# CE 421

## Term Paper on "Soft Storey"


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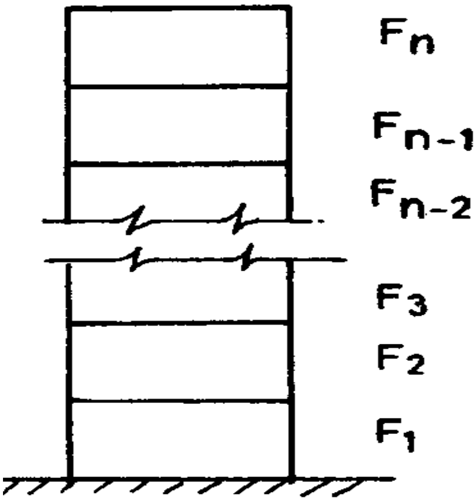
## Introduction




If one storey has less resistance to earthquake forces than the other storeys, it is referred to as a soft-storey. The soft or weak storey can be at any storey level however it generally occurs at the ground level where spaces between columns are left for parking or any other purpose.

According to IS 1893 *"A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above."*
*Expressing numerically, Soft Storey when* $F_i < .7F_{i+1}$

$$OR\ \ F_i < \left(\frac{Fi+1+Fi+2+Fi+3}{3}\right)$$

*Where $F_i$'s are the stiffness of the respective storeys*

## Causes of the Soft Storey:

There are many practical reasons for having fewer walls at the ground level of a building. A building may have larger public spaces at this entry level, such as lobbies, large meeting rooms or open-plan retail space. In urban locations, residential buildings sometimes have fewer walls at the ground level to allow for parking underneath the building.

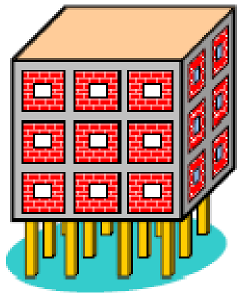


*Image Source: EQTip21 NICEE*

## The Problem

Buildings containing soft stories are extremely vulnerable to earthquake collapses. Since one floor is flexible compared to others, other storeys which are stiffened by infill walls of bracing act as a whole unit, most deformation occurs in soft storey which is less capable of taking earthquakes loads than others.

Such building act as an *Inverted Pendulum* which swing back and forth producing high stresses in columns and if columns are incapable of taking these stresses or do not posses enough ductility, they could get severely damaged and which can also lead to collapse of the building. This is also known as inverted pendulum. The main problem is that in current design practice upper stiff masonry walls are not considered in design calculation hence the inverted pendulum problem is not rectified.

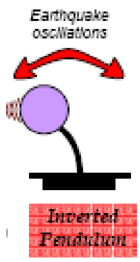
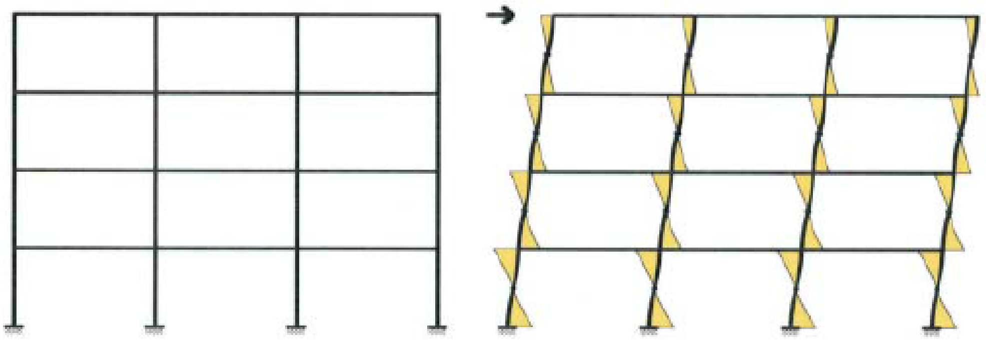
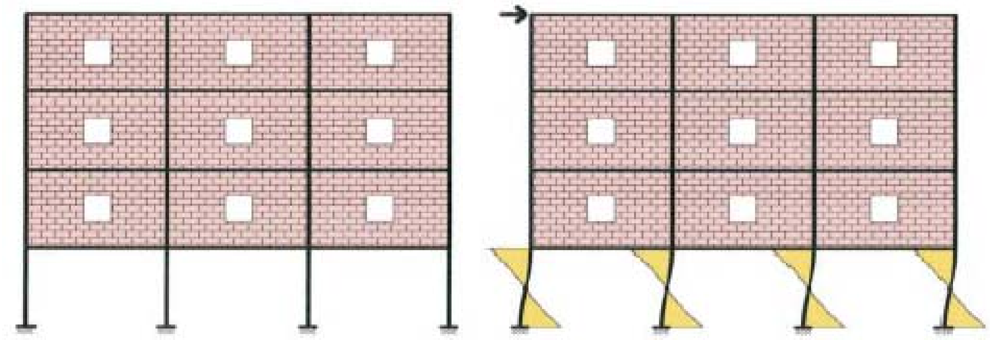



