Amit V. Khandve / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp.2100-2108

Seismic Response of RC Frame Buildings with Soft Storeys

Amit V. Khandve
Department of Civil Engineering, RTM Nagpur University, Nagpur -440009 (MH)

ABSTRACT :

Open first storey is a typical feature in the modern multistorey constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. Though multistoried buildings with open (soft) ground floor are inherently vulnerable to collapse due to earthquake load, their construction is still widespread in the developing nations like India. Social and functional need to provide car parking space at ground level far out-weighs the warning against such buildings from engineering community.

This paper highlights the importance of explicitly recognizing the presence of the open storey in the analysis of the building. The error involved in modeling such buildings as complete bare frames, neglecting the presence of infills in the storeys, is brought out through the study of an example building with different analytical models. This paper argues for immediate measures to prevent the indiscriminate use of soft storeys in buildings, which are designed without regard to the increased displacement, ductility and force demands in the storey columns.

KEYWORDS: - concrete, earthquake, infill, multistory, soft story.

INTRODUCTION:

Many urban multistorey buildings in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first storeys. The upper storeys have brick infilled 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."

Whereas the total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with soft first storey, the upper storeys being stiff, undergo smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demands on the columns in the first storey is also large, as the shear in the first storey is maximum. For the upper storeys, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiffnesses have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. This has adverse effect on the performance of buildings during ground shaking. Such buildings are required to be analyzed by the dynamic analysis and designed carefully.

The Jabalpur earthquake of 22 May 1997 also illustrated the handicap of Indian buildings with soft first storey. This earthquake, the first one in an urban neighborhood in India, provided an opportunity to assess 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 inherent risk involved in the construction of buildings with soft first storey. Himgiri apartments is a 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. The first storey columns in the parking area were badly damaged including spalling of concrete cover, snapping of lateral ties, buckling of longitudinal reinforcement bars and crushing of core concrete **(Fig. 1)**. The columns on the other side had much lesser level of damage in them. There was only nominal damage in the upper storeys consisting of cracks in the filler walls. This is a clear case of columns damaged as a result of the "soft first storey". The Ajanta apartments buildings are a set of almost identical four storey RC frame building located side-by-side. In each of these buildings, there are two apartments in each storey, excepting the first storey. One building has two apartments in the upper storeys, but only one apartment in the first storey. The open space on the other side is meant 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 badly damaged. The damage consisted of buckling of longitudinal bars, snapping of ties, spalling of cover and crushing of core concrete.

Figure 1 :: Damage to columns in Himgiri apartment.

In a two-storey (plus stilt storey) C-shaped RC frame building (Youth hostel building) in Jabalpur, the damage to the columns in the stilt storey consisted of severe X-type cracking due to cyclic lateral shear **(Fig. 2)**. 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.

Figure 2 :: Damage to columns in the stilt storey of Youth Hostel building.

BUILDING UNDER STUDY:

The plan layout of the reinforced concrete moment resisting frame building with one open storey and Un-reinforced brick infill walls in the other storeys, chosen for this study is shown in Fig. 3. The building is deliberately kept symmetric in both orthogonal directions in plan to avoid torsional response under pure lateral forces. The building is considered to be located in seismic zone III and intended for commercial use. The building is founded on medium strength soil through isolated footings (of size *2m×2m*) under the columns.

Elastic moduli of concrete and masonry are 28,500 MPa and 3,500 MPa, respectively, and their Poison's ratio is 0.25. Performance factor (K) has been taken as 1.0 (assuming ductile detailing). The unit weights of concrete and masonry are taken as 25 kN/m3 and 20 kN/m3. is considered.

The other building parameters are as follows.

