Soft Storey and Retrofit of Existing Multi Storeyed Buildings in India: A Critical Review

Authors
Nakul Singh¹, Vikram Singh Kashyap², Rishikesh kumar³
¹ M.Tech Scholar, Dept. of CE, Manipal University Jaipur
²,³ Asst Prof, Dept. of CE, Manipal University Jaipur
Email:nakulsingh@muj.manipal.edu, vikramsinghkashyap@muj.manipal.edu, rishikeshkumar@muj.manipal.edu

ABSTRACT
Soft first storey is a typical feature in the modern multi-storey constructions in urban India. Though multi-storeyed buildings with soft storey floor are inherently vulnerable to collapse due to earthquake, their construction is still widespread in the developing like India. Functional and Social need to provide car parking space at ground level and for offices open stories at different level of structure far out-weighs the warning against such buildings from engineering community. With the availability of fast computers, so that software usage in civil engineering has greatly reduced the complexities of different aspects in the analysis and design of projects. In this paper an investigation has been made to study about soft storey building with different arrangement in soft storey building when subjected to static and dynamic earthquake loading and retrofit strategies of existing multi storeyed building in Indian scenario and is observed that, providing infill wall improves resistant behaviour of the structure when compared to soft storey provided.

Key Words: Seismic Retrofitting, soft storey, Static and dynamic analysis, Seismic loads.

INTRODUCTION
Due to increasing population since the past few years so that car parking space for residential apartments in populated cities is a matter of major problem. So that constructions of multi-storeyed buildings with open first storey is a common practice in all world. Hence the trend has been to utilize the ground storey of the building itself for parking or reception lobbies in the first storey. These types of buildings having no infill masonry walls in ground storey, but all upper storeys infilled in masonry walls are called „soft first storey or open ground storey building”. Experience of different nations with the poor and devastating performance of such buildings during earthquakes always seriously discouraged construction of such a building with a soft ground floor this storey known as weak storey because this storey stiffness is lower compare to above storey. So that easily collapses by earthquake.Due to wrong construction practices and ignorance for earthquake resistant design of buildings in our country, most of the existing buildings are vulnerable to future earthquakes. So, prime importance to be given for the earthquake resistant design. The Indian seismic code IS 1893 (Part1): 2002 classifies a soft storey as “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.

The earthquake at Bhuj, Gujarat, in 2001 has been a watershed event in the earthquake engineering practice in India. The code of practice for seismic analysis, IS 1893:2002 has been revised to reflect the increased seismic demand in many parts of the country. Many existing buildings lack the seismic strength and detailing requirements of IS 1893:2002, IS 4326:1993 and IS 13920: 1993, because they were built prior to the implementation of these codes. This paper is part of a project, whose aim is to evolve methodologies to
assess the seismic vulnerability of reinforced concrete (RC) G+4 storeyed, dormitory buildings, located in Jaipur and to propose retrofit measures for the structurally deficient buildings.

**SOFT STOREY**

Due to increasing population since the past few years so that car parking space for residential apartments in populated cities is a matter of major problem. So that constructions of multi-storeyed buildings with open first storey is a common practice in all world. Hence the trend has been to utilize the ground storey of the building itself for parking or reception lobbies in the first storey. These types of buildings having no infill masonry walls in ground storey, but all upper storeys infilled in masonry walls are called „soft first storey or open ground storey building”. Experience of different nations with the poor and devastating performance of such buildings during earthquakes always seriously discouraged construction of such a building with a soft ground floor this storey known as weak storey because this storey stiffness is lower compare to above storey. So that easily collapses by earthquake. Due to wrong construction practices and ignorance for earthquake resistant design of buildings in our country, most of the existing buildings are vulnerable to future earthquakes. So, prime importance to be given for the earthquake resistant design. The Indian seismic code IS 1893 (Part1): 2002 classifies a soft storey as “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.

**GENERAL BEHAVIOUR OF SOFT STOREY**

Stability of earth is always disturbed due to internal forces and as a result of such disturbance, vibrations or jerks in earth's crust takes place, which is known as an earthquake. Earthquake produces low –high waves which vibrate the base of structure in various manners and directions, so that lateral force is developed on structure. In such buildings, the stiffness of the lateral load resisting systems at those stories is quite less than the stories above or below. 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 possess 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. Soft stories are subjected to larger lateral loads during earthquakes and under lateral loading. This lateral force cannot be well distributed along the height of structure. This situation causes the lateral forces to concentrate on the storey having large displacement. The lateral force distribution along the height of a building is directly related to mass and stiffness of each storey. The collapse mechanism of structure with soft storey under both earthquake and gravity loads. Therefore dynamic analysis procedure is accurate distribution of the earthquake and lateral forces along the building height, determining modal effects and local ductility demands efficiently.

**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 infill 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 far away 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.

