

SEISMIC ANALYSIS OF MULTI-STOREY BUILDING WITH DOUBLE CELLAR

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Abstract:

This work deals with the study of response of multi-storey building with double cellar for the effects of soil structure interaction with isolated footing for three different soil conditions i.e. hard, medium and soft soils. The seismic analysis is done by using equivalent static analysis in ETABS 2016 software as per IS-1893:2002 for zones III & V. Further, the performance point of the structure is obtained by non-linear static analysis and the respective performance levels for different structural elements are represented by various notations like Immediate occupancy (IO), Life safety (LS) and Collapse prevention (CP) as defined in FEMA 440. The results obtained concluded that the effect of soil structure interaction increases with the increase in flexibility of soil and seismic activity. Moreover, the failure of structure is unavoidable for soft soil in zone V.

Keywords: Seismic Analysis, Soil Structure Interaction, Equivalent Static Analysis, Pushover Analysis, Double cellar, Lateral Earth Pressure.

1. INTRODUCTION:

Earthquake, one of the most dangerous natural phenomenon that cause high economic and social damage. During the seismic activity it is observed that the soil particles tend to move around the structure inducing flexibility to the structure which results to increase the damage furthermore. This phenomenon is called as Soil Structure Interaction. Many researchers have been carried out in the past using different methods to determine effect of soil - structure interaction. One such method is Winkler's idealization (where it is considered that the deformation of the foundation is confined to the applied load region only). In simple terms, the effect of the soil flexibility is incorporated by considering equivalent soil spring system in the place of the footings. Even though Winkler's method has its limitations compared to finite element method (Direct method) is still advantageous because of its simple mechanism. A complete set of algebraic formulas have been given by Pais and Kausel (1988) which are further modified by Gazetas and Mylonakis. Furthermore, the lateral pressure effect is induced on the RC cellar basement wall of 200mm thickness as per Rankine's theory for at rest condition using the appropriate formulas suggested by Arora. At rest earth pressure coefficient by elastic theory is given by the formula

$$K_0 = \frac{\mu}{1 - \mu}$$

Where, μ is the Poisson's ratio.

The lateral earth pressure acting on the height H of the wall is defined by

$$\sigma_h = K_0 \gamma H$$

2. METHODOLOGY

A 2 cellar+GL+5 storeyed reinforced concrete frame building situated (Table 1) in zone III & V is taken for the purpose of the present study. The plan area of the building is 57m X 22m in Fig 3

The models that have been considered:

- Building with basement wall in zone III for
 - a. Fixed base
 - b. Three types of soils i.e. hard, medium and soft soil for soil structure interaction.

- Building with basement wall in zone V for
 - c. Fixed base
 - d. Three types of soils i.e. hard, medium and soft soil for soil structure interaction.

The properties of the soil with the elastic constant for the type of the soil upon which structure is considered to be resting are considered as per Bowels in Table 2.

2.1. Idealization by Winkler’s method

Sub-structure approach (or) Winkler method where the effect of SSI is represented by using equivalent springs with 6 degrees of freedom shown in Fig 2 given by the researches such as Mylonakis and Gazetas as per Table3.

2.2. Performance point :

The failure pattern of the structure is determined by non-linear static analysis or pushover analysis, where the structure is subjected to incremental horizontal loads until it reaches the ultimate state(i.e. Base shear Vs Roof displacement).Equivalent linearization method is adopted for the present work as per FEMA 440.

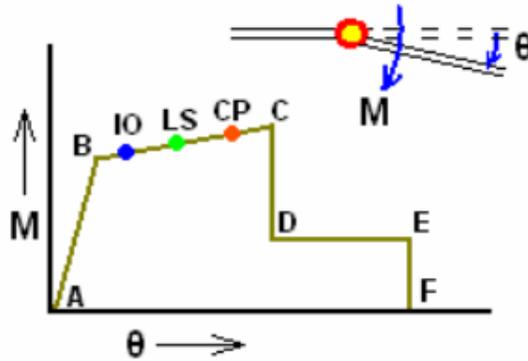


fig 1: typical flexural hinge property showing the performance level

table 1. geometric and material properties of the structure and footing

BEAM	1. 230mm x 300mm 2. 230mm x 230mm
COLUMN	1. 230mm x 460mm 2. 230mm x 530mm
SLAB	1. 5”thick slab 2. 115mm one way and two way slab
Grade of concrete	1. M20 2. M25
LIVE LOAD	2 KN/m ²
FLOOR FINISH	1 KN/m ²
FOOTINGS	1.5 m x 1.5 m

