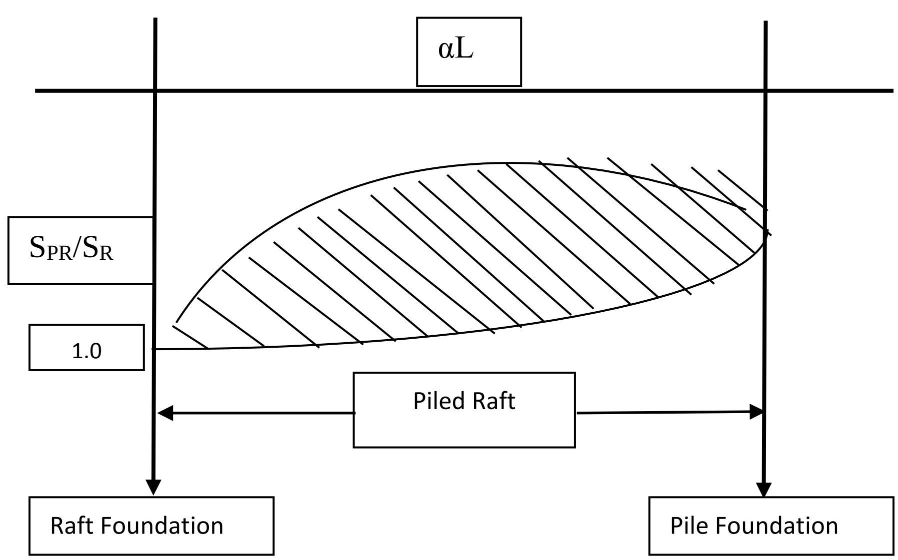
UNIT 1

INTRODUCTION

1.1 GENERAL

Piled rafts system is composite structure comprises of the raft, piles and soil (Figure 1.1). Under piled raft foundation system, raft is in direct contact with soil and is support by piles of different /similar properties. These foundation are subjected to vertical and horizontal loading, loads are transmit directly to soil by raft and piled of piled raft foundation system. The combine us of raft foundation with deep foundation element i.e. Pile foundation typically known as Piled Raft foundation is in practice from last few years. This typical foundation is adopted where there superstructure load is very high and soil strata beneath the structure don't have sufficient bearing capacity. Raft in piled raft foundation is of adequate bearing capacity and objective of installing pile is to control or minimize average and/or differential settlement. Piled raft foundation offers an economical explanation for modifying the serviceability of foundation in reducing settlement up to acceptable state. Piled raft foundation system is adopted at place where sub-soil condition is weak and foundation settlement is dominating in design of foundation system. The idea of pile-raft foundation is shown in Figure 1.1. A piled raft foundation offers an economical way to the difficulty of designing the foundation of heavily loaded building on soil of low bearing capacity.[1]



α_L = Load shared by piles/ Total Load :S_{PR} = Piled Raft settlement and S_R = Raft's settlement

Figure 1.1: Concept of Piled Raft [2]

1.2 NUMERICAL MODELING

Numerical modeling is considered as a medium in study of physical modeling. To solve partial differential equations which are derived from physical process, like heat transfer, stress and displacement, fluid flow and current flow, numerical methods are used. Simple stress and displacement problems in science and engineering are generally solved using equations of physics. In case of complex problem with non-linear material properties can only be solved by numerical methods.

Numerical models can solved variety of problems, therefore various codes have been developed. The number of available program is totally large and selection of moat suitable for a particular task is very important.

1.2.1 NUMERICAL MODELING METHODS

Finite element, discrete element, finite difference and boundary element methods, these are common numerical modeling methods which are generally used in science and engineering. Other methods are also available but these are mostly used methods. Each one has a certain physical and numerical conditions and it must be recognized which one is most appropriate for a particular problem.

1.2.2 FINITE ELEMENT METHOD

Finite element method is an intrinsic code which is based on continuum mechanics. In the finite element method, the area of problem is discretized into number of finite elements. The concerned equations are solved for each and every element and then combined to generate a combined solution. The finite element method includes the most flexible programs, and is generally used to solve various problem in science and engineering.

1.2.3 FINITE DIFFERENCE METHOD

The finite difference method is different from finite element approch is that it is an explicit method, which used an trial and error scheme to solve the equations of motion for each and every element and the equations are based on stress and force values and a specific difference from neighboring elements. The finite element and finite difference methods will give same results sometimes. In case of nonlinear model and large strain and physical instability, finite difference method is a more suitable choice. Because these conditions are applicable for rock masses, so finite difference method is well suited for rock and soil modeling.

1.2.4 DISCRETE ELEMENT METHOD

To model multiple blocks like rock masses discrete element method is used. Discrete element method is a dis-continuum code. This method admit finite displacement and rotations of finite bodies, and also allowed to detach completely from one another. Discrete element method self recognizes new contacts during calculations. Finite element and finite difference will not give accurate results in case of large number of discontinuities or large displacement occurs along discontinuities. Because of these unique characteristics discrete element method become ideal code for jointed rock mass modeling.

1.2.5 BOUNDARY ELEMENT METHOD

The another type of numerical modeling code is boundary element method. In this technique only the boundary has to be discretized. This method uses less time and computer resources in creating mesh and running of models. This method is suitable when the ore deposit is area of interest and the surrounding rock can be considered as one material

1.3 SCOPE OF STUDY

Present study consists of numerical analyzing of the influence of different design parameters of piled-raft foundation associated to piles, raft, soil and pile group that is (i) Pile diamter; (ii) Pile length; (iii) Number of Piles; (iv) Raft thickness and (v) soil's modulus of elastic (Es). For performing elastic analysis the soil considered to carry out the parametric study is a homogenous layer of (i) Sandy-silt deposit and (ii) Silty-sand deposit.

1.4 OBJECTIVE OF STUDY

In case of heavy structures where load coming over te foundation is extremely large raft foundation or pile foundations are preferable to use. Place where raft foundation has sufficient bearing capacity but settlement due to loading is not acceptable, so as to reduce settlement a pile group can be install bellow the raft foundation.

The position of this pile group will depend on the concentration of loading. Settlement influenced by different parameters of foundation system and soil deposits like diameter of pile, length of pile, raft thickness, number of piles, spacing ratio, elasticity modulus of foundation material and soil, soil parameters etc.

Main objective is to study the effect of (i) Pile Diameter (d); (ii) Pile Length (L); (iii) Number of Piles (n); (iv) Raft thickness (t) and (v) Soil's modulus of elastic modulus (Es) on settlement of foundation system and comparing the results obtained with the past studies.

For investigating effect of all the parameters mentioned in previous point, numerical analysis is to perform using Geo 5 software which is based on finite element method.

Effects of various parameters of soil and foundation have to analyse with the help of Geo 5 software and corresponding results were to compare with previous studies.

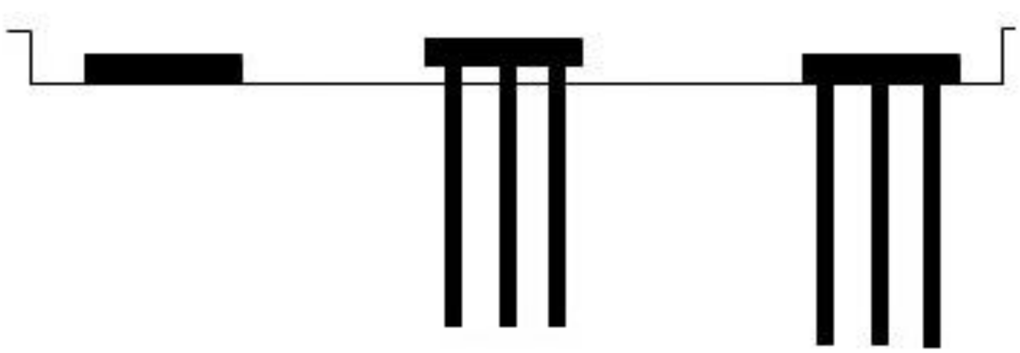
UNIT 2

LITERATURE REVIEW

2.1 IDEOLOGY OF DESIGNING PILED RAFT FOUNDATION

Contribution of both piles and cap acting as raft is taken into account in carrying design and service load in Piled raft foundation system. Some design philosophies for piled raft foundation systems[3]:

1. Convention Approach: Piles are designed mainly to carry major part load, at the other hand raft are design to carry small part of load.
2. Creep Piling: In this approach piles are design to carry working load (normally 70-80% of ultimate load capacity) at which considerable creep starts to happen. The raft is designed to carry major part of the foundation load. At the other hand piles are designed so as to minimize the net contact pressure among raft and soil below the preconsolidation pressure of the soil.
3. Differential Settlement Control: Under piled raft system, raft is mainly design to resist foundation loads and piles only carry small part of total load. Piles are placed strategically at different location beneath the raft in order to reduce average and/or differential settlement.



(a) Raft (b) Pile Group (c) Piled Raft

$\alpha_L=0$ $\alpha_L=1$ $0<\alpha_L<1$

Fig 2.1: Different foundation System and there Ratio of Load share [4]

Further more, one greater edition of creep piling, 100% load carrying capacity of piles is develop, in which few or all piles are function at 100% of there ultimate load carrying capacity.

This raises the use of piles preliminary as settelment reducer piles, on the other hand these piles also impart increase in the ultimate load capacity of complete foundation system.

Figure 1.3 shows, theoretically, action of settlement due to loading of piled raft foundation the load settlement actions of piled raft foundation designed based on variety of approaches. Curve 0 shows the performance of simple raft foundation that settles widely when design load is applied. Curve 1, shows typical design approach, in which performance of piled raft system is directed by group of pile, that can mainly linear when design load is applied. At this stage piles takes greater part of total applied load. Curve 2 explains the situation of creep piling where there piles are function at a less safety factor, but as there have few number of piles, raft bear large part of load compare to Curve 1. Curve 3 describes philosophy to use of piles as settlement reducers, developing the full capacity of the piles at design load. Therefore, it may possible that the load-settlement is non linaer at the design load, but however, in general foundation has an sufficient safety margin, and the settlement criterion is satisfied. Therefore, the design presented by Curve 3 is adequate and is likely to be significantly high reasonable than designs presented by Curves 1 and 2 [5].

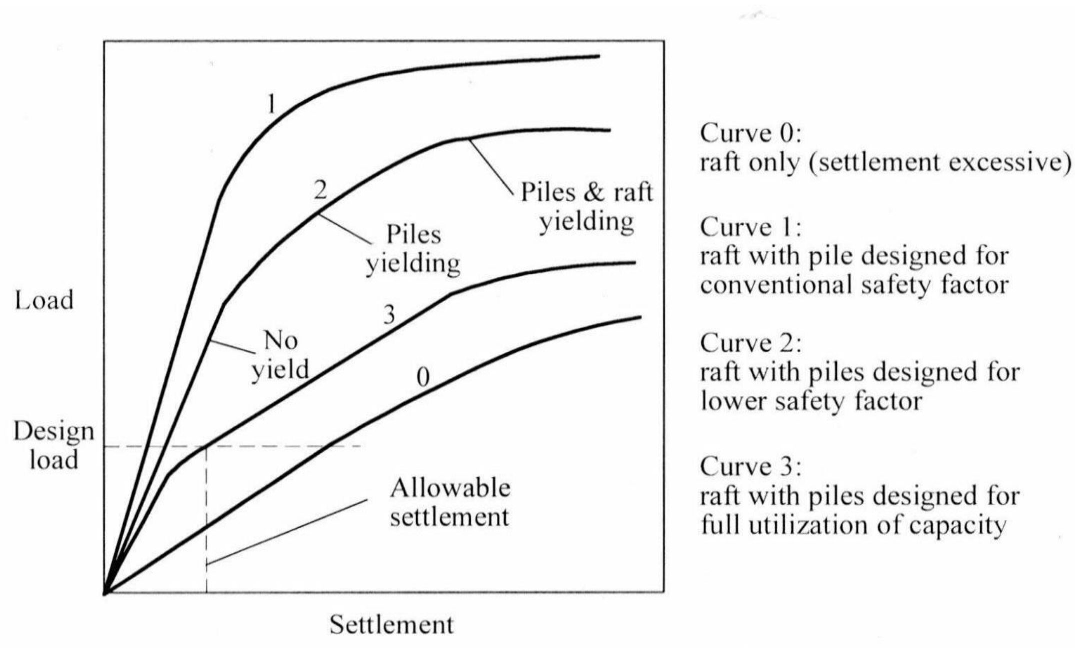


Figure 2.2: Load v/s Settlement Curve of piled rafts on the basis of different design philosophies [6]

Difference between two section of piled raft foundations[7]:

1. Small Piled Raft: In this system major cause of applying piles is to raise the safty factor. (basically consider raft of 5-15m wide)

2. Large Piled raft: Lad carrying capacity of this kind of foundation system is quite enough to carry structural load including sufficient margin of safety, but piles are introduced in this case to minimize settlement. In this case raft's width is quite large as that of pile length.

2.2 PROBLEMS IN DESIGNING PILED RAFT FOUNDATION

Some issues which must consider during design of piled raft foundation are as follows:

1. Ultimate load carrying capacity for vertical, lateral and moment loading
2. Maximum settlement
3. Differential settlement
4. Raft shear and moments, for the structural designing of raft
5. Pile load and moments, for the structural designing of piles

2.3 FACTORS INFLUENCING THE PERFORMANCE OF PILED RAFT

There are different issues which affect the performance and efficiency of piled raft foundation system, which must know for optimize design. Brief study of following issues shows that portion of load carried by piles and displacement of raft are considerably influenced by them. The major issues influencing the design are as follows[8]:

a. Physical and elastic properties of soil, raft and piles
b. Consolidation properties of different soil stratum.
c. Embedded length of piles.
d. Arrangement of pile like spacing ratio

In case when non uniform horizontal and vertical loading is applied on piled raft foundation using non identical piles can advance the performance of the piled rafts. In piled raft when vertical loading is applied, it is preferable to use long piles at the area of heavy loading. On the other hand in case of piled raft with horizontal loading piles of large diameter are more adequate to use.

2.4 DIFFERENT METHODS FOR ANALYSING PILED RAFT FOUNDATION

In present days numbers of techniques are available for the analysis of piled raft foundation. These techniques mainly categorized in 3 classes that are [9]:

a) Simplified calculation methods
b) Approximate computer based methods
c) More rigorous computer based methods.

These methods are given by different researchers9], [10] and [11]. All involve a number of simplifications in relation to the modeling of the soil profile and the loading conditions on the raft.

Approximate computer-based method:

- "Strip on springs" approach, series of strip fooing is assumed to act as raft and spring of sufficient stiffness is assumed to act as piles.
- "Plate on springs" Plate is assume to act as raft and spring is assume t ac as piles approach

More rigorous methods include*:*

- Boundary element methods, in this method piles and raft of the piled raft foundation are separated, and elastic theory is used for analysis

- Approach in which Methods combining boundary element method use for analyzing piles and use finite element method for analyzing raft

- Simplified finite element analyses, in this approach foundation structure are represented as plain strain or axis-symmetric problem [12]. An axi-symmetric problem and consequently finite difference analyses through the commercial program FLAC
- Three-dimensional finite element analyses [13] and [14] finite difference analyses

through commercial program FLAC 3D.