RETROFIT

Goals and objectives of retrofit

Retrofit strategy refers to options of increasing the strength, stiffness and ductility of the elements or the building as a whole. Several retrofit strategies may be selected under a retrofit scheme of a building. The goals of seismic retrofitting can be summarized as follows (IS 13935:1993)

1. Increasing the lateral strength and stiffness of the building.
2. Increasing the ductility and enhancing the energy dissipation capacity.
3. Giving unity to the structure.
4. Eliminating sources of weakness or those that produce concentration of stresses.
5. Enhancement of redundancy in the number of lateral load resisting elements.
6. The retrofit scheme should be cost effective.
7. Each retrofit strategy should consistently achieve the performance objective.

To decide the retrofit scheme, a performance based approach can be adopted. The performance based approach identifies a target building performance level under an anticipated earthquake level.

BUILDING DEFICIENCIES

The following two sections highlight some common deficiencies observed in multi-storeyed RC buildings in India. The building deficiencies can be broadly classified as Local Deficiencies and Global Deficiencies.

Local Deficiencies

Local deficiencies lead to the failure of individual elements of the building. The observed deficiencies of the elements are summarized.

Columns

a. Inadequate shear capacity.
b. Lack of confinement of column core. Lack of 135° hooks, with adequate hook length.
c. Faulty location of splice just above the floor, with inadequate tension splice length.
d. Inadequate capacity of corner columns under biaxial seismic loads.
e. Existence of short and stiff columns.

Beams and Beam-to-Column Joints
a. Shear reinforcement not adequate for flexural capacity.
b. Inadequate anchorage of bottom rebar.
c. Inadequate plastic hinge rotation capability due to lack of confinement.

Slab-to-Column Connections
a. Absence of drag and chord reinforcement.
b. Inadequate reinforcement at the slab-to-beam connections.

Structural Walls
a. Lack of adequate boundary elements.
b. Inadequate reinforcement at the slab-to-wall or beam-to-wall connections.

Unreinforced Masonry Walls
a. Lack of out-of-plane bending capacity.

Precast elements
a. Lack of tie reinforcement.

Deficient Construction
a. Frequent volume batching.
b. Additional water for workability.
c. Inadequate compaction and curing of concrete.
d. Top 100 to 200 mm of column cast separately, leading to deficient plastic hinge region.
e. Inadequate side face cover, leading to rebar corrosion.
f. Poor quality control.

Global Deficiencies
Global deficiencies can broadly be classified as plan irregularities and vertical irregularities, as per the Code. The items left out are listed under miscellaneous deficiencies. Some of the observed irregularities are as follows.

Plan Irregularities
a. Torsional irregularity due to plan symmetry and eccentric mass from water tank.
b. Frequent re-entrant corners.
c. Diaphragm discontinuity due to large openings or staggered floors, along with the absence of collector elements.
d. Out-of-plane offset for columns along perimeter.
e. Nonparallel lateral load resisting systems (not observed in the building studied).

Vertical Irregularities
a. Stiffness irregularity, soft storey due to open ground storey.
b. Mass irregularity (not observed in the building studied).
c. Vertical geometric irregularity from set-back towers.
d. In-plane discontinuity for columns along the perimeter of the building.
e. Weak storey due to open ground storey.

The miscellaneous deficiencies that were observed are as follows:-

Deficiencies in Analysis
a. Buildings designed as only gravity load resisting system.
b. Neglecting the effect of infill walls.
c. Inadequate geotechnical data to consider near source effects.
d. Neglecting the P-∆ effect.
Lack of integral action of the lateral load resisting elements
The building performance is degraded due to the absence of tying of the lateral load resisting elements. The beams are not framed into the elevator core walls and spandrel beams between the perimeter columns are missing.
Failure of stair slab
If the stair slab is simply supported without adequate bearing length, a collapse of the slab closes the escape route for the residents.
Pounding of buildings
Another poor design concept is not providing adequate spacing between adjacent buildings or seismic joints between segments of a building.

**RETROFIT STRATEGIES**

Retrofit strategies that are viable for the type of buildings considered, are grouped under local and global strategies. These groups need not be watertight and strategies falling in either group are expected.

**Local Retrofit Strategies**
Local retrofit strategies include local strengthening of beams, columns, slabs, beam-to-column or slab-to-column joints, walls and foundations. Local strengthening allows one or more under-strength elements or connections to resist the strength demands predicted by the analysis, without affecting the overall response of the structure. This scheme tends to be the most economical alternative when only a few of the building’s elements are deficient. The local retrofit strategies are grouped according to the elements.

**Column Strengthening**
Column strengthening techniques include the following.
- **Concrete jacketing**
- **Steel jacketing**
- **Fibre reinforced polymer sheet wrapping**

**Concrete Jacketing**
This method increases both strength and ductility of the columns. But, the composite deformation of the existing and the new concrete requires adequate dowelling to the existing column. Also, the additional longitudinal bars need to be anchored to the foundation and should be continuous through the slab.

**Steel Jacketing**
Steel jacketing refers to encasing the column with steel plates and filling the gap with non-shrink grout. It is a very effective method to remedy deficiencies such as inadequate shear strength and inadequate splices of longitudinal bars at critical locations. But, it may be costly and its fire resistance has to be addressed.

