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SEISMIC PERFORMANCE OF SOFT STOREY RC FRAMES AT DIFFERENT STOREY LEVELS FROM PUSHOVER ANALYSIS

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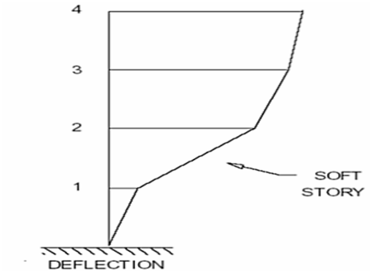
ABSTRACT:*Soft storey collapse is one of the reasons for failure of framed structures during an event of an earthquake. Such irregularities are highly undesirable in the buildings built in earthquake prone areas. In such buildings, the stiffness of the lateral load resisting systems at that storey is quite less compared to other storeys.Pushover analysis is a nonlinear static approach for the seismic analysis of structures subjected to permanent vertical load and gradually increasing lateral load at very large strains up to failure. Considering these aspects in mind, the present work focuses on the seismic performance of soft storey Reinforced Concrete (RC) frames using pushover analysis. For this purpose, ETABS, finite element software has been used. Typical two dimensional RC frames having soft storey are modeled and their seismic performance with varying stiffness ratio at different storey levels have been evaluated using pushover curves. Base shear carried, roof displacement experienced, status of performance point and number & status of hinges formed are the parameters used to quantify the performance of RC frames.It is inferred that structures with soft storey are most vulnerable to seismic excitation. They possess lower lateral load carrying capacity and experience increased roof displacement.*
Keywords *-Pushover analysis,Plastic hinge, RC frames, Soft storey, Stiffness ratio*

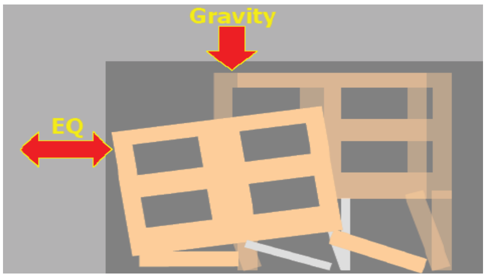
1. Introduction

An earthquake is a manifestation of rapid release of stress waves during a brittle rupture of rock. The complexity of earthquake ground motion is primarily due to factors such as source effect, path effect and local site effect. An earthquake causes the ground to vibrate and structures supported on ground in turn subject to this motion. Thus the dynamic loading on the structure during an earthquake is not external loading, but the inertial effect due tomotion of support. The various factors contributing to the structural damage during an earthquake are vertical irregularities, irregularity in strength and stiffness, mass irregularity, torsional irregularity etc.
In buildings with soft storey, the stiffness of the lateral load resisting systems at those storeys is quite less than the adjacent storeys. Other storeys being stiff undergoes smaller inter-storey drifts. During an earthquake, if abnormal inter-storey drifts between adjacent storeys 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. If 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. Such buildings are required to be analyzed by the dynamic analysis and designed carefully [1].In Fig. 1(i), the lateral displacement diagram of a building with a soft storey under lateral loading is shown. Fig. 1(ii) shows the collapse mechanism of a building structure having a soft storey. Khan et al., carried out earthquake analysis on an RC moment resisting framed tall building without an infill wall on multi storeys using pushover analysis [2].Amin et al., altered soft storey level from ground floor to top floor for each model and equivalent static analysis was carried. The results showed that inter-storey drift ratio was found to increase below the mid storey level and maximum ratio was obtained where the soft storey was located [3]. Arlekar et al., highlighted the importance of explicitly recognizing the presence of the open first store in the analysis of the building and the error involved in considering it as a bare frame without infill [4]. Lamb et al., carried out on a building with different mathematical models considering various methods for improving the seismic performance of the building with soft first storey[5]. Poluraju et al., using nonlinear pushover analysis evaluated the performance of G+3 building using SAP-2000.The results obtained from the study show that properly detailed and designed frame will perform well under seismic loads [6]. Mehmet et al., carried out push over analysis using SAP2000 comparing the performance of the building for

default hinge properties and user defined hinge properties. They have concluded that the result obtained from user defined hinge properties are more accurate than of default hinges [7].