table 2.soil data

Soil type	Shear wave velocity (m/sec)	Mass density (KN/m ³)	Poisson ratio	Shear modulus KN/m ² x 10 ⁴	SBC KN/m ²
Hard rock	1250	2.10	0.30	328.13	570
Medium	400	1.90	0.30	30.4	280
Soft soil	150	1.85	0.4	4.16	120

table 3.spring stiffness formulas

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	$[2GL/(1 - \nu)] (0.73+1.54\chi^{0.75})$
Horizontal(lateral direction)	$[2GL/(2 - \nu)] (2+2.50\chi^{0.85})$
Horizontal(longitudinal direction)	$[2GL/(2 - \nu)] (2+2.50\chi^{0.85}) - [0.2/(0.75- \nu)] GL[1-(B/L)]$
Rocking(about longitudinal)	$[G/(1- \nu)] I_{bx}^{0.75} (L/B)^{0.25} [2.4+0.5(B/L)]$
Rocking(about lateral)	$[G/(1- \nu)] I_{by}^{0.75} (L/B)^{0.15}$
Torsion	$3.5GI_{bz}^{0.75} (B/L)^{0.4} (I_{bz}/B)^{0.2}$

Where ,

$$\chi = A_b / 4L^2 ,$$

A_b = Area of the foundation considered; B and L = Half-width and half-length of a rectangular foundation respectively;

I_{bx} , I_{by} and I_{bz} = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively.

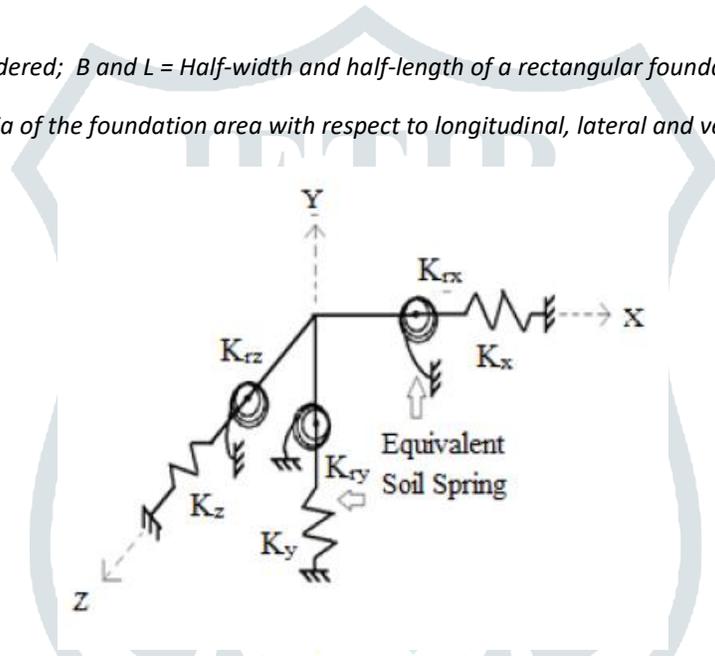


fig.2. equivalent spring stiffness

where in Fig 2, k_y , k_z = stiffness of equivalent soil springs along the translational degree of freedom along X,Y and Z axes. K_{rx} , k_{ry} , k_{rz} = stiffness of equivalent rotational soil springs along the rotational degree of freedom along X,Y and Z axes.

