

**REVIEW ON:  
SEISMIC SOIL-STRUCTURE INTERACTION OF PILE RAFT  
FOUNDATION IN MULTI-STORY MRF BUILDING**

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*Abstract— Piled raft foundations are emerging out as an effective and economical foundation system for multi storey structures. In piled raft foundation the raft and piles both contribute in load sharing. The raft carry load through contact with soil and provide a reasonable measure of stiffness and load resistance while piles carry load through skin friction and the provided to reduce the vertical settlements as well as the differential settlements in raft. Soil-structure interaction (SSI) is process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil. In general, structure and piled raft under seismic load are designed considering fixed base condition. However, soil flexibility may result significant changes in the response of soil-pile raft-structure system. The responses of the superstructure considered include the displacement at top of the frame and moments in the columns. The effect of soil-structure interaction is found to be quite significant for the type of foundation.*

*Keywords—Seismic soil structure interaction, pile raft foundation, Moment resisting framed building*

## I. INTRODUCTION

The raft foundation is a common system in construction. In the cases that there is high-rise building (external loading is very much) or settlements is more than allowed limits, placing some piles under the raft is a good method. According to soil resistance, in condition that raft and piles have bearing role, designed foundation is piled raft. Applying this system is due to decrease differential settlements and it is the main advantages of this system. In general, structural design considers fixity at base level in a soil-pile foundation-structure system. Likewise, pile head is considered to be fixed for seismic design of pile raft.<sup>[5]</sup> Hence, seismic design of structure and pile raft is performed by computing structure base shear force for a known weight and natural period of vibration of superstructure in fixed base condition. However, in reality, due to deformable characteristics of soil, foundation offers a partial fixity at structure base level and thereby alters natural period and response of the system. In contrast, design of foundation is directed by the amount of load transferred from the structure to the soil, based on extent of fixity offered by the soil. This interdependent behaviour of soil and structure changing overall response of the structure is termed as soil-structure interaction (SSI).<sup>[3]</sup> Implication of soil-structure interaction effects helps the designer to assess the inertial forces and real displacements of the soil-foundation structure system exactly under the influence of free field motion. The effects of soil flexibility are mostly ignored in seismic design of buildings leading to unnecessarily costly or unsafe design. The design in general is carried out based on the results of dynamic analysis considering fixed-base condition of structure<sup>[7]</sup>. Piled raft system has complicated behaviour under seismic loading, because of kinematic interactions between piles, raft and soil. Furthermore, the soil behaviour is not linear in high acceleration and separation at contact surfaces (pile and soil, raft and soil) is possible. Thus, there is no comprehensive studies on analysis, designing and exact behaviour of piled raft under dynamic loading. In high seismicity areas, piles must experience unexpected load and it will be more if it imposed to a big inertia force, like a tall building. In this case, that there is high stress in rigid connections between piles and raft, it is necessary to consider special requirements. When the seismic wave passes through a soil mass, it vibrates and displaces due to distortion and dilation of waves through the solid media, such vibration in the supporting soil mass is called as the kinematic interaction<sup>[1]</sup>. Once the excitation wave passes through soil and enters in to the structure starts vibrating which exerts extra dynamic force to the soil mass, refers as the inertial interaction which depends up on the inertial forces produced by the structure.

## II. FACTORS INFLUENCING SSI EFFECTS

Soil structure interaction is very complex phenomenon and its effect depends up on the many parameters including soil stratification, soil density, and wave propagation frequency. Few of these factors are discussed below.

- **Impedance contrast<sup>[4]</sup>**

Impedance contrast defined as the product of velocity and density of the material, thus varies the ground motion amplitude while travelling to the most heterogeneous soil media like soil. Seismic waves travels faster in hard rocks

as compare to softer rocks and sediments. As the waves passes from harder to softer media waves travels slower and in order to maintain the same earthquake energy attains the bigger amplitude.

- **Resonance<sup>[11]</sup>**

Resonance in earthquake phenomenon defined as the matching the magnitude of an excitation frequency (Frequency of earthquake wave) with the fundamental natural frequency of the system. Early attempts have been shown that the structural response against earthquake is different for fixed base analysis than the soil structure interaction analysis in frequency domain.

