# PERFORMANCE OF FRAMED BUILDING WITH SOFT STOREY AT DIFFERENT LEVELS

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***Abstract -*** *In high rise building or multi storey building, soft storey construction is a typical feature because of urbanization and the space occupancy considerations. Reinforced concrete framed buildings with in-fills are usually analyzed as bare frame, without considering the strength and stiffness contributions of the in-fills. However when subjected to a strong lateral loads, infill panels tends to interact with bonding frame and may induce a load resistance mechanism that is not accounted for the design. 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 containing the concrete columns were unable to provide adequate shear resistance, hence damage and collapse are most often observed in soft storey buildings during the earthquake. Open first storey is a typical feature in the modern multi-storey constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. Response spectrum analysis is chosen for the analysis of the model since it provides response to the applied loads and spectra conditions. In the current study the focus is on the performance and behavior of a structure with soft storey at different floors with the help of response spectrum method. For analysis purpose, six different cases of model are studied using ETABS V.16.03. A G+20 building with simple square plan is considered, as per IS 456:2000 and IS 1893:2002.*

***Key Words*****: *Nonlinear-static analysis, Response Spectrum analysis, Performance based assessment, Soft storey, Stiffness, Drift index.***

## 1. INTRODUCTION

Many urban multi-storey buildings in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first stories. The upper stories have brick infill wall panels. The Indian seismic code classifies a soft storey as one whose lateral stiffness is less than 70% of the storey above. Whereas the total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with ground soft storey, the upper storey's being stiff undergone smaller inter-storey drifts. However, the inter-storey drift index in the ground soft storey is large. The strength demand on the columns in the ground storey is also large, as the shear in the first storey is more.

Soft storeys are one of the typical causes of failure of structures during earthquakes. A soft storey is a structural anomaly attributed to the discontinuity of stiffness along the height of a structure. Severe structural damages suffered by several modern buildings during recent earthquakes illustrate the importance of avoiding sudden changes in vertical stiffness and strength. Classically being associated with retail spaces and parking garages, they are often seen in lower stories of the building, which means when they collapse, they can cause serious structural damage or even lead to the collapse of the whole building.

### 1.1 Behavior of Soft Storey:

Many building structures having soft stories suffered major structural damage and collapsed in the recent earthquakes. Large open areas with less infill and exterior walls in ground floor compared to upper floors are the cause of damages. In such buildings, the stiffness of the lateral load resisting systems at those stories is quite less than the stories above or below. During an earthquake, if abnormal inter-storey drifts between adjacent stories occur, the lateral forces cannot be well distributed along the height of the structure. This situation causes the lateral forces to concentrate on the storey having large displacement. In addition, if the local ductility demands are not met in the design of such a building structure for that storey and the inter-storey drifts are not limited, a local failure mechanism or, even worse, a storey failure mechanism, which may lead to the collapse of the system, may be formed due to the high level of load deformation effects.

Lateral displacement of a storey is a function of stiffness, mass and lateral force distributed on that storey. It is also known that the lateral force distribution along the height of a building is directly related to mass and stiffness of each storey. 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 important information about the structural behavior of the system.

Many RC 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. An open ground storey building, having only columns in the ground storey and both partition walls and columns in the upper storeys, have two distinct characteristics, namely:

(a) It is relatively flexible in the ground storey, i.e., the relative horizontal displacement it undergoes in the ground storey is much larger than what each of the storeys above it does. This flexible ground storey is also called soft storey.

(b) It is relatively weak in ground storey, i.e., the total horizontal earthquake force it can carry in the ground storey is significantly smaller than what each of the storeys above it can carry. Thus, the open ground storey may also be a weak storey.

Often, open ground storey buildings are called soft storey buildings, even though their ground storey may be soft and weak. Generally, the soft or weak storey usually exists at the ground storey level, but it could be at any other storey level too.