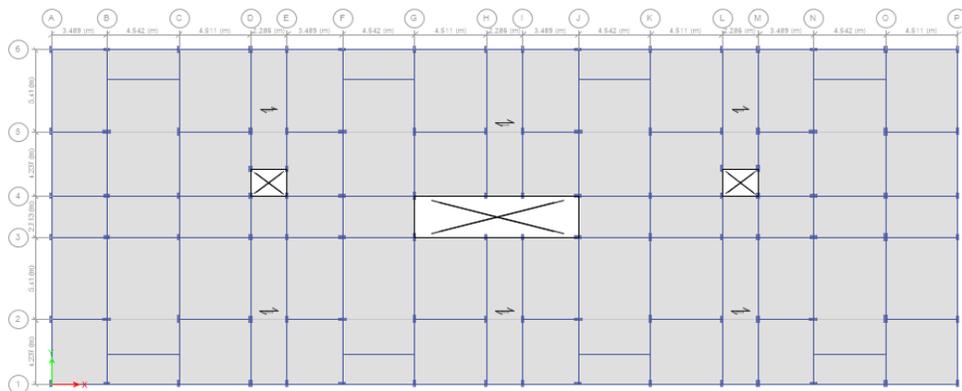


fig. 3.plan of the multi storied building

3. ANALYSIS RESULTS

➤ Storey Displacements

table 4. storey displacements of structure in zone iii

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	11.609	11.614	15.827	19.619	10.686	10.696	14.595	18.224
Fourth	10.527	10.531	14.348	17.768	9.657	9.666	13.188	16.447
Third	8.796	8.801	11.99	14.844	8.608	8.078	11.023	13.756
Second	6.537	6.541	8.913	11.046	6.012	6.023	8.226	10.302
First	3.962	3.966	5.408	6.727	3.68	3.691	5.055	6.396
G.L	1.463	1.468	2.008	2.545	1.389	1.402	1.94	2.559
Cellar 1	0.018	0.02	0.038	0.12	0.049	0.063	0.115	0.293
Cellar 2	0.005	0.009	0.02	0.086	0.01	0.02	0.046	0.154

table 5. storey displacements of structure in zone v

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	26.119	26.132	35.611	44.143	24.045	24.066	32.839	41.004
Fourth	23.685	23.696	32.284	39.978	21.279	21.75	29.673	37.006
Third	19.791	19.801	26.977	33.4	18.154	18.175	24.802	30.951
Second	14.707	14.717	20.053	24.853	13.528	13.551	18.509	23.179
First	8.913	8.924	12.167	15.135	8.279	8.305	11.373	14.39
G.L	3.292	3.303	4.519	5.725	3.126	3.155	4.366	5.758
Cellar 1	0.04	0.046	0.086	0.269	0.111	0.142	0.259	0.66
Cellar 2	0.01	0.019	0.046	0.192	0.022	0.046	0.104	0.347

➤ Storey shears

table 6. storey shears of structure in zone iii

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	200.69	200.58	272.29	331.4625	219.301	219.01	296.71	357.725
Fourth	366.004	365.8	496.58	604.789	399.94	399.41	541.11	652.386
Third	483.693	483.42	656.26	789.862	528.539	527.85	715.1	862.159
Second	561.829	561.52	762.27	927.709	613.92	613.11	830.62	1001.432
First	608.484	608.15	825.57	1004.966	664.9	664.03	899.59	1084.593
G.L	631.61	631.26	856.95	1043.16	690.17	689.2	933.789	1125.81
Cellar 1	641.71	641.45	869.88	1059.84	701.38	700.4	948.769	1143.83
Cellar 2	643.33	643.14	872.07	1062.52	703.15	702.2	951.35	1146.71

table 7. storey shears of structure in zone v

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	451.55	451.32	612.666	745.78	493.42	492.78	667.595	804.88
Fourth	823.511	823.061	1117.31	1360.1	899.86	898.69	1217.49	1467.8
Third	1088.31	1087.72	1476.58	1797.44	1189.22	1187.66	1608.98	1939.86
Second	1246.11	1263.43	1715.11	2087.79	1381.32	1379.52	1868.89	2253.22
First	1369.09	1368.32	1857.54	2261.17	1496.03	1494.08	2024.09	2440.33
G.L	1421.13	1420.35	1928.14	2347.12	1552.89	1550.86	2101.02	2533.09
Cellar 1	1444.21	1443.42	1959.05	2385.24	1578.12	1576.06	2135.16	2574.24
Cellar 2	1447.86	1447.07	1964.41	2391.26	1582.09	1580.04	2140.55	2580.73

