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Soil Structure Interaction Effects on Structure Response with Isolated Footing

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Abstract: **Owing to the difficulties involved in making dynamic analytical models of the soil system, it is common practice to ignore soil structure interaction (SSI) effects, simply by treating structures as if they are rigidly based, regardless of the soil condition. However, to evaluate the seismic response of a structure at a given site the dynamic properties of the combined soil-structure system must be examined. To understand the effect of SSI on structural behaviour of building supported on isolated foundation. A total of 14 models consisting of five and eight stories building structures supported on isolated footing such as Square & Rectangular footings are created. The parameter varied includes soil types like Hard, Medium and Soft Soil. Effect of SSI is accounted by means of point spring element and fixed support condition. Based on Comparsion of time period for point spring element and fixed support it is observed the magnitude of time period for Soft Soil Condition is higher in comparison to Fixed Support, Medium and Hard Soil types. The Story Response values such as Displacement, Base Shear and Overturning moment was always higher for Soft Soil. Thus Soft Soil condition is more crictical in all cases.**

Keywords: **soil structure interaction, E-tabs, time period, displacement, time history analysis,over turning moment, base shear, storey shear.**

1. INTRODUCTION

The Severe Damage observed in past several earthquakes such as the 1985 Mexico City earthquake (Resendiz, 1986; Avilés and Pérez-Rocha, 1998), the 1995 Kobe earthquake (Mylonakis,et al., 2000), and the 1999 Ji-Ji Taiwan earthquake (Earthquake Engineering Field Investigation Team, 2011) has proven that the seismic behavior of a structure is influenced by several parameters namely the responses of the structure, its foundation, and the ground. A complex interaction between soil and structure as well as experimental limitation due expensive approach has attracted an intensive interest among researchers on analytical study on the effect of Soil Structure Interaction (SSI) subjected to dynamic load. In general frame structures which are built on Soft Soil Condition will suffer major damage because of higher flexibility to deform, resulting in increase in natural time period of Structure.

The Simulation of SSI interaction is done two method

a) Soil is Modeled as Spring Element :The flexibility of soil is usually modeled by inserting springs between the foundation member and soil medium, translations of foundation in two mutually perpendicular principle horizontal directions and vertical direction as well as rotation of the same about these three directions are considered to simulate the effect of soil flexibility

b) Elastic continuum method: Soil is modelled using Solid Element Type (based on Finite Element Method. All the possible mechanical properties of soil such as elastic modulus, passion's ratio are assigning to the solid element. The interface between the soil and foundation is modelled using Gap elements available in the software packages.

OBJECTIVES:

The present study aims to understand the soil structure interaction on structural behaviour of building supported on isolated foundation subjected to seismic load- Time History method is used in the analysis.

The following objectives are set to achieve the aims

1. To study the effect of soil structure interaction on bare frames considering different types of soil, Such as Hard Soil, Medium soil and Soft Soil for rectangular footings.

2. To study the effect of soil structure interaction on bare frames considering different types of soil, Such as Hard Soil, Medium soil and Soft Soil for square footings.
3. To understand the effect of different conditions of the soils on Time period, maximum displacement, Storey Shear and Overturning Moment for rectangular footings.
4. To understand the effect of different conditions of the soils on Time period, maximum displacement, Storey Shear and Overturning Moment square footings.
5. To compare the analysis results of fixed frame system with different types of soil like Hard Soil, Medium soil and Soft Soil for five storey.
6. To compare the analysis results of fixed frame system with different types of soil like Hard Soil, Medium soil and Soft Soil for eight storey.

SCOPE OF THE PRESENT STUDY:

The scope of the present study is limited to Reinforced concrete building resisting on Rectangular and Square Isolated Footing of five storey and eight storey building.

2. LITERATURE REVIEW

F. Dezi et al. [2008] performed dynamic analysis of bridge structure supported on pile foundation considering SSI. Authors presented the numerical model for analysis of SSI on pile foundation based on finite element approach (FEA). This Method is applicable for single piers, variable soil condition, bridges of seismic response on pile foundation with considering of soil structure interaction. From there investigation SSI analysis is essential for soft soil and squat piers.

Yingca et al. [2008] performed nonlinear analysis of SSI for earthquake loading. Authors found that seismic response of structures built on pile foundation are extremely complex, since the soil behavior is non-linear and liquefaction may occur during earthquakes. The soil-pile-structure interaction becomes extremely important for seismic analysis and design,, so that this topic has been studied widely. In this study an approximate and practical method is described for the seismic analysis. SAP 2000 and DYNAN structural analysis software is used for the non-linear SSI analysis.

Saranya and Satyam [2011] performed a dynamic analysis on SSI of high rise structure supported by pile foundation. This analysis on high rise structure supported by pile foundation was done with and without considering the soil stiffness. Firstly, the response of the soil embedded with piles is calculated using VERSAT-P3D. A high rise structure is modeled using SAP2000 and analyzed using the El-Centro earthquake data. Secondly, the effect of soil-structure interaction on high rise structure resting on pile foundation is analyzed by FEA. The piles are modeled by frame element supported by laterally distributed springs. The stiffness of the foundation quantifies the effect of soil-structure interaction on the response of the superstructure.

Pulikanti and Ramancharlal [2014] studied the effects of SSI of structure with framed supported on the pile foundations with and without interface elements. In their study an effort was made to understand the SSI behavior of pile supported framed buildings under transients interface effects between the soil and pile. For this purpose 3D FEA Method are used for modeling the soil (pile) structure interaction using SAP 2000. A single bay five story framed structure with a pile group foundation is modeled.

First the significance of soil foundation structure interaction over fixed base analysis is studied, it has been observed that the presence of soil and foundation

Anuradha and H.M.Somasekharaiah [2015]carried a comparison study between the fixed base, spring model and soil continuum of the structure resting on isolated footing supporting on soil medium

Observations:

The Magnitude of the natural period, lateral displacement, story drift and base reaction for irregular RC building with fixed base and spring model is less compared to the soil continuum.

Summary:

From the literature survey it can be known that, to evaluate the seismic response of a structure at a given site the dynamic properties of the combined soil-structure system must be examined. The flexibility of soil can be modelled by inserting springs between the foundation member and soil medium, translations of foundation in two mutually perpendicular principle horizontal directions and vertical direction as well as rotation of the same about these three directions are considered to simulate the effect of soil flexibility. In the above reviewed papers, comparison of fixed support with different types of soil condition has not been done. In the present wok, isolated footings are considered and the comparison of fixed support with different soil condition such as hard, medium and soft soil has been carried out.

3. METHODOLOGY

Soil is modeled using Point Spring and Fixed Support. Slab is modeled using Shell elements (Shell-Thin).Beam and Columns are modeled using Frame Sections. To accomplish the objectives, total of 14 models were created, which consist of 5 Stories and 8 stories building structures supported on Isolated footing (Square & Rectangular). Three soil types are considered like Hard, Medium and Soft Soil. Effect of SSI is accounted by means of point spring element. For two models variation in structure response with conventional design is studied by assigning fixed support at base. The details of structural members of the two models are shown in Table 3.1 & 3.3.

Table 3.1: Structural Details

STRUCTURAL DETAILS FOR FIVE STOREY BUILDING		
Elements	**Properties**	**Materials**
Beams	250 x 350 mm	M30 Concrete
Columns	400 x 400 mm	M30 Concrete
Slab	150 mm	M30 Concrete
Footing Size	Square Footing	Rectangular Footing
	2 x 2 m	3.5 x 2 m
STRUCTURAL DETAILS FOR EIGHT STOREY BUILDING		
Elements	**Properties**	**Materials**
Beams	350 x 500 mm	M30 Concrete
Columns	600 x 600 mm	M30 Concrete
Slab	150 mm	M30 Concrete
Footing Size	Square Footing	Rectangular Footing
	2.5 x 2.5 m	3.75 x 2 m

Table 3.2: Mechanical Properties of Soil Material

Types of soil	**Standard Penetration Value (N)**	**Shear Modulus G =12666 $N^{0.8}$ in kN/m²**	**Poisson's Ratio**
Hard Soil	30	30502.57386	0.5
Medium soil	18	127896.1548	0.5
Soft soil	3	192458.23	0.5

For the purpose of seismic weight calculations, 1kN/m2 finishes load, 3kN/m2 live load on floors are considered. A live load reduction factor of 0 for roof and 0.25 for all floors is considered in the earthquake analysis as specified by the IS 1893:2002.

