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Seismic Analysis of Soft Storey Buildings Considering Structural and Geometrical Parameters

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Abstract: Soft storeys in a high rise building play an important role on its seismic performance. At the soft storey level, there is a discontinuity in the rigidity of the structure due to lack of infill walls or due to variation in floor height. It is this continuity which is the cause of structural failure of multi stored buildings under earthquake loads. In this study, seismic analysis of soft storey building frames have been carried out considering 3 building plans, 15 soft storeys cases and 20 load combinations. Soft storeys have been created by varying the floor heights and effect of infill is ignored. In this way, total 45 frames are analysed. STAAD.pro software has been used for analysis purpose. Results are collected in terms of max. moment, max. storey displacements, max. shear force, max. axial force and max. drift, which are critically analysed to quantify the effects of various parameters .

Keywords: Seismic; Maximum moment; Storey displacement; Shear force; Axial force; Drift

1. INTRODUCTION

Buildings are classified as having a "soft storey", if that level is less than 70% as stiff as the floor immediately above it, or less than 80% as stiff as the average stiffness of the three floors above it. Often, open-ground-storey buildings are called soft-storey buildings, even though their ground storey may be soft and weak. Generally, the soft or weak storey usually exists at the ground storey level, but it could be at any other storey level. Soft storey buildings, having first storeys much less rigid than the storeys above are particularly susceptible to earthquake damage because of large, unreinforced openings on their ground floors. Behaviour of soft storey building to seismic forces has to be critically examined considering various geometrical and seismic parameters. Some of the prominent literature on the topic are as follows:

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Ari Wibowo, et. al (2010) concluded that precast soft storey system have sufficient displacement capacity for lower seismic regions, but the performance was considered marginal for higher seismic regions. Plumier, et. al (2005) worked towards promoting safety without too much changing the constructional practice of reinforced concrete structures. He observed that most frequent failure mode of reinforced concrete (R.C.) moment–frame buildings was the so called soft storey mechanism. Mo and Chang (1995) described a practical system combining a flexible first storey with sliding frictional interfaces. The system utilized Teflon sliders at the top of the first storey reinforced concrete framed shear walls to carry a portion of the superstructure. Chen and Constantinou (1990) observed that the practical system deliberately introduces flexibility to the first storey of structures, The system utilised Teflon sliders to carry a portion of the superstructure. Energy dissipation was provided by the first storey ductile columns and by the Teflon sliders. Sivakumaran and Balendra (1994) presented a method of seismic analysis of three-dimensional asymmetric multistorey buildings founded on flexible foundations. The building-foundation system considered in this study was a linear elastic N-storey asymmetric building with a rigid footing resting on the surface of a linear elastic soil half-space. The method of analysis also included the P-Δ effects, in which the additional overturning moment and torsional moment at each storey due to P-Δ effects had been replaced by fictitious lateral forces and torques. Zekai Sen (2010) concluded that earthquake hazard assessment of existing buildings was among the most important issues for pre- and post-earthquake warning, preparation, vulnerability, and mitigation works. In any potential earthquake prone area, it was necessary to classify the existing building stoke into different categories according to rapid, simple, reliable, logical and expert view based models and software. Kirac Nevzat, et. al (2011) observed that the negative effects of this weak storey irregularity could be reduced by some precautions during the construction stage. Also, some recommendations were presented for the existing buildings with weak-storey irregularity. Manabu Yoshimura, (1995) conducted nonlinear dynamic response analysis, where strength deterioration was considered in representing member nonlinearity, The analysis was found to reproduce the observed damages well, such as residual displacement, mechanism and damages to members. It was also revealed that if first storey mechanism might occur, the collapse could be unavoidable even for buildings with a base shear strength of as much as 60% of the total weight. Sivakumaran (1990) proposed a method of analysis for the earthquake response of multi-storey mono-symmetric buildings founded on flexible foundations. The analysis also included the sway *(P-Δ)* effects. Vipul Prakash (2004) described the prospects for Performance

Based Engineering (PBE) in India. He listed the pre-requisites that made the emergence of PBE possible in California, compared the situation in India and discussed the tasks and difficulties for implementing PBE in India. In India, the criteria for earthquake resistant design of structures are given in IS 1893, published by the Bureau of Indian Standards (BIS). IS 1893-2002 reduced the number of seismic zones to four by merging zone I with zone II and adopted a modified CIS-64 scale for seismic zoning and dropped references to the MMI scale.

