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Seismic Performance of Multi-storeyed Reinforced Concrete Building with Soft Story

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Abtract

An Earthquake is a sudden, rapid shaking of earth caused by the breaking and shifting of rocks beneath the earth surface. Overtime, stresses built beneath the earth surface. Occasionally stress is released resulting in the sudden and sometime disastrous shaking which is called as earthquake. The shaking could last seconds or minutes, and there may be several earthquakes over a period ranging from hours to weeks called foreshocks and aftershocks, the later decreasing in magnitude with time.A soft storey concept is a new concept for earthquake resistance structure based on controlling the lateral forces that will occur in the structure during earthquake. The various technical problems occur in structures with soft storey because of lack of stiffness. Hence it is important to understand the behavior of such building for earthquake effects.In this paper, the behavior of multistoried building will be studied for various positions of soft storey along the height. Study will also carry out by changing the stiffness of the storey. The effect of use of light weight material in upper floor, use of bracing systems in soft storey, increasing size of column will be studied in this dissertation work. The analysis will be carried out using structural engineering software SAP 2000.

Keywords: Soft storey, multistory, earthquake, stiffness

I. Introduction

Construction of multi-storeyed buildings with open first storey is a common practice in India. This is an unavoidable feature and is generally adopted for parking of vehicles or reception lobbies. Such a building in which the upper stories have brick infill wall panel and open ground storey is called as stilt building and the open storey is called as stilt floor or soft storey. A soft storey also known as weak storey. It is a storey in a building that has substantially less resistance or stiffness than the stories above or below. A soft storey has inadequate shear resistance or inadequate ductility to resist the earthquake induced stresses. Such features are highly undesirable in buildings built in seismically active areas. The soft storey consists of discontinuity of strength stiffness which occurs the second storey connection. Soft storey concept has technical and functional advantages over the conventional construction. Because firstly, the reduction in spectral acceleration and base shear. Due to increase of natural period of the vibration of structure as in base isolated structure. Secondly, soft storey adopted for parking of vehicles and retail shopping, a large space for meeting room or a banking hall. The Indian seismic code IS 1893:2002 (Clause no.4.20 on Page no.10) 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."

II. System Development

The study is carried out on reinforced concrete moment resisting frame building with open first storey and unreinforced brick infill walls in the upper storeys. The building considered having G+9 stories, of which the ground storey is intended for parking.

Table 1: Analysis Data for Example Building

Plan dimensions	20m x 16m
Total height of building	33m
Height of each storey	3.1m

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Height of parapet	1m
Depth of foundation	1.5m
Size of longitudinal beams	300mm x 500mm
Size of transverse beams	300mm x 450mm
Size of columns	500mm x 500mm
Thickness of slab	150mm
Thickness of external wall	230mm
Thickness of internal wall	115mm
Seismic zone	IV
Soil condition	Hard soil
Response reduction factor	5
Importance factor	1
Floor finish	1.875 kN/m2
Live load at roof level	2.0 kN/m2
Live load at floor	5.0 kN/m2
Grade of concrete	M20
Grade of steel	Fe415
Density of concrete	25 kN/m3
Density of brick masonry	20 kN/m3

III Modeling of Building:

The building is modeled using the finite element software SAP 2000. The analytical models of the building include all components that influence the mass, strength, stiffness and deformability of structure. The building structural system consists of beams, columns, slab, walls, and foundation. The non structural elements that do not significantly influence the building behavior are not modeled. Beams and columns are modeled as two noded beam elements with six DOF at each node. The floor slabs are assumed to act as diaphragms, which insure integral action of all the vertical load resisting elements and are modeled as four noded shell element with six DOF at each node. Walls are modeled by equivalent strut approach and wall load is uniformly distributed over beams. 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. Walls are considered to be rigidly connected to the columns and beams. In the modeling, material is considered as an isotropic material and following designations are used for various models.

Model I	Building with Uniform Infill in all Storeys
Model II	Building with Open First Storey
Model III	Open First Storey with Walls at Specific Location in First Storey
Model IV	Open First Storey with Cross Bracings
Model V	Open First Storey with Stiffer Columns
Model VI	Open First Storey with Shear Walls
Model VII	Open First Storey with Tapered Forms of Columns
Model VIII	Open First Storey with Light Weight Infill in the Upper Storey’s

IV Results and discussion

Equivalent static and response spectrum analysis is carried out on all the models. The results are presented in the form of graphs. Results in the tabular form are given in appendix.