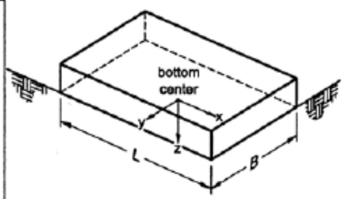
In this study of the time history analysis is performed by using the data of Bhuj earthquake on 26th jan 2001 is used as input motion. This time history parameters recorded are as below and is shown in fig 3.1 below.

Peak Acceleration = -1.0382m/s² at 46.940sec, Frequency = 1.1Hz, Duration = 133.525 Sec

Modeling of Soil Structure Interface: In the Present Study for 5 Storey Building, Square footing of Size 2x2 m and rectangular footing of size 3.5x2 m is considered and for 8 Storey Building, Square footing of Size 2.5x2.5 m and rectangular footing of size 3.75x2 m is considered. To incorporate the SSI effect impedance function proposed by Gazetas, which is later adopted in FEMA 356 have been utilized. The Expression for equivalent spring as per Gazetas are listed below

Degree of freedom	Stiffness of foundation at surface
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	$K_{yy,sur} = \frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$
Torsion about z-axis	$K_{zz,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$

Note:



Orient axes such that $L \geq B$

Where,

N- Standard Penetration Value,

G is Shear modulus of soil in kN/m2

$G = 12666\ N^{0.8}$ in kN/m²

L is the Length of footing in m,

B is the width of footing in m

ν is the Poisson's Ratio of soil

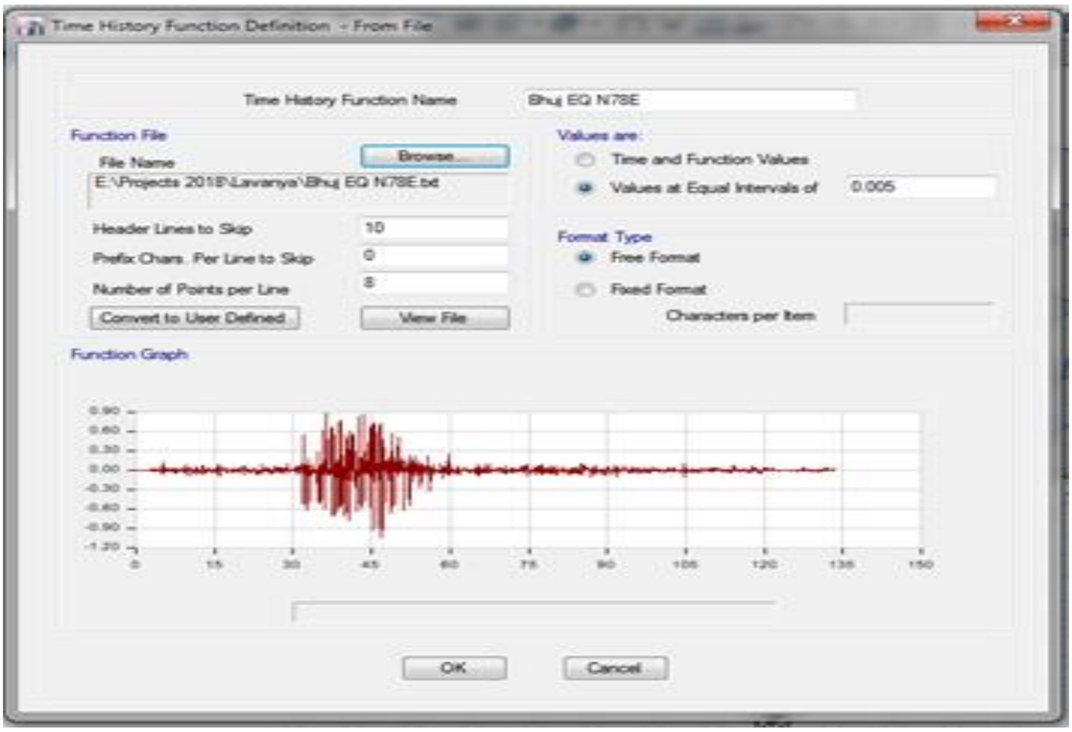


Fig 3.1: Defining Time History Analysis in ETABS

4. RESULTS AND DISCUSSIONS

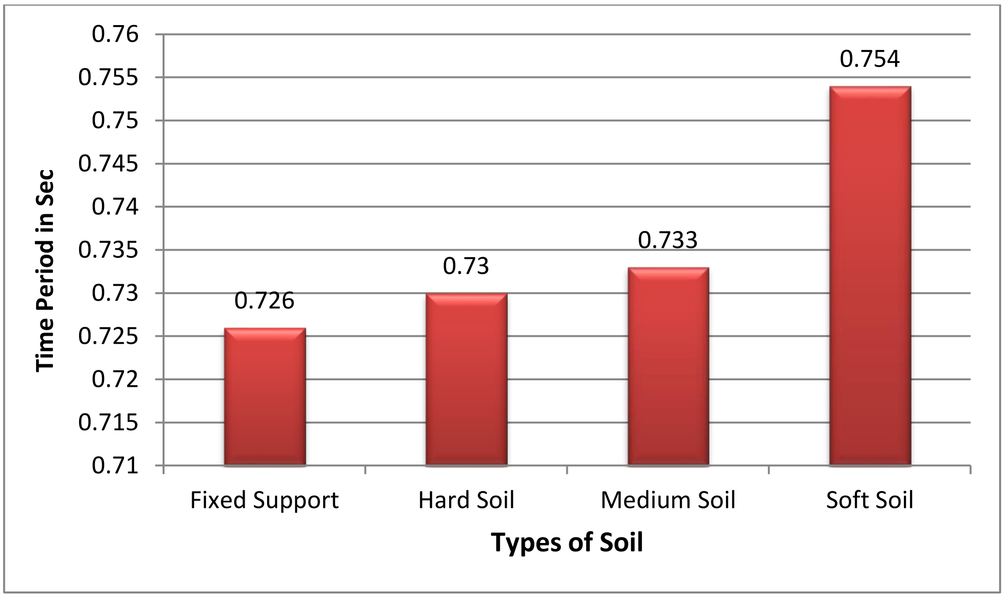


Fig 4.1: Variation of Time Period for Translation of Five Storey with Square Footing

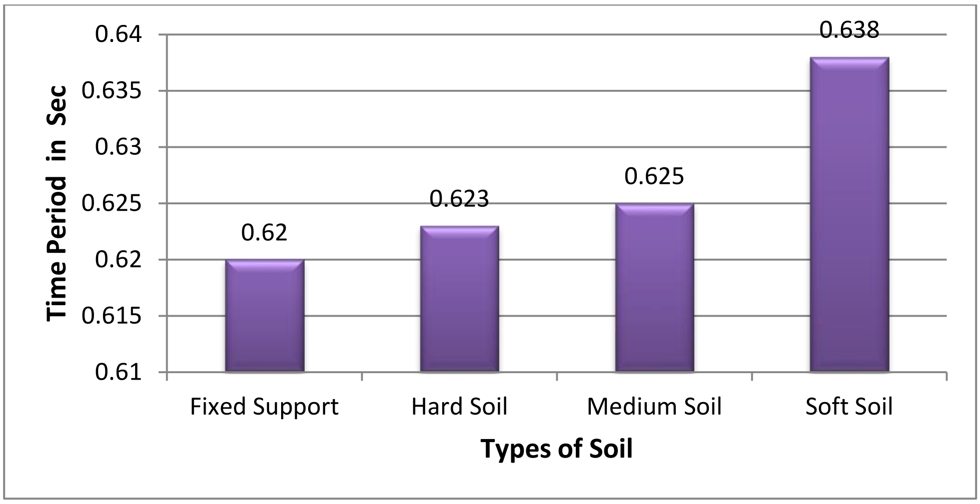


Fig 4.2: Variation of Twisting Time Period for Five Storey Building supported on Square Footing

