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Study of Soil Structure Interaction Effect on Multi-Storey RC Frame Structures Resting Over Raft Foundation under Earthquake Caused Agitation

Mr.Nitish Kumar S[1], Mr.Praveen J V[2]

[1] M. Tech student, [2]Assitant Professor, Department of Civil Engineering, Sri Siddhartha Institute of Technology, Tumkur, India

Abstract: **The main objective of this present investigation is to understand the seismic performance of superstructure considering the complex dynamic interaction between superstructures, the raft foundation resting on the soil and comparing the dynamic responses in cooperating soil flexibility with those of fixed base assumption, soil being idealized as modified Winkler model.**

In the present study the behaviour of superstructure by modelling the nonlinearities of soil, modelling the interface between raft foundation and soil. To address this problem, a Finite Element Method is used to model soil structure interaction analysis of raft foundation supported framed structures by programming in SAP 2000 V14 software . An attempt has been made to evaluate the effect of soil structure interaction of super structure by considering the systematic parameters like time period, lateral displacement, storey drift, bending moment in X-X and Y-Y direction. Time history analysis has been carried out and the parameters like base shear and roof top displacement of the building frames resting over raft foundation and soil media has been studied.

Based on the analysis results, it has been concluded that the effect of soil-structure interaction plays a significant role to increase the time period, bending moment in X-X direction, bending moment in Y-Y direction, lateral displacement.As the flexibility of the soil increases the bending moment also increases. The study shows that, the SSI will affect the behavior of the structure, the structure-foundation-soil mass shows an effective approach.

Keywords: **soil-structure interaction; Winkler model; Seismic response; SAP2000; time period; bending moment; Time history analysis.**

I. INTRODUCTION

Earlier building super structure and sub structure were analysed in full isolation; the structural and geo-technical/ foundation engineers rarely interact. While structural engineer only bothered about the structural configuration of the building, hardly care to know any known about soil other than the allowable bearing capacity and its general, provided the foundation design is within its scope of work. On the other hand the geo-technical engineer focused on the inherent soil characteristics like (sand, silt and clay) and recommending the type of foundation (Raft/Mat foundation) or at the best size and design were the same. The crux of this scenario was that nobody knows the overall reality picture; while in dynamic loading the sub structure and super structure do behave in tandem.

In general design practice for dynamic loading assumes the building frames are fixed at their base. In reality the supporting soil medium displaced to some extent due to its natural deformation this leads decreases the stiffness of the system and hence, increase in the time period of the system. Such partial fixity of the structure at the foundation level due to soil flexibility in turn alerts the response. On the other hand, the extent of fixity offered by the soil at the base of the structure depends on load, soil type, size and type of foundation to be provided. Such an interdependent behaviour between soil and structure regulating the overall response is referred to as soil structure interaction (S V Datta).

The raft foundation is used support structure and it is designed by conventional method assuming that the foundation to be rigid. The raft foundation directly connects with the soil and reactions from the structure are carried through the supporting foundation. The differential settlements obtained by the reactions are reduced by the increasing depth of the mat foundation. The super structure-mat-soil mass are considered as a single unit for the analysis. The finite element method is used to model the 3D elastic continuum model (FEM model). The superstructure, foundation and the soil mass are considered as single unit and the problem is analysed by the finite element method (FEM).The structure and the foundation are placed on different soil conditions like soft, medium and hard. The properties like young's modulus, Poisson ratio and shear wave velocity change the behaviour of the soil mass.

Analysing the structure considering soil masses increases the stiffness of the structure and this decreases the natural period of the building with increasing natural frequency. The change in natural frequency shows the overall response of the building under seismic forces. The main objective of the present study is estimate the effect of soil structure interaction on the building frames supported by the raft foundation. The variations in the behaviour for the different models are investigated with the help of generalized computer program SAP 2000.

II. METHODOLOGY

Steps of the finite element formulation;

A. Pre-processing that includes mesh generation

B. Obtaining the assembled system of equation, for which the elemental matrices and vectors need to be evaluated

C. Applying the boundary conditions

D. Solving the linear system of equations

E. Post-processing.

2.1 STRUCTURAL IDEALIZATIONP:

The building frame is idealized as 3D space frame consisting of four node elements with appropriate dimensions. The 3D model is generated in SAP -2000 software package. The slab and mat foundations are modelled as a rigid diaphragm with the help of four node plate elements. The building is analysed as bare frame with computer software package SAP-2000. To study the soil structure interaction of the 10, 15, 20 and 25storied building over a raft foundation is resting on the soil medium. A four model of 10, 15, 20 and 25story building of 6-bay and 6-bays in two mutually perpendicular directions are considered. The each building model with raft thickness of 0.8m, 1m and 1.2m is rested on the soft, medium and hard soil profiles.

