open for the purpose of parking, reception etc. Such buildings are often called open ground storey buildings or buildings on stilts. The first stories becomes soft and weak relative to the other upper stories, due absence of masonry walls in the first stories. Structurally those unbalances are unhealthy and soft storey buildings are well known for being susceptible to collapse through past earthquakes.

Behavior of Soft Storey

In buildings with soft first storey the inter-storey drift in the soft first storey is large. The strength demand on the column in the first storey for these building is also large, however in the upper stories the forces in the columns are effectively reduced due to presence of brick infill walls which share the forces. If the first floor is significantly less strong or more flexible, a large portion of the total building deflections tends to concentrate in that floor. The presence of walls in upper stories makes them much stiffer than the open ground storey. Thus the upper stories move almost together as a single block and most of the horizontal displacement of the building occurs in the soft ground storey. Thus, such building behave like an inverted pendulum with the ground story columns acting as the pendulum rod and the rest of the building acting as a rigid pendulum mass during earthquake. As a consequence, large movement occurs in the ground story alone and the columns in the open ground storey are severely stressed. If the columns are weak (do not have the required strength to resist these high stresses), they may be severely damaged which may even lead to collapse of the building.

Soft storey RC frame buildings are commonly analyzed and designed as bare frames. However actual behavior of bare frames is entirely different from that of the

bare frames. In soft storey buildings, ground storey is bare and upper stories are infilled with masonry. Therefore, it is of interest to analyze and compare displacement, stiffness etc. of the same frame, modeling it as bare frame and as soft storey frame. Such comparison will be useful to understand how the performance of soft storey frame is different from that of the bare frame. In this paper seismic analysis have been performed to study the behavior of multistoried RC frame building with four different models by equivalent static analysis (ESA) according to IS 1893 (Part 1): 2002 using commercial software ETABS v9.5.

LITERATURE REVIEW

Arlekar, Jain and Murty (1997), investigated the importance of recognizing the presence of the open first storey in the analysis of the building. They suggested some measures as increasing the size of column in the open first storey and introduction of concrete core, to reduce the stiffness irregularity and to provide adequate lateral strength. FEMA 356 (2000) stated as the elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be represented with an equivalent diagonal compression strut of width, W_{eff} , given by equation below. The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents.

(1)

Where,

$$\lambda_h =$$

(2)

Where λ_h is column height between centerlines of beams, h is height of infill

panel, E_f is modulus of elasticity of frame material, E_m is expected modulus of elasticity of infill material, I_c is moment of inertia of column, L is diagonal length of infill panel and t is thickness of infill panel and equivalent strut. Lee and Woo (2002), investigated the effect of masonry infill on the seismic performance of low rise RC frame with non seismic detailing. Authors concluded that it is essential to consider the effect of masonry infill for the practical evaluation of the seismic safety of the moment-resisting RC frame buildings. Reddy, Rao and Chandrasekaran (2007), determined natural frequency of a seven storey reinforced concrete frame structure with open stilt floor by monitoring its ambient vibrations using a triaxial seismometer and the results were compared with those of the analytical models. They suggested additional structural elements at stilt floor level without affecting parking requirements to improve the performance of the building. Kormaz, Demir and Sivri (2007), investigated a 3-story RC frame structure with different amount of masonry infill walls to understand the effect of infill walls on earthquake response of structures. The diagonal strut approach was adopted for modeling masonry infill wall as shown in figure 1. Authors concluded from the analyses that, the presence of nonstructural masonry infill walls can modify the global seismic behavior of framed buildings to a large extent. The stability and integrity of reinforced concrete frames are enhanced with masonry infill walls. Presence of masonry infill wall also alters displacements and base shear of the frame. The behavior of structure with infilled walls can be predicted by means of simplified diagonal models.

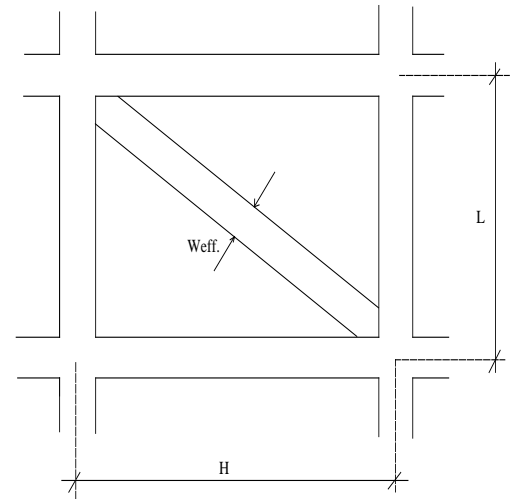


Fig. 1 Compression Diagonal Model

Haque and Khan (2008), discussed 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. 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. Helou and Touqan (2008), illustrated the importance of the judicious distribution of shear walls. They found 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. Dolsek and Fajfar (2008), studied the effect of masonry infill on the seismic response of a four-storey reinforced concrete frame using pushover analysis and the inelastic spectrum approach. Authors concluded from the analyses results that the infill can completely change the distribution of damage throughout the structure. Also they concluded that Simple modeling with equivalent diagonal struts, which carry loads only in compression, is able to simulate the

global seismic response of the infilled frames, and is suitable for practical applications. Kaushik, Rai and Jain (2009), studied several strengthening schemes for masonry infilled reinforced concrete frame buildings with an open first storey for their effectiveness in improving the performance during earthquakes. authors concluded that (a) lateral load performance especially ductility of the open first storey RC frames cannot be improved by using code specified strengthening schemes, i.e., by designing the first storey members for higher forces; and (b) the performance of such frames can be significantly improved by providing additional columns and lateral buttresses in the open first storey.

