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Influence of Provision of Soft Storey in RC Frame Building for Earthquake Resistance Design

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Abstract

Soft storey or open ground storey is an unavoidable feature in the multistorey building. It is open for the purpose of parking or reception lobbies. It is also called as stilts storey. A large number of buildings with soft storey have been built in India in recent year. But it showed poor performance during past earthquake. Therefore it is need of time to take immediate measures to prevent the indiscriminate use of soft first storeys in buildings, which are designed without regard to the increased displacement and force demands in the first storey columns. In this regard, this paper talks about the provided strength and stiffness to the building frame by modified soft storey provision in two ways, (i) By providing stiff column & (ii) By providing adjacent infill wall panel at each corner of building frame. Also study has been carried out to compare modified soft storey provisions with complete infill wall frame and bare frame models.

Keywords– Soft storey, masonry infill, RC frame, earthquake, displacement, drift.

I. INTRODUCTION

Reinforced concrete (RC) frame buildings are becoming increasingly common in urban India. Many such buildings constructed in recent times have a special feature - the ground storey is left open for the purpose of parking , i.e columns in the ground storey do not have any partition walls (of either masonry or RC) between them. Such buildings are often called open ground storey buildings or buildings on stilts. The relatively flexible in the ground storey or the relative horizontal displacement it undergoes in the ground storey is much larger than the above storeys, this flexible ground storey is called soft storey (Fig.1).

1. Performance of soft storey building

A large number of buildings with open ground storey have been built in India in recent years. Open ground storey buildings have consistently shown poor performance during past earthquakes. Huge number of similarly designed and constructed buildings exists in the various towns and cities situated in moderate to severe seismic zones of the country. The presence of walls in upper storeys makes them much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. It gives result to collapse of the building

.

2. Provisions to soft storey

2.1. By stiff column at open ground storey: The effects of stiffness is very important as if the setting of the stiffening elements at structure and their geometrical specifications are not opted accurately, the structure may undergo amplify against the earthquake waves and the structure may be subject to fracture and may even lose its practical aspects. If the stiffness of structure elements in multi-storey structures alters, it can precipitate the vibration of structural modes shape. Stiffness of a column means resistance to deformation- the larger is the stiffness, larger is the force required to deform it. In this study, the seismic vulnerability of buildings with soft first storey is shown with the help of core-study. The drift and the strength demands in the first storey columns are very large for buildings with soft ground storeys. Thus, it is important to incorporate the stiff column at open ground storey [1].

2.2. By provide adjacent infill wall panel at each corner of open ground storey in building frame: Masonry infill is normally considered as non-structural elements and their stiffness contributions are generally ignored in practice. Masonry infill has several advantages like good sound and heat insulation properties, high lateral strength and stiffness. These help to increase the strength and stiffness of RC frame and hence to decrease lateral drift, energy dissipation capacity due to cracking of infill and friction between infill and frame. This in turn increases redundancy in building and reduces bending moment in beams and columns. Masonry infill has disadvantages like very high initial stiffness and compressive strength. This also induces torsional effect in the structure if not symmetrically placed [3]. While analyzing multi storey buildings, designers usually neglect the contribution of masonry infill in resisting loads. They consider only dead weight of masonry and analysis is done by bare frame method. The present study has been carried out the effect of masonry infill at adjacent side of each corner of the open ground storey for 12 storied building using SAP 2000 software.

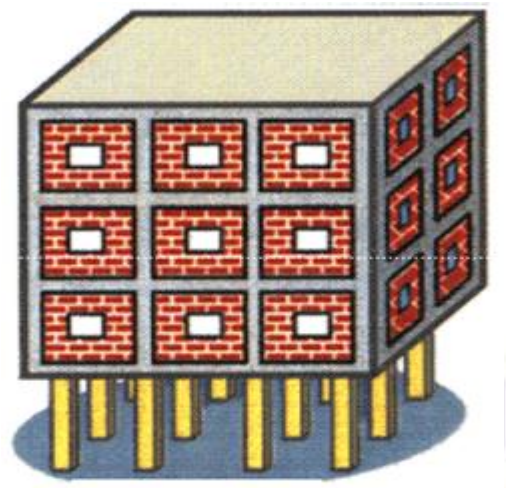


Fig1: Soft Storey or Open Ground Storey building [5].

3. Classification based on IS 1893 code:

3.1. Soft storey: It is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeyes above.

3.2. Weak storey: It is one in which the storey lateral strength is less than 80 percent of that in the storey above. The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.[5]

The aim of the present analytical work is to study the performance of soft storey building by modified provision at open ground storey with hazardous features need to be recognized immediately and necessary measure taken to improve performance of building, to minimized the lateral deflection, to assess the economic structure.

