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SEISMIC RESPONSE OF ONE WAY SLOPE RC FRAME BUILDING WITH SOFT STOREY

Prashant D[1], Dr. Jagadish Kori G[2]

[1] *P.G. Student, Civil Engineering Department, Government Engineering College, Haveri, Karnataka, India,*
[2] *Professor, Civil Engineering Department, Government Engineering College, Haveri, Karnataka, India,*

ABSTRACT

Open first storey is a typical feature in the modern multistorey construction in urban India. Such features are highly undesirable in buildings built in hill areas. A study is performed on the building situated on hill slope (27° with horizontal) to bring out effect of soft storey on the response of structure. The present paper investigates performance based seismic evaluation of building models namely: bare frame, soft storey, fully infill buildings with unreinforced masonry infill for G+9 storeys located in seismic zone V, constructed on medium soil are considered. Masonry infill is modeled as equivalent diagonal strut and hinge properties as per FEMA 356 are assigned to beams, columns and equivalent diagonal struts. The seismic vulnerability of building is assessed by carrying out non-linear static pushover analysis at IO, LS and CP performance levels. Comparative study is made by comparing the values of natural time period, base shear, lateral displacement, storey drift and also the performance of building are checked at their respective failure modes and target displacement.

The investigation concludes that the performance of non-ductile moment resisting frames can be improved by adding infill walls. The soft storey structure proves to be more vulnerable during seismic activity, when compared to other infilled structures.

Key Words: Non-Ductile MRF Buildings, Pushover Analysis, Equivalent Strut, Hill Buildings, Performance Levels.

1. INTRODUCTION

In some parts of world, hilly area is more prone to seismic activity; e.g. Northeast region of India. In these hilly regions, traditional materials like adobe, brunt brick, stone masonry, dressed stone masonry, timber, reinforced concrete, bamboo, etc., which is locally available, is used for the construction of houses. A scarcity of plain ground in hilly area compels the construction activity on sloping ground and With the high cost of land in most urban areas of India, the developers of residential and commercial buildings are eager to accommodate the vehicular parking requirements within the front foot of the building that is at the ground floor, while the upper stories of the RC concrete frames are infilled with brick masonry walls. From experience of the recent severe Bhuj earthquake 2001, the multistoryed buildings with open ground floors collapsed due to lesser strength and stiffness of ground storey compared to upper stories and also buildings constructed on hill slopes are collapsed due to the irregularity. Such buildings without conforming to seismic codal provisions have proved unsafe and, resulted in loss of life and property when subjected to earthquake ground motions.

2. Analytical Model

The building is modeled to represent all existing components that influence the mass, strength, stiffness and deformability of the structure. The RC Beams and columns are modeled as three dimensional frame elements with centerline dimensions. The rigid zone factor for beam-column joints is assigned as one. Slabs are modeled as rigid membrane elements and diaphragm constraint is assigned. The area loads are applied on the slabs. Masonry brick walls are modeled by considering equivalent diagonal strut approach, as pin jointed elements carrying axial compressive forces only. The material properties and thickness of struts are same as that of masonry wall; the effective width of strut is calculated as proposed by Stafford Smith equation for calculation of equivalent diagonal strut width is considered. The dead weight of infill is assigned as uniformly distributed load over beams and the weight of strut elements taken as zero. Foundation is modeled as isolated footing in fixed condition at the base. M_3 (moment hinge), PM_2M_3 (axial force and bi-axial moment hinge) and P (axial force hinge) hinges with hinge properties as per FEMA 356 (2) are assigned at both ends of beam, column and strut elements respectively.

3. Models Investigated

RC framed 10 storeys, one way sloped (27° with the ground) building of plan dimension 35m×35m with a floor to floor height of 3.5m as shown in the Figure 4.1 & Figure 4.2. The building is unsymmetric in one direction in plan and the columns are taken to be square to avoid the issues like orientation of columns.

Following are the models of the buildings (Fig.6 to Fig.9) studied in this paper,

Model 01: Building modeled as bare frame ignoring the stiffness contribution of walls. However, masses of the walls are as in model 02 are included.

Model 02: Building has one full brick infill masonry walls (230mm) in all the storeys.

Model 03: Building has half brick infill masonry walls (115mm) in all the storeys.

Model 04: Building has no walls up to one storey height from the ground and one full brick infill masonry walls (230mm) in the upper storeys.

Model 05: Building has no walls up to one storey height from the ground and half brick infill masonry walls (115mm) in the upper storeys.