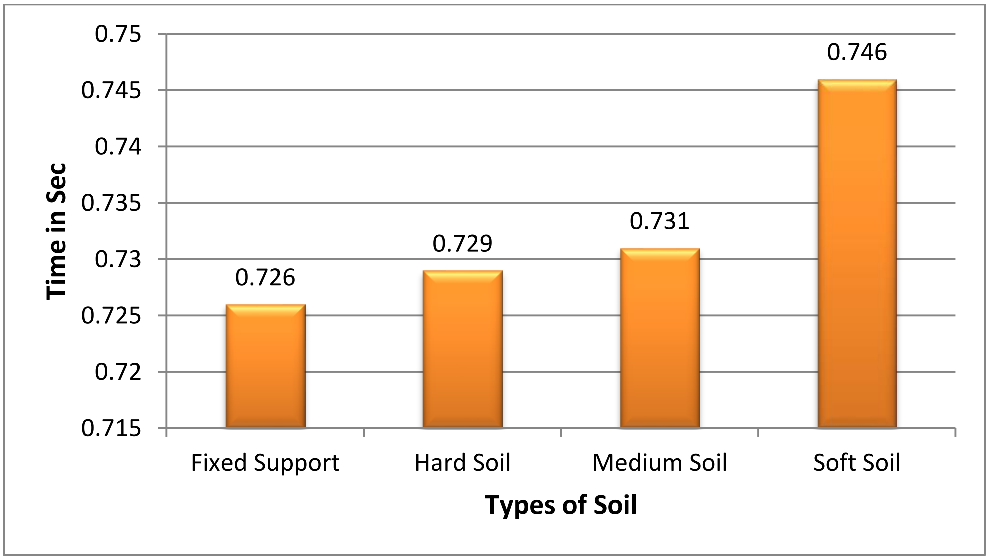


Fig 4.3: Variation of Time Period for Translation of Five Storey with Rectangular Footing

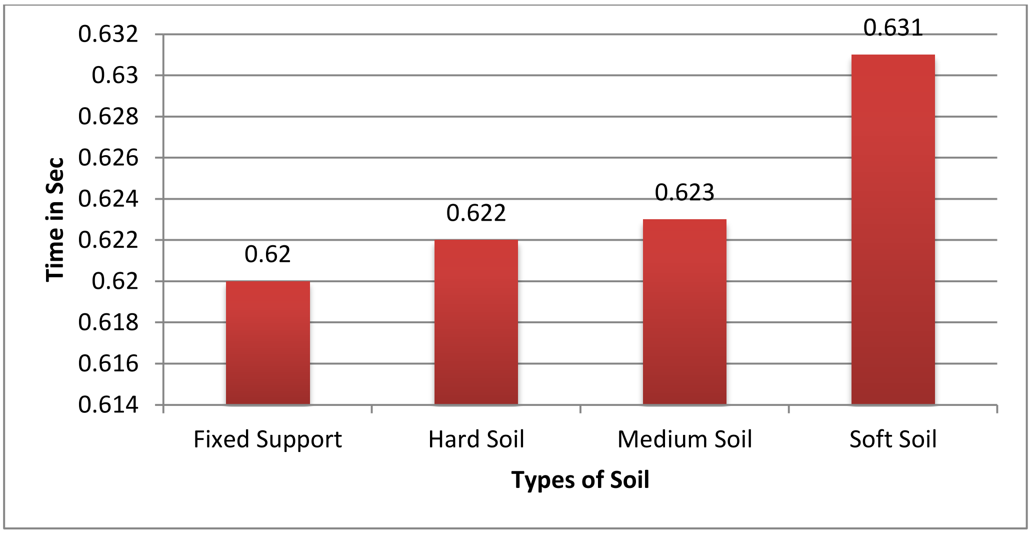


Fig 4.4: Variation of of Time Period- Twist for Five Storey with Rectangular Footing

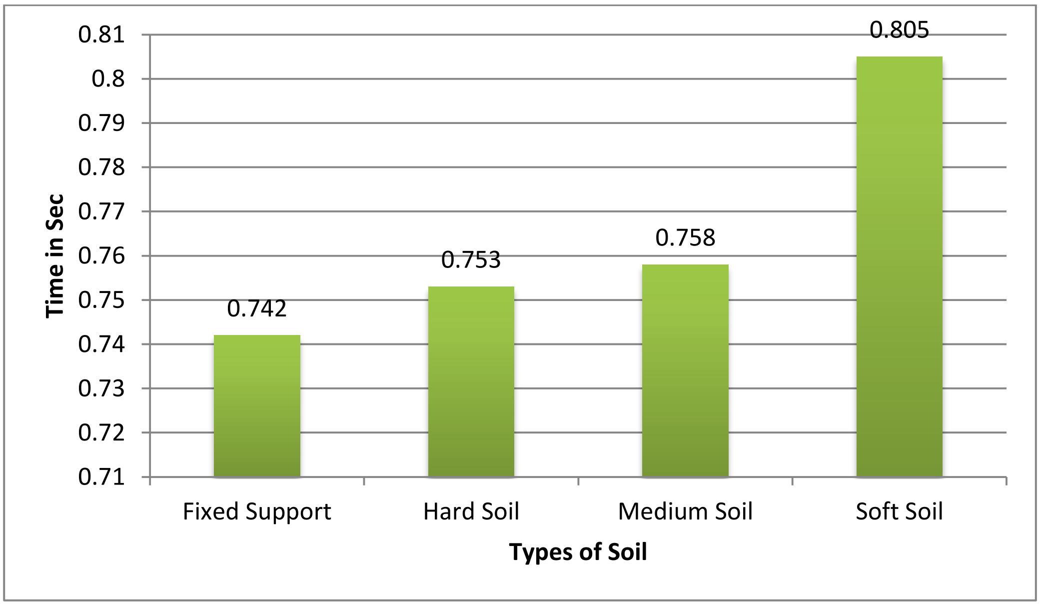


Fig 4.5: Variation of Time Period for Translation of Eight Storey with square footing

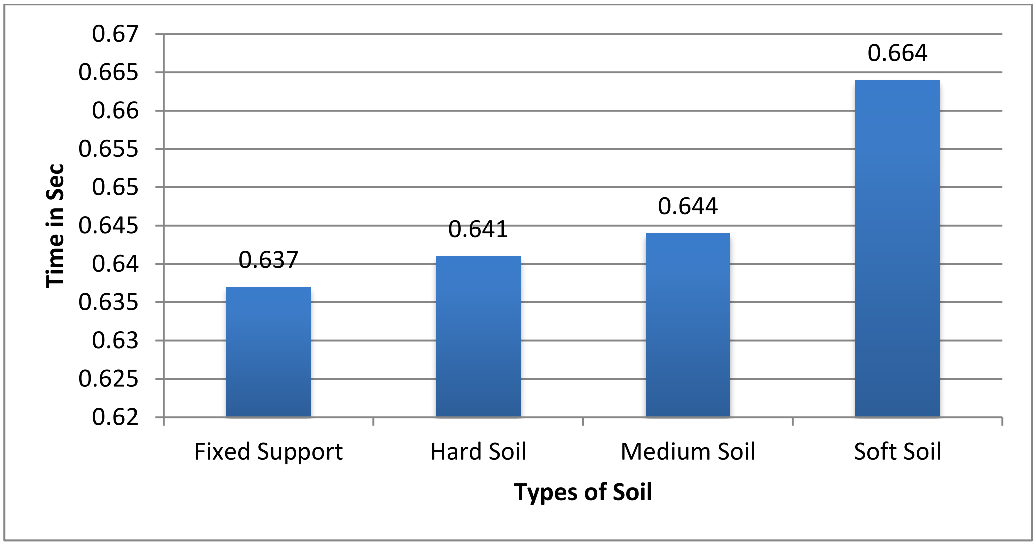


Fig 4.6: Variation of Twisting Time Period for Eight Storey Building supported on Square Footing