2.5 ADVANTAGES AND LIMITATIONS OF PILED RAFT FOUNDATION

When raft offers sufficient load carrying capacity and settlement controlled by arrangement of piles this will be the effective application of piled raft foundation, however the settlement of the raft alone exceed the allowable values. A modern application of piled-raft is its unique regulation to cases of foundation with large eccentricities and non uniformly loaded parts of structure to avoid the needs of composite settlement joints particularly below ground water table. The main advantages of piled raft foundation are:

- Decreasing of settlements, differential settlements and inclination.
- Increasing general stability of foundation
- Reduction in number of piles, while in straight approach of pile foundation system where load carried by raft is ignored resulting in increase of number of piles.
- Centralization of function and resistances for the cases of great eccentricities
- Reduction of the bending stress in the raft foundation.
- Cost minimization for complete foundation.
- Offers economical foundation system where structural loads are carried partly by piles and partly by raft.

Studied has been done on some uniform soil deposits, on the basis of studies he found ssome conditions which may acceptable for piled raft foundation [10]:

(a) soil profiles consist of comparatively stiff clays
(b) soil profiles consist of comparatively dense sands

In both situations, the raft can provide a important proportion of the required load capacity and stiffness, while the piles act as settlement reducer, somewhat than offering the mainly means of support.

From last few decays to support superstructure raft, pile group and piled raft foundation system are generally used in foundation design. Wide researches has bee carried out in past decades and plenty of methods have been developed for the analysis which are as follows:

a) Analytical Method
b) Numerical Method

In this chapter different literatures are reviewed and summery of those are arranged.

Three design ideas for the design of piled raft foundation system. These ideas are (a) Conventional method, (b) Creep Piling and (c) Differential settlement control. Other than these three ideas there is one more idea i.e. extreme version of creep piling in which full load capacity of piles are consume [5].

Method for analysis piled raft foundation. According to which bearing capacity of piled raft in vertical direction will be used lesser of the following two pressure values:

(a) Ultimate capacity including pile group and raft capacity.
(b) Ultimate capacity of section including raft, piles and the area of raft foundation which is out from the pile group.

2-D and 3-D finite element analysis for connected and non connected piles on three different case histories that are (a) 12 storey residential structure in Iran, (b) 39 storey twin towers in Indonesia and (c) 256m Messeturn tower in Germany. They had examined effect and function of different design parameters to optimize the design of piled raft foundation. According to parametric studies and some field measurements assessment results comes out that applying piled in central portion of raft foundation is more effective than any other position. This concentration of piles helps in optimizing piled raft foundation design with lesser total pile length, which is cost efficient also. They had also examine the effect of non connected piled raft foundation, in which settlement and raft internal bending reduces considerably by means of increasing sub soil deposit’s stiffness [15].

Salehi Malekshah (et. al. 2011) performed 3-D fiment element analysis using ABACUS software. They had gone through an alternate design approach to disconnect the piles form raft in piled raft foundation appearing as non connected piled raft foundation system. In general piles are introduced beneath the raft for the propose to reduce the settlement of foundation system, but in actual condition piles connected to raft have high stress developed in less number of piles. They had investigated piled raft foundation system on issues like raft thickness, pile arrangement and pile detachment on the performance of non connected piled raft foundation. Results comes out explains that while using non connected pies in piled raft foundation the value of maximum axial stress in piles reduces. Stiffness and altitude of cushion have more effect on the stress ratio of piles to entire applied load on raft. By increasing thickness of raft and applying longer piles in central portion of raft had considerable effect in minimizing the settlement of foundation system mainly differential settlement [16].

Use of finite element software i.e. ANSYS is an alternate approach for the analysis of piled raft foundation. Piles are slenderical structural element which spread the applied load of structure to deep inside the earth. But now a days use of piled raft foundation is increasing. To visualize piled raft foundation's performance a study has been made in medium dense sand, in which effect of varying diameter and length of piles in piled raft foundation. To find load carrying capacity and settlement of foundation plain strain non linear analysis in 2D is carried out in medium sand. This non linear analysis due to vertical loading is performed in finite element method based software i.e. ANSYS. This analysis shows that variation of pile diameter giver more effective influence over load carrying capacity of piled raft foundation, on the other hand variation of pile length have not much effective influence over load carrying capacity of piled raft foundation system [17].

A piled raft foundation design procedure for a high rise building on the Gold coast in Queensland Australia is described [18]. The designing of foundation system was carried out in some stages. First stage includes determination of geotechnical charactestics of site with the help of subsurface model which was prepared by borehole results at different points at that site. These results was further used for the determination of soil parameters. Raft and pile material's properties were found form empirical relations. Adopting arrangement of elastic theories primary investigation was performed to find the acceptable limit for non linear effect on foundation system. A comparison between piled raft and pile group also performed to investigate the feasibility of piled raft foundation over pile group. Later on in next stage the analysis was carried out with variations using GARP software which is based on finite element method and boundary element method.

Study of piled raft foundation with varying number of piles was studied where all other design parameters (diameter and length of pile, raft thickness and soil properties) are kept constant. Experimental investigation was carried out to find settlement of foundation model due to applied loading. Consolidation of disturbed kaolin carried out under restricted stress before starting of test. Different loading and number of piles are used for testing. Mobilization of skin friction was done before starting tests of model. Further more analytical investigation was done using PLaxis 3D software. Influence of varying number of pile and length of pile was investigated keeping all other parameters to be constant. It was concluded that after a limit, increasing number of piles there don’t have effective influence in reducing settlement [19].

Investigation of piled raft foundation’s settlement behavior was carried out using numerical analysis and field case study. Raft thickness and nonlinearity of soil was considered for the analysis proposes. Further more comparison of results obtained from numerical analysis was made with actual results (carried from field case study). During analysis, sub structure’s stiffness, soil deposit’s conditions were considered [20].

On piled raft foundation system and non connected pile group an optimization analysis was performed [21]. Variation of pile length was carried out in the analysis for the optimization of piled raft foundation system efficiency considering piles to be driven piles and load carrying capacity of pile group is due to frictional resistance. Optimization of pile group with non connected piles, different pile length, different size of raft and variation in pile group was carried out for foundation system. Conclusion came out from the above analysis is that an effective length of pile for the equivalent quantity of pile material reduces he settlement and increases the stiffness of piled raft foundation system. So adopting this optimization can effectively reduce the quantity of material required for the construction and increases the stability of foundation system.

For the analysis of piled raft foundation 3D fem model was generated [22]. This model was established in cohesionless soil whose stiffness is linearly increases with increase in depth. Influence of different design parameters of piled raft foundation was then analysed, which includes (a) influence of raft thickness, (b) influence of raft size and (c) influence of pile diameter.

UNIT 3

PARAMETRIC STUDY OF RAFT FOUNDATION AND PILE GROUP

3.1 GENERAL

A raft foundation is a large concrete slab used to interface one column, or more than one column in several lines, with the base soil. Thickness and stiffness of raft are design so that it can widen the applied load over large area. Raft foundation is favorable where base soil is of low bearing capacity and/or where structural load are great that more than 50% of total area can be covered by conventional spread footing. Raft foundation is also useful in reducing differential settlement in non-homogeneous soil. Raft foundation is designed such that applied stresses should be less than safe bearing capacity of soil. i.e. (a) Soil below foundation should not fail in shear and (b) Foundation Settlement should be in permissible limit.

3.2 ALLOWABLE SOIL PRESSURE FOR COHESSIONLESS SOIL

Bearing capacity in foundation system is load carrying capacity of soil which allows it to bear and transmit the applied load without shear and settlement failure. Ultimate Bearing capacity is the maximum pressure a foundation which would cause shear failure of foundation. Safe bearing capacity is the maximum amplitude of stresses a foundation can carry without any hazard of shear failure (irrespective to the settlement occur).Safe Bearing pressure or Net soil pressure for specified soil is the intensity of stress that cause permissible settlement or specified settlement for structure. Allowable bearing capacity is the maximum intensity of loading a foundation can withstand at which neither undergoes excessive settlement nor exceed net safe bearing capacity. In case of raft foundation on sand permissible settlement is 75mm [23]. For design of raft foundation allowable bearing capacity is used. Allowable bearing capacity for foundation design should be safe under shear criteria as well as in settlement criteria. Such that

$$q_{na} = q_{ns} \quad \text{if } q_{np} > q_{ns}$$

$$q_{na} = q_{np} \quad \text{if } q_{ns} > q_{np}$$

Where

q_{na}= Net allowable bearing pressure

q_{ns}= Net safe bearing capacity

q_{np}= Net safe settlement pressure

3.2.1 BEARING CAPACITY BASE OF SHEAR CRITERIA

Bearing capacity of foundation based on shear criteria for cohessionless soil, is calculated on the basis of formula shown below [24].

$$q_{nu} = \frac{2}{3} c N'_c s_c d_c i_c + q(N''_q - 1) s_q d_q i_q + \frac{1}{2} \gamma B N'_\gamma s_\gamma d_\gamma i_\gamma W'$$

Where

q = effective pressure at the base

W' = water table correction factor

N_c, N_q, N_γ = bearing capacity factors

s_c, s_q, s_γ = shape factor

d_c, d_q, d_γ = depth factor

i_c, i_q, i_γ = inclination factor

Values of bearing capacity factors, shape factors, depth factors, inclination factors and water table correction factors found out for IS code.

3.2.2 BEARING CAPACITY BASE ON SETTLEMENT CRITERIA

Bearing capacity of foundation based on settlement criteria [24] and [25], from which net soil pressure corresponding to permissible settlement of foundation.

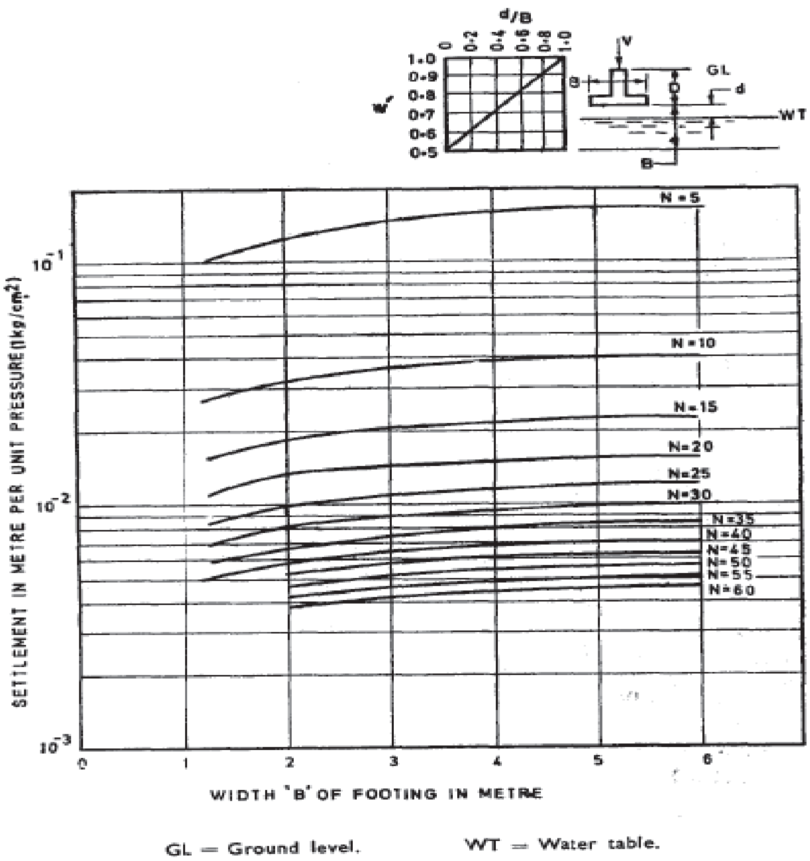


Fig 3.1 Settlement per unit pressure from standard penetration resistance[25]

3.3 CORRECTION FACTORS FOR WATER TABLE, DEPTH AND RIGIDITY AND ON TOTAL SETTLEMENT

Settlement calculated from fig 3.1 is total settlement, if water table is at great depth (below D_f + B) then there is no need for water table correction but if water table is at shallow depth (up to D_f + B) then water table correction factor is to the settlement read out from fig 3.1.Water table correction factor is also given in same fig 3.1

Correction is applied on total settlement if foundation is at certain depth. Depth factor will multiply to total settlement [25].

Corrected Settlement (S_{rd}) = S_t x Depth Factor

In case of rigid foundation (like Raft, heavy beams etc.) total settlement at centre of foundation should get reduce by rigidity factor.

$$\text{Rigidity Factor} = \frac{\text{Total aettlement of Rigid foundation}}{\text{Total settlement of flexible foundation}}$$

$= 0.8$

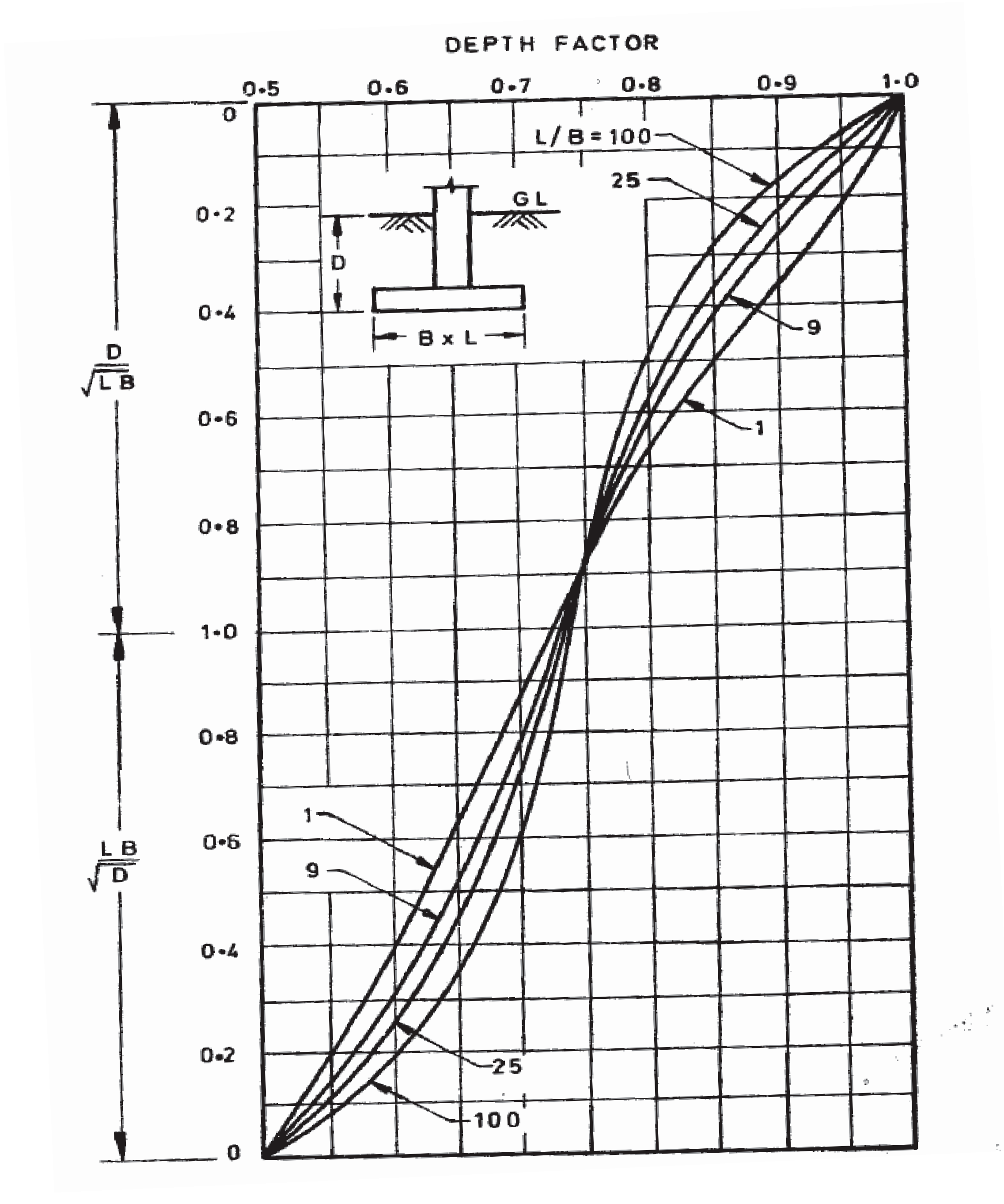


Fig 3.2 Fox's correction curves for settlements of flexible rectangularfooting of L x Bat depth D [25]