- **Damping in Soil<sup>[4]</sup>**

In dynamic analysis when the excitation/seismic waves travel through the soil mass the energy of the wave is dissipated due to the scattering the waves in to the infinite domain. Thus the energy loss takes place in this phenomenon is called as the radiation damping. The energy of the input waves also can be used in deformations of the soil mass due to which the changes the soil material properties and referred as a material damping. Absorption of energy occurs due to inelastic properties of medium in which the particle of a medium do not react perfectly elastically with their neighbour and a part of the energy in the waves is lost instead of being transferred through medium, after each cycle.

- **Trapping of Waves<sup>[4]</sup>**

Impedance contrast between adjacent layers of soil mass is one of the important factors which cause the wave trapping in the soil mass. Kawase (1996) has brought in observation in the 1995 Hyogo-kenNanbu earthquake which was the most destructive earthquake in Japan even though of moderate magnitude of 6.

- **Lateral discontinuities<sup>[11]</sup>**

Lateral discontinuities can be explained as the softer material lies besides a more rigid one and vice versa. The damages were observed in the Bhatwari- Sonar village during the 1999 Chamoli earthquake due to the layer of debris dumped situated below the stiff soil.

### III. LITERATURE REVIEW

[A] *“Behavioural study of dynamic soil structure interaction for piled raft foundation with variable sub soils by time history fem model”* by S.J. Shukla, Desai A.K. and Solanki C.H. published in *Int. J. of GEOMATE, June, 2015, Vol. 8, No. 2 (Sl. No. 16), pp. 1288-1292 Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan*

In this research, an iterative dynamic analysis was performed using SAP2000 program to carry out three dimensional time history analysis of non-linear soil-foundation-building models under a great earthquake ground motions. The interaction between the soil and structure is represented by Winkler spring model. The obtained results confirmed that the dynamic characteristics of soil structure system should be recommended for conservative nonlinear seismic response of the high building since it mitigates of earthquake hazards.

#### Details of the Problem

- Height - 90m
- Building Plane - 43.2 x 20.7m
- Column Dimension – 600mm x 600mm
- Beam Dimension – 250mm x 600mm
- Shear Wall Thickness – 300mm
- Piled raft foundation
- Analyse Type – Flexible approach (Winkler’s model)
- Thickness of raft – 1 m ,
- Area of raft – 1050.45 m<sup>2</sup>
- Pile Diameter, 1000 mm.
- Pile length (l)– 15m, 30m
- Spacing between piles :- 4.3 m atcentre,8.6 at edge
- Total no of piles:- 36 nos

This paper show that settlement in raft For ElCentro earth quake c soil gives settlement in the range of 22 to 32 mm where as c-φ soil gives it in the range of 12 to 17 mm which shows reduction of 45 to 55 % and φ soil gave 1 mm to 2 mm which shows reduction of 99% structure remain steady in all sub soil conditions because settlement within

permissible limits (65 to 100 mm for raft IS; 1904-1966) and for  $l = 30$  m,  $c-\phi$  shows reduction of 65 to 70 % and  $\phi$  soil shows reduction of 99% structure remain steady in all sub soil conditions because settlement within permissible limits (65 to 100 mm for raft IS;1904-1966 where as for Bhuj earthquake, structure fails for all sub soils for  $l= 15$  m.

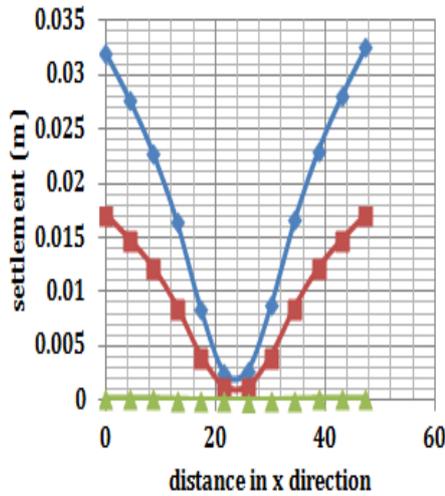


Fig A1

Settlement of raft in z direction for El Centro earth quake ( $l = 15$  m)