Model 06: Building has no walls up to one storey height from the ground except at the corners and one full brick infill masonry walls (230mm) at the corners and in the upper storeys.

Model 07: Building has no walls up to one storey height from the ground except at the corners and one full brick infill masonry walls (115mm) at the corners and in the upper storeys.

4. Description of Study Building

The details of non-ductile MRF building with open first storey and unreinforced brick infill walls in the upper storyes chosen for study are tabulated in Table1. The material properties adopted for the structural members are as shown in the Table 5. The effective width of the equivalent strut is calculated as proposed by Stafford Smith.

5. Pushover Analysis

Pushover analysis is a non-linear static procedure, there are several methods exists, here the Capacity spectrum method (ATC-40) is adopted. Pushover analysis is carried out in two stages. First, nonlinear analysis is carried out for gravity loading followed by lateral seismic loading in the second stage. The pushover load cases considered for the analysis are tabulated in Table 6.

5.1 Capacity Spectrum Method

The building model incorporating the material non-linearity is subjected to monotonically increasing lateral load, till the structure collapses. The displacement on the structure (at roof) is recorded for the corresponding base shear. The curve base shear versus roof displacement represents capacity of the structure known as pushover capacity curve. Then the capacity curve is converted to capacity spectrum (ADRS) format. The demand curve or response spectrum for a given structure & ground motion is also converted into the same ADRS format and plotted on the same graph along with the capacity spectrum. The demand spectrum determined from the values of Ca and Cv chosen according to the seismic zone and soil type and an assumed damping ratio of 5%. In present case the values corresponding to Zone III and Soil Type II (medium soil) are taken as Ca = 0.4 and Cv =0.4. The demand spectrum is iteratively scaled down for an equivalent viscous damping corresponding to the inelastic response level of the structure. The demand corresponding to the effective time period of the structure is shown by irregular line dropping down from the elastic demand spectrum to the capacity spectrum as shown in Fig.5. The point where the demand and capacity spectrum intersects is known as performance point. This performance point represents the condition for which the seismic capacity of the structure is equal to the seismic demand imposed on the structure by specified ground motion.

6. Results and Discussion

The buildings of G+9 storeys analyzed and designed for gravity loads only are evaluated for seismic load combination as per IS: 1893-2002 i.e., 1.2(DL+LL+EQ). The buildings found to be inadequate in carrying the seismic load combination. The non- ductile MRF buildings of G+9 storeys satisfying the gravity load combinations are analyzed Pushover analysis methods, using ETABS-9 software. The results are presented suitably for each models considered in the study.

6.1 Time Period

Effect of infill in soft storey building models: The natural time periods from codal formula (IS: 1893-2002) and analysis (ETABS-9) results for Model 1 to Model 7 are tabulated in Table 1. It is observed that the natural periods obtained from the code are less than that of analysis results and their variation is shown in Fig. 1. The time period of Model 1 is 136.89%, 118.25%, 109.74%, 96.09%, 134.05%, and 112.62% more than that of Model 2, Model 3, Model 4, Model 5, Model 6 and Model 7 respectively. This shows that the bare frame idealization of Model 1 leads to an overestimation of natural period compared to the infilled RC frames, which ultimately results in an underestimation of design base shear in Model 1.

Table 1 Time period of models

Model	Analytical in S	Codal (IS 1893-2002) in S
Model1	1.975	0.533
Model2	0.834	0.533
Model3	0.905	0.533
Model4	0.942	0.533
Model5	1.007	0.533
Model6	0.844	0.533
Model7	0.929	0.533

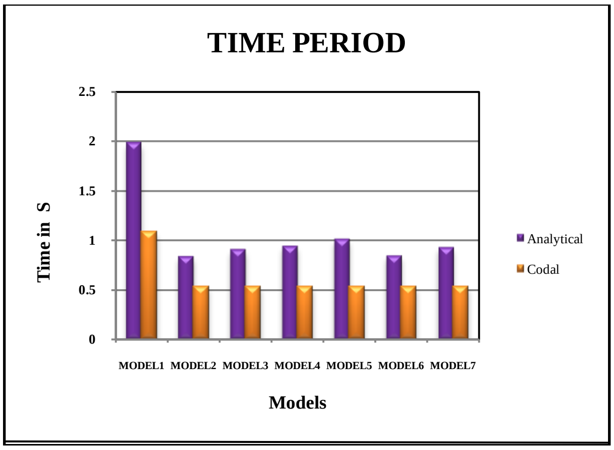

Fig. 1 Time Period

6.2 Base Shear

The base shears at 5th storey for all the models are tabulated in Table 2. The base shear of Model 1 is less when it is compared to remaining models, this shows the underestimation of Base shear in Model 1. The base shear of the infilled models increases with the increase in stiffness of the building models. The percentage increase in base shear of various models with respect to Model 1 is as tabulated in Table 2. Variations of base shear of various models are shows in Fig.2.

