

Effect of Soft Storey on Structural Response of High Rise Building

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ABSTRACT: In high rise building or multi storey building, soft storey construction is a typical and unavoidable feature because of urbanization and the space occupancy considerations. These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake for such buildings due to soft storey. This storey level is unable to provide adequate resistance, hence damage and collapse.

In the current study the focus is to investigate the effect of a soft storey for multi-storeyed high rise building with different models having identical building plan. Equivalent diagonal struts are provided as suggested in FEMA-273 in the place of masonry to generate infill effect. Soft storey level is altered at different floors in different models & equivalent static analysis is carried out using SAP 2000 analysis package.

KEYWORDS: Soft Storey, SAP 2000, Equivalent Strut, High Rise Building

I. INTRODUCTION

Many urban multi storey buildings in India today have open ground story as an unavoidable aspect, basically to generate parking or reception lobbies as shown in figure 1 & figure 2. The upper storeys have brick infilled wall panels with various opening percentage in them. These types of buildings are not desirable in seismically active areas because various vertical irregularities are induced in such buildings which have performed consistently poor during past earthquakes. It has been known since long time that masonry infill walls affect the strength and stiffness of infilled framed structures. Infill walls are generally seen as a non structural element and their effect is neglected by ignoring the stiffness of the infill wall during the modelling phase of the structure (analysed as a 'linear bare frame') leading to substantial inaccuracy in obtaining the actual seismic response of framed structures.



Figure 1: Soft storey buildings



Figure 2: showing use of Soft storey in buildings

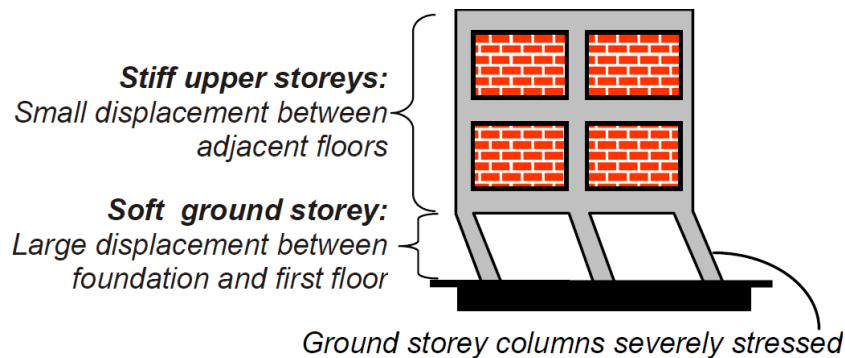
Lateral displacement of a story is a function of stiffness, mass and lateral force distributed on that story. It is also known that the lateral force distribution along the height of a building is directly related to mass and stiffness of each story. If the P-delta effect is considered to be the main reason for the dynamic collapse of building structures during earthquakes, accurately determined lateral displacements calculated in the elastic design process may provide very

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important information about the structural behavior of the system. Therefore dynamic analysis procedure is required in many of the actual codes for accurate distribution of the earthquake forces along the building height, determining modal effects and local ductility demands efficiently. The upper stories moves as single block as there is presence of infill masonry which makes it stiffer. Hence displacement is more in soft storey



Again During an earthquake, bending moment and shear strength increases on the columns and beams in the soft floors than the one in the upper storeys. As the walls do not exist in the soft storey floor, columns are stressed more. If the columns are not capable to resist shear they may be damaged or lead to collapse which is shown below in figure 3.



Figure.3 Damages in columns during earthquake

II. HIGH RISE BUILDINGS

The National Building Code (NBC 2005) of India (clause no.2.25) defines a high-rise Building as “all buildings 15 m or above in height shall be considered as high rise buildings”. The logic to the 15 meters number is explained was that NBC's decided by authorities of Bureau of Indian Standards, on the basis of the height of a manually-operated extension ladder of 35 feet (roughly 11 meters) working height. Fire departments around the country use this ladder for buildings of 15 meters height. For tackling fires in buildings beyond 15 meters in height, specialized vehicles need to be used by the fire force. Throughout India high-rises are defined by the 15 meters norm except in Mumbai (24 meters) and Ahmedabad (18 meters). This norm for high-rises in Mumbai and Ahmedabad is because of the vertical growth in the cities.

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III. METHODOLOGY

MODELLING OF EQUIVALENT STRUT

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. This section explains the procedure to calculate the modelling parameters (effective width, elastic modulus and strength) of an equivalent strut. The geometric characteristics of infilled frame follows are as shown in figure 4.

