CHAPTER 1

INTRODUCTION

1.1 General

In the recent years, due to rapid growth of cities all over the world results to increase in the number of story and height of tall buildings even in unfavorable soil condition. The foundation of any building must satisfy both design criteria given in literature i.e. the foundation should have adequate bearing foundation and the settlement should be within the permissible limits. Large settlement of the foundation affects structure stability as well as stability of adjoining structures. The settlement of the foundation is usually treated as secondary design criteria which are inappropriate in a case of a raft foundation which can satisfy the bearing capacity requirement but the excessive settlement is a problem. In that situation adding a group of pile under a raft is more effective and economical foundation system that is called piled raft foundation system. The main function of pile group in piled raft foundation is to minimize the raft settlement. Piled raft is a good example of soil structure interaction. The Piled raft foundation system proves to be very economical foundation system, where the loads coming on foundation are partly taken by the piles and partly by the raft.

Pile groups are designed by adopting a high factor of safety to the piles and the major design criteria is the bearing capacity of the pile group. The arrangement of the piles in the group is to carry the entire load of the superstructure. cap on the piles is in close contact with the soil, contribution of the pile cap or raft in the total bearing capacity and pile group behavior is considered in analysis and design. One of the most effective ways for increasing the bearing capacity of a foundation has been experienced to be the pile enhancement. The system is known as hybrid foundation or piled-raft foundation. The piled-raft foundation is a new design concept as one of the effective methods of foundation to reduce settlements of super structures. In piled-raft systems, the design procedure differs from traditional foundation design, in which the loads are assumed to be carried either by the raft or by the piles, considering the safety factor in each case. In the design of piled rafts the load sharing between the piles and the raft is taken into account, and the piles are used up to a load level that can be the same order of magnitude as the bearing capacity of a comparable single pile or even greater.

High rise buildings are usually founded on some form of piled raft foundation which is subjected to a combination of vertical, lateral and overturning forces. Combined pile-raft foundations can be a particularly effective form of foundation system for tall buildings because the raft is able to provide a reasonable measure of both stiffness and load resistance. In the piled raft foundation, piled support provides control on settlement with piles providing most of the stiffness at serviceability loads, and the raft element providing additional capacity at ultimate loading. The design of piled raft foundation considers not only the capacity of the piles and the raft, but also considers their combined capacity and interaction under serviceability loading. There are some the some basic design issues to be considered in piled raft design. Concept of piled raft foundation is shown in figure 1.1. In this figure (a) shows pile foundation which are used for heavy loads and where the hard stratum is located at deep, figure (b) shows raft foundation which is a type of shallow foundation. It is used where soil below the ground is able to carry building loads. Figure (c) shows the piled raft foundation, this type of foundation can be used when the soil below the ground is weak and raft alone does not meet design requirement, performance of the raft is increased by adding piles below the raft.

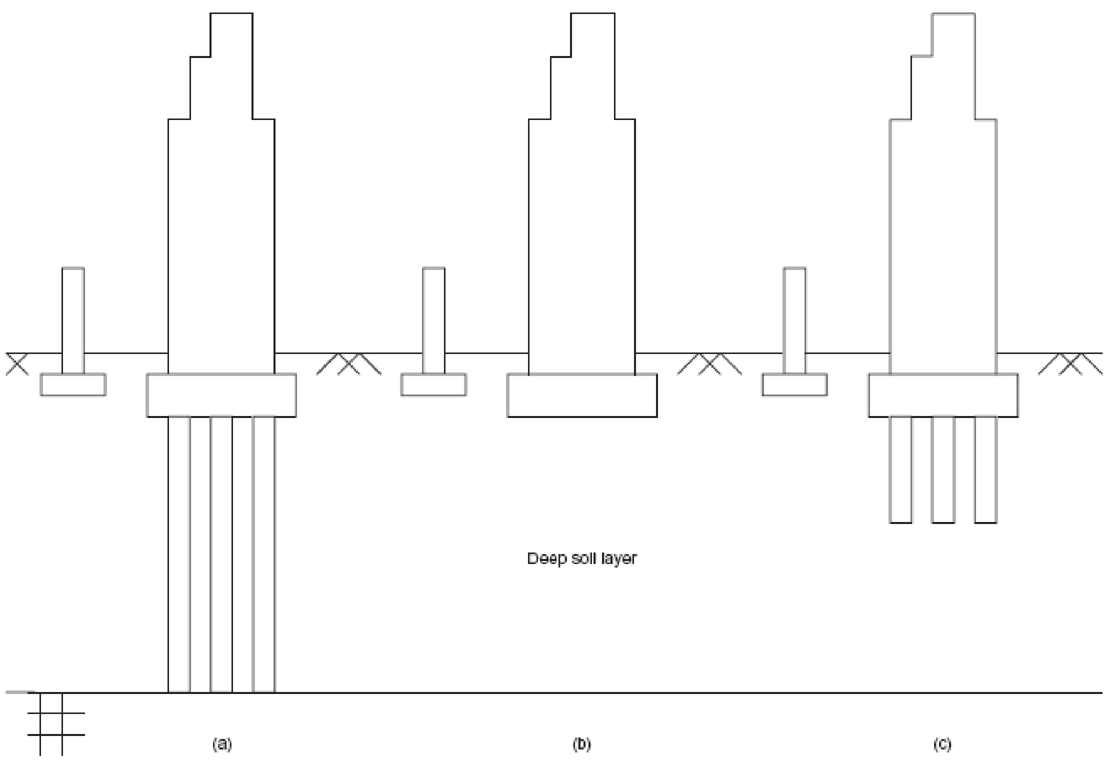


Fig 1.1 Concept of Pile Raft Foundation (a) Piles; (b) Raft and; (c) Piled Raft

1.2 Design principles

Poulos (2010) has given the following design which are generally need to be consider for the designing of piled raft foundation.

1. Ultimate capacity of the foundation when vertical, lateral and moment loading combinations are applied.
2. Effect of wind, earthquake and wave loadings
3. Total settlements.
4. Differential settlements
5. Structural design of the foundation system
6. Effects of external ground movement

1.3 Design philosophies of piled rafts

Randolph(1994) presented three design philosophies for piled raft:

1. First approach deals with the pile group, in which pile group carry large portion of the applied load and raft contributes a little.
2. Second approach deals with the creep piling, in this piles are intended to take working load at which considerable creep starts. Generally it is 70-80% of the ultimate load.
3. And last approach deals with control on settlement, in this piles are added beneath the raft to minimize the settlement not only the overall settlement

Figure no 1.2 describes, conceptually, the load-settlement behavior of piled rafts foundation system which are designed according to various philosophies. Curve 0 represents the settlement behavior of only raft foundation, which goes under the large settlement when the design loads are applied,. Curve 1 represents the settlement behavior of piled raft including pile group behavior. Curve 2 represents creep piling in which major portion of load are taken by piles. Curve 3 represents the methodology of using pile to minimize the settlement, which covers the entire load capacity.

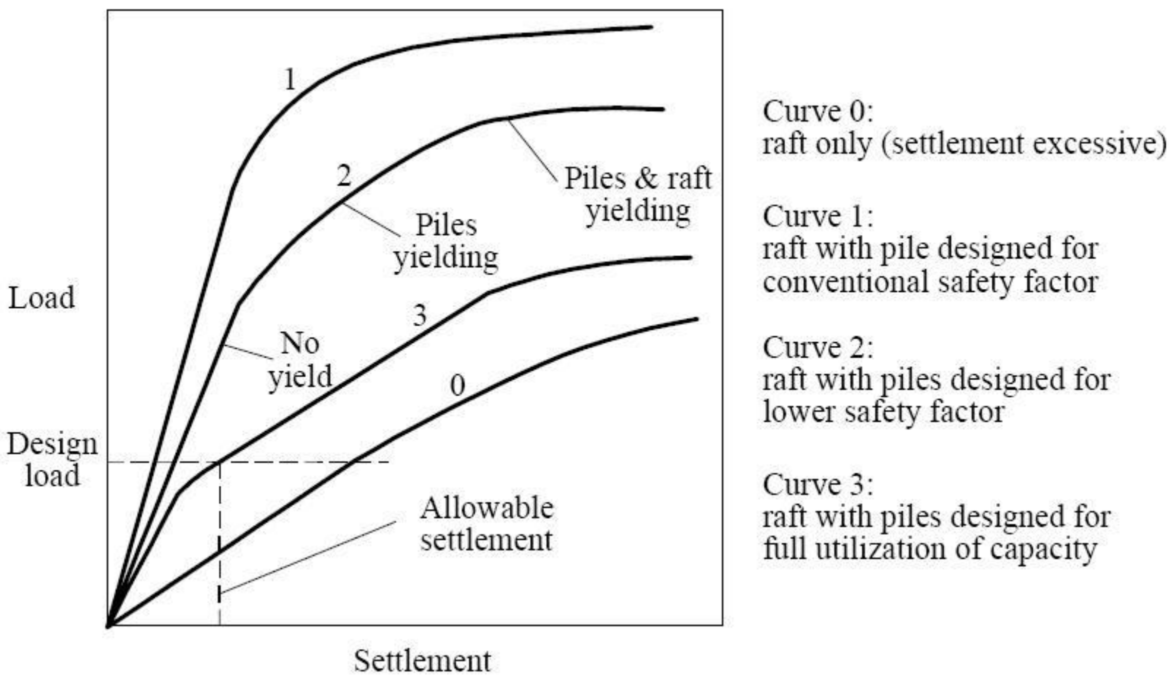


Fig 1.2 Load Settlement Curve for piled rafts as per various design philosophies

(Impe, et. al. 2001)

1.4 Methods of analysis

There are various methods to analyze piled raft foundation, some of the methods were listed by Poulos et al (1997). The main three analysis methods are

1. Simplified calculation methods
2. Approximate computer-based methods
3. More rigorous computer-based methods

Simplified methods includes the methods given by the Poulos and Davis (1980), Clerq(1995), Randolph (1983,1994), Burland and van Impe (1995). All gave simple relation for the modeling of soil profile and loads on the raft.

1.5 Advantages of piled raft foundation

Piles in piled raft foundation minimize the settlement by providing sufficient stiffness at ultimate loads, and the extra capacity is provided by raft. So when the raft provides this extra capacity it is possible to use minimum number of piles.

One of the characteristics of piled raft foundation is to increase the tangential stress between the soil and piles which results in increase in ultimate bearing capacity of piles. When the raft is not providing sufficient capacity and its settles more than the permissible limits than piled raft proves more effective foundation system

1.6 Numerical modeling

In the study of physical processes, numerical modeling is used as a tool. 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. Equations of physics are generally used to solve easy problems of stress and displacement. In case of complex problem with non-linear material properties can only be solved by numerical methods (Heasley 2003). 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.

1.7 Numerical modeling methods

Finite element, finite difference, discrete element, 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.

1.7.1 Finite element method

Finite element method is an intrinsic code which is based on continuum mechanics. The problematic area is discretized into number of finite elements. The solution from related equations of each and every element is then combined for generating combined solution. The finite element method is the most flexible programs, and is generally used to solve various problem in science and engineering.

1.7.2 Finite difference method

The finite difference method is differs from the finite element method is that it is a clear 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.

1.7.3 Discrete element method

To model multiple blocks like rock masses discrete element method is used. Discrete element method is a discontinum code. This method admits 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.

1.7.4 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.

1.8 Objective of the project

Objective of the present study are listed below

1. To determine the bearing capacity and settlement of the raft and pile group using analytical method proposed by relevant IS codes and simulate the same is simulate in finite element based software PLAXIS 2D.
2. To analyze and design of raft and pile group have been carried out using STAAD.PRO and STAAD.FOUNDATION to calculate required area of steel and concrete.
3. To investigate numerically the effects of various parameters like (i) Pile length (2) Pile diameter (3) Number of piles (4) Thickness of raft (5) Elastic modulus of soil (6) Spacing of piles on the performance of pile raft foundation
4. To compare the results of raft and piled raft foundation system for designing most economical foundation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are various researchers who studied the behavior of piled raft foundation and its settlement when the loadings are applied on it. Some of persons uses numerical modeling methods and some uses analytical methods . Study of various scientist and professor are described in this section

Poulos(2001) presented different methods of analysis of piled raft foundations. Some methods are used for preliminary designing and reviewing purposes, and others are used for complete performance and designing. Two dimensional analysis form software FLAC-2D gives the overestimations of settlement and loads on piles. Whereas FLAC-3D presented most suitable results and it can be considered as most effective numerical methods for piled raft. FLAC-3D takes more time to run and setup. Various interactions of foundation system are also considered like pile-raft, raft-soil, and pile-soil.

Eslami et. al(2010) studies the effect of connected and non connected piles under the piled raft foundation. In this study the stiffness and strength of connected elements are considered when loads are applied. Generally connected piles are used under the raft to reduce the settlement but in this study an alternative design approach is suggested which includes non-connected piles. These non-connected piles reduce settlement as well as increase the overall stiffness of the system. A new concept of foundation design was put forward in which piles are used for improving the rigidity of the soil and it was found that when the piles are concentrated in the central portion of the raft, the differential settlement get reduced and internal moment was maximized.

Leung et. al(2010) studied the effect of altering the length of pile in piled raft and pile group and it lead to optimization of material. This optimization can be converted into economy in designing of foundation. Effect of pile stiffness is studied in the Monte Carlo simulation and Taylor series method, and results have shown that it gives less optimization benefits. Therefore use design values of stiffness while estimating the benefits of variation in pile length.

Poulos(2011) presented the principles of a limit states design approach for designing of piled raft foundations for high rise buildings. In this approach all the conditions of loadings are considered like working loads, ultimate loads and cyclic loads. For the examination of behavior of piled raft the effect of depth of pile cap is also considered. Piled raft behavior is estimated in small scale test as well as large structure. The results from the small scale test shows acceptable effect of pile cap and when it is neglected it leads to underestimation of lateral load capacity and an overestimation of deflection. The results of finite element analysis on large structure shown that the deflection of raft when it rests on surface is larger as compare to when raft is below the ground surface or providing basement. When the deflection is less then the moments generated in the piles are also less. Depth of the raft gives a significant reduction in the settlement. Findings says that when high rise buildings rests on piled raft foundation system pile group analysis may be effective and conservative, for determining vertical and lateral load behavior of the foundation system.

Srilakshmi (2013) analyze the piled raft foundation using finite element method based software ANSYS. Numerical studies have been carried out by applying different combinations of pile diameter like providing large diameters piles at center of raft and small diameter piles at outer edge and it gives results that providing larger diameter piles at center is effective rather then providing equal diameter piles beneath the raft.

ISSMGE(2013) presented design and construction guideline for piled raft foundation system, which are used all over the world. Piled raft is a combined foundation that covers the bearing effect of both raft and piles by taking into account interactions between the foundation elements like raft-pile, pile-pile, raft-soil and pile-soil explain in figure 2.1

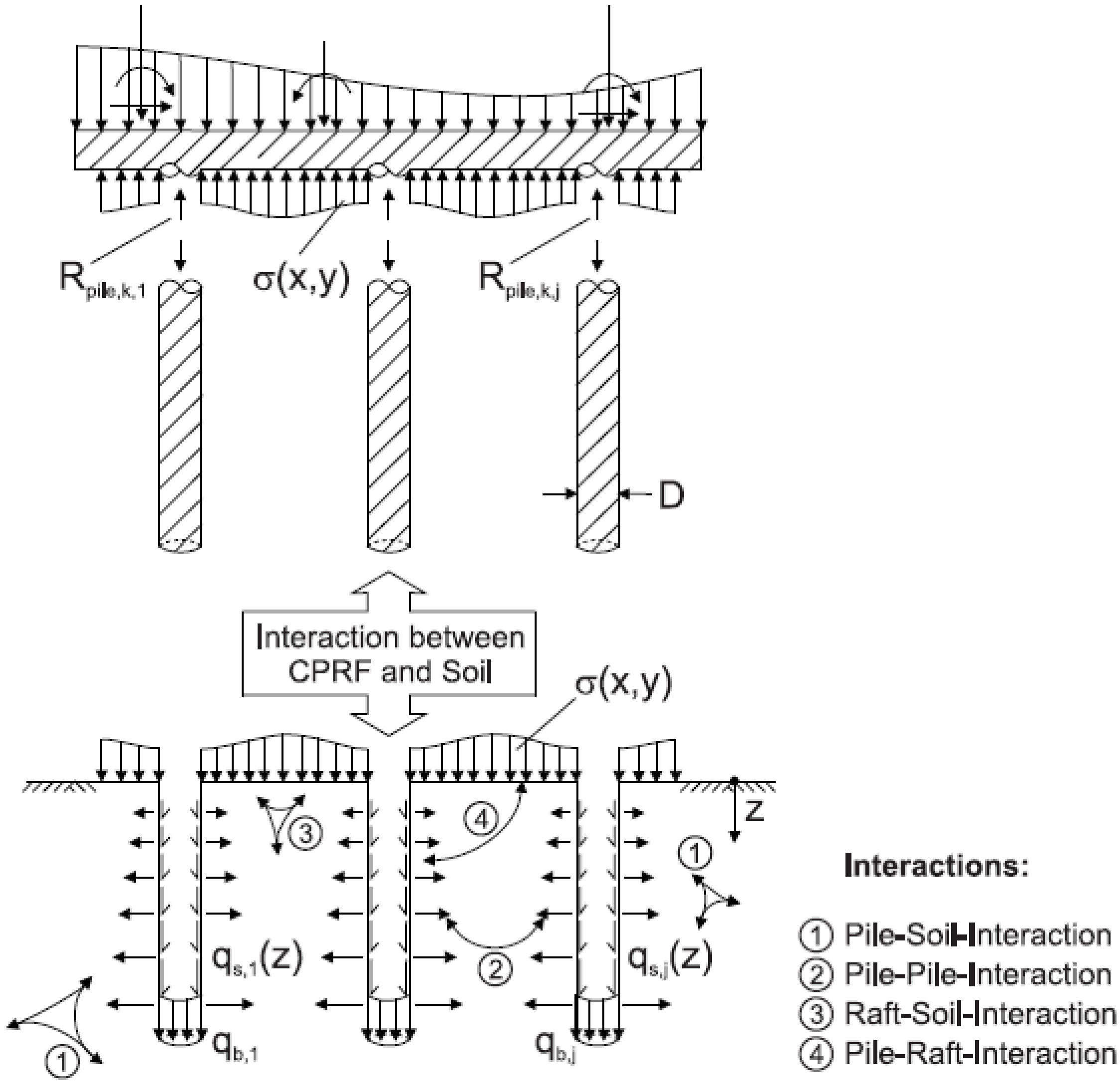


Fig 2.1 Combined pile-raft foundation(CPRF) and its interaction behavior

Total resistance $R_{tot,\,k}(s)$ of the combined piled raft depends on the settlement s of the foundation and it comprises of pile resistance $\sum_{j=1}^{m} R_{pile,kj}(s)$ and base resistance $R_{raft,k}$ (s). the base resistance can be obtained from integration of the settlement, which depends on the contact pressure σ(s, x,y) in the ground area of the raft.

$$R_{raft,k}(s) = \iint \sigma(s,x,y)\, dx\, dy$$

$$R_{tot,\,k}(s) = \sum_{j=1}^{m} R_{pile,kj}(s) + R_{raft,k}(s)$$

$$R_{pile,k,j}(s) = R_{b,k,j}(s) + R_{s,k,j}(s)$$

Piled rafts bearing behavior can be described by the pile-raft coefficient α_{pr} which is defined by the ratio between the sum of the pile resistances $\sum_{j=1}^{m} R_{pile,kj}(s)$ and total resistance $R_{tot,k}(s)$

$$\alpha_{pr} = \frac{\sum_{j=1}^{m} R_{pile,k,j}\,(s)}{R_{tot,k}\,(s)}$$

The pile raft coefficient α_{pr} varies between 0 and 1, zero for spread foundation and 1 for pure pile foundation. Fig 2.2 represent a qualitative example of the dependency between the pile raft coefficient α_{pr} and the settlement of a piled raft s_{pr} related to the settlement of a spread foundation s_{sf} with equal ground plan and equal loading. The pile-raft coefficient depends on the stress level and on the settlement of piled raft.