The story height for all the models was considered as 3m and the bay length of frames as 5m c/c. The materials for structural members are considered to be reinforced concrete of grade M25 and modulus of elasticity of 25N/mm^2 is considered. The reinforcement of 500N/mm^2 is considered. The beam, column and slabs are designed as per Indian standard code IS 456-2000

2.2 SOIL MODELING:

To analyse the soil foundation and structure under seismic loading, soil is modelled as a set of elastic continuum. Translations of foundation in two horizontal and vertical axes with rotational springs about those mutually perpendicular axes are considered in the present study. These are attached to estimate the effect of soil flexibility.

2.2.1 SSI Mode Consider For Study:

Effect of this soil for SSI is considered by considering equivalent springs with 6 DOF. The stiffness along these 6 degrees of freedom is determined as per George Gazetas, Formula and charts for impedances of surface and embedded foundations is shown in Table I.

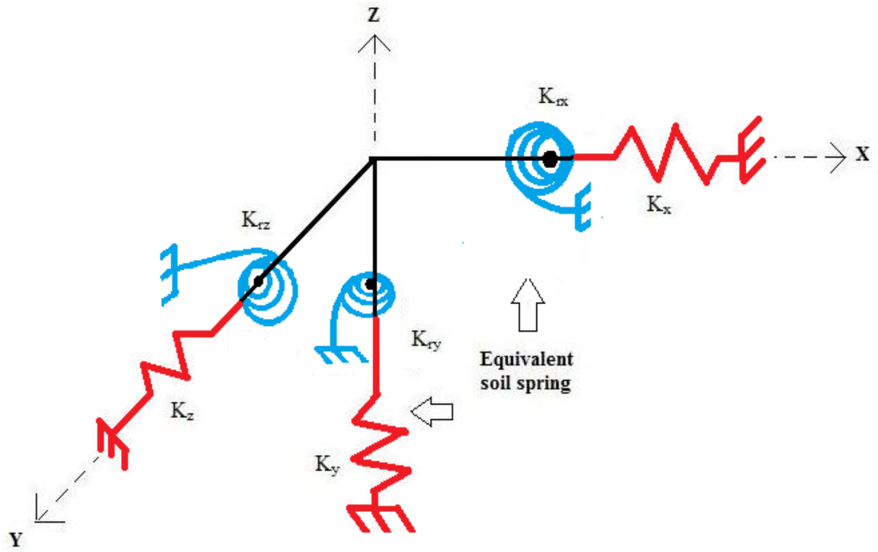

Fig: 1 Equivalent Spring Stiffness

Where in Fig 3.1, Kx, Ky and Kz are stiffness of equivalent soil springs along the translation degree of freedom along X, Y and Z direction. Krx, Kry and Krz are Stiffness of equivalent rotational soil springs along the rotational degree of freedom along X, Y and Z direction.

Table I: Spring Stiffness (George Gazeta)

Degrees of freedom	**Stiffness of equivalent soil spring**
Vertical	[2GL/(1-ν)](0.73+1.54χ0.75) with χ = Ab/4L2
Horizontal (lateral direction)	[2GL/(2-ν)](2+2.50χ0.85) with χ = Ab/4L2
Horizontal (longitudinal direction)	[2GL/(2-ν)](2+2.50χ0.85)-[0.2/(0.75-ν)] GL[1-(B/L)] with χ = Ab/4L2
Rocking (about longitudinal)	[G/(1-ν)]Ibx0.75(L/B)0.25[2.4+0.5(B/L)]
Rocking (about lateral)	[G/(1-ν)]Iby0.75(L/B)0.15
Torsion	3.5G Ibz0.75(B/L)0.4(Ibz/B4)0.2

Where, Ab= Area of the foundation considered; B and L= Half-width and half-length of a rectangular foundation, respectively; Ibx, Iby, and Ibz = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively.