- G+7Building
- Symmetrical
- Medium strength soil
- Isolated footings
- M20 and Fe415

- Column size: 300 mm X 600mm
- Beam size: 600mm X 300mm
- Office Building (Commercial)
- Zone III
- Dead load: 25KN/m^2
- Live load 3 KN/m^2
- Floor finish: 1 KN/m^2

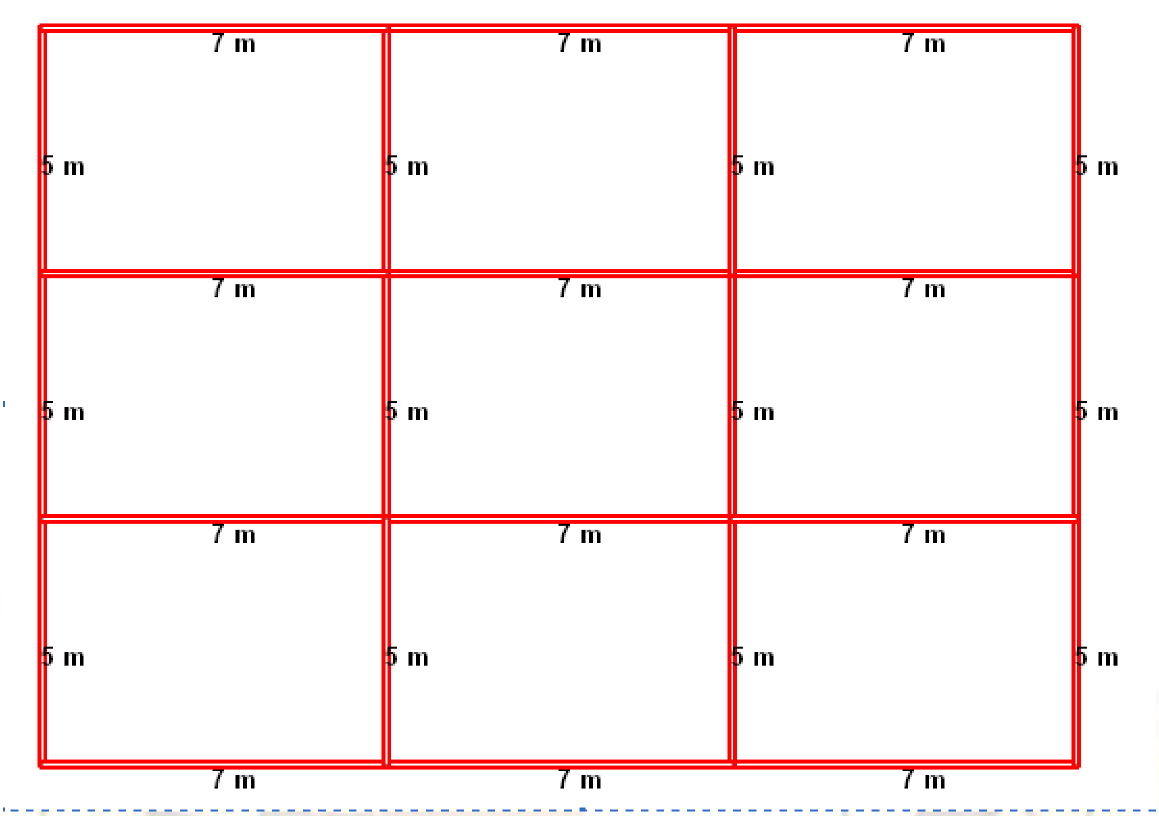
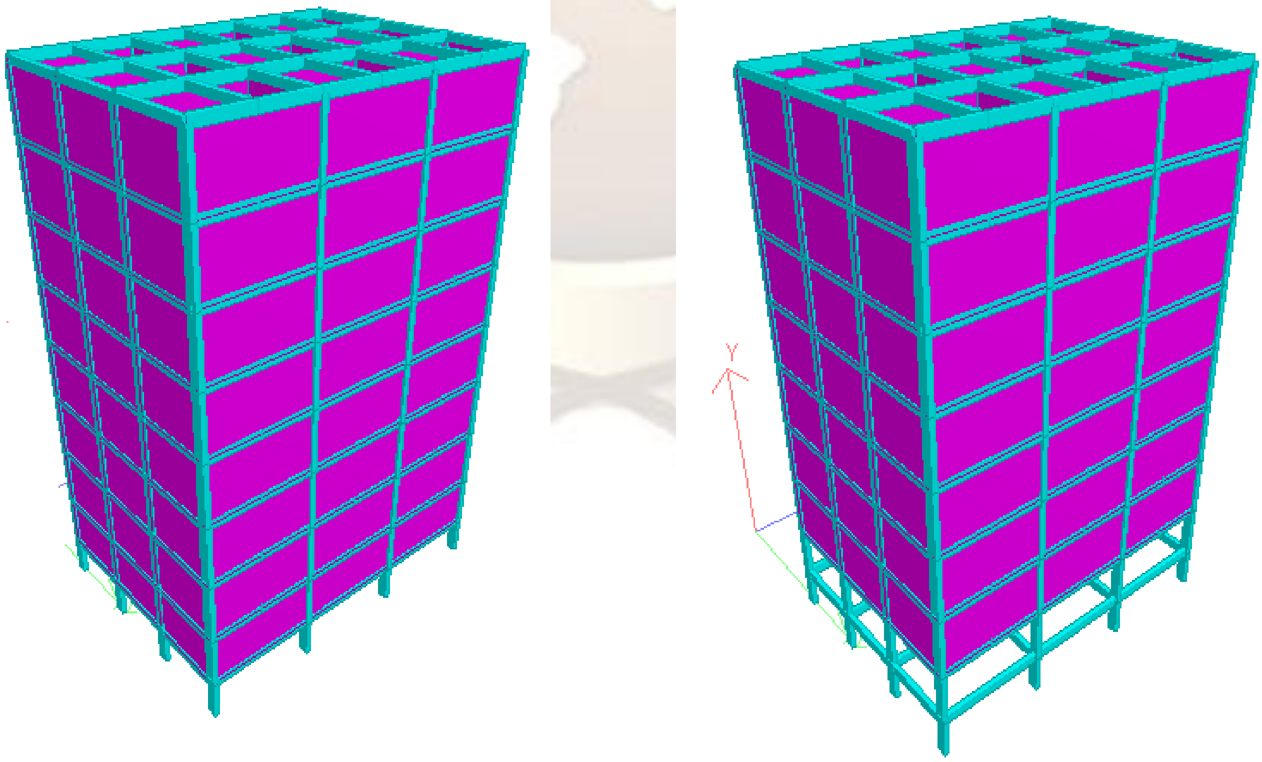
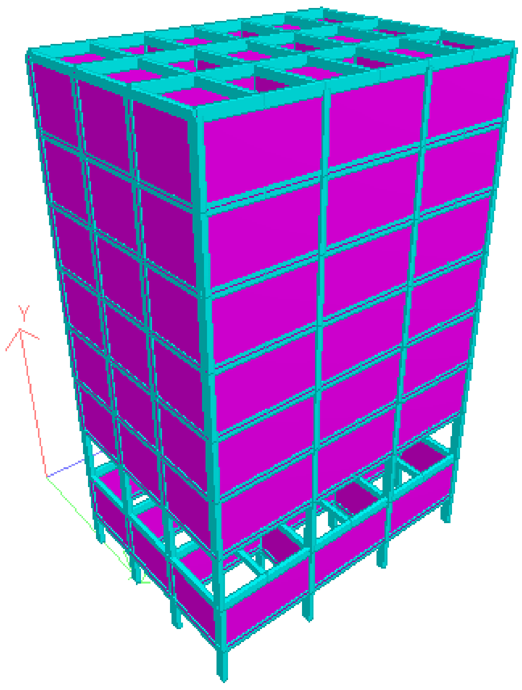