Table 2 Base shear of models

BASE SHEAR		
Models	Base shear in kn	% increase
Model1	6289.029	-----
Model2	29034.46	361.67
Model3	23179.21	268.57
Model4	23624.76	275.65
Model5	20780.03	230.42
Model6	26350.14	318.99
Model7	21354.24	239.55

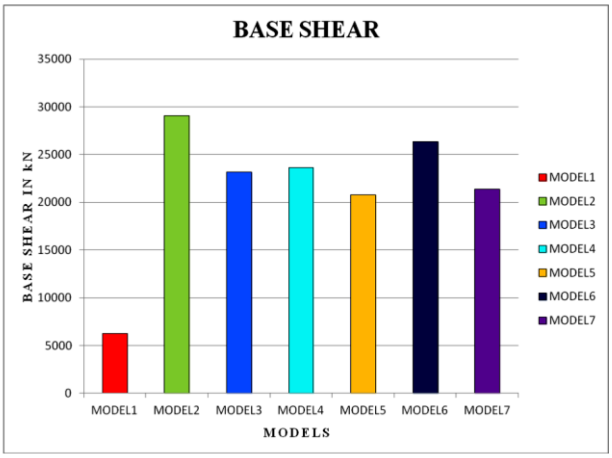

Fig. 2 Base Shear

6.3 Storey Drift

As per Clause: 7.11.1 of IS: 1893 (Part 1): 2002 the storey drift for RC building is limited to 0.004 times the storey height, that is 0.4% of storey height. From Fig. 3, the abrupt changes in the slope of the profile indicate the stiffness irregularity. This is minimized in all the models above 5th floor because of uniform stiffness. When we compare Model 01 with other models the displacement is more because of the short in stiffness. The degree of minimization is more in Model 4 and Model 6 at top storey due to the higher value of stiffness when compared to other models and even in Model 2 the degree of minimization is more when compared to Models 3, 5 & 7 at top storey because the thickness of infill in Model 2 is 50% more when compared to Models 3, 5 & 7. The storey drift of Model 2 , 4 & 6 is more in the bottom storey because the stiffness of these models at the bottom is 50% less than Models 3, 5 & 7.

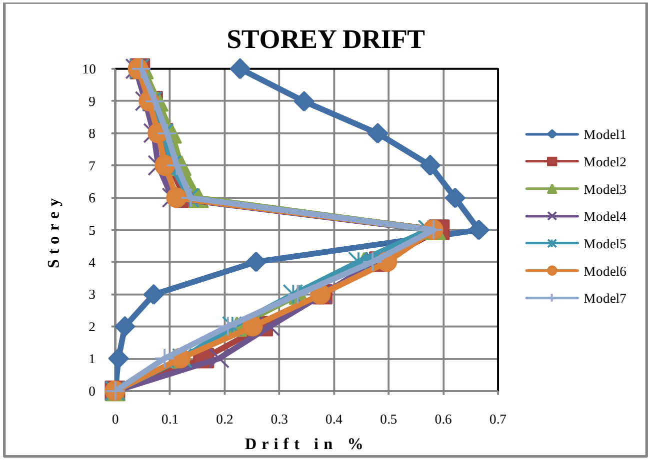

Fig. 3 Storey drift of models

6.4 Storey Displacement

The lateral displacement profiles for the models are shown in Fig. 4. It is seen that linear displacement profile of Model 1, which is an unrealistic behavior of open ground storey and infill walls in upper storey RC frame. Model 4 shows an abrupt change in the displacement profile at first floor level, indicates the stiffness irregularity of soft storey buildings at ground storey. On the other hand the fully infill or corner infill models show the smooth displacement profiles.

