STUDY OF PILED RAFT FOUNDATION ON SOFT GROUND FOR MID RISE BUILDING

(MAJOR PROJECT REPORT - II)

For partial fulfillment of the requirements

For the award of the degree of

MASTER OF TECHNOLOGY IN STRUCTURES

In

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Submitted By

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Finally, I am particularly grateful to my entire family for their love, patience and support they showed every day during my M-Tech studies.

CERTIFICATE

This is to certify that the project entitled "STUDY OF PILED RAFT FOUNDATION ON SOFT GROUND FOR MID RISE BUILDING " being submitted by me is a bonafied record of my own work carried out by me under the guidance and supervision of Dr. Munendra kumar, Professor in partial ful-fillment of

requirement for the award of the degree of Master of Engineering (Civil Engineering), with specialization in Structural ngineering, from Delhi

Technological University, Delhi.

The matter embodied in this project has not been submitted for the award of any other degree.

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Enrollment No: 16/STR/2010

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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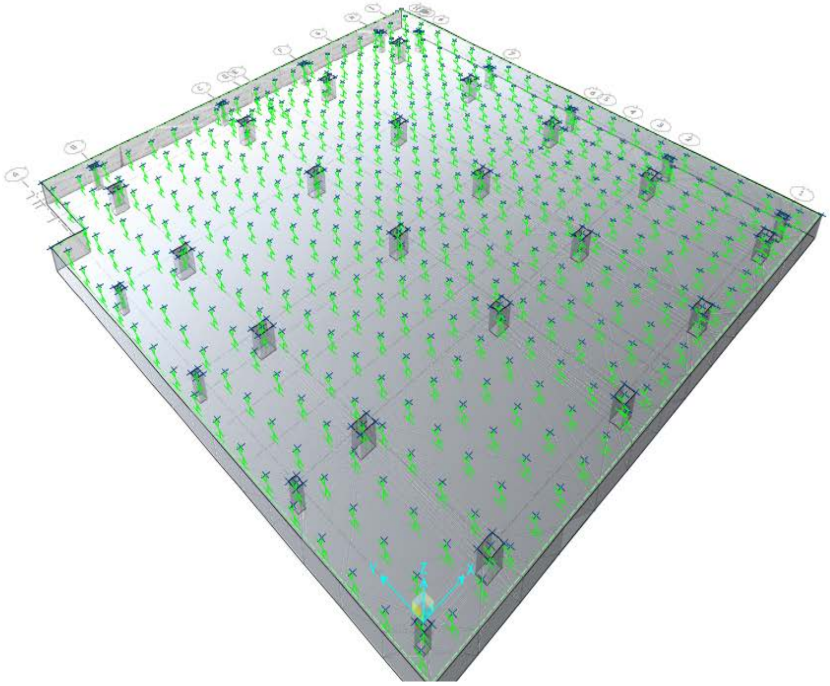
ABSTRACT

Piled Raft Foundation on Soft ground is an very Suitable foundation System where the bearing capacity of the raft is taken into under consideration in supporting the loads from the superstructure. Piled rafts can be an economical alternatives to conventional pile foundation in circumstances where the raft foundation is capable of providing significant load capacity but, on its own may settle excessively. High rise Building often rest on pile foundation, which are designed using the conventional methods, where the piles take the full load from the superstructure. Recently it is increasingly recognized that the use of piles to reduce the foundation settlement and differential settlement can lead to considerable savings.

Only a limited numbers of pile, Called Settlement Reducers, may improve the ultimate load capacity, the settlement performance, as well as the required thickness of the raft. The Application of FEM method which is used in SAFE software in design of piled raft foundation is also discussed.

In this Report the behaviour of pile raft foundation supported by piles (un - identical) is examined by the use of the Software program SAFE (only personalized use) and ETABS (commercial) based on FEM. The effect of pile length, diameter and spacing of piles on reducing overall settlement was determined and an analysis and design was undertaken. Attention has been also focused on the improvement of the foundation performance due to the raft provide a reasonable measure of stiffness and load resistance.

The friction piles in a piled raft system are located strategically to enhance the bearing capacity of the raft and also to control the settlement. therefore, piled raft is technically competent foundation system and offer significant savings in terms of overall foundation cost as compared to conventional piled foundation. This s because the conventional piled foundation usually ignore the contribution of raft and assumes the loads are supported entirely by the piles. However, the use of piled raft foundation requires careful design and analysis. In this report, design issues on piled raft foundation system will be discussed with particular references to the building on soft ground. The Piled raft system has been successfully design and constructed on soft ground



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INTRODUCTION

It is a typical practise in foundation style to contemplate initial, the utilization of a shallow foundation system like a raft to support a structure and so if this is often not adequate, {to style to style} a totally heaped-up foundation during which the complete design masses square measure resisted by the piles. Despite such style assumptions, it's common for a raft to be a part of the muse system (e.g. thanks to the requirement to produce a basement below the structure).

In the past few years, there has been associate increasing recognition that the utilization of piles to cut back raft settlements and differential settlements will result in appreciable economy while not compromising the security and performance of the muse. Such a foundation makes use of each the raft and also the piles, and is mentioned here as a pile-enhanced raft or a heaped-up raft. as an alternative, in things wherever a base alone doesn't satisfy the planning necessities, it should be doable to reinforce the performance of the raft by the addition of piles.

The use of a restricted vary of piles, strategically placed, would possibly improve every the last word load capability and thus the common settlement and differential settlement performance of the raft.

For most heaped-up raft foundations, the first purpose of the piles is to act as settlement reducers. The proportion of the load carried by the piles is taken into account as a secondary issue within the style (Chow 2007). heaped-up raft Foundations offer a cost-effective foundation once raft alone doesn't satisfy the planning criteria.

In heaped-up base, piles support for management settlement and raft provides further capability at final loading and thence cut back the potential influence of affected piles on the muse performance, below such circumstances, the presence of the raft permits some live of re - distribution of the load from the affected heaped-up to those who aren't affected (Poulos et al 1994).

Piles can also cut back the differential settlement once raft alone exceed the allowable settlement and also the raft could increase the lateral stress between the underlying piles and also the soil and thence will increase the last word load capability of a pile s compared to the free - Standing piles (Katzenbach et al 2005).

The settlement reducing piles square measure so introduced within the centre of raft to cut back diff. settlement. pile and heaped-up base are extensively studies and sensible contribution was created by Felleniusa (2004).

Piled raft foundations offer a cost-effective foundation possibility for circumstances wherever the performance of the raft alone doesn't satisfy the planning necessities. below these things, the addition of a restricted variety of piles could improve the last word load capability, the Settlement and also the differential settlement performance and also the needed thickness of the raft.

Design and construction of foundation system on soft ground (shear strength Su <40kPa) have expose numerous issues to geotechnical engineers, like excessive settlement, negative skin friction of piles and bearing capability failure.

Traditionally, pile and cluster of piles square measure introduced to deal with the problem of bearing capability and excessive differential settlement. piles square measure usually put in into competent stratum or set so as to limit the differential settlement by reducing the general total settlement of a structure. the masses from a structure square measure assumed to be supported entirely by the piles. however, this answer solely addresses short - term downside associates with SOFT ground as pile capability is additionally considerably reduced with time as a result of negative skin friction and associated voids formation and settlement downside below the bottom floor block as a result of long - term settlement.

Therefore, heaped-up base system exploitation friction piles as settlement reducer could be a technically superior foundation system because the bearing capacities of each the raft and piles square measure taken into thought. The piles within the heaped-up base comprises comparatively short skin friction piles placed strategically to reinforce the bearing capability of the raft additionally to regulate diff. differential settlement. The capacities of those piles doesn't got to be downgraded for negative skin friction. The piles square measure then interconnected with a rigid system of strip - raft to confirm uniform settlement profile and distribution of masses.

In this Report, the planning approach for ' heaped-up raft foundation' on Soft ground for middle rise Building (eight floor) square measure conferred. before that, a brief discussion on the planning criteria of building will be conferred.

Suitable and un-suitable circumstances for Piled-Raft system

The most effective application of heaped-up rafts happens once the raft will offer adequate load capability, however the common settlement and/or differential settlements of the raft alone exceed the allowable values. Poulos (1991a) has examined variety of idealized soil profiles and has found that the subsequent things is also favourable:

(i) Soil profiles consisting of comparatively stiff clays

(ii) Soil profiles consisting of comparatively dense sands.

In each circumstances, the raft will offer a big proportion of the specified load capability and stiffness, with the piles acting to enhance' the performance of the muse system , instead of providing the most important suggests that of support.

inverslyy, there square measure some things that square measure un favourable, including:-

(i) Soil profiles containing soft clays close to the surface

(ii) Soil profiles containing loose sands close to the surface,

(iii) Soil profiles that contain soft compressible layers at comparatively shallow depths,

(iv) Soil profiles that square measure possible to bear consolidation settlements

(v) Soil profiles that square measure possible to bear swelling movements as a result of external causes.

In the initial 2 cases, the raft might not be ready to offer vital load capability and stiffness, whereas within the third case, semi permanent settlement of the compressible underlying layers could cut back the contribution of the raft to the semi permanent stiffness of the muse. The latter 2 cases ought to be treated with appreciable caution. Consolidation settlements (such as those as a result of dewatering or shrinking of a vigorous clay soil) could lead to a loss of contact between the raft and also the soil.

Thus increasing the load on the piles, and resulting in inflated settlement of the muse system. within the case of swelling soils, substantial further tensile forces is also elicited within the piles thanks to the action of the swelling soil on the raft. Theoretical studies of those latter things are delineate by Poulos (1993) and Sinha & Poulos (1999).

Design problems :As with any foundation system, the planning of a piled-raft foundation needs the thought of variety of problems :

(a) Ultimate load capability for vertical, lateral and moment loadings

(b) Maximum settlement

(c) Differential settlement

(d) Raft moments and shears for the structural style of the raft

(e) Pile masses and moments, for the structural style of the piles.

In foundation style, the planning is mostly primarily based upon the bearing capability and settlement below vertical masses. tho' this is often a important facet, however there square measure different problems that has to even be addressed . for instance, in some cases, the pile necessities is also ruled by the overturning moments applied by wind loading, instead of the DL and live masses.

LITERATURE REVIEW

LITERATURE REVIEW

CHAPTER 1

RAFT FOUNDATIONS

1.1 INTRODUCTION

The substructure or foundation is that the a part of a structure that isAusually placed below the surface of the bottom. Footings and alternative foundation units transfer the masses from the structure to the soil or rock supporting the structure.

Because the soil is generally much weaker than the concrete columns & walls that must be supported, the contact area between the soil & the footing is much larger than that between the supported member & the footing.

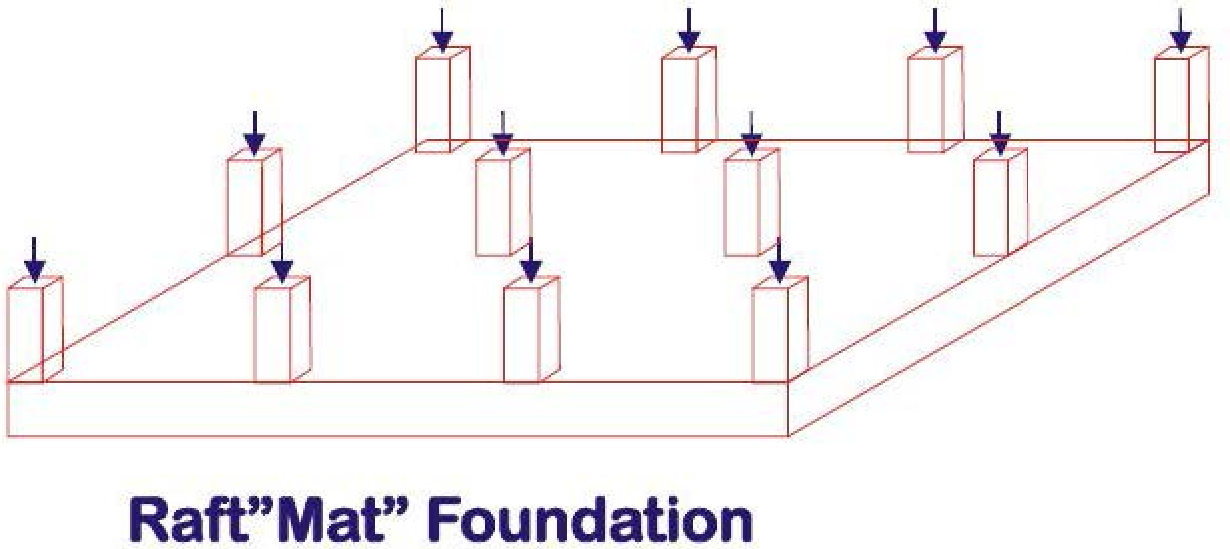

Fig. 1.1 Raft foundation

The additional common types of footings area unit illustrated in figure (1.1). Strip footings or wall footings show primarily one-dimensional action, cantilevering out on both sides of the wall. unfold Footings area unit pads that distribute the column load to a region of soil round the column. These distribute the load in 2 directions. Sometimes unfold footing have pedestals, area unit stepped, or area unit tapered to avoid wasting materials.

A pile cap transmits the column load to a series of piles, that successively, transmit the load to a robust layer at some depth below the surface ahard strataa. Combined footings transmit the masses from 2 or additional columns to the soil. Such a grip is usually used once one column is near a mete. AA raft /mat or groundwork transfers the masses from all the columns in an exceedingly building to the underlying soil. Raft /mat foundations area unit used whenavery weak soils area unit encountered..

The choice of foundation type is selected in consultation with the geotechnical engineer. Factors to be

considered are:

(a) The soil strength,

(b) The soil type,

(c)The variability of the soil type over the area and with increasing depth

(d) The susceptibility of the soil and the building to deflections.

The most basic and most common types are strip, spread, combined footings. The two essential requirements in the design of foundation are that the total settlement of the structure be limited to a tolerably small amount and that differential settlement of the various parts of the structure be eliminated as nearly as possible. With respect to possible structural damage, the elimination of differential settlement, i.e., different amounts of settlement within the same structure, is even more important than limitations on uniform overall settlement.

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To limit settlements as indicated, it is necessary to:

(a) Transmit the load of the structure to a soil stratum of sufficient strength.

(b) Spread the load over a sufficiently large area of that stratum to minimize bearing pressure.

A shallow single Foundation unit that supports all columns & walls of a structure or parts of a structure may be called a raft foundation. A raft foundation is also called as raft /mat foundation. They are usually provided for multi-story buildings, overhead water tanks, chimneys, etc. A raft foundation becomes unavoidable in submerged structure, in some multi-story structures with basement and in retaining walls, etc. The raft foundation is usually designed as a flat slab.

Foundation engineering often consider mats when dealing with any of the following conditionsThe structural loads are so high or the soil conditions so poor that spread footings would be exceptionaly large. As a general rule of thumb, if spread footings would cover more than about one-third of the building footprint area a raft or some type of very deep foundation will probability be more economical.

The soil is very weak to excessive differential settlements. The structural continuity & flexural strength of a raft will connect over these irregularities.

In the design of raft foundations, the soil can be treated as a series of individual springs - known as a Winkler model or as a continuum. The Winkler model treats the soil as a series of springs and assumes that the pressure at any point on the surface of the soil is related to the modulus of sub grade reaction (Winkler spring stiffness) and the deflection of the soil.

The same is true of mats on highly expansive soils to dangerous to differential heaves . The structural loads are erratic, and thus increase the likelihood of excessive differential settlement. Again, the structural continuity and flexural strength of the raft /mat will absorb these irregularities.

The Lateral loads are not uniformly distributed through the structure and thus may cause differential horizontal movement in spread foundation or caps of pile foundation.. The continuity of a raft will resist such movements.

The uplift loads are larger than raft /mat(spread) footings can accommodate. The greater weight and continuity of a raft may provide sufficient force to resistance the reaction.

The bottom of the structure is located beneath the ground table, so waterproofing is an important concern. Because raft are monolithic, they are much easier to waterproof. The weight of the raft also helps resist water uplift forces from the groundwater.

There are various methods have been used to raft foundations. They can be divided into two categories: rigid method & flexible methods.

Method 1 : Rigid method :- The simplest approach to structural design of mats is the rigid method (also known as the conventional method or the conventional method of static equilibrium). This method assumes the raft /matis much more rigid than the underlying soils, which means any distortion in the raft /matare too small to significantly impact the distribution of bearing pressure depends only on the applied loads and the weight of mat, and either uniform across the bottom of the raft /mat(if the normal acts through the centroid and no moment load is present) or varies linearly a cross the raft /mat(if eccentric or moment loads are present).

This simple distribution makes it easy to compute the flexural stresses and deflections (differential settlements) in the raft . For analysis purposes, the raft /matbecomes an inverted and simply loaded two-way slab, which means the shears, moments, and deflection may be easily computed using the principles of the structural mechanics. The design engineer can then decide the appropriate raft thickness & reinforcement.

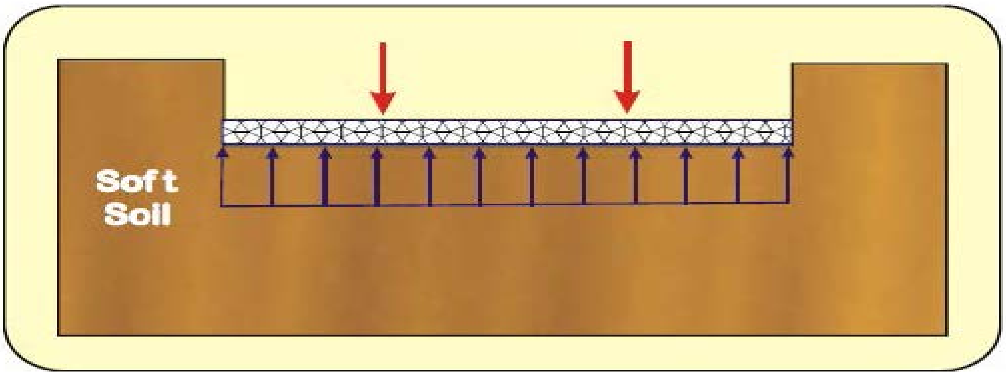

Fig. 1.2 Pressure beneath the Raft for soft soil

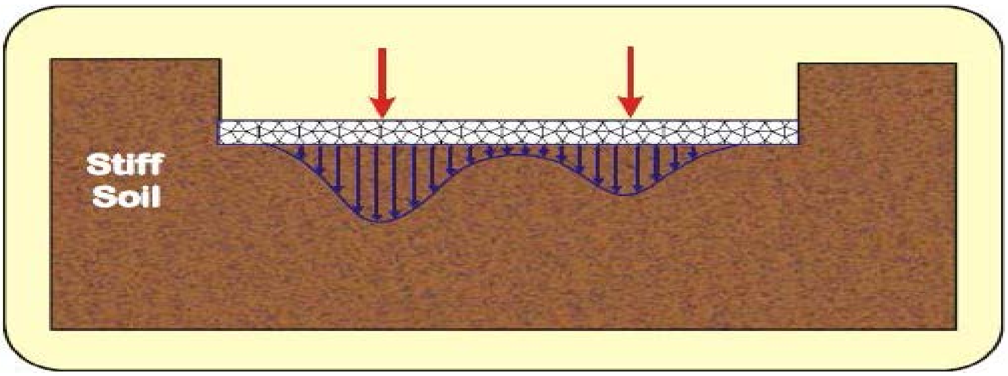

Fig. 1.3 Pressure beneath the Raft for stiff soil

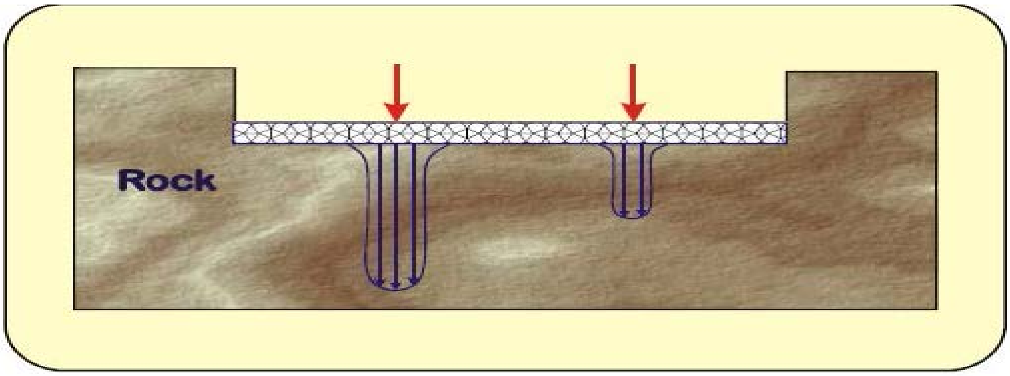

Fig. 1.4 Pressure beneath the Raft for rock soil

Because the rigid method does not consider the redistribution of bearing pressure, it doesn't produce reliable estimates of the shear forces, moments forces and deformations in the raft. even if the raft was perfectly rigid, the simplified bearing pressure distribution in figure (1.2)(1.3)(1.4) are not correct-in reality; the bearing pressure is greater on the edges and smaller in the centre than shown in these figure.

Method 2 - Flexible methods :- To become the in accuracies of the rigid method by using analyses that consider deformations in the raft /mat and their influence on the bearing pressure distribution. These are called non-rigid methods, and produce more accurate values of raft deformations and stress, but most truly the non-rigid analyses method also are very difficult to implement because they required consideration of soil-structure interaction between soil & raft, soil and soil and because the bearing pressure distribution is not as simple as we assume in design approaches.

1.2 Method of sub grade reaction :-

Because non-rigid method consider the effects of local raft /mat deformations on the distribution of bearing pressure, it is necessary to define the relation slip between settlement & bearing pressure. This is usually done using the coefficient of sub grade reaction, Ks (also known as the modulus of sub grade reaction, or the sub grade modulus).

$$K_s = \{q / \delta\} \qquad 1.1$$

Where:

Ks = coefficient of sub grade reaction.

q = Bearing pressure, δ = Settlement

The coefficient Ks has units of force length cubed. Although we use the same units to wt., Ks is not the same as the same as the unit wt. and they are not numerically equal. The interaction between the raft /mat and the underlying soil may there be represented as a bed of springs each with a stiffness Ks per unit area. Portions of the mat/raft that experience more settlement produce more compression in the springs, which represents the higher bearing pressure, whereas portions that settle less don't compress the springs as for and thus have less bearing pressure. The total sum of spring forces must equal the applied safe loads on the structure plus the wt. of the raft.

$$\sum p + W_f - u_D = \int q dA = \int s k_s dA \quad 1.2$$

Where: Σ p= sum of structural loads acting on the mat. Wf = Pore of the mat.

uD = Bearing pressure between mat & soil. A = mat-soil contact Area.

δ = settlement at a point on the mat.

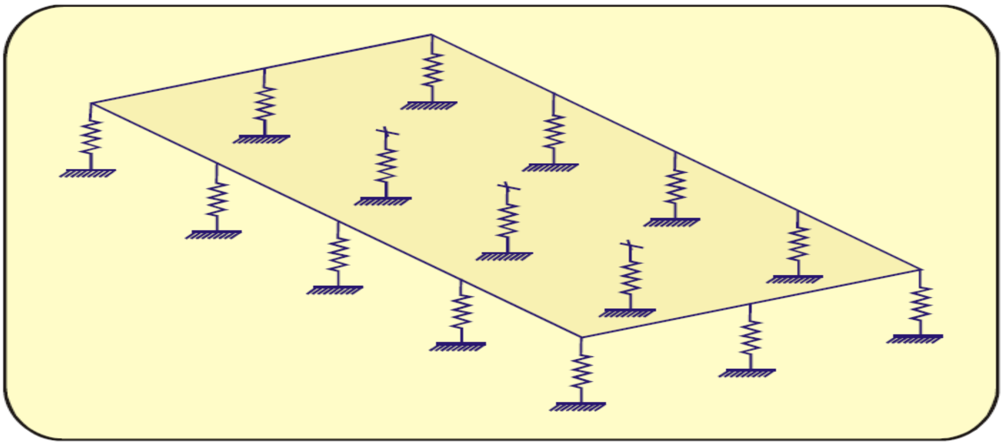

fig.1.4 The modulus of sub grade reaction as point spring in Soil

The spring stiffness depends on the characteristic of the soil and the geometry of the foundation. However, it neglects the interaction between each individual spring and the supporting soil is therefore not modelled as a continuum. An alternative approach that treats the supporting soil as an elastic continuum can better represent the physical behaviour of the supporting soil. The soil parameters used in this approach depend on the field stress state and have to be carefully evaluated (Hain and Lee, 1974).

Different methods ranging from one-dimensional to full three-dimensional models have been developed for the analysis of raft foundations.

1.3 Analytical Methods

The use of analytical methods for the analysis of rafts on elastic foundations has been investigated by numerous researchers. However, this approach is limited to simple geometrical shapes of the raft and homogeneous soils. Zhemachkin and Sinetsyn (1962) obtained the analytical solution by assuming that the contact pressures between the raft and soil were uniform blocks of pressure. The deflections of the raft and the soil due to the pressure could be determined by considering the compatibility of the displacements of the raft and the soil at a number of points beneath the raft.

Brown (1969) employed a similar method for the analysis of a circular raft on an elastic foundation of finite depth. The raft was divided into a number of equal width annular elements and the contact stress was assumed to be uniformly distributed over the annular elements. Solutions from the analysis were based on the solution presented by Burmister (1956) for a two layer system subjected to a surface point load. Based on the integral transform techniques presented by Sneddon (1951), Brown (1969) later presented an improved method which provided greater accuracy and less computation. In this improved method the contact stress was represented by a series of mathematical functions instead of uniform annular pressures. The same method was used by Booker and Small (1983) for analysis of liquid storage tanks resting on homogeneous soils.

Kay and Cavagnaro (1983) presented a method for the prediction of settlement for raft foundations by the use of field parameters in which the soil can have numerous sub layers having different properties. The raft mat was replaced by an equivalent uniformly loaded circular area such that the influence of the raft stiffness was considered in the assessment of differential settlement.and in the software they acts as spring under the whole raft.

1.4 Closed-Form solutions:

When the Winkler method is used (i.e., when all springs have the same Ks) and the geometry of the problem can be represented in two-dimensions, it is possible to develop closed-form solutions using the principles of structural mechanics. These solutions produce values of shear, moment, and deflection at all points in the idealized foundation. When the loading is complex, the principle of superposition may be used to divide the problem into multiple simpler problems.

These closed-form solutions were once very popular, because they were the only practical means of solving this problem. However, the advent and widespread availability of powerful computers and the associated software now allows us to use other methods that are more precise and more flexible. This type of finite element analysis does not consider the stiffness of the superstructure. In other words, it assumes the superstructure is perfectly flexible and offers no resistance to deformations in the raft. This is conservative.