3.4 COMPUTATION FOR RAFT FOUNDATION

3.4.1 BEARING CAPACITY OF RAFT USING SHEAR CRITERIA

Water table = 5.7 m from ground surface

Unit weight of soil of 1st Layer=16.97KN/m^2

Unit weight of soil of 2nd Layer=17.38KN/m^2

Case of Local Shear failure

ANNEXURE-2.1.1 SOIL PROFILE & BORE LOG DATA

ALLIED ENGINEERS
JOB NO. M-4/2013-14/1676 SOIL PROFILE

SOIL INVESTIGATION FOR CONTSTRUCTION OF MULTISTORIED HOSTEL BUILDING AT DELHI TECHNOLOGICAL UNIVERSITY BAWANA ROAD - DELHI

WATER TABLE 5.70M) | LOCATION BH-1 | SHEET NO-1 RL-216.215 M

TYPE OF SAMPLE	DEPTH (m)	SUB SOIL PROFILE	SOIL DISCRIPTION AND CLASSIFICATION	SPT 'N' VALUES(Measured)	SPT 'N' VALUES(Corrected)	GRAIN SIZE DISTRIBUTION SIEVE ANALYSIS: GRAVEL	COARSE	MEDIUM	FINE	HYDROM ANALY: SILTY+ CLAY %	ATTERBERGS' LIMITS: LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SHRINKAGE LIMIT	DENSITY gm / cm³: BULK DENSITY	DRY DENSITY	MAX MOISTURE CONTENT (%)	SPECIFIC GRAVITY	FREE SWELINDEX (%)/ SWELL PRESSURE	RELATIVE DENSITY	SHEAR PARAMETER UCC,TXL: COHESION (C) (KG/CM²)	FRICTION ANGLE (∅)	CONSOLIDATION PARAMETER: [illegible]	COMPRESSION INDEX	STD. PROCTOR TEST MDD GM/CC/OMC %
GL			Brownish Colour Inorganic Sandy silt (ML)																						
SPT	1.50			14	19	2	2	1	25	70															
UDS	2.00					2	2	2	21	73					1.73	1.63	6.35	2.66			*DST/CUT 0.02	26.5	0.64		
SPT	3.00		Inorganic Silty Sand (SM)	16	19	3	2	3	62	30															
SPT	4.50			10	10	2	1	1	63	33															
UDS	5.00					2	2	2	69	25					1.74	1.63	6.78	2.65			*DST/CUT 0.00	30.5	0.63		
SPT	6.00			12	12	1	1	1	62	35															
SPT	7.50			13	12	2	1	1	63	33															
UDS	8.00					2	1	1	72	24					1.76	1.64	7.04	2.65			*DST/CUT 0.00	31.0	0.61		
SPT	9.00			17	15	1	1	2	73	23															
SPT	10.50			21	17	2	2	1	74	21															
UDS	11.00					2	2	3	70	23					1.77	1.65	7.26	2.65			*DST/CUT 0.00	31.5	0.61		
SPT	12.00			25	18	1	1	1	73	24															
SPT	13.50			20	16	2	2	1	72	23															
UDS	14.00					1	2	2	68	27					1.79	1.66	7.85	2.65			*DST/CUT 0.00	32.0	0.60		
SPT	15.00			30	20	2	1	1	62	34															

ST/CUT=CONSOLIDATED UNDRAINED DIRECT SHEAR *TXL/UUT=UNCONSOLIDATED UNDRAINED TXL

(a)

ANNEXURE-2.1.2 SOIL PROFILE & BORE LOG DATA

ALLIED ENGINEERS JOB NO. M- 4/2013-14/1676 SOIL PROFILE				SOIL INVESTIGATION FOR CONTSTRUCTION OF MULTISTORIED HOSTEL BUILDING AT DELHI TECHNOLOGICAL UNIVERSITY BAWANA ROAD - DELHI														WATER TABLE 5.70M)			LOCATION BH-1		SHEET NO-2 RL-216.215 M		
						GRAIN SIZE DISTRIBUTION SIEVE ANALYSIS				HYDROM ANALY	ATTERBERGS' LIMITS				DENSITY gm/cm³						SHEAR PARAMET UCC,TXL		CONSOLIDATION PARAMETER		
TYPE OF SAMPLE	DEPTH (m)	SUB SOIL PROFILE	SOIL DISCRIPTION AND CLASSIFICATION	SPT 'N' VALUES(Measured)	SPT 'N' VALUES(Corrected)	GRAVEL	COARSE	MEDIUM	FINE	SILTY+CLAY %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SHRINKAGE LIMIT	BULK DENSITY	DRY DENSITY	MAX MOISTURE CONTENT (%)	SPECIFIC GRAVITY	FREE SWELL INDEX (%)/ SWELL PRESSURE	RELATIVE DENSITY	COHESION (C) (KG/CM²)	FRICTION ANGLE (Ø)	[illegible]	COMPRESSION INDEX	STD. PROCTOR TEST MDD GM/CC/OMC %
SPT	16.50			28	18	2	1	1	65	31											*DST/CUT				
UDS	**17.00**		Inorganic Silty Sand (SM)			2	2	1	69	26					1.80	1.66	8.12	2.65			0.00	33.0	0.59		
SPT	18.00			19	14	1	1	1	62	35															
SPT	19.50			23	16	2	2	1	22	73											*DST/CUT				
UDS	**20.00**		Inorganic Sandy silt (ML)			1	2	2	23	72					1.82	1.67	8.68	2.66			0.03	29.50	0.59		
SPT	21.00			71	33	1	2	2	72	23															
SPT	22.50			43	22	1	2	2	73	22											*DST/CUT				
UDS	**23.00**					2	1	2	71	24					1.83	1.67	9.85	2.65			0.00	33.5	0.59		
SPT	24.00			46	23	1	1	1	72	25															
SPT	25.50			56	26	2	2	1	73	22											*DST/CUT				
UDS	**26.00**					1	2	3	68	26					1.84	1.66	10.56	2.65			0.00	34.0	0.59		
SPT	27.00		Inorganic Silty Sand (SM)	56	26	3	3	2	62	30															
SPT	28.50			60	26	2	2	2	63	31											*DST/CUT				
UDS	**29.00**					2	2	2	71	23					1.85	1.66	11.57	2.65			0.00	34.5	0.60		
SPT	30.00			64	27	1	1	1	72	25															
	30.45																								

DST/CUT=CONSOLIDATED UNDRAINED DIRECT SHEAR *TXL/UUT=UNCONSOLIDATED UNDRAINED TXL

(b)

Fig 3.3 Borehole data of DTU soil

Average corrected SPT = 19.45

Average of angle of internal friction (Φ) = 31.6º

Angle of internal friction for local shear failure (Φ') = $tan^{-1}(\frac{2}{3}\tan \Phi)$

= 22.3º

Depth of the foundation = 4m

Dimensions of foundation = 30m x 30m

Bearing capacity factors

$N_c' = 17.54$, $N_q' = 8.36$, $N_\gamma' = 7.92$

Shape factors

$s_c = 1.3$, $s_q = 1.2$, $s_\gamma = 0.8$

Depth factors,

d_c = 1.048, d_q = d_γ = 1.04

Inclination factor

i_c = i_q= i_γ = 1.0

Effective overburden pressure= (16.97x2.5)+(17.38x1.5)=68.495KN/m^2

Net ultimate bearing capacity adopting IS Code: 6403-1981

$$q_{nu} = \frac{2}{3} cN'_c s_c d_c i_c + q(N'_q - 1) s_q d_q i_q + \frac{1}{2} \gamma B N'_\gamma s_\gamma d_\gamma i_\gamma W'$$

q_{nu}=688.07 KN/m^2

q_s=229.36 KN/m^2

3.4.2 BEARING CAPACITY USING SETTLEMENT CRITERIA

From IS 1904-1986: Permissible settlement for raft foundation = 75mm

Corrected Average Standard Penetration Number (N_{Avg}) =19.45

Depth Factor = 0.96

Rigidity Factor = 0.8

Water table correction factor = 0.6

Corresponding Settlement (meter per 100 KN/m^2) = 0.018m

Soil pressure calculation [25]

Soil pressure based on settlement of 0.018m = 361.11KN/m^2

Dividing by Depth and Rigidity factor and multiplying by water table correction factor

Allowable soil pressure from settlement criteria= 282.12 KN/m^2

3.5COMPUTATION FOR NUMBER OF FLOORS IN CASE OF RAFT FOUNDATION

Dead load and Imposed load on structure is considered based on code [26]. Structure on raft foundation is assumed to be residential structure. Different types of imposed loads for different habitations are as follows:

(a) Imposed load due to for habitable rooms, kitchens, toilet and bathrooms = 1.5KN/m^2
(b) Imposed loads due to corridors, passages and staircases including fire escapes = 1.5 KN/m^2
(c) Balconies = 3.0KN/m^2

Dead load to each floor = 5.0 KN/m^2

Flat, sloping or curved roofwith slopes up to and including10 degrees = 1.5 KN/m^2

Total loads = 12.50 KN/m^2

Factored load = 12.50 x1.5 = 18.75 KN/m^2

Total factored load from each floor = 18.75 KN/m^2

Bearing capacity of raft foundation = 229. 36 KN/m^2

Number of floors = total floor load/ load coming from one floor

= 229.36/18.75

= 12.23 ≈ 13 floors

3.6 NUMERICAL MODELING FOR RAFT FOUNDATION

Analysis of raft, pile group and piled raft can be easily done using finite element methods. In this report numerical models of raft foundation, pile foundation and piled raft foundation was prepared and analyzed using ‘Geo 5’ software. In this software FEM program allows for the modeling of various types of problems and analyses. Two basic type of problems can be analyze in this software i.e. axis symmetry and Plain strain. In modeling and analysis of raft, pile and combined piled raft foundation plain strain type analysis method is selected.

3.6.1 METHODOLOGY OF NUMERICAL MODELING

Geo 5 (Geo Structural Finite Element Analysis) software can be use for solving geotechnical problems, analysis is based on finite element method. Geo 5 16.13(6.0) is used for the work [27]. In this software model preparation and analysis can be done either in axis symmetry or in plain strain. Plain strain method is used for this study and analysis performed using the GEO 5 – FEM program.

3.6.2 GEO 5 ANALYSIS

Establishment of vertical extents and lateral extents of the influence zone under the raft is difficult. Though, by taking adequately large soil mass into account, the effects of soil-structure interaction can be adequately taken care of. Accordingly, a large soil mass of rectangular cross-section, having a depth equal to 30m and a width equal to three times the raft width, is considered in each case. The elastic properties of the soil, Young's modulus and Poisson's ratio are given as input. Procedure of analysis can mainly divided into three parts on the basis of construction stages comes in software. The following paragraph provides the systematic explanation of the steps procedure for complete analysis:

- Topology: settings for and modeling of the problem (interface, free points, free line, soil properties and mesh generation)
- Construction stage 1: water table depth and primary geostatic stress.
- Construction stage 2: modeling and loading on beam elements(raft), settlement analysis

a) Initially select new project for the analysis (Geo 5 have two different unit system for the analysis). Present work is performed on metric unit. Give task name, part, date and other information regarding to analysis work.
b) Select project type plain strain, analysis of stress type and analysis method of geostatic (geo static analysis will held in 1^{st} stage of construction)
c) Adequately large zone of finite soil strata were selected length of which is three times the length of raft with raft at centre, depth of soil strata 30m as the influencing zone.

Interface given to the depth where soil properties are changing so as to distinguish between to soil deposits.

d) After defining interface, soil property is to give. Material model of Mohr- Coulomb is selected for different soil deposits and then assign all these soil properties to corresponding layers of soil.

Table 3.1 :Soil properties used in software

`Layer no.	Type of soil	Density of Soil (kN/m^3) γs	Angle of internal friction Φ	Dilation angle ψ	Poisson's Ratio μ_s	Modulus of elasticity of soil (kN/m^2) E_s
1st	Sandy silt	16.97	26.5	0	.3-.4	20000-50000
2nd	Silty sand	17.38	31.6	1.6		
3rd	Sandy silt	17.85	29.5	0		
4th	Silty sand	20..05	34	4		

e) After assigning soil properties points were selected at the depth of 4m below ground level where foundation is to place. After then mesh generation is to perform. Till step (e) Topology is complete.

While mesh generation, program automatically introduce standard boundary conditions. For the analysis proposes 3 node triangular elements with mesh smoothening were used. Mesh generation parameters includes:

- Edge length(taken as 1m in the analysis
- Mesh smoothening
- Generate multi-node elements
- Generate mixed mesh

f) Now 1st stage of construction is start, where location of ground water table is inputted.

g) After giving GWT location 1st analysis is to done, where analysis is done to find geostatic stress.

h) Now 2nd stage of construction is started in which soil layer above the foundation level is deactivated.

i) Raft is generated over points which are defined in topology. These points have distance equal to length of raft. Rectangular wall of 1m thickness is selected as raft and concrete as raft material. Properties of raft are tabulated in table no 3.2

j) Area of soil deposit is then supported. And vertical cuts of both side are fixed in x and z direction.

k) Loading is given in the form of surcharge. In which surcharge of strip loading at terrain of 4 m below ground level is applied. Loading given is equal to safe bearing capacity of foundation.

l) After application of load final analysis is perform which gives the settlement of raft. Analysis performed in construction stage 2 also gives the stress contour, strain contour and displacement contour for the applied load.