Equivalent Static Analysis

Equivalent static analysis is performed on all the models. Loads are calculated and distributed as per the code IS1893:2002 and the results obtained are compared with respect to the following parameters.

1. Storey stiffness

The storey stiffness is defined as the magnitude of force couple required at the floor levels adjoining the storey to produce a unit lateral translation within the storey, letting all the other floors to move freely.A graph is plotted taking different models on X axis and storey stiffness on Y axis in the transverse and longitudinal direction as shown in figure 1 and figure 2

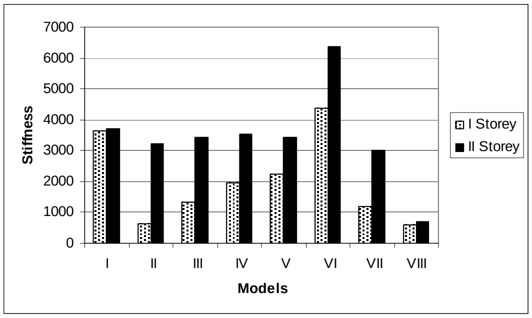

Figure 1: Comparison of stiffness at first and second floor for different models in longitudinal direction for zone IV (ESA).

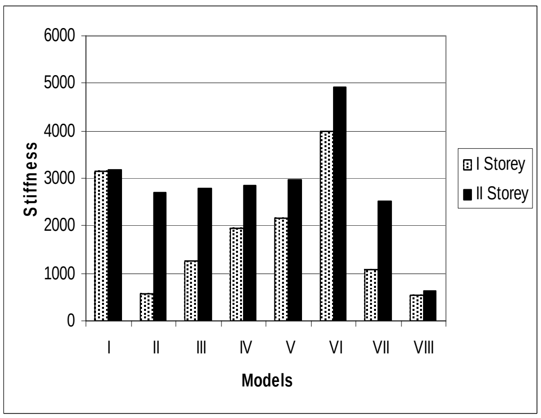

Figure 2: Comparison of stiffness at first and second floor for different

models in transverse direction for zone IV (ESA).

From the above results, it is observed that the stiffness of first storey for model II is about 20% of second storey stiffness. Model II represent the realistic situation for earthquake. It is seen that use of brick infill at some location (Model III) reduces the stiffness irregularity marginally. In case of model III stiffness of first storey is increased to 45% of second storey stiffness. The use of cross bracing (Model IV) significantly increases the stiffness of first storey. The first storey stiffness in model IV is more than 68% of the second storey stiffness. The use of stiffer column (Model V) increases the stiffness up to 73%. Shear wall (Model VI) is found to be quite effective in increasing the stiffness. In this case stiffness of first storey is increased to80%. For Model VII, the stiffness of first storey is 43% of second storey stiffness. Again, the use of light weight material in the upper storey (Model VIII) drastically reduces the stiffness irregularity about 88%.

2. Lateral displacement

A graph is plotted taking floor level as the abscissa and the displacement as the ordinate for different models in the transverse and longitudinal direction as shown in figure 3 and figure 4.

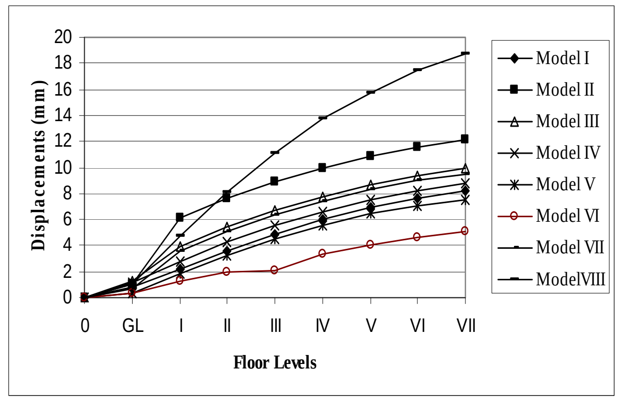

Figure.3: Displacement profile in longitudinal direction for zone IV (ESA).

