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Seismic Performance of RC Frame Building with Soft Stories at Different Level and Its Improving Measures

[1]Prof. Rahul T. Pardeshi, [2]Prof. Dr. Pravinchandra D. Dhake , [3]Prof. Ankush Pendhari
[1]Assistant Professor, SIEM Nashik, India, [2]Associate Professor, KKWIEE&R Nashik, India, [3]Assistant Professor, RHSCOEMS&R Nashik, India.
[1]rahultpardeshi@gmail.com, [2]pddhake2@rediffmail.com, [3]ankushpendhari1@yahoo.com

Abstract - The infill masonry panels are generally considered as non-structural components. However, these panels affect the structural response, the effects of masonry infill on the global seismic response of reinforced concrete structures are the part of study. Open first storey is a typical feature in the modern multistory 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. The present study highlights the seismic performance of RC frame building with soft stories at first as well as at different floor level. A parametric study is performed on an example building with soft storey. The effects of masonry infill and cross bracing on parameters such as stiffness, shear force, bending moment, drift have been studied for a building with soft storey. The modeling and post-processing is carried out using ANSYS software. The comparisons of different parameter of models have also been presented in the study.

***Keywords* —Drift, Infill masonry, Seismic Response, Soft Storey, Storey Stiffness.**

I. INTRODUCTION

Construction of multistoried building with open first storey is a common practice in India. This is an unavoidable feature and is generally adopted for parking of vehicles reception lobbies [11]. Such a building in which the upper stories have brick infill wall panel and open ground storey is called stilt building and the open storey is called as stilt floor or soft storey and such features are highly undesirable in building built in seismically active areas [8].

The Indian seismic code IS 1893:2002 defines the soft storey as the one in which the lateral stiffness is less than 70% of that in the storey immediately above or less than 80% of combined stiffness of three stories above [16]. The essential characteristics of soft storey consist of discontinuity of strength or stiffness, which occurs at the second storey level. This discontinuity is caused because of lesser strength or increased flexibility in the first storey structure that results in extreme deflection in the first storey, which in turn results in the concentration of forces at the second storey connections; in that case collapse is unavoidable. So there is a need to evolve the safe design for the building with the functional requirement of parking.

However, the building response excluding infill walls at single or different number of stories under seismic loading is very complex and math intensive. Although the infill panels significantly enhance both the stiffness and strength of the frame, their contribution is often not taken into account because of the lack of knowledge of the composite behavior of the frame and the infill [12].

The objectives of the work is to focus on seismic performance of RC frame building with soft stories and to inspect the failure mechanism of soft storey building with analytical studies by using ANSYS software.

1. To describe the performance characteristics such as stiffness, axial force, shear force, bending moment and etc. at soft storey or stories at different-different level.
2. Checking suitability of soft storey at different floor level.
3. Suggesting remedial measure to minimize the stress generated at soft storey in earthquake.

II. BUILDING DESCRIPTION

To study the behavior of RC frame building with soft storey, an apartment building with simple symmetric plan is selected. Height of each storey is 3m. The building has plan dimensions 19m x 20m and is symmetric in both orthogonal directions as shown in figure 1. The building is assumed to be located in seismic zone III and it has 15 stories and total eleven plane frames in all directions. It is assume to be built on hard soil strata. In the analysis ordinary special RC moment-resisting frame (OMRF) of M 25 Grade concrete is considered.

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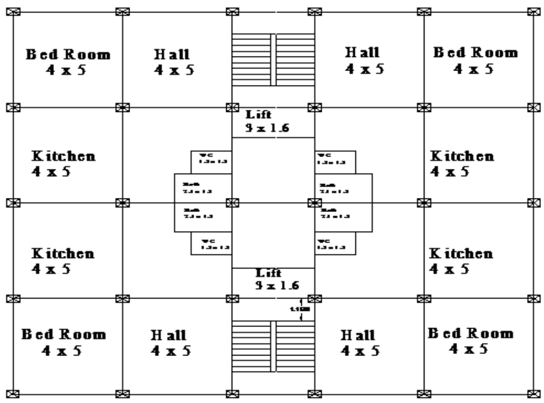