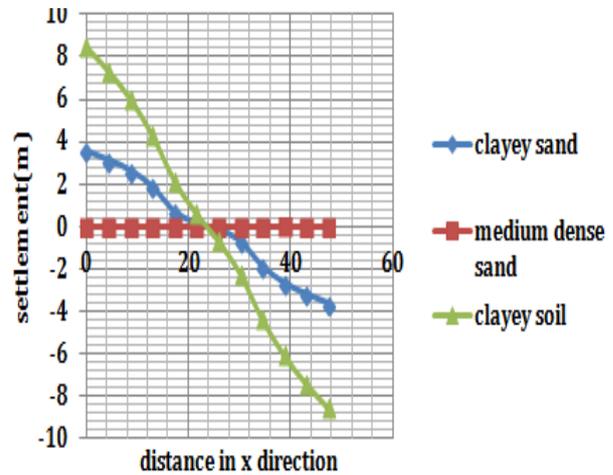


Fig A2

For bhuj earthquake settlement in z direction ( $l = 30$  m)

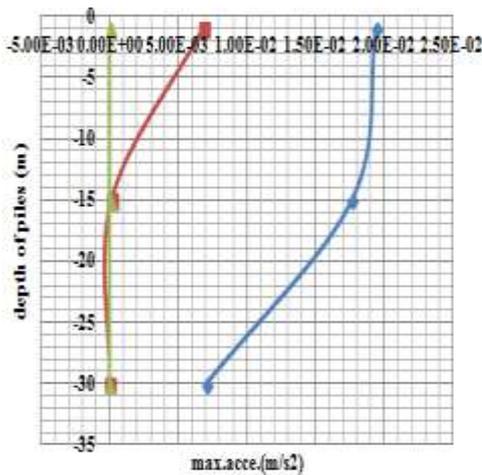


Fig A3

Maximum acceleration for El Centro earthquake.  $l = 30$  m

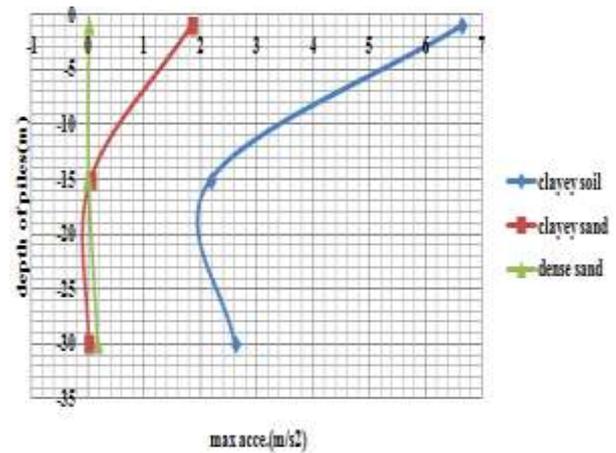


Fig A4

Maximum acceleration for Bhuj earthquake.  $l = 30$

[B] **“Optimisation Of Piled-Raft Foundation”** by **Prashant Garg, Harvinder Singh and Jagadanand Jha** (Guru Nanak Dev Engineering College Ludhiana, India) published in **International Journal of Advanced Engineering Technology/236015109**

In this research, a parametric study was carried out taking pile raft aspect ratio, space of pile to diameter ratio, thickness of raft, pile area to raft area ratio, settlement or differential settlement as variables and some guide lines are suggested to adopt various parameters of piled raft foundation elements and its geometry to optimise combined Piled Raft Foundation (CPRF). The foundation system was modelled using the PLAXIS 3D foundation finite element based software. Failure criterion for the soil media was defined using Mohr Coulomb model. Pile aspect ratio ( $l/d$ ), number of piles ( $N$ ), pile spacing ( $s/d$ ) and raft thickness ( $t$ ) were taken as variables of study. And conclude that At closer pile spacing, the overlapping of the stress-bulb and pile interference among themselves become responsible for the reduction in the carrying capacity while at very large pile spacing, it was contributed mainly by the strip, the load carrying capacity of the foundation system increases by adopting piles having higher value of  $l/d$  ratios which provides more interfacial shear resistance due to increase in the surface area at higher value of  $l/d$  ratio and number of piles in the foundation system and that the raft thickness does not have any appreciable effect on the load carrying capacity of the piled raft system.