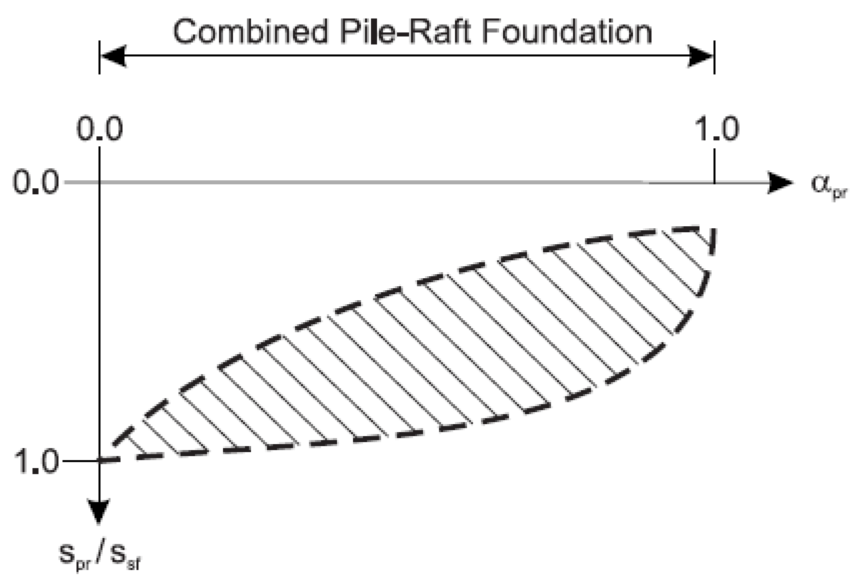


Fig 2.2 Qualitative example of a possible settlement reduction of a piled raft in function of the pile raft coefficient

CHAPTER 3

ANALYTICAL STUDY ON A RAFT AND PILE GROUP FOUNDATION

3.1 General

Raft foundation is a large slab supporting a number of column and walls under the entire structure or a large part of the structure. A raft is required when the allowable soil pressure is low or where the columns and walls are so close that individual footings would overlap or nearly touch each other. Raft foundations are useful in reducing the differential settlements on non homogenous soils or where there is a large variation in the loads on individual columns. The foundation is required for distributing the loads of the superstructure on a large area. A foundation should be designed such that (1) the soil below the foundation should not fail in shear (2) the settlement should be within the limits. The pressure which the soil can carry without failure is known as allowable bearing pressure.

Ultimate bearing capacity is the gross pressure at the base of the foundation at which soil fails in shear. And the net ultimate bearing capacity is the net increase in pressure at the base of foundation that causes shear failure of the soil. Maximum intensity of loading that the foundation will withstand without shear failure is safe bearing capacity. The intensity of loading that soil can carry without exceeding the allowable settlement. For raft foundation generally the range of maximum allowable settlement is 40 to 65 mm in sand. In IS: 1904-1978 Code the value of permissible settlement is 75mm for raft foundation in sand. The net safe settlement pressure is also known as unit soil pressure or safe bearing pressure. The net allowable bearing pressure is the net bearing pressure which can be used for the design of foundations. The requirements for the design of foundation is that it should be safe in shear criteria as well as settlement criteria, so the allowable bearing pressure is the smaller of the net safe bearing capacity (q_{ns}) and the net safe settlement pressure (q_{np}). Thus

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

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

the net allowable bearing pressure is also known as the allowable soil pressure or allowable bearing pressure or allowable bearing capacity.

3.2 Allowable soil pressure for cohesionless soil

The design of shallow foundation on cohesionless soil is generally governed by the safe settlement pressure, as the net safe bearing capacity is quite high. Generally the design of footings of usual size to use empirical methods based on N- values for the determination of the allowable soil pressure for cohesinless soils.

3.3 Bearing capacity on the basis of shear criteria

In case of cohesion less soil, ultimate net bearing capacity is calculated by the formula given IS Code : 6403-1981

$$q_{nu} = cN_c s_c d_c i_c + q(N_q-1)s_q d_q i_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$

where q = effective pressure at the base

W' = water table correction factor

N_c, N_q, N_γ = bearing capacity factors as per IS Code

s_c, s_q, s_γ = shape factor as per IS Code

d_c, d_q, d_γ = depth factor as per IS Code

i_c, i_q, i_γ = inclination factor as per IS Code

3.4 Bearing capacity as per settlement criteria

Safe bearing capacity of raft based on settlement criteria can be calculated by the fig 9 given in IS: 8009 (part 2)-1976 which is based on standard penetration number.

3.5 Settlement of foundation on cohesionless soil

In case of sandy soil, settlement of structure takes place immediately after loading on the foundation. Because of the difficulty of sampling these soils, there is no laboratory method for determining its compressibility characteristics. So the settlement of sandy soil deposits can be calculated by a semi empirical method based on the results of static cone or dynamic penetration test or plate load test

Method based on dynamic penetration test – settlement of a foundation of width B under the unit intensity of pressure resting on sandy soil with known standard penetration resistance value N may be read from figure 2. The settlement under any other value of pressure may be computed by assuming that the settlement is proportional to the intensity of pressure. If the water table is at shallow depth then the value of settlement from Fig 3.1 is multiplied by the correction factor W'.

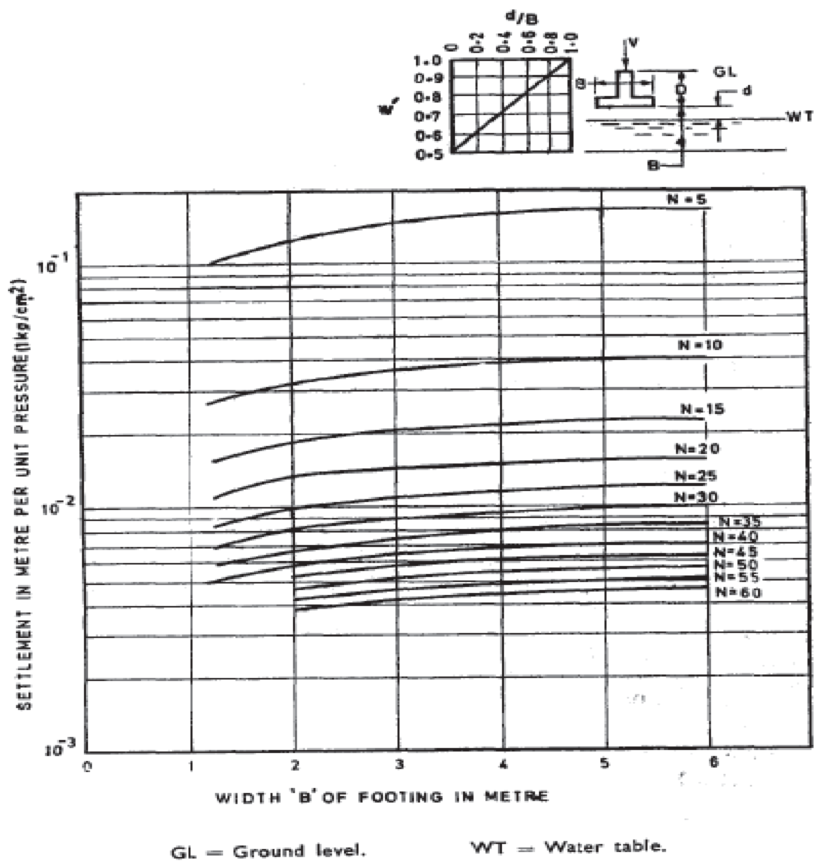


Fig 3.1 Settlement per unit pressure from standard penetration resistance (IS Code: 8009-1976)

3.6 Correction for depth and rigidity of foundation on total settlement

Effect of depth of foundation- settlement obtained from different equation given in IS Code is applicable for the foundation located at surface. When the foundation is located at certain depth below the ground surface, a correction factor should be applied for the calculation of settlement in the form of a depth factor to be read from fig 12 given in IS Code.

Corrected settlement = S_t x depth factor

Effect of the rigidity of foundation – in the case of rigid foundations, for example, a heavy beam and slab raft or a massive pier, the total settlement at the centre should be reduced by a rigidity factor,

Rigidity factor = total settlement of rigid foundation/ total settlement at the centre of flexible

Foundation

= 0.8

3.7 Calculation

In this part of dissertation a raft foundation is selected of dimension 30mx30m, thickness 1m for calculating settlement by analytical method and comparing the results with the numerical method. For the properties of soil strata a borehole data is selected and analysis is performed on that data. Bore hole data is shown in fig 3.2

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	SHEARPARAMET UCC,TXL: COHESION (C) (KG/CM²)	FRICTION ANGLE (Ø)	CONSOLIDATION PARAMETER: e_0	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			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**		Inorganic Silty Sand (SM)			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

ANNEXURE-2.1.2 SOIL PROFILE & BORE LOG DATA

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

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

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	SHEARPARAMET UCC,TXL: COHESION (C) (KG/CM²)	FRICTION ANGLE (Ø)	CONSOLIDATION PARAMETER: e_0	COMPRESSION INDEX	STD. PROCTOR TEST MDD GM/CC/OMC %
SPT	16.50			28	18	2	1	1	65	31															
UDS	**17.00**		Inorganic Silty Sand (SM)			2	2	1	69	26					1.80	1.66	8.12	2.65			*DST/CUT 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															
UDS	**20.00**		Inorganic Sandy silt (ML)			1	2	2	23	72					1.82	1.67	8.68	2.66			*DST/CUT 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															
UDS	**23.00**					2	1	2	71	24					1.83	1.67	9.85	2.65			*DST/CUT 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															
UDS	**26.00**					1	2	3	68	26					1.84	1.66	10.56	2.65			*DST/CUT 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															
UDS	**29.00**					2	2	2	71	23					1.85	1.66	11.57	2.65			*DST/CUT 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

Fig 3.2 Bore hole data

3.7.1 Bearing capacity of raft using shear criteria

Water table = 5.7 m from ground surface

Unit weight of soil = 1.793gm/cc = 1.793x9.81 = 17.58KN/m^3

Average corrected SPT = 19.45

Average of angle of internal friction Φ = 31.6

For Local shear failure, angle of internal friction Φ = 22.4

Depth of the foundation = 4m

Dimensions of foundation = 30mx30m

Bearing capacity factors

$$N_c = 17.65,\ N_q = 8.448\ \ N_\gamma = 8.025$$

Shape factors

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

depth factors,

$$d_c = 1.047,\ d_q = d_\gamma = 1.238$$

inclination factor

$$i_c = i_q = i_\gamma = 1.0$$

Effective overburden pressure = 17.58x4 = 70.32

Water table correction factor = 0.516, c = 0

net ultimate bearing capacity using IS Code: 6403-1981

$$q_{nu} = cN_cs_cd_ci_c + q(N_q-1)s_qd_qi_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$

$$q_{nu} = 70.32x(8.448-1)x1.2x1.238x1+0.5x30x0.8x8.025x0.516$$

$q_{nu} =$ 847.62KN/m^2

q_s = 282.54KN/m^2

3.7.2 Bearing capacity using settlement criteria

Bearing capacity of raft foundation using settlement criteria can be calculated with the help of Fig 9 given in IS Code 8009.1.1981, for a permissible settlement 75mm for raft foundation in sand

N = 19.45, s = 75, B = 30, W_γ = =0.528,

As per IS 8009, settlement in m per unit pressure in Kg/sq.cm = 0.018m = 18mm

Water table correction factor =0.528

Fox's depth factor = 0.98

Rigidity factor = 0.8

Corrected settlement = 14mm

Allowable bearing capacity for 75mm settlement = 280kN/m^2

The allowable pressure on raft foundation is minimum of safe bearing capacity from shear criteria and safe bearing pressure from settlement criteria

So safe bearing capacity of raft = 280.00KN/m^2

3.8 Numerical modeling

Now the raft foundation is considered above is modeled in Plaxis 2D to simulate the results between analytical method and numerical method.

3.8.1 Methodology of Plaxis 2D

In Plaxis 2D is used to generate model of geotechnical problems either in a plane strain condition or as an axis symmetric model. In this study the problem is analyzed using the plane strain alternative. After specifying the model type, define the geometry with elements and corresponding materials, define load and boundary conditions, create a FEM mesh, define initial condition, performer the FEM-calculation.

The hierarchy followed in the present study can be divided into several steps:

1. Physical model of structure: Create the 2D model of raft and define the geometry, and then it is discretized into a large number of finite elements. A enough large zone of the soil mass having length equal to twice breadth of the raft from the edge of raft and depth is equal to two times breadth of raft has been selected as the zone of influence.
2. Loads: the allowable pressure is applied over the entire area of raft in the form of uniformly distributed load. On application of load the raft is likely to undergo settlement. And stress and strains are developed as the results of application of load.
3. Meshing and calculation phase: after defining loads and geometry create the mesh, and then perform initial condition and finally go for calculation phase. After calculation deformed mesh is generated which give the settlement value of raft, and displacement contour, stress contour, strain contour is generated corresponding to raft.

3.8.2 Plaxis Analysis

3.8.2.1 The Soil mass

It is difficult to find the vertical and lateral extents of the influencing zone under the raft. However, the effects of soil structure interaction can be adequately taken care of, if a large zone of soil mass is taken into account. Accordingly, a large soil mass of rectangular cross-section, having a depth equal to width of the raft and a width equal to one and half times the width of raft is considered in each case. The elastic properties of the soil, Young’s modulus and Poisson’s ratio are given as input. Afterwards, this soil mass is discretized with the help of 15 noded element.

The raft is assumed to be rested 4m below the ground surface on a silty sand deposit. The average properties of the soil used in the analysis are tabulated here

Table 1: Properties of Soil for Raft

Type of Soil	Modulus of Elasticity (kN/m^2) E_s	Poisson's Ratio μ_s	Density of Soil (kN/m^3) γs	Unit Cohesion (kN/m^2) c
Silty sand	30000-50000	0.3-0.4	17.58	0.00

3.8.2.2 Raft

The raft used in this study having uniform thickness of 1m which is resting 4m below the ground surface. After generating model the raft, it is discretized with 15- noded brick elements. However, the volume occupied by raft is much lesser as compared to that of the soil mass. Hence elements of smaller size are used for meshing the raft.

Table 2 Properties of concrete for Raft

Elements of Structure	Poisson's ratio μc	Modulus of Elasticity (kN/m^2) Ec	Unit weight (kN/m^3) γc
Raft	0.2	$28x10^6$	25

3.8.2.3 Back Analysis

For simulation between analytical and numerical modeling perform back analysis. In back analysis, modulus of elasticity and Poisson's ratio is varied within the range of modulus of elasticity and Poisson's ratio of sandy soil and get the most appropriate value for which results of analytical and numerical methods are similar.

Table 3: Settlement vs Modulus of Elasticity of Soil

	Poisson's ratio		
	0.3	0.35	0.4
Settlement (mm) for Es=30000 (kN/m^2	160	130	100
Settlement (mm) for Es=35000 (kN/m^2)	140	110	85
Settlement (mm) for Es=40000 (kN/m^2)	120	95	76
Settlement (mm) for Es=45000 (kN/m^2)	110	85	68
Settlement (mm) for Es=50000 (kN/m^2)	95	76	60

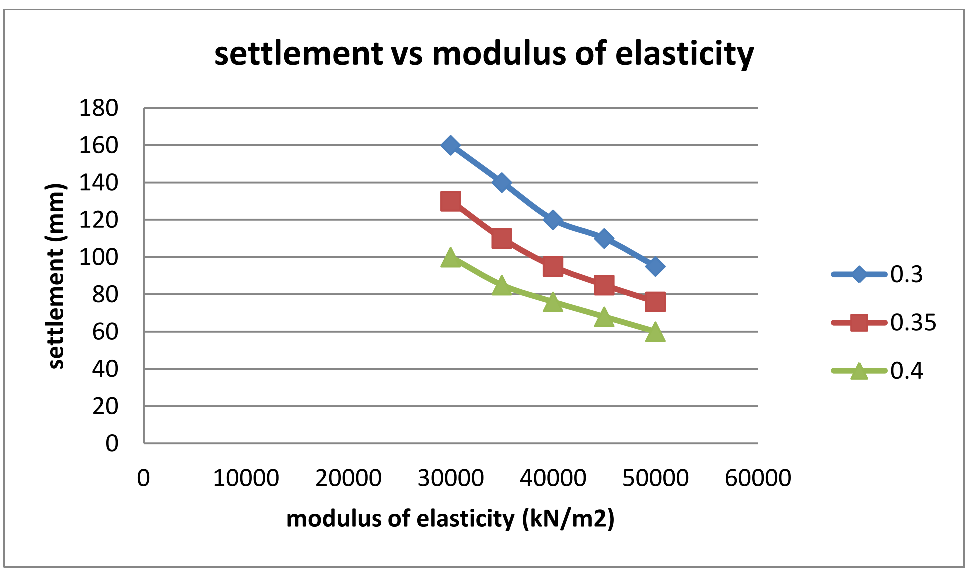


Fig 3.3 Modulus of elasticity vs settlement

From the back analysis, modulus of elasticity E = 45000KN/m^2 and Poisson's ratio μ = 0.4 gives the settlement value which is similar to the settlement value from analytical methods, so these values are selecting for further use in this dissertation.

3.8.3 Results of PLAXIS 2D analysis

Following steps are used in PLAXIS 2D to perform analysis

1. Soil and raft is modeled using soil and interface and plate element, after creating model material data set is assigned to them. Standard fixities are applied and if necessary horizontal and vertical fixities are applied for boundary conditions.
2. When the properties are assigned, loads are applied on the plate element. After applying load mesh is generated.
3. When meshing is completed check initial condition, initial conditions is necessary for checking water table and to generate pore pressure. after generating pore pressure project is updated and now it is ready to move in calculation phase.
4. In calculation phase, values of load is applied on plate and mark this phase to calculate and click on calculation tab.
5. After completion of calculation output window is appeared, in output window displacement, stress, strain, bending moment, shear forces etc. can be seen.