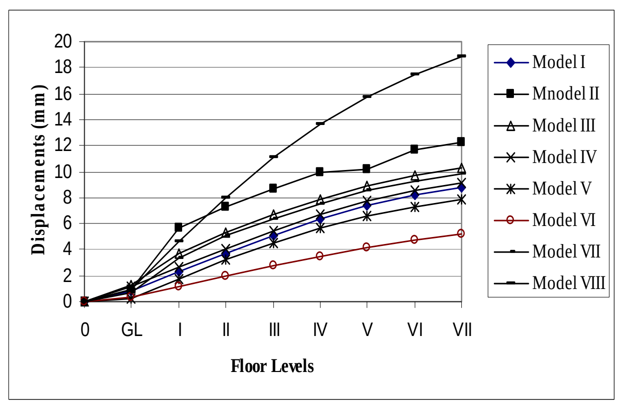

Figure 4: Displacement profile in transverse direction for zone IV (ESA).

From the above displacement profiles it is observed that large displacement occurs in case of soft storey building (model II). On the other hand if there is uniform infill in all the storeys (model I), the displacements are very small in the first storey. It is seen that the use of infill at selected locations in the first storey reduces the displacement up to 34% as compared with model II. Cross bracing (Model IV) reduces the displacement to 54% of model II. Stiffer column (Model V) reduces the displacement to 70%. By introducing the shear wall (Model VI) reduces the displacement to 80% of model II. There is not much reduction in the displacements at first floor, if we provide the tapered column or light weight materials but they certainly reduce the stiffness irregularity.

3. Storey drift

A graph is plotted taking floor level as the abscissa and the storey drift as the ordinate for different models in the transverse and longitudinal direction as shown in figure 5 and figure 6.

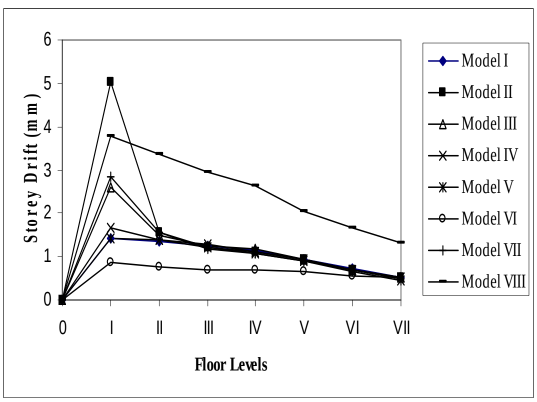

Figure 5: Storey drift profile in longitudinal direction for zone IV (ESA).

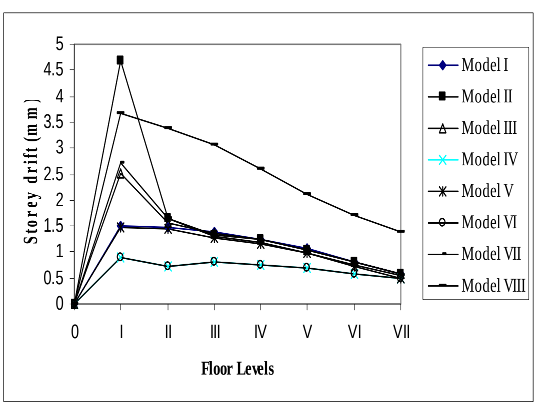

Figure 6: Storey drift profile in transverse direction for zone IV (ESA).

An abrupt change in displacement profile indicates the stiffness irregularity. There is sudden change in the slope at first storey. The graph shows the storey drift is maximum for Model II, this indicate ductility demand in the first storey column for this model is largest. However the storey drift profile becomes smoother right from III to model VI indicating large stiffness and less ductility demand. The use of tapered form of the columns also reduces the storey drift at first floor level. It is seen that in case of model VIII the storey drift at first floor is large as that of model II but there is no abrupt change in the slope, shown by the smooth curve.

4. Bending moment and shear force in columns

The maximum bending moments in the columns in longitudinal and transverse direction are shown in figure 7 and figure 8.

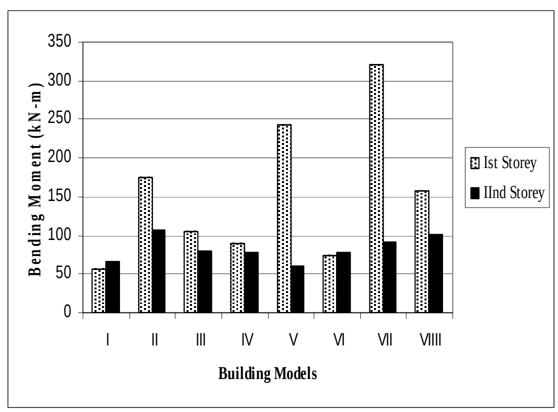

Figure 7: Comparison of maximum bending moment in longitudinal direction for zone IV (ESA).