Table 3.2: properties of raft material (concrete)

Elements of Structure	Poisson's ratio μc	Modulus of Elasticity (kN/m^2) Ec	Unit weight (kN/m^3) γc
Raft	0.2	$30x10^6$	25

3.6.2.1 CORRELATION BETWEEN E_S AND $N_{CORRECTER}$ OBTAINED FROM SPT

To get fair result from numerical model that should be near to analytical model selection of E_S and μ of soil is very important. Different researchers have given empirical relation between modulus of elasticity of soil and SPT number, which are as follows [28], [29], [30] and [31]:

Table 3.3: Empirical relations given by different researchers

Researcher	Relationship	Soil type
Begemann (1974)	$\frac{E}{p_a} = 40 + C(N_{60} - 6)$ for $N_{60} > 15$ C=3 for silty sand =12 for gravel with sand $\frac{E}{p_a} = 40 + C(N_{60} + 6)$ for $N_{60} < 15$	Sand
Kulhawy and Mayen (1990)	$\frac{E}{p_a} = \alpha N_{60}$ α=5 for sand with fines; 10 for clean normally consolidated sand; and 15 for clean over consolidated sand	Sand
Trofimenkov (1974)	$\frac{E}{p_a} = (350 \text{ to } 500)\log N_{60}$	Sand
Webb (1969)	$\frac{E}{p_a} = 5(N_{60} + 15)$	Sand
	$\frac{E}{p_a} = 3.33(N_{60} + 5)$	Clayey sand

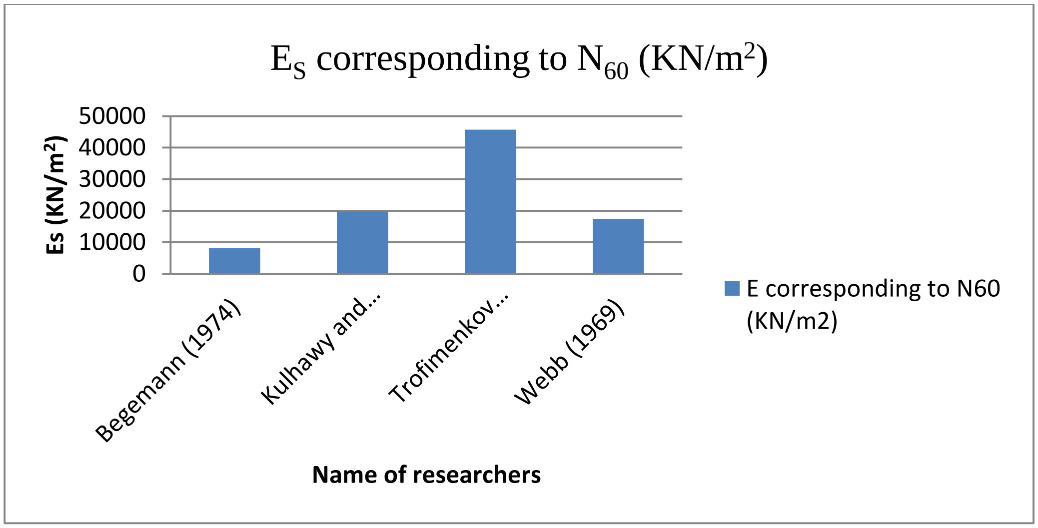


Fig 3.4 E_S v/s Empirical formulae

3.6.2.2 BACK ANALYSIS

To get fair results and for proper simulation between numerical modeling results and analytical model results back analysis is performed. Modulus of elasticity and Poisson's ratio is varied within the range of sandy soil's modulus of elasticity and Poisson's ratio. Most suitable value that gives almost same results from analytical and numerical model is selected.

Table 3.4: Settlement vs Modulus of Elasticity of Soil

	Poisson's ratio			
	0.3	0.35	0.4	0.45
Settlement (mm) for Es=20000 (KN/m^2)	217.00	162.80	148.40	127.40
Settlement (mm) for Es=30000 (KN/m^2)	138.10	115.10	104.0	87.10
Settlement (mm) for Es=40000 (KN/m^2)	107.10	88.70	79.90	67.60
Settlement (mm) for Es=50000 (KN/m^2)	87.5	72.10	64.7	54.60

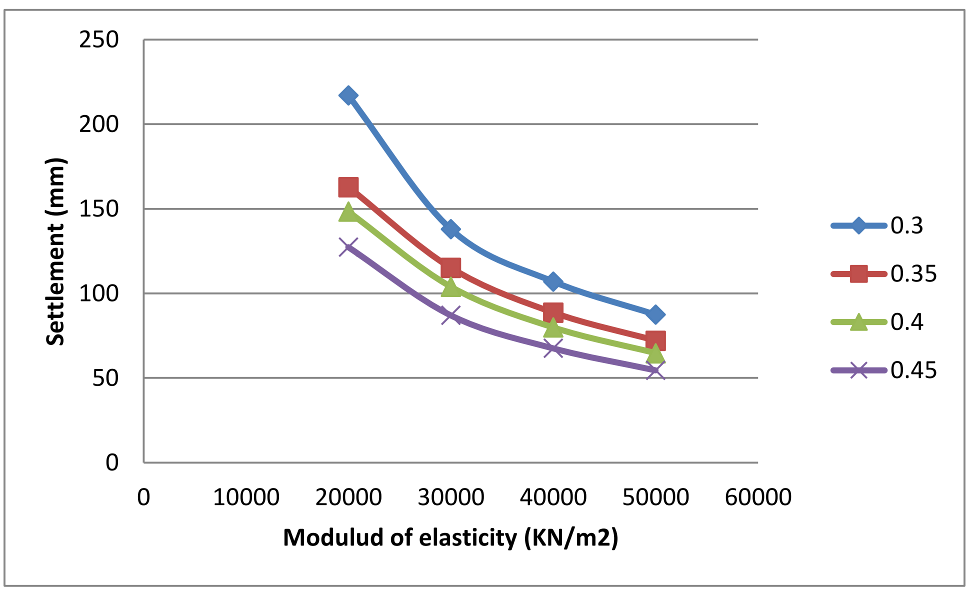


Fig 3.5 Settlement v/s modulus of elasticity corresponding to different values of Poisson's ratio

Modulus of elasticity of sol E_s =50000 KN/m^2 and Poisson's ratio = 0.4 from back analysis gives fair satisfactory settlement value which is similar to that of analytical method. So there values are selected for additional use of this work.

3.6.2.3 RESULTS OF GEO 5 2D

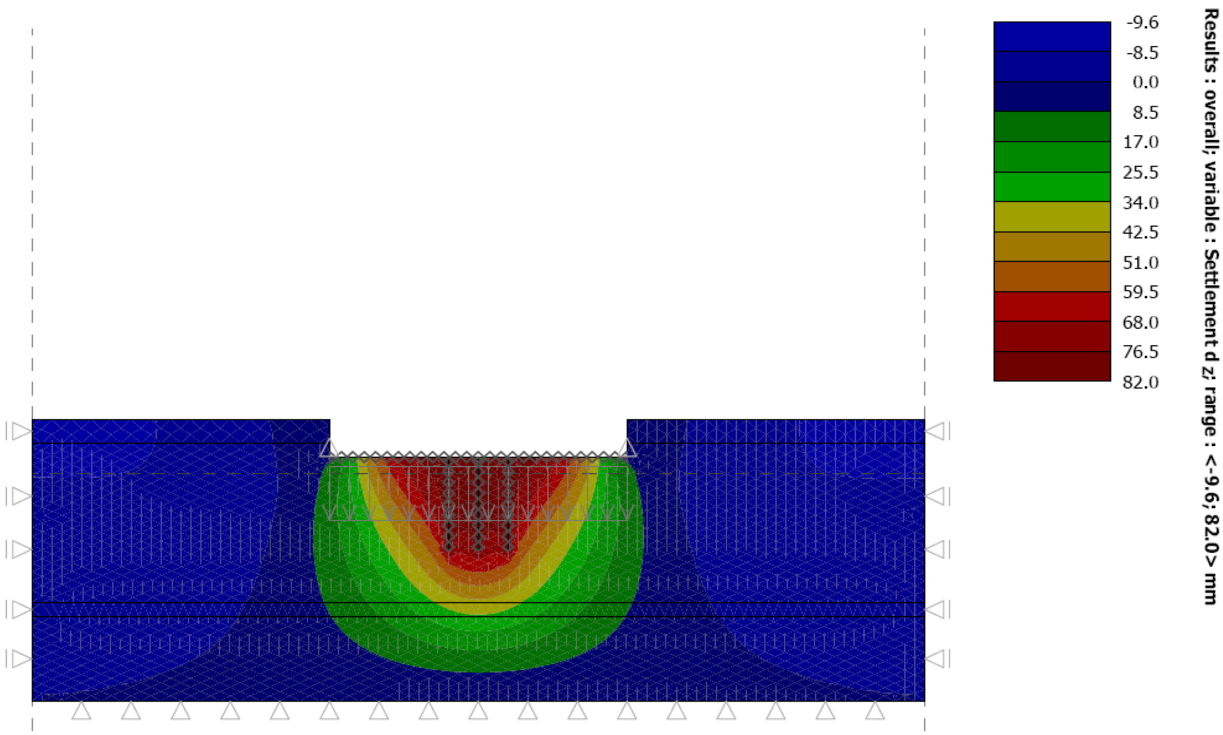


Fig 3.6 Settlement contour for raft foundation

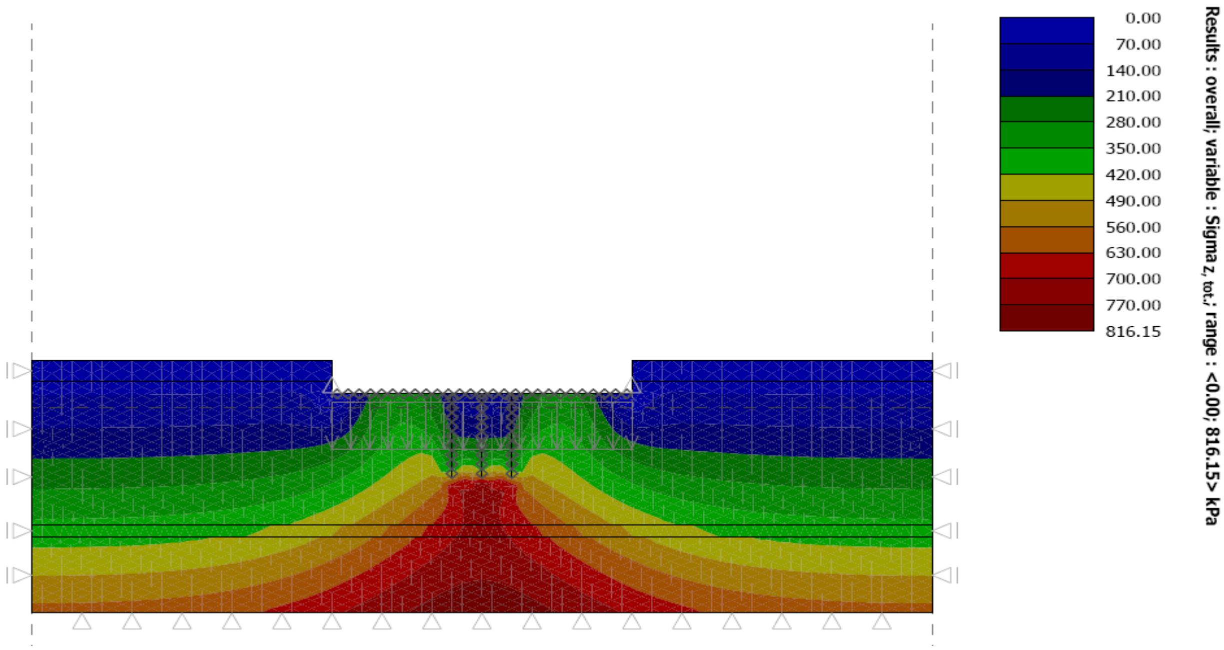


Fig 3.7 Stress contour for raft foundation

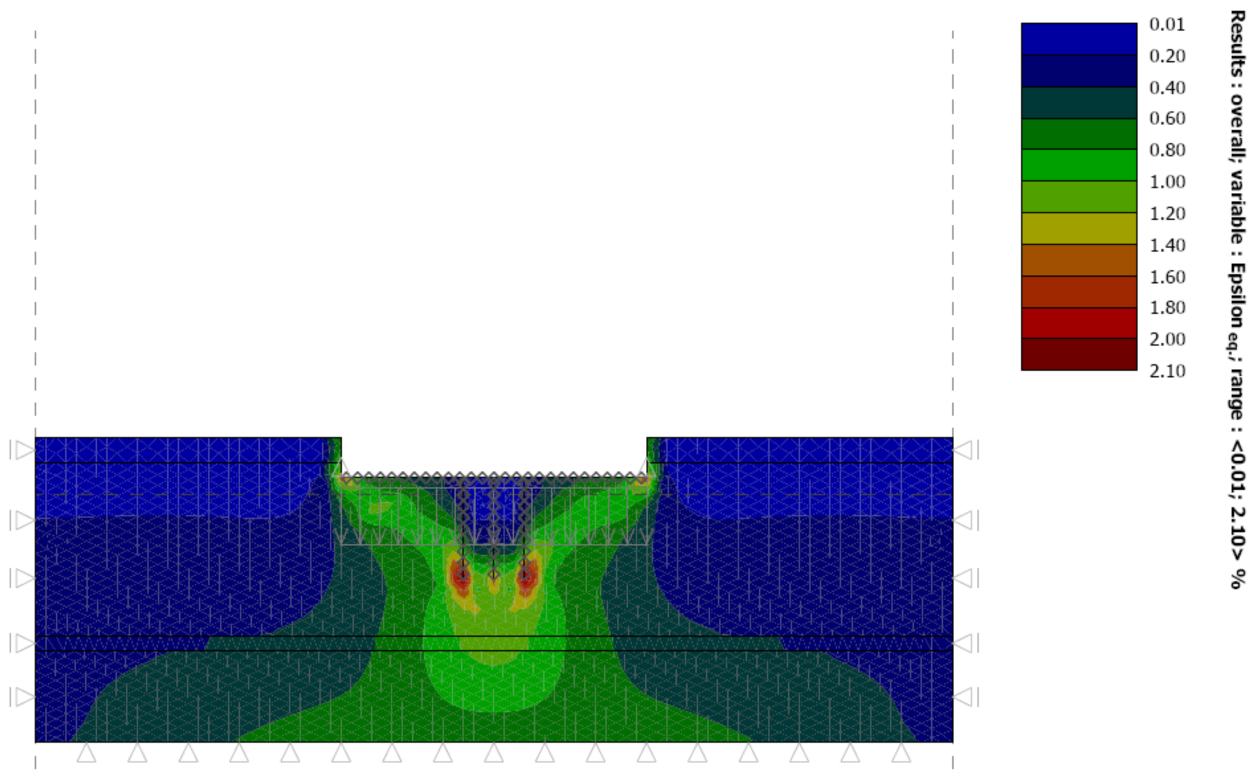


Fig 3.8 Strain contour for raft foundation

3.6.3 PILED FOUNDATION/ GROUP

Piles are kind of deep foundations, they are relatively long, slender members that are driven into the ground or cast-in-situ. Load transfer mechanism with soil strata due to pile load is very complex and difficult to realize. On the basis of load transfer mechanism, piles are of two type (a) Friction pile and (b) End bearing pile. The type of pile foundation to be select will depend on sub-soil condition, applied load and some other factors.

3.6.3.1 PILE GROUP- LOAD CARRYING CAPACITY

The capacity of a pile group is not necessarily the capacity of the individual pile multiplied by the number of individual piles in the group. Disturbance of soil during the installation of the pile and overlap of stresses between the adjacent piles, may cause the group capacity to be less than the sum of the individual capacities. In case of driven friction piles load carrying capacity of pile group is equal to 2/3 to 3/4 times the multiplication of number of piles and individual pile capacity (NQ_u). For friction piles connected with rigid pile cap, the group may be considered as a block with piles embedded within the soil.

3.6.3.2 LOAD CARRYING CAPACITY OF INDIVIDUAL PILE

The ultimate load capacity (Q_u) of piles in sandy soil is given by the formula [32]

$$Q_u = A_p\left(\frac{1}{2}D_\gamma N_\gamma + P_D N_q\right) + \sum_{i=1}^{n} K_i P_{Di} tan\delta_i A_{si} \quad \ldots\ldots.1$$

The first term giving end bearing resistance and the second term gives skin friction resistance.