2.3 SAP2000 (VERSION-14.2.4) SOFTWARE PACKAGE:

In the present analysis, a finite element method of analysis has been adopted, because of its diversity & flexibility as an analysis tool, with number of software tools available. The Popular brands of finite element analysis packages are now available like SAP2000, ETABS, STAAD-PRO, NISA and ANSYS.

In the present study, the structure is modelled as a 3-dimensional frame using software Package SAP2000 (version-14.2.4). This minimizes the numerical calculations and also Verification of results. Linear time history analysis can be performed on three dimensional Structural models.

III. MODELING

In the present study, soil structure interaction effect on multi- story RC frame structure under seismic load is investigated. RC frame structure resting on different type of soil with different height by breadth ratio and different raft thickness asbeen considered. The time history analysis of the RC frame structure has been done by subjecting the whole system to earth quack ground motion (Bhuj EQ data) using SAP 2000software.

Table II: Range of parameters considered in the present study

Structure Type	ordinary RC moment resisting frame
No. of storey	G+10,G+15,G+20,G+25
Typical storey height	3 m
Plinth height	1.5m
Type of building use	Commercial building
Seismic zone	V (Z=0.36as per IS 1989-2002)
Material Properties	
Grade of concrete(fck)	M25
Grade of steel (f_y)	Fe 500
Young's modulus of concrete, E_c	25x 10^6kN/m^2
Poisson's Ratio of reinforced concrete	0.20
Thickness of slab	150 mm
Specific weight of infill	14.6 kN/m3
Dead Load Intensities	
Roof finishes	2.0 kN/m^2(as per IS 875-1987 part I)
Floor finishes	0.5kN/m^2
Live Load Intensities	
Roof	2kN/m^2(as per IS 875-1987 part II)
Floor	1.5kN/m^2

Table III: Building aspect ratio considered in the present study

COMPONENT	**DESCRIPTION**	**BUILDING ASPECT RATIO**			
		$\frac{30}{30} = 1$	$\frac{45}{30} = 1.5$	$\frac{60}{30} = 2$	$\frac{75}{30} = 2.5$
FRAMES	Number Of Storyes	10	15	20	25
	Number Of Bays In X Direction	6	6	6	6
	Number Of Bays In Y Direction	6	6	6	6
	Storey Height	3m	3m	3m	3m
	Bay Width In X Direction	5m	5m	5m	5m
	Bay Width In Y Direction	5m	5m	5m	5m
RAFT	Raft Depth	0.8m, 1m,1.2m	0.8m, 1m,1.2m	0.8m,1m,1.2m	0.8m,1m,1.2m
	3D Model	9	9	9	9
SOIL	Soil type	Hard(Ks 45E3) Medium(Ks25E3) Soft(Ks 15E3)	Hard(Ks 45E3) Medium(Ks25E3) Soft(Ks 15E3)	Hard(Ks45E3) Medium(Ks25E3) Soft(Ks 41E3)	Hard(Ks45E3) Medium(Ks25E3) Soft(Ks 15E3)
	Solid	120x120 x45m	120x120 x45m	120x120 x45m	120x120 x45m
	3D Model	9	9	9	9