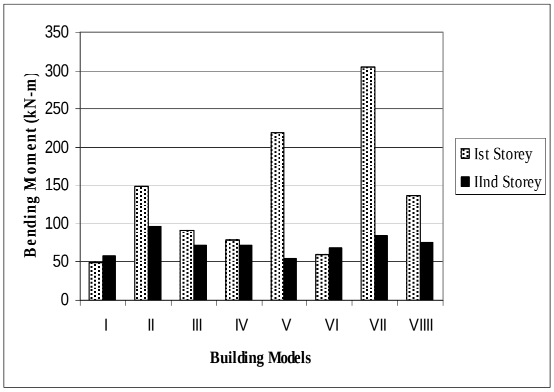

Figure 8: Comparison of maximum bending moment in transverse direction for zone IV (ESA).

The maximum shear forces in the columns in longitudinal and transverse direction are shown in figure 9 and figure 10.

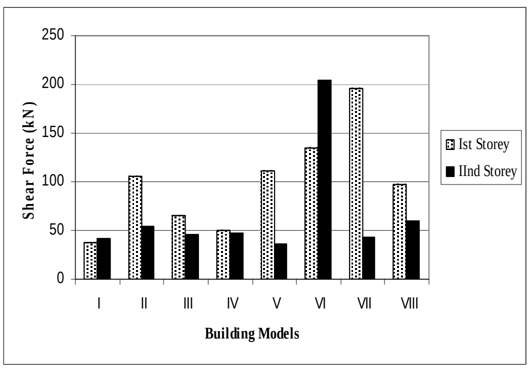

Figure 9: Comparison of maximum shear force in longitudinal direction for zone IV (ESA).

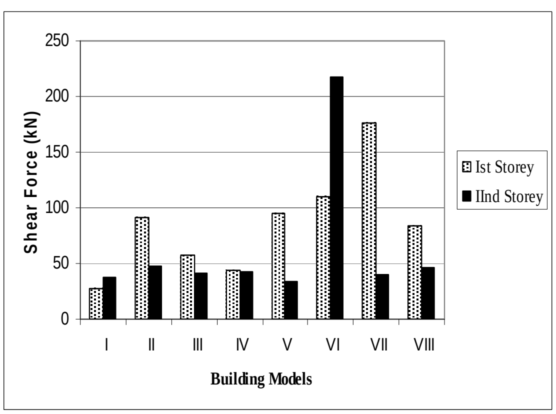

Figure 10: Comparison of maximum shear force in transverse direction for zone IV (ESA).

The bending moment and shear force demands are severely higher for first storey column in case of soft first storey buildings (Model II). The bending moment is quite large in the first storey columns as compared to the upper storeys. Shear wall (Model VI) is found to be very effective in reducing the bending moment in the columns, as the force is distributed in proportion to the stiffness of the members. In Model IV and Model VI the moments are reduced by 50-60% as compared to soft storey models and the bending moment difference between the first and upper storeys is also less. From strength point of view the performance of these models are better. The use of brick infill wall or light weight infill wall (model III and VIII) are not very effective in reducing the strength demand on first storey column. From the above observations, it is seen that the higher size of columns (Model V and VII) is effective in reducing the drift. But it increases the shear force and bending moment in the first storey. By increasing stiffness of column, displacement of column decreases and its shear force and bending moment increases.

5. Axial force and twisting moment in columns

The maximum axial forces in the columns at first and second storey are shown in figure 11.

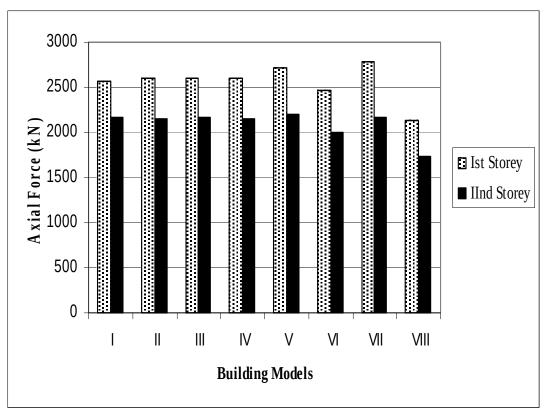

Figure 11: Comparison of maximum axial force in zone IV (ESA).