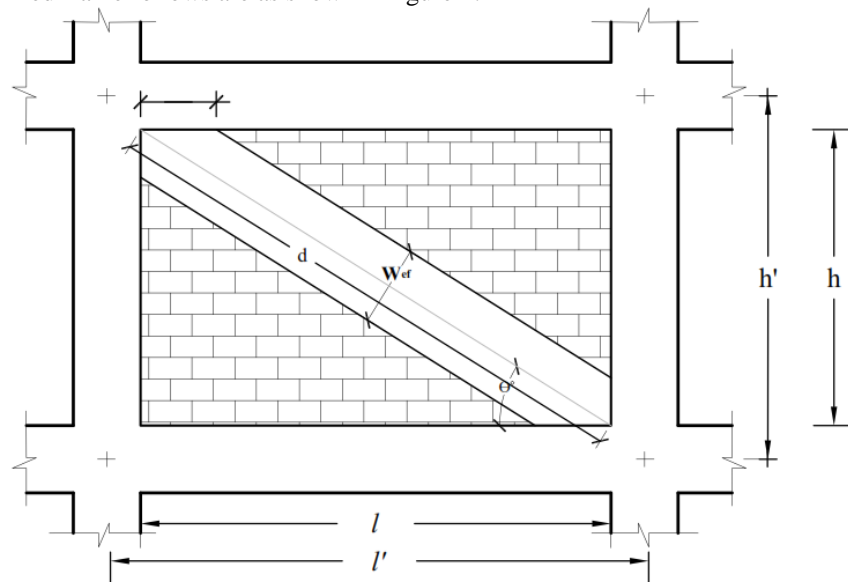


Figure 4..Geometric Characteristics of Infilled Frame

Equivalent area of strut,

$$A_e = W_e t$$

Width of strut,

$$W_e = 0.175(\lambda h)^{-0.4} d$$

$$\lambda = \sqrt[4]{\frac{E_i t \sin(2\theta)}{4E_f I_c h'}}$$

Where,

- E_i - The modulus of elasticity of the infill material, N/mm^2
- T - Thickness of the brick infill,
- θ - $\tan^{-1}(h/l)$,
- E_f - The modulus of elasticity of the frame material, N/mm^2
- I_c - The moment of inertia of column, mm^4
- h' - Height of brick infill,
- l' - Length of brick infill,
- h & l - The height & length of the frame, measured between the centerlines of the beams & columns respectively,
- d - Diagonal length of the brick infill,
- W_e - Width of diagonal strut and
- λ - a coefficient depending on properties of infill

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DESCRIPTION OF STRUCTURAL MODEL

In this work G+12 three dimensional models are selected for which the soft storey behavior is modelled. For this a typical rectangular building is taken having 5 bays in X-direction each is of 6 m span, and the 3 bays in Y-direction each of 4.5 m span each. Height of each story is taken as 3.0 m. Models are generated to get displacement, storey drift, base shear and story shear are discussed here in this work.

The common practice of building design considers infill as non structural elements and building is designed as framed structures without regard to structural action of masonry infill walls. The soft storey effect and presence of infill in any building changes the behavior of frame action due to the relative changes of stiffness of the frame by a factor of three to four times and lateral load distribution. Such buildings are required to be analyzed by the dynamic analysis and designed carefully. As the dynamic ductility demand during probable earthquake gets concentrated in the soft storey and the upper storey tends to remain elastic. Hence the building is totally collapsed due to soft storey effect shown as below in figure 5.



Figure 5. Failure due to large lateral displacement in soft storey

DETAILS OF STRUCTURAL ELEMENTS AND MATERIAL USED

Plan dimensions	30m×13.5m
Total height of building	39 m
Height of each storey	3.0m
Size of beams	300mm×450mm
Size of columns	450mm×450mm
Thickness of slab	120mm
Thickness of Shear Wall	150mm
Thickness of external walls	230mm
Seismic zone	III
Soil condition	Medium soil (Type II)
Zone factor	0.16
Response reduction factor	5
Importance factor	1
Live load at all floors	3.0 kN/m
Grade of Concrete	M25
Grade of Steel	Fe415

Concrete:

Density of Concrete	25 kN/m ³
Modulus of Elasticity	5000√f _{ck} = 25000 N/mm ²
Poisson's ratio for concrete	0.3

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Compressive strength 25 N/mm²

Masonry infill:

Density of brick masonry	19 kN/m ³
Poisson's ratio for brick	0.2
Clay burnt brick, Class A, confined unreinforced masonry	
Compressive strength of brick (fm)	10 N/mm ²
Modulus of Elasticity	550 fm = 5500 N/mm ²
Depth is thickness of wall	230mm
Width of equivalent struts	740 mm in X-direction, 570 mm in Y-direction

IV. MODELLING

ANALYTICAL MODELS CONSIDERED

- 1) Model 1. Bare Frame (RC frame without considering infill Masonry effect)
- 2) Model 2. RC frames buildings model with infill of Strut Frame at all storey
- 3) Model 3. RC frames buildings with soft storey at ground storey and infill at all above storey.
- 4) Model 4. RC frames buildings with soft storey at Sixth storey and infill at all other storey
- 5) Model 5. RC frames buildings with soft storey at Twelfth storey and infill at all other storey

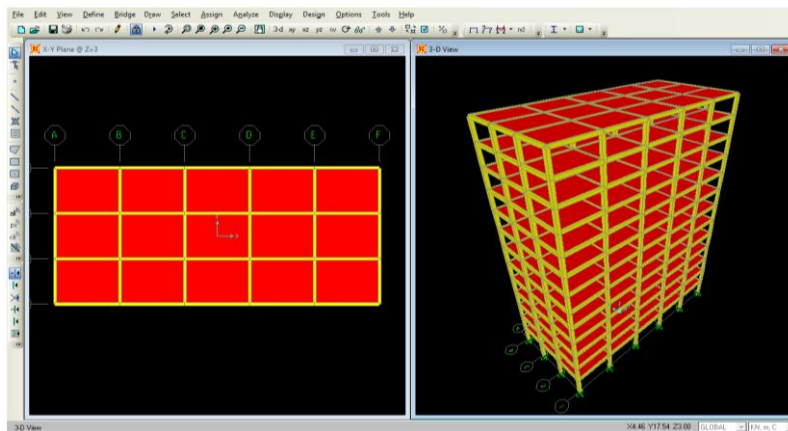


Figure 6: Model 1 showing extrude plan and 3D view of bare frame

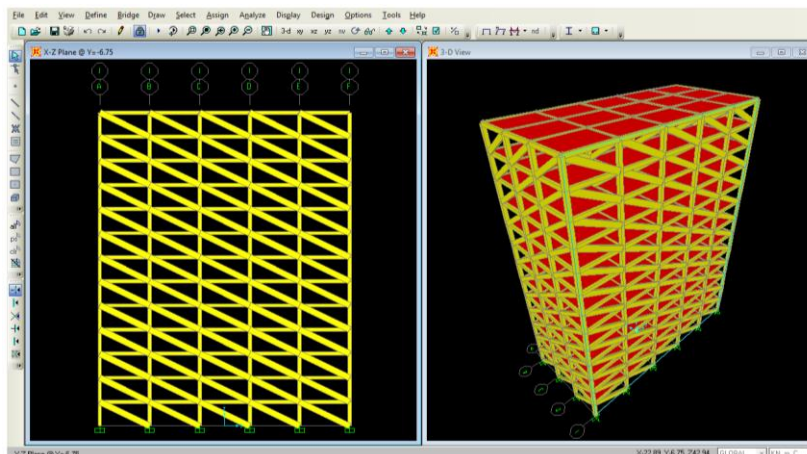


Figure 7: Model 2 showing Elevation and 3D view

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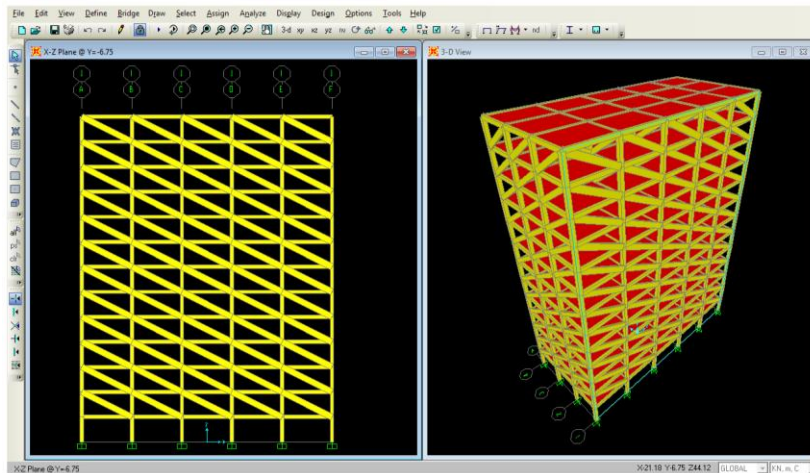