1.5 Boundary Element Methods

The boundary element method is a powerful tool that can be applied in engineering applications as only the boundary has to be discritizad which reduces the amount of computer memory and the time to solve the problem. Katsikeadelis and Armenekas (1984 and 1984) and Costa and Brebbia (1985 and 1986) used the boundary integral equation

method for the analysis of plates resting on a Winkler type elastic foundation. In this method the boundary of the plate was divided into a Finite number of elements with a node defined at the midpoint of each element. Each boundary element was approximated by a curve so that the boundary of the plate can be approximated by straight line or curved line segments. The domain was assumed to be bounded by a continuous curve. In order to reduce the domain integrals, Costa and Brebbie (1985 and 1986) suggested that the domain integrals have to be transformed into boundary integrals.

The most basic and most typical varieties strip, spread, combined footings. the 2 essential necessities within the style of foundation that the entire settlement of the structure be restricted to a tolerably bit which differential settlement of the assorted components of the structure be eliminated as nearly as potential. With regard to potential structural harm, the elimination of differential settlement, i.e.,adifferent amounts of settlement inside identical structure, is even additional necessary than limitations on uniform overallasettlement.

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1.6 Finite Element Methods

Today, most mat foundations are designed with the aid of a computer using the finite element method (FEM). This method divides the mat into hundreds or perhaps thousands of elements. Each element has certain defined dimensions, a specified stiffness and strength (which may be defined in terms of concrete and steel properties) and is connected to the adjacent elements in a specified way.

The raft components square measure connected to the bottom through a series of asprings,awhich square measure outlined victimisation the constant of sub grade reaction.a one spring is found at every corner of every part. hundreds|the hundreds|the masses} on the raft embody the outwardly applied column loads, applied line masses, applied space masses, and therefore the weight of the mat itself. These masses press the raft down facet , and this draw back movement is opposed by the soil asprings.aThese resisting forces in conjunction with the stiffness of the raft may be ascertain parallelly victimisation the algebra that permits United States to checking out the stresses, strains, and torsions within the groundwork system.. If the results of the perform analysis aren't up to mark, the planning is revised consequently and reanalyzed then.

The finite part analysis may be extended to incorporate the structure, the mat, and therefore the underlying soil in an exceedingly single three-dimensional finite part methodology. This methodology would, in essence, be a a lot of correct model of the soil structure system, and therefore might turn out a a lot of economical style. However, such analyses square measure well a lot of complicated and long, and it's terribly troublesome to develop correct soil properties for such models. Therefore, these extended finite part analyses square measure seldom performed in observe.

The first answer that utilized the finite part methodology for the ANalysis of foundation structures on an elastic half-space was obtained by Cheung and Zienkiewic (1965). The behaviour of the raft was obtained by the finite part technique within which the raft was divided into variety|variety} of rectangular components joined at a separate number of nodal points. The soil was modelled either by the Winkler model within which interactions between springs weren't thought-about or by the elastic time model within which separation between the raft and therefore the soil wasn't allowed once negative reactions existed. The stiffness matrix for the full system was fashioned by combining the stiffness of the soil (which was derived by victimisation the Boussinesque equation) with the stiffness matrix of the plate bending components. Contact stresses were portrayed by equivalent forces applied at nodal points of the finite part mesh.

Cheung and Nag (1968) explained this technique to include the shear stresses at a lower place the mat and examined the results of uplift between the raft and therefore the soil. Svec ANd Gladwell (1973) developed AN improved technique for the analysis of a skinny plastic plate on an elastic 0.5 house. The plate and therefore the surface of the elastic half-space that was involved with the plate were divided into variety of ten noded triangular components. the continual contact pressure distribution at a lower place the plate was diagrammatic by a boxy polynomial on every of the triangular regions. The displacements at the surface of the elastic half-space owing to the contract pressure were determined from the Boussinesq equation

The approach of Cheung and Zienkiewicz (1965) was conjointly extended by Wood and Larnach (1974 and 1975) to incorporate bedded soils and time-dependent consolidation effects within the analysis. Wood (1977) then extended the tactic any to incorporate applied moments. The raft is of irregular form subjected to non-uniform loadings and resting on a non-homogeneous soil mass.

Hain and Lee (1974) recommended that within the analysis of raft foundations, the structure, foundation and supporting soil have to be compelled to be analysed as a system. The stiffness of the structure will have Associate in Nursing influence on the distribution of hundreds and moments transferred to the raft. The structure-raft-supporting soil system was analysed by the "substructure" methodology developed by Przemieniecki (1968). The supporting soil was modelled by each the Winkler model and also the linear elastic model. Results have disclosed that there have been important variations within the behaviour of the raft foreseen by the employment of various soil models for the supporting soil. Flexibility of the raft has important effects on the distribution of column hundreds and moments. Results have shown that the linear elastic time model provided a a lot of realistic answer to the behaviour of the raft and is a lot of preferred to use in modelling the supporting soil.

1.7 Hybrid Approach

Zhang and tiny (1991) conferred a technique for the analysis of soil-raft interaction. This methodology used the finite layer technique to see the behaviour of the soil and also the finite part technique for the analysis of the raft. The contact pressure between the raft and also the soil was portrayed by uniform blocks of pressure. The response of the soil attributable to the contact pressure was obtained by the Fourier rework technique. This methodology will be used for the analysis of rafts of any form in set up and subjected to uniform, focused or eccentric masses. The elastic soil will be aeolotropic or non-homogeneous.

Mandel and Ghos (1999) conferred a coupled finite part and boundary part approach for the prediction of elastic settlement of a raft on a semi-infinite elastic time. The raft was modelled by iso constant quantity plate bending finite components and also the raft-soil interface was modelled by boundary components. The domain of the boundary was divided into variety of iso-parametric quadrilateral quadratic components. The raft was divided into components appreciate the boundary components of the soil and also the response of the soil attributable to the load was obtained from the Mindlin's solution for a degree load.

Rashid (2005a) developed a replacement boundary component technique for the analysis of a raft on elastic foundations. Shear deformable plate bending theory was wont to model the raft, the soil was modelled by continuous springs following the Winkler model and therefore the raft domain was divided into quadrilateral or general formed cells. The associate domain integral was replaced by mistreatment constant boundary integral on every cell contour.

CHAPTER 2

PILE FOUNDATIONS

2.0 INTRODUCTION :- Shallow foundation ar ordinarily used once the soil near the bottom and uptoa the zone of serious stress posses decent bearing strength to hold, the structure load while not inflicting distress to the structure attributable to settlement. However, wherever the highest soil is either loose or soft or of a swelling kind the load from the structure must be transferred to deeper strata. The structural loads may be transferred to deeper firm strata by means of piles. piles are long slender columns either driven bored or cast in situ.

Piles could also be classified as long or short in accordance with the L/D magnitude relation of the pile (wherever l is length of pile and D is that the diaa of piles). a brief piles behave sort of a rigid body and rotates as a unit beneath lateral hundreds. The load transferred to the tip of the pile bears a big proportion of the full vertical hundreds on the highest. blessings of piles following :-

1.0) Piles can be pre-cast or cast in situ to the required specifications.

2.0) piles of any size and length may be constructed at site.

3.0) They are suitable of soils of poor drainage qualities.

<u>Uses of piles</u>

1.0) To Carry vertical compression load

2.0) To resist uplift load

3.0) to resist horizontal and inclined loads

When the clay layer has terribly poor strength the building is supported on pile foundation transferring all load to a deeper competent layer. This in fact is most satisfactory style however the value of foundation is incredibly high attributable to massive pile length. Settlements square measure expected to be minimum (< ten mm). once the clay layer has spare strength the building will be supported on a substructure. The clay layer will give adequate bearing capability. tho' the settlements expected square measure high, if structure will face up to and there's no threat of distress to neighboring structures, the raft will be adopted economically.

2.1 Simplified Analytical Method

Randolph and Wroth (1978) developed an approximate closed type answer for the analysis of single vertically piles. during this approach, the soil was divided into 2 layers during which the bottom of the higher layer corresponded to the amount of the bottom of the pile. The Settlement of the higher layer was attributable to the load acting on the pile and the Settlement of the lower layer was attributable to the load engaged on the pile base. For the higher layer, the deformation of the soil round the pile shaft was modelled as cutting off of concentrical cylinders (Cooke, 1974). For the lower layer, the bottom of the pile was assumed to act as a rigid punch on the surface of the layer, and this layer was acting as a restraint on the deformation of the higher layer. This approach was then extended to the analysis of pile teams by a similar authors (Randolph and wroth, 1979) by incorporating the interaction between loaded piles. The interaction factors for the pile shaft and base were thought of individually. For rigid pile teams, the interaction factors were computed victimisation Associate in Nursing approximate closed-form expression, whereas for compressible pile teams, the interaction factors were obtained by Associate in Nursing unvarying procedure to ascertain a relationship that expressed the shaft displacement in terms of the pile head and pile base displacement. the general displacement of a pile with the presence of adjacent loaded piles was obtained by the principle of superposition. This approach was restricted to piles of a similar embedded length..

Lee (1993) conferred Associate in Nursing approach that was changed from expressions used by Randolph and Wroth (1978). The settlement of pile teams may then be obtained by the principle of superposition.

2.2 Hybrid Method

A hybrid foundation consists of each a soil-supported raft /mat associate degreed piles and is employed mainly to support an axial load. In Europe it's ordinarily referred to as a concentrated raft as a result of engineers planned the thought of adesigning the inspiration for high-rise buildings employing a raft resting on the bottom with piles supporting the raft . The idea was that the combined foundation would be adequate to support the applied axial loading with associate degree acceptable issue of safety which the settlement of the combined foundation at operating load would be acceptable. The settlement of a understructure is dished, with the biggest settlement at the centre of the raft. to realize a additional uniform settlement of a structure, it's been instructed that the piles be clustered close to the centre of the raft.

The analysis of such a system is difficult as a result of the settlement of the raft is littered with the presence of the piles and since a concentrated understructure consists of typical piles and a rigid raft, Considering each of these foundation elements separately leads to the conclusion that interaction is inevitable. The raft /mat lone is certainly affected by the presence of the piles because the foundation is much stiffer than with the soil alone. The piles alone are affected by the earth pressure from the raft because the increased lateral stresses on the piles affect the capacity for side resistance's Leung and Chow analyse laterally loaded pile groups. For lateral loading, the soil response was modelled by the modulus of sub grade reaction approach.

2.3 Boundary Element Method

Fredholm (1903a) established the existence of integral equation solutions to potential issues on the premise of a limiting discretization procedure and known the Fredholm integral equations (FIE) of the primary, second and third kind. the primary application of a right away BEM was in hydraulics (and specifically for the axi bilateral jet problem) by Trafftz (1926a), who used the strategy of ordered approximations to satisfy his integral equation. Prager (1928a) examined doubly bilateral potential flow past AN elliptic cylinder employing a direct-type boundary integral formulation, and later divided the surface of the matter into parts, therefore reducing the integral equations into a system of algebraical equations. Poulos and Davis explained the answer for one pile by exploitation Mindlin's equations. Poulos additionally explained the strategy to the ANalysis of pile teams by introducing an interaction issue, α, The interaction issue was outlined as

$$\alpha = \frac{\text{Additional settlement due to an adjacent pile}}{\text{settlement of a pile under its own load}} \qquad 2.1$$

In the analysis, every pile was divided into variety of cylindrical components. every component was subjected to the same load round the fringe of the component and the same circular load at the circular base of the pile as shown in Figure a pair of.1. The shaft of the pile was assumed to be absolutely rough whereas the bottom was assumed to be utterly sleek specified shear stresses weren't developed on the bottom. The vertical displacement of the soil adjacent to the pile was expressed as

$$[\rho] = ([_1I] + [_2I])[p] + ([_1Ib]+[_2I_b])\ p_b \qquad ` \qquad 2.2$$

where [p] = displacement of the soil adjacent to the pile

$[_1I]$ = vertical displacement influence factors for elements on each element on pile 1

$[_2I]$ = vertical displacement influence factors for elements on each element on pile 2

$[_1I_b]$ = vertical displacement influence factors for the pile load on the base of pile 1

$[_2I_b]$ = vertical displacement influence factors for the pile load on the base of pile 2

[p] = uniform shear load on pile shaft

$[p_b]$ = uniform vertical stress on pile base

The displacement factors were obtained by integration of the Mindlin equation for vertical displacement thanks to some extent load among a semi-inifinite soil mass. By considering the compatibility of the vertical displacement (i.e. unit displacement, p =1), equation (2.2) may be solved to get the distribution of the shear stress on the pile shaft and also the vertical stress on the pile base and afterward the displacement of the pile may be determined. For a bunch of m piles, the displacement of a single pile within the cluster was obtained by superposition

$$\rho k = \rho_1 \sum_{j=1}^{j=m} P_j \alpha_{ki} \qquad 3.3$$

where αkj = interaction factors for piles k and j

Pj = load on pile j

ρi = displacement of a single pile under unit load

$$\alpha_\theta = \frac{additional\ rotation\ due\ to\ adjacent\ pile}{rotation\ of\ pile\ under\ its\ own\ load} \qquad 2.4$$

In the analysis, every pile was assumed to be a vertical strip with a length and breadth of L and d severally. The pile was divided into (n + 1) components and every of the weather was subjected to the same horizontal stress. The length of the weather at the pile high and base were L/2n, whereas the length of components on the pile shaft was L/n. The lateral displacements at the soil surface will be obtained from the strategy given by Poulos (1968) by replacement the vertical hundreds with horizontal hundreds..

The displacement of the pile can be expressed as

$$\rho_k = \rho_H \left(\sum_{\substack{j=1 \\ j=k}}^{j=m} H_j \alpha_{\rho Hkj} + H_k\right) \qquad 2.5$$

Where Hj =load on pile j, ρH =unit reference disp. of a single free-head pile under a unit horizontal load, Pj =interaction factor for pile k and j

Lee ANd Poulos (1990a) developed an approach for the analysis of pile teams in non-homogeneous soil. This methodology concerned the event of soil models that account for the soil modulus of all soil layers and therefore the horizontal non-homogeneity of the soil thanks to soil disturbance caused by pile installation. The approach was a modification of the strategies by Poulos (1979a) and Yamashita et al. (1987a). Poulos (1979) used some equivalent soil module computed from module of the influencing and influenced parts. Yamashita et al. (1987) changed the tactic by computing identical soil modulus from the weighted averages of the soil modulus at each layer.

Xu and Poulos (2000a) developed a completely coupled load-deformation malicious program GEPAN for the analysis of single piles and pile teams subjected to three-dimensional loadings and ground movements. The analysis was supported the principles of the three-dimensional boundary component methodology and incorporated the consequences of defective piles, soil movements and on/off pile loadings. the worldwide matrix for the governing equation was derived victimization the construct of hierarchic structures and a basic influence issue matrix. The piles were assumed to be circular in cross-sectional and every pile was divided into a series of cylindrical parts on the shafts and ring parts on the bases and discontinuities. aThe cylindrical parts were then divided into many sub-elements. aThe soil-pile interface was modelled by soil parts and pile parts that were meshed in part cylindrical or ring-shaped surfaces. own the analysis, the cylindrical or ring-shaped boundary parts were reworked into rectangular parts by mathematical transforms. the oblong parts were then divided into variety of smaller rectangles and interaction between the weather was obtained from the mixing of Mindlin's equation.

The program GEPAN are often applied to a spread of pile issues like (i) the off-line effects of piles that is horizontal pile head movement because of vertical load on the pile cluster (ii) interaction factors between piles and pile teams (iii) pile teams containing defective piles (iv) non-linear and elasto-plastic analysis. Results for the off-line impact of piles have shown that for a extremely compressible and closely spaced pile cluster, loading the piles axially would cause important horizontal pile movements

2.4 Finite Element Method

Ottavieni (1975) used the threeadimensional finite component technique for the analysis of vertically loaded pile teams with or while not pile caps.aDue to the complexness of the only component stiffness computation and huge variety of parts, the piles and also the soil were assumed as weightless linearly elastic undiversified media for the examination of the load transfer mechanism. it had been found that the presence of a cap would cause a non-uniform distribution of load among the piles of the cluster. aIf the cap is connected with the soil surface, reduction of the shear stress within the soil round the higher portion of the pile was found.

Chow (1987a) conferred a way supported snap theory for the analysis of loaded pile teams embedded in isotropic soils. The axial and lateral cluster response was assumed to be unconnected.

1.0) a pile group subjected to external loads and pile-soil interaction forces

2.0) a layered soil continuum subjected to pile-soil interaction forces.

The load deformation relationship of the soil decided exploitation the flexibleness approach within which the soil flexibility coefficients were evaluated exploitation the finite component technique with a Fourier series.

By applying equilibrium of the pile-soil interaction forces and therefore the compatibility of the pile and soil displacements, the load deformation relationship of the pile decided and expressed as

$$([K_r] + [K_S])\{w_P\} = \{Q\} \qquad 2.6$$

where $[K_r]$ = stiffness matrix of piles

$[K_s]$ = stiffness matrix of the soil obtained by inverting the soil flexibility matrix, $[F_S]$, i.e $[K_S] = [F_S]^{-1}$

{wp} = vector of deformations at the pile nodes

{Q} = vector of external applied loads

The reinforcing result of all piles within the cluster was thought-about within the formulation. Non-homogeneity of the soil was taken into consideration by incorporating a unendingly variable soil stiffness into the numerical integration method throughout the formulation of the component stiffness matrices. Chow (1989a) extended the approach to analyse pile teams in cross-anisotropic soils. This was done by commutation the constitutional identical soil model with a cross-anisotropic soil model. Results have shown that the result of soil property on little pile teams embedded in solid soils was little, however, the result on massive pile teams in non-homogeneous soils was important..

2.5 Finite Layer Method

The finite layer methodology developed by little and agent (1984 and 1986a) was initial introduced into the analysis of axially loaded piles embedded inaisotropic and cross - anisotropic stratified soils by Lee and tiny (1991a). This methodology is analogous in theory to it of the infinite layer methodology of Guo et al. (1987).

A single pile embedded during a stratified soil was treated as 2 components:

(I) single isolated pile (II) layered soil.

The Researchers Zhang and tiny (2000a) planned 2 ways supported the finite layer theory to analysis the axially load piles and laterally loaded piles engaging at teams. The principle of the ways is analogous to it utilized by Lee and tiny (1991a). The finite layer theory was used for the stratified soil and straightforward beam theory for the piles. The piles were divided into a series of finite components and also the soil was divided into corresponding layers. Interaction and stiffness ways were developed to come up with the influence matrices for the soil and also the pile cluster. within the interaction methodology, every try of piles within the pile cluster was thought-about successively to reckon the soil influence and pile influence matrices. Zhang and tiny (2000a) additional explained the strategy to incorporate the pile cap within the analysis. The analysis was administrated 3 parts: the cap, the piles and also the stratified soil..

CHAPTER 3

PILED RAFT FOUNDATIONS

PILED RAFT FOUNDATIONS

3.1 Introduction

Clay deposits of enormous thickness prodigious 30m area unit usually occurring on the coastal belt. In India, such thick clay deposits area unit discovered in Visakapatnam, Cochin, Kandala etc. so as to support serious buildings on such deposit, following 3 choices area unit usually accessible

(a) a once the clay layer has terribly poor strength the building is supported on pile foundation transferring all load to a deeper competent layer. This in fact is most satisfactory style however the price of foundation is incredibly high as a result of giant pile length. Settlements area unit expected to be minimum ((< 10 mm).

(b) (b) a once the clay layer has enough strength the building may be supported on a substructure. The clay layer will give adequate bearing capability. although the settlements expected area unit high, if structure will face up to and there's no threat of distress to neighbour structures, the raft may be adopted economically..

(c) When When the clay layer has intermediate strength,aalternative (b) higher than can't be adopted because the bearing capability might not be adequate or settlements might exceed the permissible limits. Excessive settlement of the building might also cause distress to adjacent structure. as a result of the high rise in land price in urban areas, traditional tendency is toautilise all the realm out there for building construction. Therefore, considerable stress could also be transferred to foundations of adjacent structures which can be previous and weak..

Excessive settlement of the building may additionally cause distress to adjacent structure. as a result of the high rise in land value in urban areas, traditional tendency is to use all the realm accessible for building construction. So, tidy stress could also be transferred to foundations of adjacent structures which can be previous and weak.

In such things a cumulous raft may be provided wherever a part of the whole load (aabout fifty %a) is taken by the raft through contact pressure between raft and soil andathe remaining load by pile through skin friction. Piles during this case don't got to penetrate the total depth of clay layer however it may be terminated at higher elevations. so this different is economical com¬pared to the primary different however it'll lead to settlement over the pile foundation and fewer than the substructure. Such cumulous substructure are used with success in different country like Federal Republic of Germany and different elements of Europe wherever thick clay deposits ar quite common..

Butterfield Associate in Nursingd Banarjee (1971a) bestowed an elastic analysis of pile cluster regarding the interaction of ground and randomly spaced cluster. The load displacement behavior of the inspiration and therefore the load distribution between the piles within the cluster and cargo shared by the cap is analyzed. The ANalysis relies on an integral equation developed from Mandolin's analysis for some extent load embedded among a semi- infinite ideal elastic 0.5 area..

Hein and Lee (1978) analysed the heaped raft/mat considering raft as a versatile elastic plate supported on compressible piles, and soil as homogenous / non homogeneous material. the final word load capability of piles is taken into consideration by a load cut-off procedure..

Kuwabera (1989a) performed boundary part analysis supported an elastic theory to analyse the behaviour of pile raft foundations subjected to vertical load. Characteristics of settlement and cargo transfer for heaped raft foundations whose raft rest on a homogenous identical elastic 0.5 area area unit compared with free standing pile teams and single piles.

Franke (1991) showed analysis of four buildings supported on heaped raft in Federal Republic of Germany. This shows that compared to a groundwork, piled raft reduces the settlement by about 50 %. .

Methods of Analysis

3.2 Approximation Method

One approach that treated the raft as a skinny plate, the piles as springs and also the soil as AN elastic time, was utilized by Chen and Lee (1973) during which the interaction effects between the piles were neglected. Poulos (1994) developed a program GARP (Geotechnical Analysis of Raft with Piles) that used a finite distinction methodology for the raft with the thought of the interaction effects between the piles and raft. Allowances were created for the piles to succeed in their final capacities and native bearing failure of the raft.

Randolph (1983) bestowed a technique to cipher the interaction between one pile and a circular raft. A flexibility matrix technique was then accustomed calculate the general stiffness of the piled foundation by combining the individual stiffness of one pile-raft unit.

Clancy and Randolph (1993) used a hybrid methodology that combined finite components and analytical solutions. The raft was modelled by two-dimensional skinny plate finite components, the piles were modelled by one-dimensional rod finite components and also the soil response was calculated by mistreatment AN analytical resolution. The pile was connected to a raft component at a typical node, specified the vertical freedoms area unit common at the connected nodes.

Mindlin's resolution was accustomed cipher the interaction between the elements. Effects of the pile and raft stiffnessa on displacements and bending moments of the inspiration were examined and it had been incontestible that the differential displacements and bending moments were addicted to the raft-soil stiffness magnitude relation that was introduced by Hain and Lee (1978). The load sharing and also the average displacement of the raft were addicted to the pile-soil stiffness magnitude relation. This methodology took under consideration the non-linearity of pile behaviour and slip was allowed to occur at the pile-soil interface. However, this methodology is proscribed to homogenous soil conditions.

Kitiyodom and Matsumoto (2003) bestowed the same approach to Hain and Lee (1978), however the piles were modelled by elastic beams and also the interactions between structural members were approximated by Mindlin's solutions. The foundations will be subjected to each axial and lateral masses and embedded in non-homogeneous soil. This approach incorporated each the vertical and lateral resistance of the piles and also the base of the raft within the analysis.

3.3 Boundary Element Method

In this methodology, discretizetion is barely needed on the boundary of the system into consideration. this method needs the transformation of the governing partial equation into Associate in Nursing integral equation. As solely the boundaries need to be discretized, the amount of sets of equations to be solved is mostly smaller than the finite part or finite distinction ways. Solutions like stresses and displacements will be obtained directly by determination the system of equations. Since solely the boundaries area unit discretized, interpolation errors area unit confined to the boundaries. As this methodology provides an on the spot and correct answer for the analysis, is fast, and needs a moderate quantity of memory board house, it will be used for the analysis of enormous pile teams.

Butterfield and Banerje (1971) utilized the boundary part methodology to check the behaviour of a pile cluster embedded in a perfect elastic 0.5 area with a superbly rigid cap not in grips with the bottom. Soil-structure interaction was taken under consideration within the analysis. Mindlin's answer was wont to describe the soil response and also the interaction effects.

Brown and Wiesnar (1975) used the boundary element method to analyse a strip footing supported by equally housed identical piles embedded in an identical unvaried elastic 0.5 space. during this methodology, the raft and piles were divided into variety of zones within which interface forces or pressures acted on the corresponding zones. Application of Mindlin's answer was wont to confirm the interaction relationships owing to the interface forces.

Kawabata (1989) represented a boundary part analysis supported elastic theory to look at the behaviour of a piled raft foundation in a very consistent elastic soil mass. within the analysis, the raft was assumed to be rigid however sponginess of the piles was thought of. The raft was divided into a series of rectangular parts and also the pile was divided into a series of shaft and base parts. Poulos (1993) extended the strategy to include the result of free-field soil movement, load cut-offs for the pile-soil and raft-soil interfaces to look at the interaction mechanism between the cumulous raft and a soil subjected to outwardly obligatory vertical movement. The analysis is enforced via a computer program PRAWN (Piled Raft With Negative Friction).

The soil was diagrammatical by a Mindlin elastic linear unvaried 0.5 house. The raft was assumed to be a skinny plate and was delineated by integral equations. The pile was delineated by one component and therefore the shear stresses on it were approximated by a second-degree polynomial. The interaction between the raft and soil was analysed by dividing the interface into triangular parts and therefore the sub agrade reaction was assumed to vary linearly across each part.

3.4 Method of Finite Element

The finite part methodology is one amongst the foremost powerful tools for the analysis of heaped rafts. It needs the discretations of each the structural foundation system and therefore the soil. so as to scale back the process effort, problems ar typically simplified to an axis-symmetric prblm or a plane-strain prblm.

An example of the analysis of a heaped raft (the Hyde Park Barracks) was given by Hooper (1973a), within which Associate in Nursing axis-symmetric model with eight noded iso-parametric parts was used. within the analysis, approximation of the equivalent stiffness of the pile cluster was created such every concentrical row of piles was modelled by an eternal Associate in Nursingnulus with an overall stiffness that was admire the add of the stiffnessa of the individual piles. The soil was assumed to be a linear elastic isotropic material with the modulus increasing linearly with depth. the extra stiffening impact of the construction into the analysis, the same raft thickness that had identical bending stiffness because the combined raft and therefore the construction was introduced..

However, Hooper's results have shown that the contribution of the stiffening impact of the construction on the behaviour of the heaped raft was comparatively tiny within the case of the Hyde Park Barracks, though this could not be true all told cases.

Chow and Teh (1991a) bestowed a numerical methodology to look at the behaviour of a rigid heaped raft embedded in a very non-homogeneous soil. The raft was discretized into sq. sub-elements. the bottom of the raft was assumed to be absolutely sleek and therefore the interface of the raft and therefore the soil medium was approximated by sq. subdivisions (Chow 1987a)).