Table B1 Summary of the key geometrical variables

Aspect ratio ( $l/d$ )	Spacing ratio ( $s/d$ )	Strip Thickness ( $t$ ), mm
10	3	300
15	4	400
20	6	500
25	8	600
30	10	700
35	12	800
40	14	900
45	16	1000
50	18	1100

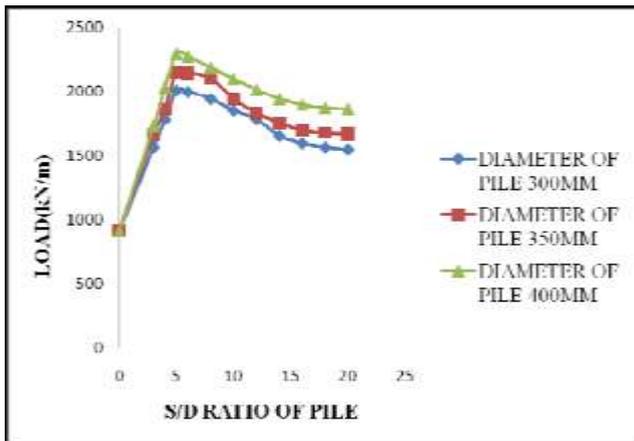


Fig B1  
Influence of s/d ratio on load carrying capacity of raft pile system

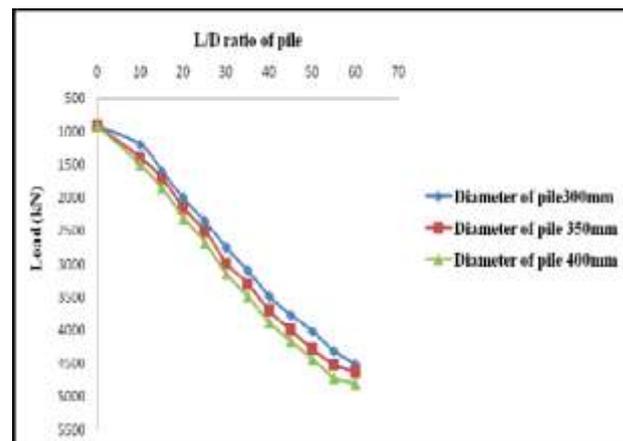


Fig B2  
Influence of l/d ratio on load carrying capacity of piled raft

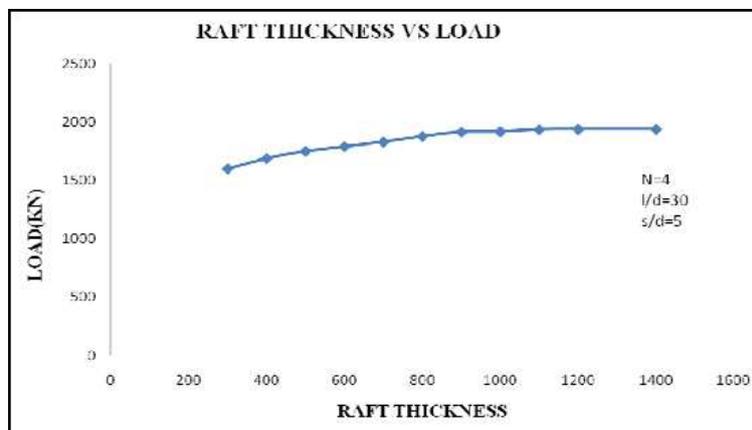


Fig B3  
Variation of the load carrying capacity with raft thickness

[C] **“The Effect of Raft Size and Pile Length on Load-Settlement Behaviour of Axisymmetric Piled Raft Foundation”** by Dilip Kumar Maharaj and Anshuman (Birla Institute of Technology and Science, Pilani, Rajasthan, India) published in *EJGP international journal* [www.ejge.com/2004/Ppr0351/Ppr0351.htm](http://www.ejge.com/2004/Ppr0351/Ppr0351.htm)

Nonlinear finite element analyses have been done to see the effect of raft size and pile length on the load settlement behaviour of axisymmetric piled raft foundation. Analyses have been done by NLAXIFEM-Nonlinear axisymmetric finite element software. The piles in the piled raft foundation have been represented as an equivalent annulus of same volume. The raft, pile and soil have been discretised into four node isoperimetric finite elements. The soil has been modelled as Von Mises elastoplastic medium. The load carrying capacity of raft foundation is found to increase with increase in size of the raft. This increase is not proportional to the increase in size of the raft. The effect of pile of length even equal to the diameter of the raft is found to reduce settlement of raft foundation significantly and also to increase load carrying capacity. Such piles of smaller length can be used successfully as settlement reducing piles in a piled raft foundation. The range of settlement reduction varies from 0 to about 50 percent. For the same size of raft and length of pile, with proportional increase of the two has been found to increase the initial overlap of the two load

settlement curves. The effect of increase in length of pile is to increase the load carrying capacity of piled raft foundation. For the same length of piles below raft, the improvement is more for smaller raft than that of the larger raft.