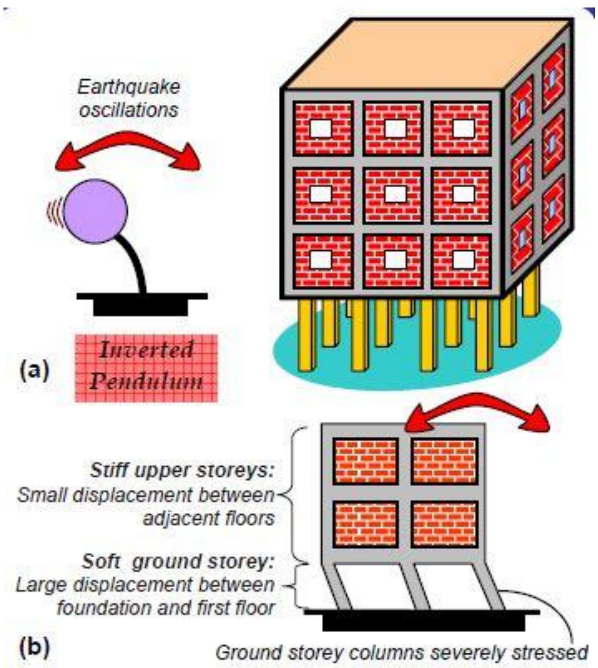


Figure 1: Upper storeys of open ground storey building move together as a single block – such buildings are like inverted pendulums.

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. In common language, this type of buildings can be explained as a building on chopsticks. Thus, such buildings swing back-and-forth like inverted pendulums during earthquake shaking, and the columns in the open ground storey are severely stressed. If the columns are weak (do not have the required strength to resist these high stresses) or if they do not have adequate ductility, they may be severely damaged which may even lead to collapse of the building. Due to this, such inverted pendulum like behavior is also seen in the cases where soft storey is created at above floors. The storeys below the soft storey and above it act individually like a single block and the upper portion moves to and fro during earthquake (oscillating like inverted pendulum).

### 1.2 Scope & Objective

The strength and stiffness of infill walls in infill frame buildings are ignored in the structural modeling in conventional design practice. The design in such cases will generally be conservative in the case of fully infill framed building. But things will be different for an open ground storey framed building. Open ground storey building is slightly stiffer than the bare frame, has larger drift especially in the ground storey, and fails due to soft storey mechanism at the ground floor. The scope of the study is to find the effect of masonry infill panel on the response of RC frames subjected to seismic action by conducting response spectrum analysis for RC frame with infill wall at varying arrangement using ETABS 2015.

The main objectives of the study are:

- To study the behaviour of reinforced concrete framed multi-storeyed building with soft storey at different floor levels.
- To study the critical condition generated due to soft storey conditions.
- To compare various parameters such as displacement, stiffness, inter-storey drift index and base shear.
- To find the minimum damage level of high rise buildings with soft storeys

## 2. Response Spectrum Analysis

There are three analysis methods for the seismic analysis of the structure, pushover analysis, time history analysis and response spectrum analysis. Response spectrum analysis is chosen for the analysis of the model since it provides response to the applied loads and spectra conditions. One of the major objectives of this paper is to analyze the effect of soft-storey at various arrangements and this method helps in studying that comparison.

In the response spectrum analysis procedure, each of the model's modes is considered to be an independent SDOF system. The maximum responses for each mode are calculated independently. These modal responses are then combined to obtain the model's overall response to the applied spectra. The response spectrum method enjoys wide acceptance as an accurate method for predicting the response of any structural model to any arbitrary base excitation, particularly earthquakes. It is easier, faster and more accurate than the static procedure so there really is not any reason to use the static procedure. Response spectrum analysis is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. It is a procedure for computing the statistical maximum response of a structure to a base excitation. Each of the vibration modes that are considered may be assumed to respond independently as a single degree-of-freedom system. It is useful for design decision-making because it relates structural type-selection to dynamic performance.