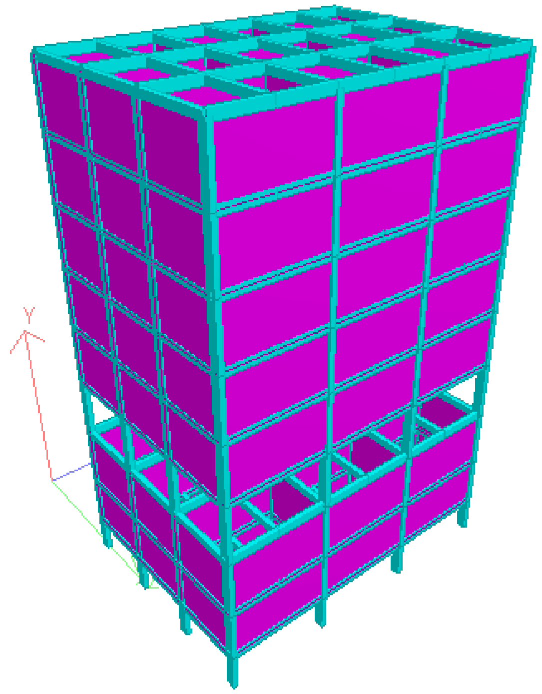
FIGURE 3 :: PLAN AT A GROUND FLOOR OF THE EXAMPLE BUILDING CONSIDERED IN THE STUDY