In this paper, seismic analysis of soft storey buildings considering structural and geometrical parameters have been carried out using STAAD. PRO software. Soft storeys have been created by increasing the floor heights. Effect of infill has been ignored. Results, in terms of moment, displacement, shear force, axial force and drift are critically examined and salient conclusions are drawn.

2. STRUCTURAL MODELLING AND ANALYSIS

(a) Modelling of building frames

All the building Frames considered are 16m x 16m in plan area and 10 storey (G+9).

Height of the buildings are 29m. Following three types of buildings are accounted-

TYPE-A: Height of soft storey 3.5 m and depth of foundation 1.5 m
TYPE-B: Height of soft storey 3.7 m and depth of foundation 1.3 m
TYPE-C: Height of soft storey 4 m and depth of foundation 1 m

Building plan is shown in Fig.1. Structural models for the three types are shown in Fig.2 to 4. Modeling of the building frames are carried out using the

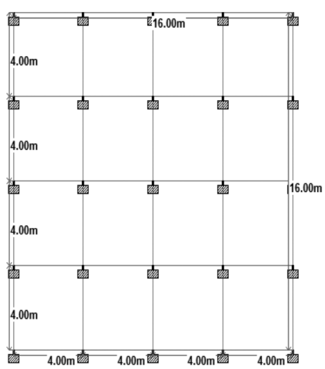

Figure 1: Plan of building

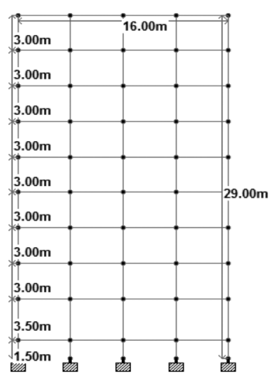

Figure 2: Soft storey building TYPE-1

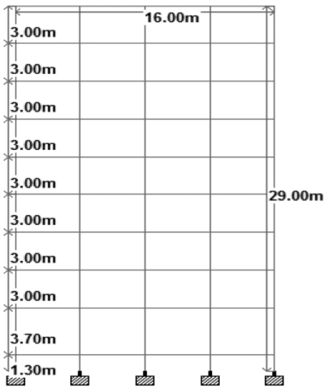

Figure 3: Soft storey building TYPE-2.

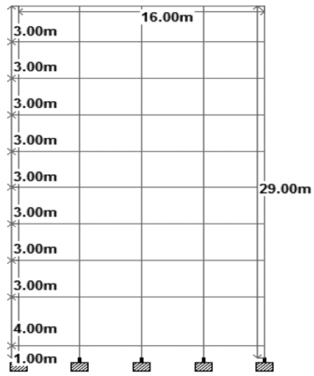

Figure 4: Soft storey building TYPE-3.

STAAD. Pro software. (Ref. 10). Numbers of beams and columns in each type are given in Table 1.

Table 1: No. of beams and columns.

Member	Type-1	Type -2	Type -3
Columns	200	200	200
Beams	250	250	250

(b) Soft storey cases

The following 15 cases have been framed for analysis purpose-

CASE- 1 : Without soft storey
CASE- 2 : Soft storey at first floor
CASE- 3 : Soft storey at second floor
CASE- 4 : Soft storey at third floor
CASE- 5 : Soft storey at fourth floor
CASE- 6: Soft storey at fifth floor
CASE- 7 : Soft storey at sixth floor
CASE- 8 : Soft storey at seventh floor
CASE- 9 : Soft storey at eighth floor

CASE- 10 : Soft storey at ninth floor
CASE- 11: Soft storey at first and second floor
CASE- 12 : Soft storey at third and fourth floor
CASE- 13: Soft storey at fifth and sixth floor
CASE- 14: Soft storey at seventh and eighth floor
CASE- 15: Soft storey at eighth and ninth floor

(c) Material and geometrical properties

Following material properties have been considered in modelling :-

Density of RCC: 25 kN/m^3
Density of Masonry: 20 kN/m^3
Poisson ratio : 0.17

The column size is 500mm x 300mm and the beam size is 450mm x 250mm.