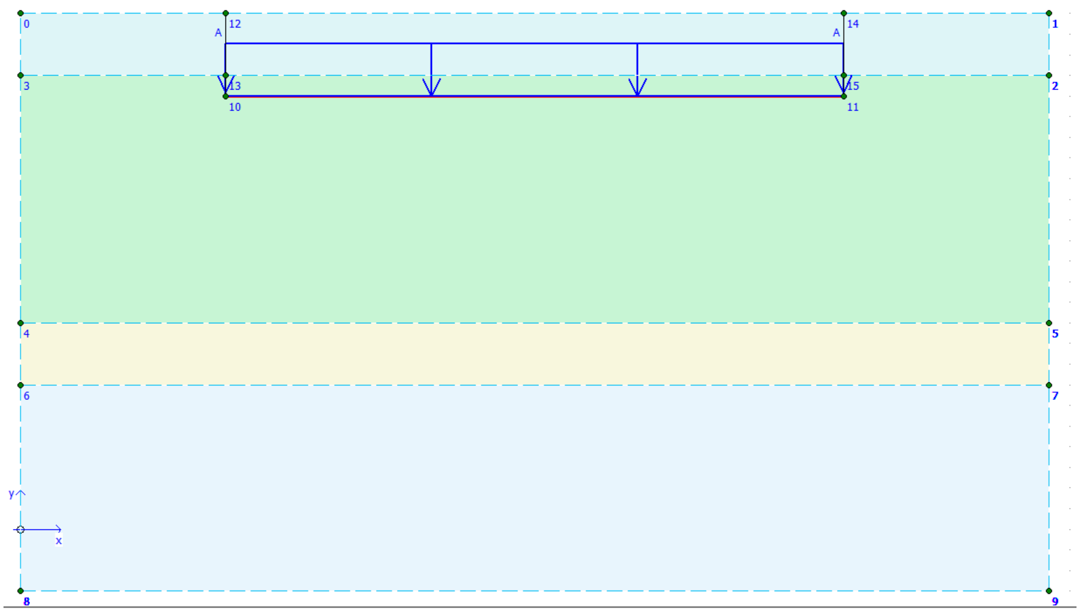


Fig 3.4 Soil model in 2D

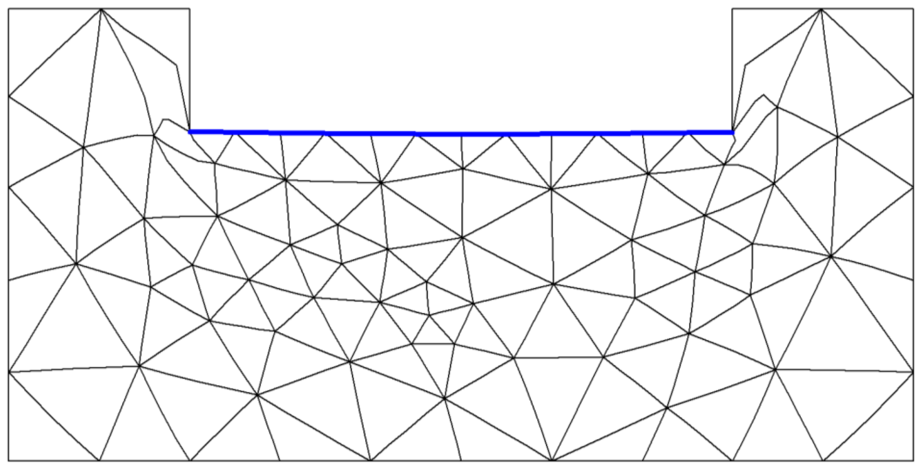


Fig 3.5 Deformed mesh

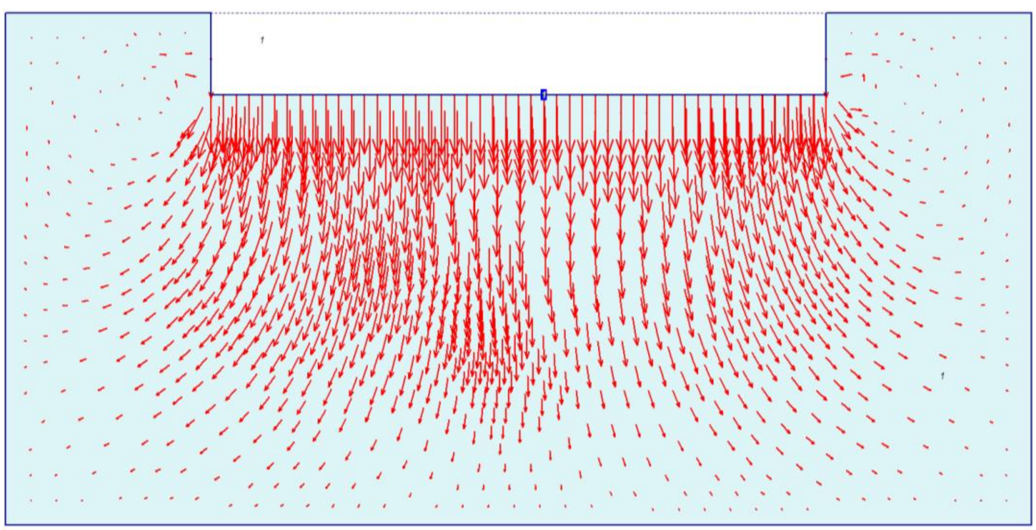


Fig 3.6 Plot of total displacement

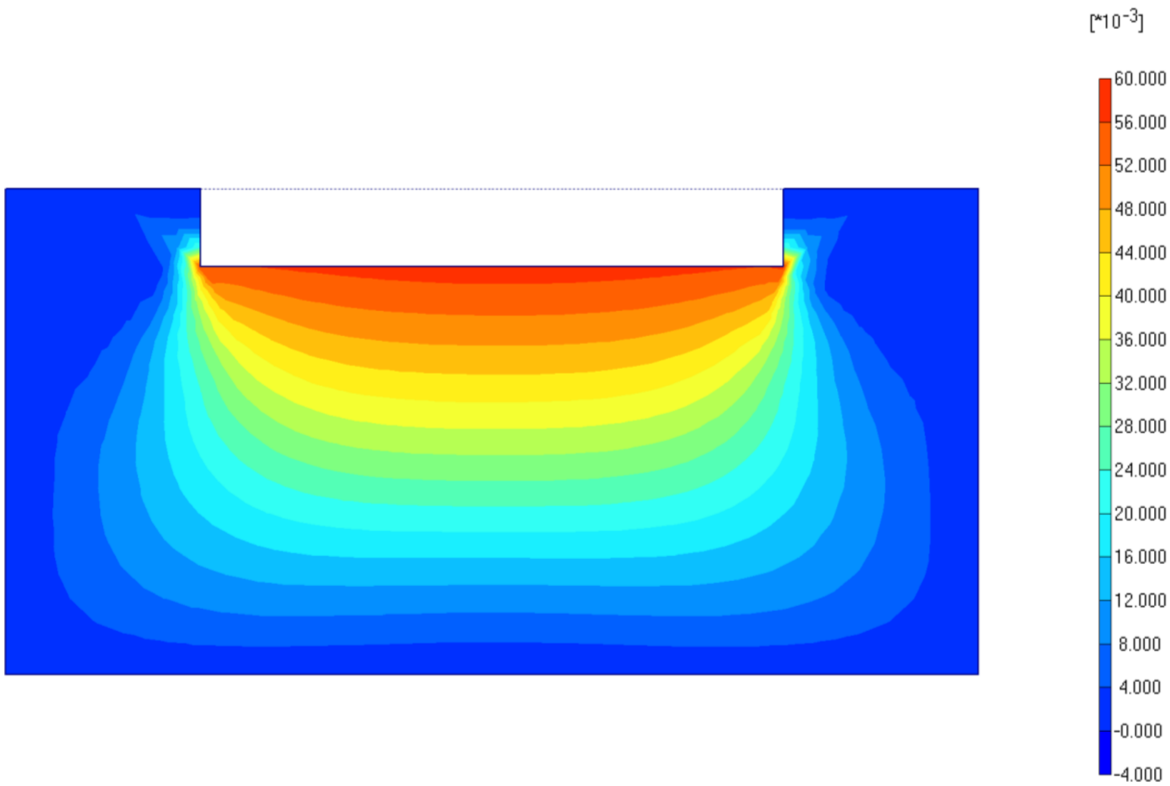


Fig 3.7 Displacement contour of Raft Foundation

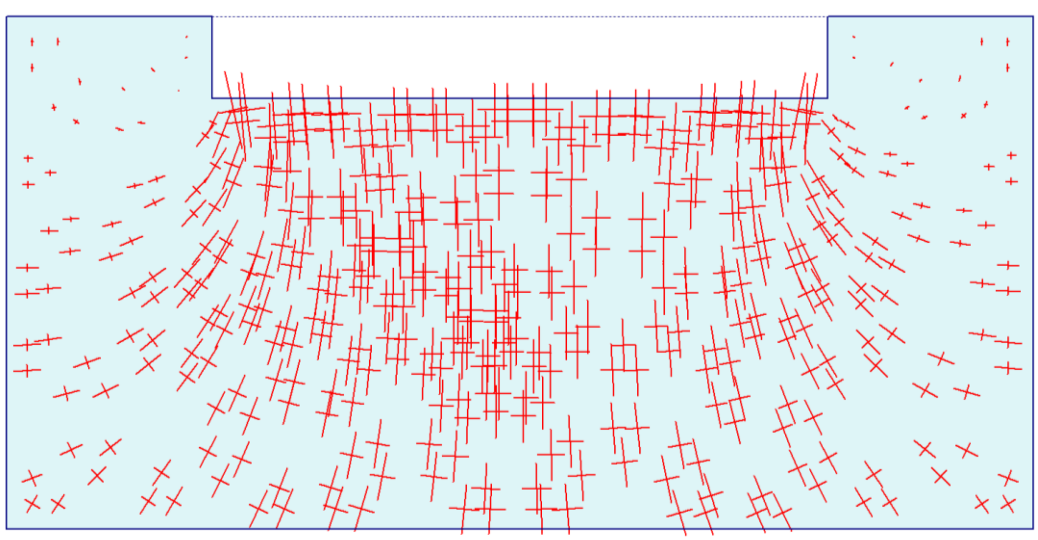


Fig 3.8 Effective Stress Contour of raft foundation

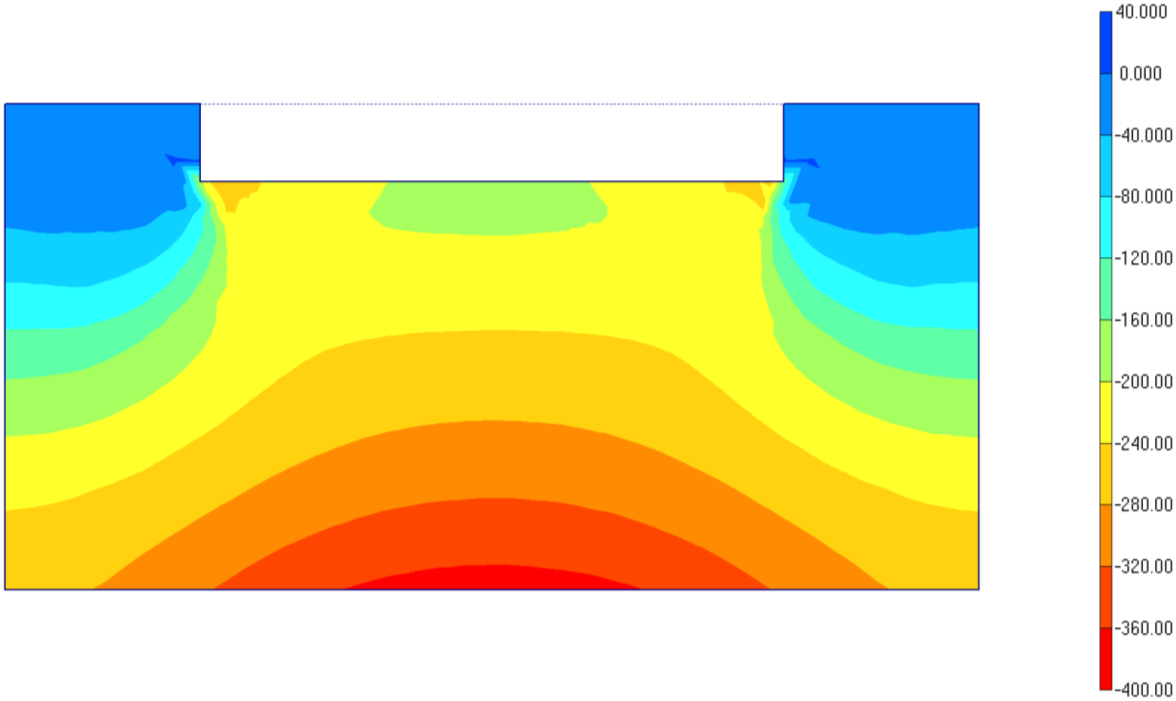


Fig 3.9 Total stress contour of raft foundation

3.8.4 Calculation of Number of Floors in case of raft foundation

Residential building is considered above the raft foundation. Dead load and live load on building is consider based on IS code 875:Part 2

Loads

Imposed load due to for habitable rooms, kitchens, toilet and bathrooms = 1.5KN/m^2

Imposed loads due to corridors, passages and staircases including fire escapes = 1.5 KN/m^2

Balconies = 3.0KN/m^2

Dead load due to each floor = 3.0 KN/m^2

Load from the brickwork = 20x.23x2.4 = 11.04/27 = 0.408 KN/m^2

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

Load from basement = 12.5KN/m^2

Factored load = 10.908x1.5 = 16.362 KN/m^2

Total factored load from each floor = 16.362 KN/m^2

Bearing capacity of raft foundation = 280.00 KN/m

For calculating number of floors, load from the basement is subtracted from bearing capacity of raft and finally divided by load coming from one floor

Load from floors = 280.00-12.5 = 267.5 KN/m^2

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

= 267.5/16.362

= 16.34 $\approx$ 17 floors

3.8.5 Analysis and Design of building in STAAD.PRO

Now 13 floors building above the raft foundation is modeled in STAAD.PRO, analyze and design. Loads applied on building as per given IS: 875 Part 2 and design all the beams and column

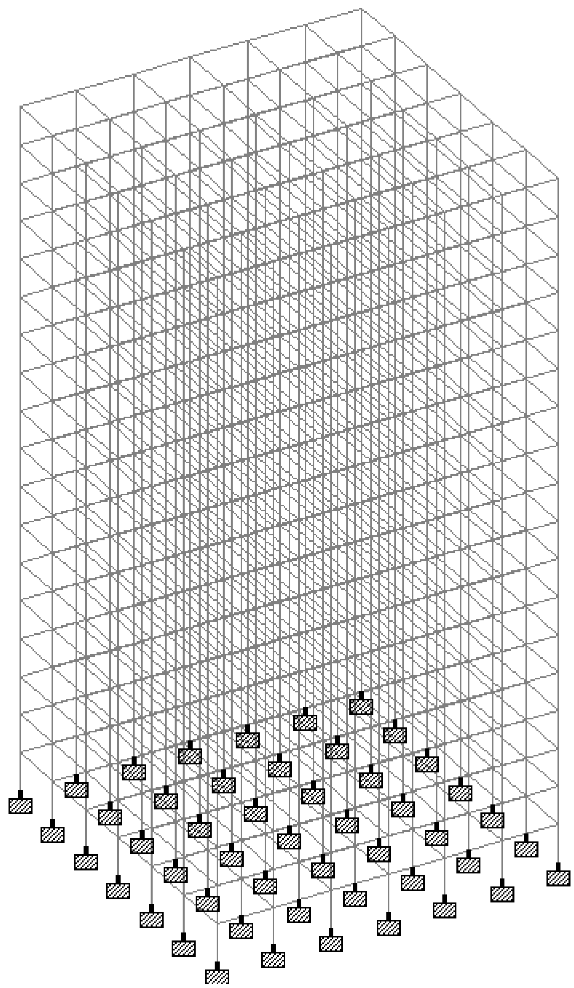


Fig 3.10 Model in STAAD.PRO

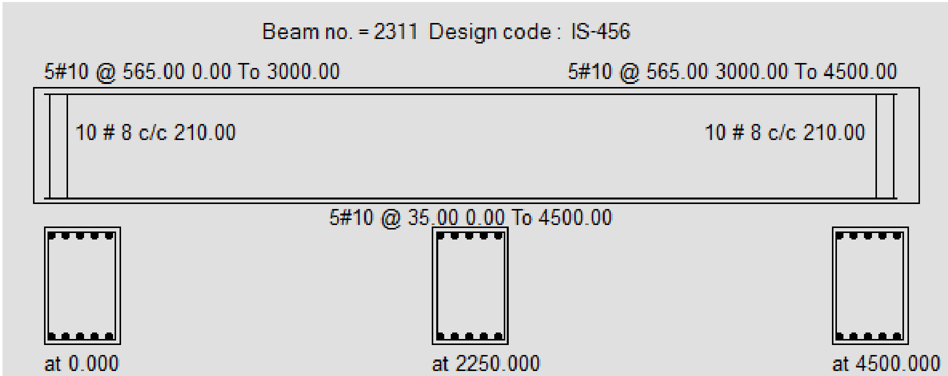


Fig 3.11 Reinforcement detailing of beam

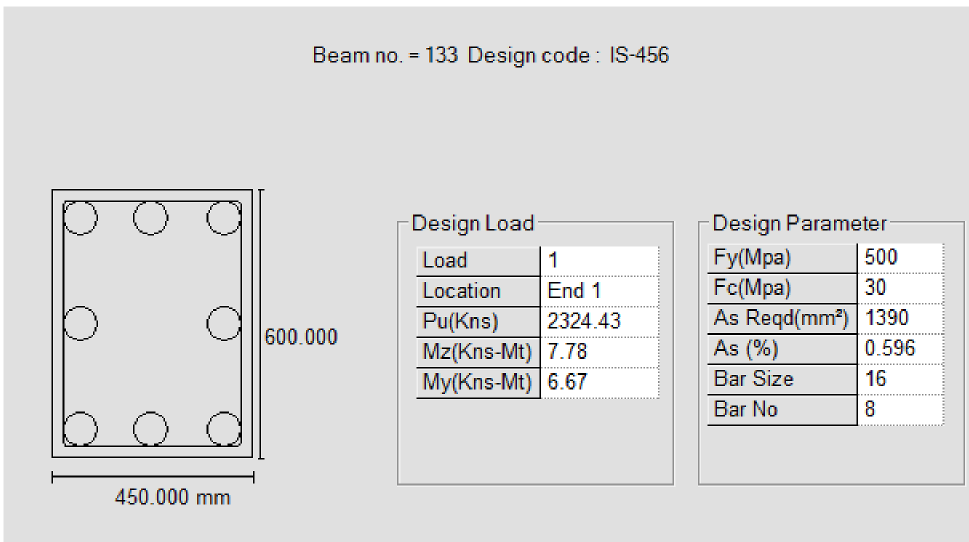


Fig 3.12 Reinforcement detailing of column

Now this building is imported into STAAD.FOUNDATION to design and analyze the raft foundation and to obtain required steel area and concrete volume.