Figure 8: Model 3 showing Elevation and 3D view

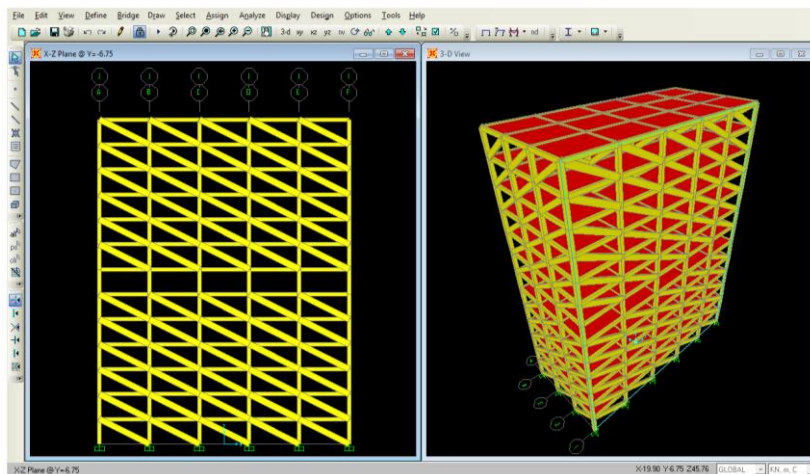


Figure 9: Model 4 showing Elevation and 3D view

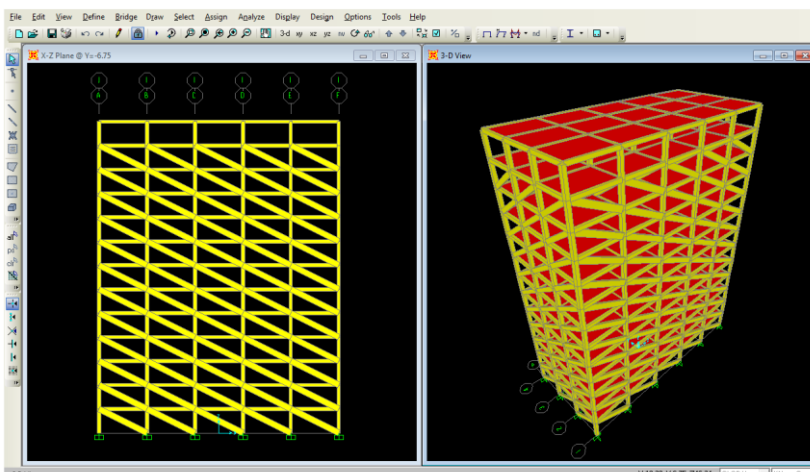


Figure 10: Model 5 showing Elevation and 3D view

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ASSIGNING LOADS

After having modeled the structural components, load cases are assigned as follows:

Gravity loads

Gravity loads on the structure include the self weight of beams, columns, slabs, walls and other permanent members. The self weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself.

The wall loads have been calculated and assigned as uniformly distributed loads on the beams.

Wall load

Wall load = unit weight of brickwork × thickness of wall × height of wall.

Unit weight of brick work = 19 kN/m³

Thickness of wall = 0.23m

Wall load on floor levels = 19 × 0.23 × 3 = 13.11 kN/m (wall height = 3m)

Live loads

Live loads have been assigned as uniform area loads on the slab elements as per IS 1893 (Part 1) 2002

Live load on floors = 3.0 kN/m²

Percentage of Imposed load to be considered in Seismic weight calculation, as per IS 1893 (Part 1) 2002, since the live load class is up to 3 kN/m², 25% of the imposed load has been considered.

The seismic weight

The seismic weight of each floor is its full dead load plus appropriate amount of imposed load.

The defined load patterns are as shown below in figure 4.9 having Dead load, live load and horizontal earthquake load in both i.e X direction and Y direction as per IS 1893(Part 1):2002.

V. RESULTS AND DISCUSSIONS

DISPLACEMENTS

The data of displacement is collected for in X & Y direction for seismic loading from that all models and shown below.