Fig. 1. Proposed Line Plan of RCC Apartment Building

ANSYS finite element software is used for analysis of different plane frames, frames with soft storey at different levels. For better understanding of pure seismic response of RC frames with soft stories at different levels, only seismic forces are considered on frames at different floor level. Size of all beams are 250mm x 400mm, Size of all columns are 400mm x 500mm, Slab thickness is 150mm, Wall thickness is 230mm and Storey Height is 3000mm used for analysis. Unit weight of concrete and brick masonry is 25 kN/m^3 and 19 kN/m^3 respectively taken. Modulus of Elasticity of concrete [17] $=5000\sqrt{fck} = 25000$ N/mm^2, Modulus of Elasticity of brick masonry [1] = 6300 N/mm^2, Poisons Ratio of concrete = 0.3, Poisons Ratio of masonry = 0.25 are used.

The modeling is done using the ANSYS finite element software. Beams and columns are modeled as two nodes beam element with six DOF at each node in preprocessor. Walls are modeled by Equivalent Strut Approach. The diagonal length of the strut is same as the brick wall diagonal length with the same thickness of strut as brick wall, only width of strut is derived manually. The strut is assumed to be pinned at both the ends to the confining frame. In the modeling material is considered as an isotropic material.

The following models have been studied and performance analysis is done in general post-processing of ANSYS software.

Model I: Building having brick infill masonry wall at all stories.

Model II: Building having no wall in the ground storey and brick infill masonry at remaining upper stories.

Model III: Building having no wall in the ground floor and second floor, brick infill masonry at remaining stories.

Model IV: Building having no wall in the second floor and fifth floor, brick infill masonry at remaining stories.

Model V: Building having no wall in the fifth floor and seventh floor, brick infill masonry at remaining stories.

Model VI: Steel bracing in stair case portion in longitudinal direction frame with infill remaining portion.

Model VII: Building having brick wall in side panel at ground floor and no wall in middle portion of ground floor in transverse direction.

Model VIII: Building having Steel Bracing in side panel at ground floor and no wall in middle portion of ground floor in transverse direction.

III. STRUCTURAL ANALYSIS

Self weight of beams, columns; slabs, infill wall panels, Stair case weight and weight of RCC lift duct and is calculate from assumed dimensions. Intensity of live load is taken as 2 kN/m^2 at each storey except at roof floor. According to IS 1893 (part 1): 2002, for Zone III, seismic coefficient method is used to calculate the seismic forces and base shear. Seismic forces at each storey level are calculated by distribution formula. Vertical distribution of base shear to different floor along the height of building is given by formula,

$$Qi = V_B \frac{x\ Wi\ x\ Hi^2}{\sum Wi\ x\ Hi^2}$$

Where, Qi is lateral forces at roof of floor i in kN and Hi is Height floor measured from the base of building in m.

Equivalent Diagonal Strut Width (Wef) is calculated by using formula

$$W_{ef} = 0.175\left(\lambda_h H\right)^{-0.4}\sqrt{H^2+L^2}$$

where

$$\lambda_h = \sqrt[4]{\frac{E_i t \sin 2\theta}{4E_c I_c H_i}}$$

Where, H and L are the height and length of the frame, Ec, and Ei are the elastic moduli of the column and of the infill panel, t is the thickness of the infill panel, q is the angle defining diagonal strut, Ic is the modulus of inertia of the column and Hi is the height of the infill panel [6].

IV. RESULTS AND DISCUSSION

The present study highlights the seismic performance of RC frame building with soft stories at first as well as at different floor level. The performance characteristics such as stiffness, deflection, shear force and bending moment are studied. The analysis results of different models are discussed. The modeling and post-processing is carried out using ANSYS software. The comparisons of different parameter of models have also been presented in this study.

