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EFFECT OF SOIL - STRUCTURE INTERACTION ON SEISMIC RESPONSE OF BUILDING

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ABSTRACT

The investigation on the energy transfer mechanism from soil to buildings during earthquake is critical for the design of earthquake resistant structure, and also current demand of high rise and economical building is raising, thus the necessity of research into soil structure interaction problem is greater than ever. Generally in the analysis of structures which is subjected to seismic forces also, is usually assumed that the structure is fixed at the base to simplify the mathematical problem. This assumption leads to an error in assessment of overall response under seismic loads. The interaction phenomenon is principally affected by the mechanism of energy transfer between the structure and soil during the earthquake. The influence of soil-structure interaction on seismic response of such high rise building is a major concern to incorporate the necessary change in the designing such structures. Hence in this study, three-dimensional FEM model is constructed to analyze the effect of different soil conditions and number of stories on the vibration characteristics and seismic response demands of building structures. Numerically results obtained using soil structure interaction model conditions are compared to those corresponding to fixed-base support conditions. The peak responses of story shear, story moment, story displacement, story drift, moment at beam ends, as well as force of inner column are analyzed. The analysis result of different approaches is used to evaluate the advantages, limitations, and ease of application of each approach for seismic analysis.

KEYWORDS

Soil Structure Interaction; RCC; Soil Spring constant; Earthquake analysis; Shear wave velocity.

1. INTRODUCTION

The rapid development of urban population and the pressure on limited space significantly influence the residential development of the city. The price of the land is high, the desire to avoid uneven and uncontrolled developing of urban area and bear on the land for needs of important agricultural production activity have all led to route residential building upwards. The local topographical restrictions in the urban area only possible solutions for construction of multi-story buildings to full fill the residential needs. The multi-storey buildings all initially a reaction to the demand by activity of business close to each other and in city center, the less availability of land in the area. The multi-storey buildings are frequently developed in the center of the city is prestige symbols for commercial organizations. Further the tourist and business community. The soil structure interaction is a special field of analysis in earthquake engineering, this soil structure interaction is defined as "The dynamic interrelationship between the response of the structure is influenced by the motion of the soil and the soil response is influenced by the motion of structure is called a soil structure interaction".

2. METHODOLOGY

The present work attempts to study the behavior of framed structures with rigid and flexible foundation. Framed structure of different height with symmetrical and irregular plans have been considered with fixed and flexible foundation resting on three different types of soil and different types of foundation. A framed structure of rectangular regular and irregular plan with10 story is analyzed for earthquake load consider in zone-IV, importance factor of 1.5, with the different soil type like hard, medium and soft soil with fixed and flexible base condition. Static analysis for 10 storied structure is done and the parameters like time period, base shear, bending moment in column and top story displacement are measured and are present below. In the flexible base condition the soil and foundation is modeled as soil spring. The stiffness of spring is calculated based on soil properties and foundation details using empirical formulae.

All the building models are analyses in ETABS. The properties of the building configurations are considered in the present work are summarized below.

2.1 SPECIFICATION OF THE BUILDING

- Height of each floor: 3m and Plan dimension: 18x18m
- Floor thickness: 0.125m and Wall thickness: 230mm
- Compressive strength of concrete fck =30 N/mm^{2}and steel used Fe = 500 N/mm^2
- Density of concrete: 25 kN/m^{2}and Brick: 20 kN/m^2
- Size of column: 3000mmx300mm to 650mmx650mm as per the structural requirement
- Size of beam: 230mmx600mm
- Seismic zone factor 'z' = (IV) and Damping ratio= 0.05
- Response reduction factor 'R'= 3 and Importance factor 'I'= 1.5
- Live load on top story: 4kN/m2and on remaining story: 4 kN/m^2
- The floor finish load is: 1.5 kN/m^2
- Wall load at floor is: 11.00kN/m and for parapet is: 4.6kN/m

2.2 Details of soil parameters considered.

Sr. no.	Soil type	Soil Parameters				
		Poisons ratio'**v**'	Modulus Of elasticity'**E**' Kn/Sq.m	Mass density '**ρ**' Kn/Cu.m	Soil **S.B.C.** Kn/Sq.m	Modulus of subgrade reaction 'Ks' Kn/Cu.m
1	Hard soil (highly dense sand)	0.3	60000	20	400	64000
2	Medium soil (sandy clay)	0.3	25000	19	200	32000
3	Soft soil (Silty sand)	0.35	15000	18	100	24000