➤ Lateral Forces

table 8. lateral forces of structure in zone iii

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	200.693	200.583	272.293	331.462	219.301	219.01	296.709	357.725
Fourth	165.312	165.22	224.29	273.028	120.693	180.4	244.4	294.661
Third	117.68	117.62	159.75	194.372	128.599	128.43	173.99	209.733
Second	78.136	78.09	106.01	129.048	85.38	85.261	115.51	139.273
First	46.656	46.63	63.3	77.056	50.981	50.91	68.976	83.161
G.L	23.128	23.11	31.38	38.197	25.272	25.23	34.19	41.223
Cellar 1	10.26	10.25	13.92	16.945	11.211	11.196	15.02	18.288
Cellar 2	1.62	1.69	2.19	2.676	1.77	1.768	2.39	2.888

table 9.lateral forces of structure in zone v

Storey	X - Direction				Y-Direction			
	Fixed	Hard	Medium	Soft	Fixed	Hard	Medium	Soft
Fifth	451.559	451.312	612.661	745.789	493.426	492.783	667.596	804.881
Fourth	371.952	371.749	504.653	614.312	406.439	405.908	549.903	662.986
Third	264.798	264.654	359.269	437.337	289.349	288.972	391.484	471.989
Second	175.806	175.706	238.528	290.358	192.106	191.855	259.915	313.365
First	104.975	104.918	142.426	173.375	114.708	114.558	155.197	187.112
G.L	52.037	52.008	70.602	85.943	56.862	56.787	76.933	92.753
Cellar 1	23.085	23.073	31.321	38.127	25.226	25.193	34.129	41.148
Cellar 2	3.646	3.643	4.946	6.021	3.894	3.978	5.389	6.498

➤ Pushover results

table 10.performance of the structure for pushx

Model	Performance Point		Hinge States									
	Base shear (KN)	Displacement (mm)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
Fixed	1747.68	33.7	4203	433	0	0	0	4636	0	0	0	4636
Hard	1748.15	33.743	4204	432	0	0	0	4636	0	0	0	4636
Medium	2063.69	42.005	4218	418	0	0	0	4636	0	0	0	4636
Soft	2882.09	100.24	3549	1087	0	0	0	4635	0	0	1	4636

table 11.performance of the structure for pushy

Model	Performance Point		Hinge States									
	Base shear (KN)	Displacement (mm)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
Fixed	1970.89	33.424	4124	512	0	0	0	4636	0	0	0	4636
Hard	1971.16	33.447	4127	509	0	0	0	4636	0	0	0	4636
Medium	2417.59	44.458	4143	493	0	0	0	4636	0	0	0	4636
Soft	3915.99	103.65	3670	966	0	0	0	4628	0	0	8	4636