The soil was assumed to be a linearly elastica, identical material and therefore the elastic modulus assumed to extend linearly with depth. The piles were assumed to possess a circular cross-sectional.

The raft was discretized into sq. sub-elementsa. the bottom of the raft was assumed to be utterly sleek and therefore the interface of the raft.

The raft was discretized into square sub-elements . The base of the raft was assumed to be perfectly smooth and the interface of the raft

Interactions between the piles, the raft and therefore the soil were taken under consideration and therefore the avertical deformation of the soil was resolute by the principle of superposition within which equilibrium of the raft-pile-soil system was thought-about. aA technique for the analysis of circular Raft with piles (piled a raft) was introduced by Wiesnar (1991a). during this technique raft is assumed a skinny plate and modelled by bending finite components in rectangular sizea. The reactions acting the this skinny plate was assumed to be block of rectangular size of uniform vertical stress and piles were modelled as elastic cylinder and soil below the raft to be assumed as linearly elastic.

The reaction forces on the pileasoil interfaces were treated as uniform vertical shear stresses on the pile shaft and as an even vertical stress at the pile base. aTo take interaction under consideration, the reciprocal theorem was applied to the pile, and influence factors were calculated supported elastic theory.

Maharaja and Gandhi (2004a) planned a non-linear finite part technique for the analysis of a heaped raft subjected to a uniformly distributed load. This technique combined associate progressive reiterative procedure with a NewtonaRaphson technique to unravel the non-linear equations concerned in an exceedingly malleability analysis. The raft, pile and soil were discretized into eight node brick components.

3.5 Combined Boundary Element and Finite Element Method

A method of research is developed by Hein & Lee (1978a) to look at the versatile behaviour of raft supported by a gaggle of piles with final capability. aThe analysis combined the finite component technique for the analysis of the raft and also the boundary component technique for the analysis of the piles and soil. The raft was treated as a skinny elastic plate and also the pile cluster asupporting soil system was modelled by the employment of the Mindlin's equation. However, the affiliation between the raft and also the pile was assumed to be a slippy ball joint that silent that no moments or lateral forces were transferred between the raft and pile heads. own the analysis, they urged that the behaviour of the heaped-up raft would depend upon the relative flexibility of the raft and also the relative stiffness of the pile to the soil. Four completely different interactions between the piles, raft and soil were introduced and totally thought of within the analysis. additionally, a `load cut-off procedure was introduced to account for the event of the final word load capacities of the piles.

Mandolini and Viggiani (1997) Mandolini and Viggiani (1997a) given an analysis to predict the settlement of piled raft foundations. the strategy is capable of taking into consideration the soil-structure interaction and non-linear behaviour at the pile-soil interface. The piles were ANalysed by the boundary component technique and also the behaviour of a pile cluster embedded in an elastic time was then analysed supported the employment of interaction factors. The raft was analysed by the employment of the finite component technique and also the interaction between the piles, raft and soil was delineate by a linear elastic model. To stimulate the non-linear behaviour, a stepwise linear progressive procedure was used and a hyperbolic load-settlement relationship for one pile was assumed. Sinha (1997a) delineated Associate in Nursing analysis for heaped-up raft foundations in expansive soil victimisation the finite component technique to model the raft and also the boundary component technique to model the piles.aThe raft was Associate in Nursingalysed as a plate resting on an elastic soil medium and was discretised into four node rectangular parts.

The pile was discretised into cylindrical parts and analysed by the boundary component technique, anda the soil was assumed to be a homogenized elastic soil mass.

Non-linear behaviour including take off of the raft from the soil and a neighborhood soil yield beneath the raft, slip at the soil-pile interface and yielding of the soil beneath the pile base were incorporated into the analysis.

The effects of free field soil movement are thought fain the analysis within which the bottom movements thanks to the method of swelling and shrinking of the soil were considered..

3.6 Combined of Finite Layer and Finite Element Method

An approach supported the finite layer technique developed by tiny and agent (1984, 1986a) to reason the behaviour of concentrated rafts subjected to vertical hundreds in bedded soils. The soil was divided into a series of horizontal layers.

The raft wasatreated as a skinny elastic plate and also the piles were divided into rod parts love the soil layers. The soil was analysed by the finite layera methodology and also the raft and piles were analysed by the finite element methodology.

Two approximation methodsa which can be accustomed reason interactions between the piles or piles and raft a lot of with efficiency. Displacement at any purpose on the soil surface will be approximated by a closed form polynomiala equation.

First Method :- piled First methodology :- apiled rafts with sq. raft parts of equal size and identical piles. A circular uniform load will then be accustomed represent the block of contact pressure underneath the raft part.

Secondt Method :- The piled rafts with sq. raft parts of equal size and identical piles. A circular uniform load will then be accustomed represent the block of contact pressure underneath the raft part.

Secondt methodology :- aThe Raft part will be of the many completely different size and also the this methodology doesn't thought of the cluster effects of piles

3.7 An Approach of Variational

A variational approach is developed by Shene et al (1999a) for analysis of pile's cluster with rigid cap in touching the below the soil. This technique uses the minimum mechanical energy principle to found the responses of the given foundation system. associate degree extension of the his technique for pile teams was created by Chow et al. (2001a) for the analysis of piled raft system.

The raft was assumed to be a skinny elastic plate. aThe deformations of the raft and pile cluster were every pictured by a finite series. The piled raft and pile cluster were analysed by the utilization of the principle of minimum P.E.. The load-settlement relationship at the interface between the pile heads and soil were incorporated into the raft analysis, and also the behaviour of the pile and soil were assumed to be elastic-perfectly plastic. so as to account for the final word bearing capability of the pile and soil, associate degree ainitial stressatechnique was accustomed limit the pile loads and soil reaction pressures to the ultimate values.

3.8 Piled raft behaviour

When the basement slabs for higher structure and also the piles foundation of the structure along support the load of the higher structure, they form a piled-raft foundation.

In cases wherever the result of the basement slabs as supporting force isn't vital or the result isn't accounted in computation, the inspiration is treated as a pile foundation in engineering style and safety check.

n cases wherever the basement slabs because the main half to hold the load from the higher structure, the inspiration is taken into account as a raft. The materials introduced during this lecture note square measure principally supported the worked reportable by Poulos (2001a) and tiny (2001).

In cases wh ere th e bas em ent slabs as th e main part to carry th e load from th e upp er structur e, th e foundation is consid er ed as a raft. Th e mat erials introduc ed in this l ectur e not e ar e mainly bas ed on th e work ed r eport ed by Poulos (2001) and Small (2001).

The performance of a typical foundation is illustrated in the Fig (Poulos, 2001).

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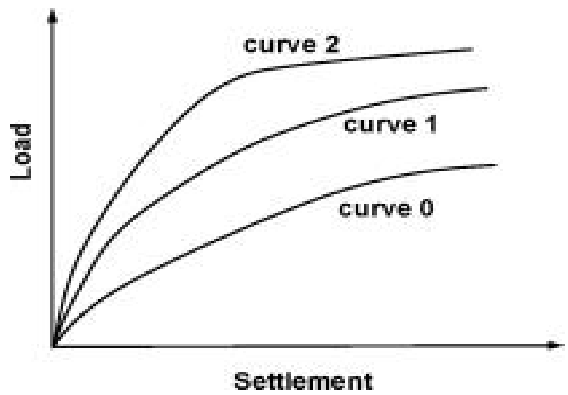

(Fig. 3.1)

Curve 0: The load is carried by the raft only (a raft foundation);

Curve 1: The load is carried by the pile foundation only (a pile foundation); In this case, the raft may be assumed totally rigid or totally flexible.

Curve 2: The load is carried by the pile and the raft together (a piled-raft foundation).

As compared with a pile foundation, both the bearing capacity and stiffness to resistance settlement are clearly improved by a piled-raft foundation. Therefore, a piled-raft foundation is an attractive choice for floating pile foundations where the underneath soil is very compressible and has a very low strength. Because of the need for basement below structure, the positive effect of the raft is increasingly taken into consideration in the design of foundations, particularly when the strength and stiffness of the pile foundation are not enough.

For an example, the Emirate Twin Towers in Dubai and the Twin Towers in Kuala Lumpur are designed with the concept of piled raft foundations.

3.9 Suitable & Unsuitable circumstances for Piled-Rafts

The most effective application of piled rafts happens once the raft will give adequate load capability, however the typical settlement and/or differential settlements of the raft alone exceed the allowable values. Poulos (1991a) has examined variety of perfect soil profiles and has found that the subsequent things is also suitable::-

(I) Soil profiles consisting of relatively stiff

(II)Soil profiles consisting of relatively dense sands

In both circumstances, the raft can provide a significant proportion of the required load capacity and stiffness, with the piles acting to boost the performance of the foundation, rather than providing the major means of support.

Conversely, there are some situations that are unfavourable :-

(I)Soil profiles containing soft clays near the surface,

(II)Soil profiles containing loose sands near the surface,

(III)Soil profiles that contain soft compressible layers at relatively shallow depths

(IV)Soil profiles that are likely to undergo consolidation settlements

(V)Soil profiles that are likely to undergo swelling movements due to external causes.

In the initial 2 cases, the raft might not be able to give vital load capability and stiffness, whereas within the third case, long settlement of the compressible underlying layers might cut back the contribution of the raft to the long stiffness of the inspiration. The latter 2 cases ought to be treated with significant caution..

Consolidation settlements (such as those thanks to dewatering or shrinking of a vigorous clay soil) might end in a loss of contact between the raft and therefore the soil, so increas¬ing the load on the piles, and resulting in augmented settlement of the inspiration system

Consolidation settlements (such as those thanks to dewatering or shrinking of a vigorous clay soil) might end in a loss of contact between the raft and therefore the soil, so increas¬ing the load on the piles, and resulting in augmented settlement of the inspiration system

In the case of swelling soils, substantial extra tensile forces could also be elicited within the piles owing to the action of the swelling soil on the raft. Theoretical studies of those latter things are represented by Poulos (1993) and Sinhaa & Poulos (1999).

3.10 LOAD TRANSFER IN PILED RAFT

The load transfer from pile to soil just in case} of a piled raft is sort of completely different from that in case of normal piles.aThis is as a result of, the raft forces the soil instantly below it to settle by a similar quantity because the settlement of piles. therefore there's no relative movement between pile and therefore, friction mobilised is negligible.

(I) Axial Load Distribution :- When single pile is loaded, the load transfer begins from prime portion of the pile and as load will increase, additional load is transferred to deeper levels.aIn case of piled raft for a similar load, the load is transmitted uptoa all-time low of the pile, and skin friction mobilises solely when the soil between the piles gets compressed. Fig.3.2ashows axial load distribution curves

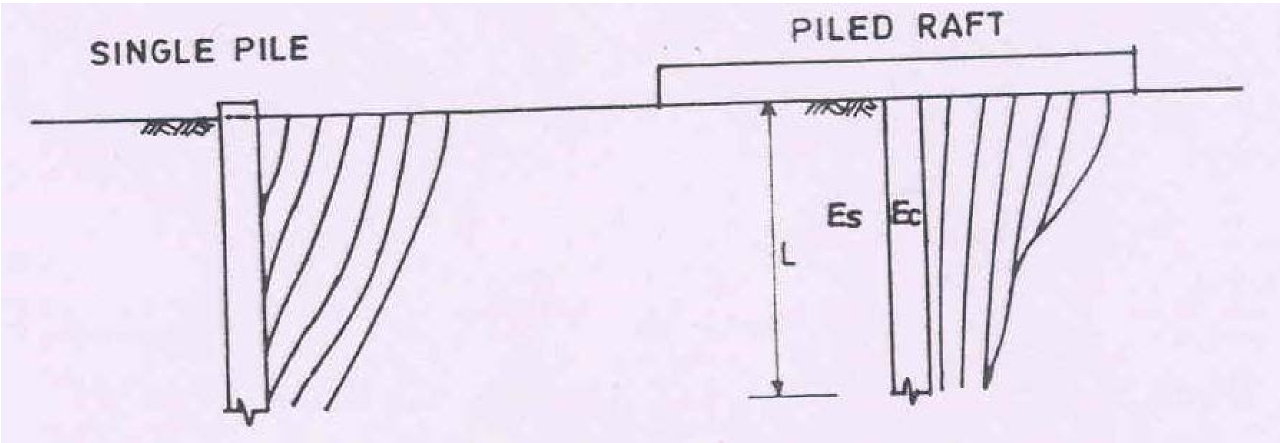

Fig. 3.2 Axial load distribution

(II) Pile Load Distribution :- In single pile the event of shaft resistance is predominant even at little magnitude of settlement . In piled raft the event of shaft resistance with settlement is veryasmall for initial value of settlement and so the shaft resistance will increase with increase in settlenent.aThis is as a result of high portion of soil in between the piles is in reality with raft and move monolithically with the pile (i.eathere isn't any relative movement between pile and soil). therefore ahere isn't any development of shaft resistance in prime portion of piled raft. The Shaft resistance in single pile develops from prime to bottom, whereas in piled raft it develops from bottom to prime.

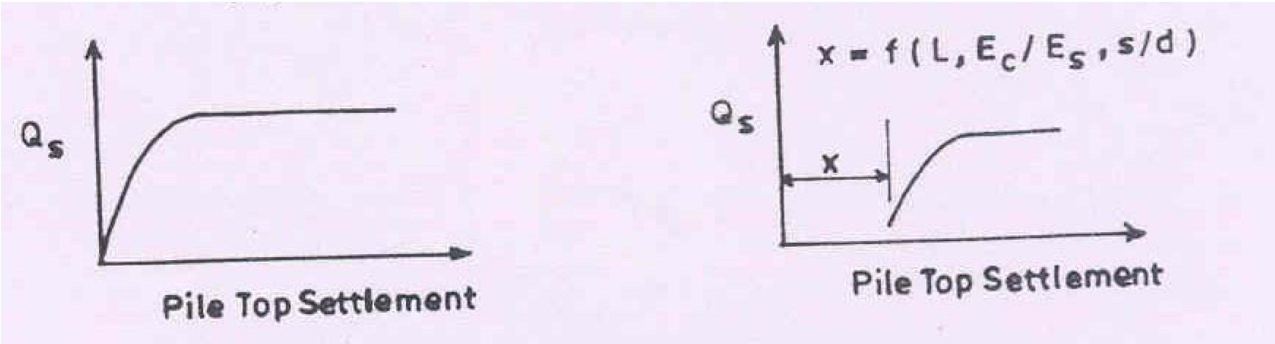

Fig. 3.3 Pile load distribution (Development of Shaft Resistance)

Single pile shows no development of end-bearing resistance for initial settlement. Increase in settlement shows development of end-bearing resistance Fig three.4.aPiled raft shows development of end-bearing resistance even at initial settlement and will increase with increase in settlement. one pile 1st takes the load through skin friction and once there's vital mobilization of skin friction it transfers the load through end-bearing.

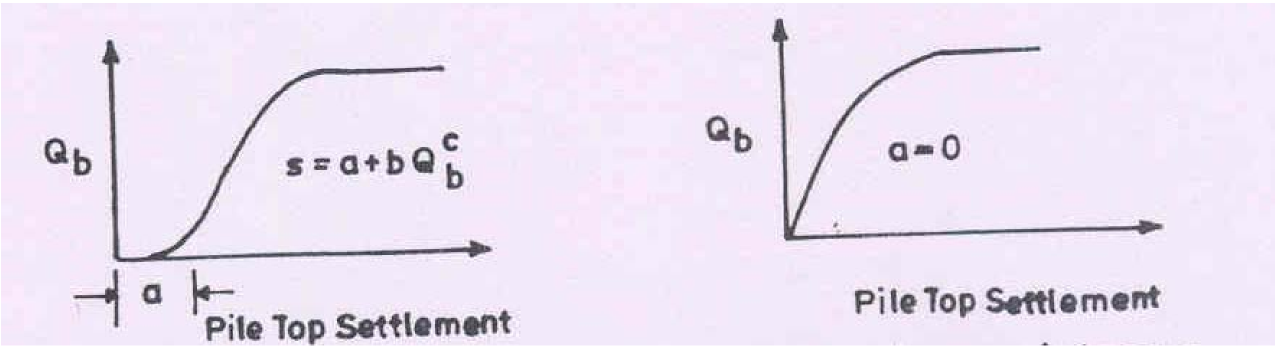

Fig. 3.4 Pile load distribution (Development of End Bearing Resistance)

3.11 Design concepts for piled raft foundations

(1) Bearing capacity;
(2) Settlement (maximum settlement and differential settlement);
(3) Raft moments and shears;
(4) Loads and moments on the piles.

In foundation style, the planning is usually primarily based upon the bearing capability and settlement underneath vertical hundreds. although this can be a vital facet, however there ar alternative problems that has got to even be self-addressed. as an example, in some cases, the pile necessities could also be ruled by the overturning moments applied by wind loading, instead of the vertical dead and live loads, etc.

3.10 Alternative design philosophies

Randolph (1994) has defined three different design philosophies with respect to piled rafts:

(I) The conventional approach , in which the piles are designed as a group to carry the major part of the load, while making some allowance for the contribution of the raft, primarily to ultimate load capacity

(II) Creep piling', in which the piles are designed to operate at a working load at which significant creep starts to occur, typically 70-80% of the ultimate load capacity.

(III) Differential settlement control, in which the piles are located strategically in order to reduce the differential settlements, rather than to reduce the overall average settlement substantially

3.11 Classification of analysis Method

Several methods of analyzing piled rafts have been developed, and some of these have been summarized by Poulos et al (1997). Three broad classes of analysis method have been identified:

(1) Simplified calculation methods

(2) Approximate computer-based methods

(3) More rigorous computer-based methods

A number of simplifications in relation to the modelling of the soil profile and the loading conditions on the raft. The approximate computer-based methods include the following broad approaches Methods employing a strip on springs approach, in which the raft is represented by a series of strip footings, and the piles are represented by springs of appropriate stiffness (e.g. Poulos, 1991). Methods employing a plate on springs approach, in which the raft is represented by a plate and the piles as springs (. Clancy and Randolph, 1993; Poulos, 1994; Viggiani,1998; Anagnas-topoulos and Georgidisa, 1998).

Simplified finite element analyses, usually involving the representation of the foundation system as a plane strain problem (Desai,1974) or an axi-symmetric problem (Hooper,1974), and corresponding finite difference analyses via the commercial program FLAC (e.g. Hewitt and Gue, 1994).

3.11 The Design Process

H.G. Poulos has been suggested mainly three Main stages for piled raft system in 2001. They are following

(1) Preliminary design stage_:- Preliminary style stage :- the primary could be a pre¬liminary stage to assess the practicableness of employing a heaped-up raft and therefore the needed range of piles to satisfy style needs. Associate in Nursing approximate analysis technique is employed to access the consequences of the amount of piles on load capability and settlement.

(2) assessment of piling requirement_: - assessment of column demand : - The second stage involves a additional elaborated examination to assess wherever piles ar need and to get the overall characteristics of the piles.

The first and second stages involve comparatively straightforward calcula¬tions, which might typically be performed while not a fancy malicious program. The elaborated stage can usually demands the utilization of an appropriate malicious program that accounts in an exceedingly rational manner for the interaction among the soil, raft and piles. The impact of the construction may additionally ought to be thought-about

1.) Preliminary design stage :- within the preliminary stage, it's necessary 1st to assess the performance of a foundation while not piles. Estimates of vertical and lateral bearing capability, settlement and differential settlement could also be created via standard techniques. If the raft alone has adequate load carrying capability, however doesn't satisfy the settlement or differential settlement criteria, then it's going to be possible to contemplate the utilization of piles as settlement reducers, or to adopt the `creep piling' approach. first the estimations area unit created with regard to the performance of the raft while not piles

(a If the raft will solely carry atiny low portion of the load, then pile foundation is required for each carrying the load and reducing the settlement..

(b) If the raft will carry the majority the load however with unacceptable settlement (uniform settlement) (differential settlement), then pile foundation is introduced as settlement reducer.

Secondarily, a piled-raft foundation is introduced within the style in the main for 2 reasons.

For assessing vertical load capability, the last word load capability will usually be taken because the lesser of the subsequent 2 values

(a (a) The add of the last word capacities of the raft and all the piles and.

(b The final capability of a block containing the piles and therefore the raft, and that of the portion of the raft outside the edge of the piles

For assessing vertical load capability, the last word load capability will usually be taken because the lesser of the subsequent 2 values:

1.) Estimate the vertical bearing capacity of the piled raft

(a) The sum of the ultimate capacities of the raft plus all the piles and

(b) The ultimate capacity of a block containing the piles and the raft, plus that of the portion of the raft outside the periphery of the piles

2.) Estimate the load and settlement behaviour of the piled raft

For assessing the load-settlement behaviour, the utilization of an easy technique of estimating the load sharing between the raft and therefore the piles, as printed by Randolph (1994) is used.

Using his approach, the stiffness of the piled raft foundation can be estimated as follows:

$$K_{pr} = \frac{K_p + K_r\,(1 - \alpha_{cp})}{1 - \alpha_{cp}^2 K_r K_p} \qquad 3.1$$

where K_{pr} = stiffness of piled raft; K_p = stiffness of the pile group; K_r = stiffness of the raft alone; and α_{cp} = raft-pile interaction factor.

The raft stiffness, K_r can be estimated via elastic theory by using the solutions of Fraser & Wardle (1976). The pile group stiffness can also be estimated from elastic theory, using approaches such as those described by Poulos & Davis (1980).

the single pile stiffness is computed from elastic theory, and then multiplied by a group stiffness efficiency factor, which is estimated approximately from elastic solutions.

The proportion of the total applied load carried by the raft is

$$\frac{P_r}{P_t} = \frac{K_r(1-\alpha_{cp})}{K_p + K_r(1 - \alpha_{cp})} = \text{X} \qquad 3.2$$

where P_r = load carried by the raft; P_t = total applied load.

The raft-pile interaction factor α_{cp} can be estimated as follows:

$$\alpha_{cp} = 1 - \frac{\ln\left({}^{r_c}/_{r_o}\right)}{\zeta}$$

where r_c = average radius of pile cap (corresponding to an area equal to the raft area divided by number of piles); r_o = radius of pile;

$\zeta = \ln\left({}^{r_m}/_{r_o}\right)$; $r_m = 0.25 + \zeta\,[2.5\,\rho\,(1 - \nu) - 0.25]XL$; $\zeta = E_{si}/E_{sb}$;

3.3

$\rho = E_{sav}/E_{si}$; ν = Poisson's ratio of soil; L = pile length;

E_{sl} = Young's modulus of soil at level of pile tip;

E_{sb} = Young's modulus of soil of bearing stratum below pile tip; and

E_{sav} = average Young's modulus of soil along pile shaft.

The above equations can be used to develop a tri-linear load-settlement curve, as shown in Fig.4 below. First, the stiffness of the piled raft is computed from equation 4.1.

This stiffnëss will rëmain opërativë until thë pilë capacity is fully mobilisëd. Making thë simplifying assumption that thë pilë load mobilisation occurs simultanëously, thë total appliëd load, P_l , at which thë pilë capacity is rëachëd is givën by

$$P_i = \frac{P_{up}}{1-X} \qquad 3.4$$

where P_{up} = ultimate load capacity of the piles in the group; and X = proportion of load carried by the piles equation 4.2.

Beyond that point (point A in Fig.4),the stiffness of the foundation system is that of the raft (K_r), and this holds until the ultimate load capacity of the piled raft foundation system is reached (point B in Fig.(4).

At that stage, the load-settlement relationship becomes horizontal.

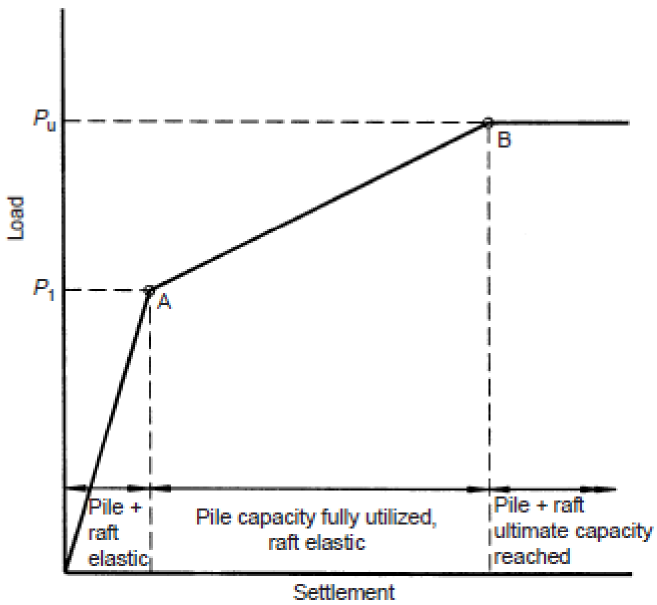

Fig.3.2

The load-settlement curves for a raft with numerous numbers of piles may be computed with the help of a laptop programme or a mathematical program like MATHCAD.

In this method, it's straightforward to cipher the connection between the quantity of piles and also the average settlement of the inspiration. Such calculations give a speedy means that of assessing whether or not the planning philosophies for creep spile or full pile capability usage square measure doubtless to be possible..

Burland's Approach :- once the piles square measure designed to act as settlement reducers and to develop their full geotechnical capability at the planning load, Burland (1995) has developed the subsequent simplified method of design:

Estimate the entire long load-settlement relationship for the raft while not piles (see Figure 4). the planning load P0 offers a complete settlement S0 Estimate the entire long load-settlement relationship for the raft while not piles (see Figure 4). the planning load P0 offers a complete settlement S0..

1) Assess an appropriate style settlement South Dakota, that ought to embody a margin of safety.

2) P1 is that the load carried by the raft similar to South Dakota.

3) The load excess P0 – P1 is assumed to be carried by settlement-reducing piles. The shaft resistance of those piles are going to be absolutely mobilized and so no issue of safety is applied. However, Burland suggests that a "mobilization factor" of regarding zero.9 be applied to the 'conservative best estimate' of final shaft capability, Psu.

4) If the piles square measure settled below columns that carry a load in way over Psu, the heaped-up raft could also be analyzed as a raft on that reduced column masses act. At such columns, the reduced load Qr is:

$$Qr = Q - 0.9\ Psu \qquad 3.5$$

5) The bending moments in the raft can then be obtained by analyzing the piled raft as a raft subjected to the reduced loads Qr.

6) The process for estimating the settlement of the piled raft is not explicitly set out by Burland, but it would

appear reasonable to adopt the approximate approach of Randolph (1994) in which:

$$S_{pr} = S_r \times K_r / K_{pr} \qquad 3.6$$

where S_{pr} = settlement of piled raft

S_r = settlement of raft without piles subjected to the total applied loading

K_r = stiffness of raft
K_{pr} = stiffness of piled raft.
Equation 1 can be used to estimate K_{pr}

Second Stage of Design: Assessment of piling requirements :-

Much of the prevailing literature doesn't contemplate the careful pattern of loading applied to the muse, however assumes uniformly distributed loading over the raft space. whereas this might be adequate for the preliminary stage delineated higher than, it's not adequate for considering in additional detail wherever the piles ought to be settled once column loadings square measure gift. This section presents Associate in Nursing approach that permits for Associate in Nursing assessment of the most column loadings that will be supported by the raft while not a pile below the column.