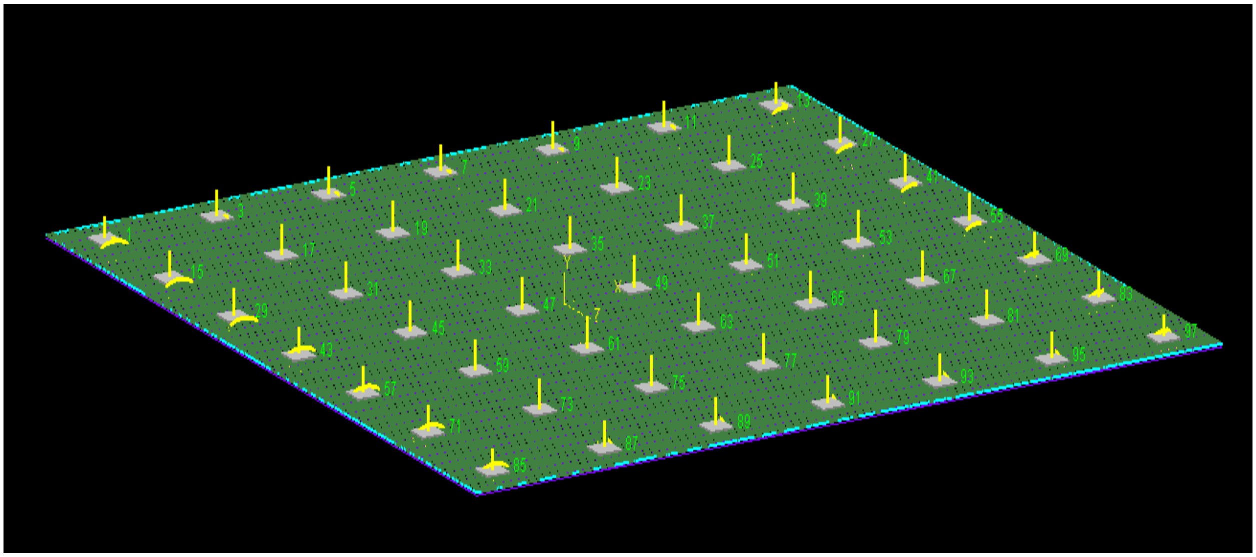


Fig 3.13 Raft model in STAAD.FOUNDATION

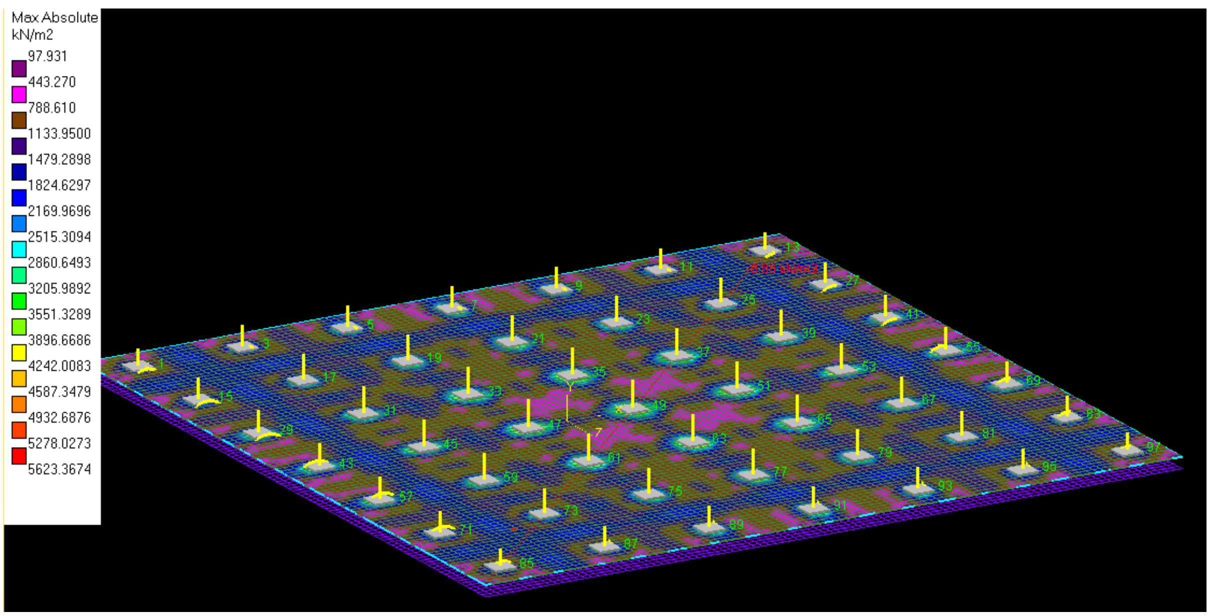


Fig 3.14 Max Absolute stress of raft foundation

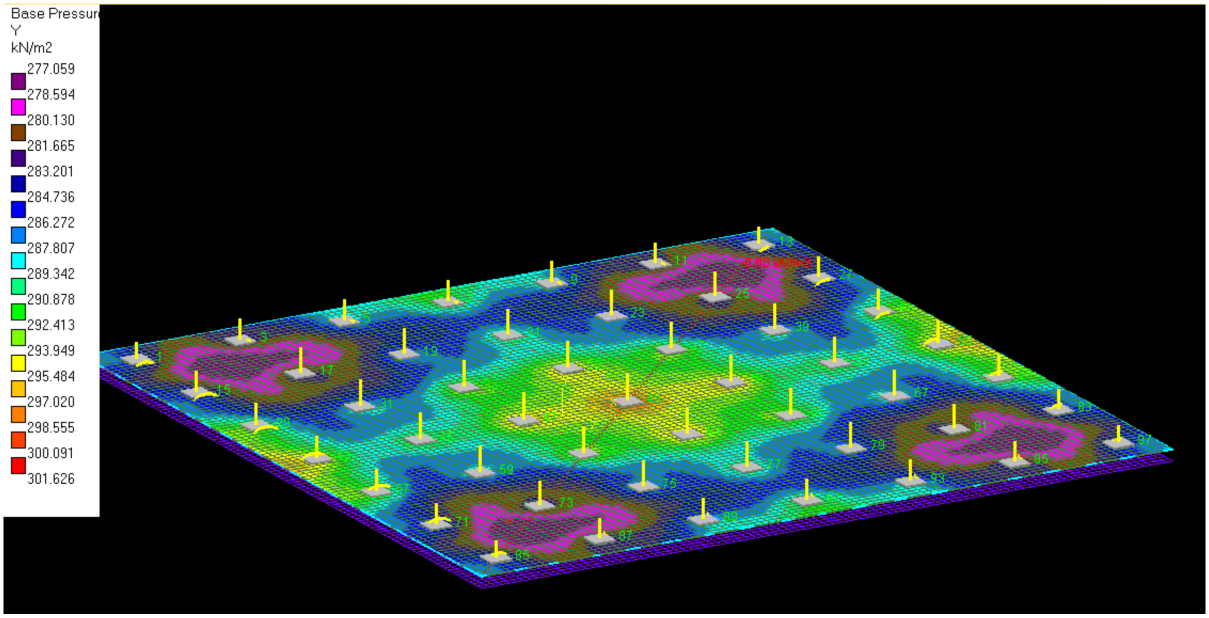


Fig 3.15 Soil Pressure of Raft foundation

Reinforcement is divided into 1 zone (i) Zone 1: 10mm dia bars are provided at 60mm center to center spacing

Provided area of steel in zone 1 = 1200 mm^2/ m

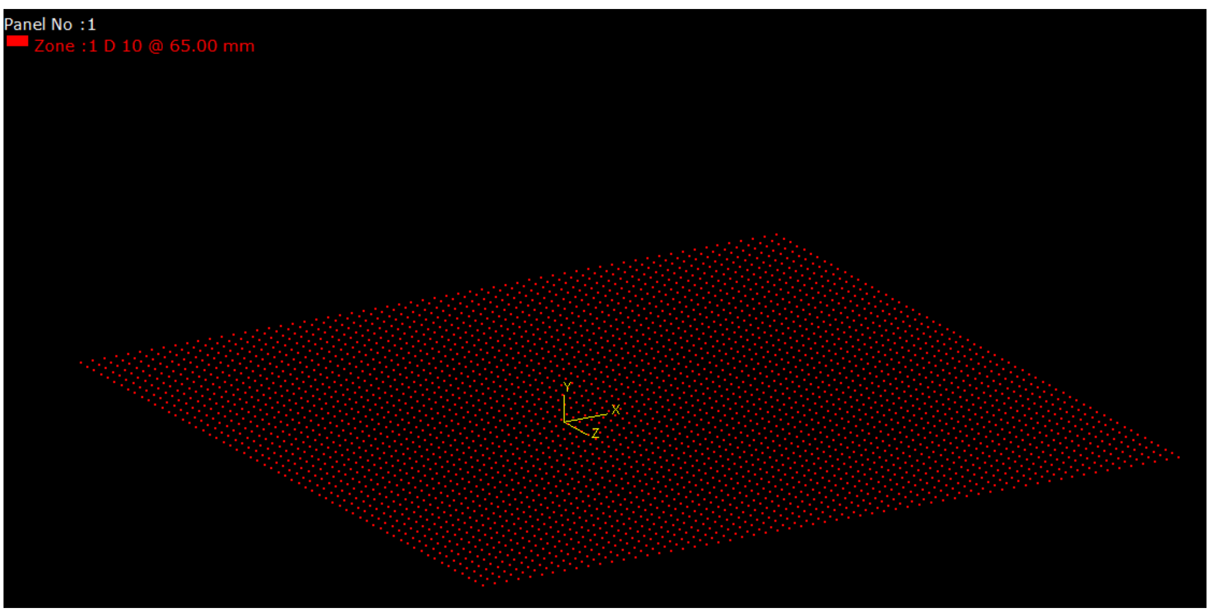


Fig 3.16 Reinforcement zoning in Raft foundation

3.8.6 Costing of raft foundation

Provided Steel area in per meter width (longitudinal directions) at top in zone 1= 1200 mm^2

Number of 12 mm dia bars in per meter width ≈ 16 bars

Length of one bar in per meter width = 35m (assume length of one rod is 5m and 60cm overlap)

Total length of all bars in per meter width at top = 35x16 = 560m

Weight of all bars in per meter width at top = 0.617x560 = 345.52 kg (unit weight of 10mm dia = 0.617)

Weight of steel bars in 30m raft = 345.52x30 = 10365.6 kg = 103.65 quintal

Cost of 10mm dia bars = 4700x103.6 = 486920 Rs

Similarly cost of 10mm dia bars at bottom in longitudinal direction = 486920 Rs

Similarly cost of 10mm dia bars at top in transverse direction = 486920 Rs

Similarly cost of 10mm dia bars at top in transverse direction = 486920 Rs

Total cost of steel = 1947680 Rs

Volume of concrete = 900m^3

Total Cost of concrete = 5000x900 = 4500000 Rs

Total cost of raft foundation = 64, 47,680 Rs

3.8.7 Pile group

Piles are the deep foundation which transfer loads from a structure to hard strata having adequate bearing capacity. Pile load transfer mechanism to the surrounding soil is complicated and it is difficult to understand. Pile transfer loads acting on it either by friction along pile shaft or end bearing resistance. Pile foundation construction depends upon the subsoil condition, characteristics of load and permissible settlement.

3.8.7.1 Load carrying capacity of pile group

Load carrying capacity of pile group may be equal to or less than the load carrying capacity of individual pile multiplied with pile number in the pile group. In case of driven friction piles load carrying capacity of pile group is equal to 2/3 to ¾ 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.

Individual pile capacity

The ultimate load capacity of piles in sandy soil is given by the formula according to IS 2911(part 1):2010

$$Q_u = A_p(1/2\ D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} K_i\ P_{Di}\ \tan \delta_i A_{si} \ \ldots\ldots 1$$

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

3.8.7.2 Calculation

In the pile group, piles of diameter 1m, length 15m are located in square pattern at 3m center to center spacing. Piles are bored friction concrete piles resting in the soil stratum having zero cohesion and average angle of friction are 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

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

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

Q_u = 462.145KN

Pile group capacity = 462.145x9 = 4159.305 KN

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

Safe group capacity = 86.65 KN/m^2

3.8.7.3 Settlement of pile group

Meyerhof (1976) suggests the following empirical relation for the elastic settlement of a pile group in sand

$$S_g = \frac{9.4\, q\sqrt{B_g}I}{N}$$

Where,

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

Data given

q = 86.65 KN/m^2

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

Group settlement = 30.45 mm

3.8.8 Settlement of pile group in PLAXIS 2D

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 4: 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	-	28x10^6	0.2
Pile cap	-	-	1	28x10^6	0.2

Table 5: 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

3.8.9 Results

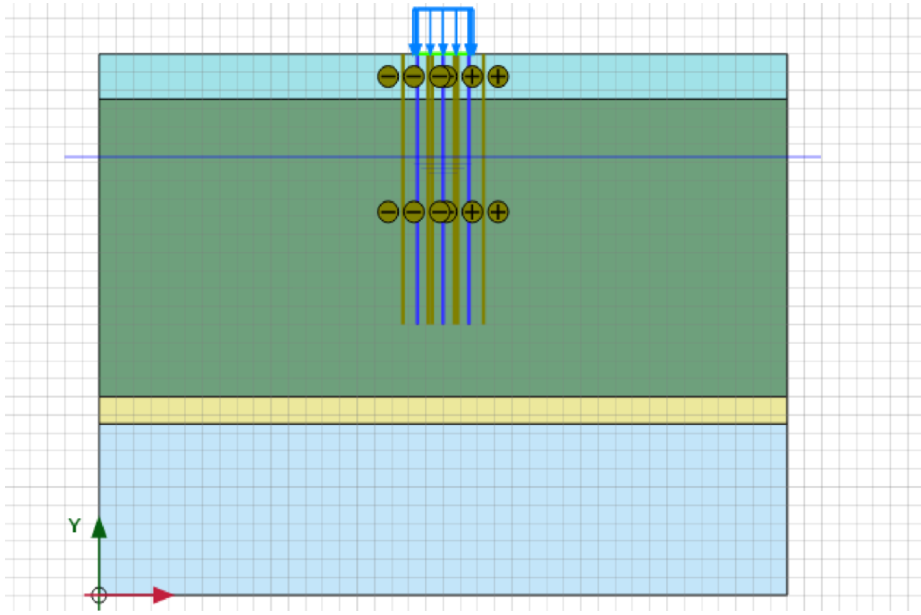


Fig 3.17 Model of pile group

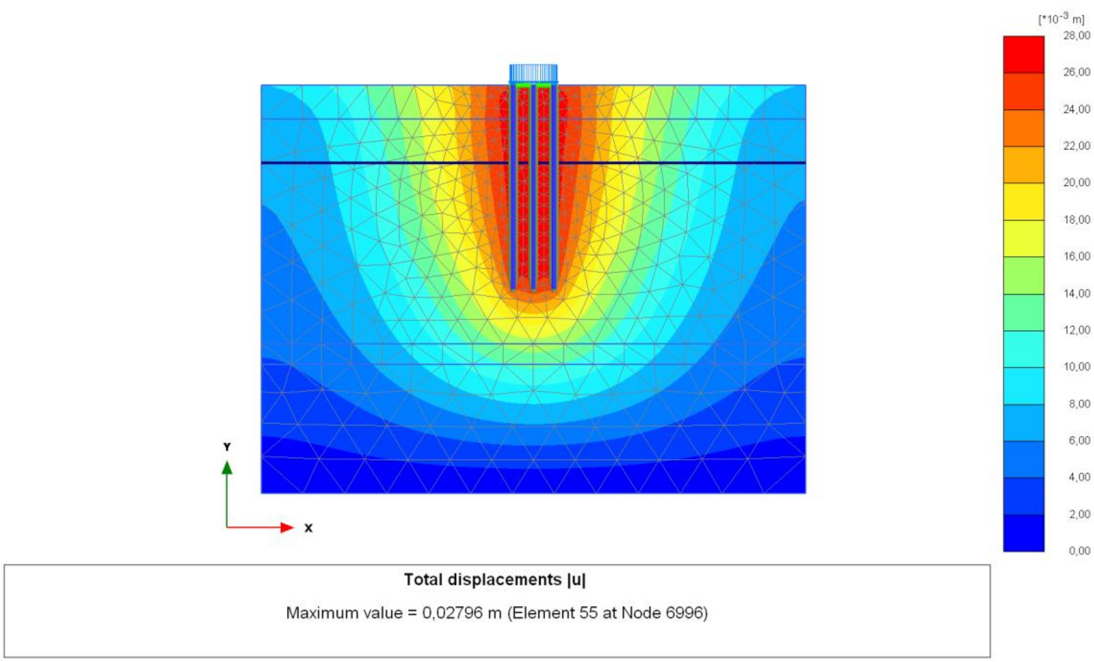
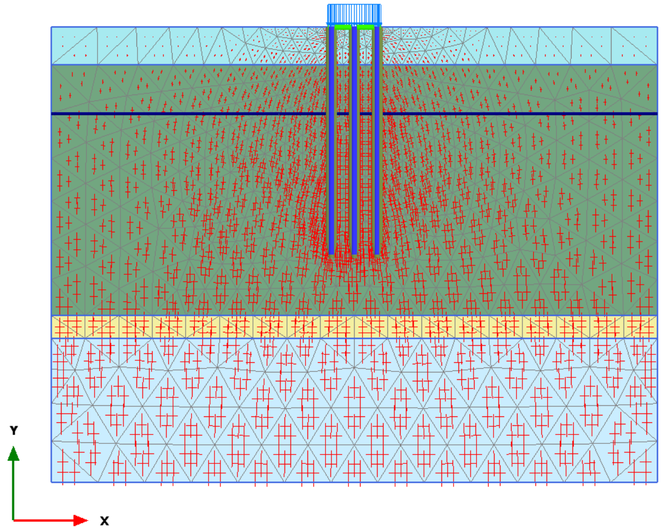


Fig 3.18 Displacement of pile group

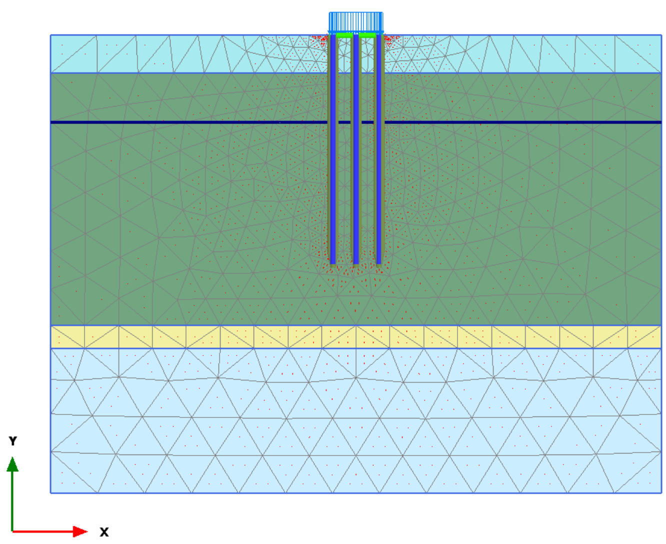


Effective principal stresses (scaled up 5,00*10^{-3} times)

Maximum value = -0,09049 kN/m^2 (Element 88 at Stress point 1045)

Minimum value = -360,7 kN/m^2 (Element 782 at Stress point 9382)

Fig 3.19 Stress contour of pile group



Total principal strain directions (scaled up 50,0 times)

Maximum value = 0,02054 (Element 50 at Stress point 589)

Minimum value = -0,02060 (Element 50 at Stress point 589)