Table no. - 01

2.3 Equivalent Spring Constant

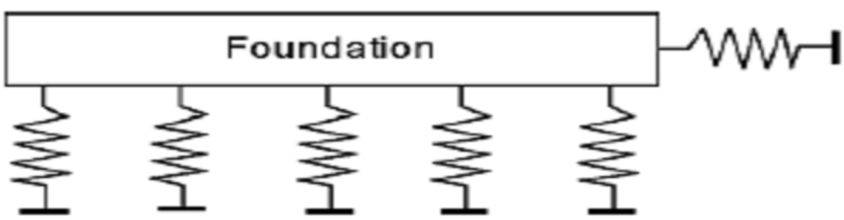


Fig. no 01

As per Winkler's model the soil medium is represented by number of identical but mutually independent, closely spaced, discrete linearly elastic springs. The movement of foundation is generally considered in two perpendicular horizontal directions and in vertical direction. The rotation of the same about these three directions should also be considered as shown in fig….. For building with isolated footing, below each column, three translation springs along three directions and three rotational spring about those mutually perpendicular axis should be put together to simulate the effect of soil flexibility,

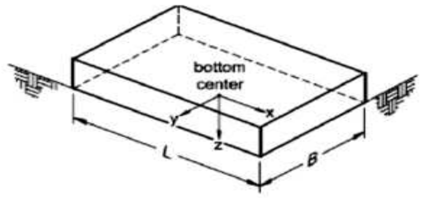
Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$	
Translation along y-axis	$K_{y,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$	
Translation along z-axis	$K_{z,\,sur} = \frac{GB}{1-v}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$	
Rocking about x-axis	$K_{xx,\,sur} = \frac{GB^3}{1-v}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$	
Rocking about y-axis	$K_{yy,\,sur} = \frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$	Orient axes such that $L \geq B$
Torsion about z-axis	$K_{zz,\,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$	

Table no. - 02

Also correction factor for depth of footing is applied to the each spring constant values, calculated from above formulas.

2.3.1 CASE A- Regular 10 story model

1) Condition 1 - Hard soil (highly dense sand, SBC = 40 T)

Column o.	Column Sizes	Column forces 'KN'	Footing sizes	Depth of Footing 'D'	Thickness of footing 'd'	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C1,4,5,8	450X450	1723	2.1x2.1	2 M	400 mm	319575	31975	229593	263554	306504	482118
C2,3,6,7,13 ,14,15,16	600X600	3103	2.8x2.8	2 M	400 mm	373112	373112	285542	542021	641331	1002293
C9,10,11,1 2	700X700	5004	3.5x3.5	2 M	400 mm	425335	425335	341413	972334	1162307	1788646

Table no. - 03Soil Spring constant

2) Condition 2 -Medium soil (Sandy clay sand SBC = 20 T)

Column no.	Colum n Sizes	Colu mn force s 'KN'	Footin g sizes	Dept h of Footi ng **'D'**	Thickn ess of footing **'d'**	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C1,4,5,8	450X450	1723	3x3	2 M	400 mm	161728	161728	125631	269996	320610	498988
C2,3,6,7,13 ,14,15,16	600X600	3103	4x4	2 M	400 mm	192519	192519	158857	579774	695861	1058970
C9,10,11,1 2	700X700	5004	5x5	2 M	400 mm	222651	222651	191998	1068124	1285982	1919413

Table no.- 04Soil Spring constant

3) Condition 3 - Soft soil (Silty sand SBC = 10 T)

Column no.	Colum n Sizes	Colu mn force s 'KN'	Footin g sizes	Dept h of Footi ng **'D'**	Thickn ess of footing **'d'**	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C1,4,5,8	450X450	1723	4.15x4.1 5	2 M	400 mm	117316	117316	101941	398618	478827	674486
C2,3,6,7,13 ,14,15,16	600X600	3103	5.6x5.6	2 M	400 mm	143165	143165	131815	910928	1096635	1505367
C9,10,11,1 2	700X700	5004	7.0x7.0	2 M	400 mm	167651	167651	160575	1708233	2050332	2765792