II. ANALYTICAL WORK

A 12- storey building with RC moment resisting frame with open first storey and unreinforced brick infill walls (panels) in upper storeys, chosen for this study. The building is deliberately kept symmetric in both orthogonal directions in plan to avoid torsional response under pure lateral forces.

1. Types of cases used for analysis of structure

There are three basic cases with sub-cases considered to analyze 12-storey (G+11) structure so that proper provision of soft storey can be predicted.

(I) General building models: (Fig.2)

(I.1) Building with one full infill masonry wall (230mm) (External &internal wall) in all storey including ground storey.

(I.2) Building modeled as bare frame. However, masses of the walls as in model **I.1** are included in the model.

(II)Building model with soft storey: (Fig.3)

(II.1) Building model with no masonry wall in first ground storey and full infill masonry wall (230mm) (External &internal wall) in all above storeyes.

(II.2) Building model with no masonry wall in first three storey (G+2) and full infill masonry wall (230mm) (External &internal wall) in all above storeyes.

(II.3) Building model with no masonry wall in first six storey (G+5) and full infill masonry wall (230mm) (External &internal wall) in all above storeyes.

(III) Building models present with modified soft storey provision: (Fig.4)

(**III.1**)Building model with no masonry wall in first ground storey and full infill masonry wall (230mm) (External &internal wall) in all above storeyes, and provided with ground storey columns much stiffer as compared to above storey columns.

(**III.2**)Building model with one full infill masonry wall at the adjacent side of each corner in first ground storey and one full infill masonry wall (230mm) (External &internal wall) in all above storeyes.

2. Structural Data

Building consists of 15 m in short & 35 m in long direction, so from preliminary design the sizes of various structural members were estimated as follows Brick masonry wall Thickness: Brick masonry wall (modulus of elasticity E=13500000KN/m^2 [2] & Poisson's ratio of masonry μ= 0.15) is provided with 230 mm thickness for all storey of different cases. And 1.5m height parapet wall is also considered. Storey height is kept as 4.1m for open ground floor and 3.1m for all upper floors. Grade Fe-415 hot rolled deformed steel is used. Concrete having M-20 ($E=5000\sqrt{f_{ck}}$ as per IS456) strength for columns, beams and slabs is to be employed. Columns were kept of 18"x18" (450x450mm) size for overall structure and 27.5″x27.5″ (700 x 700 mm) size only for stiff column provision to avoid the local eccentricity. All beams are of uniform size of 12″ × 18″ (300 × 450mm) having 6″ (150 mm) thick slab for all the spans.

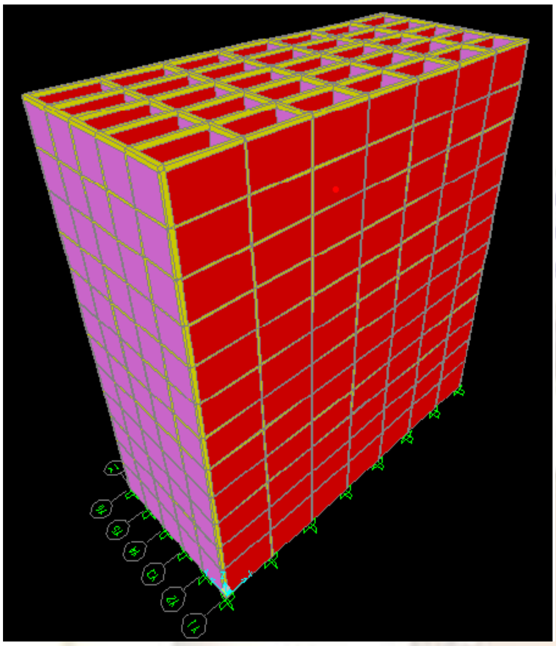
3. Gravity loading (As per IS: 456 – 2000 & IS: 875 (Part II)-1987) For Dead Load (DL), Intensity of wall =16.79KN/m (for4.1mheight) & =12.19 KN /m (for 3.1m height), Intensity of parapet wall =6.9 KN /m (for 1.5m height), Intensity of slab load=3.75 KN /m^2, Intensity of floor finish load=1 KN /m^2, Intensity of roof treatment load=1.5 KN /m^2 and Intensity of live load (LL)=3 KN /m^2.