Fig 3.20 Strain contour of pile group

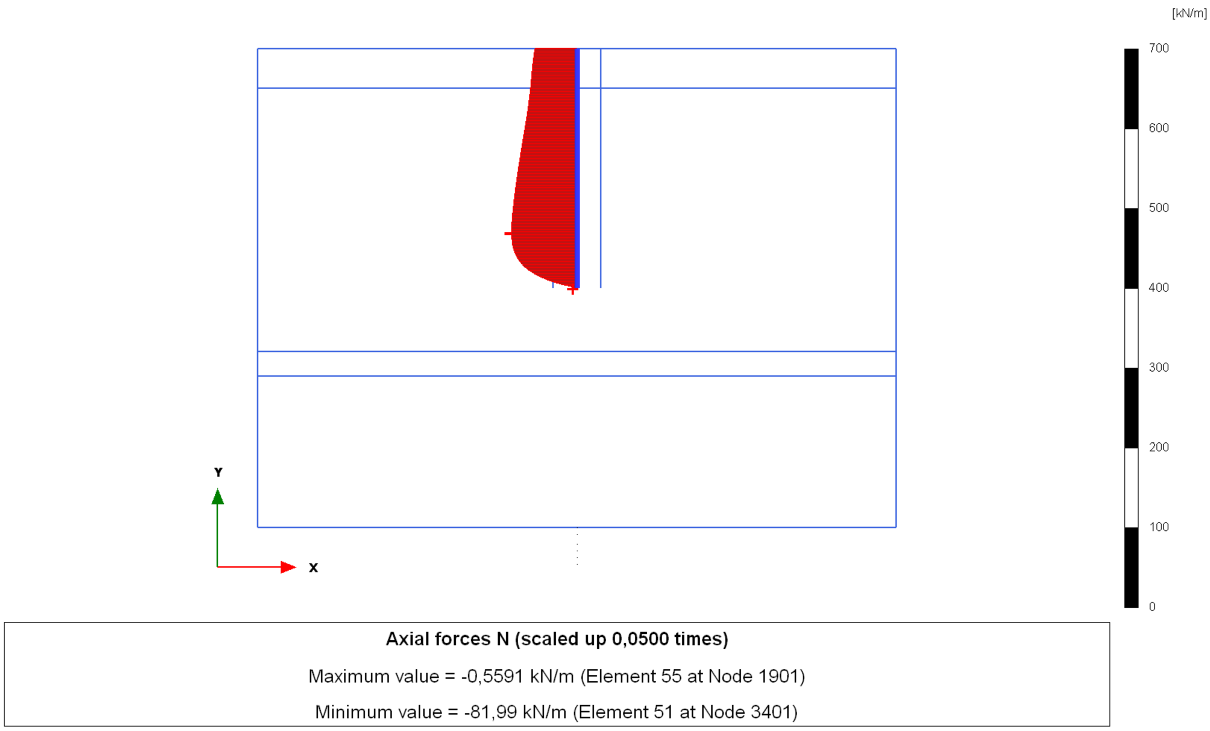


Fig 3.21 Axial force of center pile

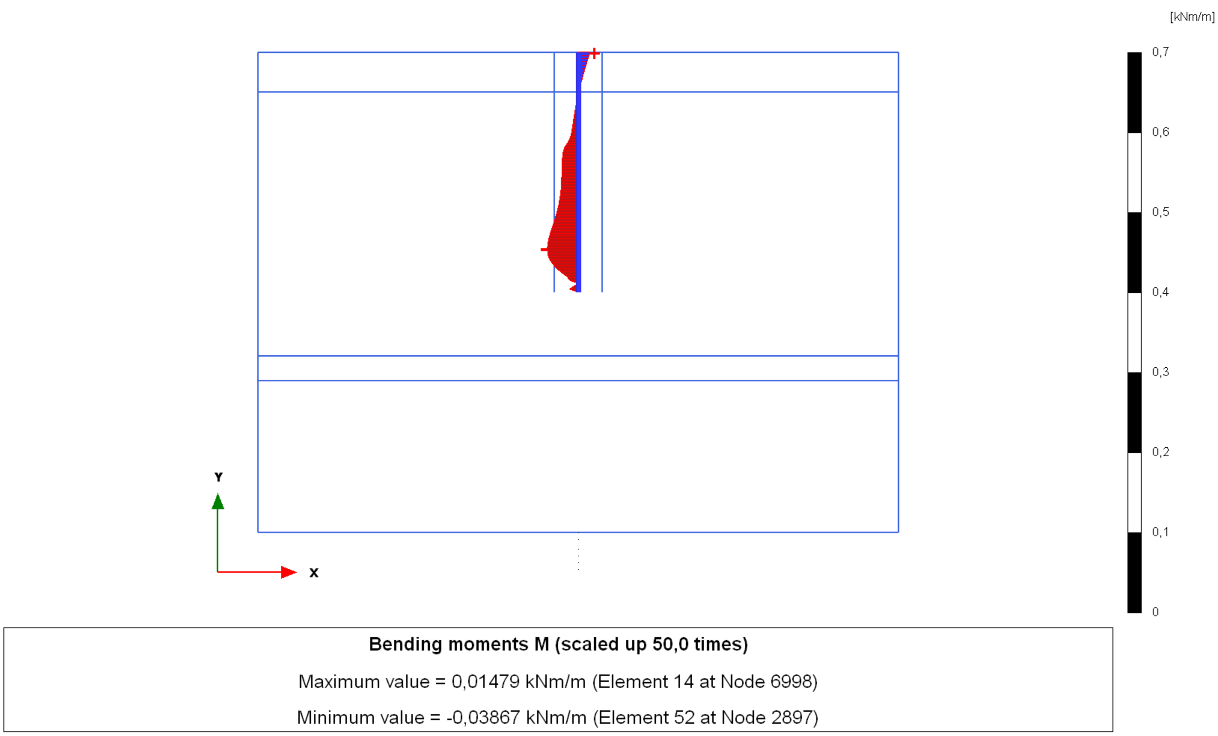
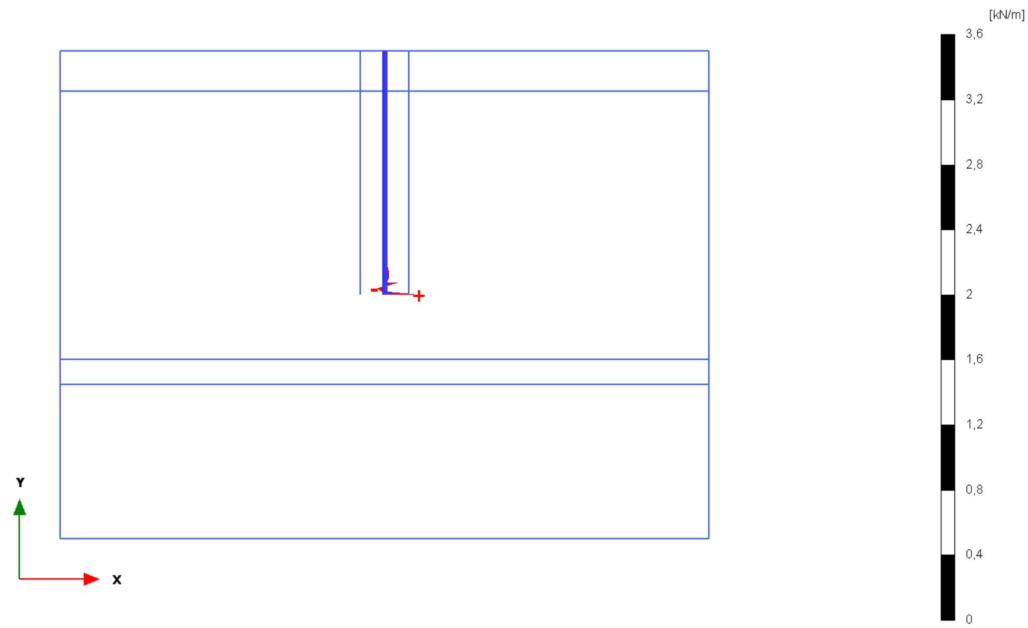


Fig 3.22 Bending moment of center pile



Shear forces Q (scaled up 10,0 times)

Maximum value = 0,1821 kN/m (Element 55 at Node 1901)

Minimum value = -0,04302 kN/m (Element 55 at Node 1903)

Fig 3.23 Shear force of center pile

3.9 Analysis and design of pile group foundation

Now Pile group foundation is designed for 13 storey building same as in case of raft foundation. 17 storey building Model is analyzed and design in STAAD.PRO to calculate forces and moments at the base column and reinforcement detailing in all the beams and column. Import this model in STAAD.FOUNDATION for design and analyze pile group and obtain required area of reinforcement.

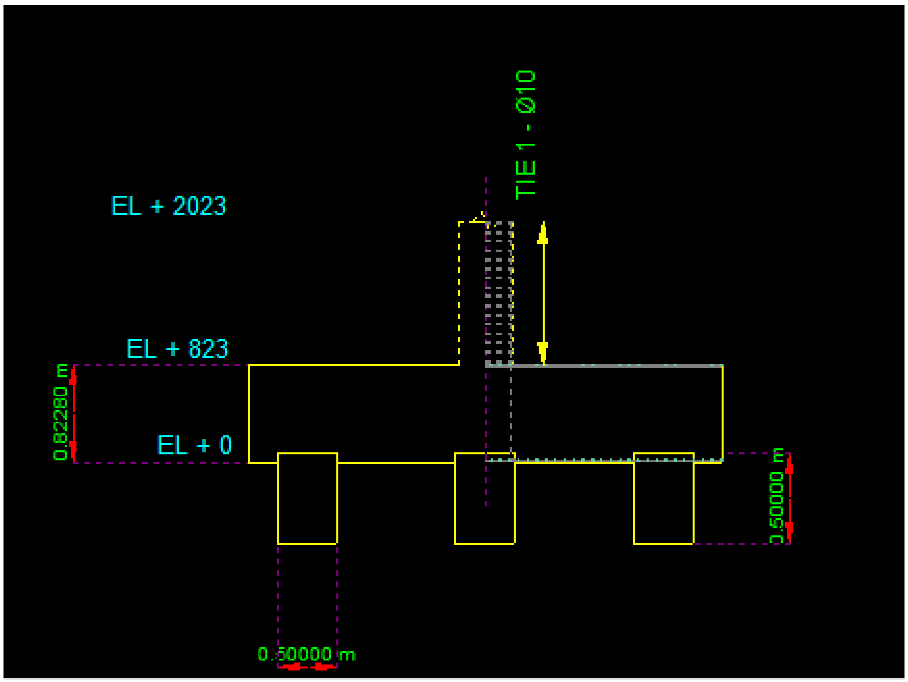


Fig 3.24 Section of pile group in STAAD.FOUNDATION

Each column have different pile cap depth and different required bar diameter. Pile cap beneath a column have been shown here. Under the Footing no 7 pile cap of size 4x4 m is used, thickness of pile cap is comes out 0.823m, and 32-12mm dia bars can be used at 114mm center to center

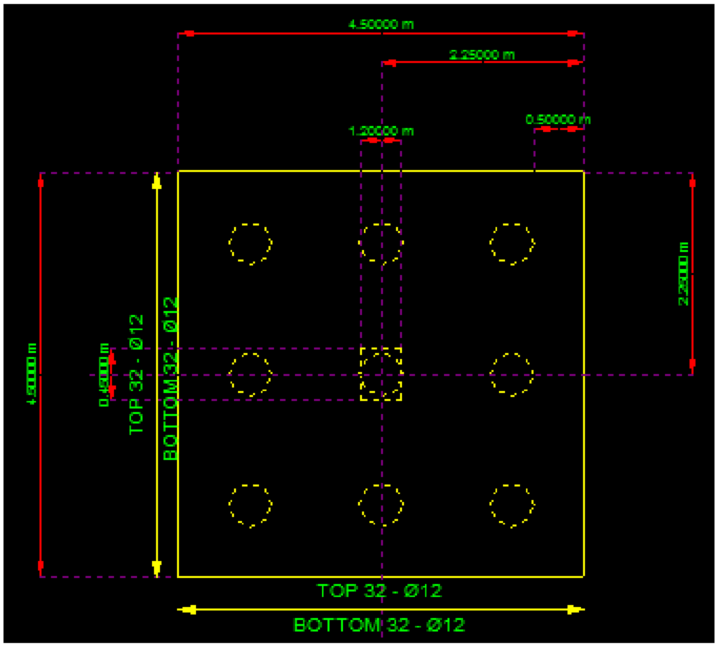


Fig 3.25 Plan of pile group in STAAD.FOUNDATION

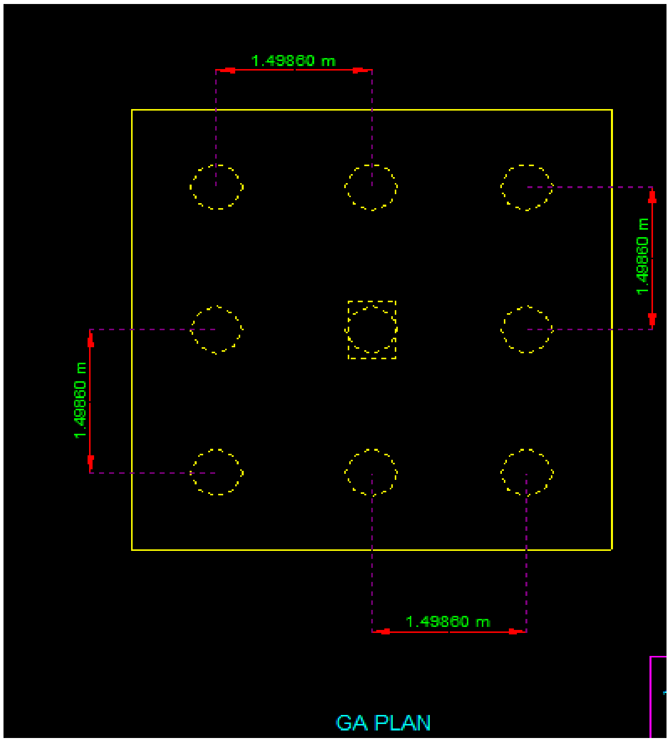


Fig 3.26 Plan of pile group in STAAD.FOUNDATION

CHAPTER 4

PARAMETRIC STUDY ON PILED RAFT FOUNDATION

4.1 Arrangement of piles and raft

Initially A pile group of nine piles have been considered for the modeling of piled raft foundation. Piles are identical, equally spaced and arranged in square pattern,. Diameter of the pile chosen is 1m, and length is 10m. Spacing is 3d(3m center to center). Lengths of the piles are varied 10m, 12m, 15m, 18m, 20m. Spacing between the piles are varied between 3 to 5m

4.2 The properties of a soil for parametric study

In this study, a borehole of DTU soil is selected which is a silty sand. Safe bearing capacity calculated in the previous chapter is increased from 230KN/m^2 to 400KN/m^2. Properties of the soil are taken from literature is given in Table 3.

Table 6: Properties of Soil Strata

Soil type	Modulus of elasticity	Poisson's ratio	Unit weight of soil	Cohesion c (KN/m^2)	Angle of friction
Silty sand	30000, 35000, 40000, 45000, 50000	.25-0.4	17.58 KN/m^2	0.00	31.5

4.3 The properties of concrete

The properties of concrete for pile and raft selected are given in table 6. The raft and pile are assumed to elastic material.

Table 7: Properties of concrete

Parameter	Pile	Raft
Grade of concrete,	M30	M30
Young's modulus, E	$28x10^6$	$28x10^6$
Poisson's ratio, μ	0.2	0.2
Type of behavior	Linear, isotropic	Linear, isotropic
Pile type	Circular	-
Diameter, D m	1	-
Raft thickness	-	1

4.4 Results of the study

A parametric study has been done by varying the Modulus of Elasticity of soil (E_s) Pile length(L) and Spacing between Piles(s/d). The variation of settlement with various Modulus of elasticity, Pile length, Pile diameter, Spacing and load is plotted in figure. The no of Piles are also varied under the raft and their effect is plotted. The results obtained for various combinations are tabulated in table as well as plotted in the graph.

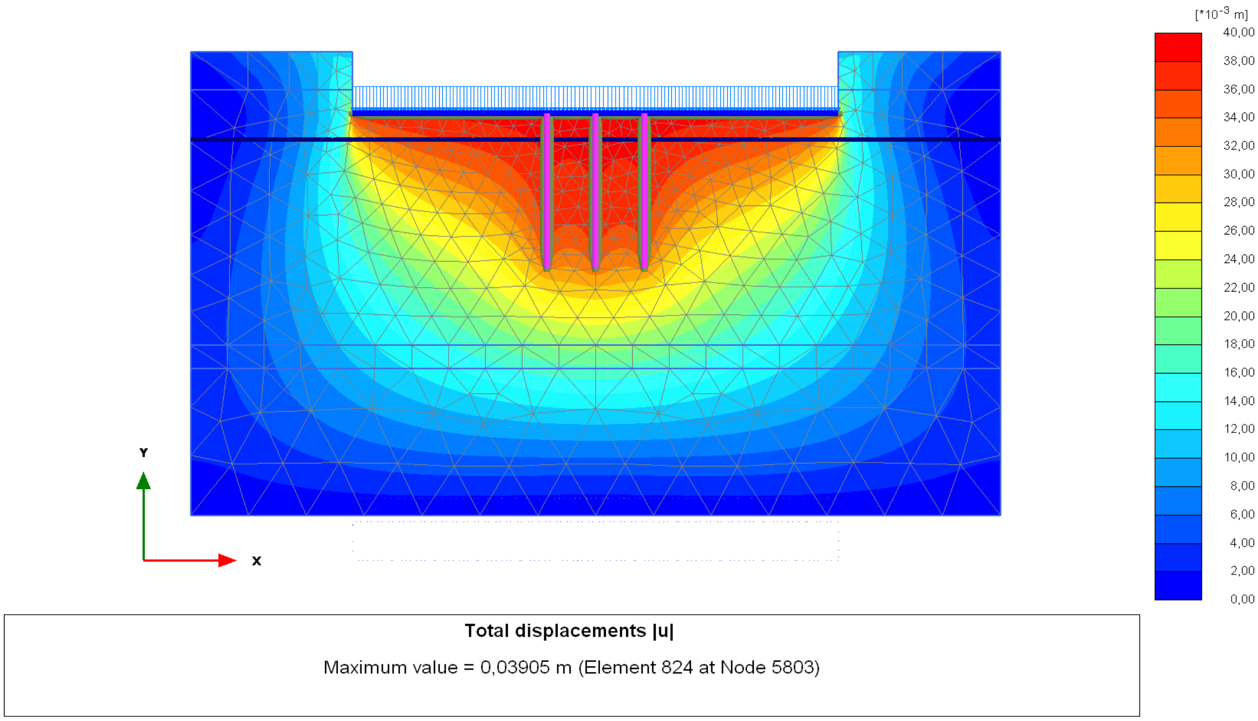


Fig 4.1 Displacement of piled raft for 280.00 KN/m^2

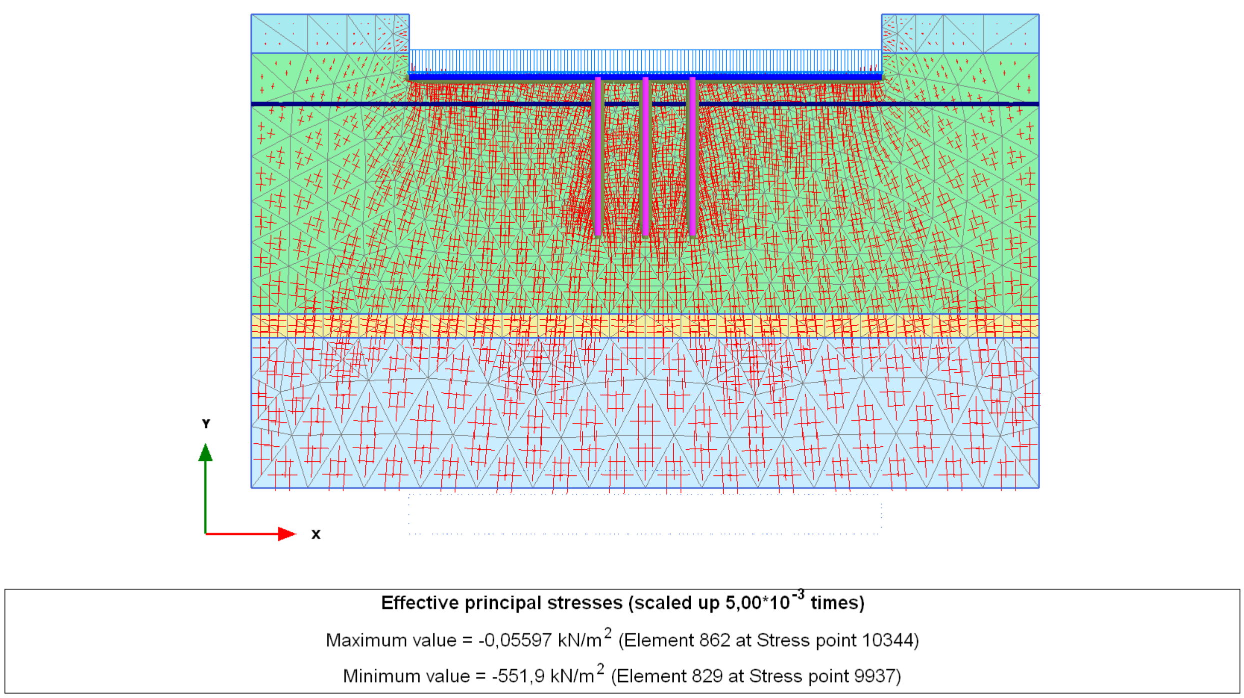


Fig 4.2 Effective stress of piled raft for raft bearing capacity (280.00 KN/m^2)