Table no.- 05Soil Spring constant

2.3.2 CASE B- Irregular 10 story model
1) Condition 1 - Hard soil (highly dense sand SBC = 40 T)

Column no.	Colum n Sizes	Colu mn force s 'KN'	Footin g sizes	Dept h of Footi ng **'D'**	Thickn ess of footing **'d'**	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C8,17,18,2 0,22	450X450	2726	2.1x2.1	2 M	400 mm	319575	31975	229593	263554	306504	482118
C1,3,5,6,7, 13,14,15,19 ,21	600X600	4792	2.8x2.8	2 M	400 mm	373112	373112	285542	542021	641331	1002293
C2,9,10,11, 12,16	700X700	7620	3.5x3.5	2 M	400 mm	425335	425335	341413	972334	1162307	1788646

Table no.- 06Soil Spring constant

2) Condition 2 -Medium soil (Sandy clay sand SBC = 20 T)

Column no.	Column Sizes	Column forces 'KN'	Footing sizes	Depth of Footing 'D'	Thickness of footing 'd'	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C8,17,18,20,22	450X450	2726	3x3	2 M	400 mm	161728	161728	125631	269996	320610	498988
C1,3,5,6,7, 13,14,15,19,21	600X600	4792	4x4	2 M	400 mm	192519	192519	158857	579774	695861	1058970
C2,9,10,11, 12,16	700X700	7620	5x5	2 M	400 mm	222651	222651	191998	1068124	1285982	1919413

Table no.- 07Soil Spring constant

3) Condition 3 - Soft soil (Silty sand SBC = 10 T)

Column no.	Column Sizes	Column forces 'KN'	Footing sizes	Depth of Footing 'D'	Thickness of footing 'd'	SPRING VALLUE					
						Kx	**Ky**	**Kz**	**Kxx**	**Kyy**	**Kzz**
C8,17,18,20,22	450X450	2726	4.15x4.15	2 M	400 mm	117316	117316	101941	398618	478827	674486
C1,3,5,6,7, 13,14,15,19,21	600X600	4792	5.6x5.6	2 M	400 mm	143165	143165	131815	910928	1096635	1505367
C2,9,10,11, 12,16	700X700	7620	7.0x7.0	2 M	400 mm	167651	167651	160575	1708233	2050332	2765792

Table no.- 08Soil Spring constant

According to above structural and loading specification, structural models are prepared as shown below,

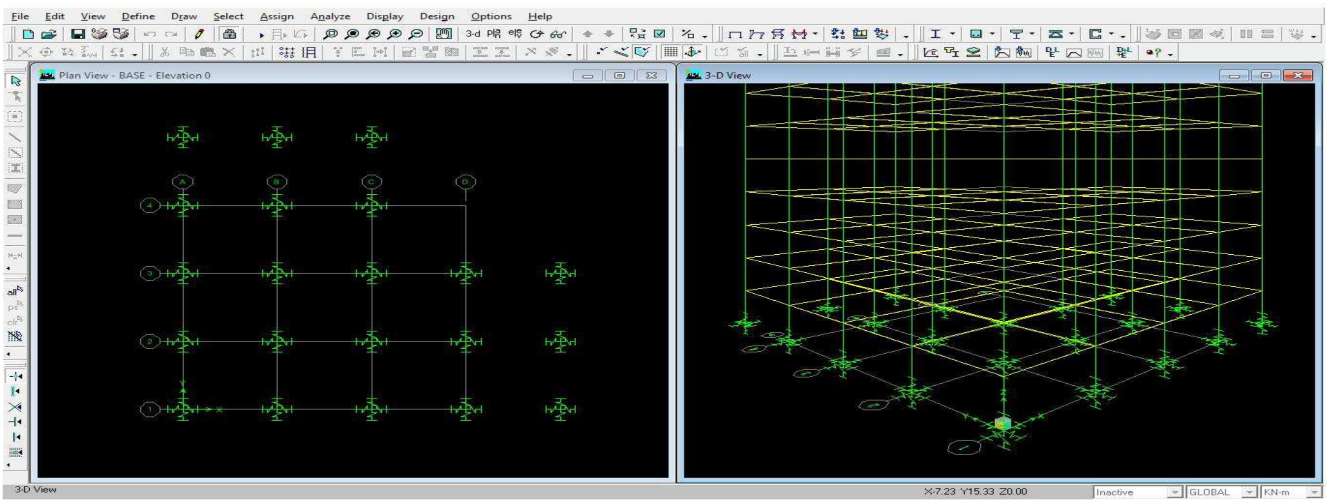


Fig. no 02Etabs Analysis model

3. RESULT AND DISCUSSION.

A sample representation of base shear, displacement for 10 story fixed footing model as per software represents is shown below in fig