(i)



(ii)

Fig.1 (i) Lateral displacement diagram of a building with a soft storey under lateral loading (ii)Collapse mechanism of a building structure having a soft storey.

2. Pushover Analysis

Pushover analysis is a static non-linear procedure in which the magnitude of the lateral load is incrementally increased maintaining a predefined distribution pattern along the height of the building. With the increase in the magnitude of loads, weak links and failure modes of the building can be found. Pushover analysis can determine the behavior of a building, including the ultimate load it can carry and the maximum inelastic deflection it undergoes. Local non-linear effects are modeled and the structure is pushed until a collapse mechanism is developed. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve. A typical pushover curve is shown in Fig. 2. The graph is plotted with base shear along the vertical axis and the roof displacement along the horizontal axis. Location of hinges in various stages can be obtained from pushover curve. The range AB is elastic, the nonlinear range BC is divided into three parts marked as IO, LS and CP that represents immediate occupancy, life safety and collapse prevention, respectively. If all the hinges are within the CP limit, then the structure is still said to be safe. On the contrary, if the hinges formed are beyond CP limit, then it is said that the structure collapses. However, depending upon the importance of structure, the hinges after IO range may also need to be retrofitted.
Basically, there are two types of pushover analysis, namely, Force control analysis and Displacement control analysis. In Force control analysis, the structure is subjected to incremental lateral force and the displacements corresponding to these forces are calculated. The force can be fixed load distribution type or variable load distribution type. In displacement control analysis the structure is subjected to incremental increase in displacement and response force or base shear is evaluated.

A pushover analysis consists of two components, namely, capacity curve and demand spectrum. The capacity curve is a plot between spectral acceleration (base shear) and corresponding spectral displacement (roof displacement) for the structure in question. With the increase in lateral load, spectral acceleration increases and displacement also increase. Initially, the curve will be linear. It becomes non-linear and later exhibits very low modulus towards failure. Further, after collapse, strain softening tendency is observed. The demand spectrum depends on the design earthquake load at a location. For this purpose, seismic zone of the location and type of the ground on which the structure is built are the necessary data. The point of intersection of these two curves is called performance point. The location (co-ordinates) of this point suggests the performance level of the structure under a design earthquake load. It indicates the maximum base shear carried by the structure and its ductility characteristics.

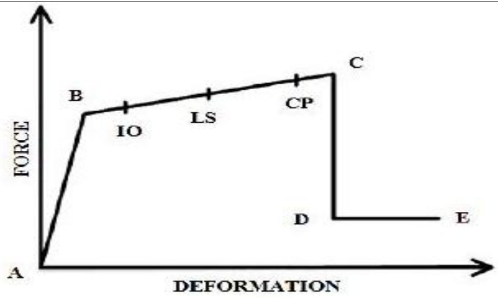


Fig.2 Typical pushover curve with different performance levels.

3. Present study

In the present work, 1- bay and 2- bay, two dimensional RC frames having 3, 5 and 7 storeys is considered as shown in the Fig. 3. The grade of concrete for column and beam is taken as M25. An imposed load of 25 kN/m for the normal storey beams and 20 kN/m for the roof floor beams is assumed which is exclusive of dead load. Initially, frames are analyzed and designed for zone III earthquake loading as per IS 1893-2002 provision using ETABS. ETABS implements the plastic hinge properties described in ATC-40. Auto hinge properties such as PMM hinges are assigned to columns and M3 hinges are assigned to the beam ends. Hinges are provided at the beginning and end of beam and column elements.Pushover analysis is carried out considering displacement controlled analysis. Here Stiffness ratio (SR) is defined as the ratio of the moment of inertia of the soft storey column to the moment of inertia of the column above or below. Stiffness ratio is varied from SR=0.125 to SR= 0.77 at soft storey. TABLE 1 show the design details of the various stiffness ratios considered. The position of the soft storey is varied to different floor each time and the performance of the structure is found.