4. Lateral loading (as per IS1893-2002) Lateral loading consists of earthquake loading. Earthquake loading has been calculated by the program and it has been applied to the mass center of the building. Since the building under consideration was in Zone –III with standard occupancy so the result was computed as follows:

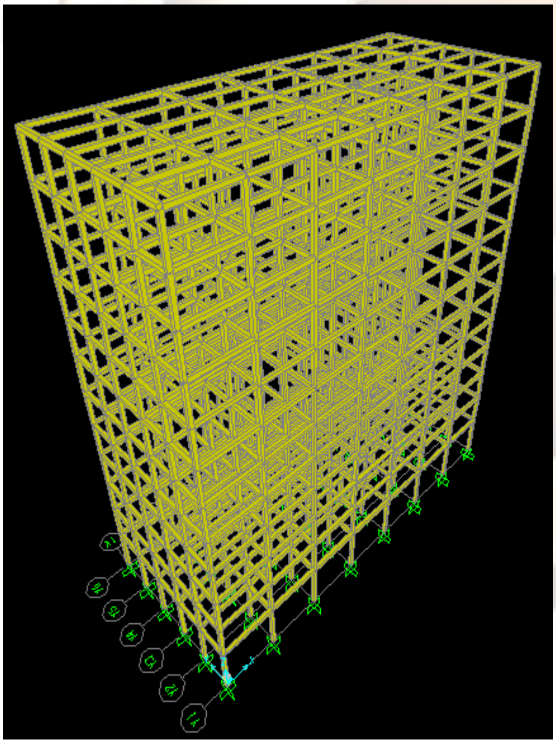
Case: 1.2(DL+LL+EQX) and 1.2(DL+LL+EQY)
Period Calculation: Program & by Code Calculated
Bottom Storey: Open ground storey or Base
Response reduction factor, R = 5

Importance factor, I = 1
Building Height H = 38.2 m
Soil Type = II (Medium Soil)
Seismic zone factor, Z = 0.16

5. Figure showing considered building models

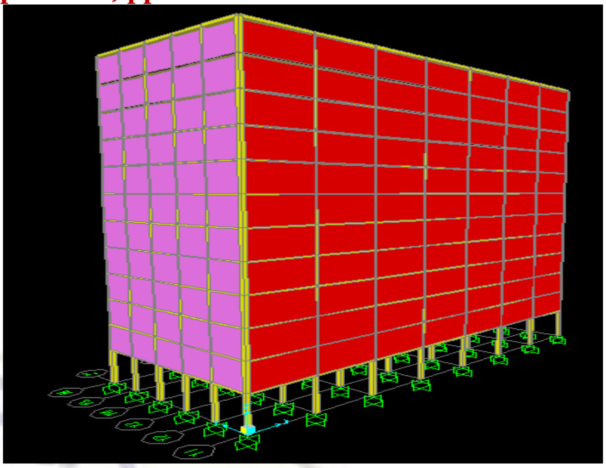


(I.1)



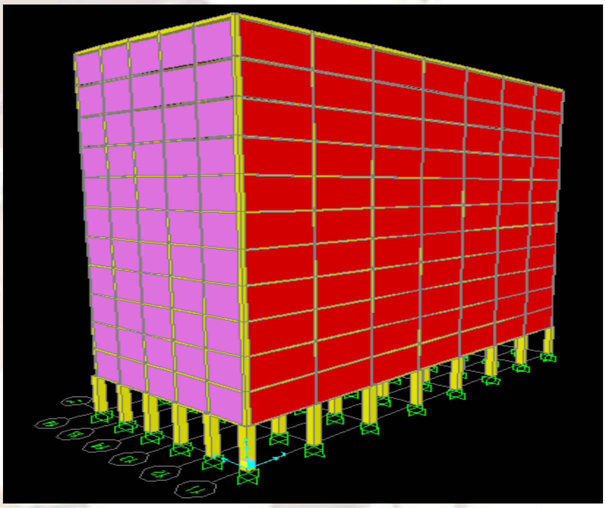
(I.2)

Fig 2: General building models – (I.1) Complete infill masonry & (I.2) Bare frame.

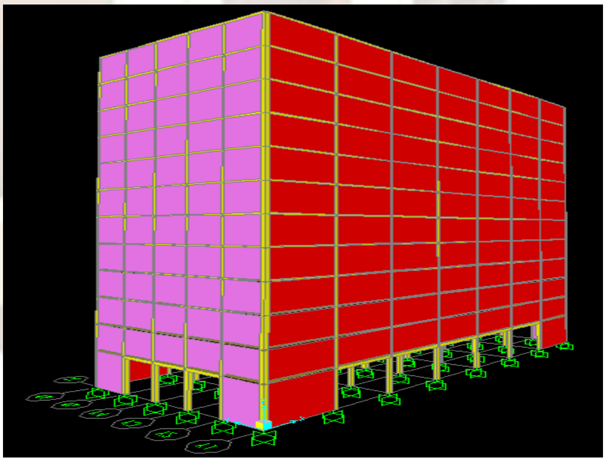


(II.1)

Fig3: Building models present with soft storey- (II.1) Ground storey as a Soft storey,



(III.1)



(III.2)

Fig4: Building models present with modified soft storey provision- (III.1) Stiff column at Open Ground Storey (i.e. Soft storey), (III.2) One full infill masonry wall at the adjacent side of each corner in Open Ground Storey.