Where,

A_p= cross sectional area of pile tip, in m^2

D = diameter of pile shaft, in m;

γ = effective unit weight of soil at pile tip, in kN/m^2

N_γ , N_q = bearing capacity factors depends on the angle of internal friction Φ

P_D = effective overburden pressure at pile tip, in kN/m^2

$\sum_{i=1}^{n} =$ Summation for layers 1 to *n* in which pile is installed and which contribute to positive skin friction;

K_i = coefficient of earth pressure applicable for the i_{th} layer

P_{Di} = effective overburden pressure for the i_{th} layer, in kN/m^2

δ_i = angle of wall friction between pile and soil for the i_{th} layer; and

A_{si} = surface area of pile shaft in the i_{th} layer, in m^2

3.6.3.3 COMPUTATION FOR PILE GROUP

Average angle of friction (Ø_{avg}) = 31.5

Number of piles = 3x3 = 9 piles

Diameter of pile = 1.0m

Length of the pile = 15m

Spacing = 3d = 3m c/c

Individual pile capacity

$$Q_u = A_p\left(\frac{1}{2}D_\gamma N_\gamma + P_D N_q\right) + \sum_{i=1}^{n} K_i P_{Di} tan\delta_i A_{si}$$

δ_i = .75Φ = 23.25, N_q = 25, A_{si} = πDL, K_i= 0.5

Q_u = 462.145KN

Pile group capacity = 462.145 x 9 = 4159.305 KN

Safe load on pile group = 4159.305/3 = 1386.435 KN

Safe group capacity = 86.65 KN/m^2

3.6.3.4 SETTLEMENT OF PILE GROUP

$$S_g = \frac{9.4\, q\sqrt{B_g} I}{N} \qquad [34]$$

S_g = settlement of pile group (mm)

q = Load intensity = Q_g/A_g

B_g = width of the group.

I = influence factor = $[1-D/(8B_g) \geq 0.5]$

D = length of pile

N = corrected standard penetration number within the seat of settlement

q = 86.65 KN/m^2

B_g = 7 m, I =[1-15/(8x7)] = 0.732, N = 19.45

Group settlement = 30.45 mm

3.6.3.5 SETTLEMENT OF PILE GROUP IN GEO 5

A model of pile group consisting 9 piles is generated in Plaxis 2D. Length of pile group is 15m and spaced at 3m center to center. 1m diameter piles are arranged in square pattern. Thickness of pile cap is assumed is 1m having offset 0.5m from the center of pile. After defining geometry load of 40.402KN/m^2 is applied and mesh is generated. Now go to calculation stage and obtain the settlement for pile group.

Table 3.5 Properties of concrete piles and pile cap

Element of structure	Length (m)	Diameter (m)	Thickness (m)	Modulus of elasticity (KN/m^2)	Poison' s ratio
Pile	15	1	-	$30x10^6$	0.2
Pile cap	-	-	1	$30x10^6$	0.2

Table 3.6 Properties of soil for pile group

Soil type	Modulus of elasticity (KN/m^2)	Poisson's ratio	Unit weight (KN/m^2)	Angle of friction
Silty sand	20000	.25	17.58	31

3.6.3.6 STEPS FOR ANALYSING PILE GROUP

Steps for analyzing pile group in Geo 5 is similar as that of analysing raft foundation, only 2 difference are there (i) assigning interaction between to consecutive piles and (ii) input of points for installing piles.

Assigning of interaction between to consecutive piles, requires two determine shear stiffness (K_s) and normal stiffness (K_n) of the system formulae of which are as follows[27]

$$K_n = \frac{E}{t}$$

$$K_s = \frac{G}{t}$$

Where

E= Elastic modulus of foundation material

G= Shear modulus of foundation material

t= Assumed thickness of contact layer

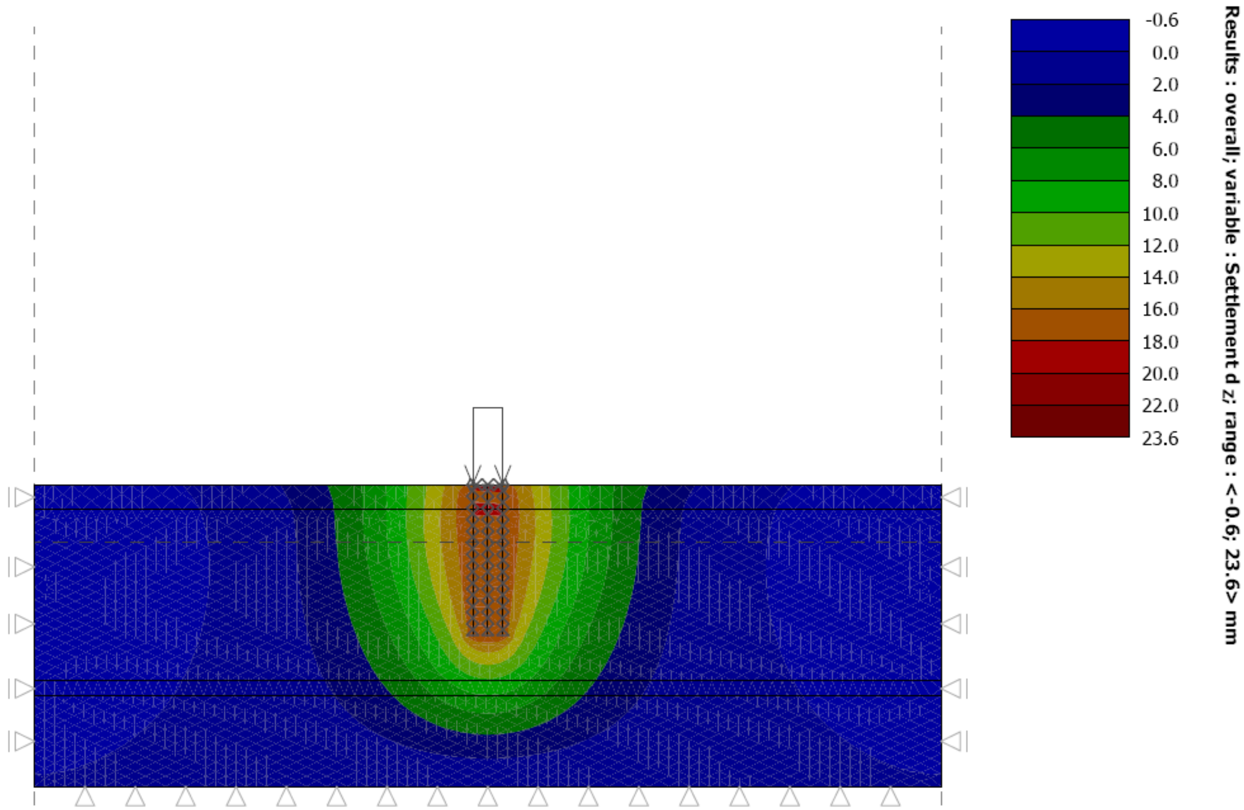


Fig 3.9 Settlement contour of pile group for pile length 15m

Settlement =23.6

Value of settlement calculated using IS 2911(Part 1/Section 1) :2010 is 30.45mm and from numerical analysis settlement is 23.6 mm.

UNIT 4

PARAMETRIC STUDY OF PILED RAFT FOUNDATION

4.1 PROPERTIES OF A SOIL USED IN ANALYSIS

A borehole of DTU soil was considered for this parametric study which is a silty sand and sandy silt. Safe bearing capacity calculated in the previous chapter is 229.36 KN/m^2. Stress applied on foundation for study is increased from 229.36KN/m^2 to 400 KN/m^2 . Properties of the soil are taken from literature is given in Table 3.

Table 4.1: Properties of Soil Strata

Soil type	Modulus of elasticity (KN/m^2)	Poisson's ratio	Unit weight of soil (KN/m^2)	Cohesion c (KN/m^2)	Angle of friction (Φ)
Silty sand	20000, 30000, , 40000, 50000	0.3-0.5	17.56	0.00	31.6

4.2 PROPERTIES OF CONCRETE USE IN PILES AND RAFT FOR ANALYSIS

Material of pile and raft was selected as of concrete and assumed to be elastic. Properties of concrete for pile and raft preferred is mentioned in table 7

Table 4.2: Properties of concrete

Parameter	Pile	Raft
Grade of concrete,	M35	M35
Young's modulus, E	30 x 10^6	30 x 10^6
Poisson's ratio, μ	0.2	0.2
Type of behavior	Linear, isotropic	Linear, isotropic
Pile type	Circular	-
Diameter, D m	1.0	-
Raft thickness	-	1.0

4.3 ARRANGEMENT OF PILES AND RAFT

At the staring for the modeling of piled raft, a pile group of nine piles has been considered which was placed in the center of raft. Piles are alike, same material (concrete) uniformly spacing, square arrangement, pile diameter chosen is 1m and length is 10m. spacing is 3d(3m c/c). Length of the piles is varied from 10m, 15m and 20m. Spacing ratio between the piles are varied between 3 to 5.

4.4 ANALYSIS OUTPUT

Modulus of elasticity (E_s), Pile length (L), Spacing ratio (S/d), Number of piles i.e. pile group of 3 x 3 to 5 x 5 piles and Pile diameter is varied in this parametric study, Variation of settlement with variation of modulus of elasticity, pile length, pile diameter and spacing ratio are tabulated and results are plotted in graph. . The results obtained for various combinations are tabulated and plotted in the graph.