DESCRIPTION OF RC FRAME BUILDING

Three dimensional reinforced concrete moment resisting frame building with open first storey and unreinforced brick infill walls in the upper stories, chosen for this study. The plan of the building is shown in figure 2. The building considered is having G+9 stories, of which the ground storey is intended for parking. The building is kept symmetric in both orthogonal directions in plan to avoid the torsional effect under pure lateral forces. Furthermore, the columns are taken to be square to keep the discussion focused only on the soft first storey effect, without being distracted by the issue like orientation of columns. Also columns in all models are assumed fixed at the base for simplicity.

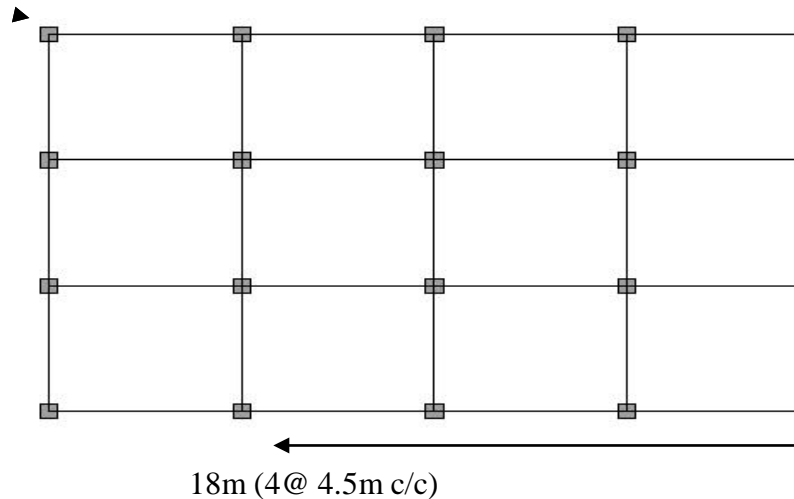


Fig. 2 Plan of Building

The height of the ground floor is 4m and upper storey heights are 3m. Columns and beams are assumed having cross section of 0.4m x 0.4m and 0.23m x 0.4m respectively. Solid slabs are modeled as shell element of 0.13m thickness for all stories. Live load on floor is taken as 3kN/m² and on roof as 1.5kN/m². Floor finish on the floor is 1kN/m². Weathering course on roof is 2kN/m². In the seismic weight calculation only 25% of floor live load is considered. The unit weights of concrete and masonry are taken as 25kN/m³ and 20kN/m³ respectively. Modulus of elasticity of concrete is 22360MPa and that of masonry is 5500MPa. The building is considered to be situated in seismic zone II and intended for residential use.

MODELS CONSIDERED FOR ANALYSIS

Following four models are analyzed using equivalent static analysis method.

Model I: Bare frame.

However, masses of infill walls are included in the model.

Model II: Soft first storey.

Building has no walls in the first storey and external walls (230 mm thick), internal

walls (110 mm thick) in the upper stories

Model III: Soft first storey with walls at corner panels in first storey.

Building has 230mm thick external walls and 110mm thick internal wall in the upper

stories. Further, 230mm thick masonry infill is provided at

corner panels in first storey.

Model IV: Soft first storey with stiffer columns.

Buildings has no walls in the first storey and external walls (230 mm thick), internal

walls (110 mm thick) in the upper stories. However, the columns in the first storey

are stiffer than those in the upper stories (0.6m x 0.6m) to reduce the stiffness irregularity between the first storey and the storey above.

MODELING OF MASONRY INFILL

In the present work, infill panel is modeled as single equivalent diagonal strut connected between two compressive diagonal corners and numerical analysis is carried out to investigate its response to earthquake. The diagonal compression struts is assumed to be pin-connected to the corners of frame at both ends. The modeling of infill panel as single diagonal strut is based on the assumption that the masonry is weak in tension. The cross section area of diagonal strut is a function of the width of strut, as thickness of the strut is taken equal to that of infill panel. The accuracy in the estimation of stiffness of infilled frame very much depends upon the width of strut. The key to the equivalent diagonal strut approach lies in

the determination of the effective width of the strut.

According to FEMA 356, the elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be represented with an equivalent diagonal compression strut of width, W_{eff} , given by equation (1). The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents.