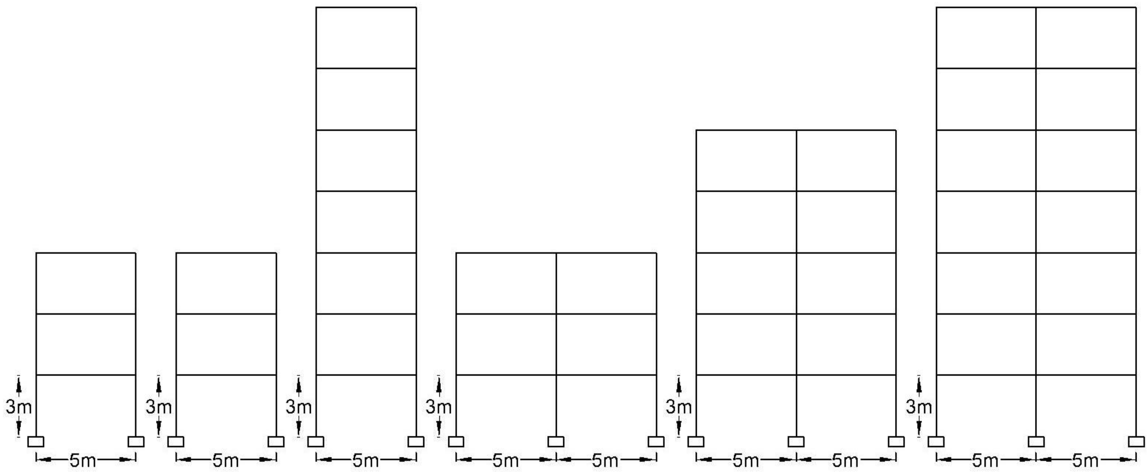


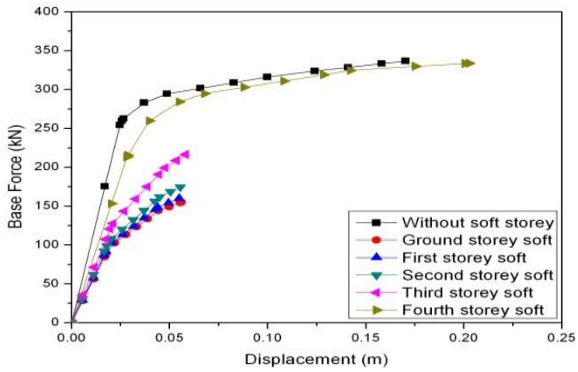
Fig.3 Models considered in the study

Table 1: Stiffness ratio considered in the model

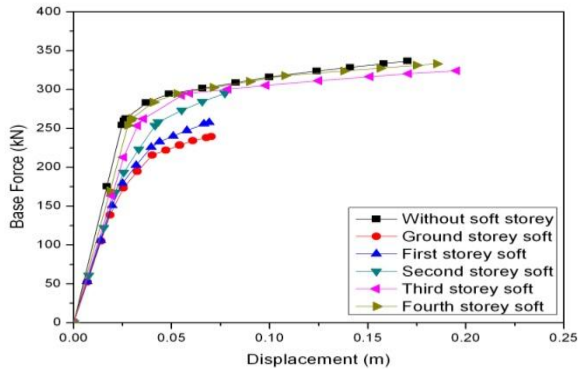
Stiffness Ratio	Column in the soft storey	Column in the rest of the storey
0.125	200mmX300mm	200mmX600mm
0.3	200mmX400mm	200mmX600mm
0.58	200mmX500mm	200mmX600mm
0.77	200mmX550mm	200mmX600mm