The response spectrum analysis procedure is based on the assumption that the dynamic response of a structural model can be approximated as a summation of the responses of the independent dynamic modes of the model. The usual application of this method is in seismic analysis. With response spectrum method, it is possible to predict the maximum response for any single degree-of-freedom (SDOF) system. By "any SDOF system", it is meant a SDOF system with any natural frequency. "Maximum response" means the maximum deflections.

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## 3. Structural & Loading Details

Table 1: Modeling and Loading of Structure

| | | |
|---|---|---|
| 1 | Plan Dimensions | 30 x 30 m |
| 2 | Number of story | G+20 |
| 2 | Floor to floor height | 3.6m |
| 4 | Slab thickness | 150mm |
| 5 | Size of beam | 450mm x 500mm |
| 6 | Size of column | 600mm x 600mm |
| 7 | Thickness of infill wall | 230mm |
| 8 | Thickness of slab | 150mm, M40 |
| 9 | Zone and zone factor | III, 0.16 |
| 10 | Importance factor | 1.5 |
| 11 | Response factor (R) | 5 |
| 12 | Grade of concrete and rebar in beam | M35, Fe500 |
| 13 | Grade of concrete (Slab) | M35 |
| 14 | Grade of concrete and rebar in column | M40, Fe415 |
| 15 | Grade of shear wall | M40 |
| 16 | Live load and floor finish load | 3kN/ m$^2$and 1kN/m$^2$ kN/ |
| 17 | Top floor load | 2kN/ m$^2$ |
| 18 | Masonry load | Half brick wall, 7.2 kN/m m$^2$ |

Equivalent Diagonal Strut Method is used for modelling the infill wall. In this method the infill wall is idealized as diagonal strut and the frame is modelled as beam or truss element. Frame analysis techniques are used for the elastic analysis. The idealization is based on the assumption that there is no bond between frame and infill.

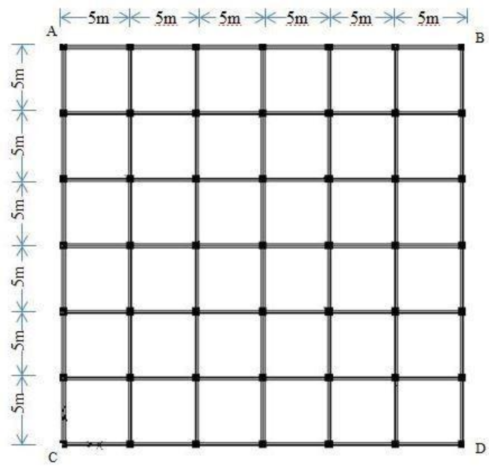



Figure 2: Plan of the bulding

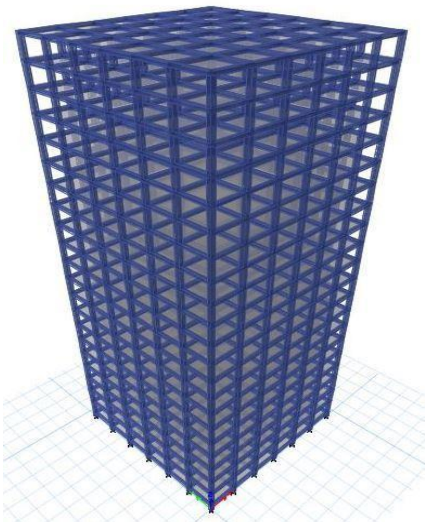


Figure 3: 3D layout of the structure

IS 1893 (Part 1): 2016 Criteria for Earthquake Resistant Design of Structures deals with assessment of seismic loads on various structures and earthquake resistant design of buildings.

As per IS 1893 (Part 1):2016, when earthquake forces are considered on a structure in the limit state design of reinforced and prestressed concrete structures, 13 load combinations shall be accounted for.