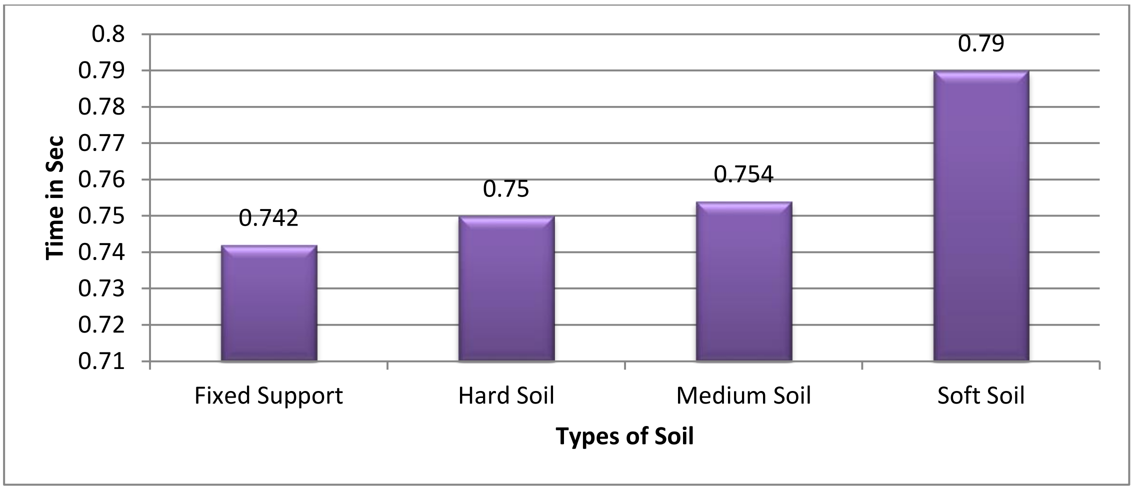


Fig 4.7: Variation of Time Period for Translation of Eight Storey with Rectangular Footing

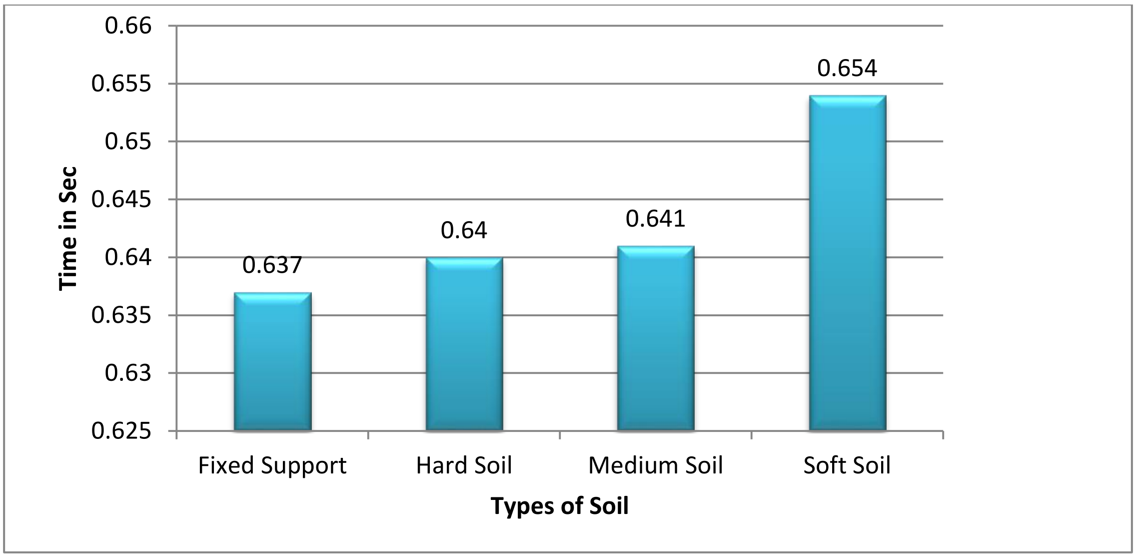
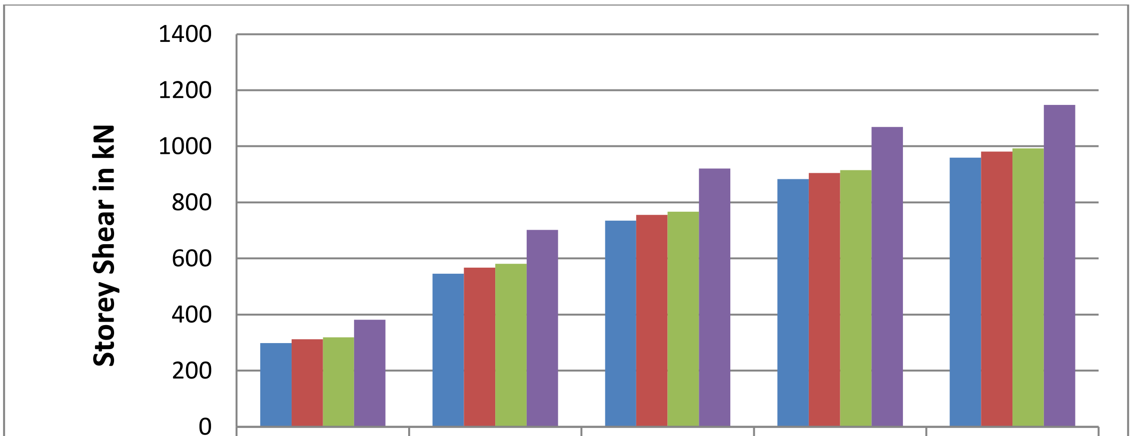


Fig 4.8: Variation of Twisting Time Period for Eight Storey Building supported on Rectangular Footing



	Storey 5	Storey 4	Storey 3	Storey 2	Storey 1
Fixed Support	298	546	735	884	960
Hard Soil	312	567	756	904	981
Medium Soil	319	581	767	915	993
Soft Soil	382	702	921	1069	1148