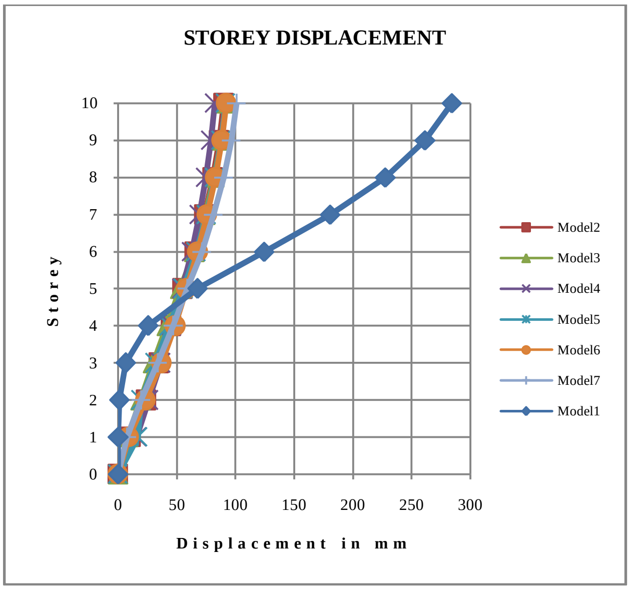

Fig.4 Storey displacement of models

6.5 Pushover Analysis Results

6.5.1 Performance Levels

All the models are compared at their failure modes, considering the performance point as the failure point. The hinge statuses at failure modes for the models are tabulated in Table 7. As the buildings are less stiff along X-direction, when building pushed in the Push-X direction more number of hinges are formed. Along Y-direction for Push-Y the hinges formed in all models are in the range of IO-LS. Hence only for Push-X hinge status are presented in Table 3.

6.5.2 Target Displacement

The target displacement, δt is determined using the equation given below:

$$\delta t = C_0\ C_1\ C_2\ C_3\ S_a\ [T_e / 2\pi]^2\ g \qquad \text{........1}$$

Where, C_0 is modification factor to relate spectral displacement of an equivalent SDOF system to roof displacement of the building MDOF system; C_1 is modification factor to relate expected inelastic displacements to displacements for linear elastic response; C_2 is modification factor to represent the effect of pinched hysteretic shape, stiffness degradation and strength deterioration on maximum displacement response; C_3 is modification factor to increased displacements due to dynamic P-Δ effects; Sa is response spectrum acceleration at the effective fundamental period and damping ratio;
g is acceleration of gravity; Te is effective fundamental period of building in the direction under consideration.

The target displacements (for Life Safety condition) with respect to fundamental periods of models and the hinge status at those displacements (along fundamental mode shape) are tabulated in Table.4. It is observed that the number of hinges formed at target displacement level in soft storey Model 4 & Model 5, are in >E range, but the two fully infilled models and two corner infill models reduces these hinges to D-E range.

7. Conclusion

From the analysis results of the given frame models the following conclusions can be drawn

1. The natural period decreases as the stiffness of the building increases and thereby leading to increase in base shear. From analysis, it is found that time period for bare frame model is almost 90 to 135 percent more, when compared to other models.
2. The base shear increases with the increase of stiffness in the building. From analysis, the base shear of infill models is almost 250 percent more when compared to bare frame model.
3. The time period of soft story model is 10.13% more than fully infill building and also base shear decreases 22.9% than that of fully infill building. This shows that the performance of the soft story building is more vulnerable than fully infill model during the earthquakes.
4. The storey drift of soft storey is effectively minimized by adding masonry infill walls in the ground storey.
5. From the study it is concluded that, the plastic hinges are more in case of bare frame model, where the stiffness of walls are neglected and also the plastic hinges are more in the soft storey building when it is compared with full infill or corner infill models. This is because of lack of stiffness in the ground storey of the building.
6. The lateral displacements of the soft storey shows the abrupt change in the displacement profile at storey 1, which indicates the stiffness irregularity due to soft storey mechanism and increases vulnerability towards seismic forces where as the models in which the stiffness of walls is neglected or full infill is considered have shown the smooth displacement profile.

8. Future Scope

1. The study can be further carried out on the varying slopes or two direction sloped buildings.
2. The study can be done on two or more equivalent strut idealization of masonry infill in the structures.
3. Rigors analysis methods like Time historey method can be carried out to get the accurate results.
4. Study can be continued further by using various lateral load resisting systems in the structure.
5. Study can be further carried out by using other methods to calculate effective strut width for the infill building.