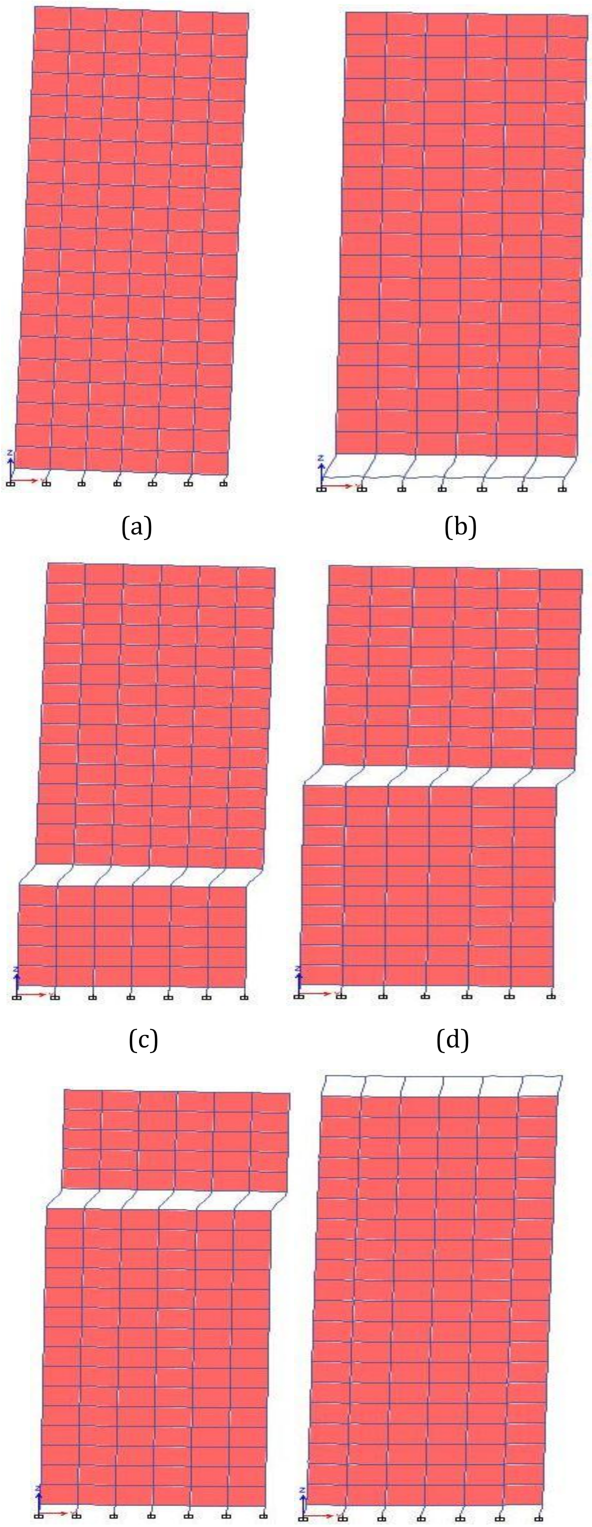
As per IS 1893:2016, for various loading classes as specified in IS 875 (Part 2), the seismic force shall be calculated for the full dead load plus the percentage of imposed load as given in below table.

Table 2: Live Load Reduction Clause as per IS 1893:2016

| Imposed Uniformity Distributed Floor Loads ( $kN/m^2$ ) | Percentage of Imposed Load |
|---|---|
| Up to and including 3.0 | 25 |
| Above 3.0 | 50 |

## 4. Behavior of the cases to be analyzed:

Six different cases are taken and analysed: Full Masonry Structure, Soft Storey at Ground Floor, Soft Storey at 5$^{th}$ Floor, Soft Storey at 10$^{th}$ Floor, Soft Storey at 15$^{th}$ Floor, Soft Storey at 20$^{th}$ Floor. Symmetrical constructions in both plan and height show a better resistance during an earthquake than those that do not have this symmetry. Since the presence of a soft storey which has less rigidity than other storeys spoils the perpendicular symmetry of the construction, and if this fact was not taken into consideration, it causes the construction to be affected by the quake because the columns in this part are forced by the quake more than the ones in the other parts of the building. Studies conducted suggest that walls increase the rigidity at a certain degree in the construction. The soft storey configuration is possible in by different arrangement in the building.