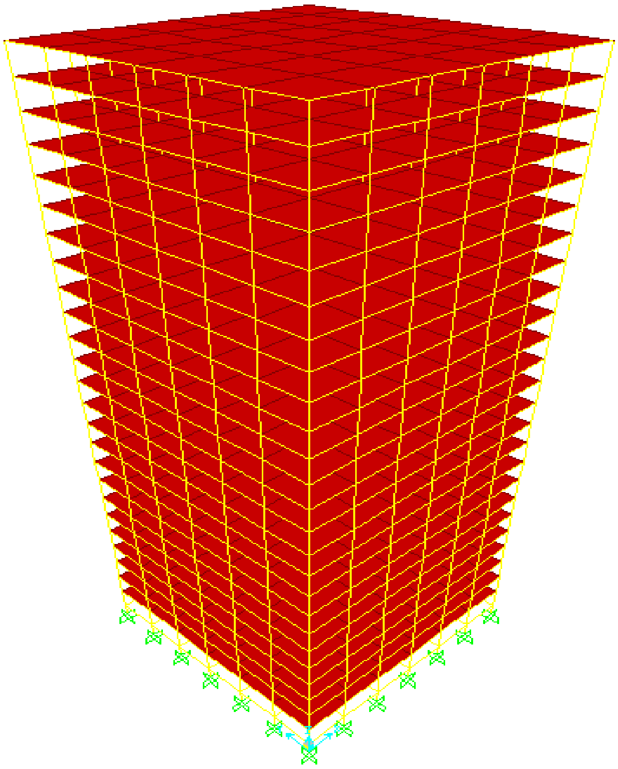

Fig: 2 Fixed base 3D model

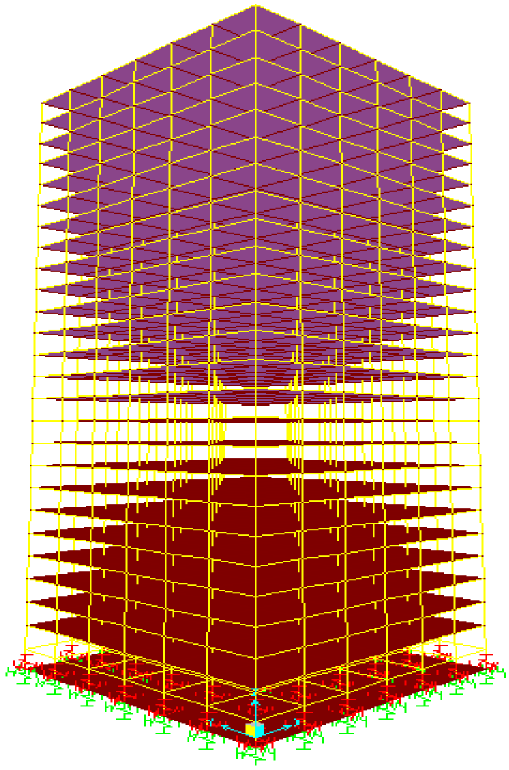

Fig : 3 Winkler3D model for Raft foundation (0.8m, 1m, 1.2m)

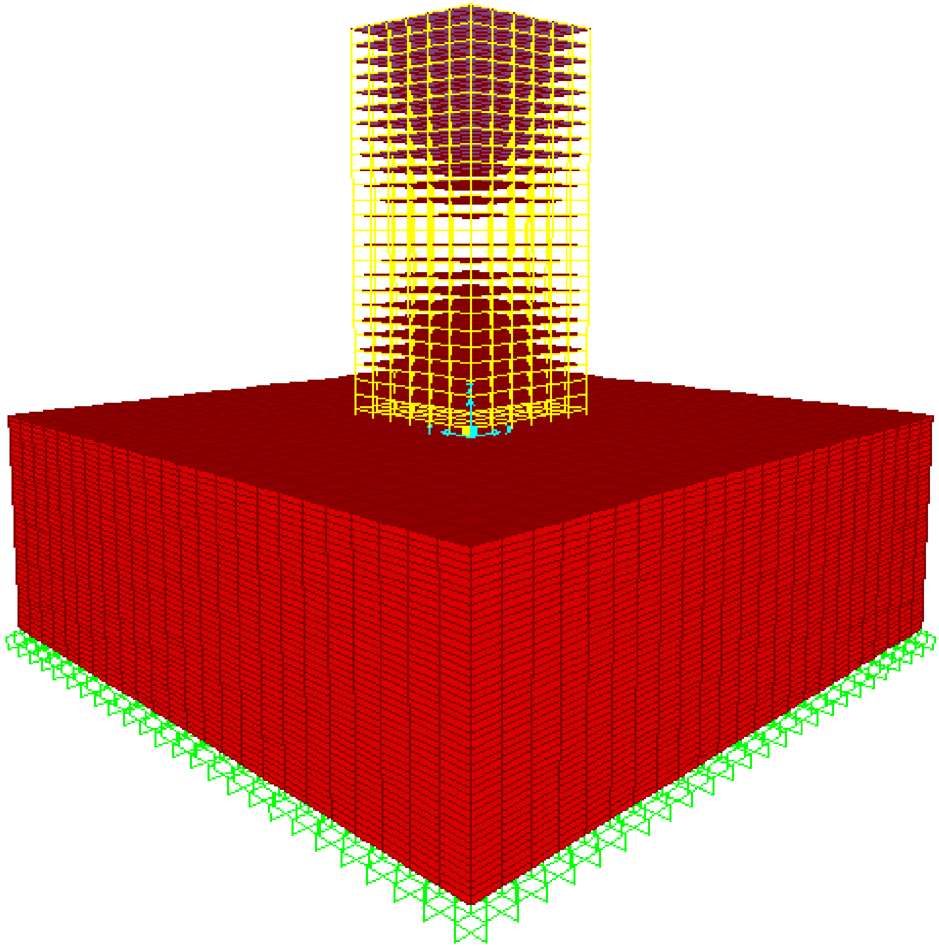

Fig: 4 3D elastic continuum (FEM)models for different types of soiln (Soil media: 120mx120mx45m).