Table.1. Displacements of Various Models in X direction & Y direction

Floor No.	Model 1		Model 2		Model 3		Model 4		Model 5	
	U _x	U _y	U _x	U _y	U _x	U _y	U _x	U _y	U _x	U _y
GL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	1.6375	1.4916	0.2734	0.3754	1.3219	1.3568	0.2686	0.3687	0.2686	0.3685
2	4.3241	3.8590	0.6349	0.8879	1.7493	1.9397	0.6239	0.8726	0.6236	0.8709
3	7.1828	6.3732	1.0152	1.4583	2.1147	2.4950	0.9978	1.4337	0.9968	1.4292
4	10.0513	8.9199	1.4082	2.0783	2.5028	3.1065	1.3856	2.0449	1.3822	2.0351
5	12.8769	11.4566	1.8080	2.7364	2.8956	3.7546	1.7668	2.6837	1.7737	2.6772
6	15.6215	13.9480	2.2084	3.4208	3.2894	4.4285	2.2581	3.4534	2.1652	3.3436
7	18.2430	16.3549	2.6027	4.1185	3.6771	5.1154	3.9737	5.3815	2.5500	4.0213
8	20.6931	18.6327	2.9834	4.8158	4.0515	5.8019	4.4244	6.1528	2.9202	4.6966
9	22.9166	20.7312	3.3421	5.4981	4.4042	6.4737	4.7712	6.8234	3.2674	5.3548
10	24.8522	22.5949	3.7268	6.1586	4.7740	7.1240	5.1526	7.4804	3.6378	5.9887
11	26.4306	24.1636	3.9567	6.7566	5.0086	7.7130	5.3842	8.0745	3.8534	6.5569
12	27.5847	25.3753	4.1922	7.3012	5.2403	8.2494	5.6185	8.6153	4.0926	7.0887
13	28.2844	26.1970	4.3671	7.7701	5.4124	8.7128	5.7927	9.0809	4.5467	7.7871

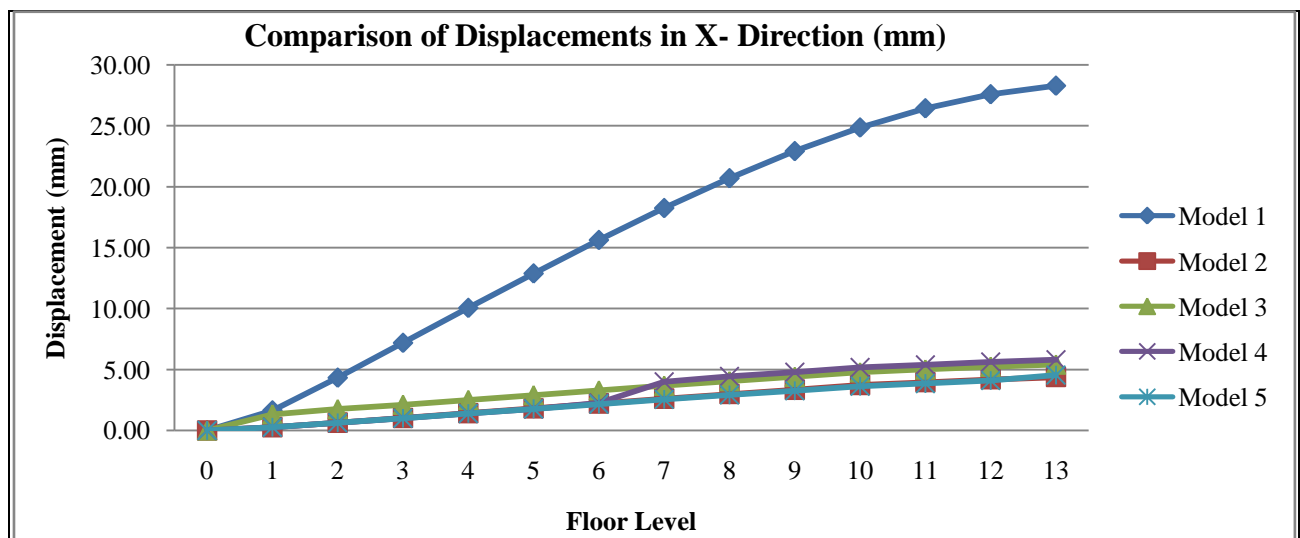
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Comparison of Displacements

For easy comparison of displacements of selected building, plots of the floor level versus displacements in both transverse and longitudinal direction are made for different models and all imposed on same graph.



Graph 1: Displacements in all Models at All Storey Levels in X Direction

STOREY DRIFT

Lateral drift and inter-storey drift are commonly used damage parameter in structural analysis. In this study, lateral drift of the 3D building frame was analyzed for earthquake load coming from long direction. Inter storey drift was also evaluated and tabulated which is given by

$$SD_i = \frac{U_i - U_{i-1}}{h_i}$$

where, $U_i - U_{i-1}$ = relative displacement between successive storey, h_i = storey height.