There square measure a minimum of four circumstances once a pile could also be needed below column.

There are at least four circumstances when a pile may be required below column.

(a) (a) If Mmaxa within the raft below the column > Mallowable price for the raft,

(b) (b) If Smaxa within the raft below the column > Sallowable price for the raft,

(c) (c) If Contact Pressuremaxa below the raft > the allowable style price for the soil and

(d) (d) If the Settlementlocala below the column > the allowable price..

To estimate the most moment, shear, contact pressure and native settlement caused by column loading on the raft, use is fabricated from the elastic solutions summarised by Selvaduri (1979).

These square measure for the perfect case of one focused load on a semi-infinite elastic raft supported by a undiversified elastic layer of nice depth, however they are doing a minimum of offer a rational basis for style. it's additionally attainable to rework more or less a additional realistic superimposed profile into a similar undiversified soil layer by mistreatment the approach represented by Fraser & Wardle (1976).

Figure below shows the pictorial assumption of the matter self-addressed, and a typical column that the stilt needs (if any) square measure being assessed..

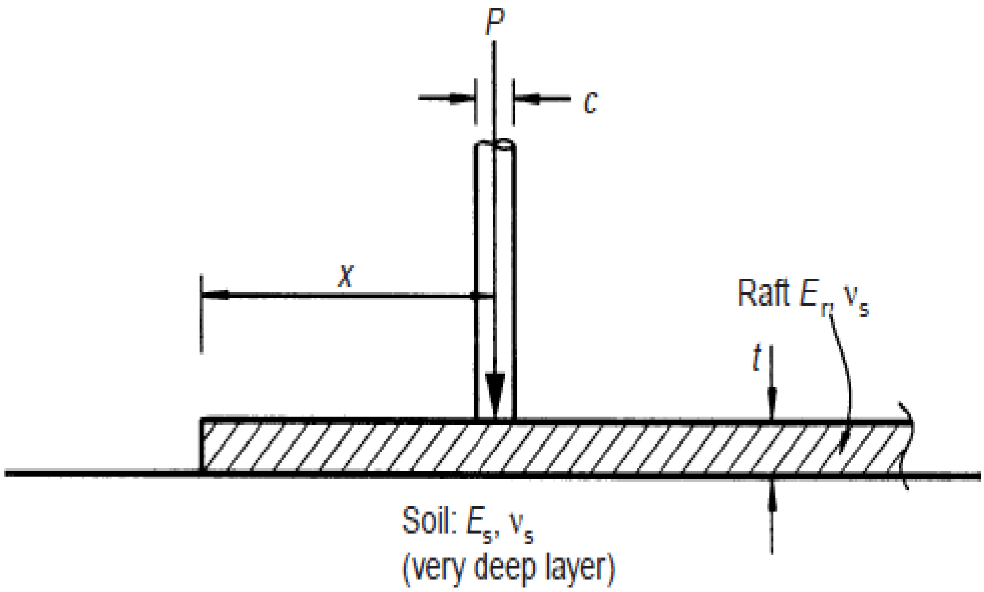

Fig. 3.3

(a) *Maximum moment criterion*: The maximum moments M_x and M_y below a column of radius c acting on a semi-infinite raft are given by the following approximations:

$$M_x = A_x.P \tag{3.6a}$$

$$M_y = B_y.P \tag{3.6b}$$

Where $A_x = A - 0.0928\ln(c/a); B_y = B - 0.0928\ln(c/a); A, B =$ coefficients depending on δ / a i.e. they are the distance of the column centre line from the raft edge; $a =$ characteristic length of raft $= t[E_r(1-\nu_s^2)/6E_s(1-\nu_r^2)]^{1/3}; t =$ raft thickness; $E_r =$ raft Young's modulus; $E_s =$ soil Young's modulus; $\nu_r =$ raft Poisson's ratio; and $\nu_s =$ soil Poisson's ratio.

The coefficients A and B are plotted in Fig. below as a function of the relative distance x/a.

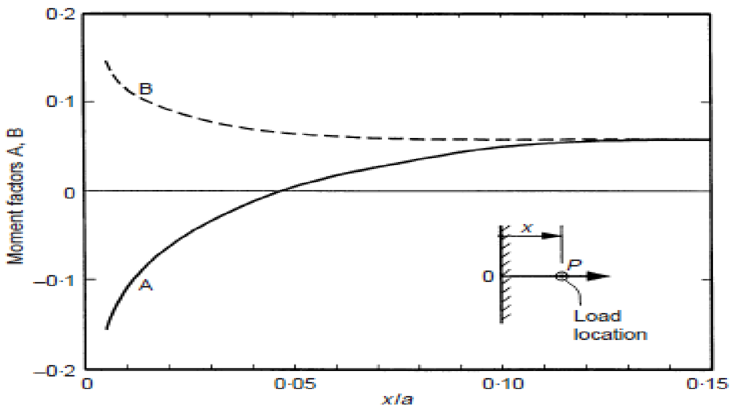

Fig. 3.4 Moment factors A, B for circular column

The maximum column load, P_{c1} that can be carried by the raft without exceeding the allowable moment is then given by

$$P_{cl} = \frac{M_d}{larger\ of\ A_x\ and\ B_y} \qquad 3.6c$$

where M_d = design moment capacity of raft.

(b) *Maximum shear criterion:*

The maximum shear, V_{max} below a column can be expressed as

$$V_{max} = \frac{(P - q\pi c^2)C_q}{2\pi c} \qquad 3.7$$

Where q = contact pressure below raft, c = column radius , c_q = shear factor

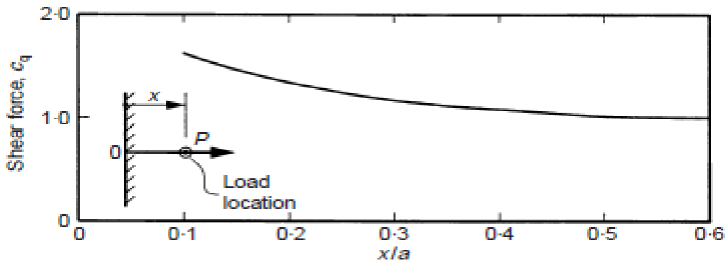

Fig.3.5 shear factor, c_q for Circular Column

Thus if the design shear capacity of the raft is V_d, the maximum column load, that can be applied to the raft is P_{c2} :-

$$P_{c2} = \frac{V_d 2\pi c}{c_q} + q_d \pi c^2 \qquad 3.8$$

Where V_q = design allowable bearing pressure below raft

(c) *Maximum contact pressure criterion:* The maximum contact pressure on the base of the raft q_{max} can be estimated as follows:

$$q_{max} = \frac{\bar{q}P}{a^2} \qquad 3.9$$

where $\bar{q}$ = factor plotted in Fig. below and a = characteristic length defined in equation (4.6a).

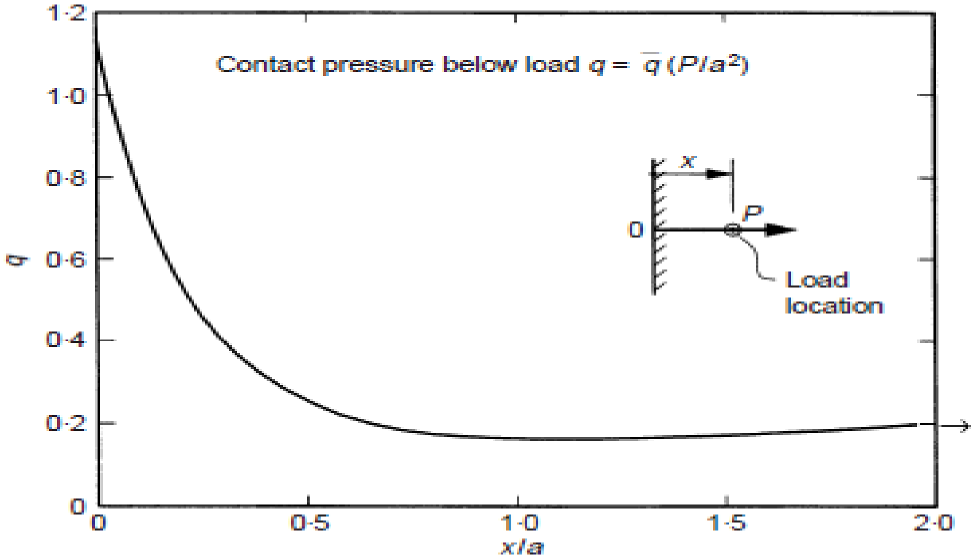

Fig.3.6 Contact Pressure factor, q

The maximum column load P_{c3}, that can be applied without exceeding the allowable contact pressure, is then

$$P_{c3} = \frac{q_u a^2}{F_s q} \qquad 3.10$$

where $q_u =$ ultimate bearing capacity of soil below raft, and $F_s =$ factor of safety for contact pressure.

Local settlement criterion: The settlement below a column (considered as a concentrated load) is given by

$$S = \frac{\omega\,(1-V_s^2)P}{E_s a} \qquad 3.11$$

where $\omega =$ settlement factor plotted in Fig. below. This expression does not allow for the effects of adjacent columns on the settlement of the column being considered, and so is a local settlement that is superimposed on a more general settlement `bowl'.

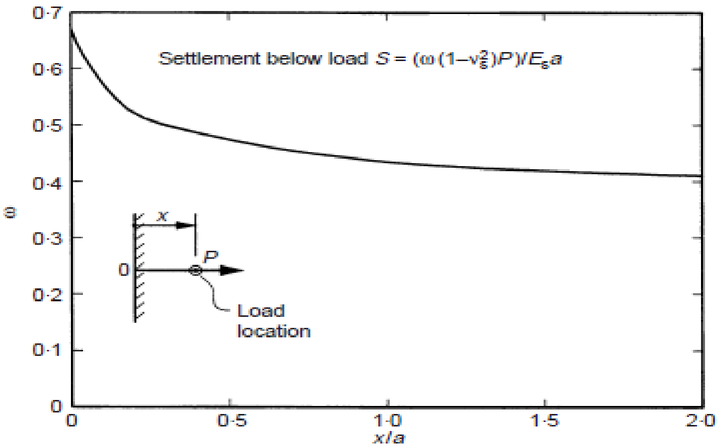

Fig.3.7 Settlement factor, ω (soil assumed to be homogeneous and very deep)

If the allowable local settlement is S_a, then the maximum column load, P_{c4} so as not to exceed this value is

$$P_{c4} = \frac{S_a E_a}{\omega(1 - V_S^2)} \qquad 3.12$$

Assessment of pile requirements for a column location

If the actual design column load at a particular location is P_c, then a pile will be required if P_c exceeds the least value of the above four criteria. That is, if

$$P_c > P_{crit} \qquad 3.13$$

where P_{crit} = minimum of Pc1, Pc2, Pc3 or Pc4

If the important criterion is most moment, shear or contact pressure (i.e P_crit is Pc1, Pc2 or Pc3) then the pile ought to be designed to produce the deficiency in load capability. Burland (1995) has steered that solely concerning ninetieth of the final word pile load capability ought to be thought of as being mobilised below a cumulous raft system. On this basis, the final word pile load capability, , at the column location is then given by

$$P_{ud} = 1.11\ F_p\ (P_c - P_{ctit}) \qquad 3.14$$

where F_p = factor of safety for piles. When designing the piles as settlement reducers, F_p can be taken as unity.

If the critical criterion is local settlement, then the pile should be designed to provide an appropriate additional stiffness. For a maximum local settlement of S_a, the target stiffness, K_{cd} of the foundation below the column is

$$K_{cd} = \frac{P_c}{S_a} \qquad 3.15$$

As a first approximation, using equation (1), the required pile stiffness, K_p, to achieve this target stiffness can be obtained by solving the following quadratic equation:

$$K_P^2 + K_P[K_r(1 - 2\alpha_{cp}) - K_{cd}] + \alpha_{cp}^2 K_r K_{cd} = 0 \qquad 3.16$$

where $\alpha_{cp} =$ raft-pile interaction factor, and $K_r =$ stiffness of raft around the column. α_{cp} can be computed from equation (3.3), while the raft stiffness, K_r can be estimated as the stiffness of a circular foundation having a radius equal to the characteristic length, a (provided that this does not lead to a total raft area that exceeds the actual area of the raft).

Third Stage of Design: Detailed design stage

Much of the prevailing literature doesn't think about the careful pattern of loading applied to the muse, however assumes uniformly distributed loading over the raft space. whereas this might be adequate for the preliminary stage represented on top of, it's not adequate for considering in additional detail wherever the piles ought to be situated once column loadings square measure gift. This section presents associate approach that enables for associate assessment of the most column loadings which will be supported by the raft while not a pile below the column.

Detailed design stage

1.) Once aOnce the preliminary stage has indicated that a cumulous foot is possible, and a sign has been obtained of the seemingly stilt needs, it's necessary to hold out a additional careful style so as to assess the careful distribution of settlement and judge upon the optimum locations and arrangement of the piles. The raft bending moments and shears, and therefore the pile masses, ought to even be obtained for the structural style of the muse..

2.) Several ways of analysing cumulous rafts are devel¬oped, and a few of those are summarised by Poulos et al. (1997).).

3.) Methods Methods using a `strip on springs' approach, within which the raft is pictured by a series of strip footings, and therefore the piles square measure pictured by springs of applicable stiffness (e.g. Poulos, 1991))

3.13 Approximate Computer methods

(a) trip on Springs Approach (GASP)

An example of a technique during this class is that bestowed by Poulos (1991). an area of the raft is described by a strip, and also the supporting piles by springs. Approximate allowance is formed for all four parts of interaction (raft-raft parts, pile-pile, raft-pile, pile-raft), and also the effects of the elements of the raft outside the strip section being analyzed area unit taken under consideration by computing the free-field soil settlements thanks to these elements.aThese settlements area unit then incorporated into the analysis, and also the strip section is analyzed to get the settlements and moments thanks to the applied loading thereon strip section and also the soil settlements thanks to the sections outside the raft..

GASP will realize of soil non-linearity in Associate in Nursing approximate manner by limiting the strip- soil contact pressures to not exceed the bearing capability (in compression) or the raft uplift capability in tension. The pile hundreds area unit equally restricted to not exceed the compressive and uplift capacities of the piles. However, the final word pile load capacities should be pre- determined, and area unit sometimes assumed to be an equivalent as those for isolated piles. In reality, as shown by Katzenbach et al (1998), the loading transmitted to the soil by the raft will have a helpful result on the pile behaviour within the cumulous raft system. Thus, the assumptions concerned in modelling piles within the GASP analysis can tend to be conservative.

In finishing up a nonlinear analysis during which strips in 2 directions area unit analyzed, it's been found fascinating to solely think about nonlinearity in one direction (the longer direction) and to think about the pile and raft behaviour within the different (shorter) direction to be linear. Such a procedure avoids false yielding of the soil below the strip and thence false settlement prediction.

(b) Plate aPlate on Springs Approach (GARP))

n this style of analysis, the raft is described by Associate in Nursing elastic plate, the soil is described by Associate in Nursing elastic time and the piles area unit modelled as interacting springs. Some of the early approaches in this class (e.g. Hongladaroump et al, 1973a) neglected some of the parts of interaction and gave pile-raft stiffness that were overlarge.

Poulos (1994a) has used a finite distinction technique for the plate and has allowed for the assorted interactions via approximate elastic solutions. This analysis has been enforced via a program GARP (Geotechnical Analysis of Raft with Piles). aAllowance has been created for layering of the profile, the consequences of piles reaching their final capability (both in compression and tension), the event of bearing capability failure below the raft, and also the presence of free-field soil settlements performing on the inspiration system. The approximations concerned area unit like those used within the program GASP for cumulous strips..

A later version of GARP (aSales et al, 2000a) has replaced the finite distinction analysis for the raft with a finite part analysis, and has used a changed approach to considering the event of the final word load capability within the piles.

Russo (1998a) and Russo and Viggiani (a1997a) have delineate an analogous approach to the higher than ways, during which the assorted interactions area unit obtained from elastic theory, and non-linear behaviour of the piles is taken into account via the idea of a hyperbolic load-settlement curve for single piles. Pile-pile interaction is applied solely to the elastic element of pile settlement, whereas the non-linear element of settlement of a pile is assumed to arise solely from loading thereon specific pile.

Most analyses of cumulous rafts area unit supported the raft being treated as a skinny plate, and it's of interest to visualize what the result of victimisation thick plate theory is on the numerical predictions.

Most analyses of piled rafts are based on the raft being treated as a thin plate, and it is of interest to see what the effect of using thick plate theory is on the numerical predictions.

Poulos et al (2001) have examined the result of the tactic of modelling the raft as a skinny plate WHO analyzed a typical drawback victimisation first of all, a 3 dimensional finite part program wherever the raft was first of all modelled victimisation skinny shell theory, and so second, by creating the raft zero.3m thick, and assignment the raft modulus thereto a part of the finite part mesh representing the raft..

It was assumed within the analysis that there was no slip between the raft and also the asoil or between the piles and also the soil. it absolutely was found that there wasn't an excellent deal of distinction within the computed deflections for the raft , for each a stiff raft and a versatile raft.aIt was ended that the employment of skinny shell parts to represent the raft can result in affordable estimates of deflections, and thus moments, as long because the raft isn't very thick. Stresses within the soil are going to be higher for the skinny shell analysis, and this result could become necessary if yield of the soil thanks to focused hundreds is of concern.

3.14 Application to Simplified Problem

In order to match the anticipated behaviour of a cumulous raft from variety of various ways has been analyzed (Poulos et al, 1997a). whereas the matter is very oversimplified, it's helpful therein the inevitable variations that area unit concerned within the assessment of parameters in real cases area unit avoided, and also the drawback involves column loading instead of simply uniformly distributed loading. The comparisons specialise in the anticipated behaviour of the cumulous raft for a given set of soil, pile and raft parameters. However, some thought is additionally given to the influence on the inspiration behaviour of a number of the pile and raft parameters. aThe ways used, and also the assumptions concerned within the use of every technique, area unit printed below.

I) Poulos-Davis-Randolph (aPDRa) technique:-

In applying this approach, the stiffness of the raft was computed by hand from elastic theory, presumptuous the raft to be a similar circular footing, and considering the centre of a versatile raft. The stiffness of the single piles was computed from the closed type approximate solutions of Randolph and wrathful (1978) whereas the cluster settlement magnitude relation (used for computing the pile cluster stiffness) was approximated by Rs = n zero.5, wherever n = the quantity of piles

II) Burland's aBurland's Approach :-

he stiffness of the raft was computed employing a numerical analysis of the raft alone victimisation the program GARP. To estimate the moments within the raft, the applied hundreds were reduced at every column location by zero.9 times the final word load capability of the pile below that column (i.e. it absolutely was assumed that the complete load capability of the piles was mobilized). To estimate the settlement of the cumulous raft, the settlement of the raft, beneath the complete hundreds, was obtained from the raft analysis, and so this settlement was reduced by the magnitude relation of the stiffness of the raft to the cumulous raft (), as calculable from Randolph's equations.

III) GASP Analysis (Strip on Springs) :-

In this analysis, the raft was divided into a series of 3 strips in every direction. nonlinear effects were thought of for the strips running within the long direction, whereas strictly linear behaviour was assumed for the strips within the shorter direction. The stiffness of the individual piles was computed via the equations of Randolph and wrathful (1978a), and simplified expressions were accustomed get the pile – pile interaction factors. For the analysis of every strip, the consequences of the opposite strips therein direction were thought of by computing the free-field settlements thanks to those strips, and imposing those settlements on to the strip being analyzed.

CHAPTER 4

DESIGN APPROACH OF RAFT FOUNDATION

4.1 Need of Raft Foundation

Raft or Raft /mat foundation could be a combined footing that covers the whole space at a lower place a structure and supports all walls and columns. This raft or raft /amat usually rests directly on soil or rock, however can even be supported on piles additionally.

Raft foundation isa typically steered within the afollowing situations:

Raft foundation is generally suggested in the following situations:

a) aWhenever building masses ar therefore serious or the allowable pressure on thereforeil so tiny that individual footings would cowl quite floor space.

b) Whenever soil contains compressible lenses or the soil is sufficiently erratic and it's tough to outline and assess the extent of every of the weak pockets or cavities and, thus, estimate the overall and differential settlement..

c) When structures and instrumentation to be supported ar terribly sensitive to differential settlement.

d) Where structures naturally lend themselves for the employment of foundation like silos, chimneys, water towers, etc, *etc*.

e) Floating foundation cases whereby soil has terribly poor bearing capability and therefore the weight of the super-structure is planned to be balanced by the burden of the soil removed.

f) Buildings wherever basements ar to be provided or pits set below well water table..

Buildings wherever individual foundation, if provided, are subjected to massive wide varied bending moments which can lead to differential rotation and differential settlement of individual footings inflicting distress within the building. allow us to currently examine every of the higher than things in larger detail. just in case of soil having low bearing pressure, use of foundation offers three-fold advantage::

a) ltimate bearing capability will increase with increasing dimension of the muse delivery deeper soil layers in the effective zone.

b) Settlement decreases with inflated depth.

c) Raft foundation equalises the differential settlement and bridges over the cavities. each structure features a limiting differential settlement that it will endure while not injury. The quantity of differential settlement between numerous elements of a structure supported on a raft /amat foundation is way less than that if an equivalent-structure was supported on individual footings and had undergone the same quantity of most settlement. With these issues, most total settlement which may be allowed for a specific structure on raft

/ mat foundation is quite what's allowable once the structure is resting on individual footings. This, therefore, permits the next bearing capability for such things.

Basically 2 approaches are steered for analysing the behaviour of raft foundation:

1.) Rigid Rigid foundation approach

2.) Flexible Flexible foundation approach

4.2 Rigid Rigid Approach

In rigid foundation approach, it's likely that raft is rigid enough to bridge over non-uniformities of soil structure. Pressure distribution is taken into account to be either uniform or variable linearly. style of rigid raft follows standard strategies wherever once more following 2 approaches are suggested:-

1) Inverted floor system

2) Combined footing approach

n rigid rafts, differential settlements ar relatively low however bending moment and shear forces to that raft is subjected ar significantly high.

4.3 Flexible Approach

In aflexible foundation approach, raft is taken into account to distribute load within the space in real time encompassing the column relying upon the soil characteristics. during this approach differential settlements square measure relatively larger however bending moments and shear forces to that the raft is subjected square measure relatively low. Analysis is usually recommended primarily on 2 theories:-

a) Flexible a versatile plate supported on elastic foundation, i.e., aHetenyi's Theory

b) Foundation supported on bed of uniformly distributed elastic springs with a spring constant determined victimisation constant of sub-grade reaction.aEach spring is probable to behave inde-pendently, i.e., aWinklers's foundation..

Based on these 2 basic approaches,amethods recommended embody simplified strategies subject to bound limitations which may be applied by manual computation. conjointly currently accessible square measure laptop based mostly strategies like finite part and finite variations strategies. AFinite variations methodology relies on the second approach of uniformly distributed elastic springs and may contemplate one worth of sub-grade modulus for the complete space.

Finite part methodology transforms theaproblem of plates on elastic foundation into a laptop directed methodology of matrix structural analysis.aIn this methodology, plate is idealized as a mesh of finite parts inter-connected solely at the nodes (acornersa), and also the soil could also be modelled as a collection of isolated springs or as associate degree elastic isotropic 0.5 house. aThe matrix structural analysis may be extended to incorporate the influence of the super-structure in addition. aThus, the interaction between the super-structure, the inspiration and also the soil may be accounted for. it's doable to think about completely different values of subagrade modulus in several areas of the base.

.

n case of heaped-up rafts against the standard assumption of entire load being carried by piles alone, stress is currently being set on sharing of load between raft supported on soil, i.e., raft soil system and raft pile system. Sufficiently correct strategies for sensible distribution of those hundreds aren't nonetheless accessible.

As a simplification of treating the complete raft as a plate, thought of beam on elastic foundation is additionally being employed. For this purpose raft is taken into account to contains beams in each the directions.aEach of those beams is treated as supported on springs having spring constant calculated victimisation modulus of subagrade reaction and carrying column hundreds. aThe beam is then analysed as a beam on elastic foundation.

Parameters for Raft Design

In all these strategies, ahowever, 3 basic parameters, i.e.,arigidity of the raft,apressure distribution underneath the raft and worth of subagrade modulus become vital additionally to no matter alternative data is received from soil investigation report.aThese 3 parameters and methodology of their determination square measure mentioned in subsequent paragraphs..

4.4 Pressure Distribution Under the Raft

A problem that should be solved whereas coming up with a base is to judge the particular contact pressure of the soil against the raft. AThis downside has occupied several researchers on paper and a lesser range by experimentation with no actual values being renowned.AContact pressure, settlement of foundation, thusil charac¬teristics and its behaviour square measure most inter-related and their relationship so complicated, that soil foundation astructure interaction isn't clear even currently.aConsidering of these aspects it may be aforesaid that the contact pressure distribution underneath the raft depends upon:

1 .)aThe nature of the soil below the raft, i.e., one homogeneous mass or a superimposed formation, thicknesses of varied layers and their relative locations

2.)a Properties of the soil

3.)aThe nature of the inspiration, i.e., whether or not rigid, versatile or soft

4.)a Rigidity of the super-structure

5.) aThe quantum of hundreds and their relative magnitude

6.)aPresence of conterminous foundation .

(7) aSize of raft

(8) Time at that pressure measurements square measure taken the overall settlement underneath the raft foundation may be thought of to be created of 3 elements, i.e.,

aS = Sd+ Sc + Ss

where aSd is that the immediate or distortion settlement, aSc the consolidation settlement and aSs is that the secondary compression settlement.

The immediate part is that portion of the settlement that happens simul¬-taneously with the load application, primarily as distortion at intervals the inspiration soils. The settlement is mostly not elastic though it's calculated victimisation elastic theory. The remaining elements result from the gradual expulsion of water from the void and corresponding compression of the soil skeleton. the excellence between the consolidation and secondary compression settlement is created on the premise of physical method that management the time rate of settlement. Consolidation settlements square measure mostly owing to primary consolidation {in that|during which|within which} the time rate of settlement is controlled by the speed at which water may be expelled from the void areas within the soil.

he asecondary compression settlement, athe speed of settlement is controlled mostly by the speed at that the soil skeleton itself yields and compresses. aThe time rate and also the relative magnitude of the 3 elements take issue for various soil varieties. Water flows thus pronto through most clean granular soil that the expulsion of water from the pores for all sensible functions is instant and therefore foundation settles nearly at the same time with the applying of load. own cohesive soil, it takes considerable time for water to flee and therefore settlement in cohesive soils continue for much longer. In fact, it's been reportable that the pressure underneath a raft /mat foundation on clay could vary from time to time.

