column forces of the ground storey of the given mid-rise open ground storey building. It is found that the infill panels increases the stiffness of the upper storeys of the structure, thereby increasing the forces, displacement, drift and ductility demand in the soft ground storey. This could become the cause of failure of open ground storey buildings during earthquake.

INDEX TERMS: Open ground storey, masonry infill walls, non-structural element, bare frame, infill stiffness.

1. INTRODUCTION

Reinforced concrete framed buildings have become common form of construction in urban and semi urban areas around the world which is masonry infill. Numerous such buildings constructed in recent times have a special aspect - the ground storey is left open, which means the columns in the ground storey do not have any partition walls between them. These types of buildings having no infill masonry walls in ground storey, but having infill walls in all the upper storeys, are called as 'Open Ground Storey (OGS) Buildings'. This open ground storey building is also termed as building with 'Soft Storey at Ground Floor'.

There is significant advantage of such type of building functionally but when seismic performance point of view such building is considered it is found to have increased vulnerability. The open ground storey buildings are generally designed as framed structures without regard to structural contribution of masonry infill walls. The presence of infill walls in all the upper stories except in the ground storey makes the upper stories much stiffer as compared to 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 itself and hence the ground storey columns are heavily stressed. IS 1893 (2002) recommends a magnification factor of 2.5 to be applied on bending moments and shear forces in the columns of ground storey calculated for the bare frame under seismic loads.

The salient objectives of the present study have been to study the effect of infill strength and stiffness in the seismic analysis of open ground storey (OGS) buildings, to check the applicability of the multiplication factor

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of 2.5 as given in the Indian Standard IS 1893:2002 for design of a mid rise open ground storey building and to assess the influence of varying the infill arrangements on the analysis results by taking various combinations of infill thickness, strength, modulus of elasticity and openings.

2. DESCRIPTION OF STRUCTURAL MODEL

2.1 GEOMETRY

For the study five different models of a six storey building are considered. The building has five bays in X direction and four bays in Y direction with the plan dimension 22.5 m × 14.4 m and a storey height of 3.5 m each in all the floors and depth of foundation taken as 1.5 m. The bay width along longitudinal direction is 4.5m and along transverse direction is 3.6m. The building is kept symmetric in both orthogonal directions in plan to avoid torsional response under lateral force. The column is kept square and size of the column is kept same throughout the height of the structure to keep the discussion focused only on the soft first storey effect without distracted by the issues like orientation of column. The building is considered to be located in seismic zone IV and intended for residential use.

2.2 MATERIAL PROPERTIES

M-25 grade of concrete and Fe-415 grade of reinforcing steel are used for all the frame models used in this study. The unit weights of concrete and masonry are taken as 25.0 kN/m^3 and 20.0 kN/m^3 respectively. The modulus of elasticity of the bricks found in India varies from 350 MPa to 5000 MPa. To represent the extreme cases of strong and weak infill walls 2 combinations of infill walls are considered for modelling. The thicker wall of 230mm thickness is combined with strong infill wall having E = 5000 MPa and thinner wall of 115mm thickness is combined with weak infill wall having E = 350 MPa. The poison ratio of concrete is 0.2 and of masonry is 0.15.

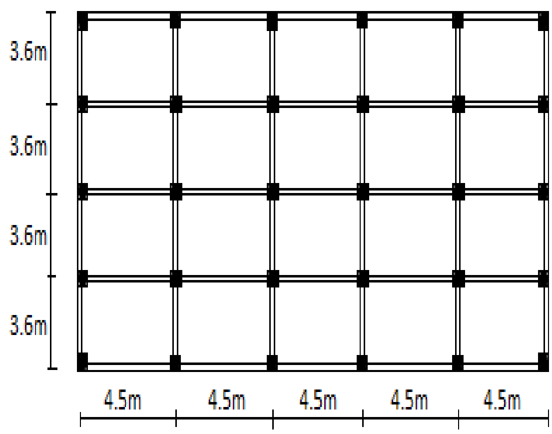

Figure 1: Plan of the structure

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3. MODEL CONSIDERED FOR ANALYSIS

Following five models are analyzed using response spectrum analysis –

i) Model I: Bare frame model (reinforced concrete frame taking infill masonry weight, neglecting effect of stiffness).

ii) Model II: Building with strong infill (effect of stiffness is also considered in addition to taking weight of infill).

iii) Model III: Building with strong infill having openings (model II with openings at certain panels).

iv) Model IV: Building with weak infill (effect of stiffness is also considered in addition to taking weight of infill).

v) Model V: Building with weak infill having openings (model IV with openings at certain panels).