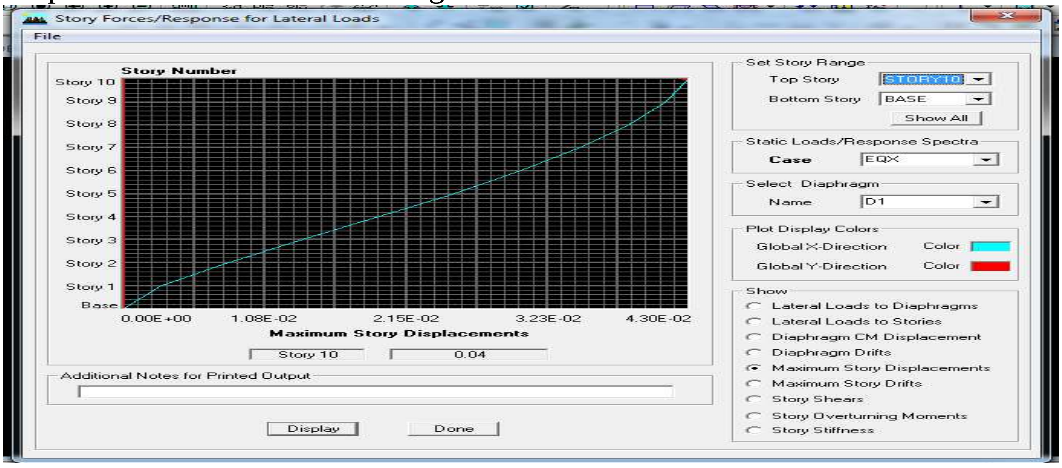


Fig. no. 03- Story Discplacement Diagram (10 st. regular shaped with fixed footing)

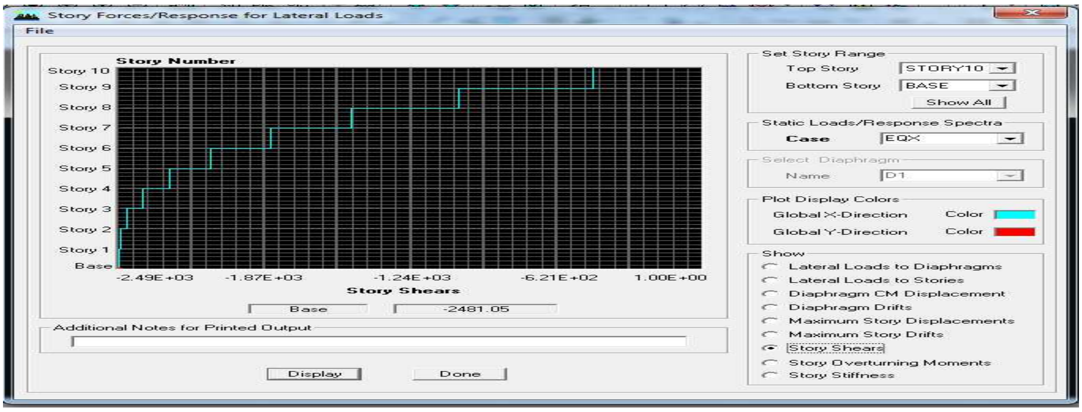


Fig. no. 04- Story Shear Diagram (10 st. regular shaped with fixed footing)

Similarly, story shear and story Displacement results for regular shaped but flexible footing also shown below,

3.1. 10 story Regular shaped structure standing on different type of footings.

STRUCTURE CASE	SOIL CONDITION	FOUNDATION CONDITION		STRUCTURAL PARAMETERS		
				Base shear (KN)	Time Period(Sec)	Deflection(mm)
10 STORY REGULAR SHAPE	HARD	FIXED		1683.71	1.4718	41.64
		FLEXIBLE		1563.46	1.5851	44.5
	MEDIUM	FIXED		2283.64	1.4718	56.42
		FLEXIBLE		2052.976	1.6461	63.85
	SOFT	FIXED		2811.792	1.4718	69.05
		FLEXIBLE		2487.793	1.6666	79.8

Table no.- 09Results for 10 stories regular shape structure.

Graphical representation of above results.