It is usual to assume that the soil below the inspiration is associate degree isotropic uniform material for its entire depth. touch unremarkably this is often not the case and that we get completely different layers in varied thickness, having completely different properties below foundation. If the thickness of the higher most layer is giant relative to the dimension of the loaded space, it might in all probability be ample if the soils were thought of as a uniform layer of indefinite depth. However, if the higher stratum is comparatively skinny ignoring the impact of layering, it's going to have associate degree considerable influence on the contact pressure distribution and consequently settlements. this is often seemingly to be of special importance once a compressive stratum is underlain by rock or a awfully onerous or dense soil. Such presence decreases the settlement significantly.

It is terribly important once this happens at intervals a depth adequate breadth of the footings. Incase, there's a stiff stratum underlain by a soft stratum like layer of sand over soft clay layer, impact is negligible if depth is bigger or adequate three.5 b2.In case of raft, dimensions of raft square measure typically such the probabilities of encountering a unique soil layer at intervals the many depth square measure quite giant and per se it might be necessary to account for the various soil layers at intervals the many depth. what is {more} it's to be remembered that properties of soil constituting every layer that confirm the shear strength charac¬teristics and settlement characteristics of the soil become more vital as rafts square measure typically adopted in square measureas wherever soils of poorer varieties are encountered and that some years past might need not been preoccupied for construction in the least..

Effect of groundwater table is considerable on the load carrying capability of the soil and consequently settlements. It is, therefore, necessary to think about the expected spring water table in life time of the structure together with the temporary rises as throughout floods. Even in areas wherever sub-soil formation isn't gift, it's necessary to think about future engineered up water for style of basement and base. If porousness constant of the soil is below zero.1 millimeter per second, soil is cohesive and chance of surface water accumulated against basement walls exist. In such things, it's going to be necessary to style raft foundations of basement for water uplift conjointly.

The conventional analysis of footings, in general, uses the thought of a rigid footings and with rigid footing square measure associated the thought of uniform soil pressure. really to own a homogenous soil pressure distribution, we tend to need a awfully versatile footing..

The conventional analysis of footings, in general, uses the thought of a rigid footings and with rigid footing square measure associated the thought of uniform soil pressure. really to own a homogenous soil pressure distribution, we tend to need a awfully versatile footing.

If at the same time we tend to settle for the thought of soil being elastic (modulus of physical property or constant of sub-grade modulus), settlement of rigid footing are uniform which for a versatile footing the settlement would be non-uniform and however if this is often be} the case then however can the contact pressure be uniform (under a rigid footing). really we've got a soil structure interaction downside and there's a non-uniform soil pressure and differential settlements at intervals the footings.

It has been recommended that just in case of sq. footing resting on clay on the average contact pressure of zero.6 P/A with further zero.1 P/A on edges would be affordable pressure distribution. For an oblong footing of huge length it's recommended that it might be affordable to own a median pressure adequate zero.8 P average + zero.1 PIB for the sides. Here P is total load, A, area and B, length of the footing..

Rigidity of foundation gets changed by the rigidity of super-structure. Arigid super-structure won't enable differential settlement to require place in foundation. scenario will arise once a specific column of the building could also be hanging from the super-structure and even sending the load of hooked up soil mass to the super structure instead of sending any load from the super-structure to the inspiration soil. In fact, a rigid foundation with a rigid super structure means that less differential settlement, giant variation of contact pressure and high bending and shear stress in foundation members. {a versatile|a versatile} foundation with flexible super structure means that giant differential settlements, uniform contact pressure and lower values of bending and shear stresses in foundation members..

Quantum of hundreds and their relative magnitude have an effect on the contact pressure. once the hundreds square measure thus high that bearing pressures square measure exaggerated to the purpose of shear failure within the soil, the contact pressure is modified resulting in a rise in pressure over the centre of the loaded space all told cases.

The consolidation pressure involves expulsion of water from the soil being compressed. This takes time and at any time between the applying of the load manufacturing consolidation and also the time at that basically final or one hundred per cent consolidation has occurred, the measured settlements and consequently contact pressure distribution would differ. again and again it's going to take many years to attain final settlement.

There square measure things in engineering follow wherever footings square measure placed thus near one another that their zones of influence overlap. Studies have shown that impact of adjacent footings could vary significantly with angle of cutting off resistance. For low values they're negligible. For higher values they seem to be important significantly if footing is encircled by others on all sides. There square measure much no effects just in case of punching shear failure. it's typically suggested that interference impact could also be neglected.

footings could vary significantly with angle of cutting off resistance. For low values they're negligible. For higher values they seem to be important significantly if footing is encircled by others on all sides. There square measure much no effects just in case of punching shear failure

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view of various factors affecting the pressure distribution under a raft foundation and difficulties in determining affect of each, it is generally believed that contact pressure distribution under a raft could be of the following type as shown in Fig. 5.1.

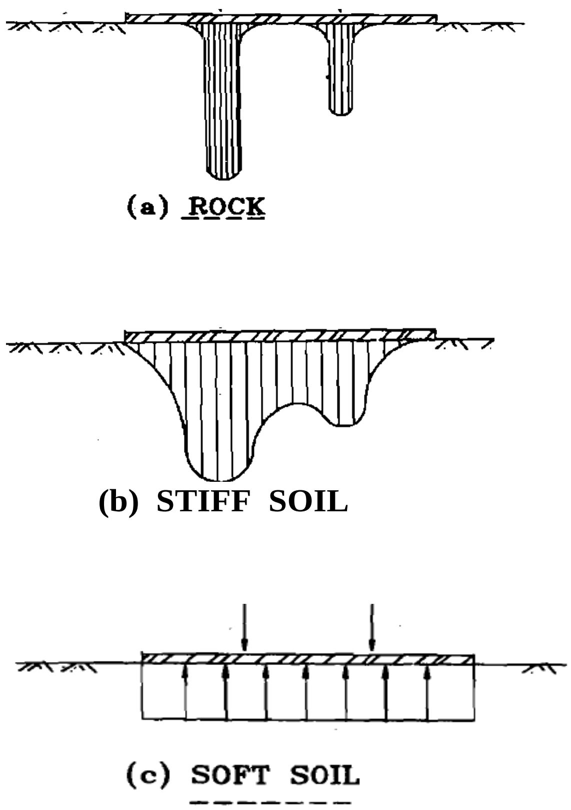


Fig. 4.1 Contact pressure distribution under a raft

Fig. 5.1 (a) is applicable when the raft /matis supported on hard rock and column loads are transmitted to the rock on areas of relatively small size directly under the columns.

If the raft rests on a stiff dense soil, then loads are distributed to the sub-soil in relatively large areas, as shown in Fig. 4.1 (b).

It is solely on terribly soft soils that the contact pressure against the raft /matfoundation approaches linear distribution as shown in Fig. 4.1 (c).

Therefore, it's normally even to style a raft /ma ton mud, soft clay, peet or organic soil by the traditional rigid methodology victimisation uniform pressure. really assumption of rigid footings with uniform soil pressure leads to planning the raft for assumed bending moments that area unit larger than the particular bending moments. The ensuing style is conservative typically however might not be economica.

Therefore, it's normally even to style a raft /ma ton mud, soft clay, peet or organic soil by the traditional rigid methodology victimisation uniform pressure. really assumption of rigid footings with uniform soil pressure leads to planning the raft for assumed

4.5 Rigidity Criteria

Whether a structure behaves as rigid or versatile, it depends on the relative stiffness of the structure and therefore the foundation soil. The behaviour of the muse as rigid or versatile will rely on the rigidity of the super-structure on top of and properties of soil below. In physical terms, a rigid foundation would mean a foundation that is capable of bridging over pockets of soil with totally different properties and so attempt to even out the settlements at numerous points. A rigid foundation would, therefore, have relatively lower values of differential settlement however higher values of stresses. A rigid foundation with a rigid super-structure on a relatively compressible soil can lead to uniform settlements of structure..

A flexible foundation with a versatile super-structures and a relatively rigid soil below can behave as a versatile foundation and would lead to giant differential settlements and low stresses. Thus:

(i) (i) A rigid member is defined by high bending moments and comparatively tiny, uniform deflections. Over all differential settlements area unit tiny.

(ii) associate degree intermediate member, because the term implies, has intermediate bending and deflection value.

(iii) The versatile member has relatively smaller bending moments and deflection is most in neighborhood of the masses and tiny values elsewhere. Overall differential settlement would be of upper orders..

<u>Rigidity criteria proposed by various authorities are discussed below:</u>

4.6 Determination of the Rigidity of the Structure

The flexural rigidity EI of the structure of any section may be estimated according to the relation given below (see also Fig. 5.2):

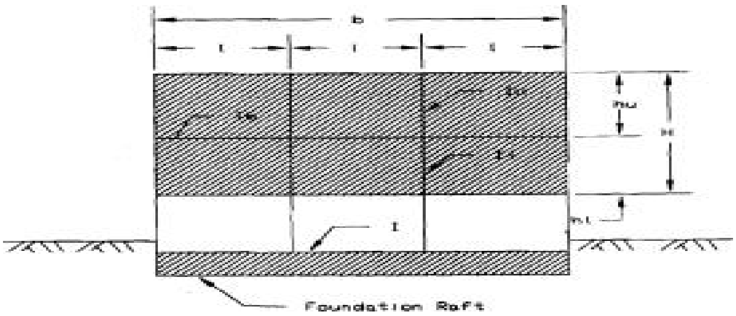


Fig. 4.2 Determination of rigidity of a structure

Proposed by IS: 2950 (Part I) 1981

$$EI = \frac{E_l I_l}{2H^2} \sum E_2 I_b \left(1 + \frac{(I''_u + I'_l)b^2}{(I''_b + I'_u + I'_l)l^2}\right) \qquad 4.1$$

where E_s = modulus of elasticity of the infilling material (wall material) in kg/cm ,

/, = Moment of inertia of the infilling in cm^4,

b = length or breadth of the structure in the direction of bending.

H = total height of the infill in cm,

E_2 - modulus of elasticity of frame material in kg/cm^2

I_b - moment of inertia of the beam in cm^4

$$I'_u = \frac{I_w}{H_u} \qquad 4.1a$$

$$I'_t = \frac{I_t}{h_t} \qquad 4.1b$$

$$I'_b = \frac{I_b}{l} \qquad 4.1c$$

where

I = Spacing of columns in cm,

h_u — Length of upper column in cm,

h_l = Length of lower column in cm,

$$I'_f = \frac{I_f}{l} \qquad 4.1d$$

I_u = Moment of inertia of upper column in cm^4,

I_l = Moment of inertia of lower column in cm^4

I_f = Moment of inertia of foundation beam or raft in cm^4,

Relative Stiffness Factor K:

I Whether a structure behave as rigid or flexible depends on the relative stiffness of the structure and the foundation soil. This relation is expressed by the relative stiffness factor K given below:

(a) For the whole structure

$$K = \frac{EI}{E_3 b^3 a}$$

(b) For rectangular rafts or beams

$$K = \frac{E}{12E_3}(\frac{d}{b})^3$$

(c) For circular rafts

$$K = \frac{E}{12E_s}(\frac{d}{2R})^3$$

where

El = Flexible rigidity of the structure over the length (a) in kg/cm^2

E_s = Modulus of compressibility of the foundation soil in kg/cm^2

b = Length of the section in the bending axis in cm,

a = Length perpendicular to the section under investigation in cm,

d = Thickness of the raft or beam in cm,

R = Radius of the raft in cm

4.7 Modulus of Sub-Grade Reaction

One of the vital terms needed in analysing foundation on the premise of versatile footings is worth of modulus of sub-grade reaction conjointly referred to as constant of sub-grade reaction for the actual soil within the foundation of the buildings. Mathematically, this will be axpressed as intensity of soil pressure needed to make a unit deflection. in theory, it are often determined by activity a plate load take a look at and plotting a curve of soil pressure versus deflection. In actual apply, however, several different factors enter and actual worth in field is totally different from what are often determined by an easy plate load take a look at. Major issues associated are:

(a) Soil isn't absolutely elastic and results area unit settled by the magnitudes of soil pressure and deflection
(b) Footing size affects the worth
(c) Footing form conjointly affects
(d) Depth at that footing is found conjointly affects
(e) Soil stratification and different changes with depth which can not show once testing with atiny low plate
(f) In ways wherever soil modulus is decided in laboratory, website condition can-not be specifically duplicated in field laboratory
(g) Various authors have urged various factors to require these issues into consideration account

On the other hand, certain authors have suggested very simple values for modulus of sub-grade reaction which can be determined from bearing capacity factors used in Terzaghi bearing capacity equation.

Recommended by Bowles :-

Has related value of modulus of sub-grade reaction with safe bearing capacity by the relation

$$K_s = 12\,(c.N_c.S_c) + 12\,(y.N_q.S_q)$$

K_s = 36 qa where qa is the allowable bearing capacity in Kips per sq ft. A slightly improved values are also suggested by the equation.

where c is cohesion, N_c and N_q are bearing capacity factors, S_c and S_q are shape factors for particular soil in foot units.

SI : $$K_s = 40\,(SF)qa\ kN/m^3$$

FPS: $$K_s = 12\,(SF)qa\ k/ft^3$$

where SF = Safety factor and qa is the allowable bearing capacity.

Soil	*Range of Ks. Kef*
Loose sand	30 - 100
Medium sand	60 - 500
Dense sand	100 - 800
Clayey sand (Medium)	200 - 500
Silty sand (Medium)	150 - 300
Clayey soil :	
$qu \leq 4$ Ksf	75 - 150
$4 < qu \leq 8$ *Ksf*	150 - 300
$8 < qu$	> 300

IS: 2950 Part I Indian Standard Code of Practice for Design and Construction of Raft Foundation 2950-1981 :-

Provision regarding determination of modulus of sub-grade reaction square measure enclosed in Appendix B (code). this is often reproduced below. Figures given in bracket in Tables I and II square measure in Kips/c foot. units.

Provision regarding determination of modulus of sub-grade reaction square measure enclosed in Appendix B (code). this is often reproduced below. Figures given in bracket in Tables I and II square measure in Kips/c foot. units.

The modulus of subgrade reaction (k) as applicable to the case of load through a plate of size thirty x thirty cm or between thirty cm wide on the soil is given in Table five.1 for cohesionless soils and in Table five.2 for cohesive soils. Unless additional specific determination of K is finished these values is also used for style of fundament in cases wherever the depth of the soil plagued by the dimension of the footing is also thought-about identical and also the extrapolation of plate load check results is valid..

Table 4.1 Modulus of Subgrade Reaction (K) for Cohesionless Soils

Soil Characteristic		*Modulus Of Subgrade Reactions (K) in kg/cm³*	
Relative Density	*Standard Penetration test value (N)*	*For dry or moist state*	*For submerged state*
(1)	*(2)*	*(3)*	*(4)*
Loose	*< 10*	*1.5 (95)*	*0.9 (57)*
Medium	*10 to 30*	*1.5 to 4.7 (95 to 300)*	*0.9 to 2.9 (57 to 185)*
Dense	*30 and over*	*4.7 to 18.0 (300 to 1146)*	*2.9 to 10.8 (185 to 687)*

** The above values apply to a square plate 30 X 30 cm or beams 30 cm wide*

Table 4.2 Modulus of Subgrade Reaction (K) for Cohesive Soil

Soil Characteristic		*Modulus of Subgrade Reaction (K) in Kg/cm³*
Consistency	*Unconfined compressive strength, kg/cm²*	
(1)	*(2)*	*(3)*
Stiff	*1 to 2*	*2.7 (172)*
Very stiff	*2 to 4*	*2.7 to 5.4 (172 to 344)*
Hard	*4 and over*	*5.4 to 10.8 (344 to 688)*

**** The values apply to a square plate 30 × 30 cm. The above values are based on the assumption that the average loading intensity does not exceed half the ultimate bearing capacity.***

Field Determination

n cases wherever the depth of the soil plagued by the dimension of the footing is also thought-about as identical the worth of K is also determined in accordance with IS: 9214 - 197920. The check shall be administered with a plate of size not but thirty cm

The average worth of K shall be supported variety of plate load tests administered over the realm, the amount and placement of the tests relying upon the extent and importance of the structure

IS:9214 - 1979 KS will be determined as slope of the secant drawn between the purposes like zero settlement and point like 1.25 millimetre settlement of a load settlement curve obtained from a plate load check on the soil employing a seventy five cm military intelligence plate or smaller military intelligence with corrections for size of the plate used

Laboratory Determination

For stratified deposits or deposits with lenses of various materials, analysis of K from plate load are going to be phantasmagorical and its determination shall be supported laboratory tests (see IS: 2720

(Part XI)-1972 and IS: 2720 (Part XII)-1981

In ending the check, the continued cell pressure is also thus elect on be representative of the depth of average stress influence zone (about zero.5 B to B).

The value of K shall be determined from the following relationship

$$K = 0.65 \sqrt[12]{\frac{E_s B^4}{EI}} \cdot \frac{E_s}{1 - \mu^2} \cdot \frac{1}{B}$$

E_s = Modulus of elasticity of soil

E = Young's modulus of foundation material

μ = Poisson's ratio of soil

I = Moment of inertia of structure of the foundation

In the absence of laboratory test data, appropriate values of E_s and I

When the structure is rigid, the average modulus of sub grade reaction may also be determined as follows:

K s = Average contact pressure / Average settlement of the raft.

Equation in above is based on work carried out by Vesic (1977) .

Bowles has observed that the 12th root of any value will be close to 1 and equation can be considered to be equivalent to

$$K_s = \frac{E_s}{1 - \mu^2}$$

and suggested that value of Ks can be calculated by the equation Ks = 36 qa where qa is allowable bearing capacity in kips per sq. ft.

I.S. 9214-1979 - Method of Determination of Modulus of Subgrade Reaction (k value) of Soils in Field :-

Modulus of sub-grade reaction is outlined as a quantitative relation of load per unit space (applied through a centrally loaded rigid body) of a surface of a mass of soil to corresponding settlement of the surface. it's determined because the slope of secant drawn between the purpose like zero settlement and also the points of one.25 millimetre settlement, of a load settlement curve obtained on a soil exploitation seventy five cm military intelligence or smaller loading plates with corrections for size of the plate..

he value of modulus of subgrade reaction thus determined is needed to be corrected for

a) once exploitation plates smaller than seventy five cm in military intelligence

b) correction for bending of the plate.

c) correction for saturation.

Average worth of k is to be supported variety of plate load tests administered over the realm, the amount and placement relying upon the extent and importance of the structure.

Final correction is needed to be applied for the dimensions of actual raft being totally different from plate..

Correlation Between SBC & Ks Recommendation :- Recommended by mr. Apurba Tribedi (Bentley Expert)

definition of Ks

which is that the pressure per unit settlement. So, in different words, soil capability to face up to pressure for a given displacement. From earlier discussions, it's additionally clear that even bearing capability has associate degree allowable settlement. So, it's tempting to conclude that modulus of subgrade reaction is that the bearing capability per unit settlement..

For a people unit system it's usually expressed in kip/in2/in and in metric system in kN/m2/m. Some usually expresses this term in kip/in3 (or kN/m3) that may well be dishonest . Numerically kip/in3 is correct however doesn't properly represent the physical significance of the measured worth and it may well be mistaken

as density unit or a volumetrical mensuration

Mathematically, the constant of subgrade reaction is expressed as

$$K_s = \frac{p}{s}$$

where p = contact pressure intensity and s = soil settlement

This term is measured and expressed as load intensity per unit of displacement..

As Terzaghi mentioned, correct estimation of contact pressure for a versatile foundation might be terribly cumbersome, thus it is assumed that American state remains constant for the entire footing. In other

words, the quantitative relation between pressure and settlement at all locations of a footing can stay

constant. thus the displacement diagram of a footing with a load at center can have a dishing effect. A purpose at the center of the footing can expertise the highest displacement.. A point at the center of the footing will experience the highest displacement.

The most common and possibly safestanswer is that there's no correlation. however there ought to be one,as each square measure the measurements of soil capacities and any of those 2 parameters are often wont to style a daily foundation.

Let us scrutinize the definition of American state once more,which is that the pressure per unit settlement. So,in different words,soil capability to face up to pressure for a given displacement. From earlier discussions,it's also clear that even bearing capability has associate degree allowable settlement.So,it's tempting to conclude that modlus of subgrade reaction is that the bearing capability per unit settlement.

SI : $K_s = 40\ (SF)qa\ kN/m^3$

FPS: $K_s = 12\ (SF)qa\ k/ft^3$

where SF = factor of safety and qa is that the allowable bearing capability.

In the on top of equations, the allowable bearing capability is initial reborn to final bearing capacity by multiplying with a security issue. assumed one in. or twenty five metric linear unit settlement..

The final equation is then developed dividing the final word bearing capability by the assumed settlement.

The more generic form of the equation can be written as:

$$K_s = \frac{Iqa}{\delta} = stress/displacement$$

I = factor of safety, qa is that the allowable bearing capability is that the allowable soil settlement.

From on top of equations, it's evident that the acceptable factor of safety should be used and therefore the American state worth are often higher compared the allowable bearing capability.

The safety issue will vary looking on comes and geotechnical engineers. the opposite necessary issue is that the assumed allowable settlement for the calculated bearing capacityHowever the on top of mentioned equations have its limitations. It are often applied to the footings wherever settlement failure governs however can not be associated with the footings wherever shear failureoccurs before reaching allowable settlement limit. So, Engineers should exercise caution -before victimisation these equations..

Finally We use the generic Equation in calculation of modulus of sub-grade Reactions.

This is suggested by Mr. Apurba Tribedi (Bentley Expert).

4.8 Structural design Methods

The structural design of mat foundations must satisfy both strength and serviceability requirements.

Design Step (a):

Evaluate the strength needs result from the load mixtures and LRFD style strategies (which ACI calls final strength design). The mat/raft should have a sufficient thickness, T, and reinforcement to satisfy resists these masses. like unfold footings, T ought to be massive enough that no shear reinforcement is required..

Design Step (b):

Evaluating mat deformations (which is that the primary usefulness requirement) victimisation the unfactored masses. These deformations square measure the results of targeted loading at the column locations, attainable non-uniformities within the mat, and variations within the soil stiffness. In effect, these deformations square measure the equivalent of differential settlement. If they're excessive, then the mat should be created stiffer by increasing its thicknes.

CHAPTER 5 PILED RAFT FOUNDATION

PILED RAFT FOUNDATION :-DESIGN APPROACH

5.1 Design Approach

The usual apply of style being followed is to figure out preliminary sizes of the raft, i.e., thickness of the slabs, if it's uniformly thick raft or beam size and block thickness just in case it's beam and block system on the premise of shear and analyse the raft for vertical masses alone. As associate improvement wherever laptop facilities and larger experience area unit on the market, raft is analysed as versatile raft choosing one specific price of modulus of subgrade reaction, one assumed size of the raft and vertical masses alone. Values of bending moments so obtained area unit used. In each these styles unless the preliminary sizes elect area unit found to be structurally unsafe in resisting moments and shears, even once addition of permissible reinforcement, the planning is completed and finalised. As already acknowledged in previous chapters the important position isn't thus easy.

Different designers might choose totally different preliminary sizes, totally different values of modulus of sub grade reaction even for a similar soil, and pattern of pressure distribution beneath the raft. In actual buildings, columns have base moments that area unit resisted by the junction of the raft and therefore the columns. Buildings subjected to earthquake forces haven't solely increased column base moments however additionally endure cyclic result within which vertical masses in numerous teams of columns decrease and increase. Studies have, therefore, been dispensed to contemplate on the planning of fundament the result of neglecting a number of these aspects and creating assumptions that in truth don't seem to be true. These studies are dispensed in four components.

n subtle versatile analysis, utilising laptop, it's soil properties that relate an oversized extent. In actual analysis all soil properties matter, however in usually adopted analysis wherever soil-raft interaction is perfect as a spring of proverbial rigidity most significant soil property is modulus of sub-grade reaction. The rigidity of raft that is set by the dimensions of the raft and result of super-structure on a similar, is another very important parameter that comes into play in any analysis. The result of variation in values of each these parameters on the worth of bending moments and shear forces, one gets on associate analysis, has been studied during this study. Effects has been created to gift results, in numerical values and show the massive variation that, one will get for a similar structure, having a specific loading pattern based on a similar soil once totally different sizes of raft or values of modulus of sub grade reaction determined by varied strategies on the market in literature area unit adopted

While ending this study, solely vertical masses and earth Quake masses are thought-about. Contribution created by super structure within the rigidity of raft has been neglected..

5.2 Design Procedures being Used

Rafts supported on piles square measure being more and more used for multi-storeyed buildings with basements in poor soils with high water level conditions. The piles square measure necessary to transmit the super-structure masses to a deeper competent soil strata additionally the} raft is needed to transmit the column/wall masses equally to the piles and also to resist the buoyancy forces of the bottom water. Piles square measure generally wont to decrease the settlement of the raft. The raft as a solid medium integrated with the holding walls with necessary water proofing layer additionally is a water proofing medium..

The analysis of concentrated raft could be a complicated downside even over that of a soil supported raft as too several parameters influence the behaviour of the system. little or no is thought regarding the precise behaviour of concentrated raft foundations in commission. the matter is to be understood by considering the composite behaviour of the whole system, viz., super-structure, sub-structure, raft, piles and also the soil medium. These factors influence sharing of load between piles and raft, between piles themselves and consequently the settlements, shears and moments within the raft..

For style of concentrated raft, completely different practices square measure followed by varied designers. simplest methodology followed is that the standard rigid approach, whereby the raft is assumed to be rigid. Piles square measure uniformly distributed throughout the raft and a flat distribution of pressure is taken into account on the raft owing to the piles. As a variation of this methodology, some designers attempt to concentrate additional pile underneath the heavily loaded columns as compared to gently loaded columns forward that it'd provides a higher uniform distribution on the piles. In another approach individual pile caps below every column square measure provided and square measure connected either by a block of the thickness adequate that of the pile cap or of a lesser thickness, neglecting the result of 1 pile cap on the opposite. wherever laptop facilities square measure on the market, some designers use the construct of beam on elastic foundation. Here once more varied ways square measure on the market.

Some designers assume the same distribution of load on piles substitution the piles by a soil medium having a hypothetic bearing capability. K price reminiscent of this bearing capability is chosen and used for analysis. As more improvement to the present methodology, raft is taken as a plate supported on springs.

The properties of the spring square measure determined relying upon the kind and elastic properties of the piles neglecting the result of 1 pile on the opposite and completely different soil layer on one another. result of 1 pile on another and completely different soil layers also can be thought-about. this can be worn out laptop programmes whereby the spring substitution piles square measure coupled each horizontally and vertically which means that the deflection of any spring is stricken by adjacent springs. The raft /matsuper-structure inter-action is sometimes neglected. None of those ways take under consideration the result of the soil foundation interaction except to the restricted extend mentioned in every of the tactic higher than. Sharing of masses between piles and raft soil system has additionally been advised and followed by some. However, there are not any sensible ways on the market for figuring out this extent of sharing..