Elevation 1 : Building with No Soft Storey

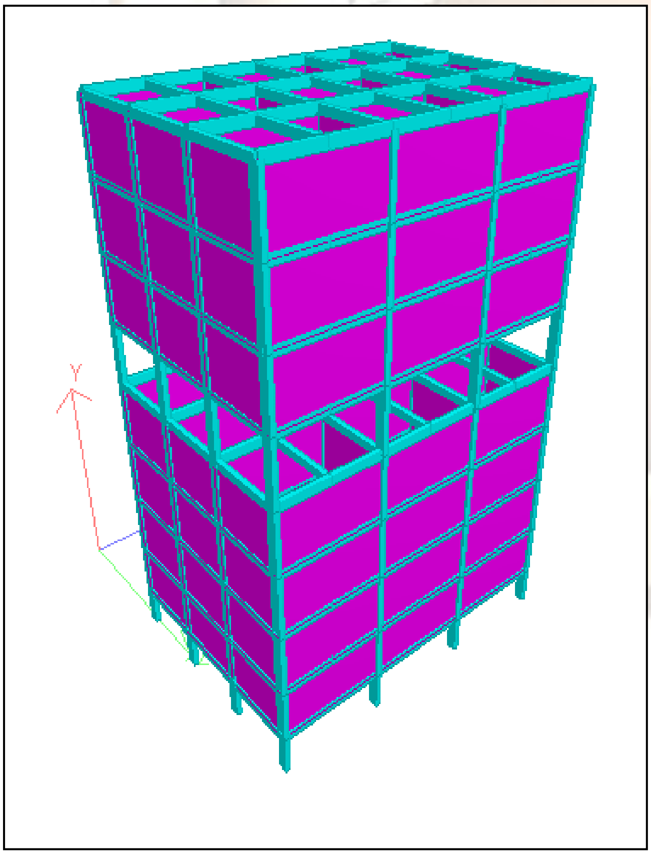


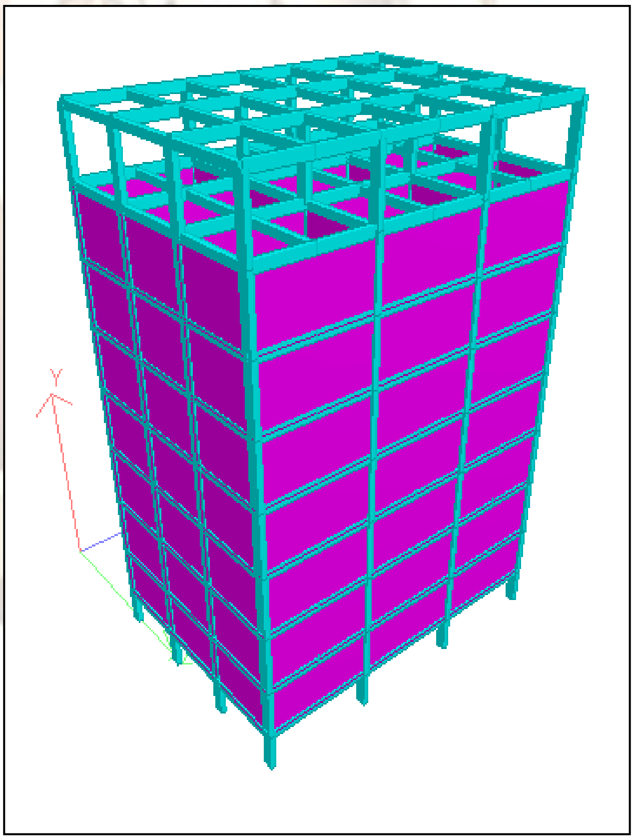
Elevation 2 : Building with Ground Floor as Soft Storey