From the above Displacements, the table no 8.2 is obtained showing storey drift values of all models in X & Y directions.

Table 2.Storey Drift of Various Models in X direction & Y direction

Floor No.	Model 1		Model 2		Model 3		Model 4		Model 5	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
GL	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1	0.00055	0.00050	0.00009	0.00013	0.00044	0.00045	0.00009	0.00012	0.00009	0.00012
2	0.00090	0.00079	0.00012	0.00017	0.00014	0.00019	0.00012	0.00017	0.00012	0.00017
3	0.00095	0.00084	0.00013	0.00019	0.00012	0.00019	0.00012	0.00019	0.00012	0.00019
4	0.00096	0.00085	0.00013	0.00021	0.00013	0.00020	0.00013	0.00020	0.00013	0.00020
5	0.00094	0.00085	0.00013	0.00022	0.00013	0.00022	0.00013	0.00021	0.00013	0.00021
6	0.00091	0.00083	0.00013	0.00023	0.00013	0.00022	0.00016	0.00026	0.00013	0.00022
7	0.00087	0.00080	0.00013	0.00023	0.00013	0.00023	0.00057	0.00064	0.00013	0.00023
8	0.00082	0.00076	0.00013	0.00023	0.00012	0.00023	0.00015	0.00026	0.00012	0.00023
9	0.00074	0.00070	0.00012	0.00023	0.00012	0.00022	0.00012	0.00022	0.00012	0.00022

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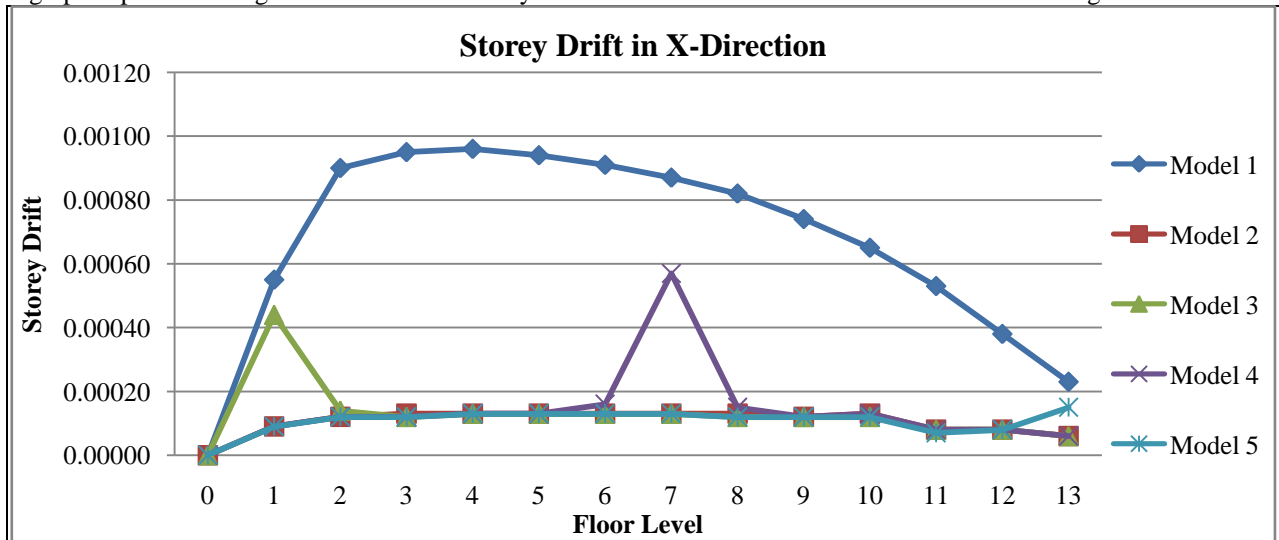
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10	0.00065	0.00062	0.00013	0.00022	0.00012	0.00022	0.00013	0.00022	0.00012	0.00021
11	0.00053	0.00052	0.00008	0.00020	0.00008	0.00020	0.00008	0.00020	0.00007	0.00019
12	0.00038	0.00040	0.00008	0.00018	0.00008	0.00018	0.00008	0.00018	0.00008	0.00018
13	0.00023	0.00027	0.00006	0.00016	0.00006	0.00015	0.00006	0.00016	0.00015	0.00023

Comparison of Storey Drift

A graph is plotted taking floor level versus storey drift for different models in both transverse and longitudinal direction.