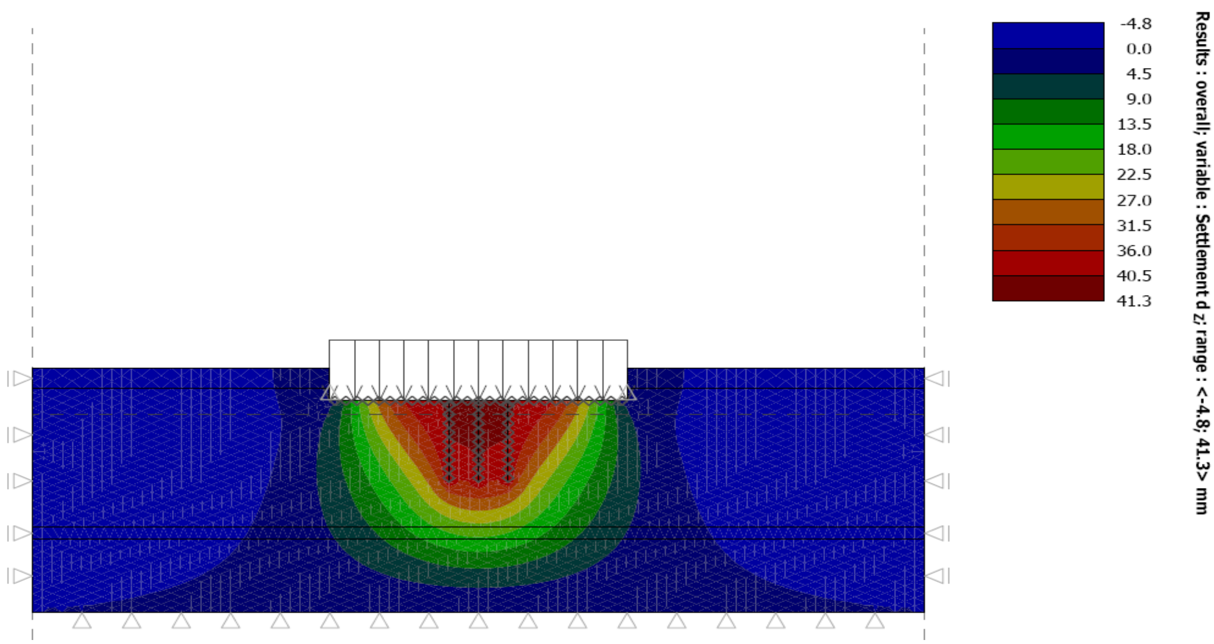


Fig 4.1: Settlement contour of piled raft for applied load 229.36 KN/m^2

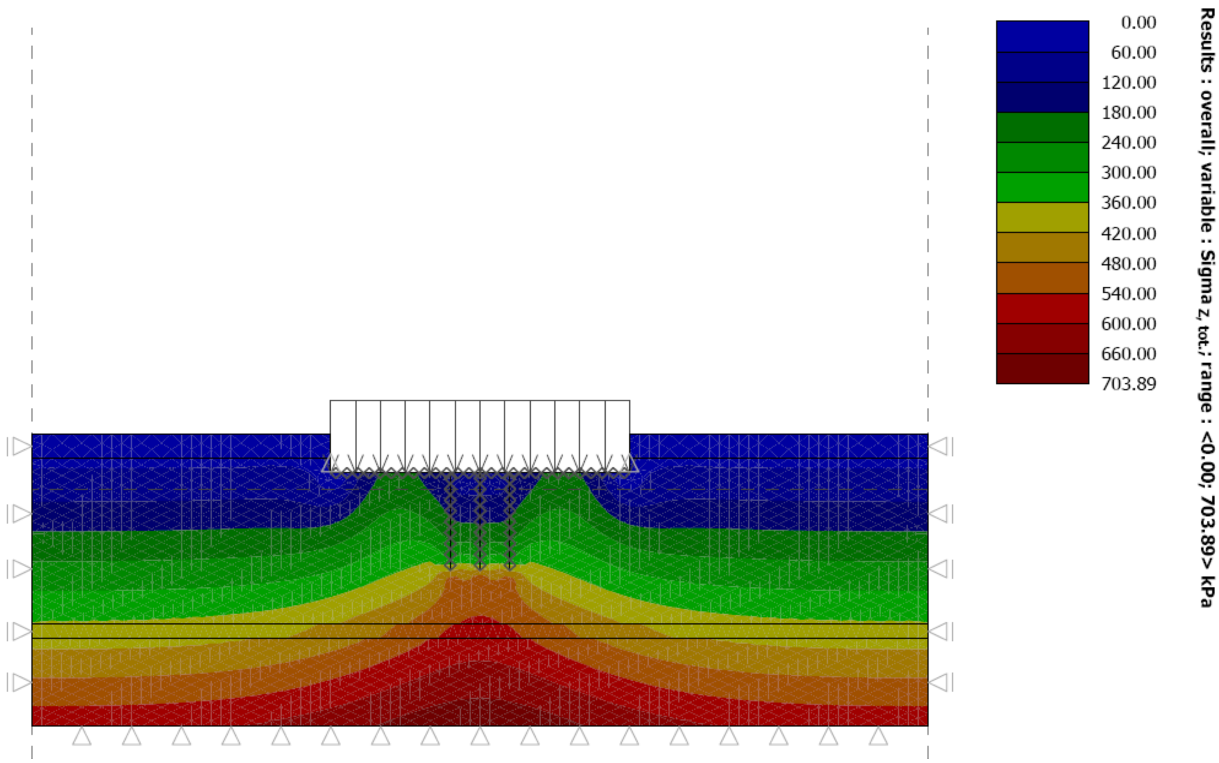


Fig 4.2: Stress contour of piled raft for applied load 229.36KN/m^2

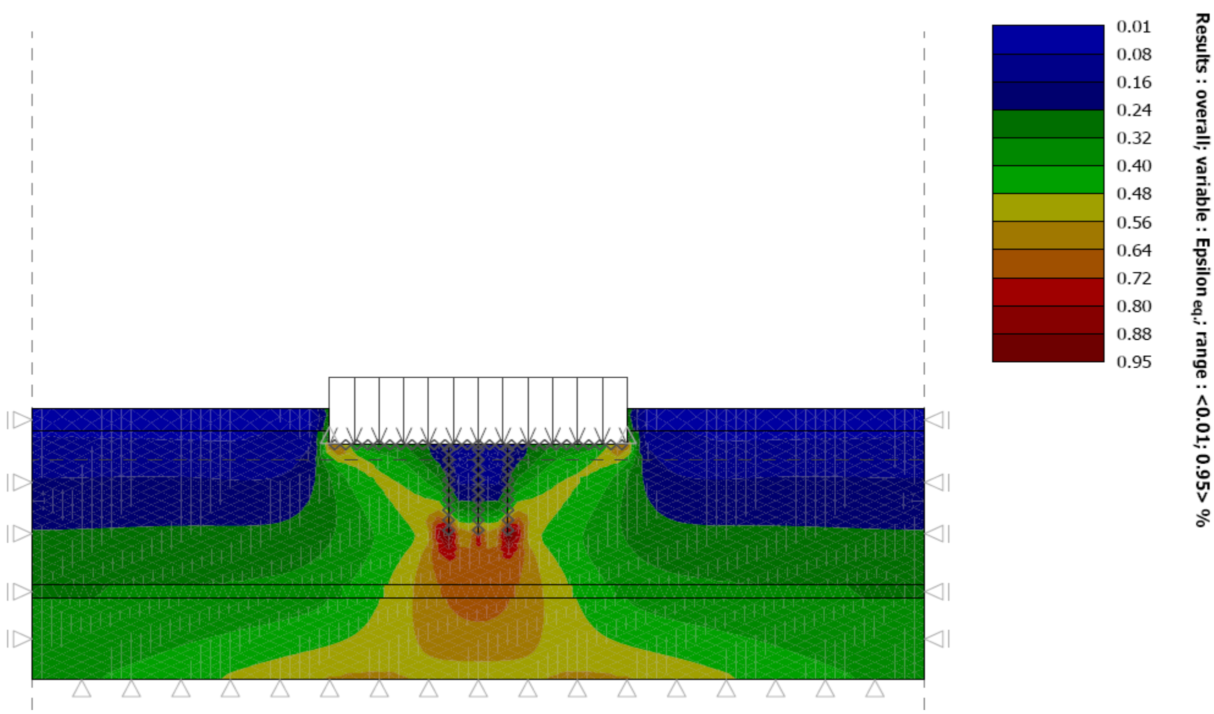


Fig 4.3: Strain contour of piled raft foundation applied load 229.36KN/m^2

Results of analysis performed on piled raft shows that settlement will reduce in case of piled raft foundation for the bearing capacity of raft that is 229.36KN/m^2, further more, applied load on piled raft system is increased so that a high rise building can be constructed and settlement beneath the foundation will be with in the permissible limits.

Table 4.3: Settlement of piled raft for different pile length with stress 400KN/m^2

	Pile length (m)		
	10	15	20
Settlement (mm) for Es=20000 (KN/m^2)	193.20	154.00	99.80
Settlement (mm) for Es=30000 (KN/m^2)	133.80	105.90	70.30
Settlement (mm) for Es=40000 (kN/m^2)	101.90	80.50	55.50
Settlement (mm) for Es=50000 (KN/m^2)	82.00	65.40	46.50

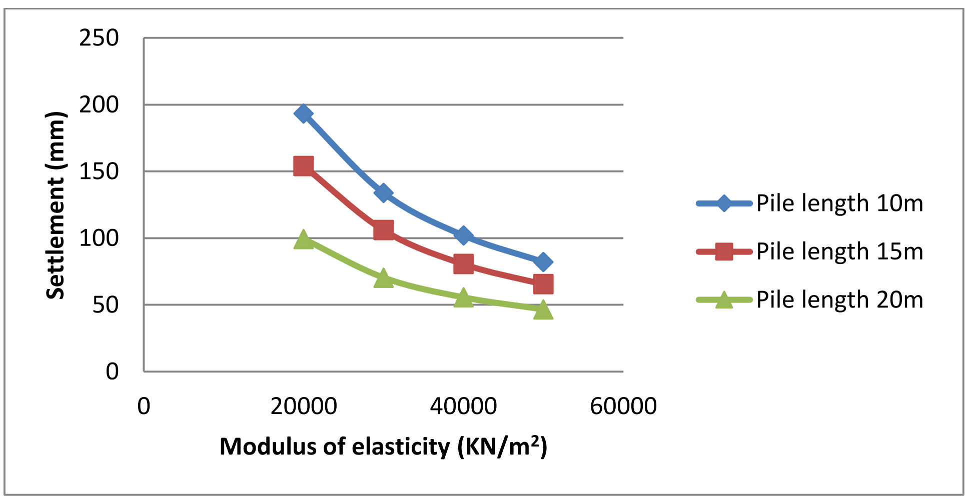


Fig 4.4: Settlement v/s Modulus of elasticity

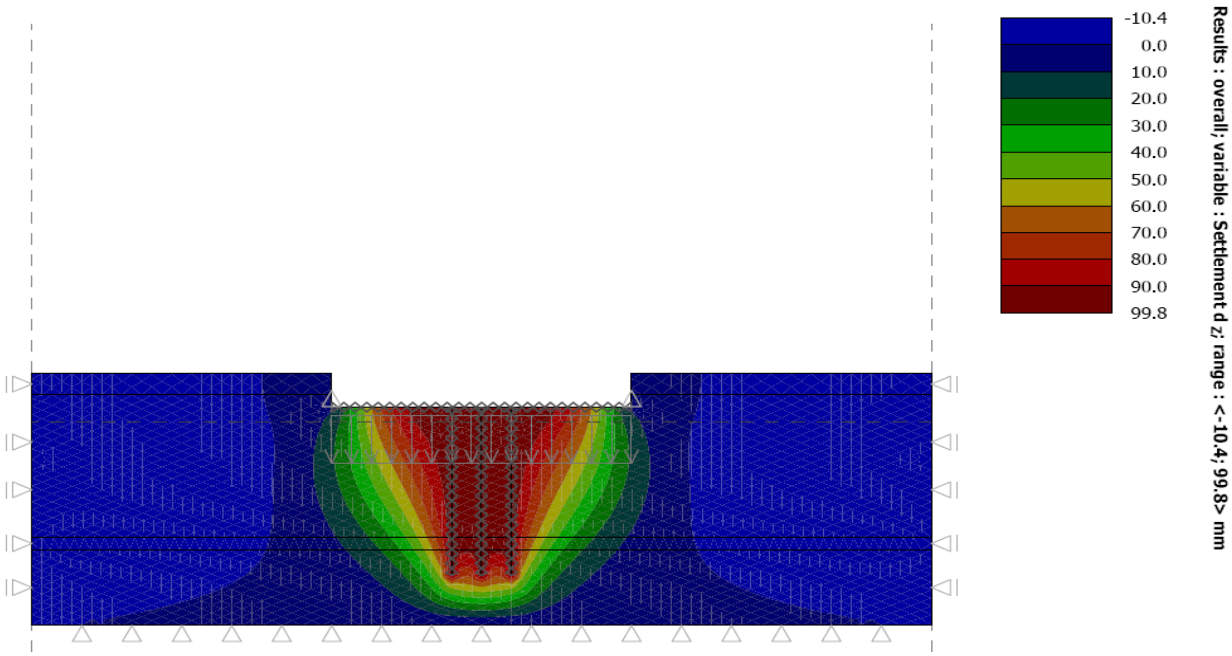


Fig 4.5: Settlement contour of 20m pile under E_S = 20000KN/m^2

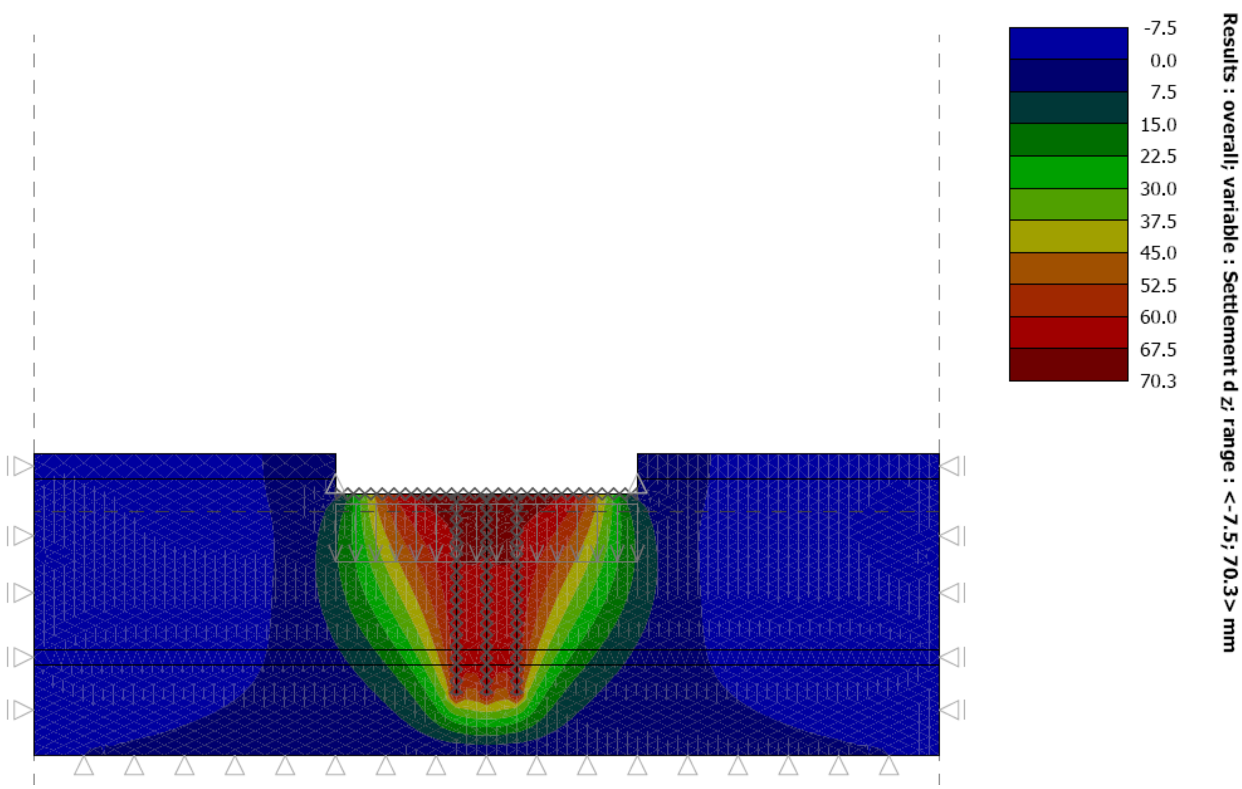


Fig 4.6: Settlement contour of 20m pile under E_S = 30000KN/m^2

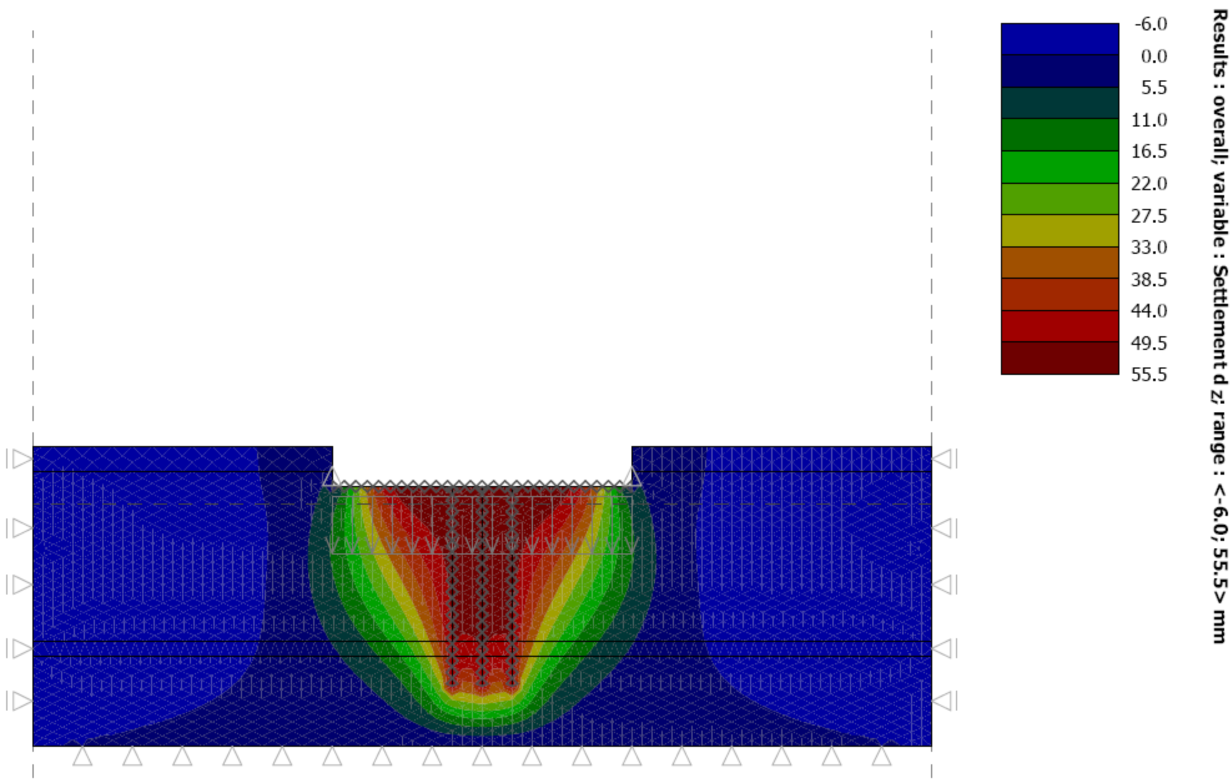


Fig4.7: Settlement contour of 20m pile under E_S = 40000KN/m^2

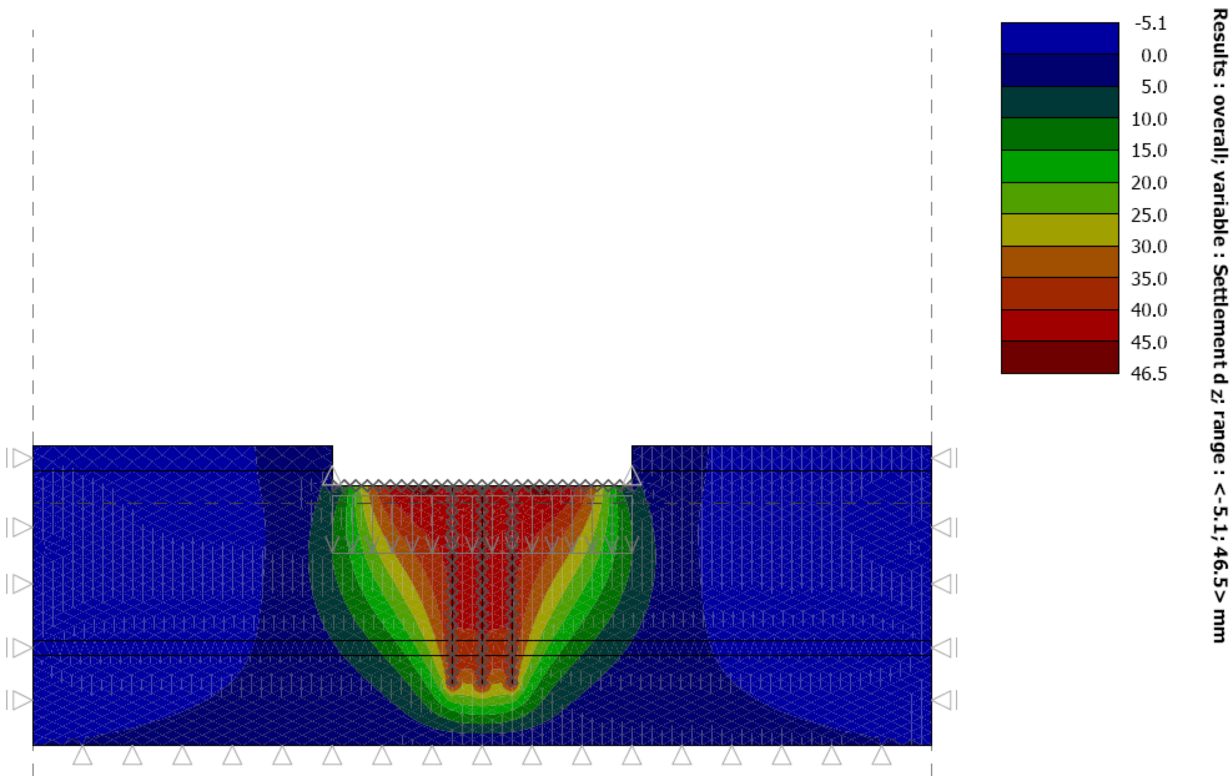


Fig 4.8: Settlement contour of 20m pile under E_S = 50000KN/m^2

Table 4.4 Settlement of piled raft for different applied load values with $E_S = 50000$ KN/m^2