Fig 4.9: Variation of Storey Shear for Five Storey with Square Footing

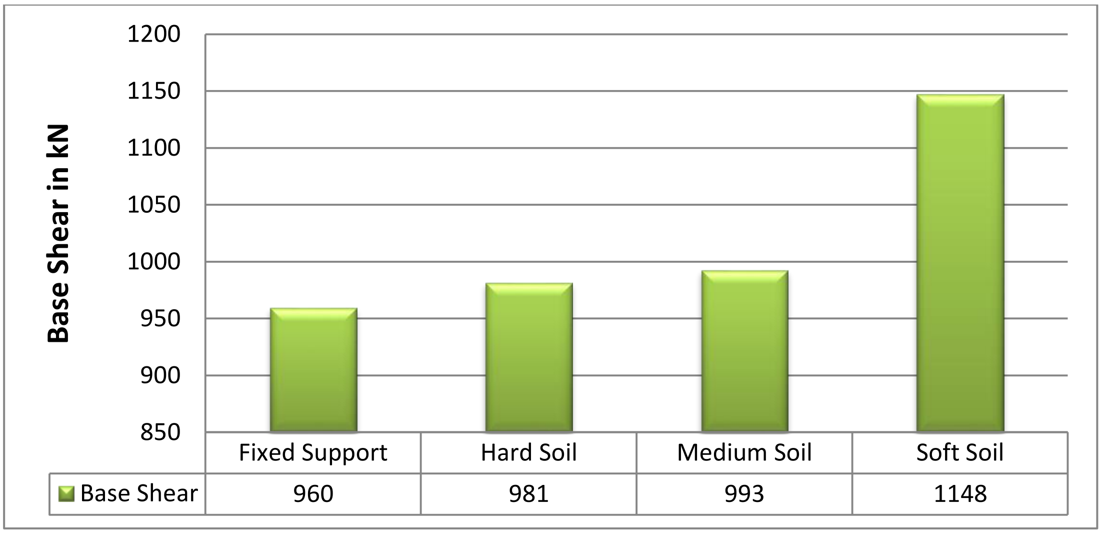


Fig 4.10: Variation of Base Shear for Five Storey building with Square Footing

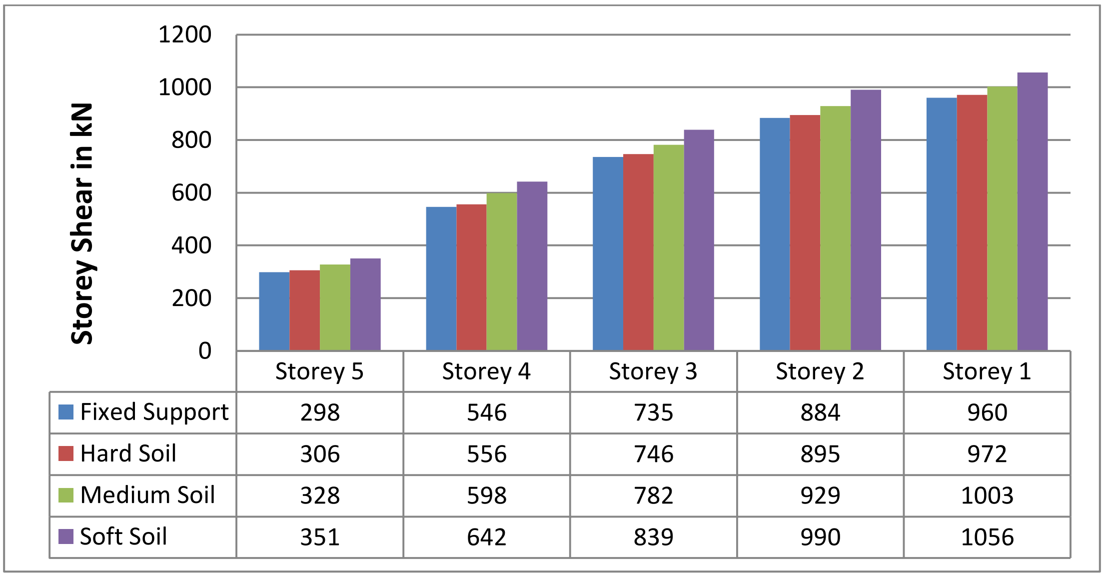


Fig 4.11: Variation of Storey Shear for Five Storey building with Rectagular Footing

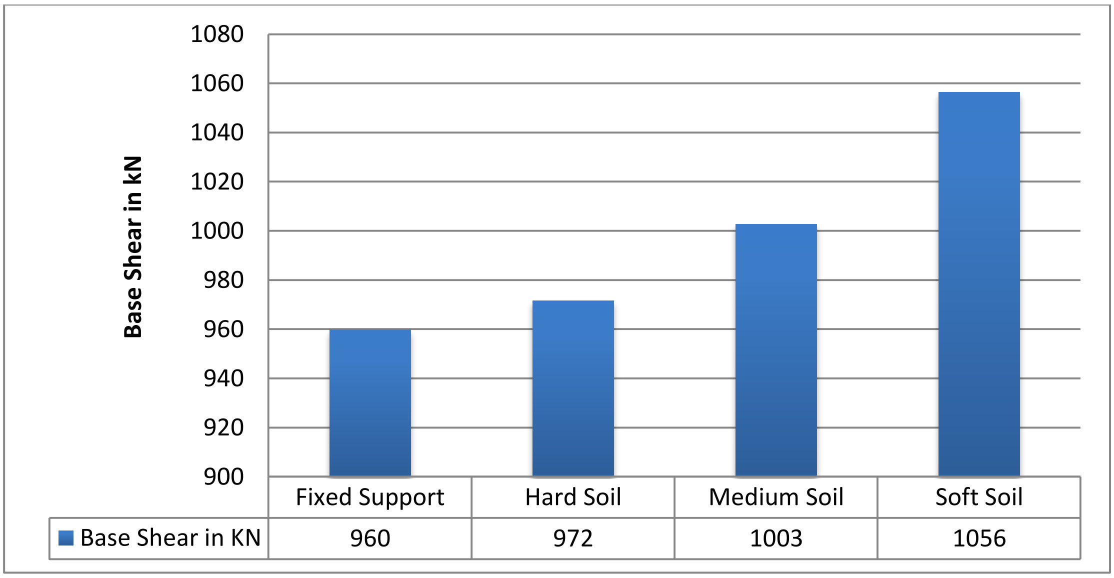
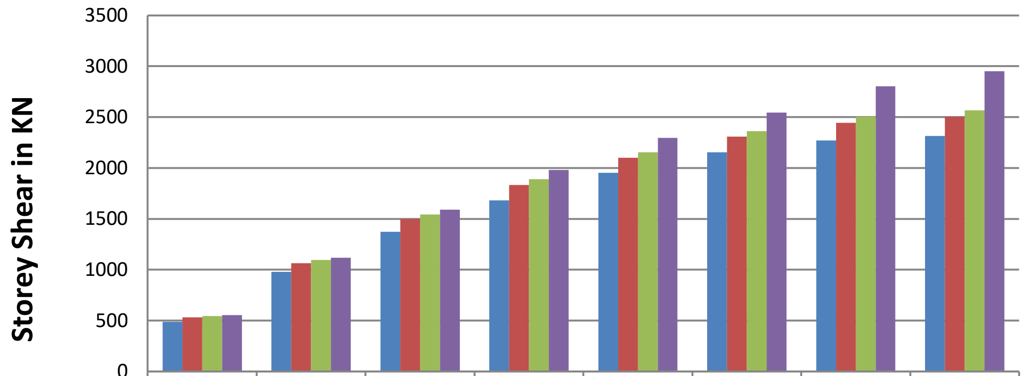
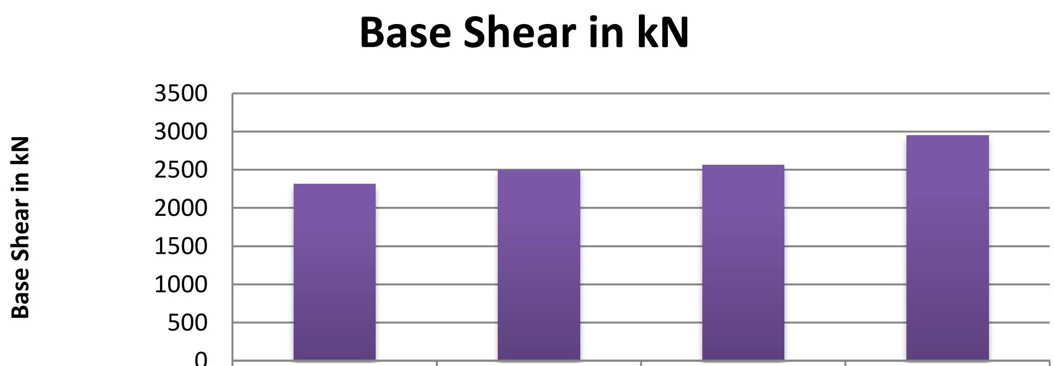


Fig 4.12: Variation of Base Shear for Five Storey building with Recatagular Footing



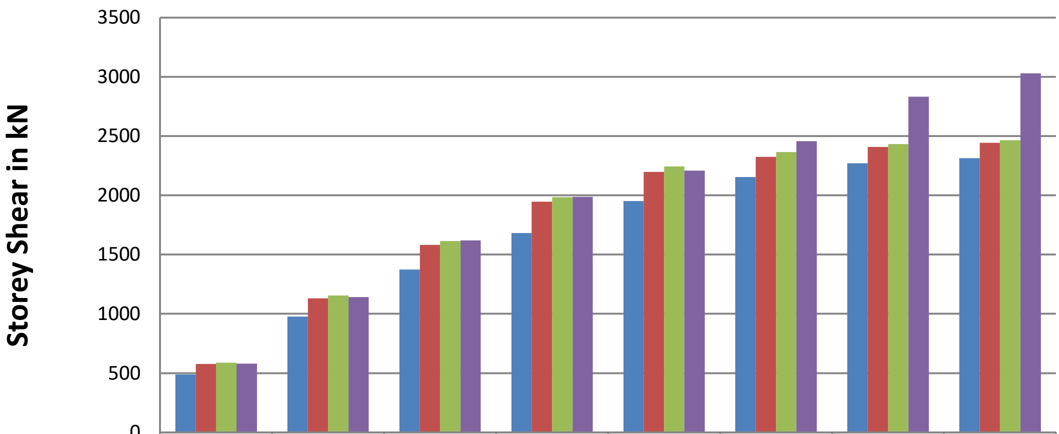
	Storey 8	Storey 7	Storey 6	Storey 5	Storey 4	Storey 3	Storey 2	Storey 1
Fixed Support	489	978	1374	1683	1952	2155	2271	2315
Hard Soil	530	1064	1499	1834	2099	2309	2444	2502
Medium Soil	545	1096	1544	1889	2154	2362	2505	2567
Soft Soil	553	1117	1589	1982	2294	2545	2803	2951