Graph 2: Storey Drift in all Models at All Storey Levels in X Direction

SHEAR FORCES

Table 3. Displacements of Various Models in X direction & Y direction

Storey No.	Model 1 SF	Model 2 SF	Model 3 SF	Model 4 SF	Model 5 SF
GL	21.594	4.353	29.456	4.271	4.277
1	16.696	2.101	-5.711	2.056	2.064
2	16.211	2.353	3.559	2.298	2.311
3	15.792	2.238	1.985	2.133	2.195
4	15.376	2.178	2.159	2.727	2.133
5	14.795	2.092	2.040	-4.739	2.043
6	14.008	1.982	1.939	24.704	1.928
7	12.970	1.839	1.798	-6.513	1.777
8	11.636	1.654	1.618	2.960	1.583
9	9.970	1.419	1.388	1.159	1.329
10	7.891	1.120	1.094	1.113	1.142
11	5.537	0.790	0.770	0.750	-0.659
12	1.555	0.095	0.086	0.055	3.792

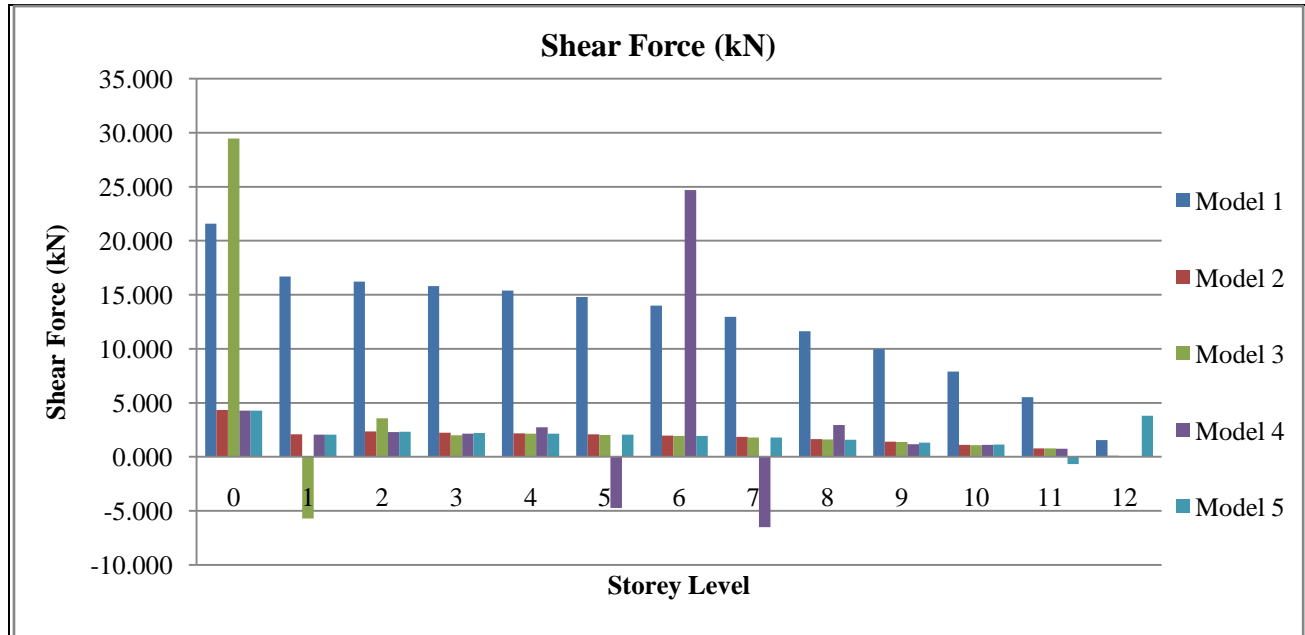
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Comparison of Shear Force

The maximum shear forces in the columns in longitudinal direction for all models are shown below in graphs.