IV. RESULT AND DISCUSSIONS

A Study of three Dimensional multi-story RC frame structure models with different height / breadth ratio, with different raft thickness of square raft and resting on three type of soil ranging from vary soft to stiff has been carried out, structure is subjected to acceleration time history of BHUJ earthquake ground motion. Here, soil is idealized as a **Winkler model** and **3D elastic soil continuum model** and prescribed ground motion is used for soil structure interaction analysis.

4.1 VARIATION IN TIME PERIOD:

A variation in time period due to soil flexibility, The structure is assume to be resting on three different soil condition with modules of sub grade reaction Ks 15E3,Ks 25E3 and Ks 45E3modelled using 3D elastic soil continuum model and the result are show in fig 5.

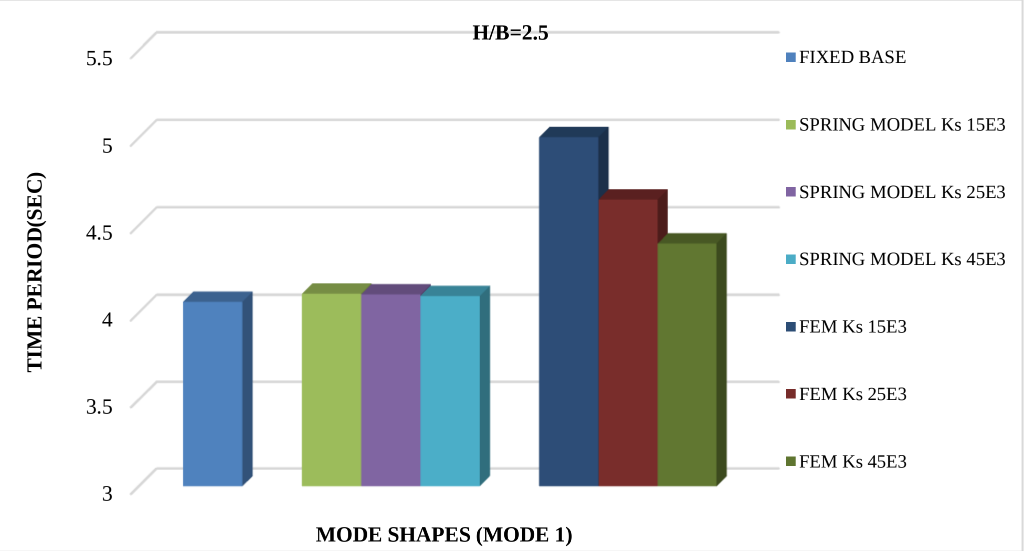

Fig: 5 show the variation of time period of fixed base, spring model and FEM model for 25floors.

From the Fig 5, it can be seen that for maximum increase in time period is observed in FEM model than Winkler model and fixed base for mode 1.

4.2 VARIATION OF LATERAL DISPLACEMENT:

In this discussion comparison is carried out for fixed base, Winkler model and 3D elastic soil continuum model with different soil types for a 10, 15, 20 and 25 storey building.

It is observed here that, lateral displacement increases as the number of storey increases. The variations of lateral displacement with number of stores are shown in figures 6.