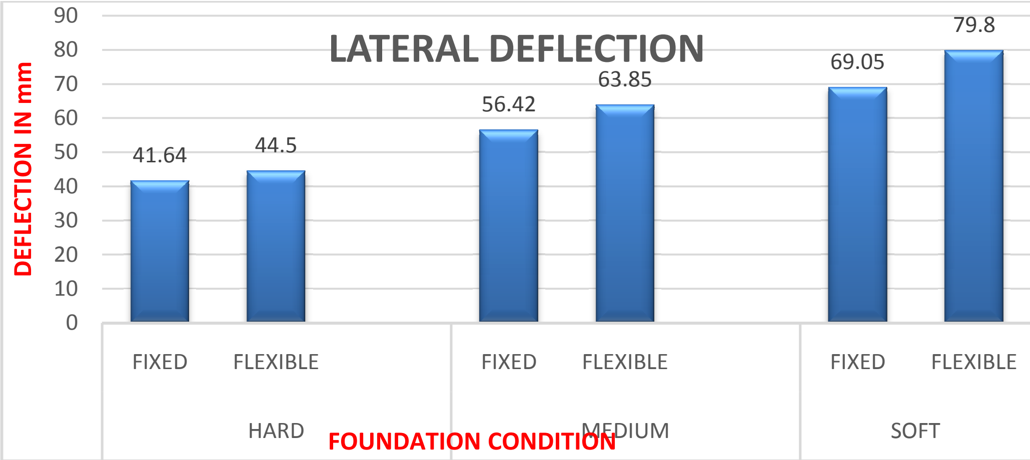


Fig. no. 05- Lateral Deflection for 10 stories regular shape structure.

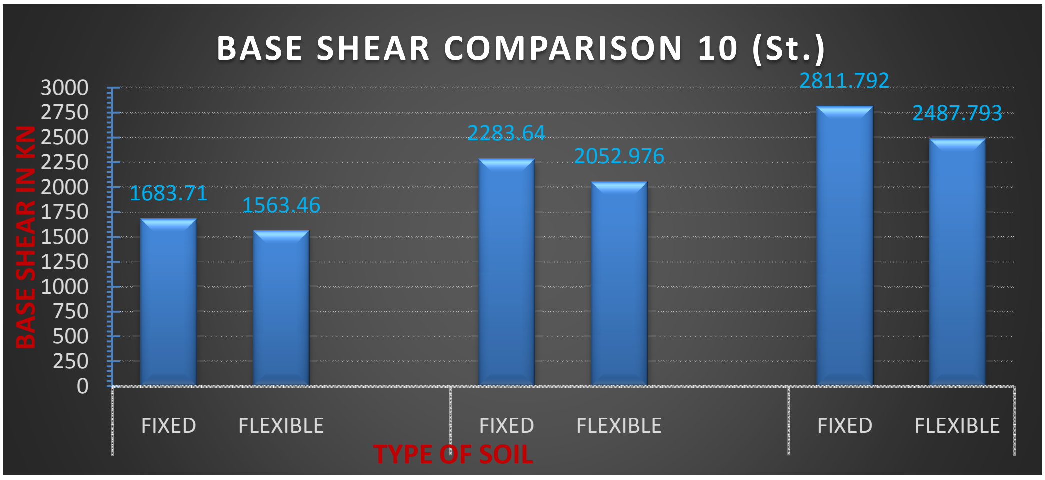


Fig. no. 06- Base shears Comparison for 10 stories regular shape structure.

3.2. Summary of results for 10 stories Irregular shaped structure standing on different type of footings.

STRUCTURE CASE	SOIL CONDITION	FOUNDATION CONDITION		STRUCTURAL PARAMETERS		
				Base shear (KN)	Time Period(Sec)	Deflection(mm)
10 STORY IRREGULAR SHAPE	HARD	FIXED		2228.645	1.4845	42.38
		FLEXIBLE		2092.73	1.5828	46.7
	MEDIUM	FIXED		3022.74	1.4845	57.89
		FLEXIBLE		2763.561	1.6447	66.85
	SOFT	FIXED		3721.84	1.4845	70.85
		FLEXIBLE		3362.67	1.666	83.9

Table no.-10 Results for 10 stories Irregular shape structure.

Graphical representation of above results.