6. Analysis of the building

Response spectrum analysis is performed for the seven models of the building using SAP2000. The frame members are modeled with rigid end zone, the walls are modeled as panel element and floor are modeled as diaphragms rigid in plane. The lateral loads generated by SAP correspond to the seismic zone III and the 5% damping response spectrum given in IS 1893-1984. The natural period values are calculated by SAP, by solving the eigen value problem of the model. Thus the total earthquake load generated and its distribution along the height corresponding to the mass and stiffness distribution as modeled by SAP.

III. RESULTS AND DISSCUSSIONS

The maximum displacement, maximum bending moment & shear force and fundamental natural period results for the 12-storey structure are obtained on the of three different cases i.e. (I) General building models I.1 & I.2, (II) Building models present with soft storey II.1, II.2 & II.3 and (III) Building models present with modified soft storey provision III.1 & III.2 for 1.2(DL+LL+EQX) (earthquake force from X-direction) & 1.2(DL+LL+EQY) (earthquake force from Y-direction).

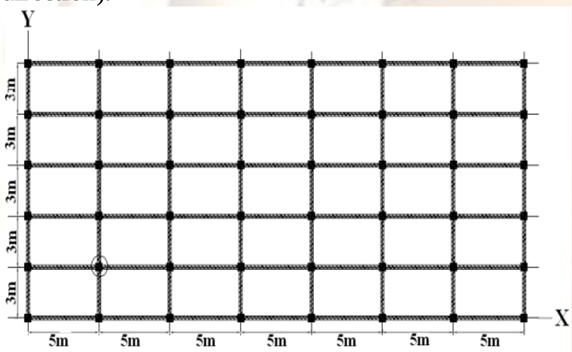


Fig 5: Plan of structure.

1. Maximum Lateral Displacement:

Table 1: (I) General building models

Comparison of max. disp. of Models I.1 & I.2 in X-dir.

Joint No.	Storey Height(m)	Model (I.1) (mm)	Model (I.2) (mm)
1	0	0	0
2	4.1	0.0718	12.7
3	7.2	0.135	23.9
4	10.3	0.204	34.5
5	13.4	0.276	44.3
6	16.5	0.350	53.2
7	19.6	0.424	61.4
8	22.7	0.497	68.6
9	25.8	0.567	74.8
10	28.9	0.633	80
11	32	0.695	84
12	35.1	0.750	86.8
13	38.2	0.799	88.2

Table 2: (I) General building models

Comparison of max. disp. of Models I.1 & I.2 in Y-dir.

Joint No.	Storey Height(m)	Model (I.1) (mm)	Model (I.2) (mm)
1	0	0	0
2	4.1	0.0903	7.07
3	7.2	0.183	12.7
4	10.3	0.292	18
5	13.4	0.414	22.9
6	16.5	0.545	27.6
7	19.6	0.683	31.8
8	22.7	0.826	35.7
9	25.8	0.696	39.1
10	28.9	1.11	42.1
11	32	1.25	44.5
12	35.1	1.38	46.3
13	38.2	1.51	47.5

Table 3: (II)Building models present with soft storey

Comparison of max. disp. of Models II.1, II.2 & II.3 in X-dir.

Joint No.	Storey Height (m)	Model (II.1) (mm)	Model (II.2) (mm)	Model (II.3) (mm)
1	0	0	0	0
2	4.1	9.10	11.9	10.1
3	7.2	9.21	22.3	19.2
4	10.3	9.29	30	27.9
5	13.4	9.38	30.2	36.3
6	16.5	9.47	30.3	44
7	19.6	9.56	30.4	49.7
8	22.7	9.64	30.6	49.9
9	25.8	9.72	30.7	50
10	28.9	9.79	30.8	50.2
11	32	9.86	30.9	50.3
12	35.1	9.93	31	50.4
13	38.2	9.99	31.1	50.6

Table 4: (II)Building models present with soft storey				
Comparison of max. disp. of Models II.1, II.2 & II.3 in Y-dir.				
Joint No.	Storey Height (m)	Model (II.1) (mm)	Model (II.2) (mm)	Model (II.3) (mm)
1	0	0	0	0
2	4.1	5.59	6.66	5.63
3	7.2	5.79	12	10.2
4	10.3	5.98	16.2	14.6
5	13.4	6.18	16.5	18.9
6	16.5	6.39	16.8	23
7	19.6	6.60	17.2	26.2
8	22.7	6.81	17.5	26.6
9	25.8	7.02	17.8	27.1
10	28.9	7.23	18.2	27.5
11	32	7.44	18.5	27.9
12	35.1	7.64	18.8	28.3
13	38.2	7.83	19.1	28.7