Width of equivalent diagonal strut using eqⁿ (1) is,

$$= 492.14 \text{ mm}$$

ANALYSIS OF THE BUILDING

Equivalent static analysis has been performed as per IS 1893 (Part 1): 2002 for each model using ETABS analysis package. Lateral load calculation and its distribution along the height is done. The seismic weight is calculated using full dead load plus 25% of live load.

RESULTS AND DISCUSSIONS

Equivalent static analysis is performed on model I, II, III, IV. Loads are calculated and distributed as per code IS 1893 (Part I):2002 using ETABS. The results obtained from analysis are compared with respect to the following parameters.

Fundamental Time Period

Table 1 shows comparison of time period calculated by ESA for each model. From table it is observed that Model I gives higher time period compare to other models. The lower time period estimated, imposes larger base shear on the building. Due to inclusion of infill in models time period get reduced.

Table 1: Comparison of Fundamental time period

Model	Longitudinal	Transverse
	ESA	
Model I	0.985	0.985
Model II	0.65	0.86
Model III	0.65	0.86
Model IV	0.65	0.86

Storey Stiffness:

Table 2: Storey Stiffness of first and second storey for each model

Model	Storey Stiffness (kN/mm)			
	Longitudinal		Transverse	
	First	Second	First	Second
Model I	178.8	424.0	178.8	424.0
Model II	178.8	1491.52	178.8	935.58
Model III	550.84	1491.52	360.28	935.58
Model IV	905.58	1491.52	905.58	935.58

From the above results, it is observed that the stiffness of first storey for model I is about 42.16% of second storey stiffness. The stiffness of first storey for model II is about 11.98% and 19.11% of second storey stiffness in longitudinal and transverse direction respectively. Model II represent the realistic situation for earthquake. It is seen that use of brick infill at specific locations (Model III) reduces the stiffness irregularity marginally. In case of model III stiffness of first storey is increased to 36.93% of second storey stiffness. The use of stiffer columns (Model IV) increases the stiffness up to 60.77% and 96% in longitudinal and transverse direction respectively.

is more than the other three models. Model II, III and IV having displacement values 8.61 mm, 6.16 mm, 5.67 mm respectively. This indicates the influence of MI on the displacement of the structure. The reduction in displacement is attributed to the enhanced stiffness of the structure.

Lateral Displacement

Table 3 represents displacement value for each Model along X and Y direction. The result indicates that, the displacement of Model I *i.e.* bare frame is 23.81 mm, which

Table 3: Displacement for each model along longitudinal direction

Storey No.	Displacement (mm)							
	Model I		Model II		Model III		Model IV	
	X dir.	Y dir.	X dir.	Y dir.	X dir.	Y dir.	X dir.	Y dir.
10	23.81	22.73	8.61	9.00	6.16	7.18	5.67	6.50
9	23.05	21.87	8.35	8.65	5.89	6.74	5.44	6.13
8	21.72	20.51	7.98	8.10	5.52	6.20	5.10	5.64
7	19.88	18.69	7.52	7.47	5.00	5.57	4.67	5.00
6	17.62	16.50	7.00	6.77	4.54	4.87	4.18	4.42
5	15.06	14.06	6.43	6.00	3.98	4.14	3.64	3.74
4	12.28	11.45	5.84	5.30	3.38	3.39	3.00	3.00
3	9.37	8.74	5.24	4.54	2.78	2.64	2.50	2.36
2	6.40	6.00	4.66	3.83	2.19	1.93	1.94	1.70
1	3.39	3.22	3.94	3.00	1.57	1.22	1.30	1.00

Fig. 3 Comparison of Displacement Vs Storey for each model along X direction

A graph is plotted taking Storey on X axis and displacement (mm) on Y axis. From graph it is clear that model I have the largest displacement. Most sudden change in slope appears to be in model II from first to second storey, and then it is followed by a smooth displacement distribution. Model III and IV show uniform behavior of displacement from bottom to top of the building. In Model III masonry infill panels are provided at specific locations and in model IV stiffer columns are provided in first storey. Due to this stiffness of first storey get increased. This implies that the crucial displacement may be effectively reduced if the stiffness of the first storey is

made within order of magnitude equal to the stiffness of the story above.

In model III and IV, first storey displacements get reduced up to 60.15% and 67 % respectively as with model II.

CONCLUSIONS

Lateral displacement of bare frame model is higher than other models because of less lateral resistance and stiffness of storey, due to absence of masonry infill walls.

First storey displacement of soft first storey model is maximum than other models due to absence of infill in the first storey.

In soft first storey frame, there is sudden change in drift between first and second storey. Second storey drift is only 18.28% of first storey.

By providing infill at specific locations in first storey and stiffening the first storey columns by increasing the size, there is significant increase in the stiffness, reduction of lateral drift demand, in the first storey column.

Infill increases lateral resistance and initial stiffness of the frames, so they appear to

have a significant effect on the reduction of the lateral displacement.

The use of equivalent diagonal struts at specific positions (Model III) significantly increases the first storey stiffness. The first storey stiffness comes out to be 36.93% of second storey stiffness. It considerably reduces the lateral displacement and shows the smooth drift profile.

Inclusion of infill reduces the fundamental time period of building.

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