Fig 4.13: Variation of Storey Shear for Eight Storey with Square Footing



	Fixed Support	Hard Soil	Medium Soil	Soft Soil
Base Shear in kN	2315	2502	2567	2951

Fig 4.14: Variation of Base Shear for Eight Storey with square footing



	Storey 8	Storey 7	Storey 6	Storey 5	Storey 4	Storey 3	Storey 2	Storey 1
Fixed Support	489	978	1374	1683	1952	2155	2271	2315
Hard Soil	576	1130	1582	1947	2198	2325	2408	2443
Medium Soil	589	1154	1613	1985	2243	2365	2432	2464
Soft Soil	579	1143	1620	1986	2207	2458	2831	3030

Fig 4.15: Variation of Storey Shear for Eight Storey with Rectagular footing

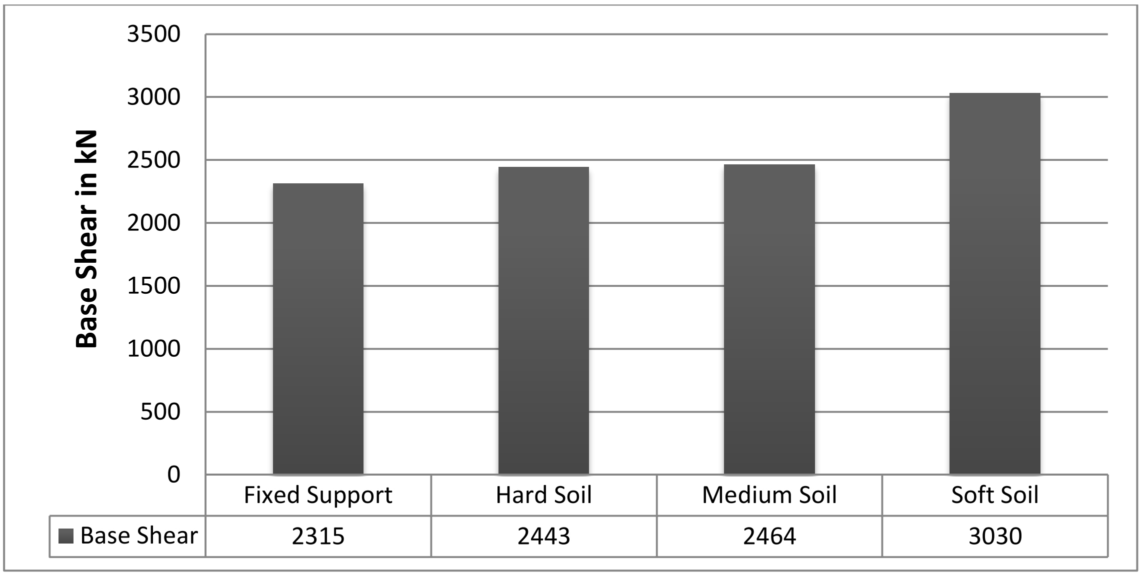


Fig 4.16: Variation of Base Shear for Eight Storey with Rectagular footing

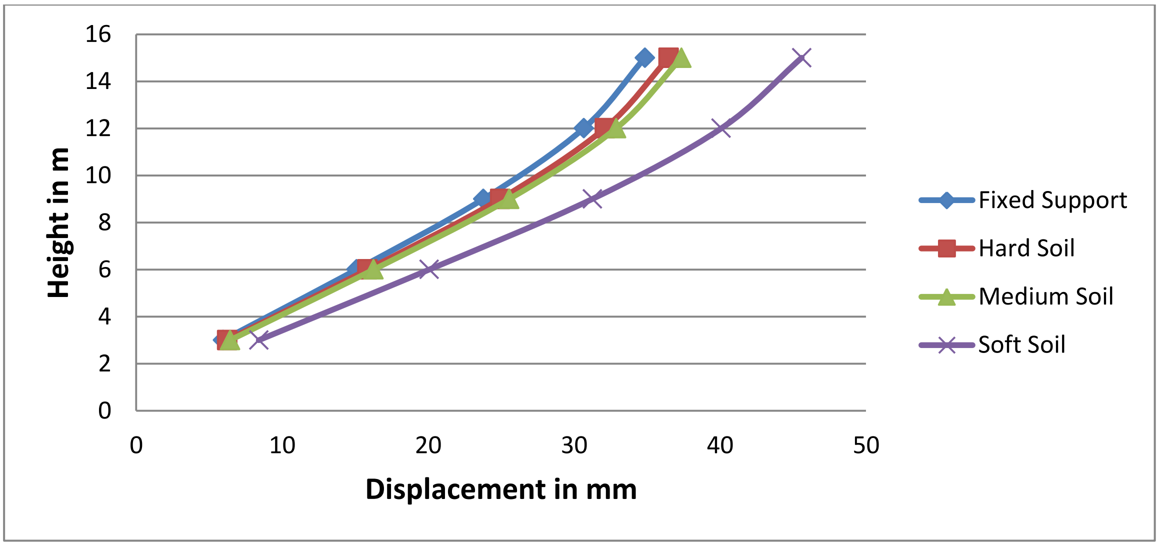


Fig 4.17: Comparison of Displacement v/s Height for Five Storey Building with square footing

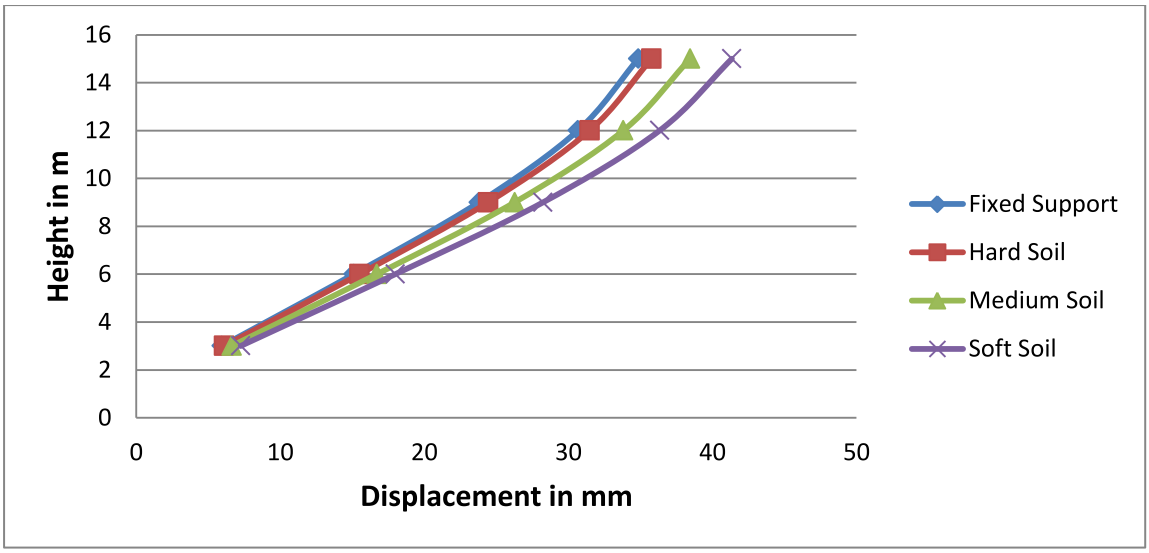


Fig 4.18: Comparison of Displacement v/s Height for Five Storey Building with rectangular footing

