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# Seismic behaviour of soft storey RC building during earthquake

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***Abstract*****—**Soft storey is one of the main reasons for building damage during an earthquake and has been mentioned in all investigation report. Soft storey due to increase storey height is well known subject. Change in amount infill walls between stories also results in soft story. These are usually not considered as a part of load bearing system. This study investigates the soft storey behavior due to increase in storey height, lack of infills at ground floor storey and existence of both these cases by means of nonlinear static and dynamic response history analysis for midrise reinforced concrete building displacement capacity at immediate occupancy , life safety and collapse prevision, performance level and storey drift demands. Soft storey behavior due to change in storey height and or infills amount is evaluated in view of the displacement capacities, drift demand and structural behavior.

***Keywords****- Soft storey, infill wall, performance evalution (key words)*

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## I. INTRODUCTION

Many urban multistory buildings in India today consist of an open first storey as an unavoidable feature. This is primarily being practiced and adopted to accommodate parking or reception lobbies in the first stories. The upper stories consist of brick unfilled wall panels. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than *50%* of the storey above or below [Draft IS: 1893, 1997]. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey." Total seismic base shear as experienced by a building during an earthquake is dependent on its natural period whereas the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with soft first storey, the upper storey's being stiff is subjected to smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demand on the columns in the first storey is also large since the shear in the first storey is maximum. For the upper storey's, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiffness's have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. As a result, the performance of buildings is adversely affected during ground shaking [1].

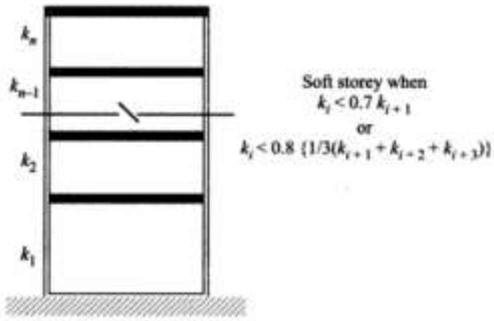


Fig-1 Stiffness irregularities- Soft storey

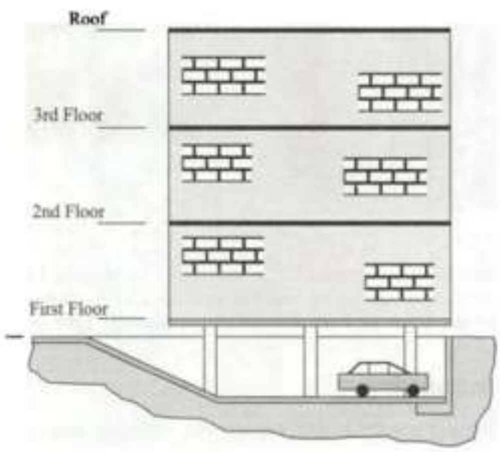


Fig-2 Soft storey type construction [From Agrawal & shrikhande book]

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## II. SOFTSTOREY

The building in which the ground storey consist of open space for parking area is known as stilt building and the parking storey is called as stilt floor or soft storey . The soft storey is most common features of the building irregularity. It is usually present in modern frame building when large number of nonstructural rigid components such as masonry infill attached to the column of upper floor of reinforced concrete frame structure with first storey is left empty of walls or with a reduced number of walls in comparison to the upper floor. The rigid nonstructural component limits the ability to deform of the column, modifying the structural performance of the building to the horizontal force. As compared to irregular building, in regular building, the earthquake shear force increase towards the first storey.

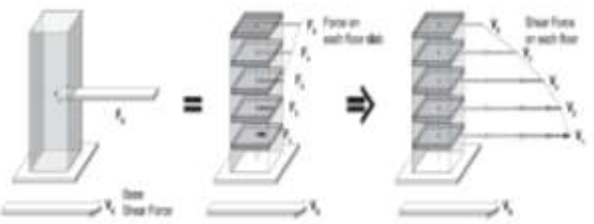
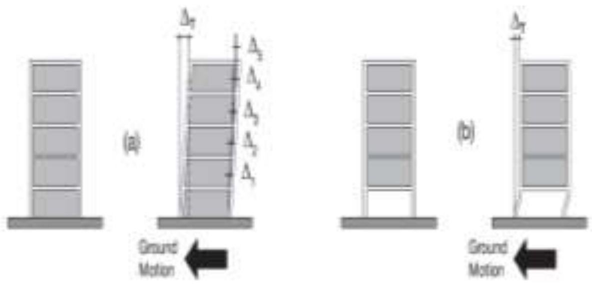


Fig-3 Lateral forces and Shear forces generated in buildings due to ground motion

The total displacement induced by an earthquake tends to distribute homogeneously in each floor by means of the height of the building. Each floor would exhibit similar deformation. When a more flexible portion of lower part of the building supports a rigid and more massive portion, the bulk energy will be absorbed by the lower significantly more flexible storey while small remainder of energy will get distributed amongst the upper storey, producing on the most flexible floor, large relative displacement between the lower and upper slab of the soft storey (interstorey drift) and therefore, the column of this floor will be subjected to large deformation.