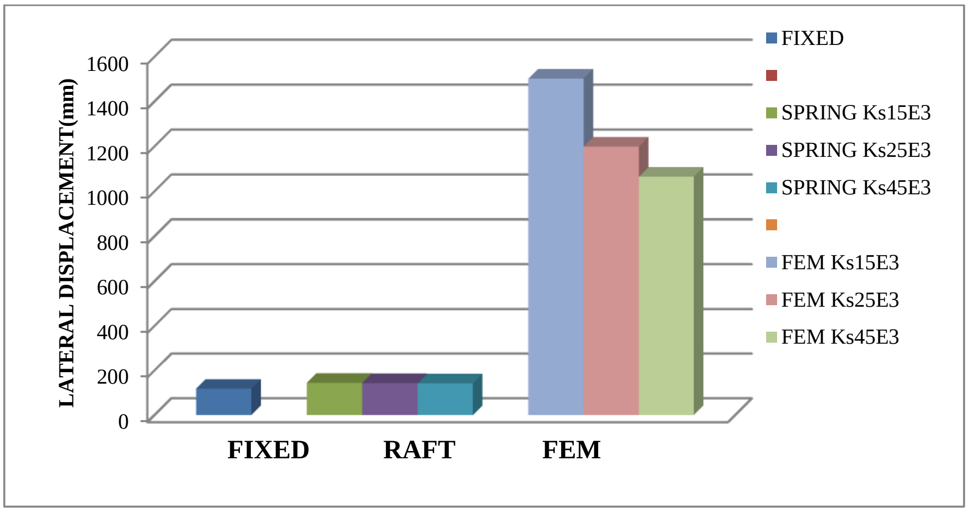

Fig: 6 show the variation of lateral displacement of fixed base, spring model and FEM model for 25 floors.

From the Fig 5.31 it can be seen that for maximum increase in lateral displacement is observed in FEM model than Winkler model and fixed base for mode1.

4.3 VARIATION OF BENDING MOMENT IN TRANSVERSE DIRECTION Y-Y (M22):

In this discussion comparison is carried out for each soil model with different soil flexibility for a 10, 15, 20 and 25 storey building. It is observed here that bending moment Y-Y direction M22increases as the soil flexibility and the percentage variation of bending moment Y-Y direction M22 increases with increase in number of storey. The percentage variations for different soil flexibility with different number of stores are show in the fig 7.

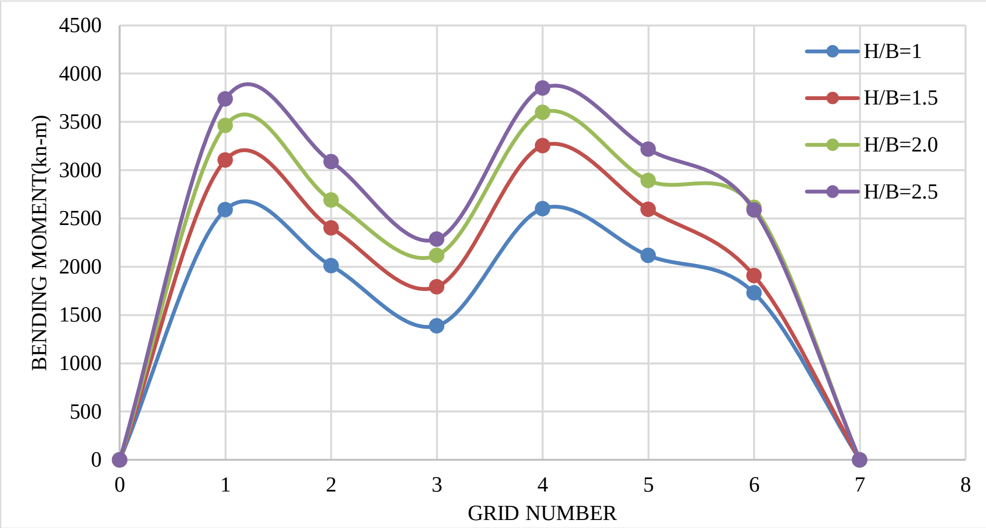

Fig: 7 show the variation of Bending Moment in Y-Y direction for 10, 15, 20 and 25 floors.

V. CONCLUSION

The thesis attempts to study the effect of soil-structure interaction under transient loading for multi-storey RC frame structure with square raft. This study has been mainly carried out to determine the change in various seismic response quantities due to consideration of flexibility of soil, height by breadth ratio of RC frame structure and different thickness of raft.

1. The time period of the building on the different soil with varying raft thickness is increased as compared with the fixed conditions. The time period on the different soil types is increases this reduces the natural frequency of the building.

2. The displacement varies due to the soil flexibility. As the width of the building increases, the displacement also increases. The stiffness of the soil increases causes a reduction in displacement. The varying raft thickness has no influence on the displacement of the building it behaves as a rigid.

3. Increase in soil flexibility increases the bending moment. This shows increase of bending moment due to soil flexibility with increase in raft thickness and height of the building.

4. The influence of the parameters like soil types and properties, varying raft thickness, soil media and change in height of the building shows increase in the displacement, time period and bending moments as the soil flexibility varies.

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