Table 5: (III) Building models present with modified soft storey provision			
Comparison of max. disp. of Models III.1 & III.2 in X-direction			
Join t No.	Storey Height(m)	Model (III.1) (mm)	Model (III.2) (mm)
1	0	0	0
2	4.1	2.60	0.689
3	7.2	2.68	0.767
4	10.3	2.74	0.846
5	13.4	2.81	0.926
6	16.5	2.88	1.01
7	19.6	2.94	1.08
8	22.7	3.00	1.16
9	25.8	3.06	1.23
10	28.9	3.11	1.30
11	32	3.16	1.37
12	35.1	3.21	1.43
13	38.2	3.25	1.49

Table 6: (III) Building models present with modified soft storey provision			
Comparison of maximum displacement of Models III.1 & III.2 in Y-direction			
Joint No.	Storey Height(m)	Model (III.1) (mm)	Model (III.2) (mm)
1	0	0	0
2	4.1	1.54	0.732
3	7.2	1.67	0.880
4	10.3	1.79	1.04
5	13.4	1.93	1.21
6	16.5	2.07	1.39
7	19.6	2.21	1.58
8	22.7	2.36	1.77
9	25.8	2.50	1.95
10	28.9	2.64	2.14
11	32	2.78	2.32
12	35.1	2.92	2.50
13	38.2	3.04	2.67

Table 7: Comparison of I.1,II.1,III.1 & III.2					
Maximum displacement in X-direction					
Joint No.	Storey Height (m)	Model (I.1) (mm)	Model (II.1) (mm)	Model (III.1) (mm)	Model (III.2) (mm)
1	0	0	0	0	0
2	4.1	0.0718	9.10	2.60	0.689
3	7.2	0.135	9.21	2.68	0.767
4	10.3	0.204	9.29	2.74	0.846
5	13.4	0.276	9.38	2.81	0.926
6	16.5	0.350	9.47	2.88	1.01
7	19.6	0.424	9.56	2.94	1.08
8	22.7	0.497	9.64	3.00	1.16
9	25.8	0.567	9.72	3.06	1.23
10	28.9	0.633	9.79	3.11	1.30
11	32	0.695	9.86	3.16	1.37
12	35.1	0.750	9.93	3.21	1.43
13	38.2	0.799	9.99	3.25	1.49

Table 8: Comparison of I.1,II.1,III.1 & III.2					
Maximum displacement in Y-direction					
Joint No.	Storey Height (m)	Model (I.1) (mm)	Model (II.1) (mm)	Model (III.1) (mm)	Model (III.2) (mm)
1	0	0	0	0	0
2	4.1	0.0903	5.59	1.54	0.732
3	7.2	0.183	5.79	1.67	0.880
4	10.3	0.292	5.98	1.79	1.04
5	13.4	0.414	6.18	1.93	1.21
6	16.5	0.545	6.39	2.07	1.39
7	19.6	0.683	6.60	2.21	1.58
8	22.7	0.826	6.81	2.36	1.77
9	25.8	0.696	7.02	2.50	1.95
10	28.9	1.11	7.23	2.64	2.14
11	32	1.25	7.44	2.78	2.32
12	35.1	1.38	7.64	2.92	2.50
13	38.2	1.51	7.83	3.04	2.67

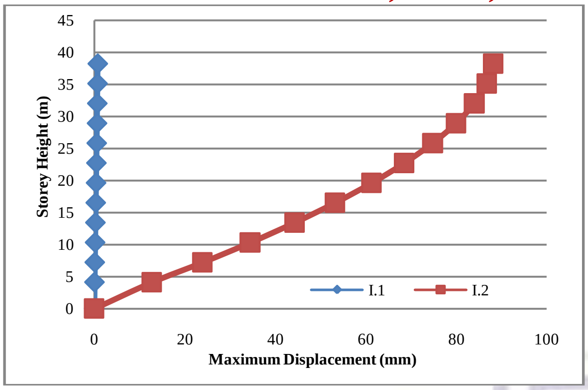


Fig 6: Comparison of max. disp. for General building models I.1 & I.2 in X-dir. with respect to height. (Table 1)

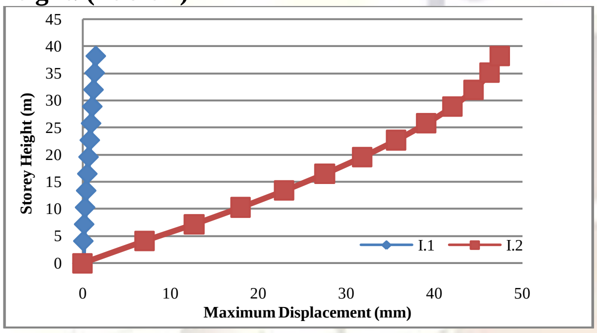


Fig 7: Comparison of max. disp. for General building models I.1 & I.2 in Y-dir. with respect to height. (Table 2)