*a) Regular building* *b) Building with soft story*

Fig.4 Distribution of total displacement generated by an earthquake

## III. SOFT STOREY FAILURE

During the earthquake, 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. In other words, these types of buildings sway back and forth like an inverted pendulum

Fig. 5 Behavior of OGS buildings like as inverted pendulum

Producing high stresses in column and if column are no capable of taking these stresses or do not possess enough ductility, severe damage can take place which may also lead to collapse of the building. Soft storey is subjected to large lateral load during earthquake and under lateral loading this lateral force cannot be evenly distributed along the height of the structure. Such a situation causes the lateral force to concentrate at the storey with large displacement. The lateral force distribution along the height of the building is directly associated to mass and stiffness of each storey. The collapse mechanism of structure can take place with the soft storey under both earthquake and gravity load. Therefore dynamic analysis procedure is accurate regarding distribution of the earthquake and lateral force along the building height determining modal effect and local ductility damage efficiency [2].

## IV. EXAMPLES OF PAST EARTQUAKES

### *A. Jabalpur Earthquake of 22May1997*

This earthquake, the first one in an urban neighborhood in India, provided an opportunity helped in accessing and evaluating the performance of engineered buildings in the country during ground shaking. The damage incurred by Himgiri and Ajanta apartments in the city of Jabalpur are very good examples of the high risk involved in the construction of buildings with soft first storey. Himgiri apartments are RC frame building with open first storey on one side for parking, and brick infill walls on the other side. The infill portion of the building in the first storey is meant for shops or apartments. All the storeys on top have brick infill walls. In parking area, the first storey columns were badly damaged with spalling of concrete cover, snapping of lateral ties, buckling of longitudinal reinforcement bars and crushing of core concrete (Fig. 6). The columns on the other side were not much damaged. There was only nominal damage in the upper storeys consisting of cracks in the filler walls. This is a clear case of column damage due to “soft first storey”. The Ajanta apartment’s buildings are a set of almost identical four storey RC frame building located side-by-side. In each of these buildings consist of two apartments in each storey, except the first storey. One building consists of two apartments in the upper storeys, but only one apartment in the first storey. The open space on the other side is utilized for parking, and hence has no infilled wall panels. Whereas, only nominal damages were reported in the building with two apartments the first storey, the first storey columns on the open side in the other building were very extremely damaged. This damage includes buckling of longitudinal bars, snapping of ties, spalling of cover and crushing of core concrete.

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Fig-6 Damage to columns in Himgiri apartment.

Fig-8 Damage to columns in the stilt storey of Youth Hostel building.

In Jabalpur, in a two-storey (plus stilt storey) C-shaped RC frame building (Youth hostel building), the damage to the columns in the stilt storey consisted of severe X-type cracking due to cyclic lateral shear (Fig. 8). Here also, the two storeys above the stilt storey have brick infilled wall panels. This makes the upper storeys very stiff as compared to the storey at the stilt level. There was no damage to the columns in the storeys above. The "soft first storey" at the stilt level is clearly the primary reason for such a severe damage [3].

*B. Bhuj eartuake 26 January 2001*

It has been observed from survey that the damage is due to collapse and bucking of column where parking space is not covered appropriately. The damage is reduced considerably where the parking space are covered adequately. It is recognized that this type of failure results from the combination of several other unfavorable reasons such as torsion, excessive mass on upper floor, p-delta effects and lack of ductility in the bottom storey. Fig- 6 shows some of examples of soft/flexible storey and or weak storey failure in Bhuj earthquake. Fig-6 shows Appolo Apartment in Ahmedabad nearly 15-20 years old where ground floor is used for parking purpose got significantly damaged. There was complete collapse of 2 blocks of this apartment's at the entrance and the upper floor were found to be resting on ground in significantly tilted condition [4].

Fig-6 Apollo Apartment at Ahmedabad

## V. REVIEW OF LITERATURE

A significant amount of research work on seismic behavior of soft storey building has been done by many investigators such as

**[1] Suchita Hirde and Ganga Tepugade (2014),** Discussed the performance of a building with soft storey at different level along with respect to ground level. The nonlinear static pushover analysis carried out concluded that plastic hinges are developed in columns of ground level soft storey and is not an acceptable criteria for safe design. It was also found that the displacement reduces when the soft storey is provided at higher level.