(d) Loading conditions

Following loading are conducted for analysis:-

1) Dead Loads:
   Self wt. of slab considering 150mm thick. Slab = 0.15*25 = 3.75 kN/m^2
   Floor Finish load = 1 kN/m^2
   Water Proofing Load on Roof = 2.5 kN/m^2
   Masonry Wall Load = 0.25 x 2.55 x 20 = 12.75 kN/m
2) Live Loads:
   Live Load on typical floors = 2 kN/m^2
   Live Load on Roof = 1.5 kN/m^2
3) Earthquake Loads:
   The earth quake loads are derived for following seismic parameters as per IS: 1893(2002)-
   a. Earthquake Zone-III
   b. Response Reduction Factor : 5
   c. Importance Factor : 1
   d. Damping : 5%
   e. Soil Type: Medium Soil

(e) Structural Analysis

Structural analysis of the building frames are carried out using STAAD.Pro software (Ref.10). All the columns are rigidly supported at ground and 20 load combinations, given in Table 2, are considered for the analysis purposes.

Table 2 : Details of load cases.

Load Case No.	Load cases details
1	E.Q. IN X DIR.
2	E.Q. IN Z DIR.
3	E.Q. IN -X DIR.
4	E.Q. IN -Z DIR.
5	Dead load
6	Live load
7	1.5 (DL + LL)
8	1.2 (DL + LL + EQX)
9	1.2 (DL + LL - EQX)
10	1.2 (DL + LL + EQZ)
11	1.2 (DL + LL - EQZ)
12	1.5 (DL + LL + EQX)
13	1.5 (DL + LL - EQX)
14	1.5 (DL + LL + EQZ)
15	1.5 (DL + LL - EQZ)
16	0.9DL + 1.5EQ(+X)
17	0.9DL + 1.5EQ(-X)
18	0.9DL + 1.5EQ(+Z)
19	0.9DL + 1.5EQ(-Z)
20	LOAD FOR CHECK

3. RESULTS AND DISCUSSION

Results of structural analysis can be described under following heads -

a. Moments in columns and beams

Comparison of max. bending moment are given in Table 3. Plot of max. moment vs soft storey for all types of buildings is given in Fig.5. It is observed that case 11 and case 14 are most critical for Type A building. It is also observed that case 11 has max. moment at first floor. Case 11 and 12 are most critical for Type B building. Max. moment for Type B building is at first floor for case 11. Case 2,3 and 5 are most critical for Type C building. Max. moment for Type

Table 3 : Comparison of Max. Moment(kN-m).

FLOOR	TYPE A		TYPE B		TYPE C	
	Moment	CASE	Moment	CASE	Moment	CASE
GROUND	231.266	2	231.81	2	232.539	2
FIRST	237.253	11	243.046	11	238.493	3
SECOND	232.339	11	233.458	11	234.147	3
THIRD	234.679	12	236.475	12	234.876	4
FOURTH	234.215	13	234.164	12	234.705	5
FIFTH	231.273	14	234.181	13	229.754	5
SIXTH	232.332	14	234.074	14	229.659	10
SEVENTH	233.636	7	228.018	4	223.277	2
EIGTH	225.51	2	225.437	8	225.32	2
NINTH	198.795	15	199.915	15	201.131	10

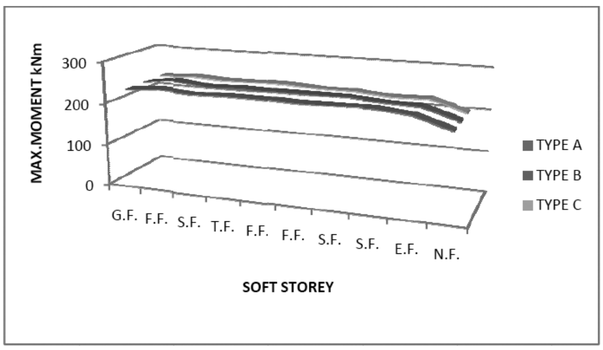

Figure 5 : Max. Moment in buildings

C building is at first floor for case 3. Max. moment for all types of buildings are at first floor.

b. Storey displacement

Comparison of max. storey displacement are given in Table 4. Plot of max. storey displacement vs soft storey buildings for all types of buildings is given

Table 4 : Comparison of Max. Displacement (mm).