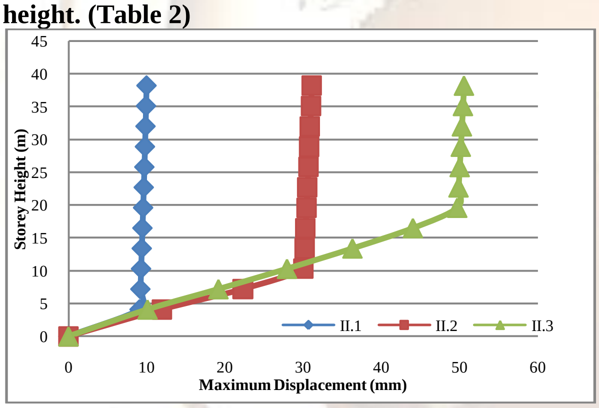


Fig 8: Comparison of max. disp. of Building models present with Soft storey II.1, II.2 & II.3 in X-dir. (Table3)

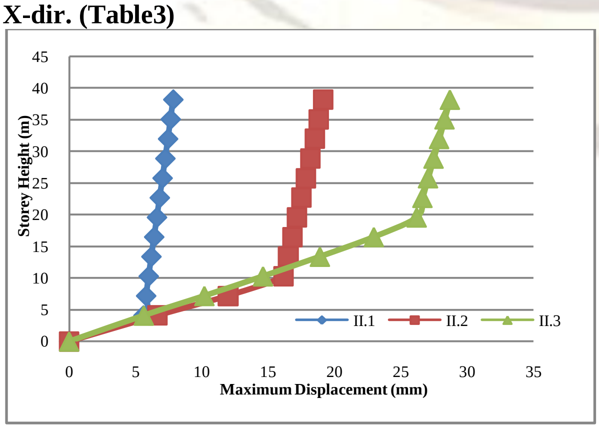


Fig 9: Comparison of max. disp. of Building models present with Soft storey II.1, II.2 & II.3 in Y-dir. (Table4)

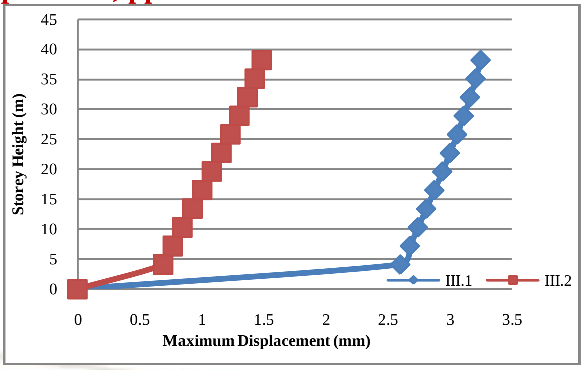


Fig 10: Comparison of Max. disp. of Building models present with modified soft storey provision III.1 & III.2in X-dir.(Table5)

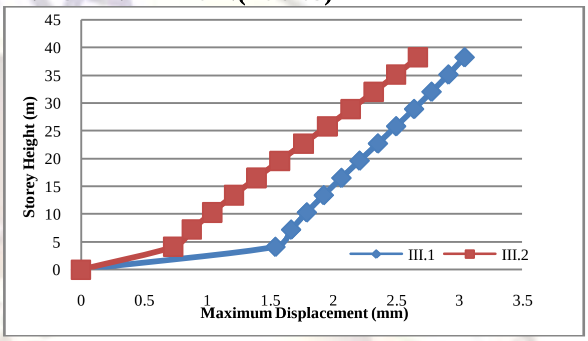


Fig 11: Comparison of Max. disp. of Building models present with modified soft storey provision III.1 & III.2in Y-dir.(Table6)

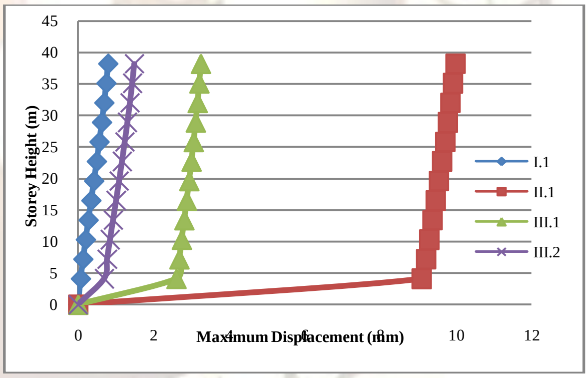


Fig 12: Comparison of Max. disp. of Building models I.1, II.1, III.1 & III.2 in X-dir. with respect to height.