Storey Stiffness: In present analysis, for calculation of storey stiffness for building models I to V in transverse as well as longitudinal direction, the blank lower storey without infill and corresponding upper storey with infill are considered. The storey stiffness is defined as the magnitude of the force couple required at the floor levels adjoin the storey to produce a unit lateral translation within the storey, letting all the other floors to move freely. For stiffness calculation separate modeling of building frame is done in ANSYS software and from result of deflection storey stiffness is worked out. For different building frame models the stiffness of storey without infill and corresponding upper storey as well as presence of soft storey is shown in table no. 1

TABLE NO. 1
STOREY STIFFNESS

Model Name	Lower Storey	Storey Stiffness		K_i	$0.7K_{i-1}$	Is It Soft Sotrey? ($K_i < 0.7K_{i-1}$)
		Blank Storey	Upper Storey			
Model 1st	G-Floor	361010.8	361010.83	361010.8	252707	No
Model 2nd	G-Floor	121876.9	354484.23	121876.9	248139	Yes
Model 3rd	G-Floor	125580.8	343760.74	125580.8	240632	Yes
	2nd-Floor	126103.4	360620.27	126103.4	252434	Yes
Model 4th	2nd-Floor	126103.4	359841.67	126103.4	251889	Yes
	5th-Floor	126103.4	360620.27	126103.4	252434	Yes
Model 5th	5th-Floor	125580.8	343760.74	125580.8	240632	Yes
	7th-Floor	126103.4	360620.27	126103.4	252434	Yes

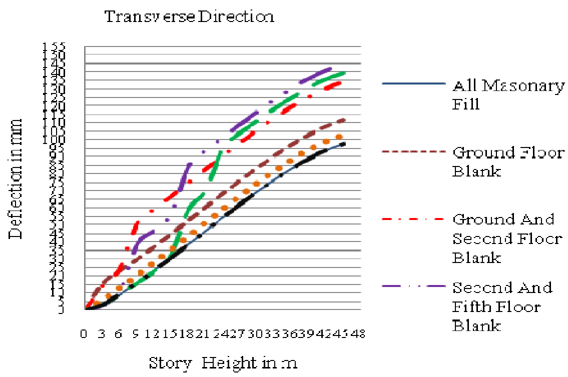
From results of stiffness, it is clear that all models except first one show soft storey. The stiffness irregularity in building models with soft storey is evident from the fact that the stiffness of blank storey for models II to V is about 35% less than that of corresponding upper storey stiffness, as the clause no. 4.20 of IS 1893 (Part I): 2002 says if storey in which the lateral stiffness is less than 70 % of that in the storey above or less than 80 % of the average lateral stiffness of the three storey above. While model I show no stiffness irregularity as because stiffness of all floor are same as they are fully infill storey.

Lateral Displacement: Maximum displacements of different building models using equivalent static analysis are shown in following table no. 2

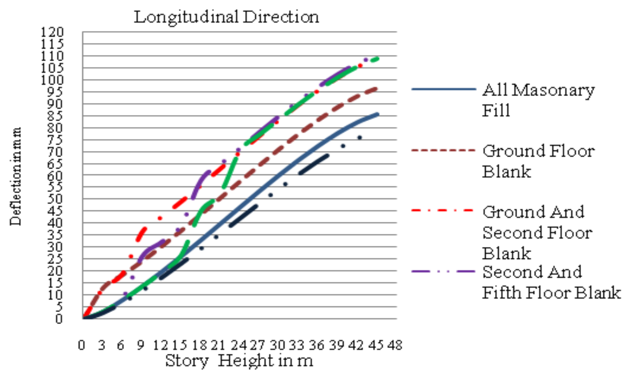
TABLE NO. 2
MAXIMUM DISPLACEMENT

Building Models	Maximum Displacement (mm)	
	Transverse Direction	Longitudinal Direction
Model I	98.76	87.84
Model II	112.81	98.73
Model III	134.70	110.89
Model IV	145.49	112.71
Model V	140.39	111.15
Model VI	-	81.78
Model VII	103.82	-
Model VIII	98.75	-

The Abrupt change in displacement profile indicates the stiffness irregularity. As well as graph shows that if soft storey shifted above and above the displacement values increases. As comparison of maximum displacement of model II with III and V, it concludes that while increase in number of soft storey in building displacement percentage increases upto15% to 20%. Model IV shows most severe and maximum value of displacement as compared to other models. As comparison of result of model IV with other model it is clear that if spacing between two soft stories increases deflection of building increases. The provision of side masonry in ground floor in model VII shows 8% to 10% reduction in displacement value as compared to model II in transverse direction. As well as the provision of side steel bracing in ground floor in model VIII shows near about same value of displacement of model I and also shows smooth displacement curve. The graph of transverse direction shows grater displacement as compared to graph of longitudinal direction. Model VI shows less value of displacement as compared to other model because of provision of steel bracing in staircase portion. It shows 25% of reduction in displacement in longitudinal frame. Graph no. 1 and 2 are plotted taking storey height as the ordinate and the storey displacement as the abscissa for different models in the transverse and longitudinal direction.