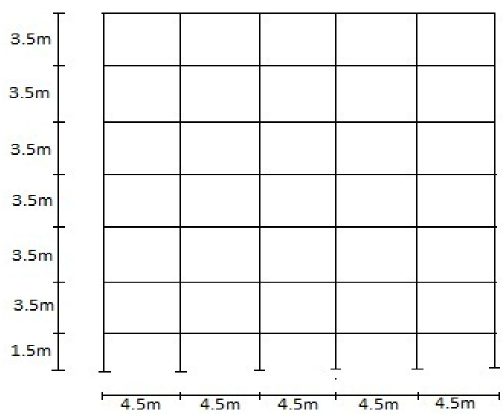
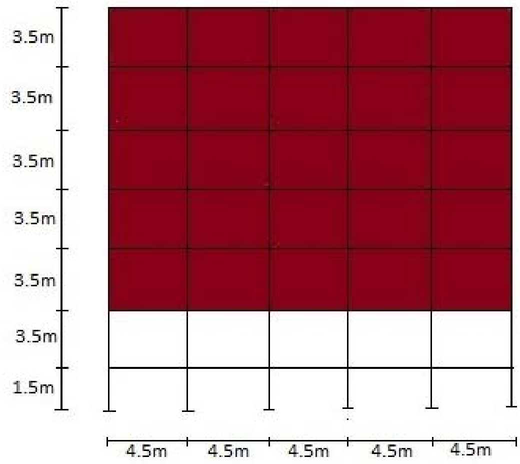
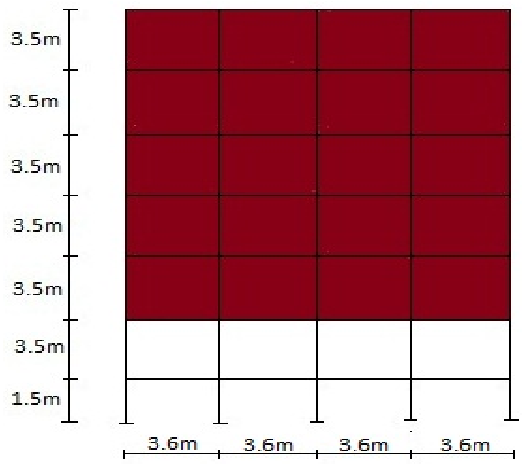


Figure 2: Model I: Bare frame

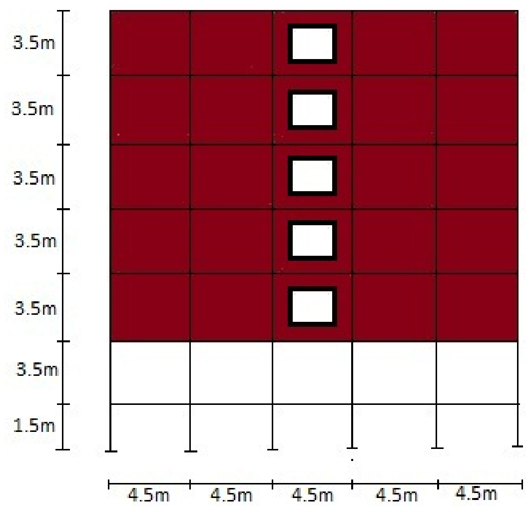


(a) Front elevation



(b) Side elevation

Figure 3: Model II & IV – Infilled frames



(a) Front elevation

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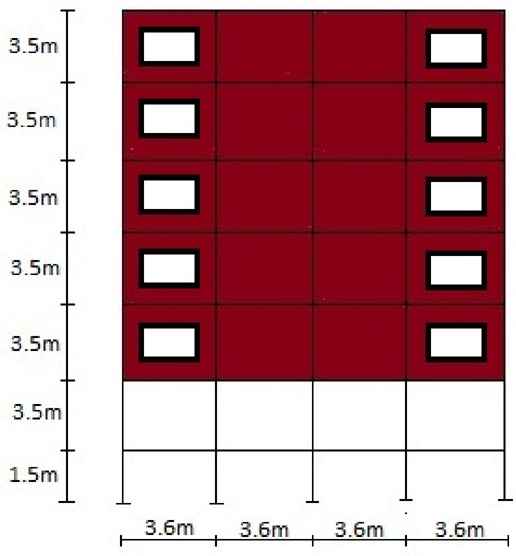

(b) Side elevation

Figure 4: Model III & V – Infilled frames with openings

4. MODELLING OF FRAME MEMBERS AND INFILL WALLS

The structural members are modelled with the aid of commercial software ETABS v 9.7.1 in compliance with the codes IS 456-2000 and IS 1893-2002. The frame members are modelled with rigid end conditions. The floor slabs were assumed to act as diaphragms, which ensure integral action of all the lateral load-resisting elements. The floor finish on the floors is taken to be 1.0 kN/m^2. The live load on floor is taken as 3.0 kN/m^2 and that on the roof to be 1.5 kN/m^2. In seismic weight calculations, 25 % of the floor live loads are considered in the analysis.