**Fibre Reinforced Polymer Sheet Wrapping**
The use of Fibre Reinforced Polymer (FRP) sheets is becoming popular in India, FRP sheets are thin, light and flexible enough to be inserted behind service ducts, thus facilitating installation. In retrofitting of a column there is no significant increase in the size. The main drawbacks of FRP are high cost, brittle behaviour and fire resistance.

**Beam Strengthening**
Addition of Concrete
There are some disadvantages in this traditional retrofit strategy. First, addition of concrete increases the size and weight of the beam. Second, the new concrete requires proper bonding to the existing concrete. Third, the effects of drying shrinkage must be considered as it induces tensile stresses in the new concrete. Instead of regular concrete, fibre reinforced concrete can be used for retrofit.
Steel Plating
Gluing mild steel plates to beams is often used to improve the beam flexural and shear performances. The addition of steel plate is simple and rapid to apply, does not reduce the storey clear height significantly and can be applied while the structure is in use. Glued plates are of course prone to premature de-bonding.

FRP Wrapping
Like steel plates, FRP laminates are attached to beams to increase their flexural and shear capacities. The amount of FRP attached to the soffit should be limited to retain the ductile flexural failure mode.

Use of FRP bars
FRP bars can be attached to the web of a beam for shear strengthening. FRP bars can be used as tendons for external pre-stressing.

Beam–To-Column Joint Strengthening
The different methods of strengthening are as follows.

Concrete Jacketing
The joint can be strengthened by placing ties through drilled holes in the beam, But the placement of such ties is difficult.

Concrete Fillet
Use of a concrete fillet at the joint to shift the potential hinge region away from the column face to the end of the fillet.

Steel Jacketing
Steel jacketing helps in transferring moments and acquiring ductility through confinement of the concrete. Steel plating is simpler as compared to steel jacketing, where plates in the form of brackets are attached to the soffits of beams and sides of the column.

Wall Strengthening
A concrete shear wall can be strengthened by adding new concrete with adequate boundary elements. For the composite action, dowels need to be provided between the existing and new concrete. Steel braces or strips, FRP or steel sheets, external pre-stressing or reinforced grouted core can be employed for strengthening unreinforced masonry walls.

Foundation Strengthening
Foundation strengthening is done by strengthening the footing as well as the soil.

Global Retrofit Strategies
Global retrofit strategies aim to stiffen the building, by providing additional lateral load resisting elements, or to reduce the irregularities or mass.

Structural Stiffening
Addition of Infill Walls
The addition of masonry infill wall is a viable option for the buildings, with open ground storeys. Of course masonry infill walls increase strength and stiffness of the building, but do not enhance the ductility. Infill walls with reinforced concrete masonry units can act as shear walls. For cast-in-place RC infill walls, the significant parameter that defines the lateral strength of the frame is the presence of dowels between a wall and the bounding frame. The use of modular precast panels involves minimal on-site casting and modest handling equipment. Connections between the panels and the frame are critical. Use of infill steel panels is an alternative to bracing system.

Addition of Shear Walls
New shear walls can be added to control drift. Critical design issues involved in the addition of shear walls are as follows.

a) Transfer of floor diaphragm shears into the new wall through dowels.

b) Adding new collector and drag members to the diaphragm.
Reactions of the new wall on existing foundations.

Addition of Steel Braces
A steel bracing system can be designed to provide stiffness, strength, ductility, energy dissipation, or any combination of these. Connection between the braces and the existing frame is the most important aspect in this strategy. The uses of pre-stressed tendons and un-bonded braces have been proposed by some investigators to avoid the problems associated with the failure of connections and buckling of the braces, respectively.

Reduction of Irregularities
Torsional irregularities can be corrected by the addition of frames or shear walls. Eccentric masses can be relocated. Seismic joints can be created to transform an irregular building into multiple regular structures. Partial demolition can also be an effective measure, although this may have significant impact on the utility of the building. Discontinuous components such as columns can be extended beyond the zone of discontinuity. As mentioned earlier, walls or braces can alleviate the deficiency of soft and weak storey.

Mass Reduction
Reduction of mass results in reduction of the lateral force demand, and therefore, can be used in specific cases in lieu of structural strengthening.

Energy Dissipation Devices and Base Isolation
For the multi-storeyed buildings addressed in this paper, the use of energy dissipation and base isolation devices is not cost effective at present. Hence, these devices are not addressed.

CONCLUSION
RC frame buildings with soft story are known to perform poorly during in strong earthquake shaking. Because the stiffness at lower floor is 70% lesser than stiffness at storey above it causing the soft storey to happen. 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. In such a situation, an investigation has been made to study the seismic behaviour of such buildings subjected to earthquake load so that some guideline could be developed to minimize the risk involved in such type of buildings. It has been found earthquake forces by treating them as ordinary frames results in an underestimation of base shear. Investigators analysis numerically and use various computer programs such as Staad Pro, ETABS, SAP2000 etc. Calculation shows that, when RC framed buildings having brick masonry infill on upper floor with soft ground floors subjected to earthquake loading, base shear can be more than twice to that predicted by equivalent earthquake force method with or without infill or even by response spectrum method when no infill in the analysis model.

REFERENCES

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