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TABLES:

Table 3 Hinge Status

HINGE STATUS											
Model	Displacement in mm	Base Force in kN	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
1	352.8	6289.029	1142	86	104	238	0	1	7	2	1580
2	117.6	29034.46	1533	170	21	12	0	1	2	1	1740
3	126.7	23179.21	1527	183	18	8	0	1	1	2	1740
4	106.8	23624.76	1559	118	28	13	0	1	0	1	1720
5	119.8	20780.03	1492	191	19	16	0	1	0	1	1720
6	112.8	26350.14	1548	132	23	14	0	1	1	1	1720
7	115.1	21354.24	1530	162	16	10	0	1	0	1	1720

Table 4 Hinge Status at target displacement

HINGE STATUS		
Model	Target displacement in mm	Hinge status
Model1	203	>E
Model2	102	D-E
Model3	108	D-E
Model4	107	>E
Model5	120	>E
Model6	103	D-E
Model7	112	D-E

Table 5 Detailed data of buildings

General details of building		
No. of storeys		G+9
Storey height	Ground storey	3.50 m
	Upper storey	3.50 m
Building frame system		SMRF
Building use		Residential
Foundation type		Isolated footing
Seismic zone		Zone Type-III
Soil type		Medium soil
Material Properties		
Grade of concrete		M25
Grade of steel		Fe 415
Young's modulus of M25concrete, E		25x10^{6} kN/m^{2}
Density of concrete		25 kN/m^{2}
Poisson's ratio (of concrete)		0.20
Modulus of elasticity of brick masonry		4200 x 10^{3}kN/m^{2}
Compressive strength		3.80 kN/m^{2}
Density of brick masonry		20 kN/m^{3}
Poisson's ratio (of brick masonry)		0.15
Structural members		
Thickness of slab		0.150 mm
All Beam size		0.25 x 0.50 m
All Column size		0.55 x 0.55 m
Thickness of wall	Full brick wall	0.230 mm
	Half brick wall	0.115 mm
Assumed Dead Load Intensities		
Roof finishes		2.0 kN/m^{2}
Floor finishes	Floor	1.0 kN/m^{2}
	Roof	2.0 kN/m^{2}

Table 5 Detailed data of buildings (Continued)

Live Load Intensities	
Roof	1.5 kN/m^2
Floor	3.0 kN/m^2
Earthquake LL on slab as per clause 7.3.1 and 7.3.2 of IS 1893(part 1)-2002	
Roof	0 kN/m^2
Floor	0.25 x 3.0 = 0.75kN/m^2

Table 6 Load cases for Pushover Analysis

Pushover cases	Names	Loads	Controlled by	Previous case
1	GRAV	DL+0.25LL	Forces	---
2	PUSHX	EQX	Displacements	GRAV
3	PUSHY	EQY	Displacements	GRAV

Figures:

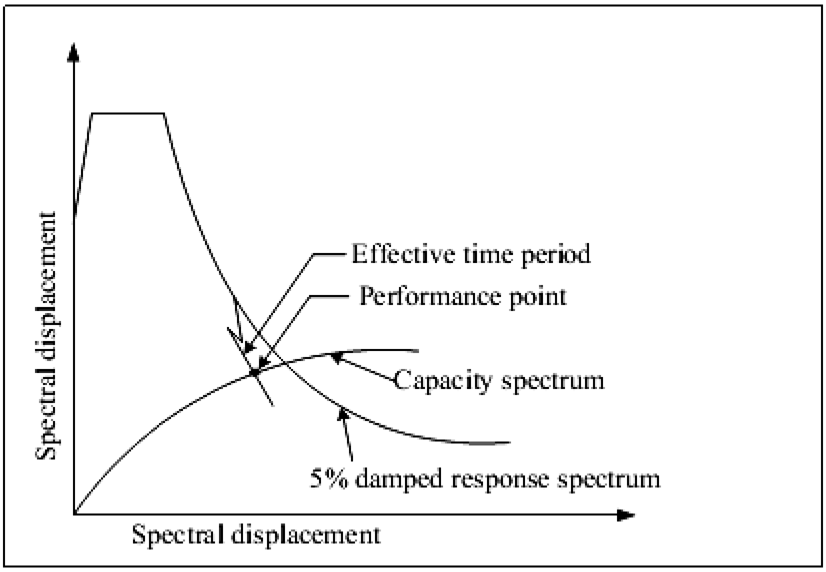

Fig.5 Performance point

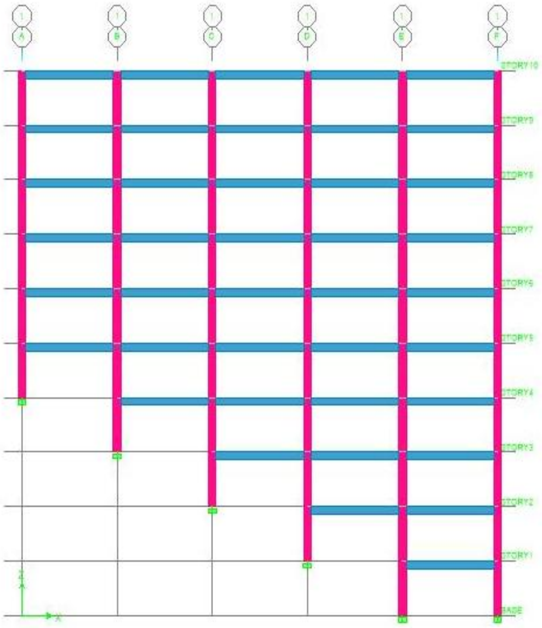

Fig.6 Model 01(Bare frame)

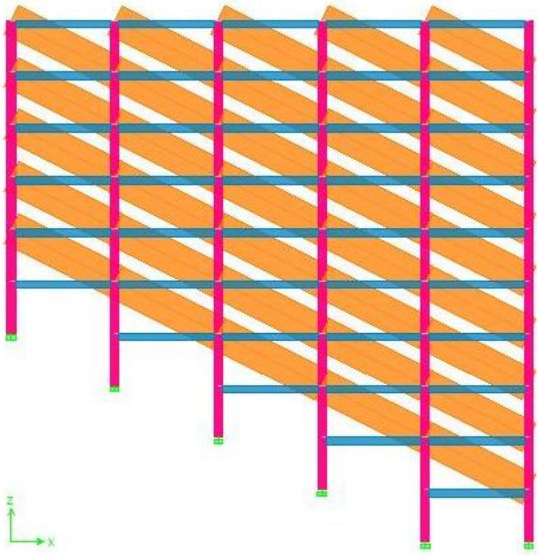

Fig. 7 Model 02 & 03 (Soft ground storey)

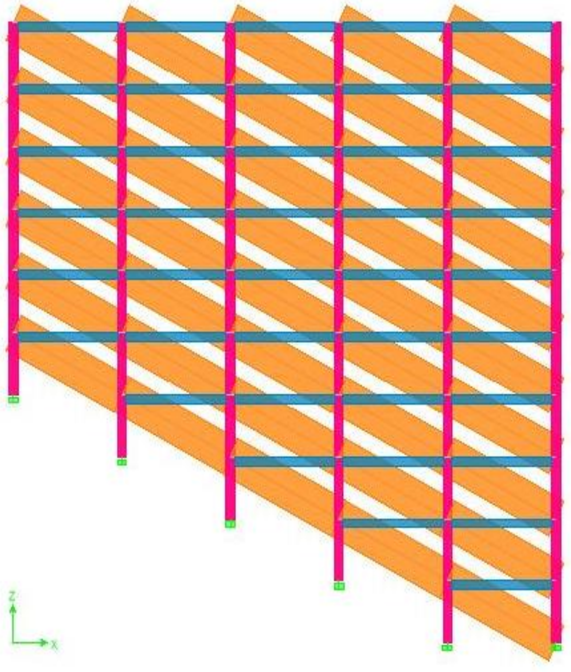

Fig. 8 Model 04 & 05 (Full infill)

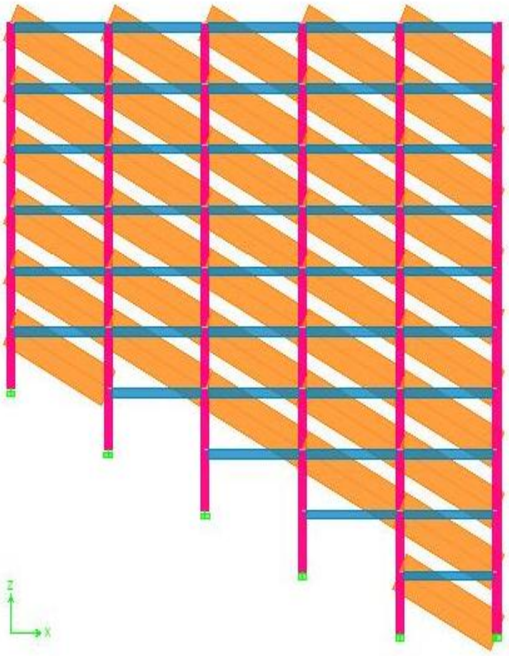

Fig. 9 Model 06 & 07 (Soft ground storey except corners)