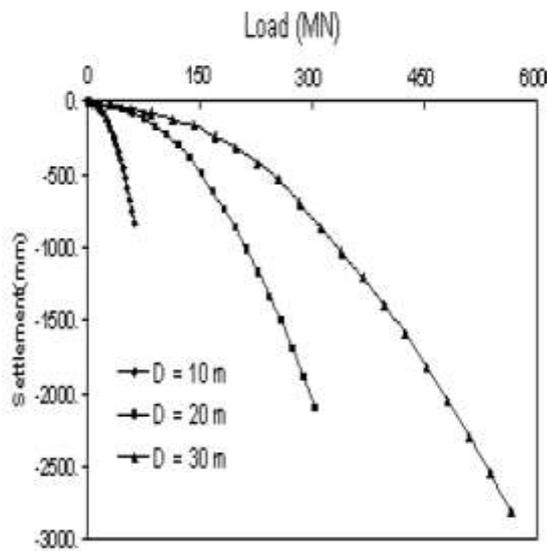


Fig. C1  
The effect of size of raft on load-settlement curves for raft foundation

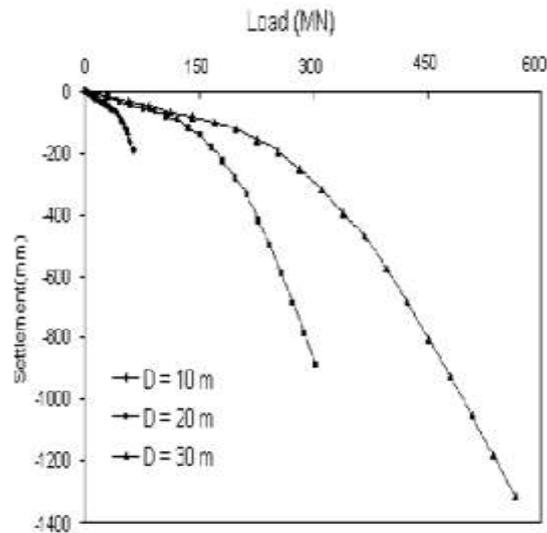


Fig. C2  
Load-settlement curves for piled-raft foundation for different diameter of rafts ( $l/d = 75$ ,  $S/d = 5$ )

**[D] “Seismic Response of Soil-Pile Foundation-Structure System”** by Saha, R.; Haldar, S.; Dutta, S.C. (School of Infrastructure, IIT Bhubaneswar, Bhubaneswar) Published in *Indian Geotechnical Conference – 2010, GEOTrendz December 16–18, 2010 IGS Mumbai Chapter & IIT Bombay.*

This paper presents an initial effort to investigate seismic response of soil-pile-structure system considering soil structure interaction effect. Soil-pile-structure system is considered to have an idealised one storey system consisting of a mass in the form a rigid deck supported by four columns. This in turn rests on raft foundation with pile. The piles are modelled by beam-column element supported by laterally distributed springs. A parametric study encompassing feasible variations of parameters is made under spectrum consistent ground motion. A significant change in shear force carried columns and that transmitted to soil is observed as compared to what obtained in fixed base condition due to the soil-structure interaction effect. Summarily study indicates that the column shear may be overestimated while total shear transmitted to soil may be underestimated if the base shear in fixed base condition is considered. The total shear transmitted closely reflects the design shear force to be carried by pile. Hence, there is a possibility of an over-safe column design and unsafe pile design from fixed base assumption. The issue needs further detailed investigation for modifying relevant clauses of design standards. This limited study indicates that columns may be overdesigned while pile may be under designed for structure supported on raft pile system in soft soil if a fixed base condition is considered. However, this is an indicative study which points out the need of making a further detailed study in this direction to avoid over safe column design and unsafe pile design.

**[E] “Non-Linear Analysis of Soil-Pile-Structure Interaction Under Seismic Loads”** by Yingcai Han and Shin-Tower Wang published in *The 14<sup>th</sup> World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.*

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. Stiffness and damping of the pile foundation are generated from a computer program *DYNAN*, and then input into a finite element model by *SAP2000* program.