	Pile Length (m)		
	10	15	20
Settlement (mm) for q = 300 KN/m^2	57.60	45.0	33.30
Settlement (mm) for q = 350 KN/m^2	69.70	54.90	39.70
Settlement (mm) for q = 400 KN/m^2	82.00	65.40	46.50
Settlement (mm) for q = 450 KN/m^2	95.20	76.10	53.70
Settlement (mm) for q = 500 KN/m^2	108.70	87.00	61.20

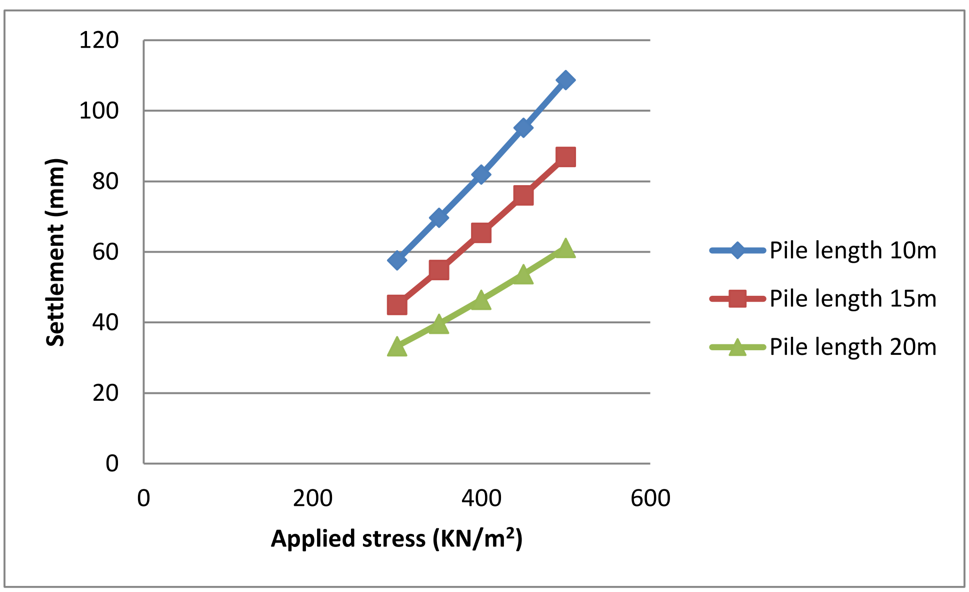


Fig 4.9: Settlement v/s applied load

4.5 COMPUTATION FOR NUMBER OF FLOORS

Dead load and Imposed load on structure is considered based on IS 875 (Part 2): 1987 code. Structure on raft foundation is assumed to be residential structure. Different types of imposed loads for different habitations are as follows:

(a) Due to for habitable rooms, kitchens, toilet and bathrooms = 1.5KN/m^2
(b) Due to corridors, passages and staircases including fire escapes = 1.5 KN/m^2
(c) Balconies = 3.0KN/m^2

Dead load to each floor = 3 KN/m^2

Total load = 9 KN/m^2

Flat, sloping or curved roof with slopes up to and including 10 degrees = 1.5 KN/m^2

Factored load = 10.5 x1.5 = 15.75 KN/m^2

Total factored load from each floor = 15.75 KN/m^2

Bearing capacity of piled raft foundation = 400 KN/m^2

Number of floors = Total floor load/ load coming from one floor

= 400/15.75 = 25.39 floors

= 25.369 ≈ 26 floors

Table 4.5 Settlement of piled raft for different spacing ratio with pile diameter 1m

Spacing ratio	Pile length (m)	Settlement in soil (mm)
S/d = 3	10	82.00
	15	65.40
	20	43.30
S/d =4	10	83.40
	15	66.10
	20	44.50
S/d = 5	10	84.70
	15	66.80
	20	45.80
S/d = 6	10	85.80
	15	67.20
	20	46.50

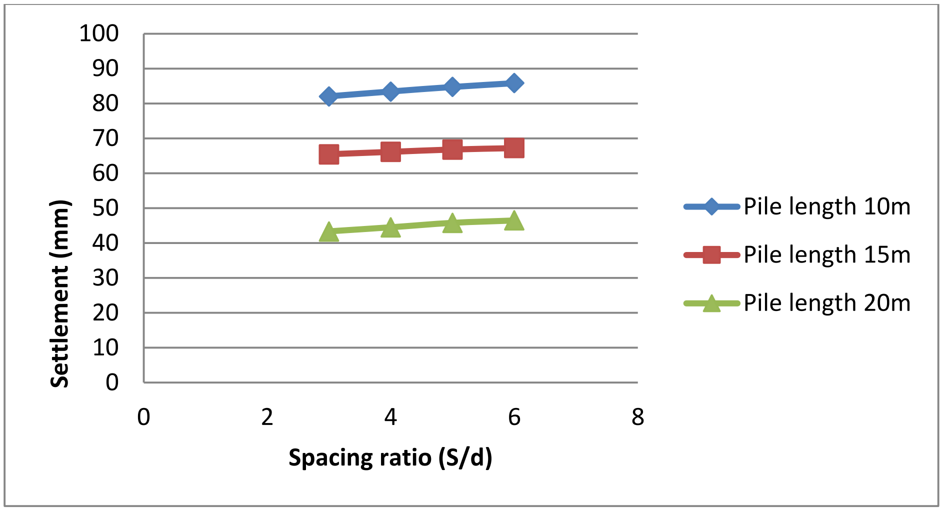


Fig 4.10: Settlement v/s Spacing ratio

Table 4.6 Settlement of piled raft for different pile group with raft thickness 1m

Pile Length (m)	Settlement of piled raft (mm)		
	Pile Group: 4 x 4	Pile Group:5x5	Pile Group:6 x 6
10	84.60	82.40	81.10
15	64.00	61.80	57.80
20	42.30	38.50	36.60

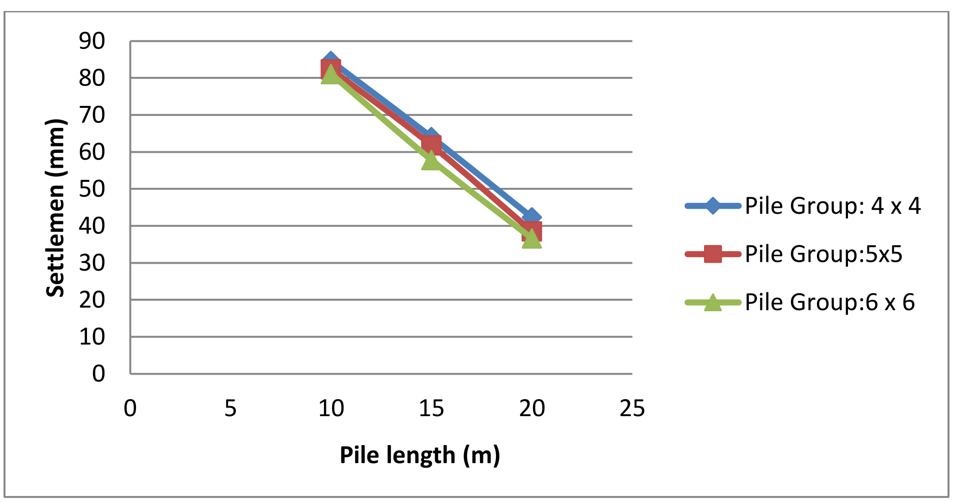


Fig 4.11: Settlement v/s Pile group

Table 4.7 Settlement of piled raft for different raft thickness with pile diameter 1m

Raft thickness (m)	Settlement (mm)
1	82.00
1.5	77.90
2	65.30
2.5	51.00
3	38.90

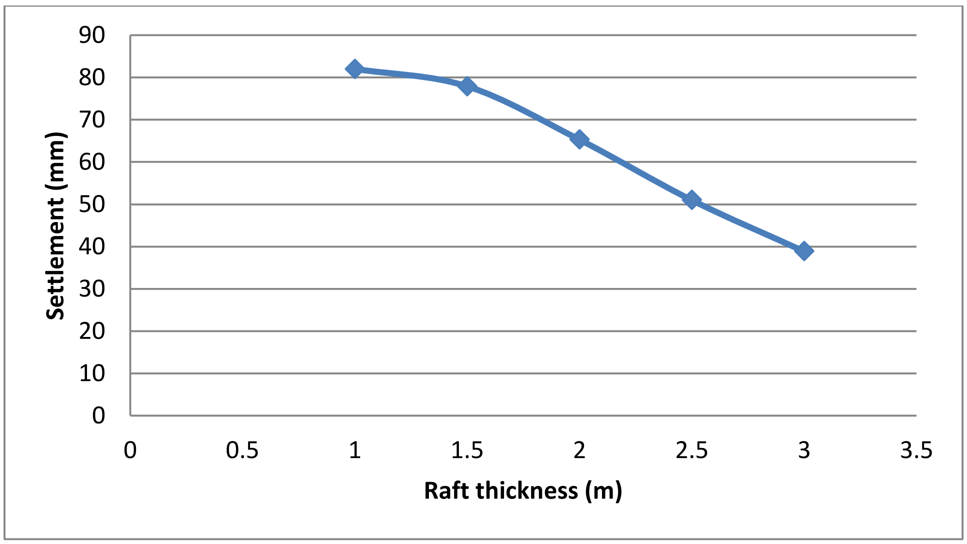


Fig 4.12: Settlement v/s raft thickness

Table 4.8 Settlement of piled raft for different pile diameter with pile length 20m

Pile diameter (m)	Settlement of Piled raft (mm)	
	3x3	5x5
1	43.30	35.10
1.5	41.00	35.00
2	40.50	34.60

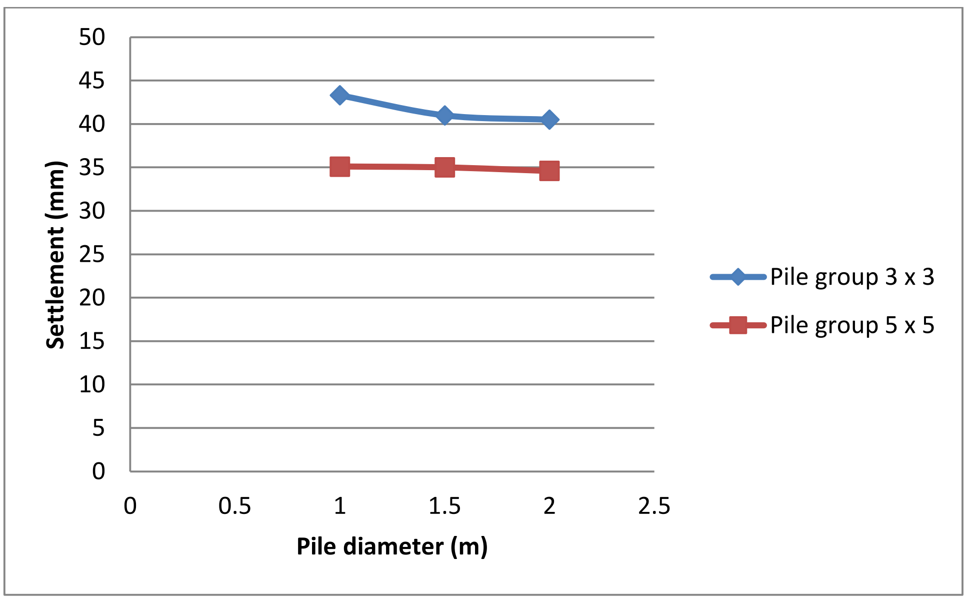


Fig 4.13: Settlement v/s pile diameter

UNIT 5

COMPARISON WITH RESULTS

Results of piled raft obtained from Plaxis 2S and results obtained from Geo 5 have been compared in this chapter. Analysis performed by varying different design parameters from both the softwares was tabulated and corresponding graph have been plotted.

5.1 INFLUENCE OF MODULUS OF ELASTICITY WITH DIFFERENT PILE LENGTH

Variation is tabulated in table and corresponding graphs has been plotted in form of graph.