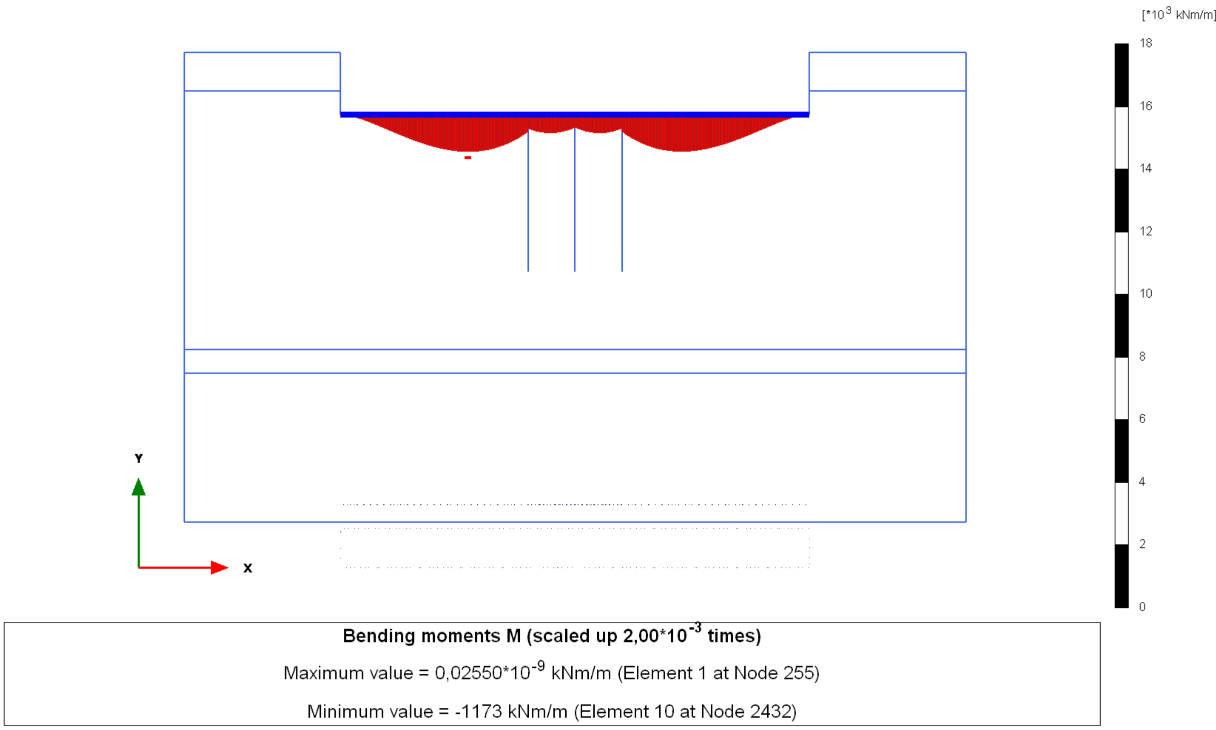


Fig 4.3 Bending moment of raft in piled raft

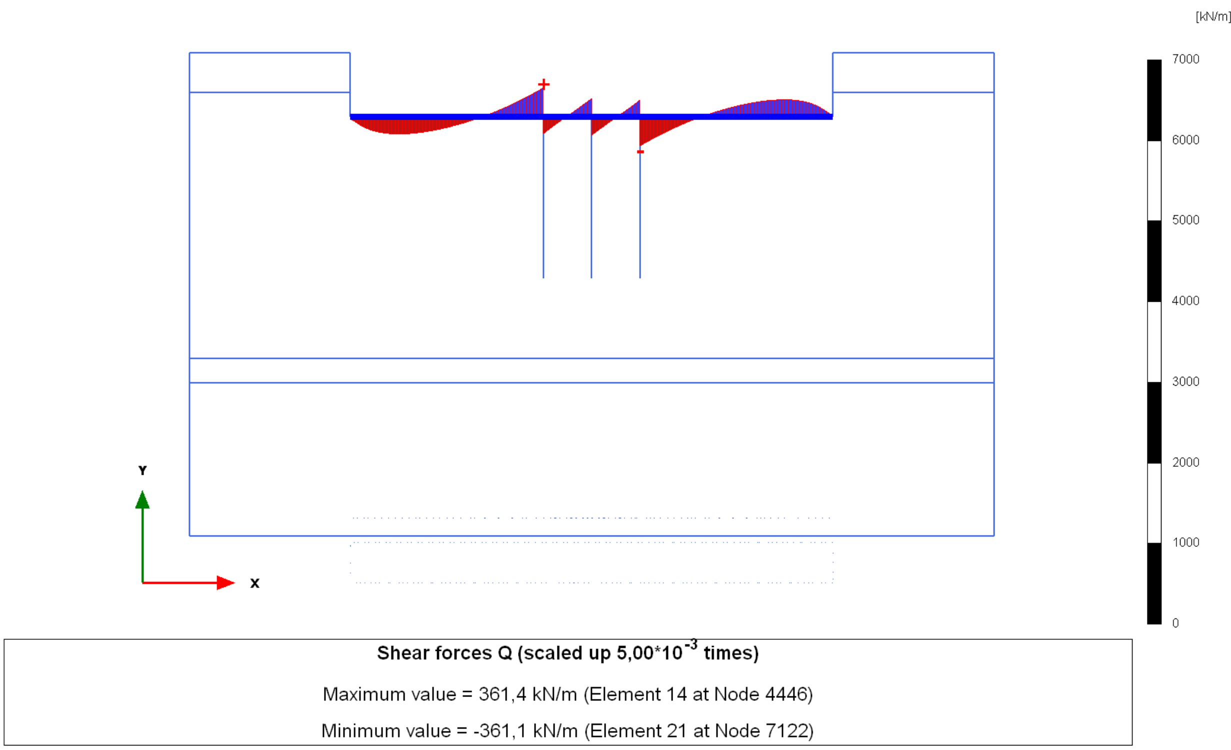


Fig 4.4 Shear force of raft in piled raft

From these results, it is clear that settlement will reduce in case of piled raft foundation for the bearing capacity of raft that is 280.00 KN/m^2, now the load on piled raft is increased so that a high rise building can be constructed and settlement beneath the foundation will be within the permissible limits in the same soil condition.

Table 8: Settlement of piled raft for different pile length with stress 300KN/m^2

	Pile length (m)			
	10	12	15	18
Settlement (mm) for Es=30000 (kN/m^2)	89.77	86.69	80.50	75.17
Settlement (mm) for Es=35000 (kN/m^2)	77.08	74.44	69.95	64.95
Settlement (mm) for Es=40000 (kN/m^2)	67.57	65.25	61.40	57.21
Settlement (mm) for Es=45000 (kN/m^2)	60.16	58.09	54.75	51.17
Settlement (mm) for Es=50000 (kN/m^2)	54.31	52.37	49.40	46.34

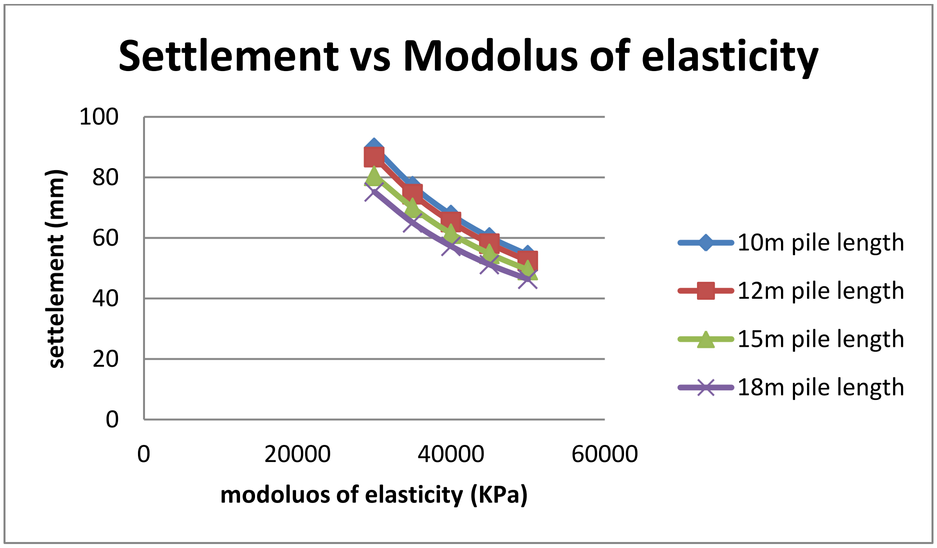


Fig 4.5 Settlement vs modulus of elasticity under 300KN/m^2

Table 9: Settlement of piled raft for different pile length with stress 400KN/m^2

	Pile length (m)			
	10	12	15	18
Settlement (mm) for Es=30000 (kN/m^2)	126.4	122.2	114.9	107.7
Settlement (mm) for Es=35000 (kN/m^2)	108.6	104.9	99.89	92.95
Settlement (mm) for Es=40000 (kN/m^2)	95.10	92.00	87.69	81.89
Settlement (mm) for Es=45000 (kN/m^2)	84.65	81.97	78.19	73.23
Settlement (mm) for Es=50000 (kN/m^2)	76.29	73.76	70.56	66.29

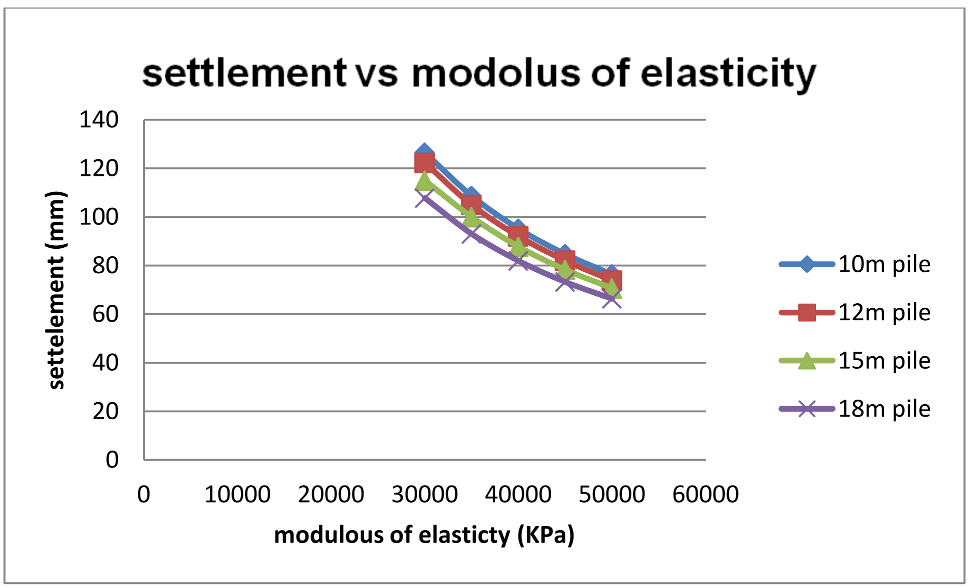


Fig 4.6 Settlement vs modulus of elasticity under 400 KN/m^2

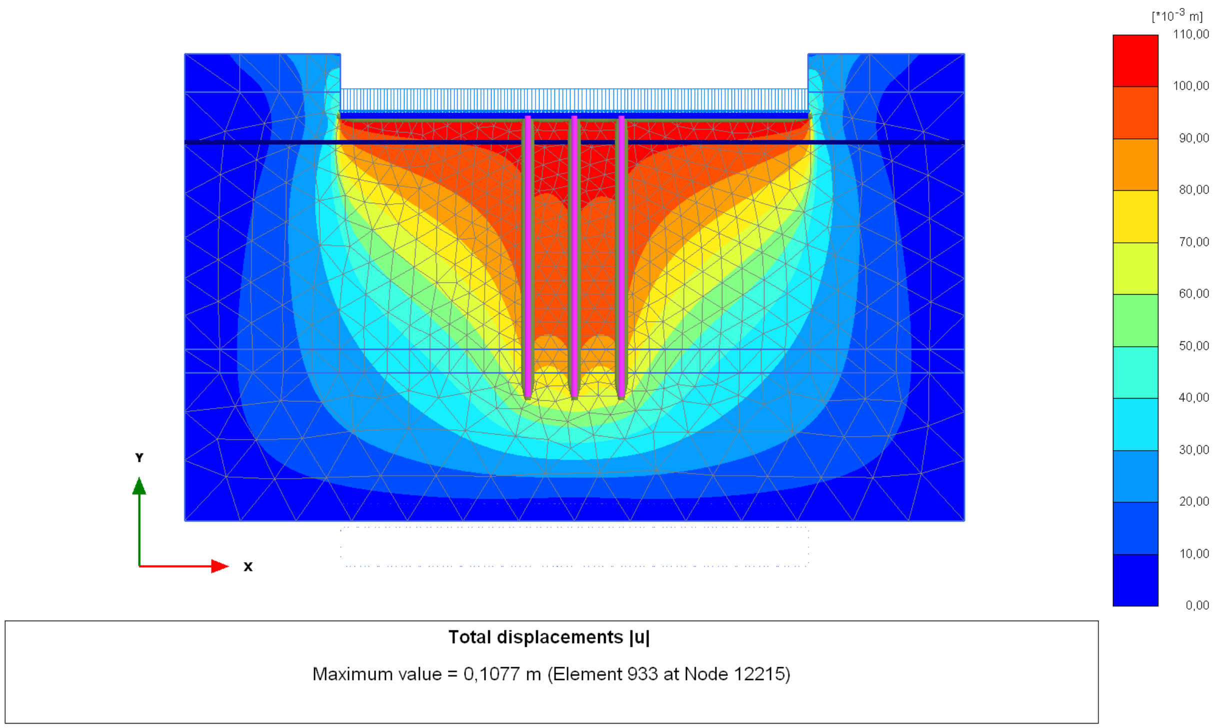


Fig 4.7 Displacement contour of 18 m pile under 400KN/m^2 for 30000MPa

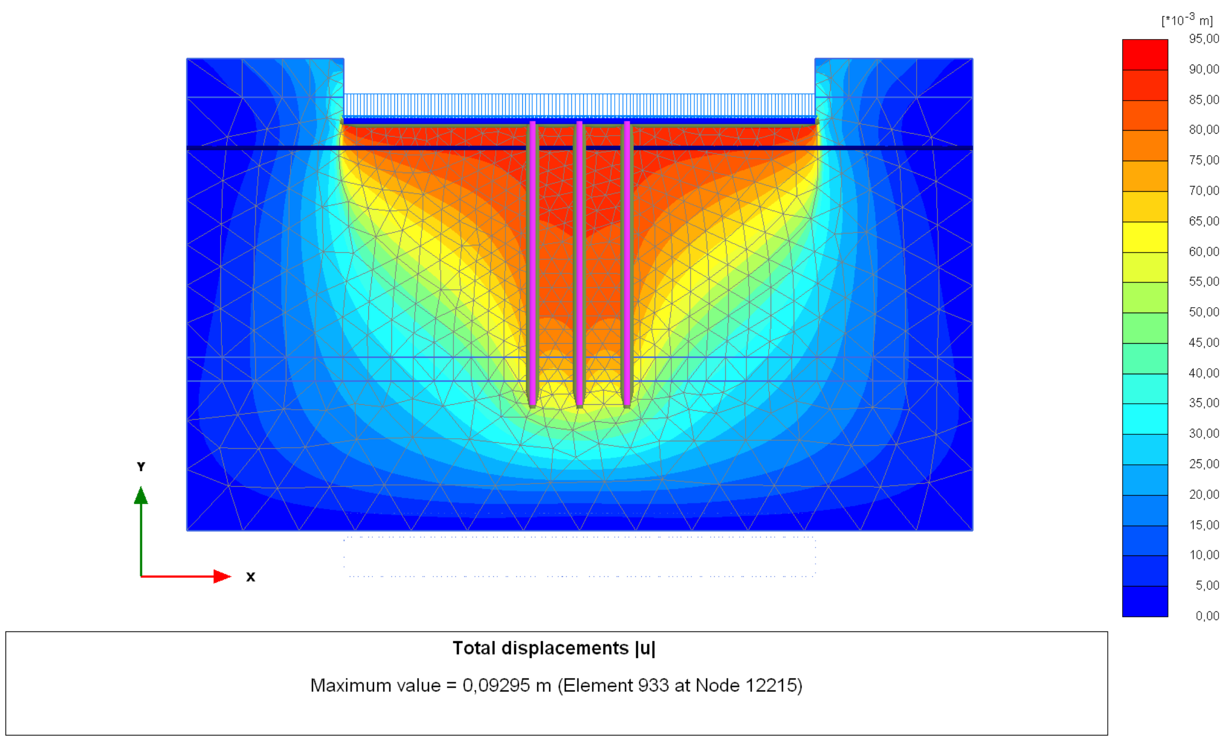


Fig 4.8 Displacement contour of 18m pile under 400KN/m^2 for 35000MPa

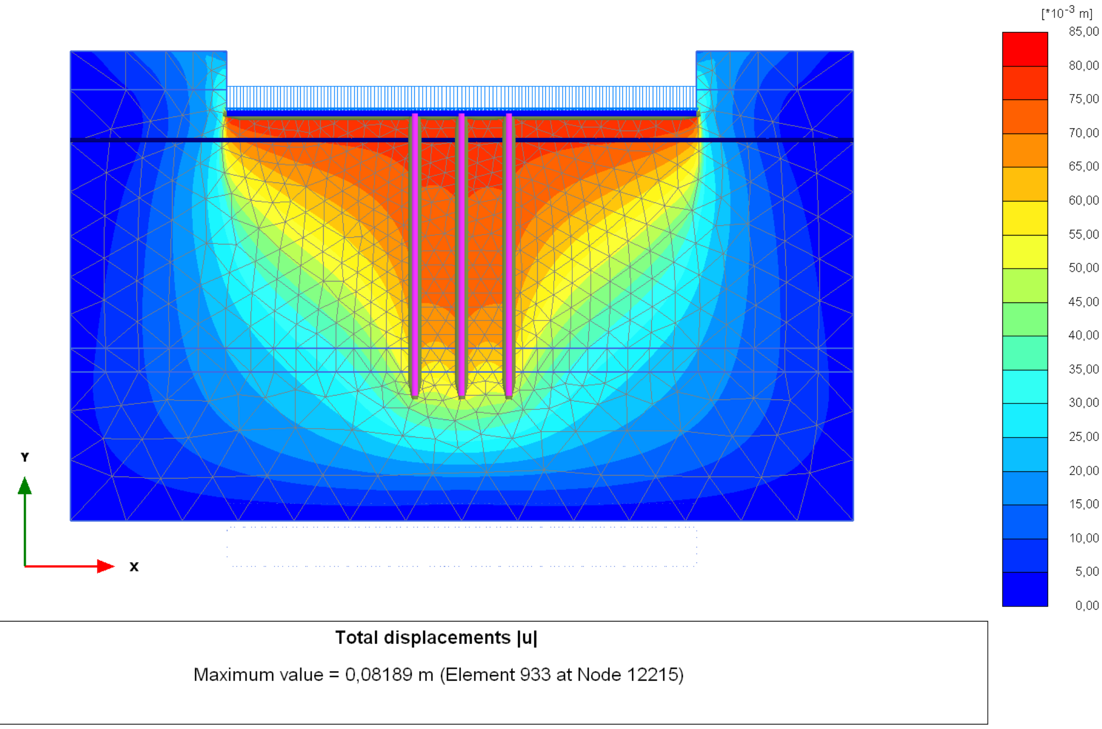


Fig 4.9 Displacement contour of 18m pile under 400KN/m^2 for 40000MPa

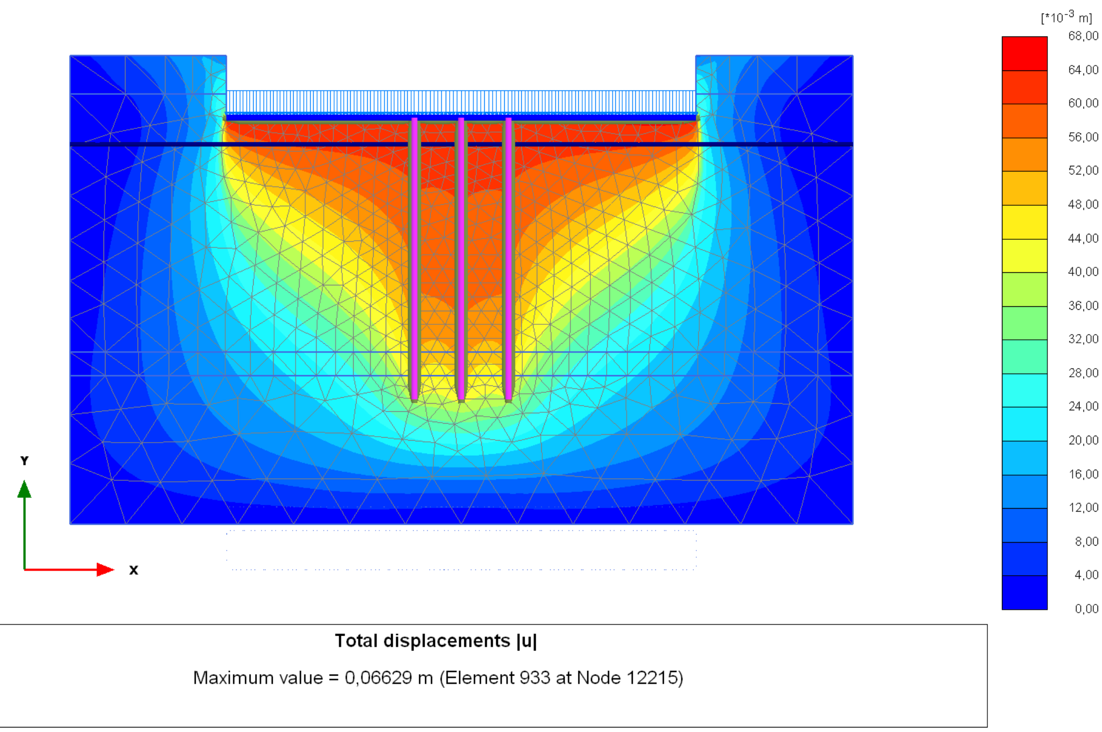


Fig 4.10 Displacement contour of 18m pile under 400KN/m^2 for 50000MPa

4.5 Calculation of Number of Floors in case of piled raft foundation

Residential building is considered above the pile group foundation. Dead load and live load on building is consider based on IS code 875: Part 2

Loads

Imposed load due to for habitable rooms, kitchens, toilet and bathrooms = 1.5KN/m^2

Imposed loads due to corridors, passages and staircases including fire escapes = 1.5 KN/m^2

Balconies = 3.0KN/m^2

Dead load due to each floor = 3KN/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

Load from basement = 12.5KNm^2

Factored load = 10.5x1.5 = 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

Load from floors = 400-12.5 = 387.5 KN/m^2

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

= 387.5 /15.75 = 24.60 floors

= 24.60 ≈ 25 floors

4.6 Analysis and design of piled raft foundation using STAAD.FOUNDATION

Building of 28 floors can be constructed in case of piled raft foundation, building is assumed residential, now this building is modeled in STAAD.PRO and loading is applied according to IS: 875 part 2-1987. After applying loading analysis is performed and concrete design of all beams and columns has been carried out.