To illustrate the effects of soil-pile-structure interaction on the seismic response of structure, three different base conditions are considered, rigid base, i.e. no deformation of the foundation; linear soil pile system; and nonlinear soil-pile system. An examination of the computation results for the seismic response of the vacuum tower structure, supported with different foundation conditions, suggests the following conclusions:

- The nonlinear behaviour of the soil-pile system can be simulated using the model of boundary zone. The validity of the model has been verified by dynamic experiments on full-scale pile foundations for both linear and nonlinear vibrations.
- The soil – pile interaction is an important factor which affects the stiffness and damping of foundation. The liquefaction of a layer of saturated fine sand can reduce the horizontal stiffness significantly, and further damage is possible.
- The soil-pile-structure interaction should be considered in a seismic analysis. The theoretical prediction for a structure fixed on a rigid base without the interaction does not represent.

[F] “Effect Of Raft And Pile Stiffness On Seismic Response Of Soil-Piled Raft-Structure System” by Rajib Saha, Sekhar C. Dutta and Sumanta Haldar published in *Structural Engineering and Mechanics*, Vol. 55, No. 1 (2015) 161-189

Exhibiting the possibility of increase in pile shear due to SSI. However, in this context, relative stiffness of raft and that of pile with respect to soil and length of pile plays an important role in regulating this effect. In this paper, effect of relative stiffness of piled raft and soil along with other parameters is studied using a simplified model incorporating pile-soil raft and superstructure interaction in very soft, soft and moderately stiff soil. It is observed that pile head shear may significantly increase if the relative stiffness of raft and pile increases and furthermore stiffer pile group has a stronger effect. Outcome of this study may provide insight towards the rational seismic design of piles. The effect of various parameters pertaining to piled raft foundation, such as relative stiffness of raft and soil, relative stiffness of pile and soil, slenderness ratio of pile, spacing of pile and soil consistency were outlined as controlling factors in design of such foundation. The objective of the present study is to gaze the increasing effect on seismic forces due to extra inertia contributed by raft influenced by various influential parameters associated with piled raft system. Effect of soil-pile foundation-structure interaction on seismic response of structures (primarily of ground storey columns and piles) encompassing different associated parameters, viz., relative stiffness of raft ( $krs$ ) and pile ( $kp=Ep/Es$ ), length to pile diameter ( $L/d$ ) ratios and pile spacing ( $s$ ) to diameter ( $d$ ) ratios ( $s/d$ ) of pile is studied in this paper. Results are presented in the form of normalised design forces at column and pile head to the same obtained due to fixed base idealization. Pile-soil deformation is considered to be linear. Dynamic effect during seismic shaking is attempted to be captured considering an idealized one storey system supported by piled raft foundation. This parametric study may provide crucial inputs in refining design guidelines of soil-pile raft-superstructure system.

#### IV. CONCLUSIONS

From the study of above research papers it can be concluded that,

- The soil – pile interaction is an important factor which affects the stiffness and damping of foundation. The liquefaction of a layer of saturated fine sand can reduce the horizontal stiffness significantly, and further damage is possible
- The soil-pile-structure interaction should be considered in a seismic analysis. The theoretical prediction for a structure fixed on a rigid base without the interaction does not represent the real seismic response, since the stiffness is overestimated and the damping is underestimated.
- The load carrying capacity of raft foundation increases with increase in size of the raft. This increase is not proportional to the increase in size of the raft.
- The piles configurations in raft have the most important effect on significantly reducing maximum settlement and the differential settlement, particularly by concentrating the piles in the centre of raft.

#### V. SCOPE OF WORK

As per the state-of art literature review on the Soil Structure Interactions analysis, it has been noted that among the available techniques Numerical modelling can best simulate the soil computational time required for the interaction analysis. The following points which need to address for carrying out the research on Soil Structure Interaction analysis for asymmetrical tall structure supported by pile foundation are as follows.

- Soil Structure Interaction analysis for the asymmetrical building supported with the pile foundation system.
- Soil Structure Interaction analysis for the tall symmetrical building supported by the pile foundation system.
- Soil Structure Interaction analysis considering the torsion in foundation system for the symmetrical and asymmetrical buildings.
- Soil Structure Interaction analysis considering the soil heterogeneity needs to carry out considering the effect of pore water.

The scope of the present study is to study Soil Structure Interaction effect for the pile supported asymmetrical buildings in the stratified soil. The study focuses to present a new numerical approach to optimize the computational time to get the results of the integrated SSI model with the direct approach.

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