FLOOR	TYPE A		TYPE B		TYPE C	
	Displacement	CASE	Displacement	CASE	Displacement	CASE
GROUND	0.414	13	0.409	1	0.409	1
FIRST	2.521	2	2.662	2	2.955	2
SECOND	4.978	11	5.376	11	5.513	11
THIRD	7.02	11	7.448	11	7.256	11
FOURTH	9.013	12	9.532	12	9.199	4
FIFTH	10.891	12	11.448	12	11.025	4
SIXTH	12.533	12	13.104	12	12.654	4
SEVENTH	13.906	13	14.487	12	14.022	4
EIGTH	14.915	12	15.503	12	15.027	4
NINTH	15.5	12	16.091	12	15.611	4

in Fig. 6. It is observed that case 11 and 12 are most critical for Type A building. Max. displacement is at ninth floor for case 12. Case 12 is most critical for all types of floor for Type B building. Max. displacement for case 12 is at ninth floor. Case 4 and 11 are most critical for all types of floors for Type C building. Max. displacement for case 4 is at ninth floor. Ninth floor has max. displacement.

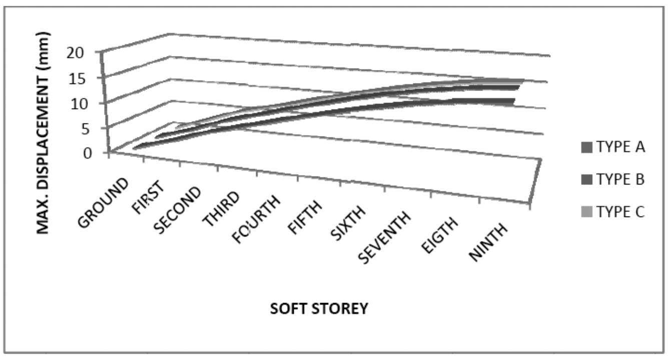

Figure 6 : Max. Displacement in buildings

c. Shear force

Comparison of max. shear force is given in Table 5. Plot of max. shear force vs soft storey for all types of buildings is given in Fig. 7. It is observed that case

Table 5 : Comparison of Max. Shear force(kN)

	TYPE A		TYPE B		TYPE C	
FLOOR	Shear Force	CASE	Shear Force	CASE	Shear Force	CASE
GROUND	202.283	2	202.886	2	202.912	2
FIRST	206.672	11	209.681	11	206.994	3
SECOND	202.475	12	203.721	12	204.186	4
THIRD	200.646	12	202.636	12	200.948	5
FOURTH	200.437	4	201.087	8	200.437	4
FIFTH	201.327	5	201.315	5	201.296	5
SIXTH	201.335	5	201.412	2	201.377	2
SEVENTH	199.815	7	199.801	7	199.734	2
EIGTH	199.818	2	199.791	2	199.75	2
NINTH	194.28	15	195.461	15	196.602	10

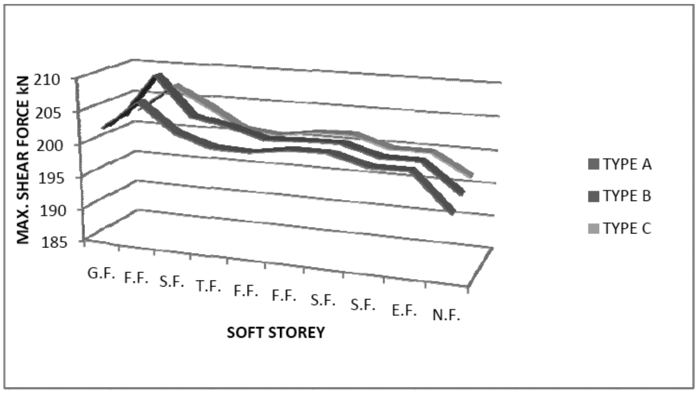

Figure 7 : Max. Shear force in buildings

5 and 12 are most crucial for Type A building and max. shear force is for case 11 at first floor. It is observed that case 2 and 12 are most crucial for Type B building. Max. shear force for Type B building is at first floor in case 11. Case 2 and 5 are most crucial for Type C building. Max. shear force is at first floor for case 3. Max. shear force for Type A, Type B, and Type C building is at first floor and Type B building has max. shear force among the three.

d. Axial force

Comparison of max. axial force is given in Table 6. Plot of max. axial force vs soft storey for all types of buildings is given in Fig. 8. It is observed that max. axial force in Type A is in case 15 for all types of floor. It is also observed that max. axial force is at ground floor. Max. axial force for Type B building is at ground floor for case 10. Case 10 has max. axial force for all type of floor in

Table 6 : Comparison of Max. Axial force (kN).