For an infill wall located in a lateral load-resisting frame, the stiffness and strength contribution of the infill has to be considered. Non-integral infill walls subjected to lateral load behave like diagonal struts. Thus an infill wall can be modelled as an equivalent 'compression only' strut in the building model. Rigid joints connect the beams and columns, but pin joints connect the equivalent struts to the beam-to-column junctions. The length of the strut is given by the diagonal distance (d) of the panel and its thickness is equal to the thickness of the infill wall. The elastic modulus of the strut is equated to the elastic modulus of masonry (E_m). Smith (1966) proposed a formula to calculate the width of strut based on the relative stiffness of the frame and the infill walls.

5. RESULTS AND DISCUSSION

5.1 BENDING MOMENT AND SHEAR FORCE IN COLUMNS

As can be seen from the tables 1 & 2 (model II to V) and figures 5 to 8 the bending moments and shear forces (strength) demands are severely higher for the ground storey columns with respect to first storey columns, in case

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of the soft ground storey buildings when they are analyzed by considering infill as structural component taking into consideration their stiffness also with their weight. The introduction of walls in the first storey (model II to V) reduces the force in the first storey columns. In model I, the bending moment and shear forces are the maximum as compared to other models, as there is no effect of infill walls considered in their analysis which shows the force demands depends upon the stiffness of the members. Also the forces in the first storey columns of model I are almost equal to the forces in the ground storey columns or even more for shear forces which is drastically opposite behaviour as compared to the other models. Therefore the importance of modelling and considering the infill walls as structural component and also the description of infill materials, their type, strength and their elastic modulus definition is realized here.

Table 1: Maximum bending moment in ground storey and first storey columns

Maximum Bending Moment (kNm)				
Model	**Longitudinal**		**Transverse**	
	Ground Storey	**First Storey**	**Ground Storey**	**First Storey**
I	79	74	77	73
II	86	48	90	40
III	82	51	84	36
IV	70	27	71	28
V	66	26	68	28

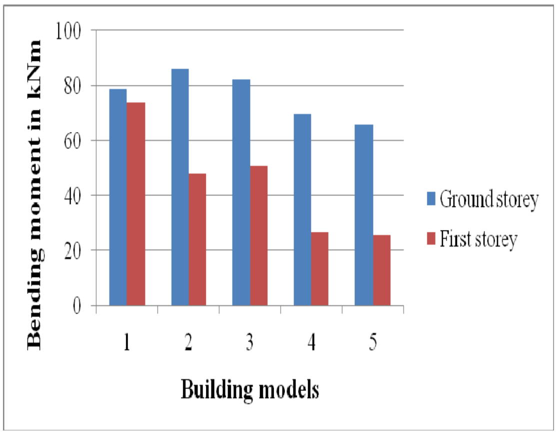

Figure 5: Comparison of maximum bending moments in longitudinal direction

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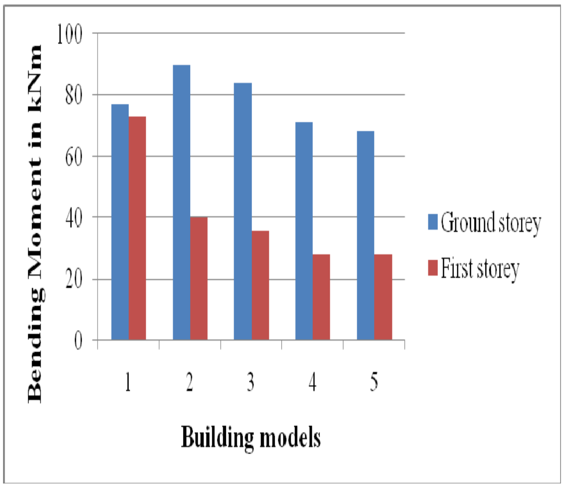

Fig -6: Comparison of maximum bending moments in transverse direction

Table -2: Maximum shear force in ground storey and first storey columns

Shear Force (kN)				
Model	**Longitudinal**		**Transverse**	
	Ground Storey	**First Storey**	**Ground Storey**	**First Storey**
I	40	42	40	41
II	51	21	52	15
III	49	21	51	14
IV	39	15	40	18