(a) (b)

(c) (d)

(e) (f)

Figure 4: Behavior of structure with soft storey at different floor during earthquake

Soft storey configuration in structures is a type of construction where any one storey of the building is more flexible (less stiff) when compared with other floors. This may be located at the bottom, or at any intermediate points, where the floor above or below it may be stiffer compared to itself. This accounts to be a weak element in the perspective of seismic forces. This weakness may be a sharp variation in the stiffness, drift index or in the strength parameters. These variations result in the poor distribution of masses throughout the floor, which is undesirable.

## 5. RESULTS

### 5.1 BASE SHEAR

Base reactions are assessed for all the cases and further calculations are done accordingly. Base shear is reviewed due to all the modes reported in the Response Spectrum Base Reaction Table. If the dynamic base shear reported is more than 85% of the static base shear, no further action is required. However, if dynamic base shear is less than 85% of the static base shear, then the scale factor should be adjusted such that the response spectrum base shear matches 85% of the static base shear.

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It is a very important parameter for earthquake resistant design of buildings. Among all the cases, base shear is highest for full masonry structure and least for soft storey at ground level. This indicates that the case 2, i.e. soft-storey at ground level is most vulnerable during earthquake. The whole structure is critical under this case. Full masonry structure is the most reliable one.

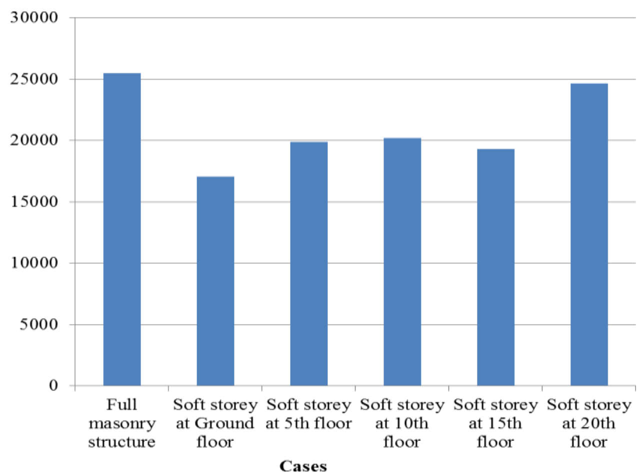



Figure 5: Bar graph showing variations in base shear of all the cases on Y-axis

### 5.2 INTER-STOREY DRIFT INDEX

Storey drift is the drift of one level of a multi- storey building relative to the level below. 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 analysed for earthquake load coming from long direction.

Inter-storey drift index was also evaluated and tabulated which is given by

$$SD_i = \frac{V_{Ui} - V_{Ui-1}}{h_i}$$

Where, $V_{Ui} - V_{Ui-1}$ = Relative displacement between successive storey.

$h_i$ = Storey height.

It is observed that for all cases there is a sudden increment in drift index at soft storey level, which is due to absence of masonry infill. The lateral load is more effective at that floor. The drift index value of soft storey at ground floor of the building is more. The drift index value is very less when soft storey is at top of the building.

### 5.3 STOREY STIFFNESS

Stiffness is the rigidity of an object i.e., the extent to which it resists deformation in response to an applied force. As per IS 1893:2016, soft storey is one in which the lateral stiffness is less than that in the storey above. As per IS 1893:2002, soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 per cent of the average lateral stiffness of the three storeys above.

At the soft-storey level there is a decrement in the storey stiffness. The stiffness decreases as we move upwards, meaning that as the storey height increases, storey stiffness decreases. After the decrement point the previous curve proceeds. This means that the upper portion has lesser value of storey stiffness than the lower portion.