Elevation 3 : Building with First Floor as Soft Storey

Elevation 4 : Building with Second Floor as Soft Storey





Elevation 5 : Building with Fourth Floor as Soft Storey

Elevation 6 : Building with Top Floor as Soft Storey

FIGURE 4 :: ELEVATIONS WITH DIFFERENT SOFT STOREYS OF THE EXAMPLE BUILDING CONSIDERED IN THE STUDY

EQUIVALENT STATIC ANALYSIS:

The natural period of the building is calculated by the expression, T=0.09H/√D given in IS:1893-2002, wherein *H* is the height and *D* is the base dimension of the building in the considered direction of vibration. Thus, the natural periods for all the models in this method, is the same. The lateral load calculation and its distribution along the height is done as per IS:1893-1984.

RESULTS AND DISCUSSIONS:

- After analyzing the building with no soft storey in STAAD, the output is as follows.

CALCULATED FREQUENCIES FOR LOAD CASE 3

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.832	1.20124	2.597E-16
2	1.225	0.81612	1.199E-16
3	1.292	0.77380	2.155E-16
4	1.900	0.52639	7.979E-16
5	2.467	0.40530	3.548E-16
6	2.790	0.35845	5.550E-16
7	3.018	0.33133	1.581E-16
8	3.834	0.26079	0.000E+00
9	4.167	0.23998	1.658E-16
10	4.215	0.23724	9.725E-16
11	4.751	0.21050	1.276E-16
12	8.493	0.11775	2.859E-11
13	8.748	0.11431	4.438E-12
14	10.301	0.09708	5.188E-07
15	10.801	0.09258	6.132E-08

- After analyzing the building with Ground Floor as soft storey in STAAD, the output is as follows.

CALCULATED FREQUENCIES FOR LOAD CASE 3

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.409	2.44713	5.389E-16
2	0.637	1.57054	2.220E-16
3	0.650	1.53944	2.133E-16
4	1.664	0.60085	1.040E-15
5	2.017	0.49589	3.541E-16
6	2.653	0.37690	1.150E-12
7	2.719	0.36782	1.389E-13
8	3.195	0.31296	2.310E-13
9	3.304	0.30266	3.082E-12
10	3.725	0.26845	2.315E-10
11	4.100	0.24388	1.054E-09
12	5.579	0.17925	3.955E-09
13	5.983	0.16715	9.053E-09
14	7.254	0.13786	4.798E-07
15	7.291	0.13716	4.878E-08

- After analyzing the building with First Floor as soft storey in STAAD, the output is as follows.

CALCULATED FREQUENCIES FOR LOAD CASE 3

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.422	2.36809	5.047E-16
2	0.695	1.43844	0.000E+00
3	0.697	1.43482	5.558E-16
4	1.676	0.59660	1.281E-16
5	2.043	0.48955	2.657E-14
6	2.539	0.39383	2.872E-13
7	2.655	0.37658	4.156E-12
8	2.735	0.36563	7.475E-12
9	3.077	0.32501	2.916E-11
10	3.635	0.27513	4.323E-11
11	3.672	0.27232	1.252E-10
12	3.727	0.26830	2.942E-10
13	3.828	0.26124	1.600E-09
14	4.459	0.22428	1.194E-08
15	4.578	0.21842	7.596E-11

- After analyzing the building with Second Floor as soft storey in STAAD, the output is as follows.