*Image source: EQTip21 NICEE*

Model 1



Model 2

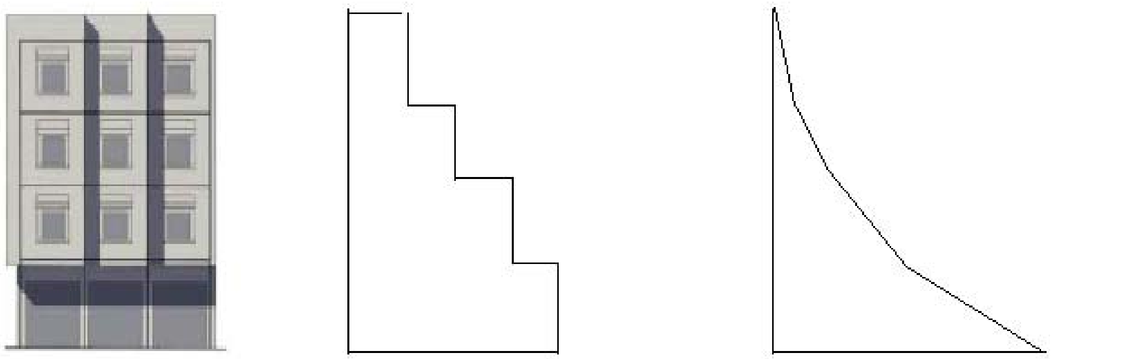


*Source: the Al-Hoceima earthquake report, Patrick Murphy Corella*

In an idealized situation the structural repose to lateral loading is as the top model 1.
Now consider the building arrangement shown in Model 2, where the storeys above the ground floor which are stiffened by infill walls move as a single unit and the flexible ground storey act as soft storey on account of its least flexibility compared to other storeys and give rise to maximum deflection.

## Soft Storey Failure Mechanisms

If we consider the bending moment and shear force diagram of a typical building, we know that the bending moment and shear force increases as we go down.



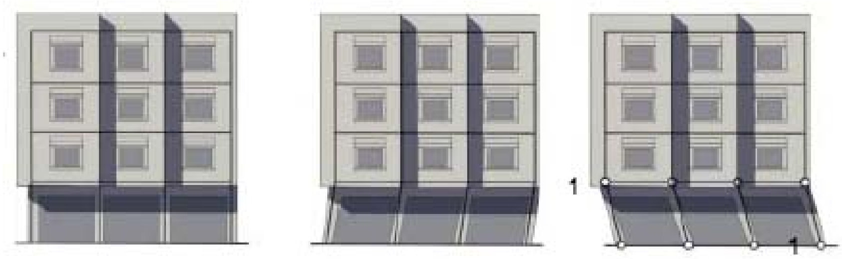
Shear Force Diagram Bending Moement Diagram

Now as shown in the shear force and bending moment diagram of the building, ground storey experiences maximum shear force and bending moment. But ground storey has minimum stiffness compared to other storeys. Hence the ground storey experiences maximum deflection on account of its max shear force and bending moment and less stiffness.