Table 5.1: Settlement of piled raft for different pile length with stress 400KN/m^2

	Pile length (m)		
	10	12	15
	Results from Geo 5		
Settlement (mm) for Es=30000 (kN/m2)	133.8	123.2	105.9
Settlement (mm) for Es=40000 (kN/m2)	101.9	95.8	80.5
Settlement (mm) for Es=50000 (kN/m2)	82	75.4	65.4

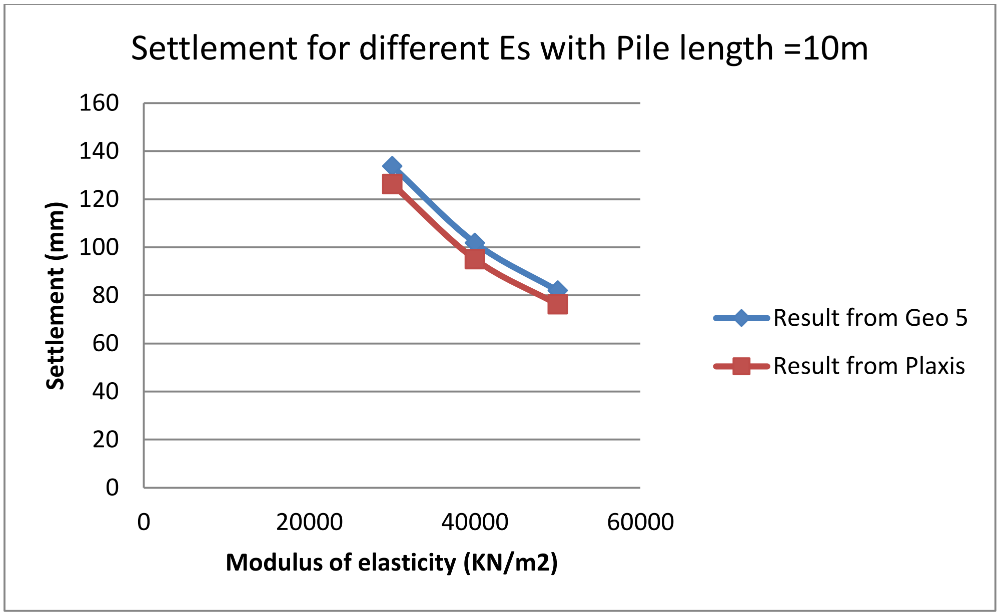


Fig 5.1 Settlement v/s Modulus of elasticity for pile length 10m

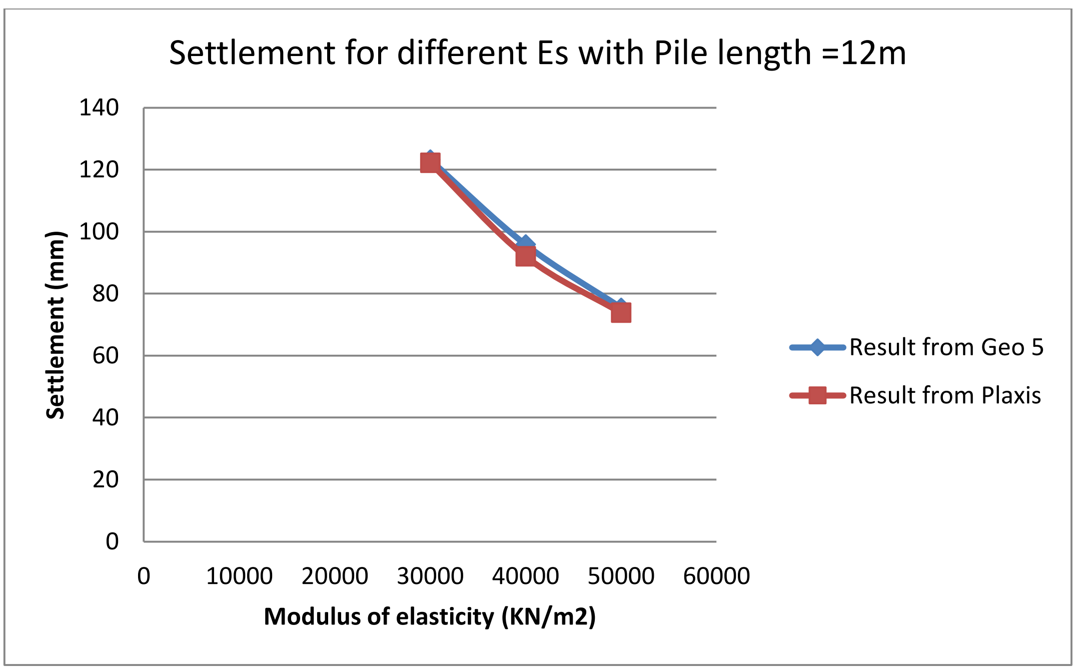


Fig 5.2 Settlement v/s Modulus of elasticity for pile length 12m

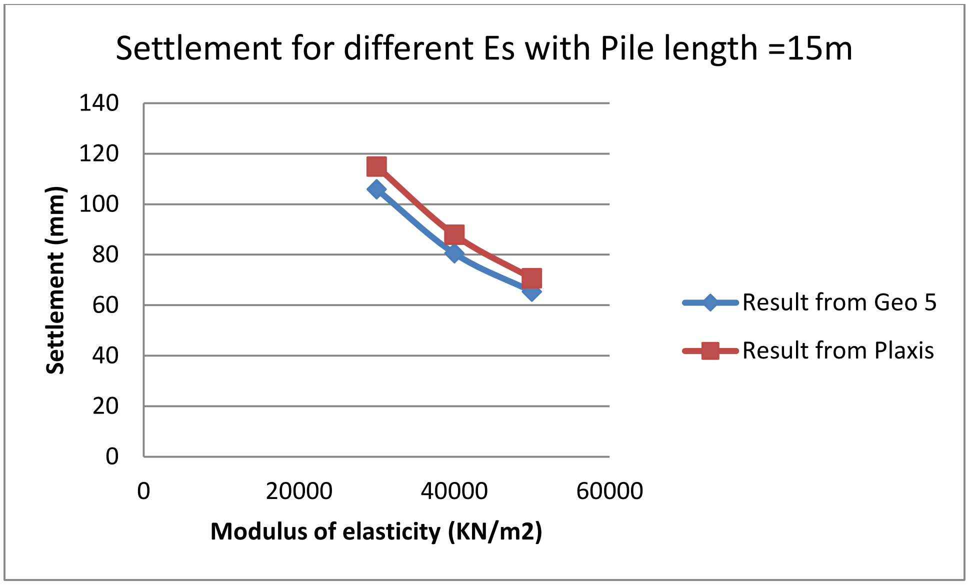


Fig 5.3 Settlement v/s Modulus of elasticity for pile length 15m

From above graphs shown in fig 5.1, 5.2 and 5.3 results from Geo 5 and Plaxis were plotted. Results from both the software are nearer to each other. So it can be conclude that Geo 5 is giving satisfactory results in terms of settlement v/s modulus of elasticity for pile length of 10m

5.2 INFLUENCE OF PILE LENGTH WITH DIFFERENT PILE GROUP

Variation is tabulated in table and corresponding graphs has been plotted in form of graph.

Table 5.4 Settlement of piled raft for different pile group with raft thickness 1m

Pile Length (m)	Settlement of piled raft (mm)	
	Pile Group: 4 x 4	Pile Group:5x5
10	84.6	82.4
12	75.4	74.1
15	64	61.8

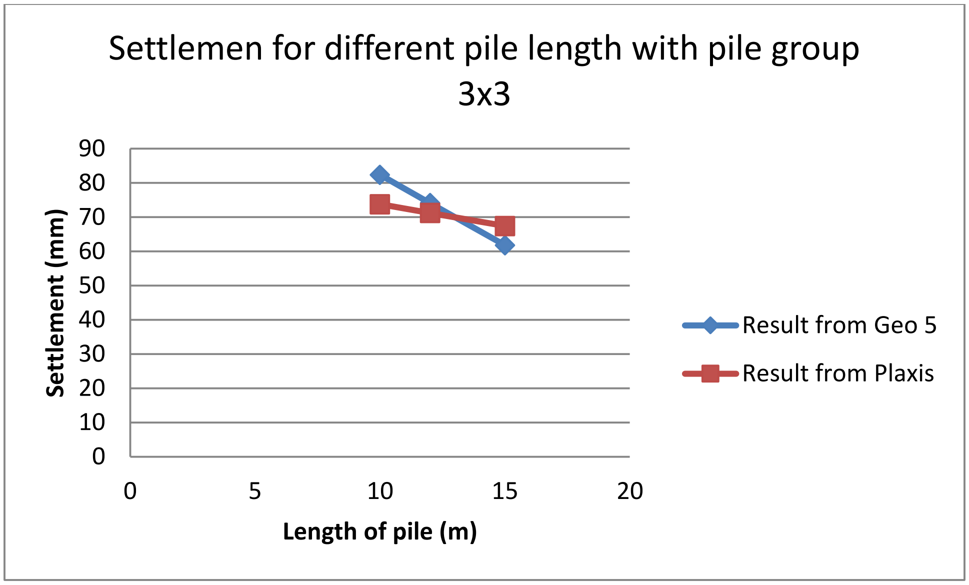


Fig 5.4 Settlement v/s pile length for pile group 3 x 3

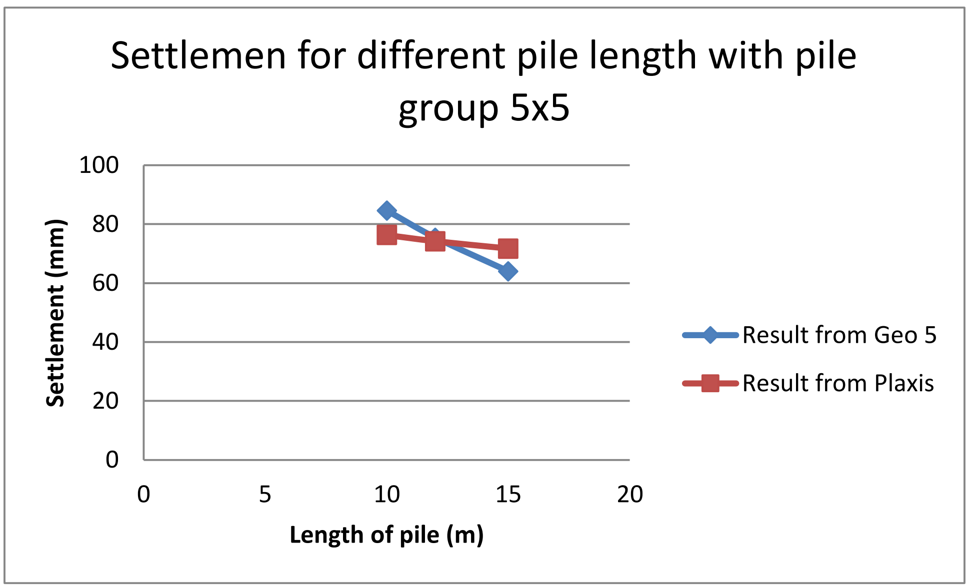


Fig 5.5 Settlement v/s pile length for pile group 5 x 5

Settlement curve obtained from Geo 5 is showing more reduction in settlement as compare to that of Plaxis2-D. this may possible because of difference in interface selection in both the software. As Geo % select the interface as contact and in Plaxis the interface is selected in form of interface only. So results up to pile length of 15 m will be more acceptable which are obtained from Geo 5 software.

5.3 INFLUENCE OF PILE LENGTH WITH RAFT THICKNESS 1m

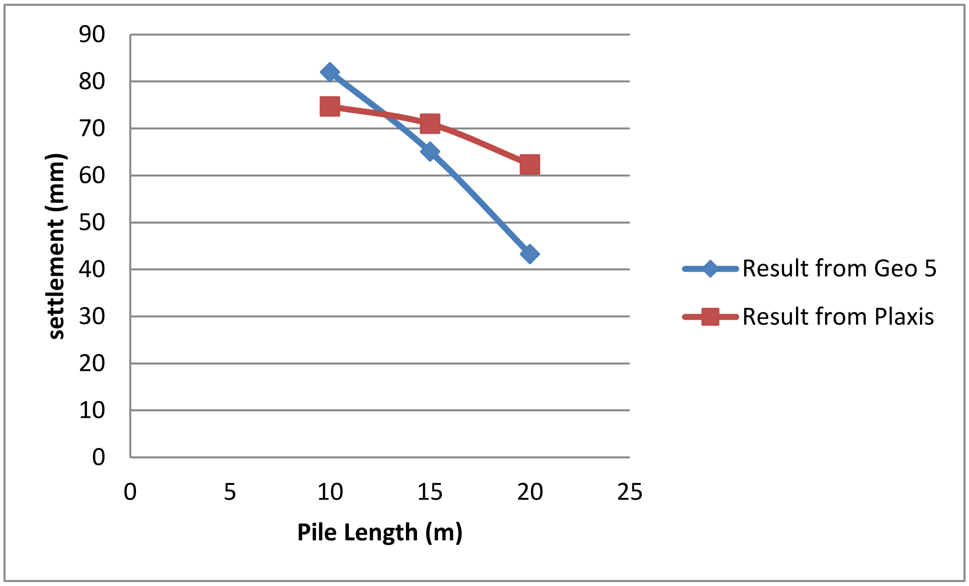


Fig 5.6 Settlement v/s pile length for raft thickness 1m

From Fig 5.6 slope of curve for result through Geo 5 is more as compare to that of Plaxis2-D. It shows that rate of decrease in settlement with increase in raft thickness is more in case of analysis through Geo 5 software but in case of analysis through Plaxis2-D the rate of reduction in settlement is less as compare to that of Geo 5.

CHAPTER 6

RESULT’S DISCUSSION AND CONCLUSION

The results acquired from parametric study for the piled raft in silty sand has been tabulated in table. Number of graphs has been plotted for the understanding of results obtained from variation in design parameters that are (i) Pile Length (L), (ii) Pile Diameter (d), (iii) Spacing (S), (iv) Number of Piles and (v) modulus of elasticity (E_S) various

6.1 DISCUSSION

6.1.1 INFLUENCE OF PILE LENGTH (L)

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different pile length (L=10m, 15m and 20m). Plotted graphs shows that settlement of foundation system decreases with increase in pile length. As resistance against vertical loading increase with increase in pile length. Increased length of piles helps in mobilization of shear resistance..

6.1.2 INFLUENCE OF SPACING RATIO (S/D)

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different spacing ratio (s/d=3, 4, 5 & 6). Plotted graphs shows that settlement of foundation slightly increase with increase in spacing ratio Increase in settlement of piled raft with increase in spacing ratio is more effective in large spacing. On the other hand in lesser spacing, increase in settlement is comparatively less.

Reason behind this increase in settlement with increasing spacing is that. In piled raft system Raft bear large percentage of load therefore pressure bulb produced below the raft will direct the settlement of piled raft. Whereas at lesser spacing ratio piles carries more percentage of load rather than raft, hence settlement is directed by the pressure bulb formed by the pile at the two-third length of the pile.

6.1.3 INFLUENCE OF PILE DIAMETER

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different pile diameter (d= 1m, 1.5m and 2m). As seen form graph settlement beneath the piled raft slightly decreases with increase in pile diameter. Surface area and base area of pile increases with increase in pile diameter thus increases the load sharing percentage and pile capacity of pile in piled raft.

6.1.4 INFLUENCE OF RAFT THICKNESS

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different raft thickness (t=1m, 1.5m, 2m, 2.5m and 3m). Settlement decreases with increase in raft thickness and it also reduces differential settlement. Maximum column loading increases with increasing the raft thickness because resistance against punching shears from both piles and column loading is increase.

6.1.5 INFLUENCE OF NUMBER OF PILES

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different number of piles that are 16 piles (4 x 4 pile group), 25 piles (5 x 5 pile group), 36 piles (6 x 6 pile group). Settlement decreases with increase in number of piles. Thus increasing number of pile is ne of the effective strategy to improve the performance of piled raft system.

6.1.6 INFLUENCE OF MODULUS OF ELASTICITY

Graphs plotted by results obtained from settlement for piled raft foundation in silty sand deposit consequent to different values of modulus of elasticity (E_S= 20000 KN/m^2, 30000 KN/m^2, 40000 KN/m^2, 50000 KN/m^2. Settlement of foundation system decreases with increase in E_s value. This is because when stiffness of soil increases it increases the load carrying capacity thus settlement decreases.

6.2 CONCLUSION

- Settlement of piled raft foundation reduces with increasing the elasticity modulus of soil.
- The settlement decreases up to 35% with increase in pile length from 10m to 20m. This because the resistance against vertical loading increases with increase in length. Thus increasing pile length is more successful design approach for improving the foundation performance

- Varying number of piles i.e. group of piles from 3 x 3 to 6 x 6 settlement of foundation reduces up to 5%.
- Increasing S/d ratio from 3 to 6 the settlement of piled raft foundation increases 3 to 4%.
- Increasing the pile diameter results in reducing settlement 15-20%.
- From above points it can be says that variation in length and diameter optimally reduces the settlement and increases the stability of structure

6.3 SCOPE OF FUTURE STUDY

- Analysis of piled raft foundation using other software like ANSYS, PLAXIS.
- Study of differentia settlement of piled raft foundation
- Comparison between analysis made on other software

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