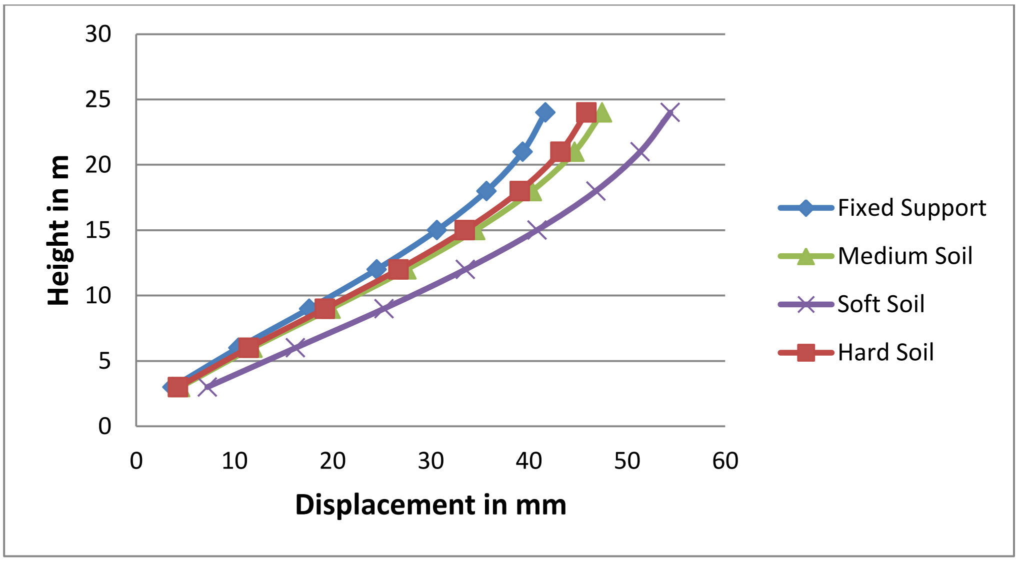


Fig 4.19: Comparison of Displacement v/s Height for Eight Storey Building with Square footing

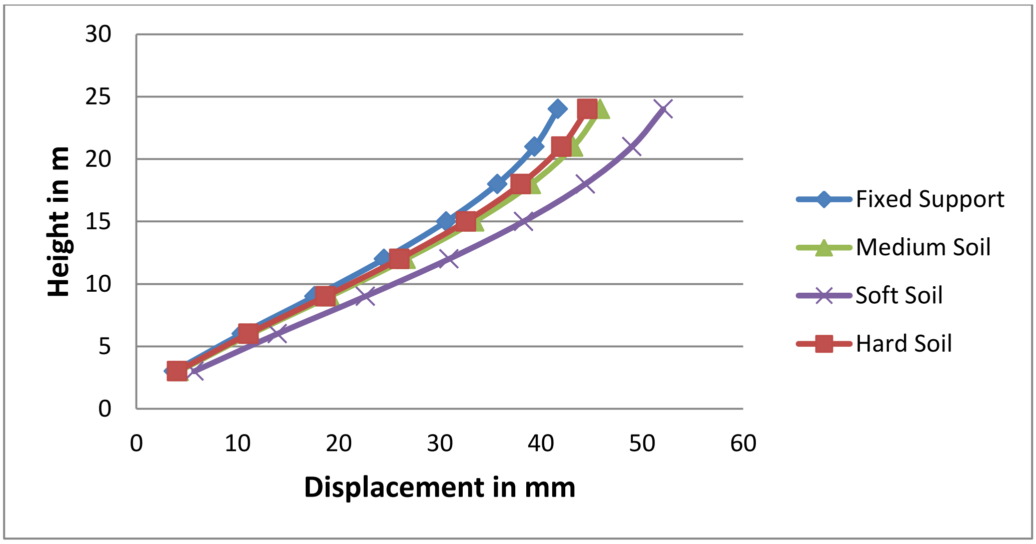


Fig 4.20: Comparison of Displacement v/s Height for Eight Storey Building with rectagular footing

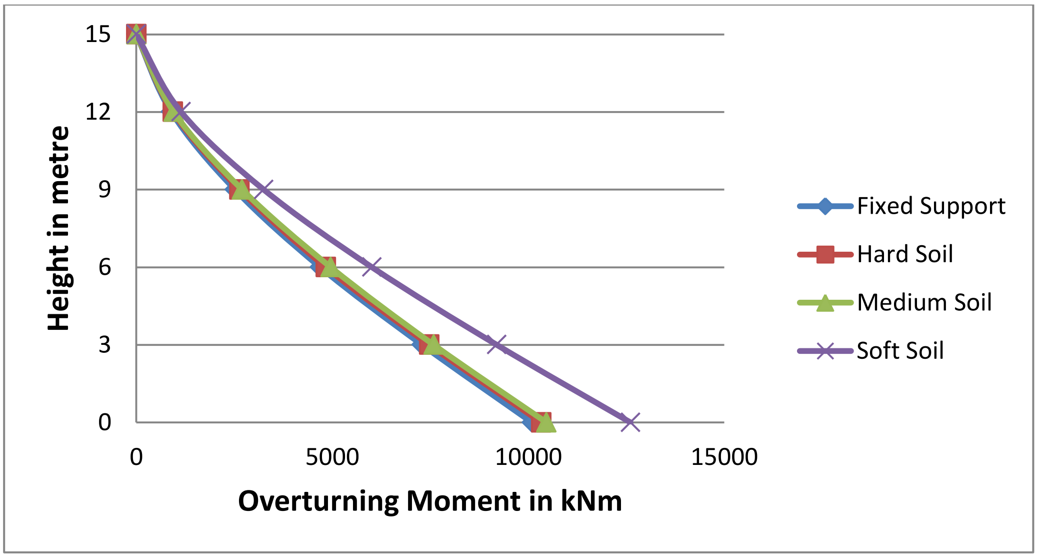


Fig 4.21: Overturning Moment v/s Height for five Storey building with Square footing

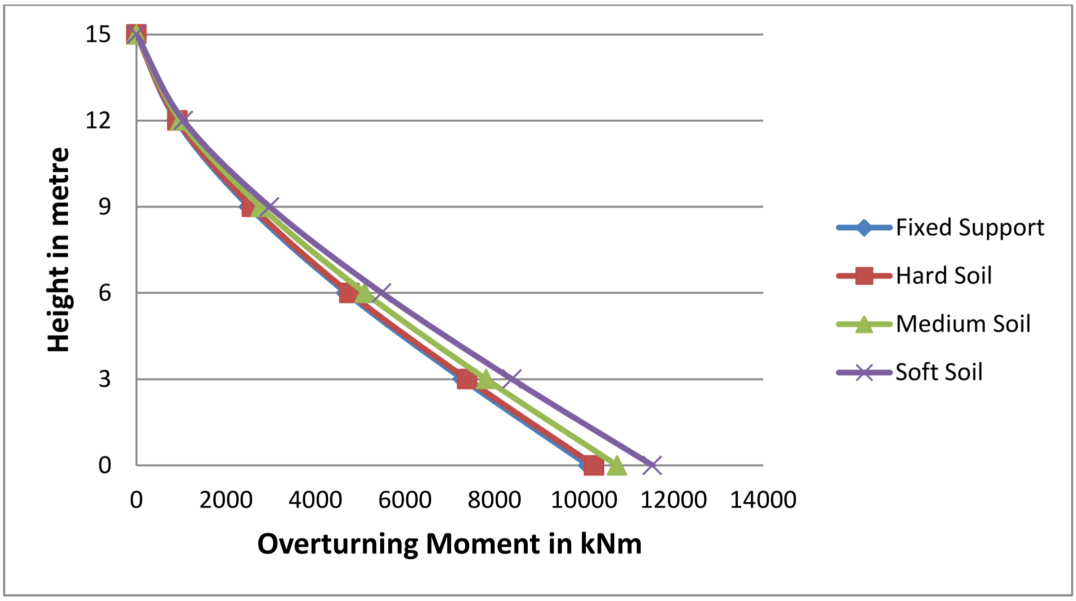


Fig 4.22: Overturning Moment v/s Height for Five Storey Building with Rectagular footing