CALCULATED FREQUENCIES FOR LOAD CASE 3

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.463	2.15988	4.198E-16
2	0.764	1.30955	9.260E-16
3	0.766	1.30508	9.197E-16
4	1.697	0.58944	2.501E-15
5	1.883	0.53110	1.015E-15
6	2.079	0.48103	2.849E-14
7	2.418	0.41361	6.454E-13
8	2.663	0.37550	1.214E-12
9	2.756	0.36280	4.076E-12
10	3.252	0.30747	3.799E-12
11	3.315	0.30162	5.207E-11
12	3.675	0.27208	3.278E-10
13	3.729	0.26820	4.380E-09
14	4.078	0.24523	3.873E-09
15	4.269	0.23424	6.970E-09

- After analyzing the building with Fourth Floor as soft storey in STAAD, the output is as follows.

```
CALCULATED FREQUENCIES FOR LOAD CASE       3

MODE          FREQUENCY(CYCLES/SEC)        PERIOD(SEC)      ACCURACY

  1                 0.575                  1.73885          2.177E-15
  2                 0.931                  1.07368          2.075E-16
  3                 0.933                  1.07182          2.068E-16
  4                 1.387                  0.72102          5.614E-16
  5                 1.752                  0.57064          1.758E-15
  6                 1.933                  0.51746          2.949E-14
  7                 2.182                  0.45833          2.193E-14
  8                 2.428                  0.41194          2.382E-14
  9                 2.688                  0.37205          1.877E-12
 10                 2.817                  0.35502          1.768E-12
 11                 2.869                  0.34856          6.448E-11
 12                 3.011                  0.33212          2.310E-11
 13                 3.350                  0.29847          5.360E-11
 14                 3.609                  0.27705          1.834E-09
 15                 3.737                  0.26763          3.651E-10
```