The axial force in model I, II, III and IV is fairly same. The use of shear wall reduces the axial force to some extent. But in case of model V and VII the axial force is increased to 10% of model II because of their large sizes. However the axial force is considerably reduced by the use of light weight material (model VIII), it is reduced to 18% of model II.

The twisting moments in the columns in longitudinal and transverse direction are shown in figure 12 and figure 13.

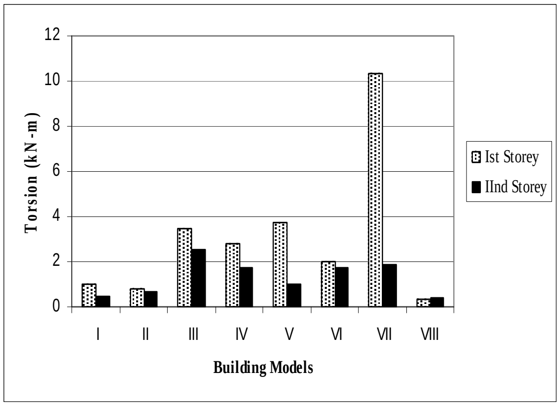

Figure 12: Comparison of maximum twisting moment in longitudinal direction for zone IV (ESA).

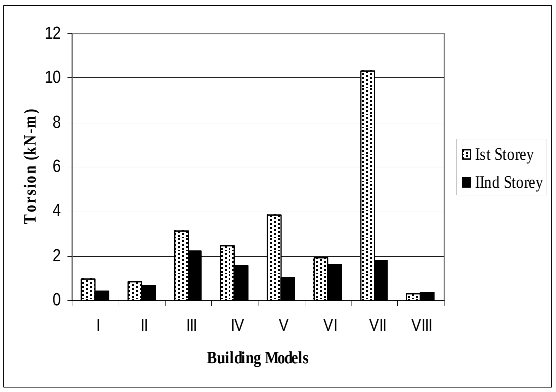

Figure 13: Comparison of maximum twisting moment in transverse direction for zone IV (ESA).

From above charts it is clear that, though the performance of the other parameters is better in models excluding I and II, the induced torsion is however larger in these models. Because of presence of non prismatic section in model VII, the induced torsion is 10 times more than model I and II. However, in model VIII the twisting moment is reduced to 60% of model I.

6. Base shear

The base shear for different building models in both the directions is shown in figure 14.

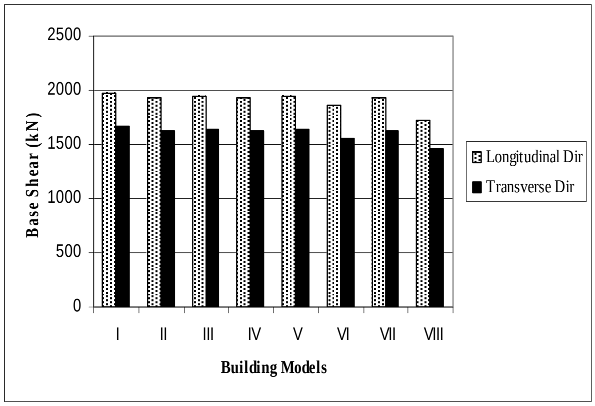

Figure 14: Base shear in longitudinal and transverse direction for zone IV (ESA).

Base shear of all the above models are fairly constant except model VII in which it is reduced to 10% of model II because of use of light weight material infill in the upper storeys.

V Concluding Remarks

The main objective of the study is to increase the first storey stiffness, so that the stiffness irregularity can be minimize and inter storey drift can be reduced. To improve the seismic performance of soft first storey different alternative measures are suggested. It is observed that there is significant increase in the stiffness, reduction of lateral drift demand, and hence the stress resultants, on first storey column if the described improving measures are used. It is found that the use of cross bracing, stiffer column, shear wall, light weight material infill increases the stiffness of first storey and reduces the lateral drift demand. However it is seen from the observations that by increasing stiffness of column, (as in case of model V and VII) displacement of column decreases and its shear force and bending moment increases. Though model VIII is effective in reducing the stiffness irregularity but it has less strength.

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