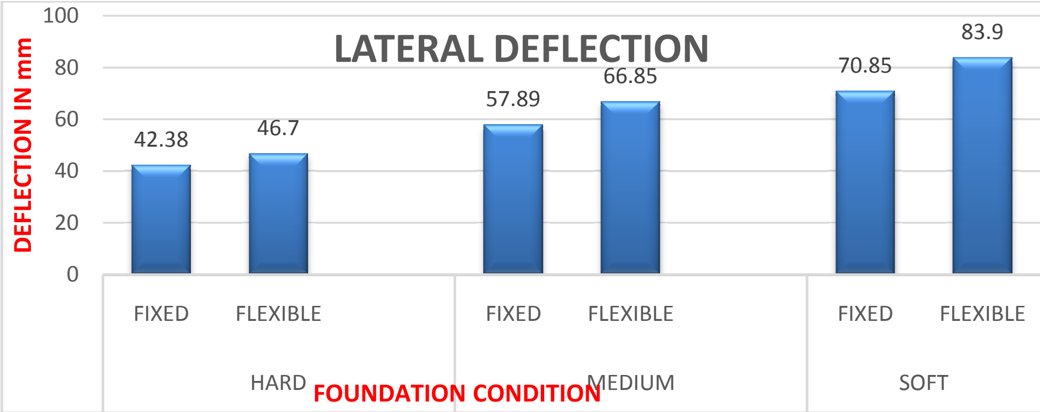


Fig. no. 07- Lateral Deflection for 10 stories Irregular shape structure.

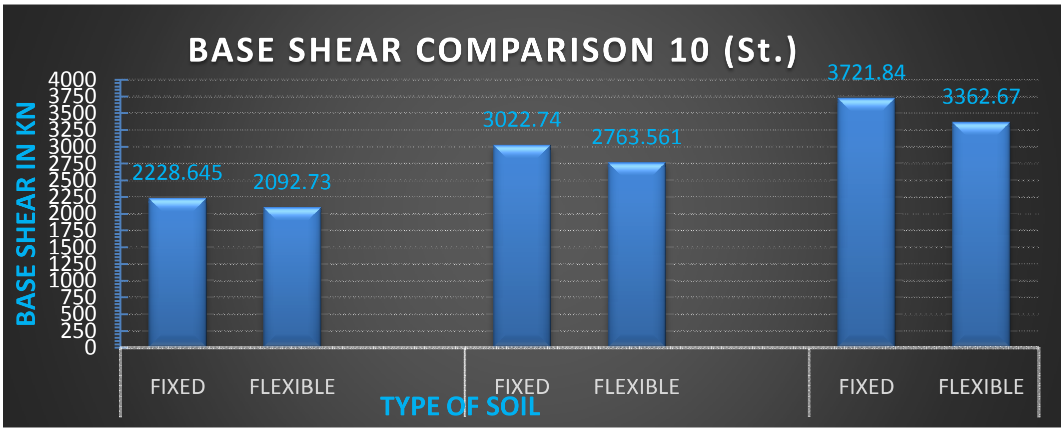


Fig. no. 08- Base shears Comparison for 10 stories Irregular shape structure.

4. DISCUSSION

As per the above observations, comparative calculation for various factor has been worked out for further study of structural behaviour due to soil structure interaction.

Some of the comparative factor has worked out and tabulated for simplifications of assessment

SR. NO.	STRUCTURE TYPE	% CHANGE IN BASE SHEAR			CHANGE IN DEFLECTION		
		HARD	**MEDIUM**	**SOFT**	**HARD**	**MEDIUM**	**SOFT**
1	10 STORY REG.	7.15	10.1	11.53	2.86	7.43	10.75
2	10 STORY IRREG.	6.1	8.57	9.65	4.32	8.96	13.05

Table no.-11 Overall Result comparison

As shown in the above table, Percentage changes of seismic base shear and Displacement for the entire case are summaries; these variations are among fixed rigid footing and Flexible footings representing respective soil condition.