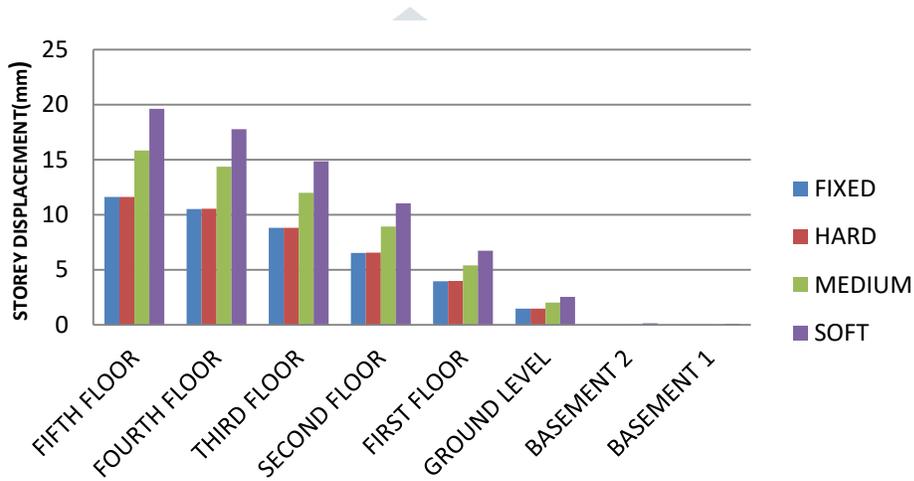


fig 4.graphical representation of storey displacements in x direction zone iii

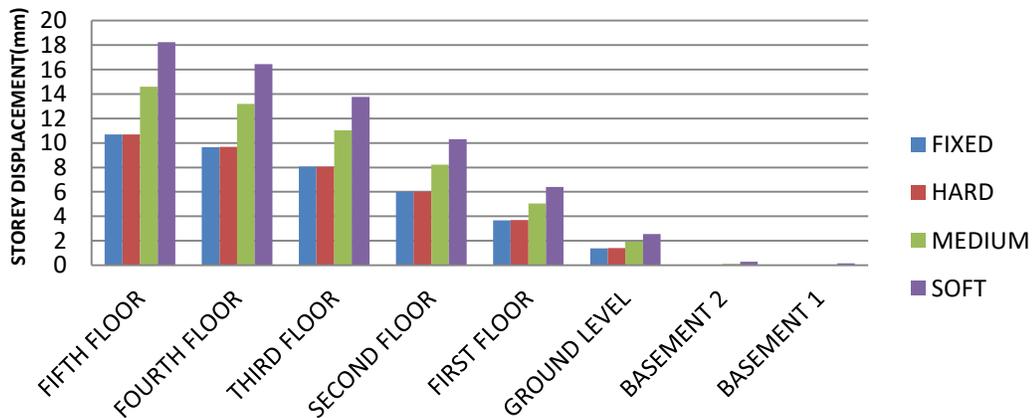


fig 5.graphical representation of storey displacements in y direction zone iii

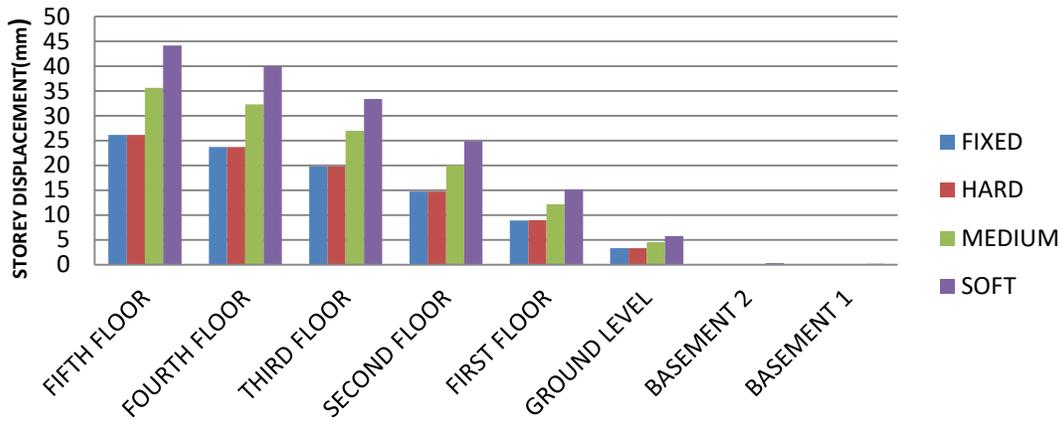


fig 6.graphical representation of storey displacements in x direction zone v

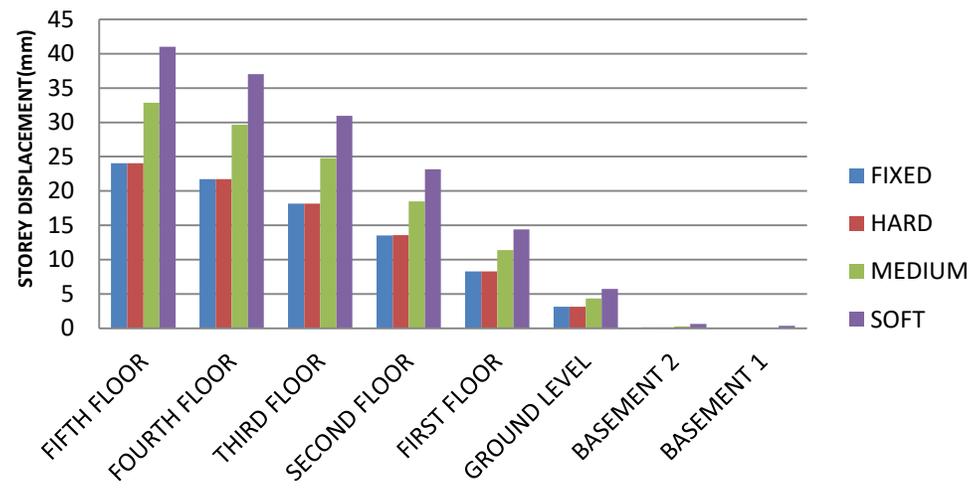


fig 7.graphical representation of storey displacements in y direction zone v

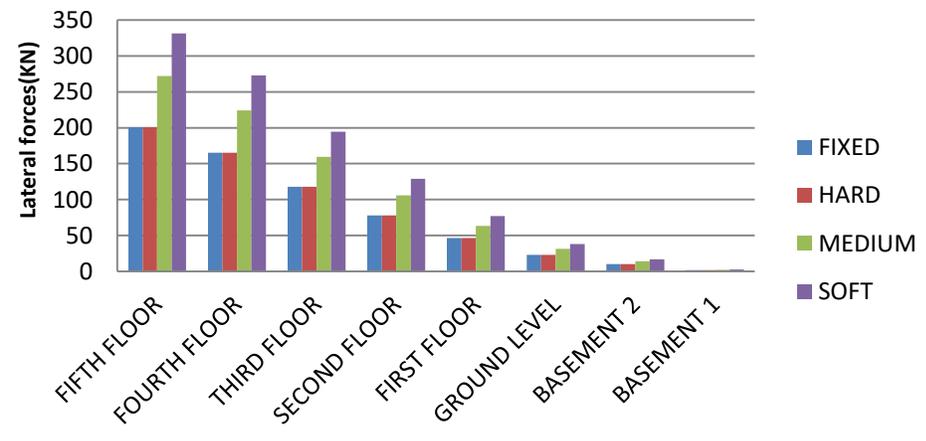


fig 8.graphical representation of lateral forces in x direction in zone iii

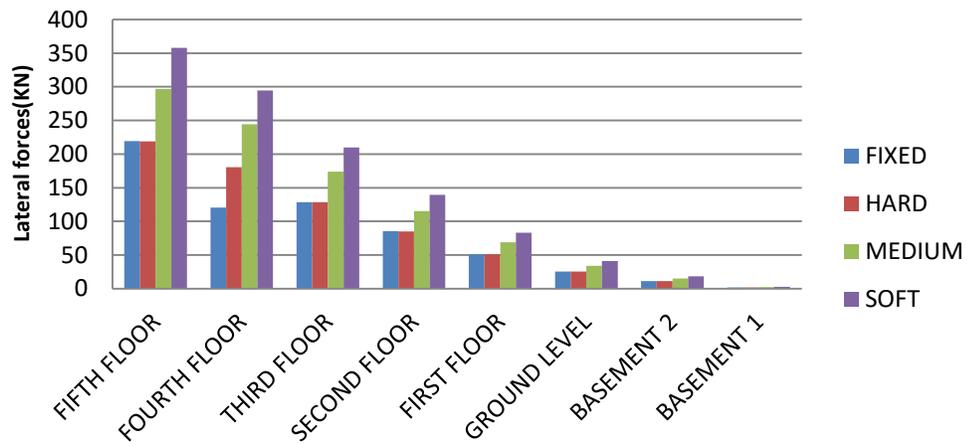


fig 9.graphical representation of lateral forces in y direction zone iii

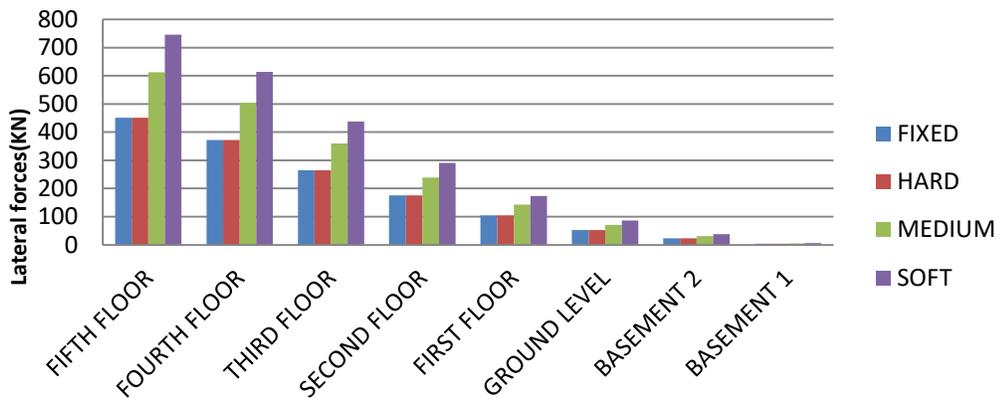


fig 10.graphical representation of lateral forces in x direction zone v