4. Results and discussions

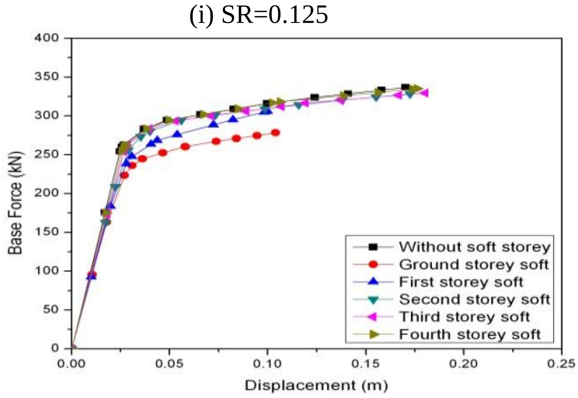
Fig. 4 and Fig. 5, shows the variation in roof displacement for soft storey at different levels for varying stiffness ratios in 1 and 2 bay frames. The results are compared with those of a building without a soft storey. It can be seen that when the stiffness ratio SR is 0.77, the performance is similar to the structure without a soft storey. The base shear carrying capacity of the structure is lower when the soft storey is on the ground floor and it goes on increasing as the soft storey is shifted to a higher level. Thus, it can be observed that the structure is more vulnerable to seismic force when the soft storey is on the ground floor. Also, base force carrying capacity of the 2- bay is more than that of the 1- bay frame.



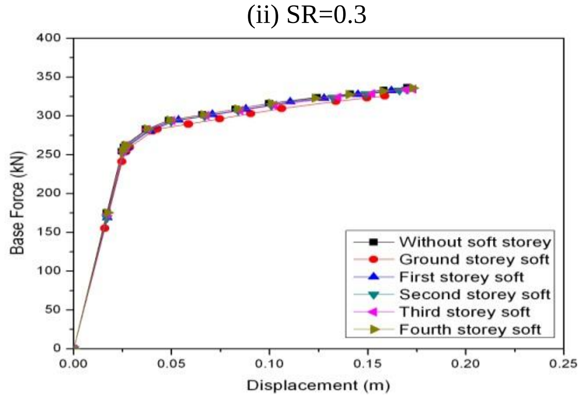
(i) SR=0.125



(ii) SR=0.3

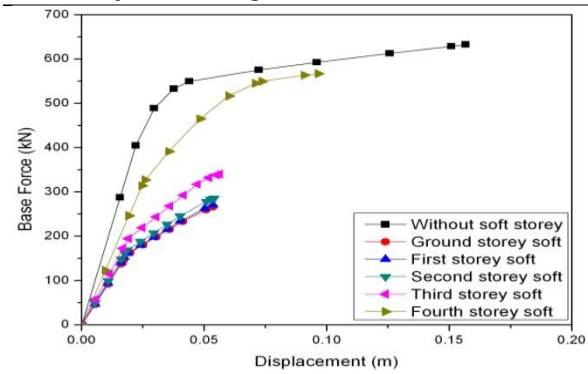


(iii) SR=0.58

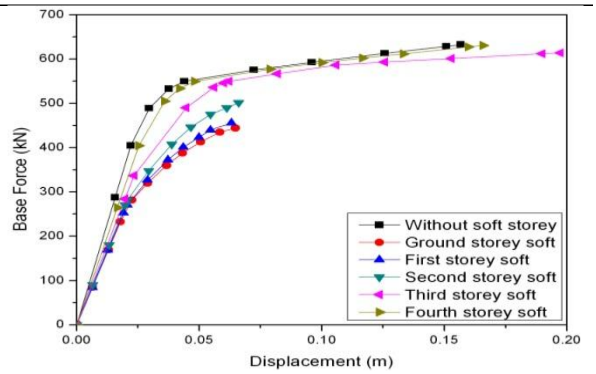


(iv) SR=0.77

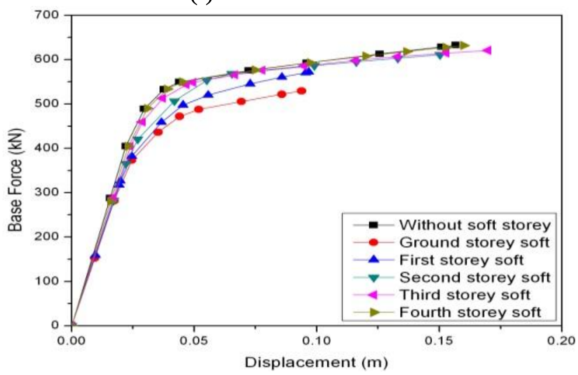
Fig.4Behavior of 5 storey 1 bay frame for soft storey at different floors and stiffness ratios