Graphical representation of variation in story deflection of the entire Structural model configuration

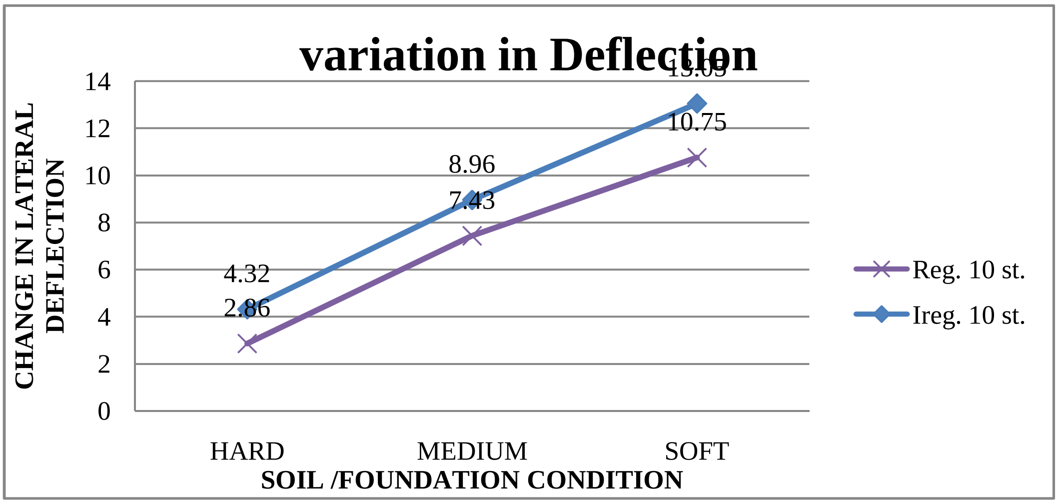


Fig. no. 09- Graph for deflection variation

Graphical representation of variation in Base shear of all the Structural model configuration.

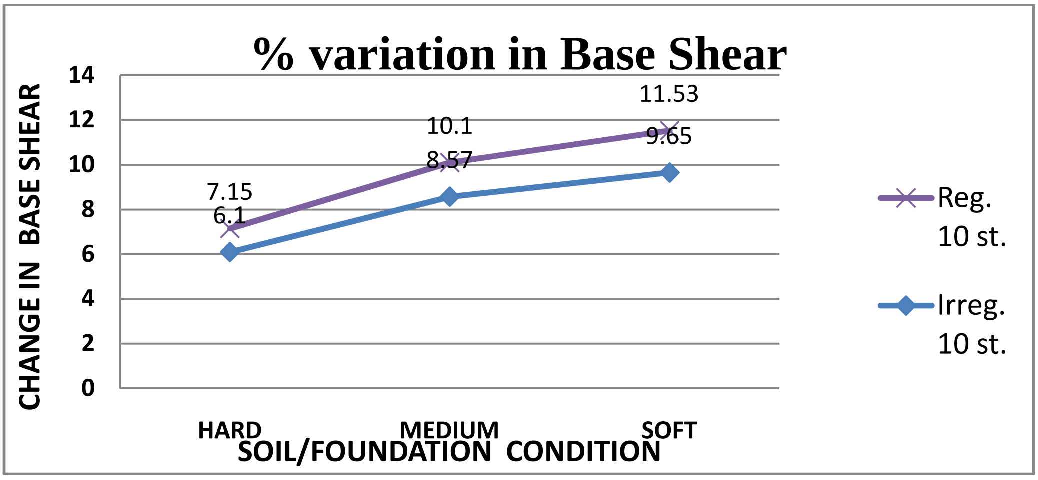


Fig. no. 10- Graph for Base shear variation

5. CONCLUSION

The study as a whole may prove useful in formulating design guidelines for seismic design of building frames incorporating the effect of soil-flexibility.

1) Fundamental natural period and Base shear

- The fundamental natural period of a specific structures and their base shear are increases as soil foundation moves on hard soil to Soft soil.
- The fundamental natural period of specific structures and their base shear are increases as soil foundation moves on Rigid footing to Flexible footing.
- Natural frequency of the structure reduces as foundation condition changes from fixed to flexible.

- Variation in time period in irregular shaped building is quite more than compare to regular shaped building.
- The variation of base shear of the structures between Rigid and flexible footing are increases as soil condition changes hard to soft.
- Variation in Base shear in irregular shaped building is quite lesser than compare to regular shaped building.

2) Maximum lateral displacement

- Structures shows more deflection as soil foundation moves on hard soil to Soft soil.
- The variation in the deflection of the structures with Rigid and with flexible footing is comparatively higher as soil condition changes hard to soft.
- Lateral displacement of the structures increases as foundation condition changes from Fixed Rigid footing to Flexible footing.
- Variation in deflection in irregular shaped building is higher than compare to regular shaped building.

3) Change in Superstructure reaction

- Due to the application of column moments at the base is reduced.
- Reaction of beams also changes by some minor extent.
- The variation of reaction in elements is more in case of soft soil condition.

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