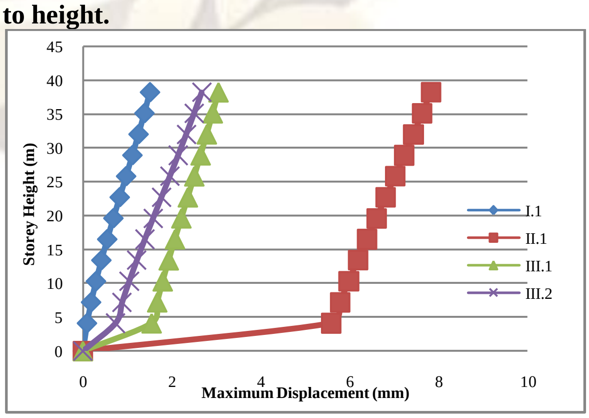


Fig 13: Comparison of Max. disp. of Building models I.1, II.1, III.1 & III.2 in Y-dir. with respect to height.

Table 1/2 and Fig. no. 6/7 shows comparison of the lateral displacement profile of complete infill wall (panel) model I.1 & bare frame model I.2 in both X-dir. and Y-dir. respectively. It indicates the effect of displacement variations of adopted modeling between them. Table 3/4 and Fig. no. 8/9 shows the comparison of the lateral displacement profile of building model present with soft storey Models II.1, II.2& II.3 in both X-dir. and Y-dir. respectively. It indicates the abrupt change in drift at storey level by soft storey. Table 5/6 and Fig. no. 10/11 show the comparison of the lateral displacement profile of building model present with modified soft storey provision Models III.1 & III.2 in both X-dir. and Y-dir. respectively. It indicates to control the sudden change in drift at first storey level by modified soft storey provision. From the above tables & figures, the abrupt change in the slope of the profile indicates the stiffness irregularity. All the displacement profiles corresponding to model having stiffness irregularity (i.e. Models II.1, II.2 II.3) have sudden change of slope at next floor level. However the other models (i.e. Models I.1, I.2, III.1 & III.2) shows smooth displacement profiles. The interstorey drift is largest in the first storey for the model with soft storey (i.e. Model II.1). This implies that the ductility demand on the columns in the first storey for this model is the largest [4]. For the models I.1, III.1 & III.2 which do not have stiffness irregularity and the first floor displacement is small.

2. Maximum Bending Moment (BM) and Shear Force (SF):

Table 9: Maximum BM and SF in X-direction.

	Max Moment(KNm)		**Max Shear(KN)**	
Model	First Column	Second Column	First Column	Second Column
I.1	0.497	0.892	0.957	1.416
I.2	153.641	163.487	97.104	99.764
II.1	177.617	24.996	94.709	31.521
III.1	127.980	17.547	94.982	22.928
III.2	13.969	2.991	6.411	0.442

Table 10: Maximum BM and SF in Y-direction.

	Max Moment(KNm)		**Max Shear(KN)**	
Model	First Column	Second Column	First Column	Second Column
I.1	0.571	0.445	0.755	0.875
I.2	110.848	112.840	61.23	61.496
II.1	115.973	13.036	60.097	14.030
III.1	90.488	9.874	60.677	11.203
III.2	18.227	5.861	5.767	3.229

From Table no. 9 & 10 shows maximum bending and shear force in the columns in the ground and first floor. In case of soft storey building the BM and SF (strength) demands are severely higher for first storey columns. The introduction of walls panels in the first storey (i.e. Model I.1 & III.2) reduces the forces in the first storey columns. As the forces is distributed in proportion to the stiffness of the member, the force in the columns of the upper storey for models I.1, II.1, III.1 & III.2 except bare frame model I.2 are significantly reduced due to presence of brick walls. The use of brick infill wall (panels) in complete infill model (i.e. Model I.1) and adjacent infill wall provided at each corner of the ground floor building model (i.e. Model III.2) are reduced the BM and SF at first storey column compared to the other models. Interestingly, the drift demand on the first storey columns in case of Model I.1, Model III.1 and Model III.2 are very close as showing in lateral displacement result. But in this section, in case of models having stiff column at first storey level (i.e. Model III.1), BM and SF on first storey columns is very large as compared to complete infill model (i.e. Model I.1) and adjacent infill wall provided at each corner of the ground floor building model (i.e. Model III.2).

3. Natural Periods:

Table 11: Fundamental Natural Periods

	Fundamental Natural Period (sec)			
	X-direction		Y-direction	
Models	Code	Analysis	Code	Analysis
I.1	0.58	0.3556	0.89	0.3556
I.2	0.58	2.3937	0.89	2.3937
II.1	0.58	1.0263	0.89	1.0263
III.1	0.58	0.6010	0.89	0.6010
III.2	0.58	0.5165	0.89	0.5165

Above Table no.11 shows the codal (IS 1893-2002) and analytical (by using SAP2000 software) natural periods of building models I.1, I.2, II.1, III.1 & III.2. It is seen that the analytical natural periods do not tally with the natural periods obtained by empirical expression of the code. Introduction of infill panels in the RC frame reduces the time period of bare frames and also enhances the stiffness of the structure. The bare frame idealization in model I.2 lead to severe overestimation of the natural period compared to the open first storey building model II.1.