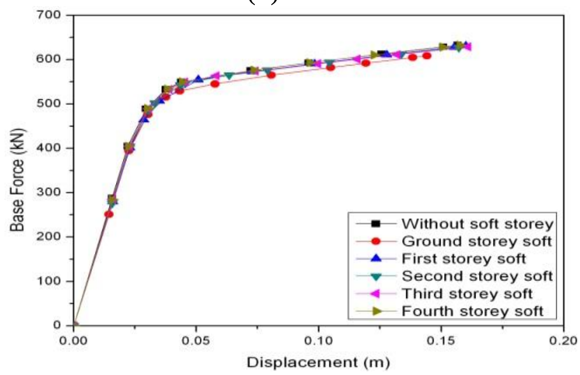
(i) SR=0.125



(ii) SR=0.3



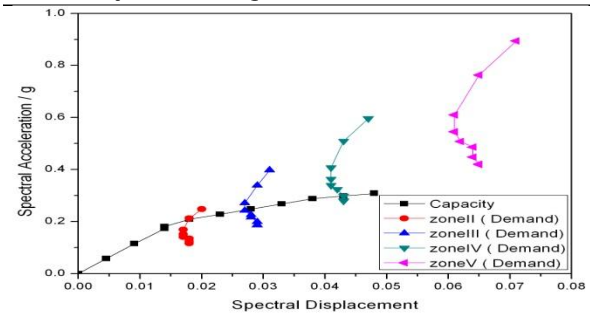
(iii) SR=0.58



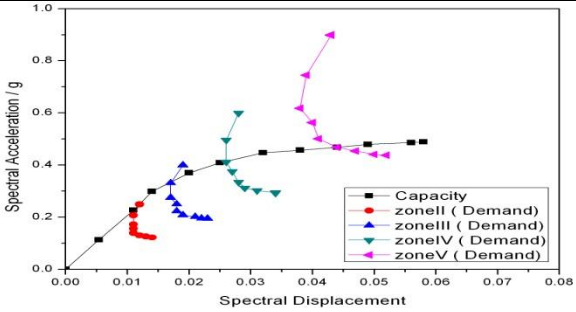
(iv) SR=0.77

Fig.5Behavior of 5 storey 2 bay frame for soft storey at different floors and stiffness ratios

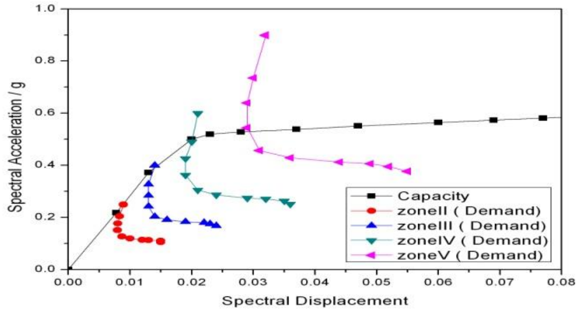
Fig. 6 and Fig. 7shows the typical capacity and demand curve of a 5 storey 1 bay frame for the soft storey at the ground and fourth floor for the varying stiffness ratio. It can be seen that the performance point shifts towards the left as the soft storey shifts to higher levels indicating the decreased vulnerability to seismic loading. Also, as the stiffness ratio decreases the performance point shifts rightwards indicating more vulnerability. Thus, the best performance is observed when the soft storey is at higher levels. Also, the performance of the structure with soft storey having SR=0.77 is similar to that of structure without a soft storey. Similar results were obtained for both 3 and 7 storey of 1- bay and 2- bay RC frame for varying stiffness ratio.