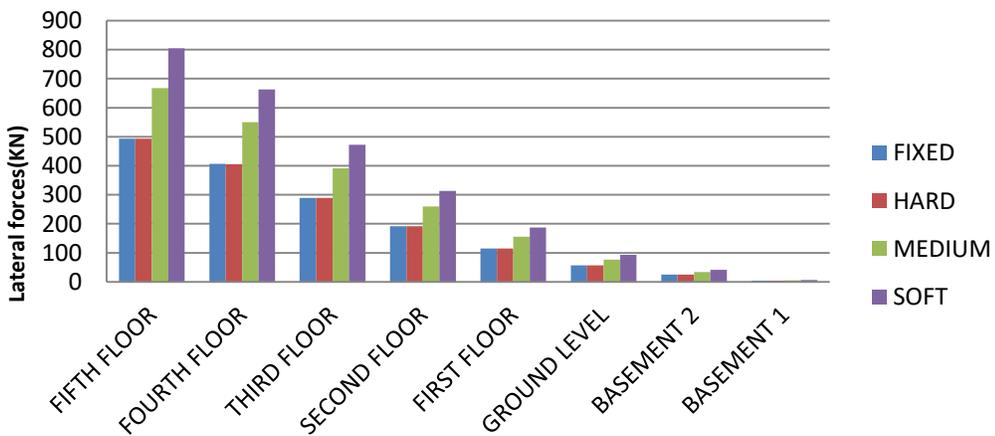


fig 11.graphical representation of lateral forces in y direction zone v

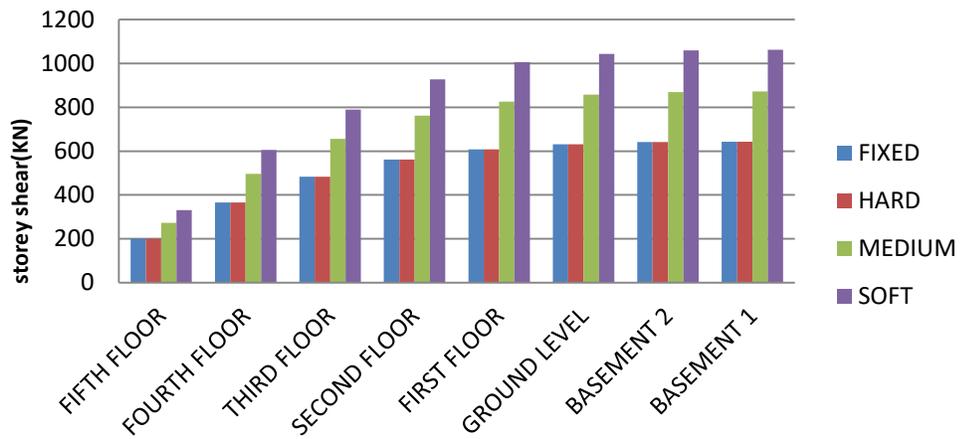


fig 12.graphical representation of storey shears in x direction zone iii

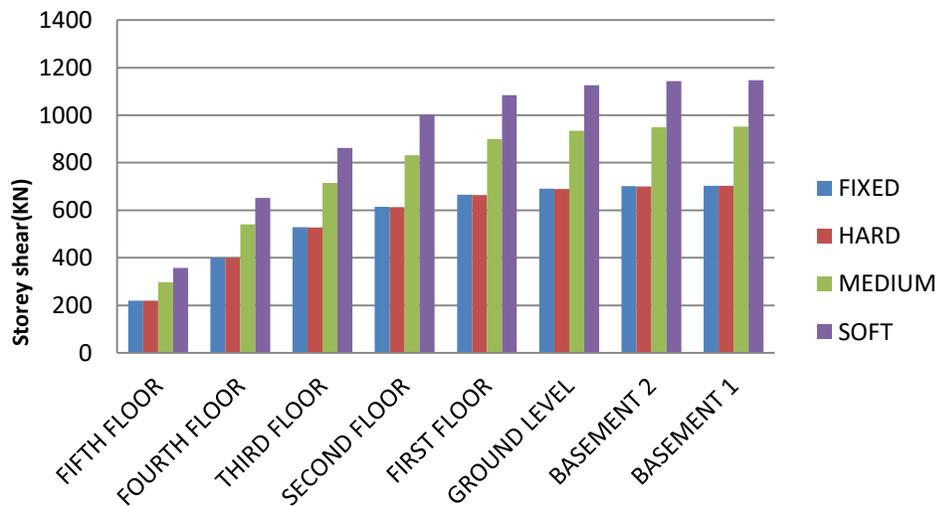


fig 13.graphical representation of storey shears in y direction zone iii

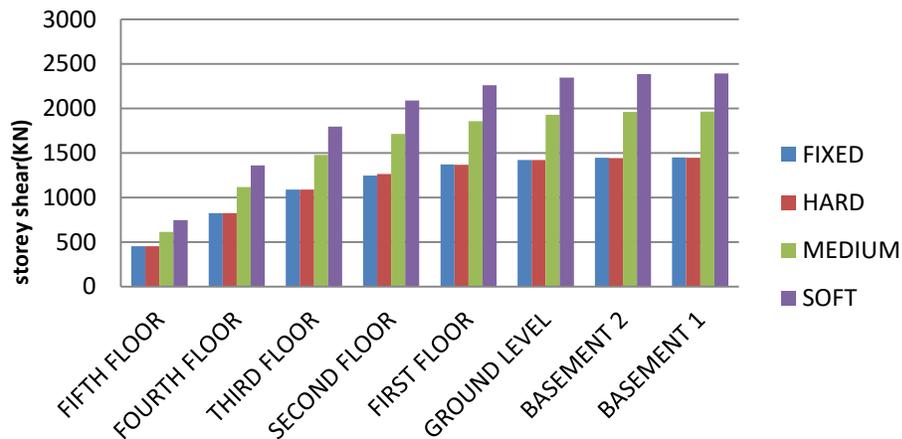


fig 14.graphical representation of storey shears in x direction zone v

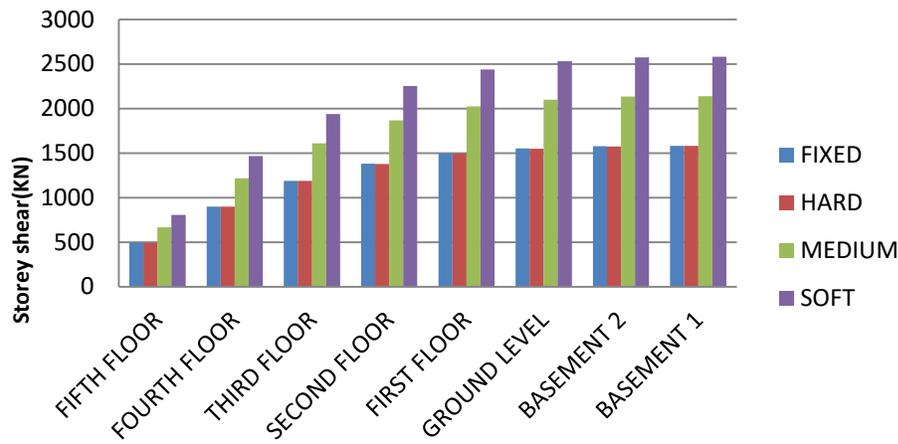


fig 15.graphical representation of storey shears in y direction zone v

4. Conclusion:

- In zone III& V it is observed that there is negligible increase in storey displacements and base shear incase of hard soil compared to the fixed base condition.