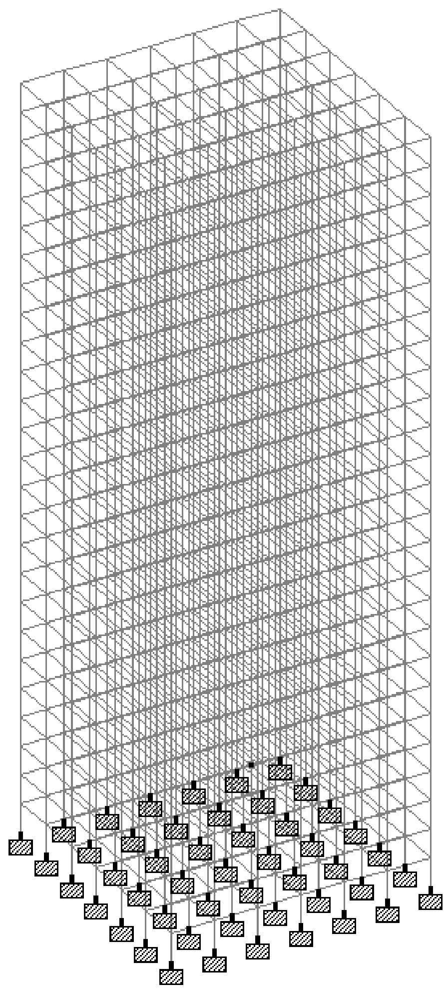


Fig 4.11 Model of 25 floors building in STAAD.PRO

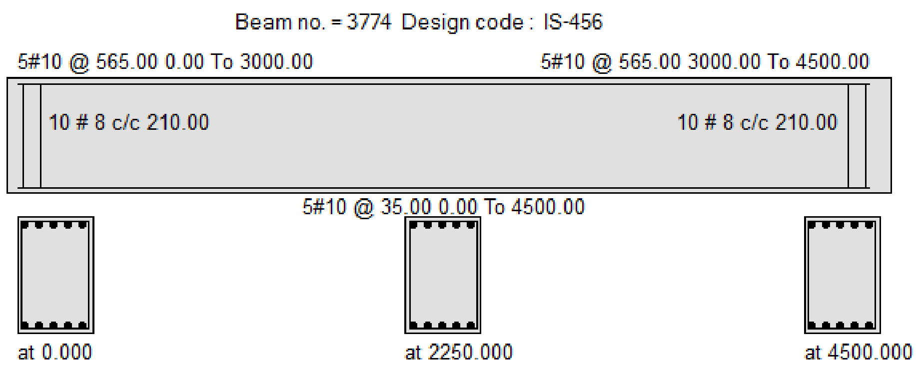


Fig 4.12 Concrete design of beam

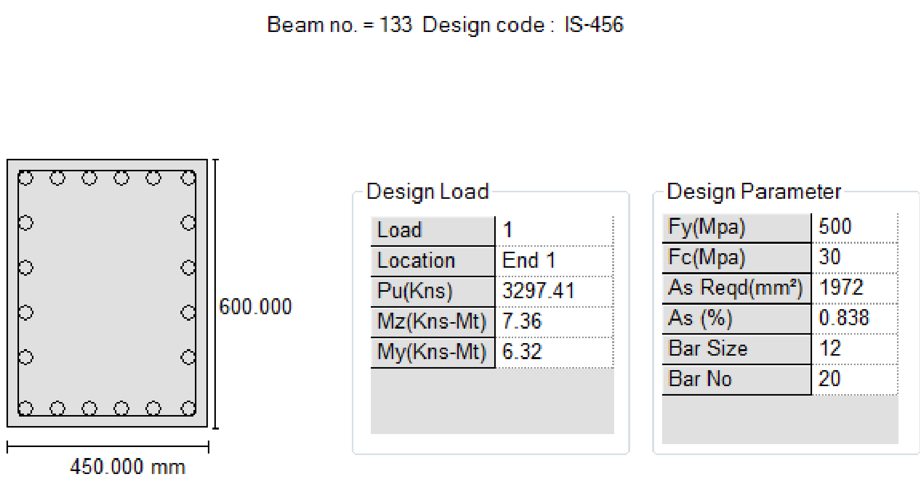


Fig 4.13 Concrete design of column

Now this 25 storey building is imported in STAAD.FOUNDATION, and analysis and design of piled raft has been carried out.

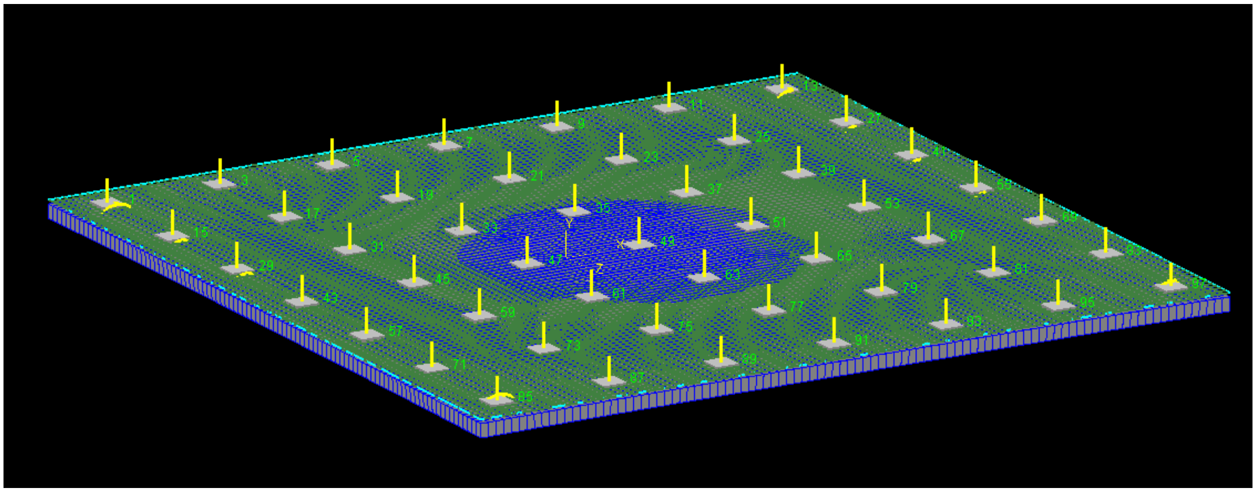


Fig 4.14 3D model of piled raft

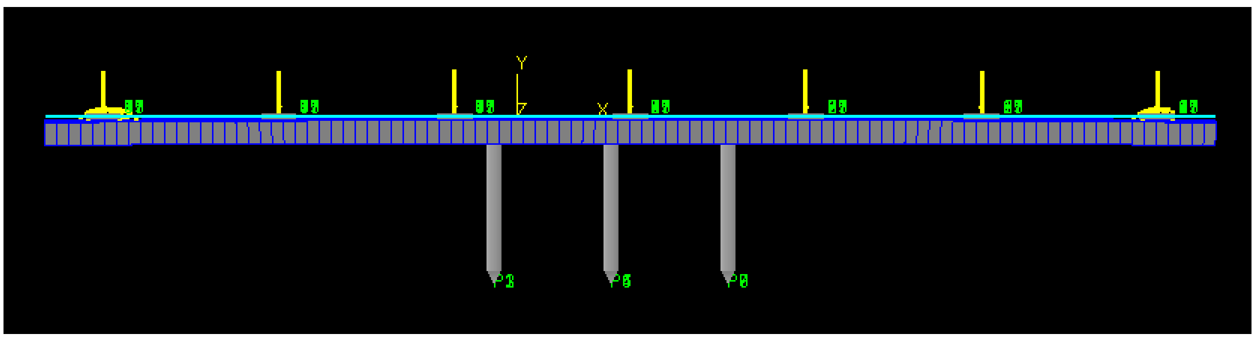


Fig 4.15 3D model of piled raft

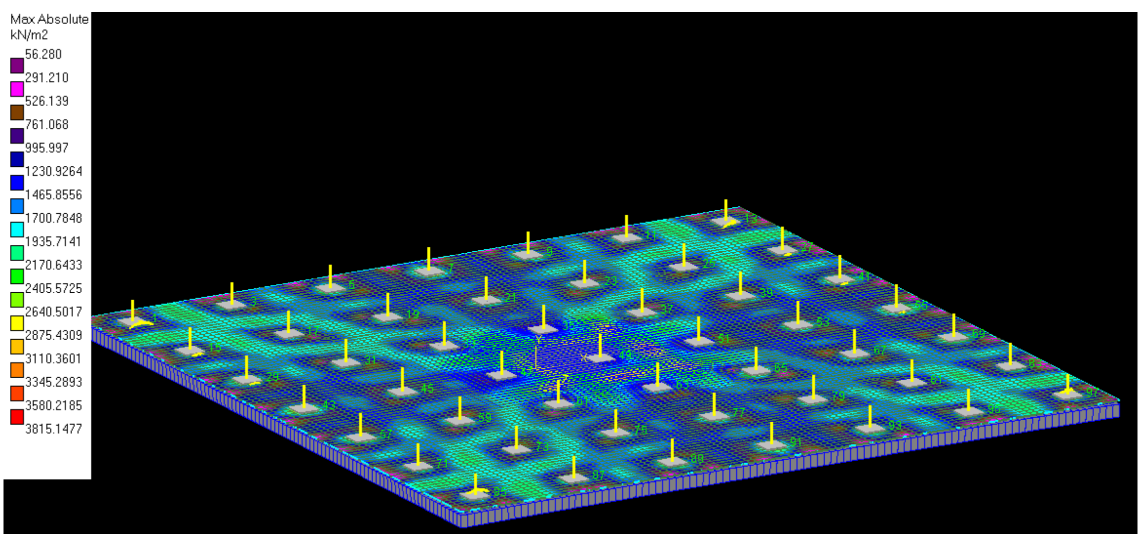


Fig 4.16 Max absolute stress of piled raft

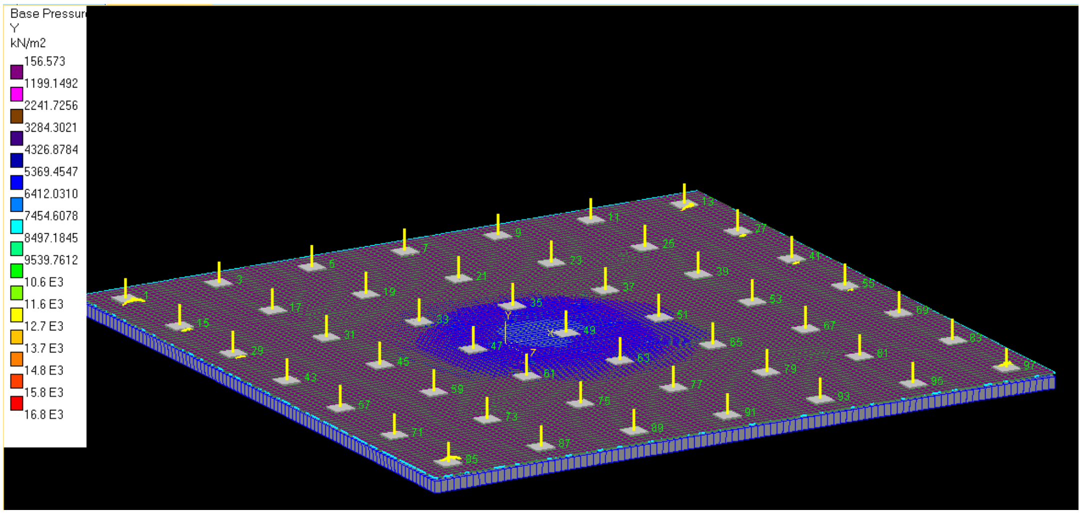


Fig 4.17 Soil pressure of piled raft

After designing the piled raft area of steel has been worked out. Reinforcement in piled raft is divided into 2 Zones (i) Zone 1: In this Zone 10mm dia bars are provided at 60mm center to center (ii) Zone 2: In this Zone 10mm dia bars are provided at 50mm center to center.

Provided area of steel in Zone 1 = 1413.962mm^2 /m

Provided area of steel in Zone 2 = 1616.695mm^2/m

4.7 Costing of piled raft foundation

Provided Steel area in per meter width at top in zone 1= 1413.962 mm^2

Number of 10 mm dia bars in per meter width ≈ 18 bars

Length of one bar in per meter width = 35m (assume length of one rod is 5m and 60cm overlap)

Total length of all bars in per meter width at top = 35x18 = 630m

Weight of all bars in per meter width at top = 0.617x630 = 388.71 kg (unit weight of 10mm dia = 0.617)

Weight of steel bars in 30m raft = 388.71x30 = 11661.3 kg = 116.61 quintal

Cost of 10mm dia bars = 4700x116.61 = 545670 Rs

Similarly cost of 10mm dia bars at bottom = 545670 Rs

Similarly in transverse direction = 1091340 Rs

Provided Steel area in per meter width (longitudinal directions) at top in zone 1= 1616.695 mm^2

Number of 10 mm dia bars in per meter width ≈ 21bars

Length of one bar in per meter width = 35m (assume length of one rod is 5m and 60cm overlap)

Total length of all bars in per meter width at top = 35x21 = 735 m

Weight of all bars in per meter width at top = 0.617x735 = 453.495 kg (unit weight of 10mm dia = 0.617)

Weight of steel bars in 30m raft = 453.495x30 = 13604.85 kg = 136.04 quintal

Cost of 10mm dia bars = 4700x136.04 = 639388 Rs

Similarly cost of 10mm dia bars at bottom = 639388 Rs

Similarly in transverse direction = 1278776 Rs

Total cost of steel = 47, 40,232 Rs

Volume of concrete = $900m^3$

Total Cost of concrete in raft = 5000x900 = 4500000 Rs

Volume of concrete in 1m dia, 10m length pile = 7.853 m^3

Total cost of concrete in 9 piles = 7.85x9x5000 = 353250 Rs

Total cost of piled raft foundation = 95, 93,482 Rs

Table 10: Settlement of Piled- Raft with Raft Thickness of 1.0 m

Pile Length (m)	Settlement of piled raft (mm)		
	Pile Group: 3x3	Pile Group:5x5	Pile Group:7x7
10	76.29	73.79	70.76
12	74.24	71.14	67.25
15	71.63	67.34	62.24
18	66.90	61.18	53.75