**[2] Hiten L. Kheni and Anuj K. Chandiwala (2014),** Investigated many buildings that collapsed during the past earthquake exhibited exactly the opposite strong beam weak column behaviour means columns failed before the beams yielded mainly due to soft storey effect. For proper assessment of the storey stiffness of buildings with soft storey building, different models were analyzed using software. The study concluded that the displacement estimates of the codal lateral load patterns are observed to be smaller for the lower stories and larger for the upper stories and are independent of the total number stories of the models.

**[3] Dhadde Santosh (2014),** Investigated and conducted nonlinear pushover analysis to the building models using ETABS and evaluation is carried for non-retrofitted normal buildings and retrofitting methods are suggested like infill wall, increase of ground story column stiffness and shear wall at central core. The study concluded that the storey drift values for soft storey models were maximum values as compared to other storeys and the values of storey drift decreases gradually up to the top.

**[4] Rakshith Gowda K.R and Bhavani Shankar (2014),** the soft storeys were provided at different level for different load combinations and ETABS was used for modeling and analysis of RC buildings. The storey drift was observed to be maximum in vertically irregular structure when compared with that of regular structure.

**[5] Mr. D. Dhandapany (2014),** the seismic behavior of RCC buildings with and without shear wall under different soil conditions. Analyzed using ETABS software for different soil conditions (hard, medium, soft). The values of Base shear, axial force and Lateral displacement were used for comparison between two frames. The design in STAAD is found to bear almost equal results when compared to that in ETABS for all structural members.

**[6] Susanta Banerjee, Sanjaya K Patro and Praveena Rao (2014),** Analyzed response parameters such as floor displacement, storey drift, and base shear. Modeling and analysis of the building are performed by nonlinear analysis program IDARC 2D. The study concluded that the lateral roof displacement and maximum storey drift is reduced by consideration of infill wall effect than a bare frame.

[7] **D. B. Karwar and Dr. R. S. Londhe (2014),** Investigated the behaviour of Reinforced Concrete framed structures by using nonlinear static procedure (NSP) or pushover analysis in finite element software "SAP2000".and the Comparative study made for different models in terms of base shear, displacement, performance point. It was concluded that the base shear is minimum for bare frame and maximum for frame with infill for G+8 building.

**[8]** Miss **Desai Pallavi T (2013),** Investigated the behaviour of reinforced concrete framed structures by using STAAD Pro. Modelled four structures and compared stiffness this models. The study emphasized on provision of stiffer column in first storey.

**[9] Amit and S. Gawande (2013),** Investigated the seismic performance and design of the masonry infill reinforced concrete structure with the soft first storey under a strong ground motion.

**[10] Nikhil Agrawal (2013),** Analyzed the performance of masonry infilled reinforced concrete (RC) frames including open first storey with and without opening. The increase in the opening percentage leads to a decrease on the lateral stiffness of infilled frame. The study reflected that Infill panels increase stiffness of the structure.

**[11] A.S.Kasnale and Dr. S.S.Jamkar (2013),** Investigated the behavior of five reinforced RC frames with various arrangement of infill when subjected to dynamic earthquake loading. It was found that provision of infill wall in RC building controlled the displacement,

**[12] Dande P. S. and, Kodag P. B. (2013),** Investigated the behavior of RC frames with provided strength and stiffness to the building frame by modified soft storey provision in two ways, (i) By providing stiff column & (ii) By providing adjacent infill wall panel at each corner of building frame. The study concluded that the walls in upper storeys make them much stiffer than open ground storey. It is difficult to provide such capacities in the columns of the first storey.

**[13] Narendra Pokar and Prof. B. J. Panchal (2013)**, Investigated the behaviour of RC frames with Testing of scaled models. Testing of scaled models is essential to arrive at optimal analytical model and special design provisions for such structures. Structure is modeled and analyzed using SAP platform including seismic effect. It was found that both steel and RCC model gives nearest result for full scale model.

**[14] N. Sivakumar and S. Karthik (2013),** Investigated the behavior of the columns at ground level of multi-storeyed buildings with soft ground floor subjected to dynamic earthquake loading. ETABS was used for modeling the six and nine storey structure, line element was used for columns and beams and concrete element was used for slabs. The study highlighted that the drift as well as the strength demands on the first storey columns can be reduced with provision of stiffer columns in the first storey.