Poulos' has steered a technique, however it's applicable for piles but forty in range and makes assumptions that area unit arguable. There has additionally been a observe of planning the foundation for vertical masses alone excluding the impact of column base moments or the impact of horizontal load,, earthquake and wind. altogether these analysis, thickness of the raft and therefore the safe load carrying capability of the pile is set before hand. In beam on elastic foundation idea the rigidity of the raft plays a awfully vital role and, therefore, the probable thickness of the raft affects final shears and bending moments within the raft and therefore the masses on the piles. No effort is, however, usually created to quantify this impact and optimise the thickness of the raft.

In this study, impact of rigidity of the raft, i.e., thickness elite, the impact of construction rigidity, variation in column masses and base moments thanks to earthquake and therefore the kind of piles, on pile masses and raft moments, has been calculated and studied.

5.3 Methods of Analysis Studied

In this study the following methods have been adopted :

(a) Conventional rigid method with simplified models as
   (i) Combined footing approach
   (ii) Continuous beam analogy or inverted floor

(b) Using finite element approach

Conventional Rigid Method with Combined footing approach

The forceful simplification adopted during this model is that the closely spaced piles, (spacing nearly adequate or but the raft thickness) are often approximated as a bed of equivalent soil strata. The raft is analysed by typical rigid approach mistreatment easy statics with none thought for the elastic properties of the raft and therefore the soil. Here the raft is perfect as an oversized beam member severally in each the direction. The row of column masses perpendicular to the length of the beam area unit clubbed along as single column load. Then for these famed column masses performing on the beam the upward soil pressure is decided and therefore the moments and therefore the shears at any section is decided by easy statics. Then the instant per unit dimension of the raft is decided by dividing the instant values by the corresponding dimension of the section.

5.4 Piled Raft Analysis Based on Finite Element Approach

A a lot of subtle methodology of study models the entire system, viz., the super-structure, raft, piles and soil medium with acceptable finite component varieties and do the analysis by considering the interaction between these parts. In such analysis, the construction is modelled as a 3 dimensional house frame, the raft discretised as plate bending parts, piles as compressible elastic axial parts. The supporting soil is treated as consisting of various layers of undiversified linear elastic material with corresponding coefficient of elasticity determined with respect to soil properties. commonly the soil medium is discretised into variety of rectangular prism parts. This generalised approach needs huge process efforts, time intense and quite pricy and therefore can't be utilized in traditional style observe.

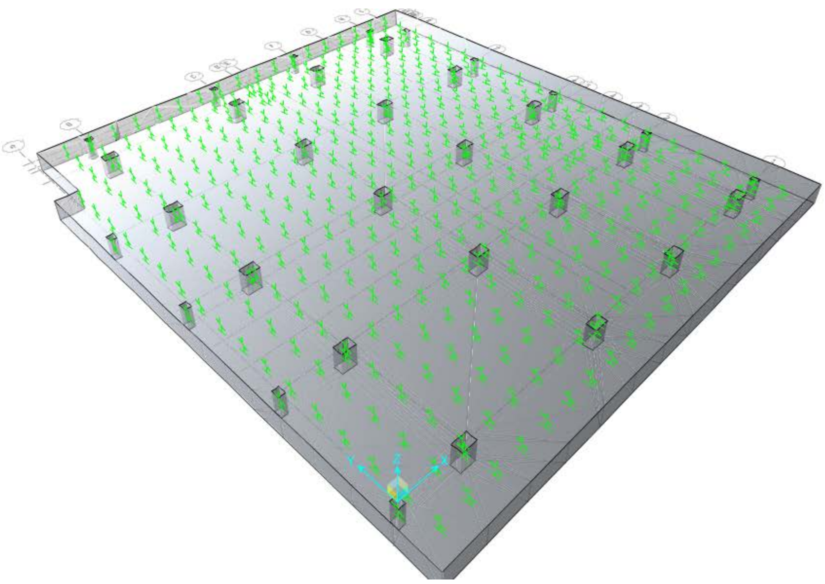
However, simplified versions of finite component approach area unit normally adopted with the employment of computers. during this study a general purpose 3 dimensional finite component package (SAFE) Structural Analysis Package) has been used. within the gift case of heaped raft, the raft has been modelled as plate bending parts and therefore the piles area unit modelled as axial parts. The piles being preponderantly resistance piles, as suggested by Bowles and Teng the axial stiffness of the pile component has been taken as EA/Le wherever E is that the modulus of snap, A is space of cross section of the pile and autoimmune disorder is that the effective length of the pile. No exclusive modelling of the soil medium has been done, though the confining impact of soil on the resistance piles is taken into account by considering the effective length of the pile as 0.5 the length of the pile

.

Similarly, no separate modelling of the superstructure has been done. However, its stiffness contribution on the overall behaviour of the system has been approximately considered as discussed subsequently. The raft is considered to be entirely supported on the piles and do not have any soil support underneath. This is particularly true in the present case where the building is located in a pond.

CHAPTER 6

CASE STUDY & RESULT



The problem is studied by considering a true building with concentrated raft with associate eight storied. the complete building contains a basement and contains a Appx. sq. - formed arrange. The basement is to accommodate station, air-con plant, stores etc.

The foundation is planned to be supplied with concentrated raft with overall dimensions as shown in Fig. 7.27. There would be planned 395 bore cast-in-situ piles. The piles area unit preponderantly friction DUR piles of forty cm diameter and ten.5m length. The thickness of raft thought-about is one.350 m.

6.1 Geo Technical Investigation report

The primary object of sub soil investigation is to work out the physical Properties of the soil beneath lying within the varied strata, facilitate within the planning the foundation ,safe and economical. Soil sample were collected at totally different depth and field check were disbursed from bore hole and therefore the soil stratum is bestowed in the form of bore log sheet. Disturbed and undisturbed soil samples were collected and located out the different properties by relevant tests in keeping with IS code of practices..

Scope of Investigation :-

The scope of labor enclosed drilling of twoborehole at such location by the project accountable were done. Soil sample at1.5m depth interval were collected for testing within the laboratory. check information weregives the result to determine the advice the sort of foundation as wellas Safe Bearing capability of S-oil at sure depth.

.Analysis of foundation

Foundation analysis square measure supported the shear failure and settlement Criteria forobtaining the worth of SBC at the foundation level of structural foundation .Considering the dimension of foundation additionally as depth of foundation for safeand economical. Depth and size were thought of as per service load and zonal resistance for earth quake

Type of foundation:-

Pile/raft combination [at 2.5m depth b.g.l.]Pile length= 10.5m [service load] Dia= 400mm.

Raft Foundation: - NET SBC 7.5(T/M2)

Depth (m)	Size of Raft Foundation		Allowable Settlement(mm)
	5m x 5m		
2.5m	7.5 t/m^2		40 mm

Pile Foundation :- Safe pile Capacity - Bearing [T] [FOS=3-FOR PILE] =Q/FOS

Safe Pile Capacity:- (T) at depth [Dia of pile=400mm]

DEPTH[M]	CAPACITY [T]	**FOS**
DEPTH=**7.5m**	SUR- 18.28[T]	[3.0]
	DUR- 27.45[T]	[3.0]
DEPTH=10.5M	SUR- 23.79[T]	[3.0]
	DUR- 31.52[T]	[3.0]

The raft cum pile foundation is recommended after considering allthe investigation such as soil profiles , SPT values, width of foundation,shear strength, angle of internal friction, at 2.5m depth. with water co rrectionfactor and factor of safety (F.O.S. = 2.5).

Percolation of ground water may cause effect during foundation.

The safe bearing capacity of proposed tower is recommended as 7.5 t/m2at a depth below existing gro und level.= 2.5 m

6.2 Building Modelling in Etabs

This style basis report contains the fundamental options, assumptions and provisions to be thought of for the structural style and description of the project. The planned show space building consists of single block, this is often Four level building with Basemet. The planned structure is rcc framed structure with beam block system.

The structural styles can cater to the subsequent needs. :

1) Safety, Economy and usableness,

2) Construction ease

3) Aesthetics as per beaux arts wants

4) Durability

The structural system adopted for the buildings is that the area frame. The structural system for the building would have adequate resistance to vertical hundreds (Dead hundreds, obligatory Loads) and lateral hundreds (seismic loads) for the applicable seismal zone IV.

The building shall be designed for earthquake importance clotting factor =1.0 because the building is business building. The building shall be designed with Bynamic Analysis methodology of study on ETabs nonlinear 15.1.1 code.

IS code references

1. IS 875:1987 Part (I) code of practice for design loads (Other than Earthquake) for buildings and structures.
2. IS 456:2000 Code of practice for Plain and Reinforced concrete
3. IS 1893 (part 1):2002 Criteria for Earthquake resistant design of structures. General provisions and Buildings.
4. IS 4326- 1993 Code of practice for Earthquake Resistant design and construction of buildings
5. IS 13920:1993 Code of practice for Ductile Detailing of Reinforced Concrete structures subjected to seismic forces
6. IS 1904 Code of practice for design and construction of foundations in soils.
7. IS 2950 Code of practice for design and construction of Raft foundations.
8. SP 34 (S&T) Hand book on concrete reinforcement and detailing.
9. SP 16 Handbook on Design Aids for Reinforced concrete.

Seismic forces as Per IS 1893-2002

Earthquake Zone : IV,

Zone factor (Z) = 0.24

Importance factor (I) = 1.0

Load combinations for analysis and design:

1. 1.5 (DEAD LOAD + LIVE LOAD)
2. 1.0 (DEAD LOAD + LIVE LOAD)
2. 1.5 (DEAD LOAD + SEISMIC LOAD (X) DIRECTION)
3. 1.5 (DEAD LOAD + SEISMIC LOAD (Z) DIRECTION)
4. 1.5 (DEAD LOAD - SEISMIC LOAD (X) DIRECTION)
5. 1.5 (DEAD LOAD - SEISMIC LOAD (Z) DIRECTION)
6. 1.2 (DEAD LOAD + LIVE LOAD + SEISMIC LOAD (X) DIRECTION)
7. 1.2 (DEAD LOAD + LIVE LOAD + SEISMIC LOAD (Z) DIRECTION)
8. 1.2 (DEAD LOAD + LIVE LOAD - SEISMIC LOAD (X) DIRECTION)
9. 1.2 (DEAD LOAD + LIVE LOAD - SEISMIC LOAD (Z) DIRECTION)
10. 0.9 DEAD LOAD+ SEISMIC LOAD (X) DIRECTION *1.5
11. 0.9 DEAD LOAD + SEISMIC LOAD (Z) DIRECTION *1.5
12. 0.9 DEAD LOAD - SEISMIC LOAD (X) DIRECTION *1.5
13. 0.9 DEAD LOAD - SEISMIC LOAD (Z) DIRECTION *1.5

Structural System

1) The building structure shall be designed as framed structure.

2) Structural Members shall be designed as per '**Limit State Method'** of design.

3) The Grade of concrete used for **M25** for Beam/Slab and M30 For Column work.

4) All Reinforcing steel to be used in R.C.C. works shall be Grade
Fe 500 conforming to IS 1786.

5) The bearing capacity for the design of foundation, shall be considered as per soil report.

Building Modelling Details

The superstructure is first analysed in ETABS 15.1.0 Software and the following design parameters are to be considered i.e.

Dead load FF	=	1.5 kN/m2
Live load	=	3.0 kN/m2
Partition Load	=	1.0 kN/m2
Water load	=	10 kN/m2
9" Wall Load	=	16 kN/m
4.5" Wall Laod	=	8 kN/m
Number of Story	=	Basement Plus 8 Storey
Total Height	=	32.65 m

Slab is modelled mistreatment rigid diaphragm and Earth-Quake Load is taken into account as per IS: 1893 (2002) with response reduction issue of five and Zone IV and 5% damping us provided.

The Building is analyzed for dynamic load mistreatment Response Spectrum methodology. The load combination square measure thought-about as per IS: 875 (Part5) for decilitre, LL, EQ loads. Twenty 5 % of obligatory load has been accounted on the burden for unstable weight calculation of building as per IS: 1893 (2002). the utmost prime Story Displacement for earth quake in X and Y direction square measure fourteen.7mm and 21.3mm severally..

Here is that the 3d model of construction that analyzed in ETABS computer Software

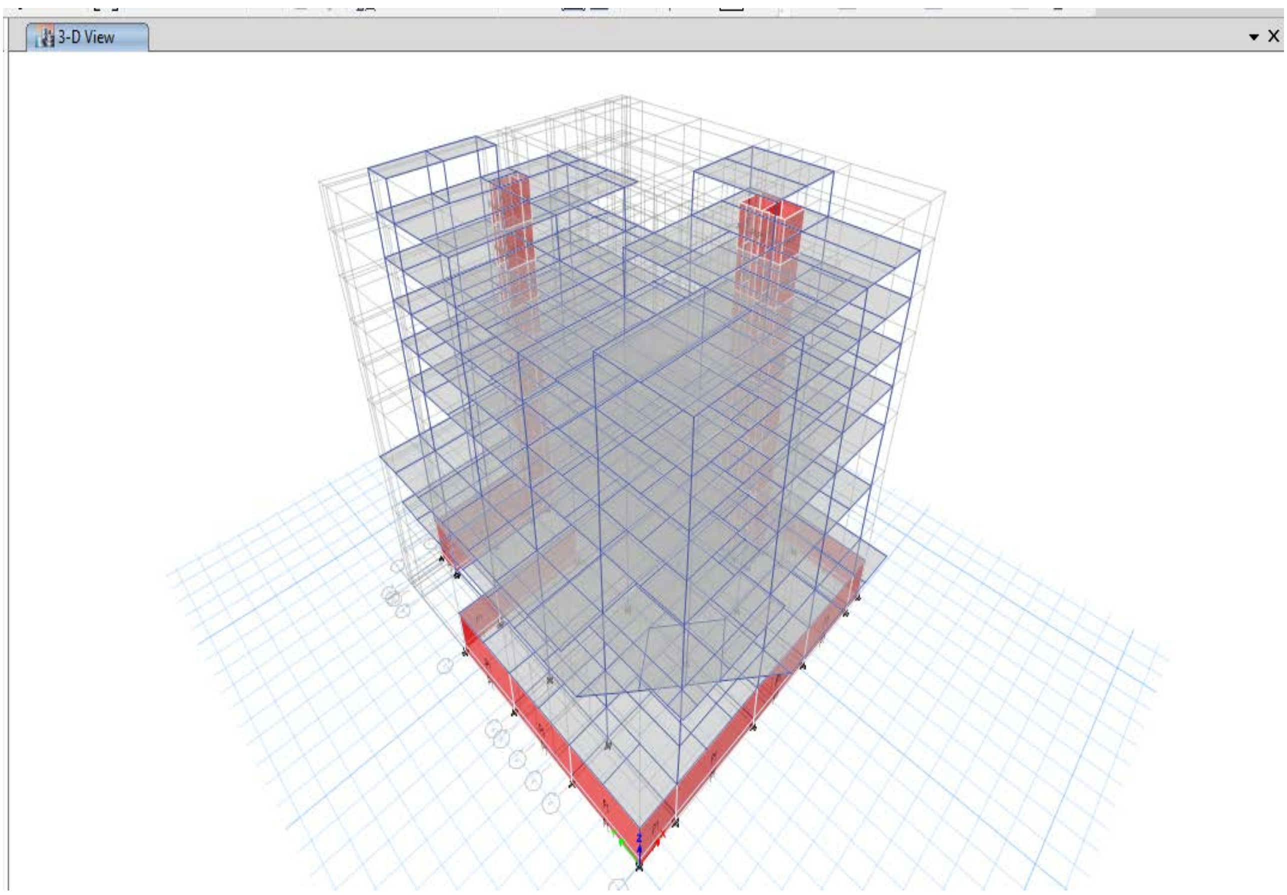


Fig. 6.1 3d Model

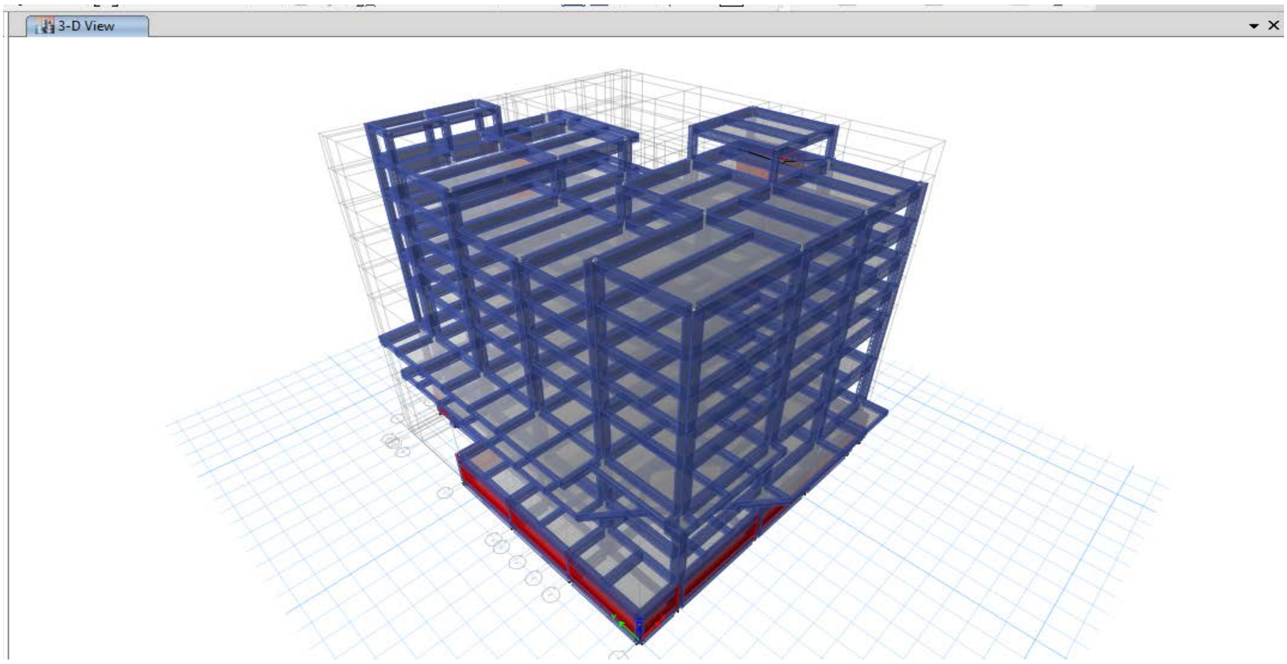


Fig. 6.2 3d Model (Extruded)

Plan View - 6th Floor Level 6 - Z = 26.4 (m)

Modal Participating Mass Ratios

1 of 25 Reload Apply

	Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	
		5	0.154	0.0737	0.0099	0	0.6942	0.6922	0	0.0116	0.12
		6	0.131	0.0148	0.0038	0	0.7089	0.6961	0	0.0057	0.02
		7	0.117	0.0049	0.0449	0	0.7138	0.741	0	0.0388	0.00
		8	0.112	0.0025	0.0061	0	0.7163	0.7471	0	0.0074	0.00
		9	0.097	0.0006	0.0058	0	0.7169	0.7528	0	0.0051	0.00
		10	0.078	0.0372	4.774E-06	0	0.7541	0.7528	0	2.551E-06	0.03
		11	0.073	0.0082	0.0202	0	0.7623	0.773	0	0.0225	0.00
		12	0.067	0.0016	0.0091	0	0.7638	0.7821	0	0.0126	0.00
		13	0.061	0.0104	0.0097	0	0.7742	0.7919	0	0.0108	0.01
		14	0.054	0.0002	0.0095	0	0.7744	0.8013	0	0.0122	0.00
		15	0.048	3.676E-05	0.0006	0	0.7744	0.8019	0	0.0014	0.00
		16	0.047	0.0234	0.006	0	0.7979	0.8079	0	0.0083	0.03
		17	0.04	2.756E-05	0	0	0.7979	0.8079	0	1.076E-05	2.07
		18	0.039	0.0085	0.009	0	0.8064	0.8169	0	0.013	0.01
		19	0.038	0.0151	0.004	0	0.8215	0.8209	0	0.0057	0.02
		20	0.031	0.0076	0.0064	0	0.8291	0.8273	0	0.0094	0.01
		21	0.03	0.0002	0.0017	0	0.8293	0.8291	0	0.0026	0.00
		22	0.028	0.0006	0.0069	0	0.8299	0.8359	0	0.0107	0.00
		23	0.027	0.0002	0.0937	0	0.8301	0.9296	0	0.1456	0.00
		24	0.023	0.0104	0.0002	0	0.8405	0.9298	0	0.0003	0.01
		25	0.022	0.0809	0.0004	0	0.9213	0.9303	0	0.0007	0.12

Fig. 6.3 Model Participation Ratio

Plan View - 6th Floor Level 6 - Z = 26.4 (m)

Centers of Mass and Rigidity

Story	Diaphragm	Mass X kg	Mass Y kg	XCM m	YCM m	Cumulative X kg	Cumulative Y kg	XCCM m	YCCM m
Mumty	D1	65438.21	65438.21	18.2174	18.2511	65438.21	65438.21	18.2174	18.2511
Terrace	D1	439572.71	439572.71	15.7669	14.8279	505010.92	505010.92	16.0844	15.2715
6th Floor Level 6	D1	641422.51	641422.51	14.9372	14.706	1146433.42	1146433.42	15.4425	14.9551
5th Floor Level 5	D1	700733.11	700733.11	14.548	14.8404	1847166.54	1847166.54	15.1032	14.9116
4th Floor Level 4	D1	688502.78	688502.78	14.634	15.1252	2535669.31	2535669.31	14.9758	14.9696
3rd Floor Level 3	D1	726417.16	726417.16	14.7013	15.2602	3262086.48	3262086.48	14.9147	15.0343
2nd FloorLevel 2	D1	866806.63	866806.63	14.6035	16.0712	4128893.11	4128893.11	14.8493	15.252
1st FloorLevel 1	D1	858969.71	858969.71	15.4116	16.0181	4987862.82	4987862.82	14.9462	15.3839
G Floor Level 0	D1	992860.25	992860.25	15.7642	15.4085	5980723.07	5980723.07	15.082	15.388