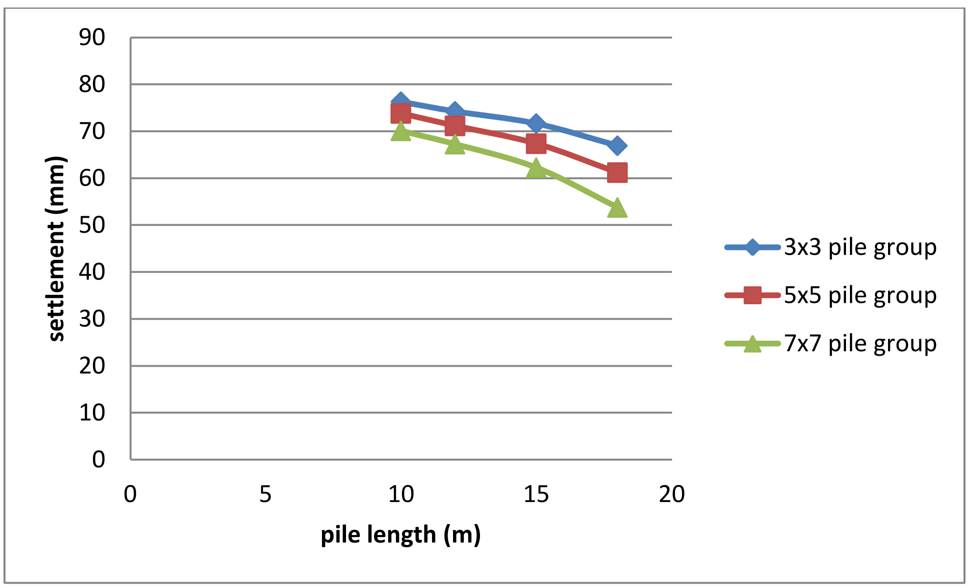


Fig 4.18 Settlement vs pile length

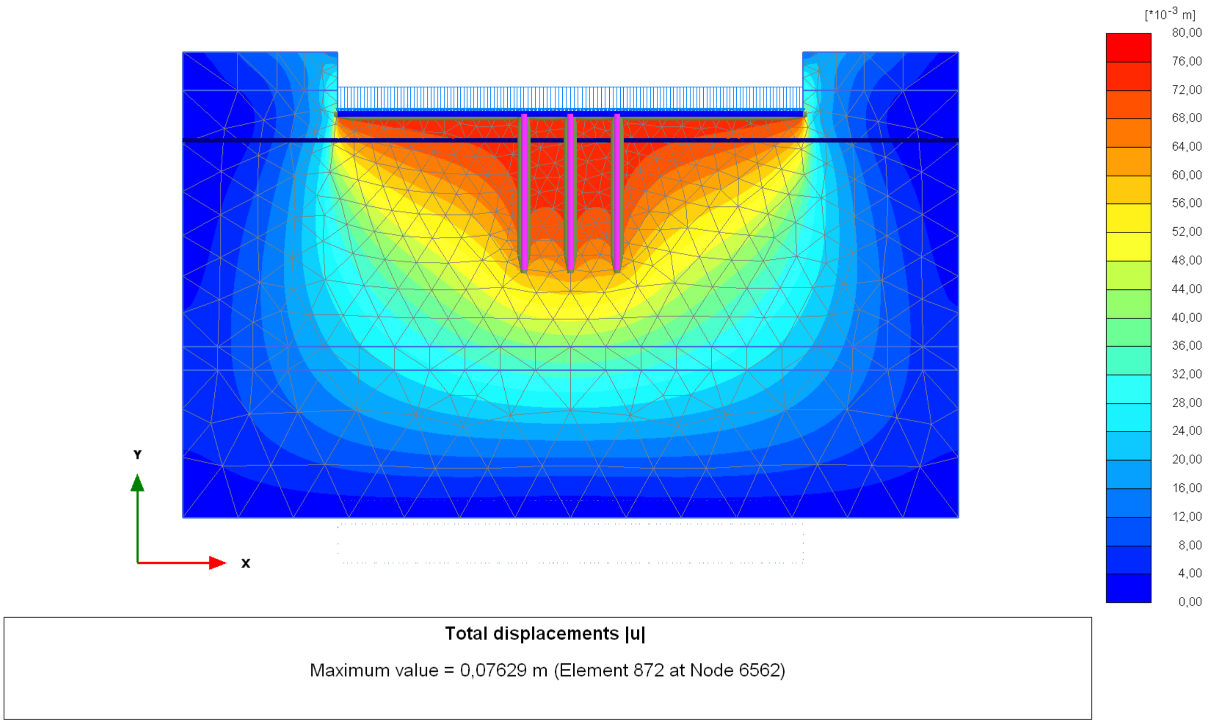


Fig 4.19 Settlement of piled raft with 10m pile length in 3x3 pile group

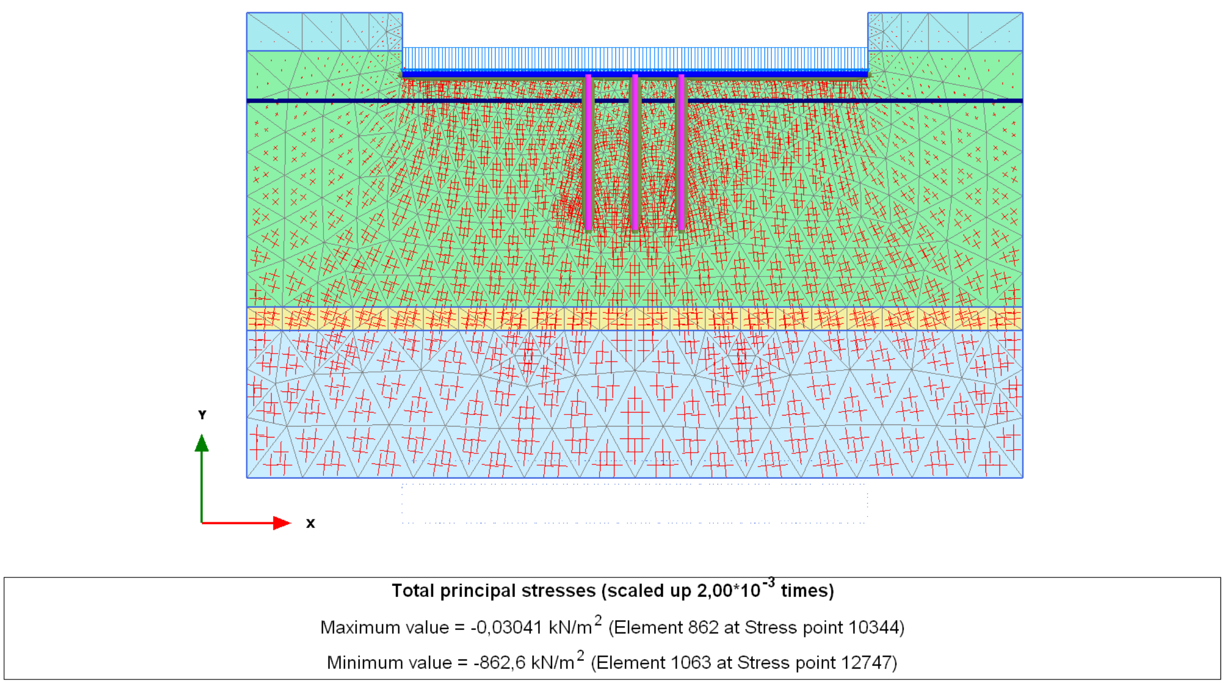
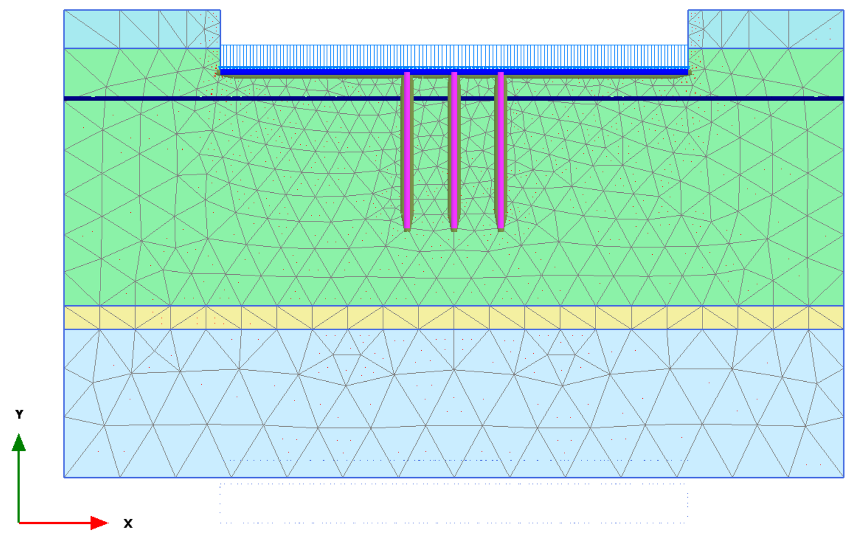


Fig 4.20 Stress of piled raft with pile length 10m in 3x3 pile group

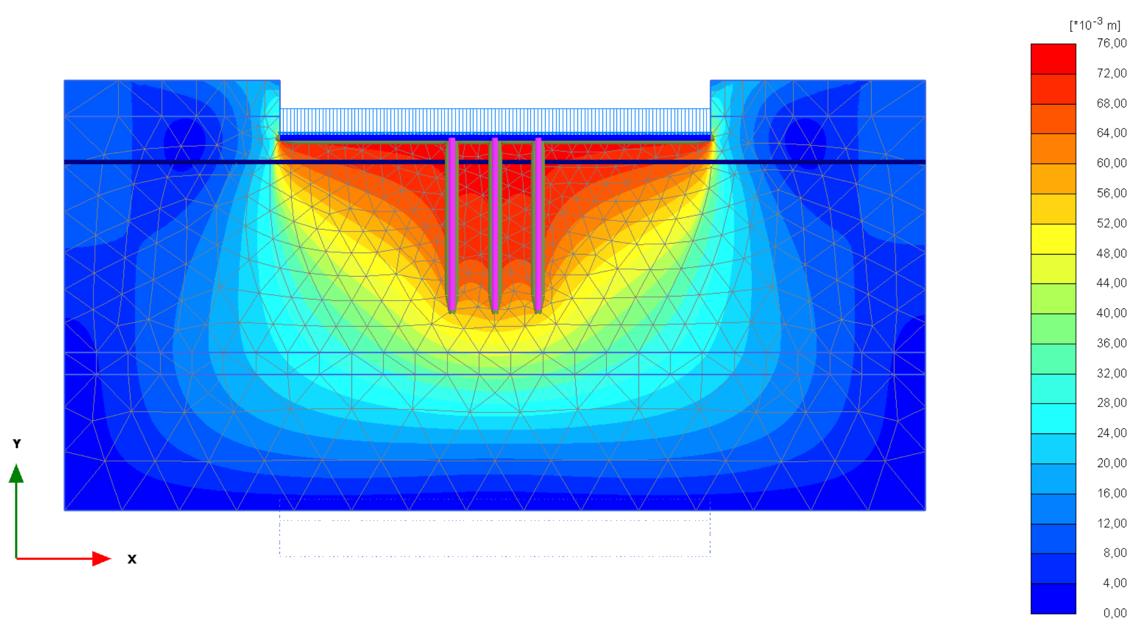


Total principal strain directions (scaled up 5,00 times)

Maximum value = 0,09472 (Element 1007 at Stress point 12074)

Minimum value = -0,09405 (Element 1007 at Stress point 12074)

Fig 4.21 Strain of piled raft for 10m pile length in 3x3 pile group



Total displacements |u|

Maximum value = 0,07424 m (Element 919 at Node 7365)

Fig 4.22 Settlement of piled raft for 12m pile length in 3x3 pile group

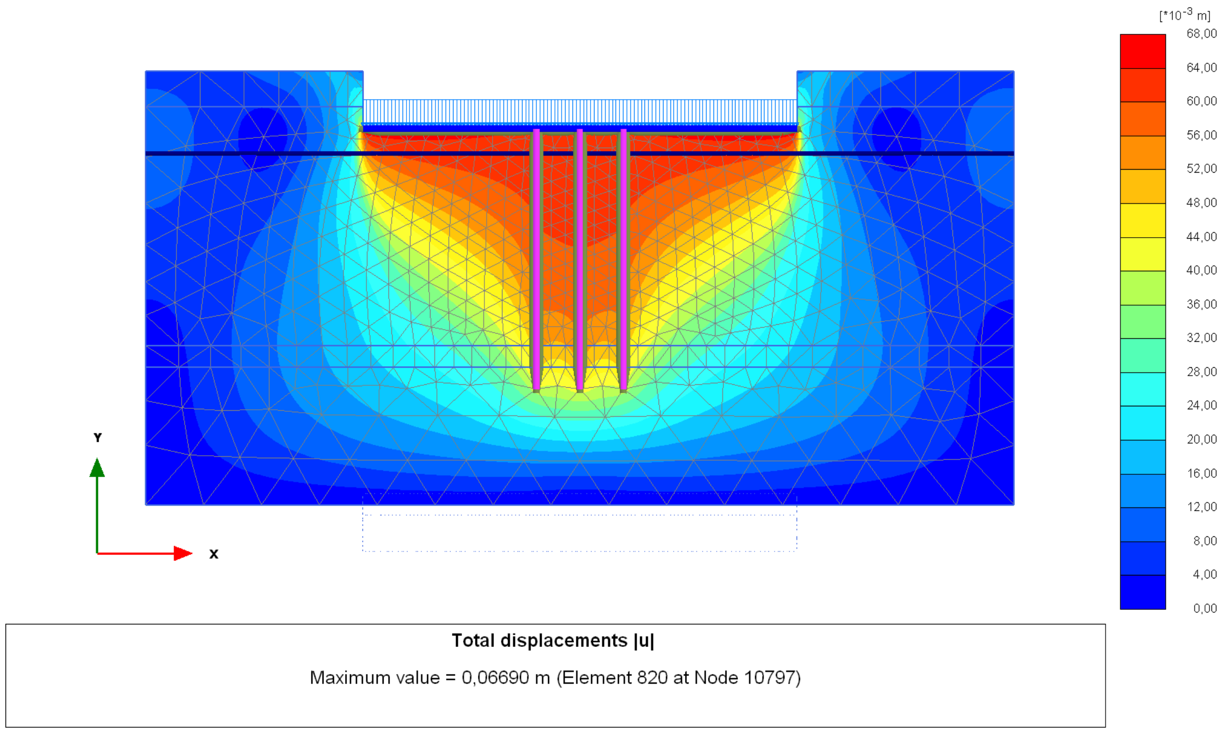


Fig 4.23 Settlement of piled raft for 18m pile in 3x3 pile group

Table 11: Settlement of Piles for Different Spacing Ratio with Pile Diameter of 1.0m

Spacing ratio	Pile length (m)	Settlement in soil (mm)
S/d = 3	10	76.29
	12	75.32
	15	73.88
	18	72.89
S/d =4	10	75.79
	12	74.92
	15	73.57
	18	72.57
S/d = 5	10	75.54
	12	73.95
	15	72.77
	18	72.13

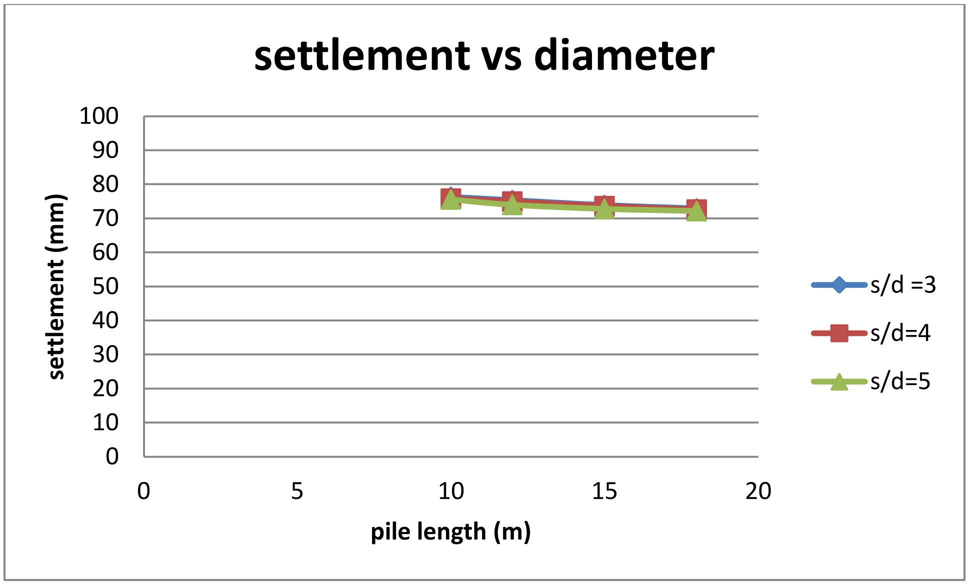


Fig 4.24 Settlement vs Pile length for different spacing ratio

Table 12: Settlement of Piled- Raft with Raft Thickness in pile group 3x3

Raft thickness (m)	Settlement (mm)
1	78.78
1.5	77.28
2	76.63
2.5	76.25
3	75.99

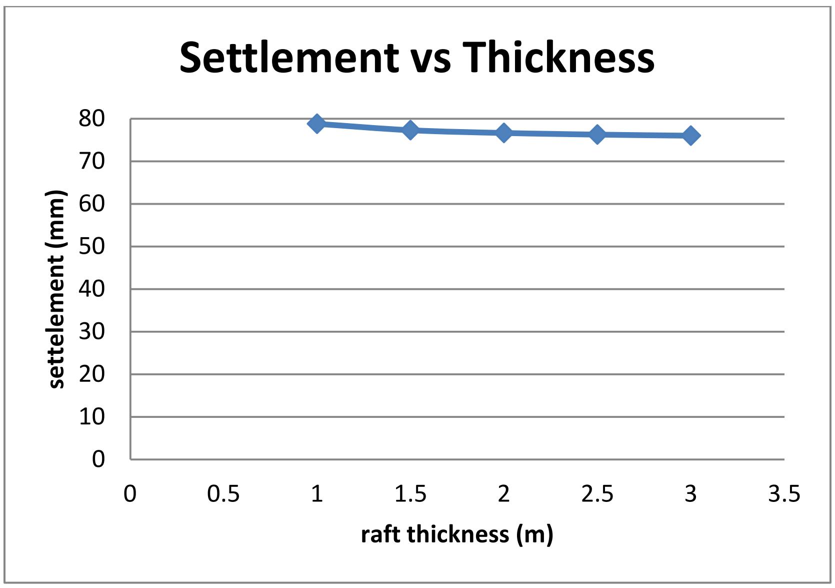


Fig 4.25 Settlement vs Raft thickness

Table 13 Settlement with pile diameter for 10m pile length

Pile diameter (m)	Settlement of Piled raft (mm)	
	3x3	5x5
1	76.29	77.77
1.5	75.98	77.29
2	75.55	76.66

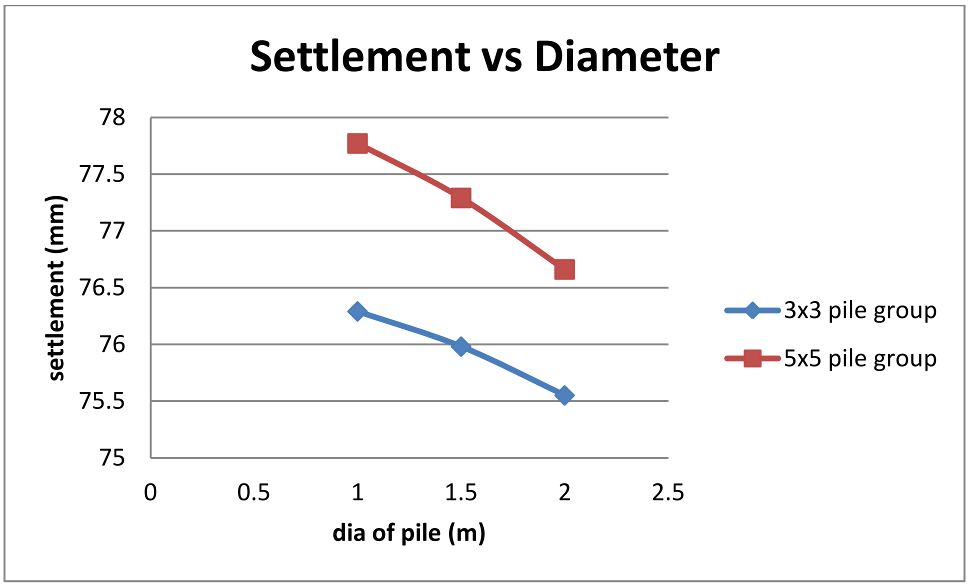


Fig 4.26 Settlement vs Diameter of pile

CHAPTER 5

DISCUSSION OF THE RESULTS

5.1 Results for Elastic analysis

The study for the piled raft in silty sand deposit revealed the result which has been tabulated in table, table. The graph has been plotted for the interpretation of result due to variation in design parameters including pile spacing, pile diameter, length, and number of piles & modulus of elasticity

5.1.1 Effect of pile length

After analyzing the figure it has been derived that the settlement of piled raft in silty sand show a decreasing character when pile length is increased. More is the pile length more is the resistance offered to vertical loading. And large length of pile provides shear resistance mobilization. Thus for improving performance of foundation, increasing pile length is most effective design strategy.

5.1.2 Effect of spacing ratio

After analyzing the figure it has been derived that the settlement of piled raft in silty sand show very small change when spacing ratio s/d is increased (3, 4, 5). For a particular spacing, when the pile length is increased the settlement of piled raft decreases. At larger spacing the decrease in settlement of piled raft at larger spacing with increase in pile length is comparatively less than at smaller spacing with increasing pile length.

When the spacing between piles is increased the raft carry more load as compared to piles and settlement of piled raft is governed by the pressure bulb formed below the raft. I other case with smaller spacing the load carried by raft is less than that of the pile, therefore settlement is governed by the pressure bulb formed at the two-third length of the pile.

5.1.3 Effect of pile diameter

It is clear from the table that when pile diameter is increased the settlement beneath the piled raft decreases very slowly. This is due to the fact that surface as well as base area of pile increases which hence increases the load shared by pile and raft.

5.1.4 Effect of raft thickness

After analyzing the figure and table it has been derived that the settlement of piled raft in silty sand show a decreasing character when raft thickness is increased(t = 1m, 1.5m, 2m, 2.5m, 3m). The reduction in differential settlement is the result of increase in thickness of rafts. The punching shear resistance from piles and column loading both can be achieved by increasing the thickness of raft

5.1.5 Effect of number of piles

As derived from the Figure, as the number of piles are increased, there is a decrease in settlement from 9 piles (pile group 3x3), 25 piles (pile group 5x5) to 49 piles (pile group 7x7). The most effective method to reduce settlement under a piled raft foundation is pile length and pile number.

5.1.6 Effect of modulus of elasticity

It is clear from table and graphs that with increase in modulus of elasticity of soil the settlement of piled raft decreases. (E= 30000 KN/m^2, 35000KN/m^2, 40000 KN/m^2, 45000 KN/m^2, 50000 KN/m^2) . When the stiffness of soil increases settlement decreases thus increasing load carrying capacity. The settlement of piled raft is more in soft soil as compared to stiffer soil

CHAPTER 6

CONCLUSION

1.1 CONCLUSION

The thesis consists of the study of piled raft and its load settlement behavior in a silty sand. The elastic analysis is done to study its behavior by creating a model based on finite element analysis by using PLAXIS 2D analysis software for piled- raft- soil-system. The design parameters consists of (i) Pile Length (L); (ii) Pile Diameter (d); (iii) Spacing Ratio (S/d) ; (iv) Number of Piles; (v) Raft Thickness (t) and; (vi) Modulus of Elasticity of Soil (Es) .

The following conclusions can be drawn from the elastic analysis carried out:

1. As the pile length is increased it is found that settlement decreases by the amount varying between 5% to10% per meter increase in pile length.
2. As the spacing ratio (S/d) is increased it is found that the settlement decreases slowly.
3. As the pile diameter is increased the settlement is found to be decreasing in magnitude. The percentage of decrease was highest for S/d =3 and lowest for S/d=8
4. The lowest settlement was found in corner piles and the settlement in center pile was found greater than side piles.
5. The thickness of raft does not affect the maximum settlement.
6. As the modulus of elasticity of soil increases the settlement of piled raft decreases.
7. The increase in number of piles decreases the settlement.
8. Raft foundation may be the economical foundation system in buildings but for high rise building in same soil condition piled raft foundation system can be prove more effective and economical.

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