PERFORMANCE BASED STUDY ON SOFT STOREY BEHAVIOUR OF RC FRAME BUILDINGS

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ABSTRACT
Reinforced concrete frame buildings are common building structure. Masonry infill in such buildings serves as cladding and partitions. The infill increases the stiffness of the building. However, infill may be absent in ground storey or other storey for free parking, open entrance etc. In such situation, the storey without infill has less stiffness. This storey is said to be a soft storey. There is utility of soft storey buildings functionally, but from a seismic performance point of view such buildings are vulnerable to damage. From the performance of soft storey buildings in past earthquakes it was evident that the major type of failure that occurred in open storey buildings included snapping of lateral ties, crushing of core concrete, buckling of longitudinal reinforcement bars etc. Due to the presence of infill walls in the entire upper storey except for the open storey makes the upper storeys much stiffer than the open 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 storey itself.

Key words: Masonry infill, Soft Storey, Storey stiffness and Pushover Analysis.

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1. INTRODUCTION
A Soft Storey building is that where a particular storey has substantially less stiffness in comparison with adjacent storeys. As per Indian seismic code IS 1893 (part 1): 2002 a soft storey is one in which lateral stiffness of a storey is,
• Less than 70% of the above one storey.
  Or,
• Less than 80% of the average stiffness of three storeys above.

It is a most common type of the vertical irregularity occurs in buildings.

A soft storey in a building is introduced by absence of infill walls at that storey where as other storeys are having full infill due to which that storey without infill have less stiffness as compare to other storeys. This irregularity in building causes serious earthquake damage and can occur at any storey of a building.

Storey stiffness \((k)\) for the building

\[
k_i < 0.7k_{i+1}
\]

Or,

\[
k_i < 0.8\left[\frac{k_{i+1}+k_{i+2}+k_{i+3}}{3}\right]
\]

2. CODAL METHOD OF DESIGN
2.1. Indian standards IS-1893 (Part 1): 2002

As per bureau of Indian standard the building which have soft storey, special arrangement should be made to increase the lateral strength and stiffness of soft storey. The dynamic analysis for the building is carried out including the strength and stiffness effect of infill’s and inelastic defamation in the members, particularly, those in the soft storey and the member designed accordingly. The design criteria are to be adopted as pe IS 1893 (pat 1): 2002 after carrying out the earthquake analysis, neglecting the effect of infill walls in other storeys the columns and beams of the soft storey have to be designed for 2.5 times the storey shears and moments calculated under seismic loads.
2.2. Eurocode 8 EN 1998-1: December 2003
There is no suggestion to check criteria of vertical irregularity in Eurocode, as in of other codes. It recommends increasing the resistance of columns in the less infilled storey in proportion to the amount of deficit in strength of masonry infill (MI). If there is a drastic reduction of infill walls in any storey compared to the adjoining storeys, seismic forces in the less infilled storey shall be increased by a multiplication factor (MF) $\eta$. Thus seismic design forces in columns only, are increased by a factor as follows:

$$\eta = \left[ 1 + \frac{\Delta V_{GW}}{\Sigma V_{Ed}} \right] \leq q$$

Where, $\Delta V_{GW}$ is the total reduction of the lateral resistance of MI in the ground storey compared to that in the storey above, $\Sigma V_{Ed}$ is the sum of seismic shear forces acting on all structural vertical elements of the storey concerned. The term $q$ is called behavior factor, which accounts for energy dissipation capacity of the structure and the value varies from 1.5 to 4.68 depending upon the type of building systems, ductility classes, and plan regularity in the building. The maximum vertical irregularities allowed in buildings are such that $q$ is never more than 4.68, which is larger than the factor 2.5 given in the Indian code IS 1893 (Part1): 2002.

3. SCOPE OF THE PRESENT STUDY
A number of RC frame buildings having same plan but with different storeys have considered in this study.

**Storey Groups:** Following different storeys have considered,
- 4-Storey
- 6-Storey
- 8-Storey
- 10-Storey

4. PERFORMANCE OF BARE FRAME BUILDINGS
Reinforced concrete frame buildings without infill have been studied. For the analysis purpose buildings having regular plan with different storeys has been considered. Zone factor has been taken as zone V and soil site has been considered as medium. The importance factor for all buildings has been taken as 1. The material have been used, M25 grade of concrete and Fe500 for steel.

The performance point of the buildings has been evaluated by pushover analysis under: (a) Uniform load and (b) Mode proportional load. The performance point has been found for DBE level and MCE level separately.