Graph 3: Shear Forces in all Models at All Storey Levels

BENDING MOMENT (kN-M)

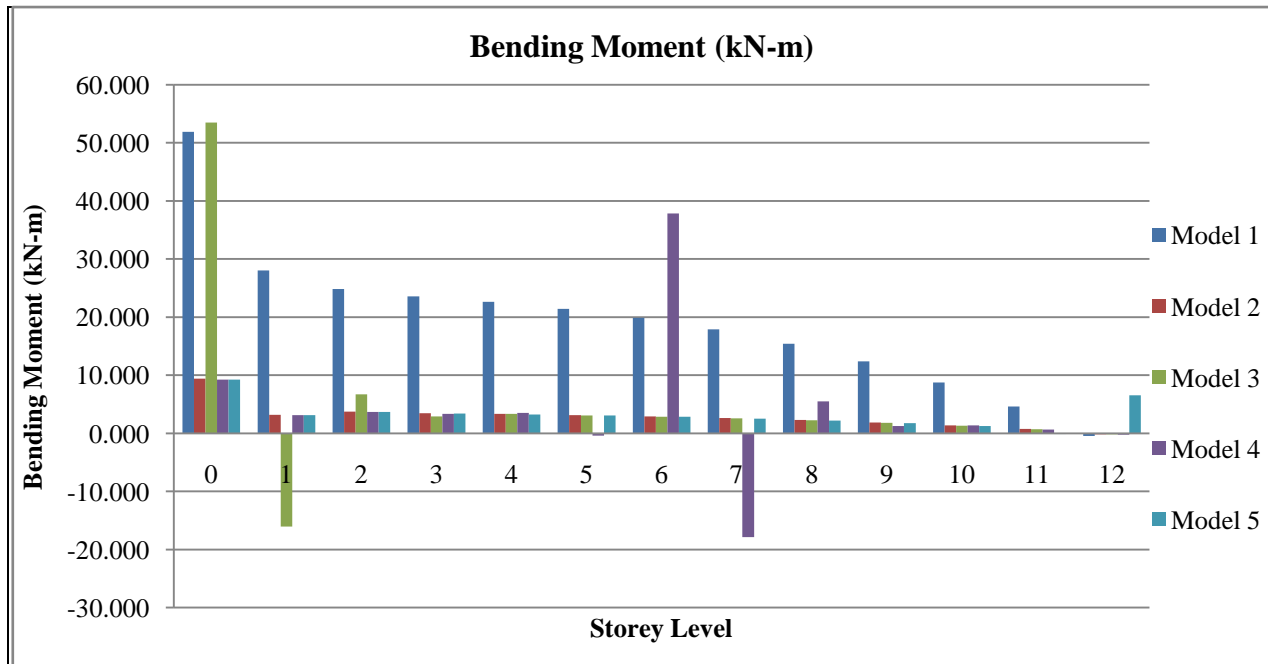
The data of shear force is collected for seismic loading from that all the eight models and shown below

Table 4: Bending Moments in the columns in longitudinal direction

Storey No.	Model 1 BM	Model 2 BM	Model 3 BM	Model 4 BM	Model 5 BM
GL	51.922	9.391	53.519	9.220	9.226
1	28.045	3.168	-16.065	3.104	3.112
2	24.856	3.734	6.699	3.648	3.664
3	23.553	3.458	2.891	3.352	3.388
4	22.609	3.326	3.322	3.494	3.252
5	21.417	3.140	3.058	-0.426	3.060
6	19.873	2.915	2.851	37.860	2.827
7	17.897	2.634	2.575	-17.883	2.535
8	15.425	2.287	2.235	5.510	2.173
9	12.399	1.860	1.817	1.271	1.725
10	8.747	1.337	1.304	1.357	1.232
11	4.588	0.728	0.707	0.665	-0.140
12	-0.446	-0.181	-0.186	-0.228	6.536

Comparison of Bending Moment

The maximum bending moments in the columns in longitudinal direction for all models are shown below in graphs.



Graph 4: Bending Moments in all Models at All Storey Levels

VI.CONCLUSION

- RC frame buildings with open first storeys are known to perform poorly during in strong earthquake shaking. In this paper, the seismic vulnerability of buildings with soft first storey is shown through an example building. The drift and the strength demands in the first storey columns are large for buildings with soft ground storeys and hence necessary measures should taken to improve capacities of the columns in the soft first storey.
- From the analysis it is seen that, deflection is more in case of bare frame as compare to that of infill frame, because presence of infill contributes to the stiffness of building. This effect is clear from Model 1.
- When we compare the results obtained of Model 5 with Model, we can see that Model 5 gives better results than Model 4. Thus intermediate soft storey should be avoided and if at all needed should be provided at top storey.
- When the position of soft storey moved to higher level then parameters tends to reduced.
- Results shows that Moments & Shear forces are always maximum at soft storey level in all Models.
- These results will help design engineers in fast & reliable assessment of effects of soft storey.
- Thus proper care, expert design, detailing and execution are needed in soft storey buildings.

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