IV. CONCLUSION

The object of this investigation is to study the effect of horizontal loading on reinforced concrete frame with brick masonry infill wall (panel) for different conditions including soft storey models. Deflections are one of the most important parameter to be considered in the design and analysis of tall building. Therefore deflection and other important parameters for lateral loads have been studied. The following conclusions can be drawn.

(i)The displacement and force demands (i.e. BM & SF) in the first storey columns are very large for building with soft ground storey. It is difficult to provide such capacities in the columns of the first

storey. When incorporated the infill wall (panel) at soft ground storey, these demand are significantly reduced.
(ii)From the fundamental time period, it has been found that when there is no infill wall (panel) i.e. for bare frame model, the time period value is more than the value predicted by code. This indicates that modeling of RC frame building without infill wall (panel) or bare frame model may not be appropriate for the analysis. When infill wall (panel) is incorporated, then shorten the time periods of other than bare frame models.
(iii) When the bare frame model is subjected to lateral load, mass of each floor acts independently resulting each floor to drift with respect to adjacent floors. Thus the building frame behaves in the flexible manner causing distribution of horizontal shear across floors. In presence of infill wall (panel), the relative drift between adjacent floors is restricted causing mass of the upper floors to act together as a single mass. In such case, the total inertia of the all upper floors causes a significant increase in horizontal shear force at base or in the ground floor columns. Similarly increases the bending moment in the ground floor columns.
(iv)The presence of walls in upper storeys makes them much stiffer than open ground storey. Hence the upper storey move almost together as a single block and most of the horizontal displacement of the building occurs in the soft ground storey itself. Such building swing back and forth like inverted pendulums during earthquake shaking and columns in the open ground storey are severely stressed.
It is clear that building with soft storey will exhibit poor performance during a strong shaking. But the open first storey is an important functional requirement of almost all the urban multistory buildings and hence cannot be eliminated. Alternative measures need to be adopted for this specific situation. The under-lying principle of any solution to this problem is in (a) increasing the stiffness of the first storey; (b) provide adequate lateral strength in the first storey. The possible schemes to achieve the above are (III.1) stiff column provided at open ground storey model and (III.2) adjacent infill wall provided at each corner of soft storey building model. The configuration of infill in the parking frame changes the behavior of the frame therefore it is essential for the structural system selected to be thoroughly investigated and well understood for catering to soft ground floor. The former is effective only in reducing lateral displacement on the first soft storey columns.

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REFERANCES

Journal Papers:

[1] J. N. Arlekar, S. K. Jain and C.V.R. Murty, *"*Seismic Response of RC Frame Buildings with Soft First Storeys," Dept. of Civil Engineering, I.I.T., Kanpur, India.(*CBRI*) 1997.

[2] Sujatha A., Jiji Anna Varughese, Bindhu K.R, "The Influence of Masonry Infill in RC Multi-Storey Buildings," (*NCTT09) 6-7* Nov 2009.

[3] S. Haque, Khan M. A., "Seismic Vulnerability of Columns of RC Framed Buildings with Soft Ground Floor," *International Journal Of Mathematical Models And Methods In Applied Sciences, Issue3,Volume2,*2008.

[4] M.R. Amin, P. Hasan, B.K.M.A. Islam, "Effect of soft storey on multistoried reinforced concrete building frame," Bangladesh, *ISBN: 978-984-33-4363-5, 4th Annual Paper Meet and 1st Civil Engineering Congress, December 22-24,* 2011.

[5] C V R Murty, the Classroom section, a series of short articles, '*Earthquake Tips*', related to earthquakes design & construction of buildings. IIT Kanpur and *BMTPC*, New Delhi. August 2004.

[6] A.K**.** Chopra, D.P. Clough, R.W. Clough, "Earthquake Resistance of Building with a 'SOFT' First Storey", *Earthquake Engineering and Structural Dynamics, Vol.1, 347-355,* 1973.

[7] Bento R., Azevedo J., " Behaviour coefficient assessment for Soft Storey Structures", *12WCEE,*2000.

Books:

[8] P.Agrawal, M. Shrikhande *Earthquake resistant design of structure* (PHI Learning Pvt.Ltd. New Delhi, 2009).

[9] Mario Paz & William Leigh, *Structural Dynamics* (Springer Pvt. Ltd. New Delhi, 2007).