**[15] Dr. Saraswati Setia and Vineet Sharma (2012),** Analyzed seismic response of R.C.C building with soft storey where in equivalent static analysis is performed for five different models by using the computer software such as STAAD Pro. It concluded that minimum displacement for corner column is observed in the building in which a shear wall is introduced in X-direction as well as in Z-direction.

**[16] P.B.Lamb and Dr R.S. Londhe (2012), A**nalyzed multistoried building with soft first storey, located in seismic zone IV. The performance characteristics of building such as stiffness, shear force, bending moment, drift were studied which concluded that shear wall and cross bracings are found to be very effective in reducing the stiffness irregularity and bending moment in the columns.

**[17] V. Indumathy and Dr.B.P. Annapurna (2012),** Investigated the four storied one bay infilled frame with soft storey at ground floor and window openings in higher floors. Shape of opening was compared. Square opening showed lower lateral deformation compared to rectangular opening and on other hand rectangular opening oriented horizontally exhibit lower lateral deformation than vertical orientation. Concluded square opening showed lower lateral deformation compared to rectangular opening and on other hand rectangular opening oriented horizontally exhibit lower lateral deformation than vertical orientation.

**[18] M.Z. Kabir and P. Shadan (2011),** Investigated the effect of soft story on seismic performance of 3D-panel buildings. Results verified numerically with finite element model using ABAQUS program and 3D-panel system has considerable resistance which concluded that applying several ground motions, final cracks developed at the end of columns and beam-column connections. However, upper stories had no crack during shaking table test.

**[19] G.V. Mulgund and D.M. Patil (2010),** Investigated the behaviour of RC frames with various arrangement of infill when subjected to dynamic earthquake loading and result of bare and infill frame were compared. It highlighted that the masonry infill panels in the frame substantially reduce the overall damage.

**[20] A. Wibowo and J.L. Wilson, (2009), Analysis** an analytical model to predict force-displacement relationship of the tested frame was prepared. This experimental investigation of load deflection behavior and collapse modeling of soft storey building with lateral loading concluded that the large drift capacity of the precast soft storey structure was attributed to the weak connections which allowed the columns to rock at each end.

**[21] Sharany Haque and Khan Mahmud Amanat (2009),** Investigated the effect of masonry infill in the upper floors of a building with an open ground floor subjected to seismic loading where the number of panels with infill varied from bare frame condition (zero percent infilled panels) and 10, 30, 50 and 70 percent of panels with infill on the upper floors. Comparison of base shear concluded that the design shear and moment calculated by equivalent static method may at least be doubled to achieve safer design of the columns for soft ground floor.

**[22] Seval Pinarbasi and Dimitrios Konstantinidis (2007),** Investigated the hypothetical base-isolated building with a soft ground story. Comparison is made with how soft-story flexibility affects the corresponding fixed-base building. The performance of a soft-story building was found to be effective in particularly reducing the seismic demand (i.e., inter-story drift) on the soft-story level, which is the primary cause of catastrophic collapse in these types of buildings.

**[23] Dr. Mizan Dogan and Dr. Nevzat Kirac (2002),** Investigated the earthquake results and observed that partitioning walls and beam fillings enable buildings to gain great rigidity. Also solutions were investigated for making the soft storeys in the present constructions and in the ones to be built resistant to quake.

**[24] Jaswant N. Arlekar, Sudhir K. Jain and C.V.R. Murty (1997),** investigated the behavior of reinforced concrete framed structures by using ETABS [5].

## VI. SCOPE OF THE STUDY

The phenomena of soft story may arise due to many different reasons such as change in load carrying and slab system between stories. The abrupt changes which take place in the amount of the infill walls between stories is also one of the frequent reasons of the soft storey behavior. Since infill walls are not regarded as a part of load carrying system, generally civil engineers do not consider its effects on the structural behavior. Therefore, many civil engineers are not aware enough regarding soft story occurrence because of infill walls and are thus neglected. In this study, effect of infill walls on structural behavior, mainly for the soft story, is investigated in order to increase the level of knowledge and awareness on the subject.

## VII. CONCLUSION

The open first storey is an important functional requirement of almost all the urban multi-storey buildings, and hence, cannot be eliminated. Hence, it is necessary to adopt alternative measures for this specific situation. The under-lying principle of any solution to this problem is in

(a) Stiffness's of the first storey shall be increased in such a way that the first storey is at least *50%* stiff in comparison to the second storey.

(b) There shall be provision of adequate lateral strength in the first storey.

(c) Soft storey building exhibits poor performance during earthquake.

(d) Damage induced for ground floor columns and ground storey are very large for soft storey building because it demands larger strength due to mass and stiffness irregularity thus influencing the lateral force distribution of the building during an earthquake

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