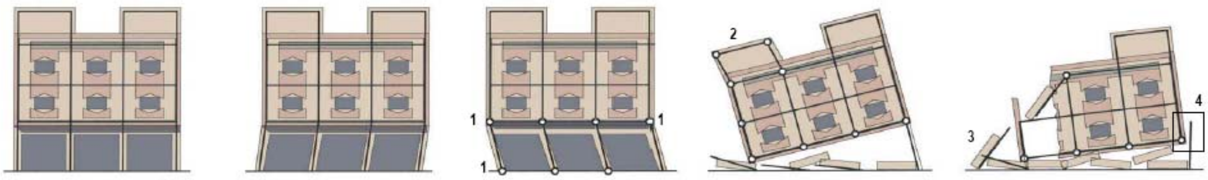
The figure shows typical state of building with soft ground storey after earthquake.

## Failure Models

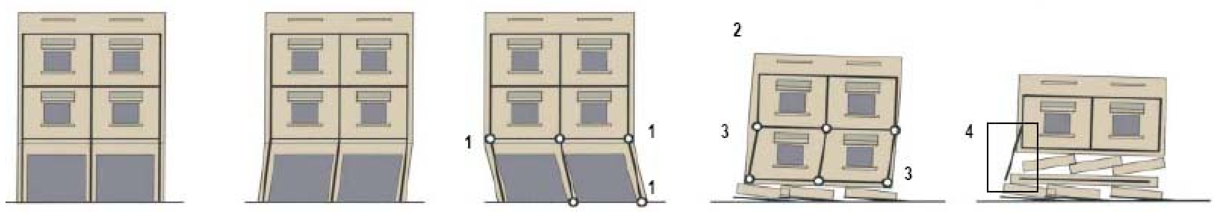
We will now discuss some failure models




Very stiff upper floors drifts over an open plan ground floor with insufficient resistance to moment in column to slab connections resulting in plastic hinges (1) permanent drift.




Open plan shows and densely compartmented flats above result in a soft storey situation. Beyond the limited elastic range of the column to slab connections, plastic hinges are formed. (1) With reduced stiffness, plastified connections fail, throwing the building to the ground left side first. (2) Impact with ground probably causes the failure to left tower and its roof falls to the road.(3) The last column to detach is number (4) settling the building on its own scree.




Building with open plan shops and two floors of densely compartmented flats above. Past the elastic range of column to beam connections of the ground floor hinge (1) and building drifts to one side and collapses. (2) Impact with ground probably causes hinging in the first floor connections and a new "soft storey" is formed. (3) Note the column piercing the slab (4) suggesting the first floor failed drifting towards the last.

## Avoiding Soft Storey Problem

IS 1893: 2002 guidelines for buildings with soft storey problem:

***7.10.2*** *In case buildings with a flexible storey, such as the ground storey consisting of open spaces for parking that is Stilt buildings, special arrangement needs to be made to increase the lateral strength and stiffness of the soft/open storey.*
***7.10.2*** *Dynamic analysis of building is carried out including the strength and stiffness effects of infills and inelastic deformations in the members, particularly; those in the soft .storey, and the members designed accordingly.*
***7.10.3****Alternatively, the following design criteria are to be adopted after carrying out the earthquake analysis, neglecting the effect of infill walls in other storeys:*

***a)****. columns and beams of the soft storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads specified in the other relevant clauses: or,*

***b)*** *besides the columns designed and detailed for the calculated storey shears and moments, shear walls placed symmetrically in both, directions of the building as faraway from the centre of the building as feasible: to be designed exclusively for 1.5 times the lateral storey shear force calculated as before.*

If we face soft storey problem in an existing building we need to take some measures to avoid the problem in future. In existing buildings, it is more difficult but still feasible to add lateral bracing to overcome the openness of a ground story.
Retrofit options include (with associated foundation work): **Shear walls** that are parallel to the open side or sides;
• Diagonal bracing, such as X-braces. Usually made of steel, these **braced frames** are often seen in storefront retrofit situations;
• Steel or reinforced concrete frames that resist lateral forces, which can be arranged around openings; these column-beam frames have **moment-resisting** joints.

Some famous earthquakes in which destruction was due to Soft Storey problem:

1. The San Francisco Earthquake, 1906
2. The Bingol, Turkey Earthquake of the 1 of May 2003
3. 2001 Bhuj earthquake, India

References:


- Earthquake Tips on NICEE website, IIT Kanpur.
- *The Al-Hoceima earthquake report, Patrick Murphy Corella*
- *DYNAMICS, VIBRATION & EARTHQUAKES Teaching Pages, James Watson and Robert Sedman.*