## 6. CONCLUSIONS

RC frame buildings with soft storey are known to perform poorly during in strong earthquake shaking. In this project, the seismic vulnerability of buildings with soft storey at different floor levels is shown through an example building. Tall building of G+20 storeys is provided with soft storey at different floor levels to be analysed for the load as per IS 1893:2016, using software package ETABS 2015. The building is located in seismic zone III. The results may help to the future construction of soft storey buildings. From the result it is concluded that,

- The displacement of storey increases at soft storey level due to increase in application of dynamic forces on it. The presence of infill wall can affect the seismic behaviour of frame structure to large extent, and the infill wall increases the stability of the building.

- There is a drop in the storey stiffness at soft storey level in all cases. From this more care is need design the columns in the soft storey. Infill panels increases the stiffness of the structure. Hence behaviour of building varies with the change in infill arrangements.

- The buildings with soft storeys resist smaller forces as compared to the stiff structures. The base shear at different floor levels is lesser for the buildings with soft storeys as compared to the stiff buildings. The base shear in the building with no soft storey is found maximum i.e. 25482.2 kN.

- On comparing the storey response of the cases, it is observed that the storey drift index in case of buildings with soft storey is very large as compared to a stiff building. This high relative drift index in the building lead to a large amount of undesirable additional bending moments in columns which leads to the failure of the structure as a whole. In case of an open first storey frame structure, the storey drift index is very large than in the upper storeys i.e. 0.002068, which may cause the collapse of structure during strong earthquake shaking.

- The soft storey columns require more percentage of reinforcement.

- It is advisable to provide soft storey at higher levels. The presence of walls in upper storey makes the 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 moves to and fro when earthquake occurs. Thus it is clear that building with only column in the ground storey has poor performance during earthquake as compared to building with both wall and column in the ground storey.

Earthquake vulnerability of buildings with open ground floors is well known around the world. For a building that is not provided any lateral load resistance component such as shear wall or bracing, the strength is consider very weak and easily fail during earthquake. Other possible schemes to achieve the above objective are:

(i) Provision of stiffer columns in the first storey in case of ground soft storey, and

(ii) Provision of a concrete service core in the building.

The former is effective only in reducing the lateral drift demand on the first storey columns. However the latter is effective in reducing the drift as well as the strength demands on the soft storey columns

## REFERENCES

[1] A. Madan, A. M. Reinhorn, J. B. Mander, R. E. Valles, "Modelling of Masonry Infill Panels for Structural Analysis", Journal of Structural Engineering, October 1997.

[2] Abhishek Arora, "Alternative Approach to Soft Storey in Seismic Analysis of R.C.C Building Structures", April 2015.

[3] Agarwal, P. and Shrikhande, M., "Earthquake Resistant Design of Structures", PHI Publication, 2004.

[4] Bhakti Narayan Harne, R. R. Shinde, "Seismic Performance of Multi-Storied RC Building with Soft Storey", International Journal of Emerging Technology and Advanced Engineering, Volume 5/ pp.116-122/ 2015.

[5] Bureau of Indian Standards, "Criteria for Earthquake Resistant Design Of Structures" IS: 1893 (Part I): 2016 (Sixth Revision).

[6] Bureau of Indian Standards, "Code Of Practice For Design Loads (Other Than Earthquake) For Buildings And Structures: Special Loads And Combinations" IS: 875 ( Part 5 ) – 1997 (Second Revision).

[7] Bureau of Indian Standards, "Plain and Reinforced Concrete – Code of Practice" IS: 456-2000 (Fourth Revision).

[8] Bureau of Indian Standards, "Earthquake Resistant Design And Construction Of Buildings —Code Of Practice" IS: 4326-1993 (Second Revision).

[9] C. V. R. Murty, "How do Brick Masonry houses behave during Earthquakes?", Building Materials and Technology Promotion Council, New Delhi.

[10] C. V. R. Murty, "Why are Open Ground Storey Buildings vulnerable in Earthquake?", Indian Institute of Technology, Kanpur.