Fig. 6.4 Centre of mass and centre of Rigidity

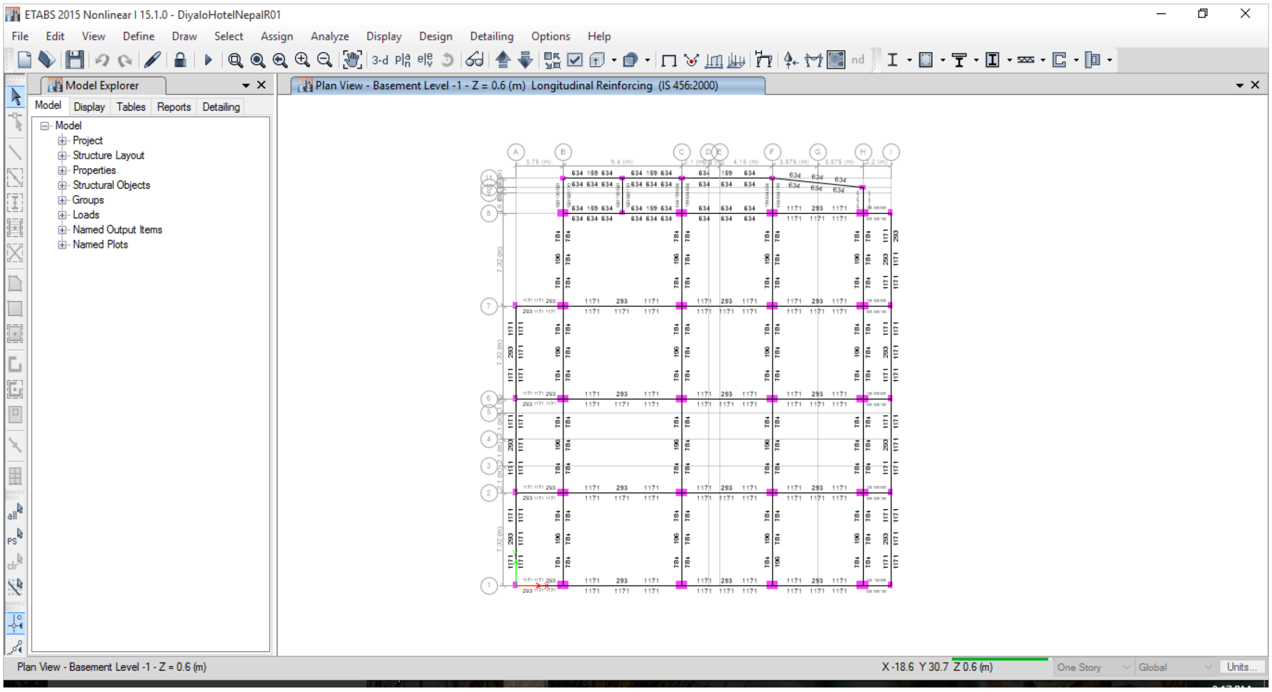


Fig. 6.5 Plinth Level Floor Beam

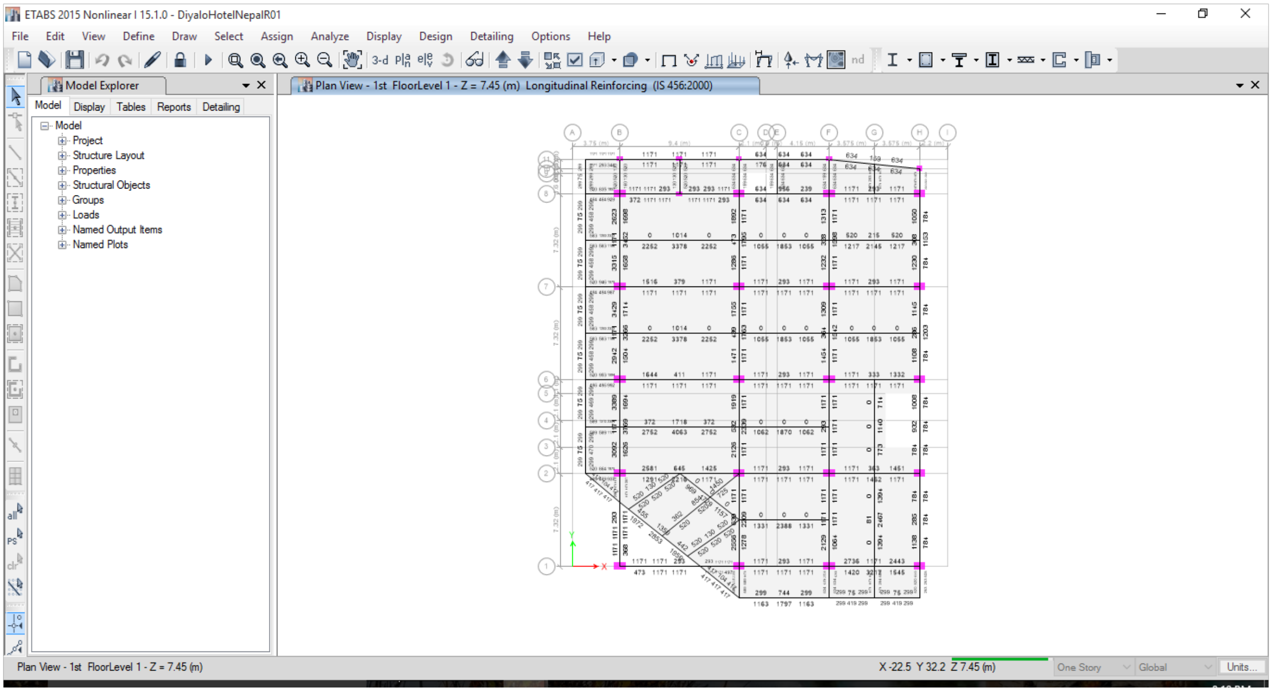


Fig. 6.6 1st Floor Beams

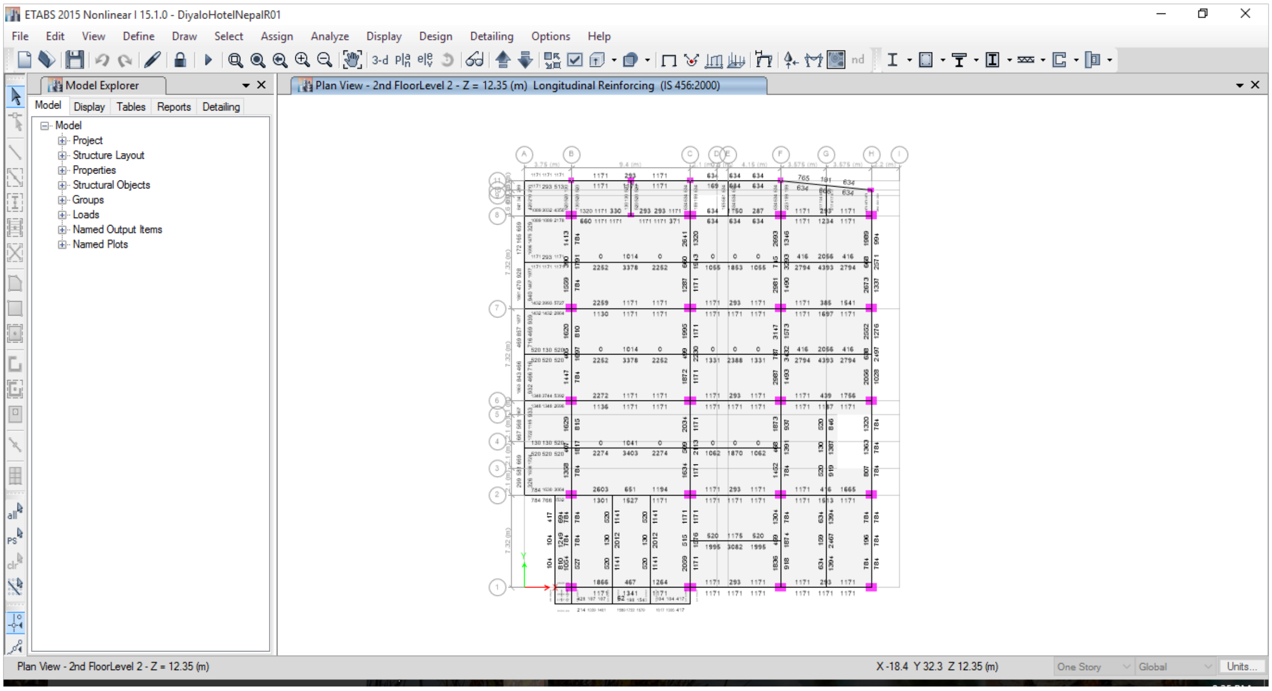


Fig. 6.6 2nd Floor Beams

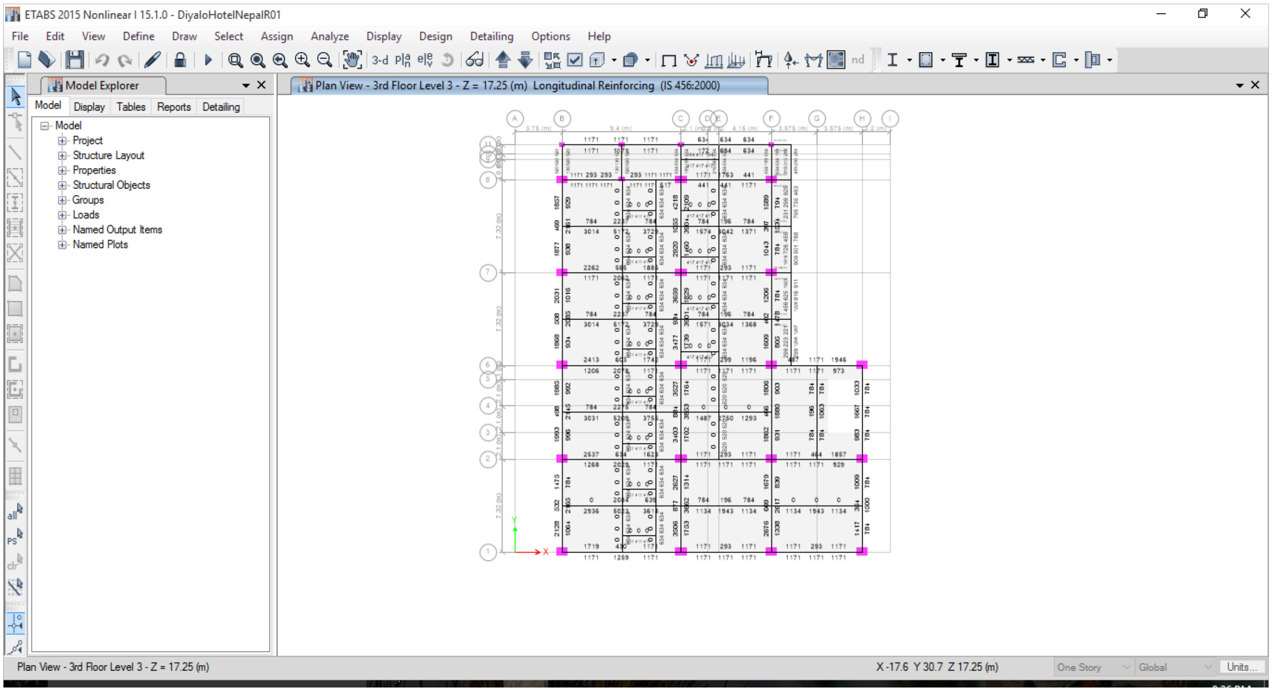


Fig. 6.7 3rd Floor Beams

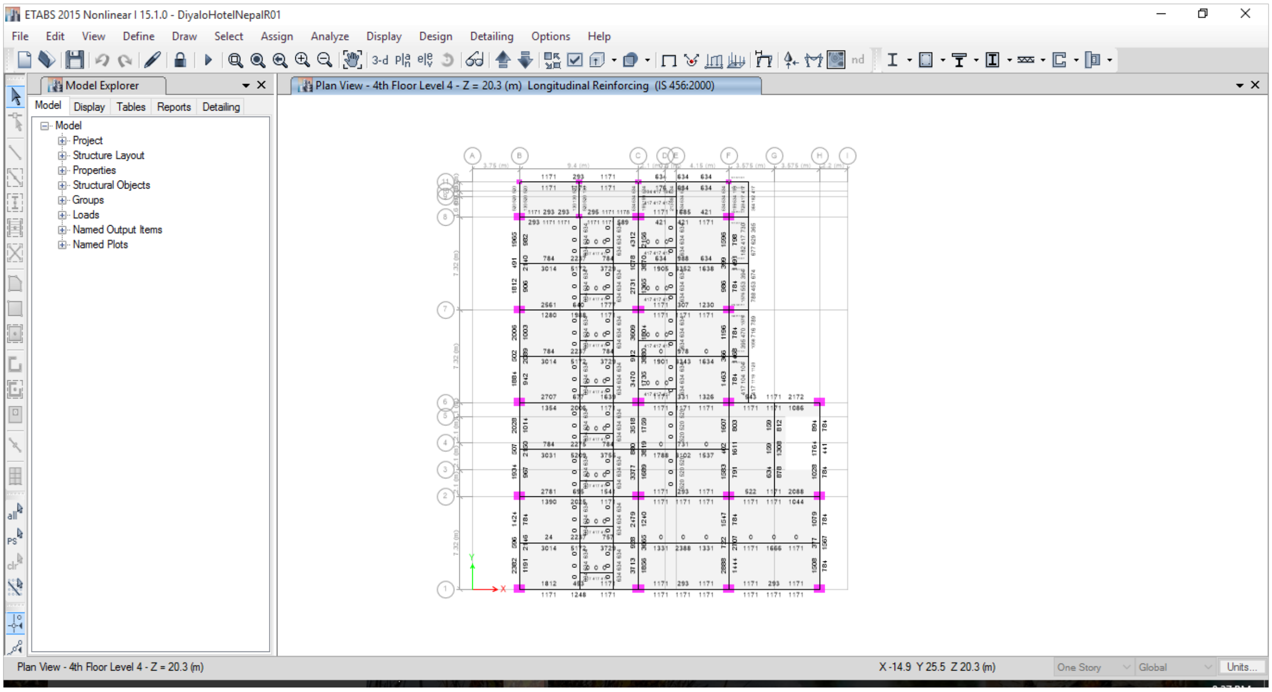


Fig. 6.8 4th Floor Beams

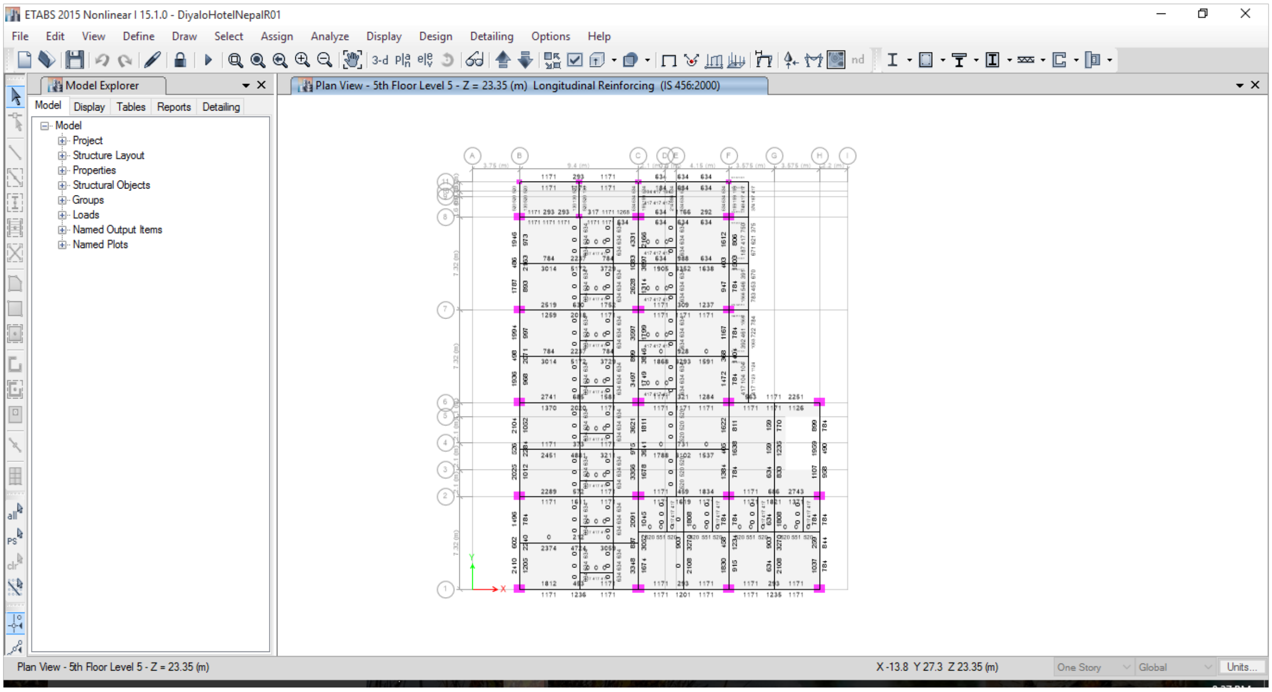


Fig. 6.9 5th Floor Beams

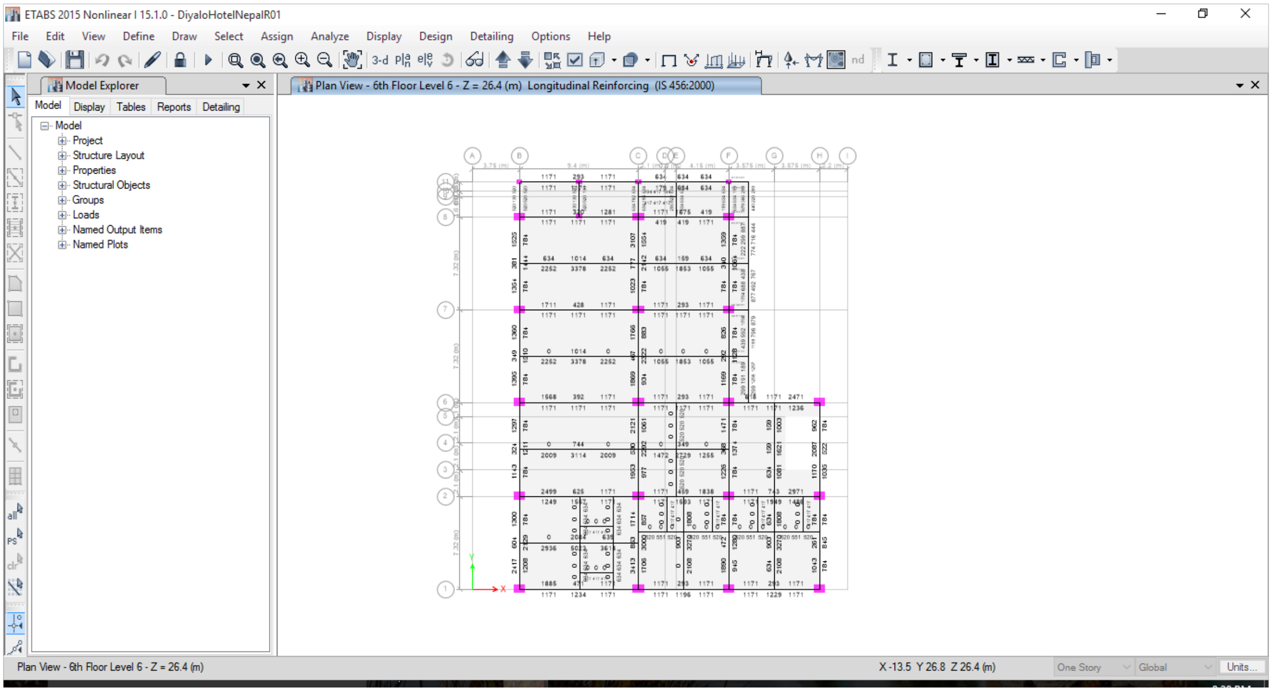


Fig. 6.10 6th Floor Beams

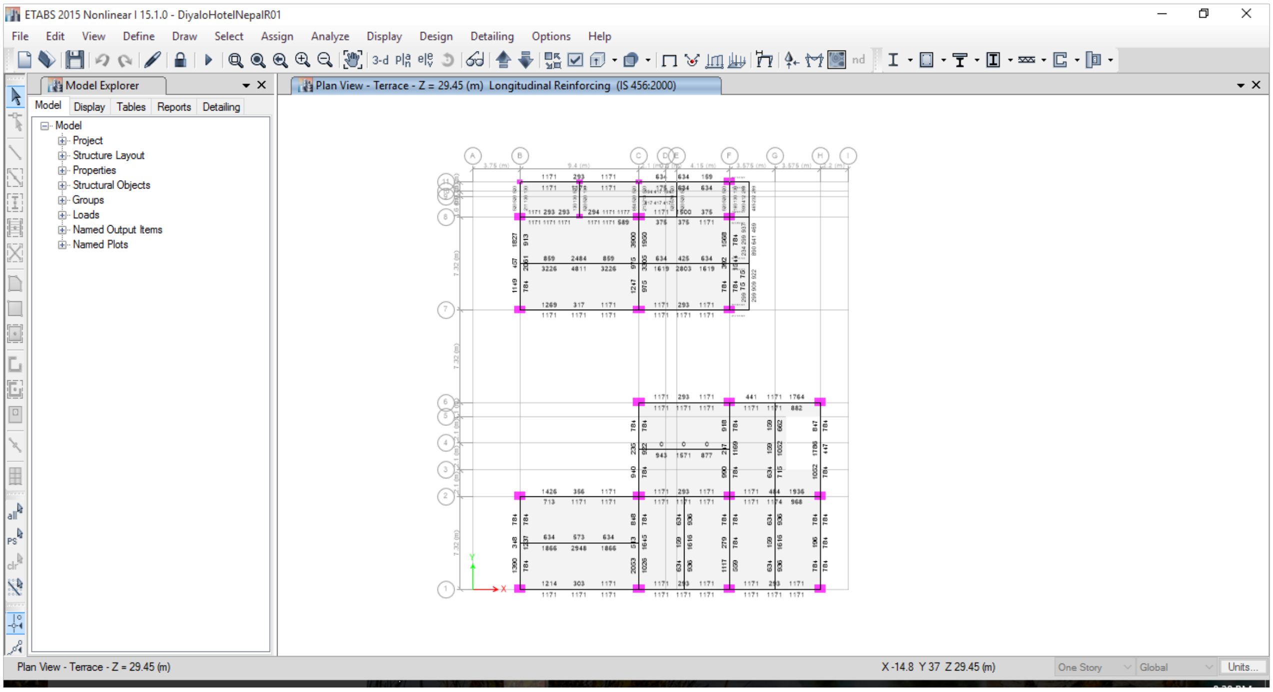


Fig. 6.11 Terrace Floor Beams

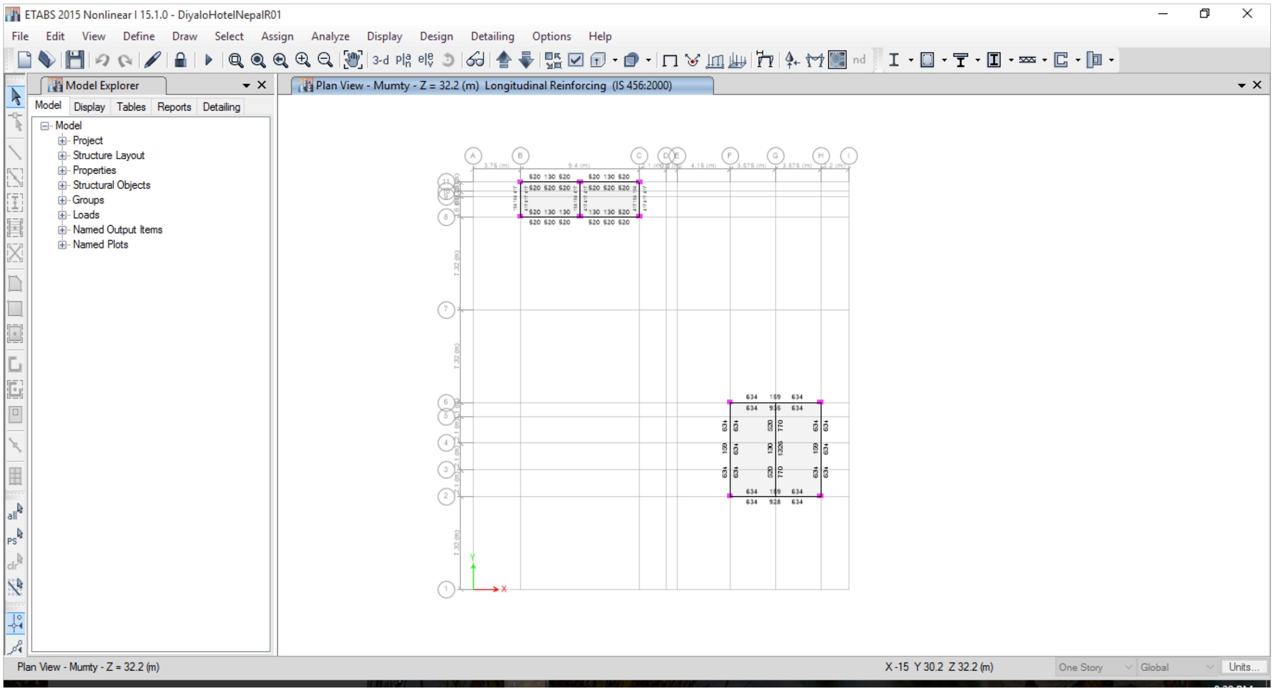


Fig. 6.12 mumty Beams

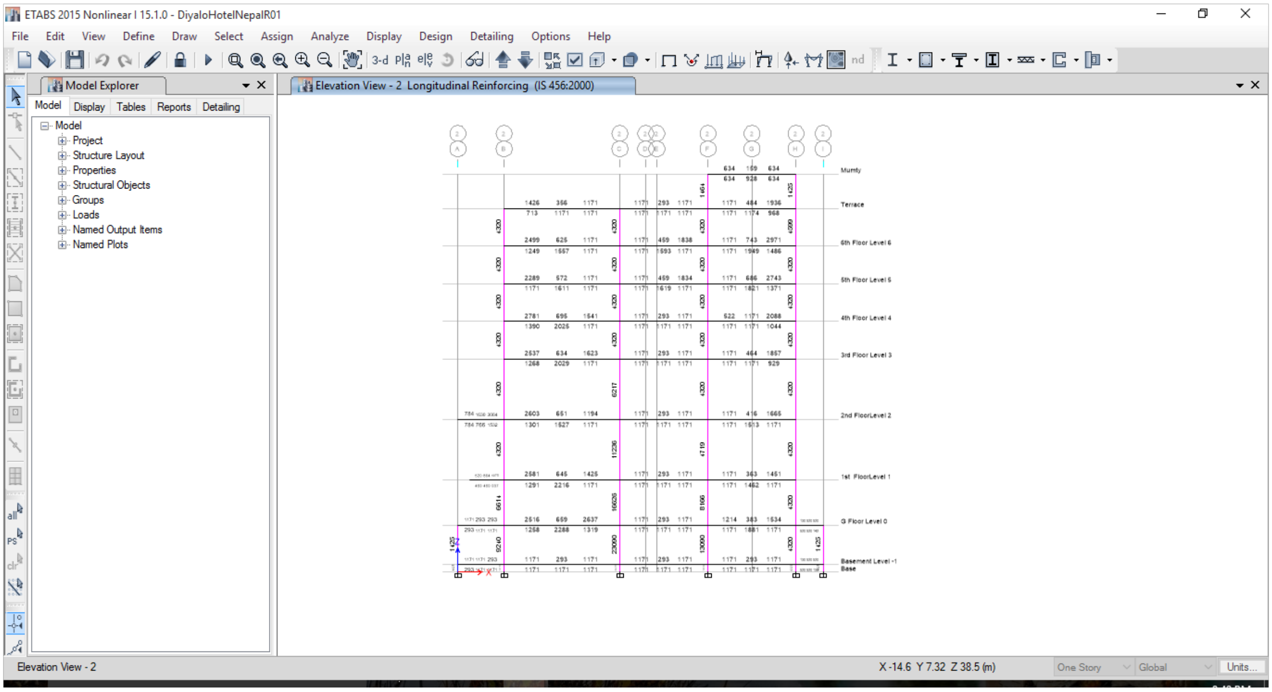


Fig. 6.13 Col. reinforcement G-1

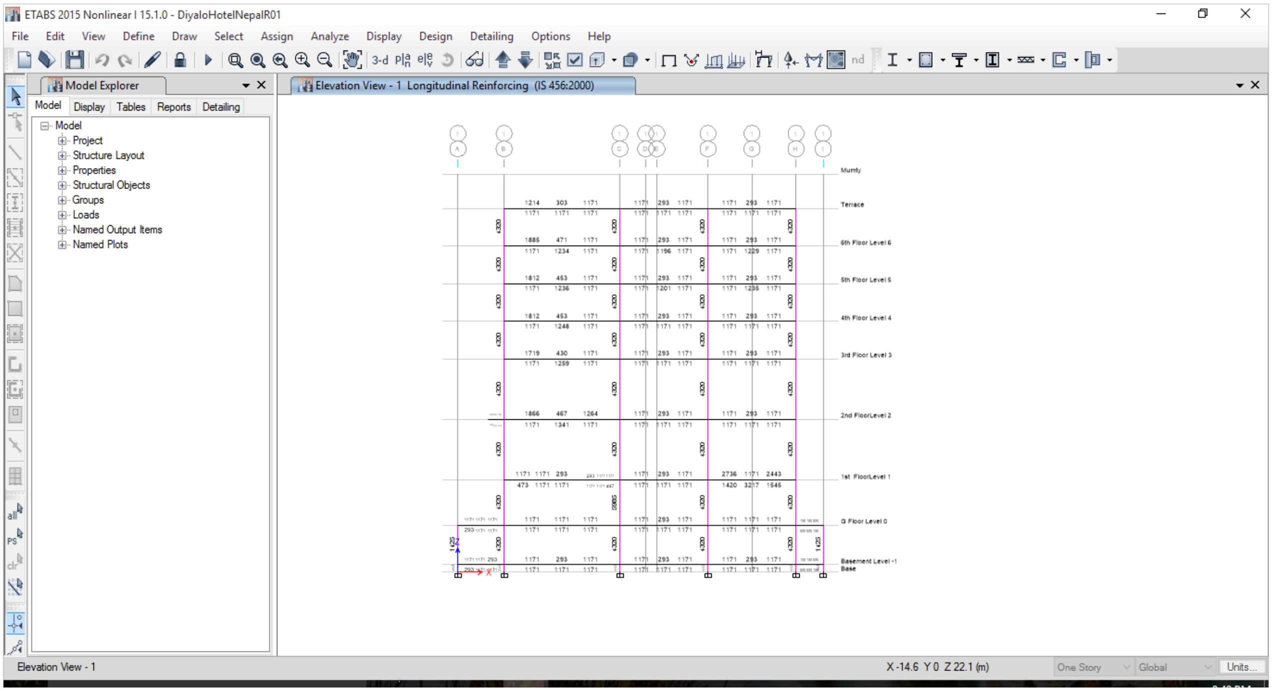


Fig. 6.14 Col. reinforcement G-2

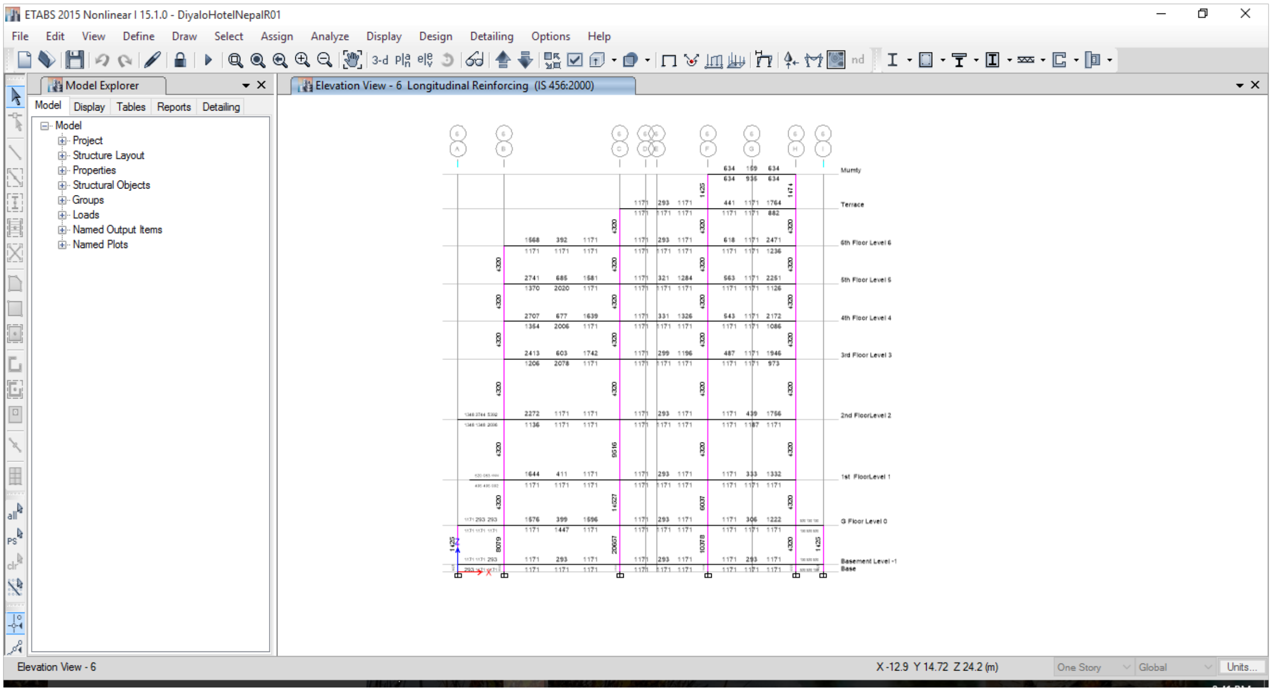


Fig. 6.15 Col. reinforcement G-6

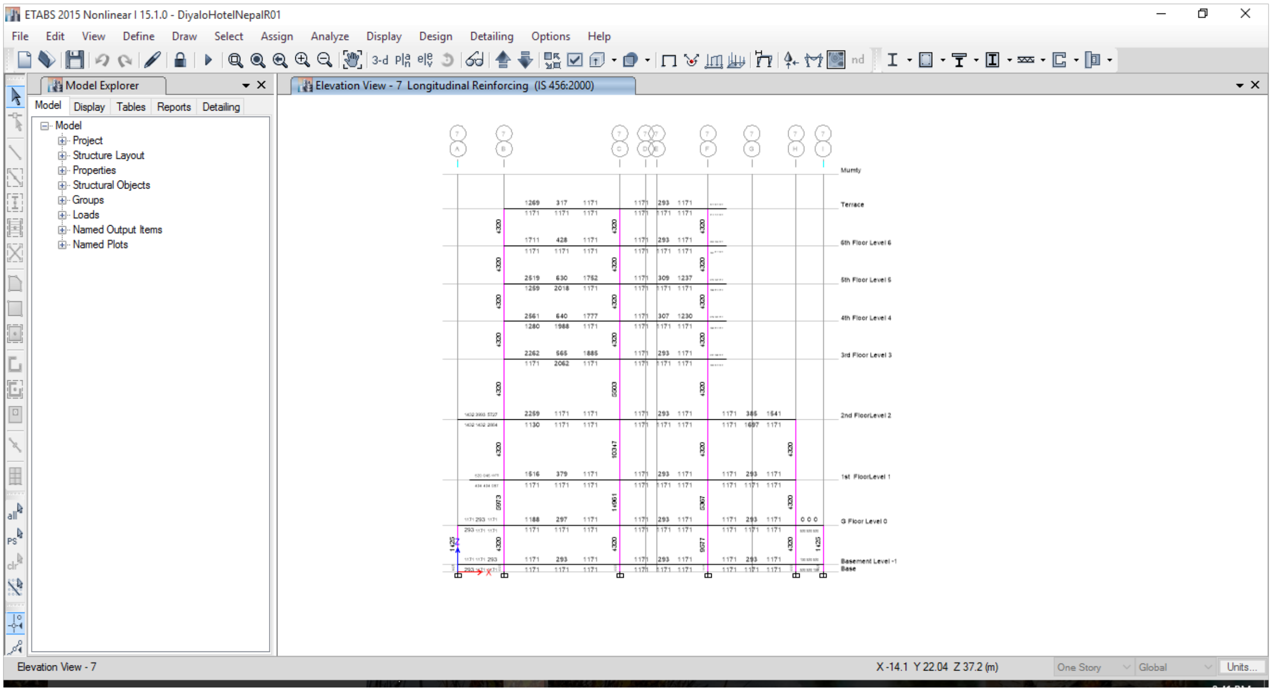


Fig. 6.16 Col. reinforcement G-7

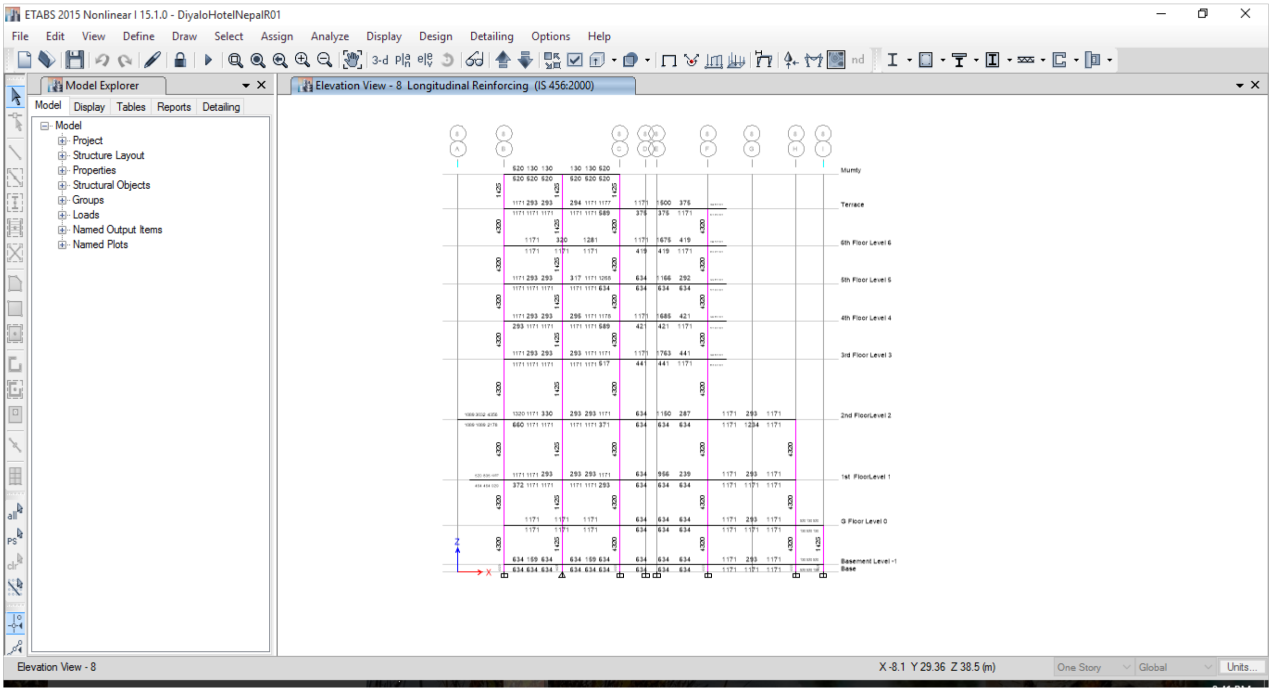


Fig. 6.17 Col. reinforcement G-8

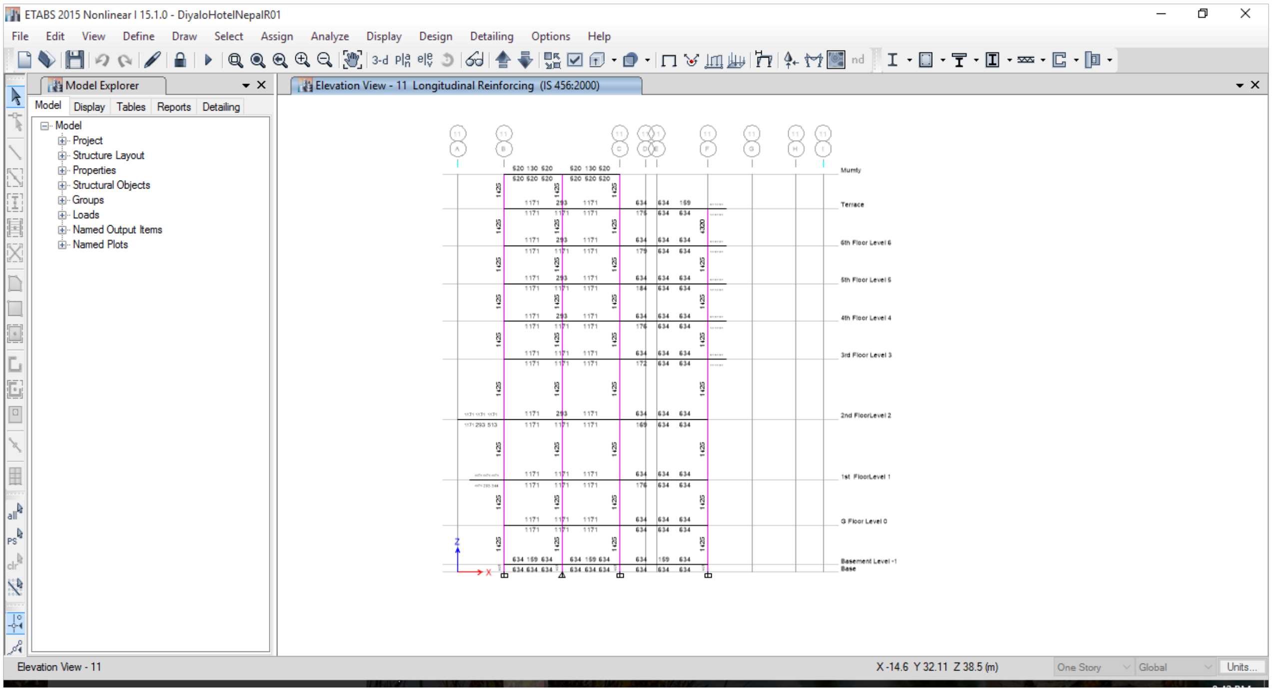


Fig. 6.18 Col. reinforcement G-11

6.3 Modelling of Raft in SAFE