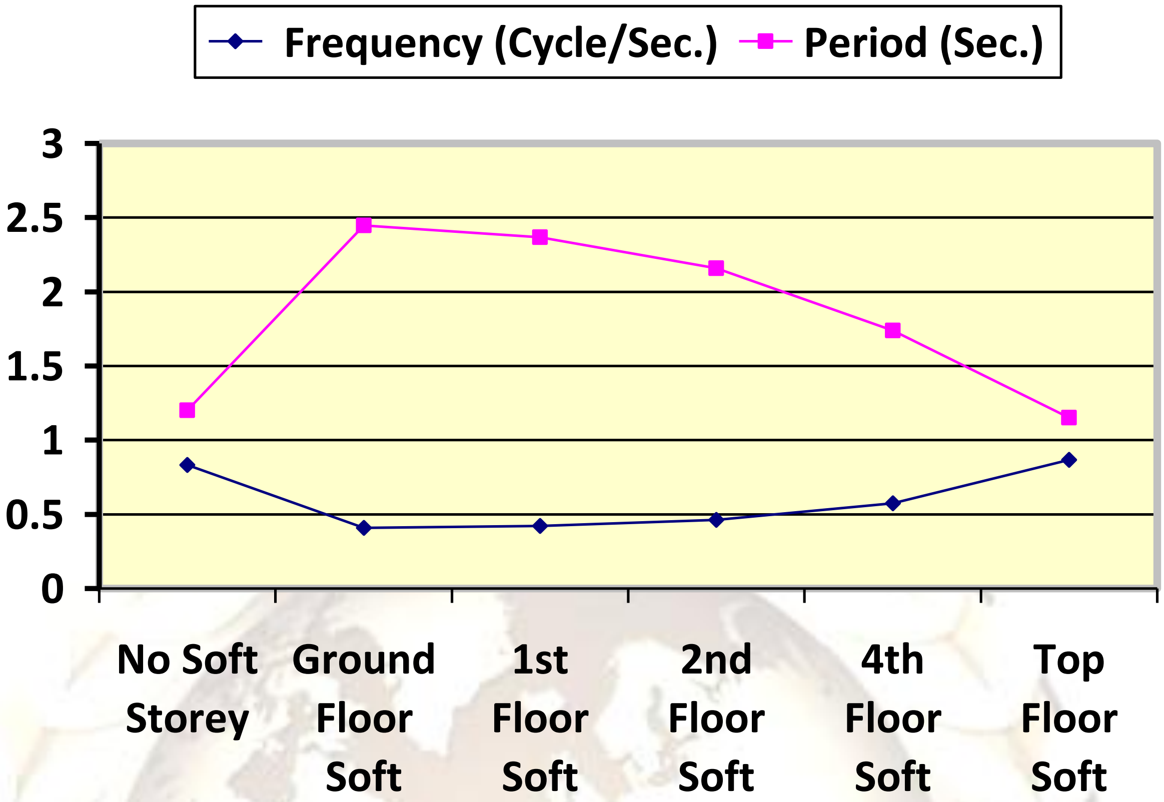
- After analyzing the building with Top Floor as soft storey in STAAD, the output is as follows.

```
CALCULATED FREQUENCIES FOR LOAD CASE       3

MODE          FREQUENCY(CYCLES/SEC)        PERIOD(SEC)      ACCURACY

  1                 0.868                  1.15222          9.558E-16
  2                 1.303                  0.76720          1.907E-15
  3                 1.346                  0.74279          7.944E-16
  4                 1.931                  0.51783          4.981E-14
  5                 2.246                  0.44525          1.570E-15
  6                 2.504                  0.39931          6.473E-13
  7                 2.781                  0.35955          4.441E-12
  8                 2.811                  0.35575          7.330E-11
  9                 3.020                  0.33114          1.990E-11
 10                 3.274                  0.30547          2.273E-12
 11                 3.594                  0.27827          4.728E-11
 12                 3.708                  0.26968          3.770E-10
 13                 3.788                  0.26398          8.168E-09
 14                 4.093                  0.24431          9.338E-08
 15                 4.452                  0.22460          2.704E-08
```

The Base Shear and Mass Participation Factors for different elevations are summarized in the following table.