- In zone III & V the storey displacements increases gradually with the increase in the flexibility of the soil. It is observed that the storey displacement is increased by 68% in case of building resting on the soft soil when compared to the fixed base condition.
- In zone III & V the base shears increases gradually with the decrease in the hardness of the soil. The storey shear is increased by 68% in case of building resting on the soft soil when compared to the fixed base condition.
- The storey displacements and base shears of the structure in zone V is increased by 125% compared to structure in the zone III.
- The results of non-linear static analysis are represented in tables 10 & 11. The values performance point for the structure for the considered models are recorded along with their respective performance levels i.e. IO,LS, CP.
- It can be said that the structure is safe against failure since no hinge lies beyond the CP level for fixed, hard soil and medium soil conditions.
- But in the case of soft soil there is a hinge which is beyond collapse prevention state in zone III. Similarly, in zone V there are 8 hinges formed beyond CP.
- Therefore, the chances of failure of the structure is more in soft soil condition compared to others.
- It can also be said that the probability of failure of structure is more in zone V compared to zone III.
- It can be concluded that the effect of soil structure interaction increases with the increase in the flexibility of the soil, intensity of the seismic activity prevailing in that location and increase in the height of the structure .
- Hence, it is required to consider the effect of SSI in the construction of important structures in the region of high seismic intensity and high soil flexibility.

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