All buildings have been designed as per IS 1893 (Part 1): 2002 and IS 456: 2000. For infilled buildings base shear correction factor has been applied as per codal provisions with period formula. Capacity design has been done for achieving the strong column weak beam concept. The code has incorporated the effect of infill panels through periodic formula which is also known as period capping. The nonlinear static pushover analysis has been done for the finding out the performance of the buildings. In design of building the infill strut element is not modelled and the design is done with period capping formulae.
Nomenclature: Following Nomenclature have been used for different type of buildings,

<table>
<thead>
<tr>
<th>Building Nomenclature</th>
<th>Meaning</th>
<th>Name of considered building</th>
</tr>
</thead>
<tbody>
<tr>
<td>An</td>
<td>(n) Storey Frame building</td>
<td>A4, A6, A8, A10</td>
</tr>
</tbody>
</table>

**Table 1 Nomenclature of Building considered**

![Figure 1 Pushover curves for 8 storey building](image1.png)

(a) A8 in long direction under DBE  
(b) A8 in long direction under MCE

![Figure 2 Plastic hinges at PP for typical frames](image2.png)

(c) A8 in Short direction under DBE  
(d) A8 in Short direction under MCE

![Figure 3 Plastic hinges at PP for typical frames](image3.png)
Table 2 Performance level of RC Frame buildings under DBE and MCE level

<table>
<thead>
<tr>
<th>Name of Building</th>
<th>DBE Long Direction</th>
<th>DBE Short Direction</th>
<th>MCE Long Direction</th>
<th>MCE Short Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4</td>
<td>IO</td>
<td>IO</td>
<td>LS</td>
<td>LS</td>
</tr>
<tr>
<td>A6</td>
<td>IO</td>
<td>IO</td>
<td>LS</td>
<td>LS</td>
</tr>
<tr>
<td>A8</td>
<td>IO</td>
<td>IO</td>
<td>IO</td>
<td>LS</td>
</tr>
<tr>
<td>A10</td>
<td>IO</td>
<td>IO</td>
<td>IO</td>
<td>LS</td>
</tr>
</tbody>
</table>

From push over analysis it has been observed that there is IO and LS level performance found at performance point in all the buildings and there is no performance level above these two levels. Further, it is also observed that there is no LS level of performance at PP in the buildings when they are analyzed under DBE. The LS level of performance occurs in the buildings only under MCE.

The plastic hinges at the performance point have been shown. The colour pattern to identify the performance level, pink colour indicates member to be in IO limit, blue colour indicates that member is within LS limit and cyan colour indicates that member is within CP limit. All other colour indicates that the member is beyond the CP level.

5. PERFORMANCE OF SOFT STOREY BUILDINGS

Reinforced concrete frame buildings with infill have been studied. The effect of infill have been taken by infill strut modeling as per FEMA 356 by keeping ground storey open means there will be no infill strut element, the codal provisions have been applied on this open storey and the analysis have been done for all the buildings.

Nomenclature: Following Nomenclature have been used for different type of buildings,

Table 3 Nomenclature of Building considered

<table>
<thead>
<tr>
<th>Building Nomenclature</th>
<th>Meaning</th>
<th>Name of considered building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bn-m</td>
<td>n Storey Frame building, all with infill strut element excepting mth level</td>
<td>B4-0, B6-0, B8-0, B10-0</td>
</tr>
</tbody>
</table>

Figure 4 Pushover curves for B8-0 building
From pushover analysis it has been observed that IO level of performance occurs at performance point in all the buildings, where as LS level of performance occur under MCE in 10-storey building only. There is no performance level above IO and LS level of performance. It is also observed that there is no LS level of performance at PP in the buildings when they are analysed under DBE.
6. RESULT AND DISCUSSION
From present study the following results have been obtained:

No soft storey behaviour has been observed when the buildings was designed as per codal provisions for base shear correction and with capacity design without infill strut element, even soft story design provisions are not applied.

The soft storey formations have been observed in all the buildings when the factor suggested by IS 1893 (Part 1) : 2002 is not applied on members of ground storey.

There is no plastic hinges formed in the columns when the infill effect have been considered and ground storey members are designed with 2.5 times storey shears and moments.

Most of the buildings perform IO level of performance under MCE which is safe. By increasing the number of storey the change in performance can be observed and LS level of performance have been observed in 10 storey building that means there is possibility of higher level of performance in increasing the number of storey in the building under MCE. Only IO level of performance has been observed when the buildings have been analyzes under DBE.

7. CONCLUSIONS
On the basis of present study it can be concluded that the value of multiplication factor specified in IS 1893 (Part 1) : 2002 is over estimated.

REFERENCES