Graph No. 1 Lateral Deflection of Different Models of Building Frame in Transverse Direction



Graph No. 2 Lateral Deflection of Different Models of Building Frame in Longitudinal Direction

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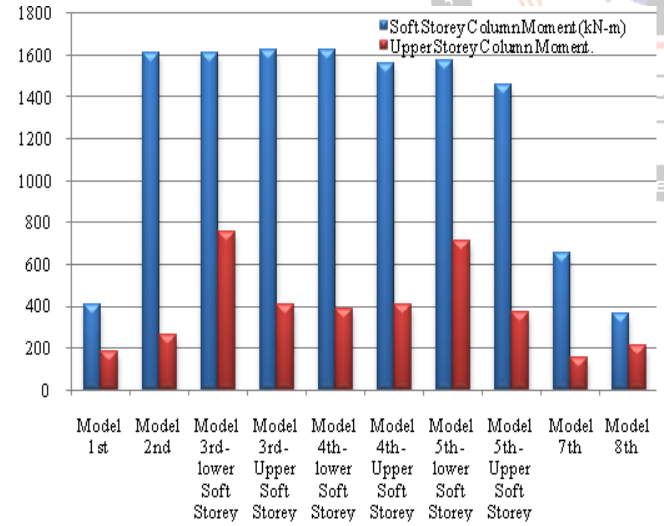
Bending Moment and Shear Force: Maximum moment and maximum shear forces in soft storey columns and maximum forces in the columns of the storey above for different models for transverse frame are shown in following table no. 3

TABLE NO. 3

TRANSVERSE FRAME BENDING MOMENT AND SHEAR FORCE

Transverse Frame							
Parameter		Maximum Moment (kN-m)		Maximum Shear Force(kN)			
				Along X Direction		Along Y Direction	
Model Name	Lower Floor	Blank Storey	Upper Storey	Blank Storey	Upper Storey	Blank Storey	Upper Storey
Model 1st	G -Floor	404.61	183.39	3249.3	3069.8	134.87	61.13
Model 2nd	G -Floor	1608.0	262.80	3242.3	3134.3	536.01	90.919
Model 3rd	G -Floor	1611.0	758.53	3259	3205.7	537.01	252.84
	2nd -Floor	1627.4	403.20	2639.3	2562.6	536.84	134.40
Model 4th	2nd -Floor	1622.2	388.51	2681	2602.3	540.74	129.50
	5th- Floor	1562.0	407.49	1770.6	1697.0	520.66	135.83
Model 5th	5th- Floor	1574.6	712.94	1814.2	1749.1	524.86	237.65
	7t - Floor	1455.8	367.74	1210.3	1145.0	485.26	122.58
Model 7th	G -Floor	656.88	154.35	3491.8	3112.9	218.96	51.451
Model 8th	G -Floor	365.72	213.08	3367.6	3006.3	121.87	71.027

Graph no. 3 is plotted taking different models as the ordinate and the results of bending moments are as the abscissa for different models in the transverse direction.