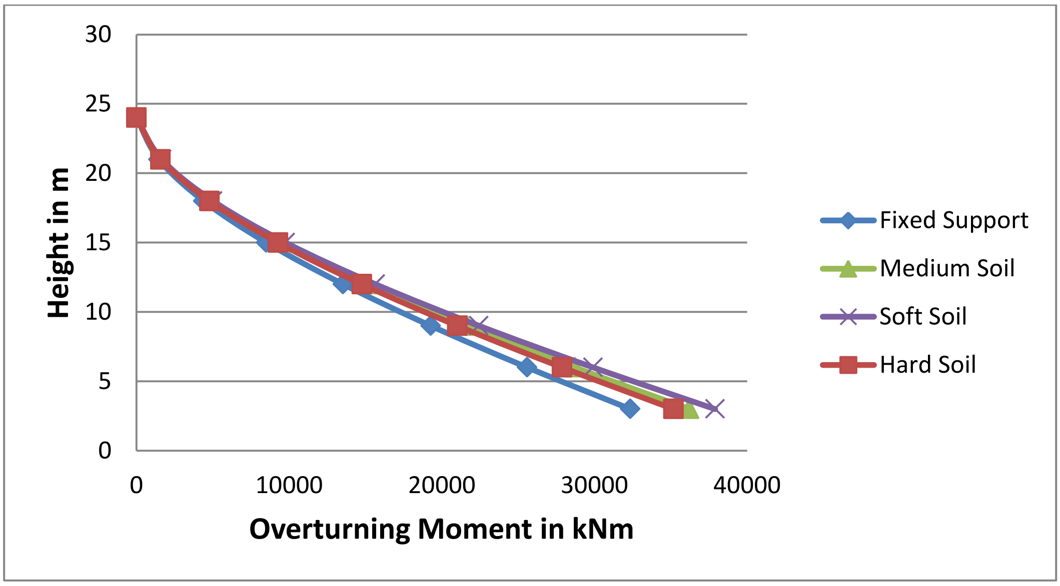


Fig 4.23: Overturning Moment v/s Height for Eight Storey Building supported on Square Footing

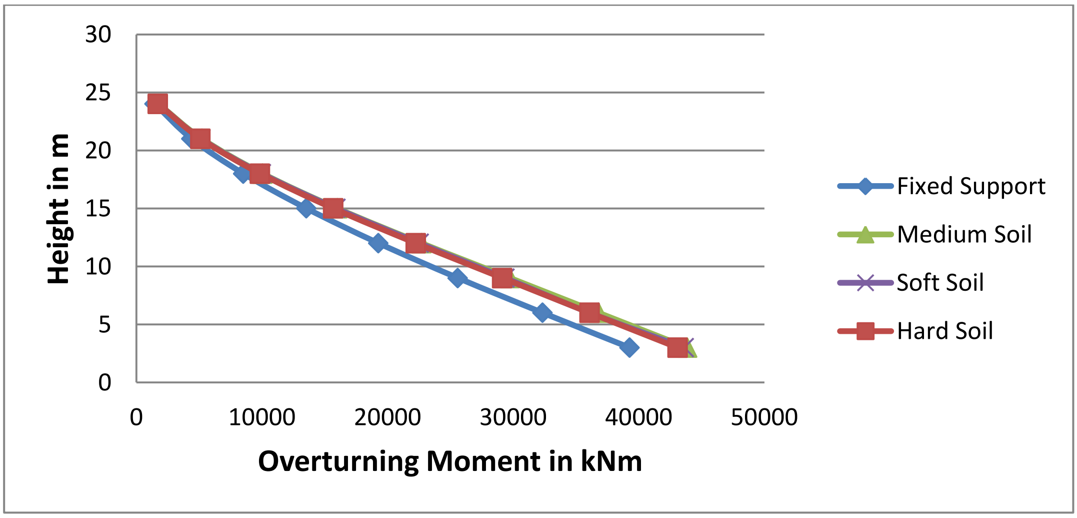


Fig 4.24: Overturning Moment v/s Height for Eight Storey Building supported on Rectagular Footing

5. CONCLUSION

1. Based on Comparsion of time period for fixed support and point spring element it is observed that, the magnitude of time period (T) for Soft Soil Condition is higher in comparison to Fixed Support, Medium and Hard Soil types.
   i. For 5 Storey Building – Time Period was 0.754, which is 1.038 Times of Fixed Support and 0.746 sec(1.028 times of Fixed Support)- Square footing and Rectangular Footing .
   ii. Thus Time period for Square footing is 1.01 times of the Rectangular footing.
   iii. For 8 Storey Building – Time Period was 0.805 (1.085 Times of Fixed Support) and 0.79 sec(1.064 times of Fixed Support)- Square footing and Rectangular Footing .
   iv. Thus Time period for Square footing is 1.02 times of the Rectangular footing.
2. Observations Based on Comparison of Base Shear and Storey Shear
   i. For 5 Storey Building – The Base Shear value for fixed support building was 960 kN. The Magnitude of Base Shear for square and rectangular footing were are almost similar. The Scale factor for Hard, Medium, and Soft Soil is found to be 1.021, 1.034 and 1.195 times of Fixed Support Condition.
   ii. For 8 Storey Building – The Base Shear value for fixed support building was 2315 kN. The Magnitude of Base Shear for square and rectangular footing were are almost similar. The Scale factor for Hard, Medium, and Soft Soil is found to be 1.08, 1.10 and 1.27 times of Fixed Support Condition.
3. Conclusion Based on Comparison of Storey Displacement
   i. For 5 Storey Building – The horizontal displacement of structure is found to be maximum for soft soil (45.6 mm-Square, 41.353-Rectangular) at 15 m height and for Fixed support model is 34.852 mm. The Soft Soil is displaced by 1.308 & 1.186 (Square,Recatagular), times of Fixed Support condition. Similarly Hard Soil and medium Soil are displaced by 35.774, 38.448 mm and are 1.02 and 1.103 times of Fixed Support condition.
   ii. For 8 Storey Building –The horizontal displacement of structure is found to be maximum for soft soil (54.426mm) at 24m height, whereas for Fixed support model least horizontal displacement is observed (41.698mm). Thus soft soil is displaced by 1.31 times of Fixed Support condition. Similarly Hard Soil and medium Soil are displaced by 45.87, 47.464 mm and are 1.1 and 1.14 times of Fixed Support condition
4. Conclusions Based on Comparison of Overturning Moment
   i. For 5 Storey Building- The Overturning Moment for Fixed support was 10099 kNm, whearas for Hard Soil, Medium soil, and Soft soil values are scaled by 1.024, 1.04 and 1.25 times of Fixed Support for Sqaure footing, Similar for Rectangular footing scale factor are 1.01, 1.06 and 1.16
   ii. For 8 Storey Building- The Overturning Moment for Fixed support was 39292 kNm, whearas for Hard Soil, Medium soil, and Soft soil values are scaled by 1.09, 1.12 and 1.25 times of Fixed Support for Sqaure footing, similarly for Rectangular footing scale factor are 1.1, 1.12 and 1.11
5. The Story response values for Square, and Rectagular footings were also similar, However Scale factors for rectagular footing is always lesser than square footings.
6. The Story Response values was always higher for Soft Soil. Thus Soft Soil condition is more crictical.
7. From present study it is obsereved that the scale factor for Soft Soil with square footing in comparasion with fixed supports are,
   i. For 5 Storey Building - Base Shear 1.195, Displacement- 1.186,Overturning Moment-1.25. Thus in absence of detail test results of Soil, designer can follow convientional fixed support procedure and a adapt scale factor of 1.20 for Base Shear and Displacement, 1.25 for overturning moment.
   ii. For 8 Storey Building – Base Shear 1.27, Displacement 1.31, Overturning Moment 1.11. Thus in absence of detail test results of Soil, designer can follow convientional fixed support procedure and a adapt scale factor of 1.3 for Base Shear and Displacement, 1.15 for overturning moment.

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