	TYPE A		TYPE B		TYPE C	
FLOOR	**Axial Force**	**CASE**	**Axial Force**	**CASE**	**Axial Force**	**CASE**
GROUND	6142.867	15	6127.894	10	6144.234	10
FIRST	5527.688	15	5552.812	15	5529.056	10
SECOND	4904.444	15	4927.208	15	4905.818	10
THIRD	4286.716	15	4308.683	15	4288.098	10
FOURTH	3674.198	15	3695.245	15	3675.594	10
FIFTH	3066.453	15	3086.583	15	3067.863	10
SIXTH	2463.453	15	2482.66	15	2464.895	10
SEVENTH	1781.194	15	1799.527	15	1782.547	10
EIGTH	1204.574	15	1221.074	15	1207.596	10
NINTH	615.123	15	623.179	15	634.391	10

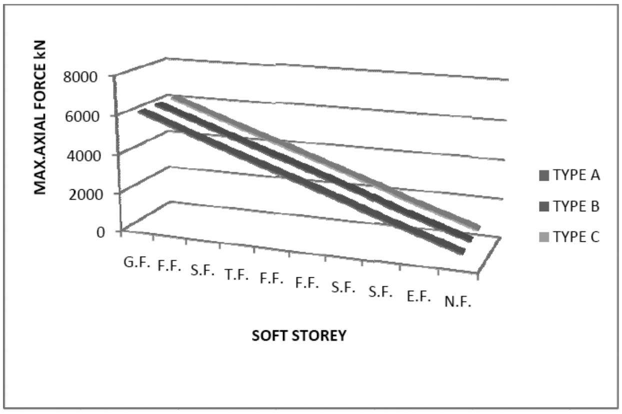

Figure 8 : Max. Axial force in buildings

Type C building. Type C and type B have maximum and minimum axial force among the three.

e. Drift

Comparison of max. drift is shown in Table 7. Plot of max. drift vs soft storey for all types of buildings is given in Fig. 9. For type A building, max. drift is in case 11 at second floor. For type B building, max. drift is at third floor for case

Table 7 : Comparison of Max. Drift (mm).

	TYPE A		TYPE B		TYPE C	
FLOOR	DRIFT	CASE	DRIFT	CASE	DRIFT	CASE
GROUND	0.584	1	0.584	1	0.584	1
FIRST	3.47	2	3.898	2	4.6	2
SECOND	3.897	11	4.434	11	5.14	3
THIRD	3.882	12	4.435	12	5.111	4
FOURTH	3.742	13	4.268	12	4.925	5
FIFTH	3.473	13	4.015	13	3.69	13
SIXTH	3.09	14	3.573	14	3.249	14
SEVENTH	2.51	14	2.91	14	2.569	14
EIGTH	1.847	15	2.169	15	2.106	15
NINTH	0.992	15	1.172	15	1.321	10

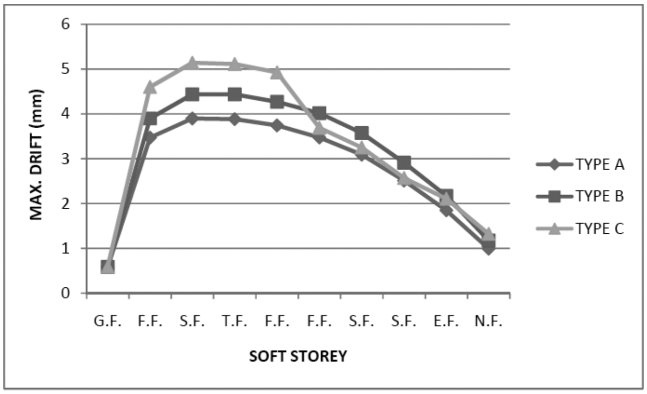

Figure 9 : Max. Drift in buildings

12. For type C building max. drift is at second floor for case 3. Type C and type A have maximum and minimum drifts among the three.

4. CONCLUSIONS

In this study, performance of building frames are studied considering various geometrical and seismic parameters. Results of this parametric study show that moments and shear forces are always maximum when first storey is soft for all types of buildings. Similarly, axial forces and drifts are also found to depend on structural and geometrical parameters. These results will help design engineers in fast and reliable assessment of the effects of soft storeys.

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