Graph No. 3 Bending Moments of Different Models of Building Frame in Transverse Direction

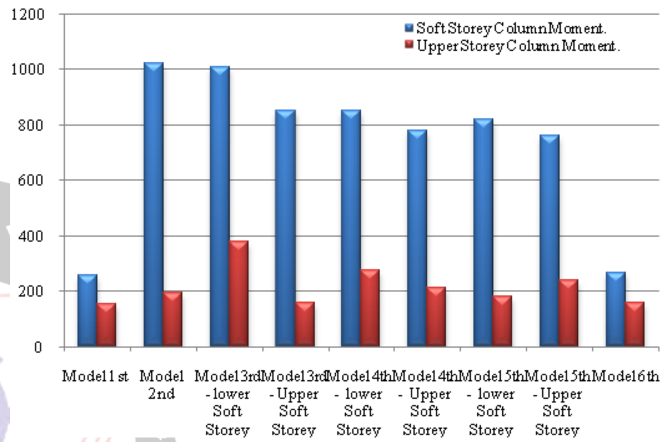
Maximum moment and maximum shear forces in soft storey columns and maximum forces in the columns of the storey above for different models for longitudinal frame are shown in following table no. 4

TABLE NO. 4

LONGITUDINAL FRAME BENDING MOMENT AND SHEAR FORCE

Longitudinal Frame							
Parameter		Maximum Moment (kN-m)		Maximum Shear Force(kN)			
				Along X Direction		Along Y Direction	
Model Name	Lower Floor	Blank Storey	Upper Storey	Blank Storey	Upper Storey	Blank Storey	Upper Storey
Model 1st	G-Floor	256.34	155.26	3110.4	2921.2	170.89	116.97
Model 2nd	G-Floor	1022.2	194.37	3096.6	2973.9	681.46	129.58
Model 3rd	G-Floor	1008.7	375.70	2991.6	2932.9	660.09	125.23
	2st- Floor	848.34	157.55	2530.5	2464.6	419.25	155.87
Model 4th	2st- Floor	850.54	275.84	2483.1	2416.6	443.23	183.89
	5th- Floor	778.37	213.71	1750.6	1687.2	412.43	134.64
Model 5th	5th- Floor	818.91	178.73	1676.6	1619.9	418.92	119.15
	7th- Floor	760.75	239.64	1240.9	1181.2	394.99	159.76
Model 6th	G-Floor	266.64	155.90	2938.4	2786.8	177.76	103.93

Graph no. 4 is plotted taking different models as the ordinate and the results of bending moments are as the abscissa for different models in the longitudinal direction.



Graph No. 4 Bending Moments of Different Models of Building Frame in Longitudinal Direction

The results show that the bending moment and shear force (strength) demands are severely higher for soft storey columns, in case of the soft storey buildings. As the force is distributed in proportion to the stiffness of the members, the force in the columns of the upper storey above soft storey, for all the models are significantly reduced due to the presence of brick infill walls. From comparison of results of bending moment of full infill model (Model I) with soft storey model (Model II to V), it is clear that presence of soft storey in building increases bending moments by 75% in soft storey columns. In model II, the bending moments are 85% higher in soft storey columns as compared with upper infill storey columns. In model III, the bending moments are 53% higher in ground soft storey are 75% higher in 2nd floor soft storey columns as compared with upper infill storey columns respectively. The provision of side masonry in ground floor in model VII shows 60% reduction in bending moment value as compared to model II in transverse direction. As well as the provision of side steel bracing in ground floor in model VIII shows near about same value of bending moment of model I in transverse direction. The

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provision of steel bracing in staircase portion in model VI does not affect much more the results of bending moment with comparison of model I results in longitudinal frame.

V.CONCLUSIONS

In multistoried building for parking of vehicles, ground storey is always used with open spaces. As well as by adoption of new practices, now a day's parking area is also provided in upper stories. But it is necessary to check their behavior during earthquake. So the present study as a dissertation part highlights the behavior of RC frame with soft storey at ground floor as well as at upper stories also. From results of analysis the following conclusions are found.

The stiffness irregularity in building models with soft storey is evident from the fact that the stiffness of blank storey is less than that of corresponding upper storey stiffness.

If soft storey shifted above and above the displacement values increase.

If spacing between two soft stories increases, the deflection of building increases.

The provision of side masonry and side steel bracing significantly increase stiffness and it considerably reduce the lateral deflection and show smooth drift profile without affecting parking utility. Steel bracings are found to be most effective in reducing stiffness irregularity, storey drift and strength demand in building with soft storey without affecting utility.

In case of the soft storey buildings the bending moments and shear forces value are severely higher for soft storey columns as compare to upper storey columns.

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