V	36	15	38	18

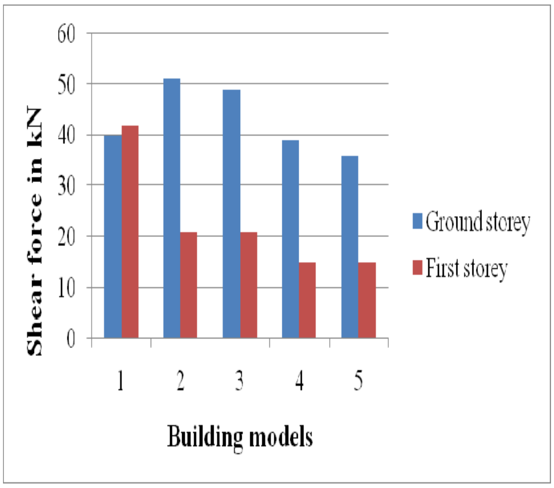

Fig -7: Comparison of maximum shear force in longitudinal direction

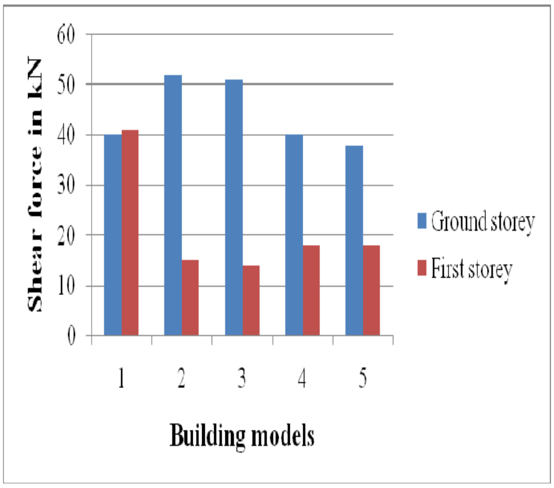

Fig -8: Comparison of maximum shear force in transverse direction

5.2 LATERAL DEFORMATION

Table -3: Displacement (in mm) in longitudinal direction

Model	**Storey 1**	**Storey 2**	**Storey 3**	**Storey 4**	**Storey 5**	**Roof**

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I	7.8	15.9	23.7	30.4	35.3	38.0
II	8.1	9.3	10.3	11.1	11.8	12.2
III	7.9	9.1	10.2	11.0	11.7	12.2
IV	6.8	10.7	13.8	16.6	18.7	19.9
V	6.6	10.4	13.6	16.4	18.5	19.8

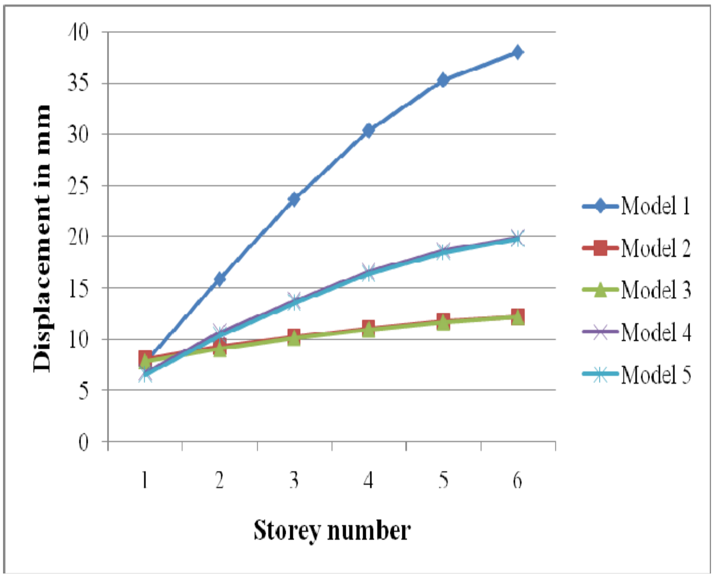

Figure 9: Displacement profile along longitudinal direction

Table -4: Storey drift (in mm) in longitudinal direction

Model	Storey 1	Storey 2	Storey 3	Storey 4	Storey 5	Storey 6	Roof
I	0.6	2.0	2.3	2.2	1.9	1.4	0.8
II	0.8	2.0	0.36	0.28	0.24	0.19	0.12
III	0.8	1.9	0.37	0.30	0.26	0.20	0.14
IV	0.60	1.7	1.0	0.90	0.78	0.60	0.35
V	0.60	1.6	1.1	0.92	0.80	0.62	0.36