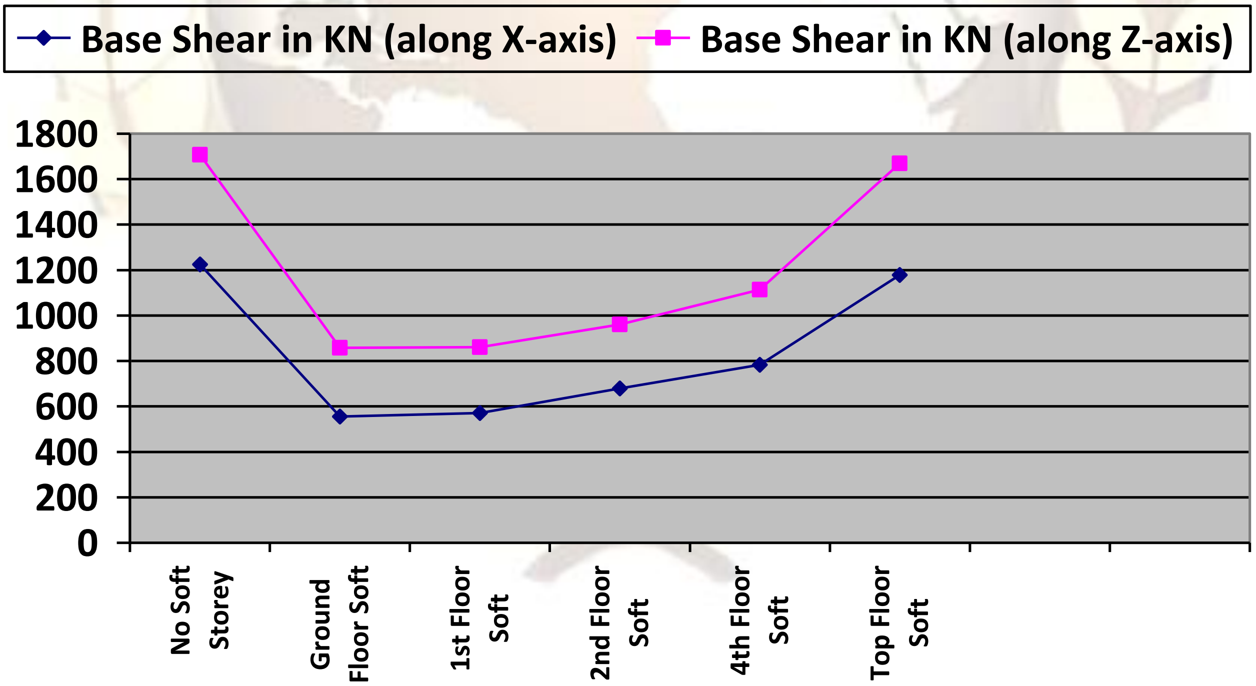
Sr. No.	***ELEVATION***	***BASE SHEAR (IN KN)***		***MASS PARTICIPATION FACTORS (IN %)***	
		X	***Z***	***X***	***Z***
1	Building with No Soft Storey	1225.25	1706.98	99.998	99.960
2	Building with Ground Floor as Soft Storey	555.38	857.34	100.0	98.632
3	Building with First Floor as Soft Storey	570.86	861.17	99.998	97.602
4	Building with Second Floor as Soft Storey	679.71	940.22	99.997	99.791
5	Building with Fourth Floor as Soft Storey	782.63	1113.06	99.984	99.628
6	Building with Top (7^{TH}) Floor as Soft Storey	1177.96	1668.79	99.843	96.950

The Frequency and Period for different Soft Storeys can be analyze from the **Graph 1**.



GRAPH 1

The Relation between different soft storey and base shear can be derived from **Graph 2.**



Graph 2

CONCLUSIONS:

RC frame buildings with open first storeys are known to perform poorly during in strong earthquake shaking. In this paper, the seismic vulnerability of buildings with soft first storey is shown through an example building. The drift and the strength demands in the first storey columns are very large for buildings with soft ground storeys. It is not very easy to provide such capacities in the columns of the first storey. Thus, it is clear that such buildings will exhibit poor performance during a strong shaking. This hazardous feature of Indian RC frame buildings needs to be recognized immediately, and necessary measures taken to improve the performance of the buildings.

The open first storey is an important functional requirement of almost all the urban multi-storey buildings, and hence, cannot be eliminated. Alternative measures need to be adopted for this specific situation. The under-lying principle of any solution to this problem is in (a) increasing the stiffnesses of the first storey such that the first storey is at least *50%* as stiff as the second storey, *i.e.*, soft first storeys are to be avoided, and (b) providing adequate lateral strength in the first storey.

REFERENCES:

- AIJ, 1995, "Preliminary Reconnaissance Report of the 1995 Hyogoken-Nanbu Earthquake, **Architectural Institute of Japan**, Tokyo, Japan.
- EQEI, 1994, "The January 17, 1994 Northridge, California Earthquake - An EQE Report," **EQE International**, San Francisco, USA.
- Hall,J.F., (Editor), 1994, "Northridge Earthquake January 17, 1994 – Preliminary Reconnaissance Report," Report No.94-01, **Earthquake Engineering Research Institute**, Oakland, USA.
- IS:13935-1993, Repair and Strengthening of Buildings - Indian Standard Guidelines, **Bureau of Indian Standards**, New Delhi, 1993.
- Murty,C.V.R., and Jain,S.K., (1996), "Draft IS:1893 Provisions on Seismic Design of Buildings," **Bureau of Indian Standards**, New Delhi.