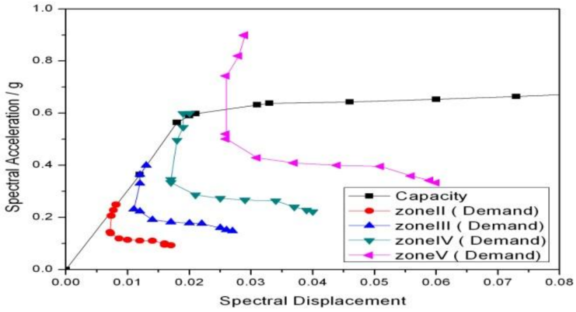
(i) SR=0.125



(ii) SR=0.3

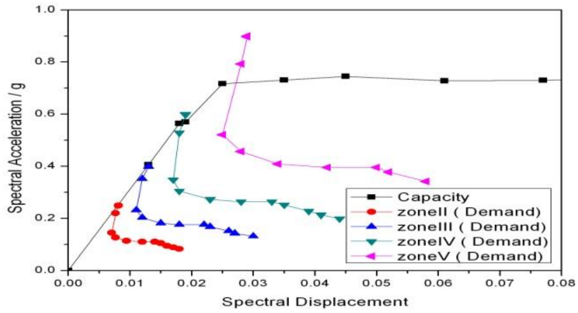


(iii) SR=0.58

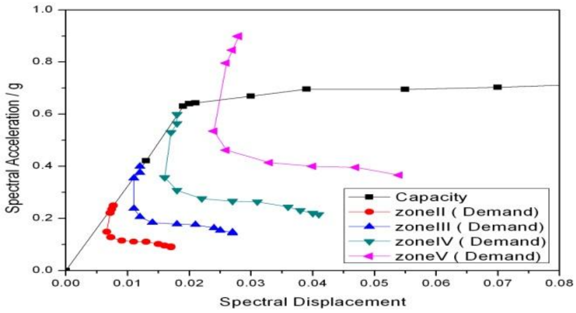


(iv) SR=0.77

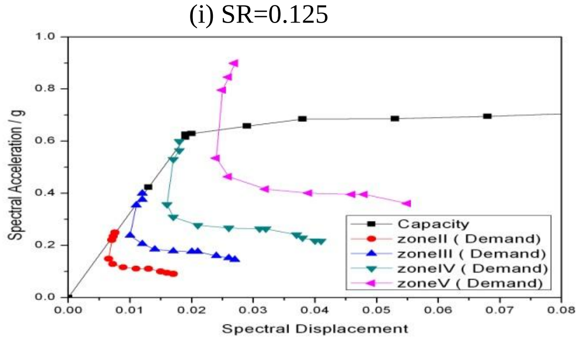
Fig.6 Capacity and demand curve for 5 storey 1 bay frame with soft storey at ground floor for different stiffness ratio



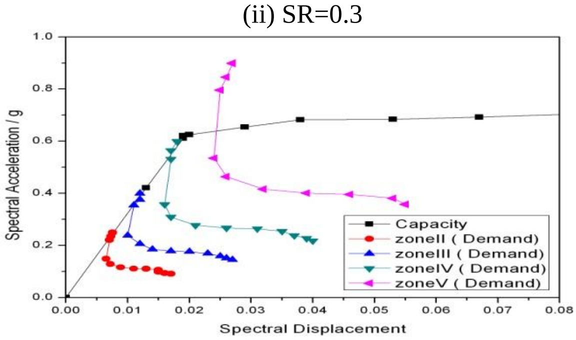
(i) SR=0.125



(ii) SR=0.3



(iii) SR=0.58



(iv) SR=0.77

Fig.7 Capacity and demand curve for 5 storey 1 bay frame with soft storey at fourth floor for different stiffness ratio

5. Conclusions

The following are theconclusions arrived from the present study.

1. The seismic performance of structures is very sensitive to stiffness ratio. The lower the stiffness ratio of soft storey more vulnerable the structure will be to the seismic forces.
2. Soft storey at lower floors is more vulnerable to seismic force because it attracts more force due to high seismic weight.
3. The performance of RC frames with soft storey having stiffness ratio of 0.77 is comparable to that of a frames without soft storey. Hence, as per the definition of IS 1893:2002 it is acceptable but needs further analysis.
4. When stiffness ratio decreases the performance point shifts rightwards indicating more vulnerability of the structure.
5. It is also observed that for a given structure, seismic performance depends on the seismic zone in which the structure is located. The structure becomes more vulnerable to seismic force at higher zones. Hence, proper care should be taken while designing a soft storied structure at these locations.

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