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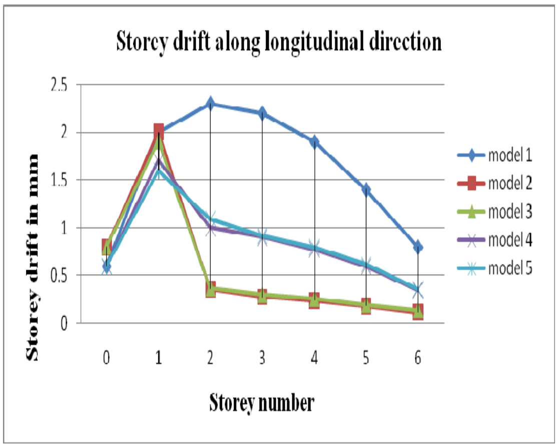

Figure 10: Storey drifts

The displacement of the model I at all the floors is the maximum with respect to that of all the other models. There is a huge difference between the displacement values of model I and all other models. This gap of difference is increasing uniformly with the increase in the storey level. Also the displacement of model IV & V is more than the displacement of model II & III throughout the floors. The displacement of model I is of such amount because there is no lateral stiffness provided to the structure by the infill wall.

As can be seen from figures and tables for storey drift, the storey drift profile of model I is smooth throughout whereas for model II to V the storey drift changes abruptly from ground storey to first storey. This sudden change of slope of storey drift profile along profile of each model signifies stiffness irregularity between soft storey and infilled storey, encountered because of modelling stiffness of infill wall for soft ground storey buildings. Such stiffness irregularity of soft ground storey buildings is critical from failure point of view when subjected to earthquake forces because of resemblance of its behaviour with the behaviour of inverted pendulum. The upper storeys move together as a single block and most of the horizontal deformation of the building occurs in the soft ground storey itself.

5.3 MAGNIFICATION FACTOR

Table 5 indicates that the magnification factor values is found to vary between 0.88 to 1.17 for the bending moment and for shear forces between 0.95 to 1.33 in the ground storey columns of the models II to V in comparison to the corresponding values of bending moment and shear force in the ground storey columns of model I (bare frame).

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Table 5: Magnification factors for bending moment and shear force

Model		**I**	**II**	**III**	**IV**	**V**
Maximum BM in ground storey (kNm)	Exterior Column	76	89 (1.17)#	83 (1.09)	71 (0.93)	68 (0.89)
	Interior Column	77	90 (1.17)	84 (1.09)	71 (0.92)	68 (0.88)
Maximum shear force in ground storey (kN)	Exterior Column	39	52 (1.33)	51 (1.31)	40 (1.03)	38 (0.97)
	Interior Column	40	52 (1.30)	50 (1.25)	40 (1.0)	38 (0.95)

Magnification factor values for bending moment & shear force obtained by dividing with the corresponding values for the bare frame.

6. CONCLUSIONS

The following are the main findings of the present study –

i) The structural member forces, deformations do vary with the different parameters associated with the infill walls. Such variations are not considered in current codes and thus the guidance for the design of buildings having infill walls is incomplete and specifically for buildings with soft ground storey it is imperative to have design guidelines in detail.

ii) Infill panels increases the stiffness of the structure and the increase in the opening percentage leads to a decrease on the lateral stiffness of infilled frame. Hence behaviour of building varies with the change in infill arrangements. This indicates that modelling of reinforced concrete frame building without infill wall (panel) or bare frame model may not be appropriate for the analysis.

iii) The analyses result shows that column forces at the ground storey increases for the presence of infill wall in the upper storeys. But design force magnification factor found to be much lesser than 2.5. This is particularly true for mid-rise open ground storey buildings. It is seen from response spectrum analysis that the

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magnification factor decreases when the stiffness of infill panels are decreased either by reducing infill strength (thickness and modulus of elasticity) or by providing openings in the infill panels.

iv) When a 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.

v) From the present results it is found that, lateral displacement is very large in case of bare frame as compare to that of infilled frames. If the effect of infill wall is considered then the deflection has reduced drastically. 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.

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BIOGRAPHIES

Dharmesh Vijaywargiya, Post Graduate Student, Civil Engineering Department MANIT, Bhopal, Madhya Pradesh, India

Dr. Abhay Sharma, Associate Professor, Civil Engineering Department MANIT, Bhopal, Madhya Pradesh, India

Dr. Vivek Garg, Assistant Professor, Civil Engineering Department MANIT, Bhopal, Madhya Pradesh, India