The Raft is modelled in SAFE as a RAFT /MATsupported on Soil with modulus of subgrade property. in the process of analysis of raft behaviour has been observed and tabulated for explaining purpose. the following snap shots of raft has been observed.

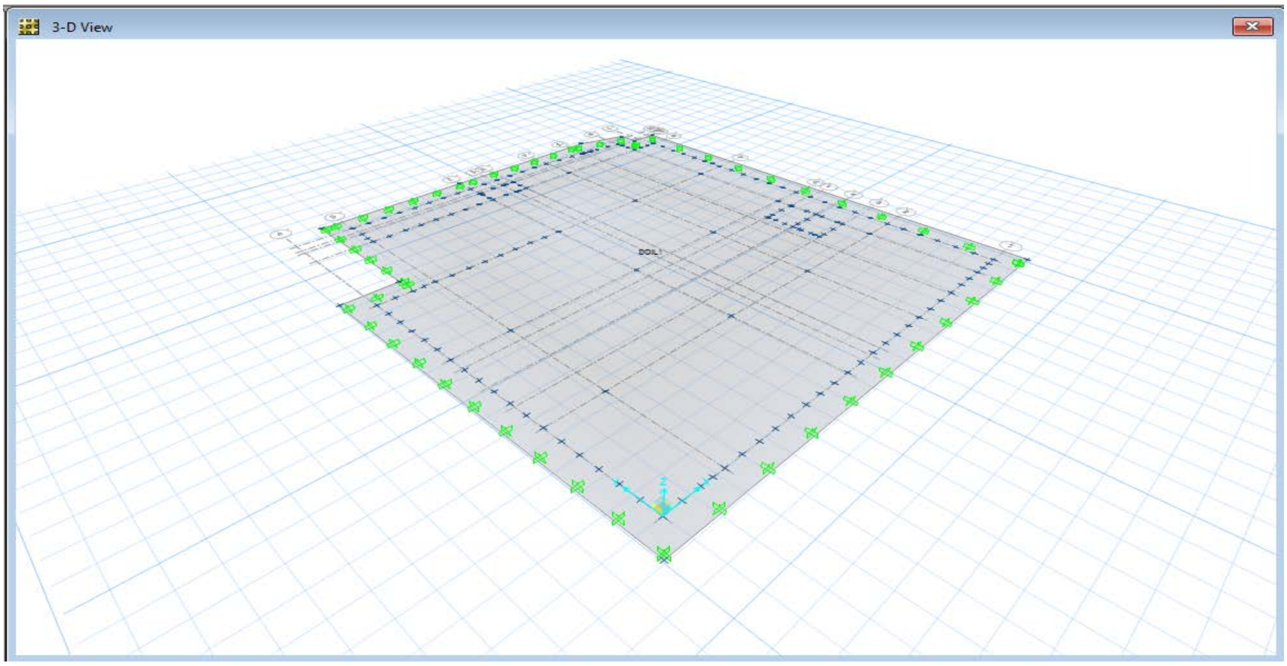


Fig.6.19 plan view Raft only

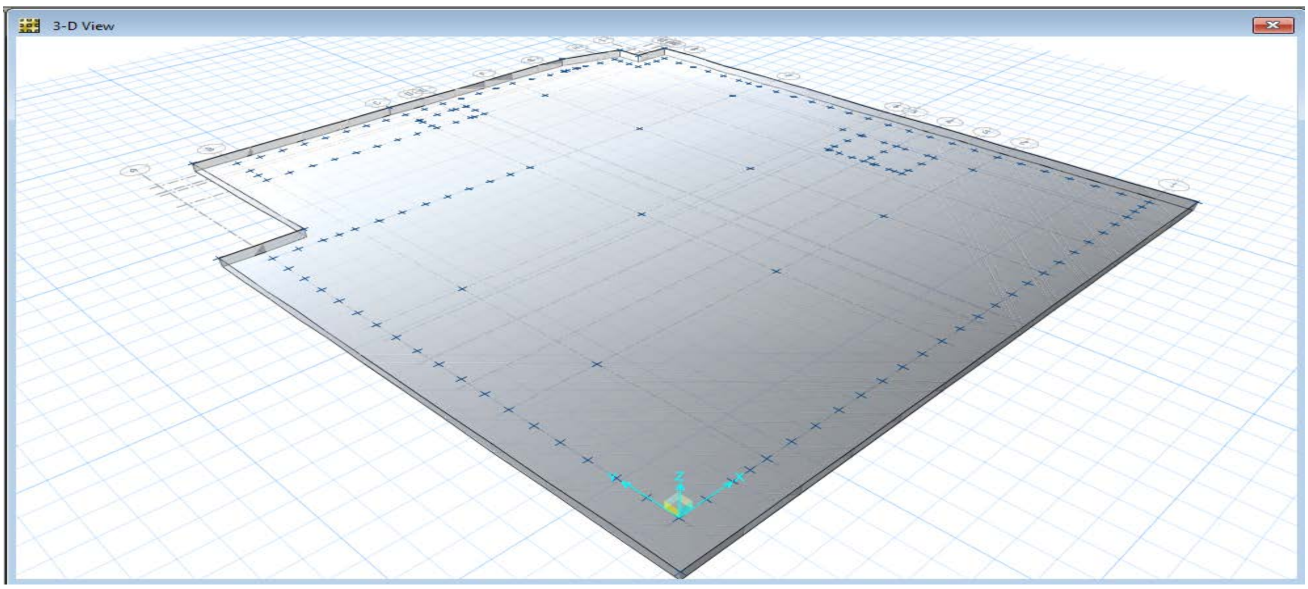


Fig.6.20 plan view Raft only (Extruded)

Raft Settlements and Soil Pressure under Raft

CASE 1 Size of Raft (32.65m x 34.5m) SBC given 75 kN/m2

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	Punching
600	87.5	272.0	Fail
900	79.9	244.8	Fail
1200	78.8	246.0	Fail
1500	78.7	245.0	Pass
1800	78.8	246.3	Pass
2100	79.2	247.0	Pass
2500	80	251.0	Pass
3000	81.7	255.4	Pass
3500	84.1	262.8	Pass

Settlement 1200 mm thk (78.8mm)

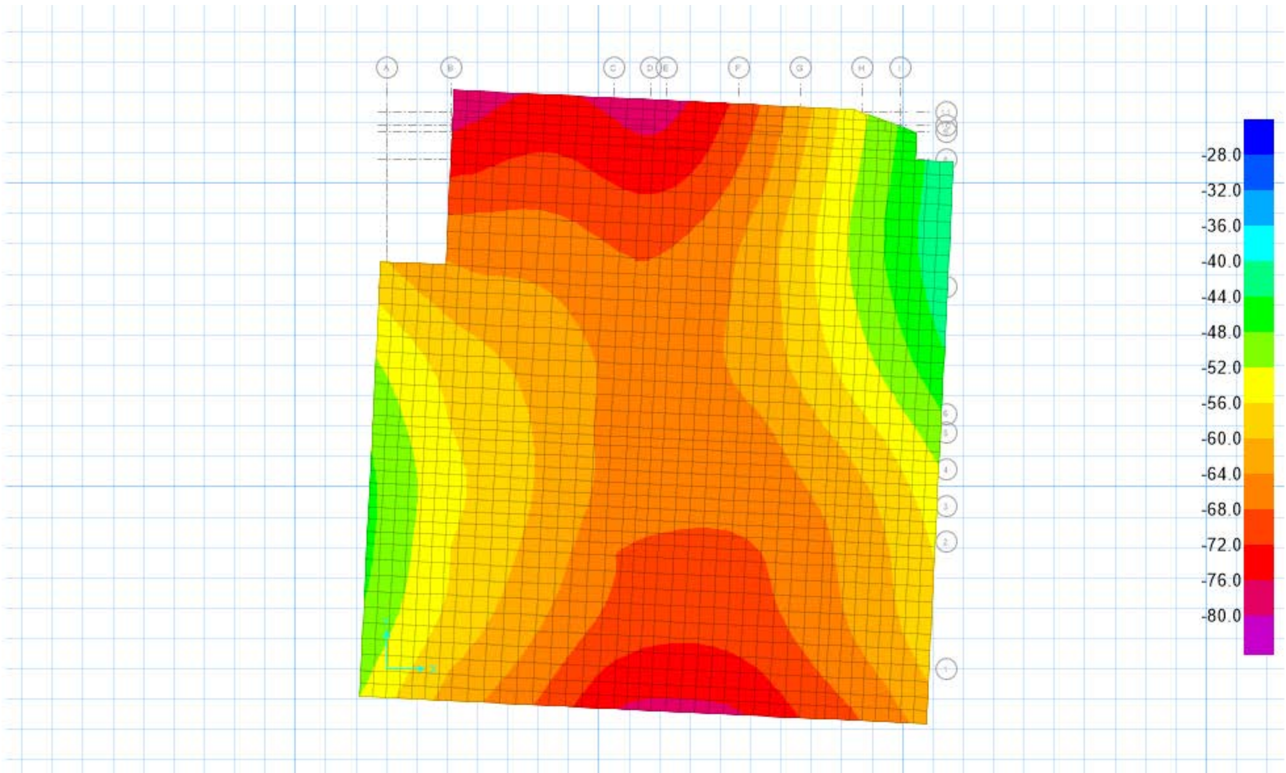


Fig.6.21

Soil Pressure 1200 mm thk (246.4kN/mm2)

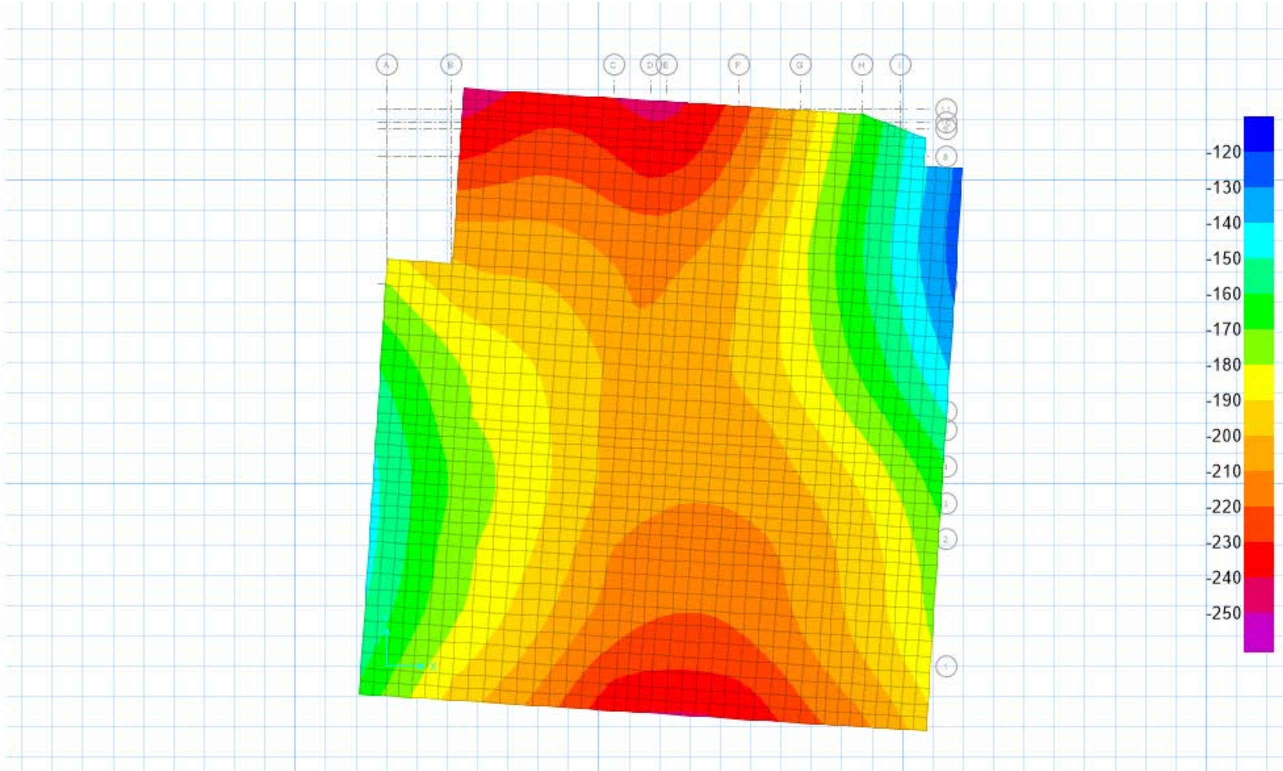


Fig.6.22

Case 2 Size of Raft (37.65m x 37.5m) SBC given 75 kN/m2

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	Punching
600	76.5	272.7	Fail
900	70.1	252.0	Fail
1200	70.5	241.6	Fail
1500	70.2	236.3	Pass
1800	69.5	234.1	Pass
2100	68.8	235.1	Pass
2500	68.6	236.5	Pass
3000	64.9	214.9	Pass
3500	70.2	219.5	Pass

Settlement(only Raft)1350 77.3mm

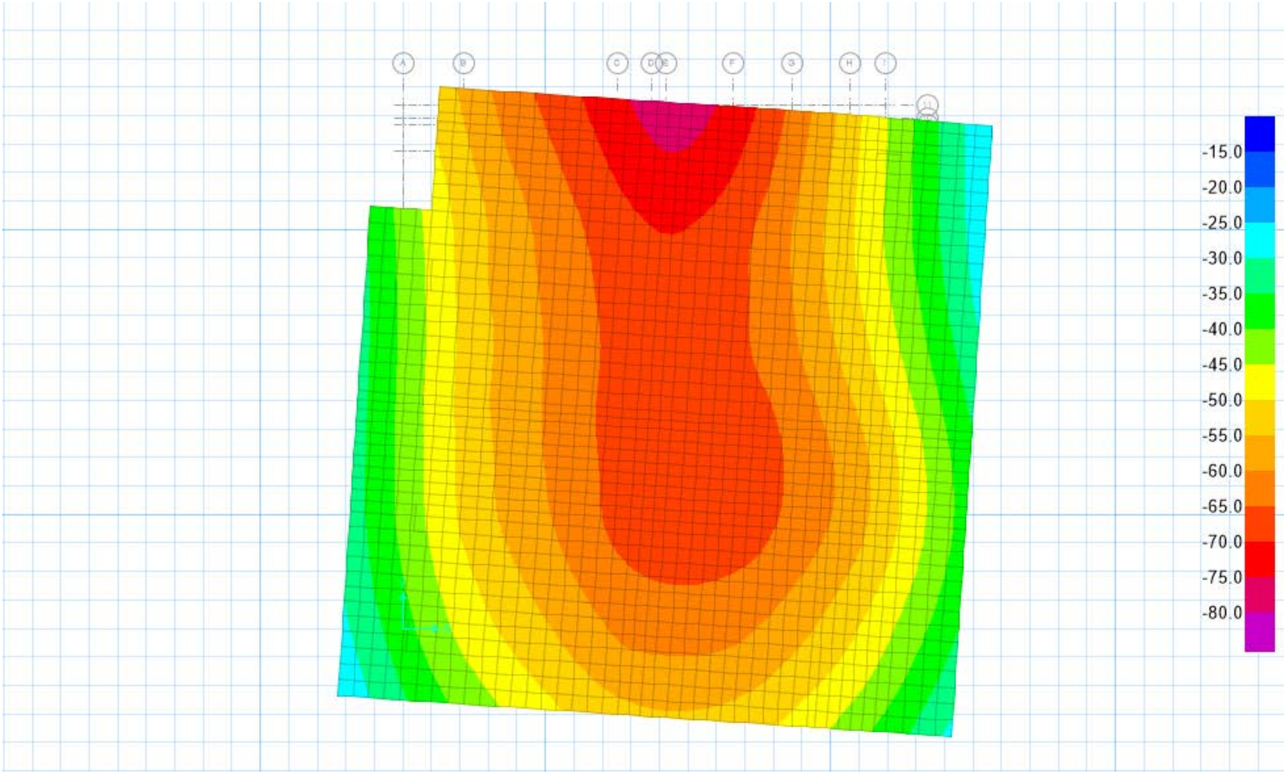


Fig.7.23

Soil Pressure(only Raft)1350 241.6 kN/mm2

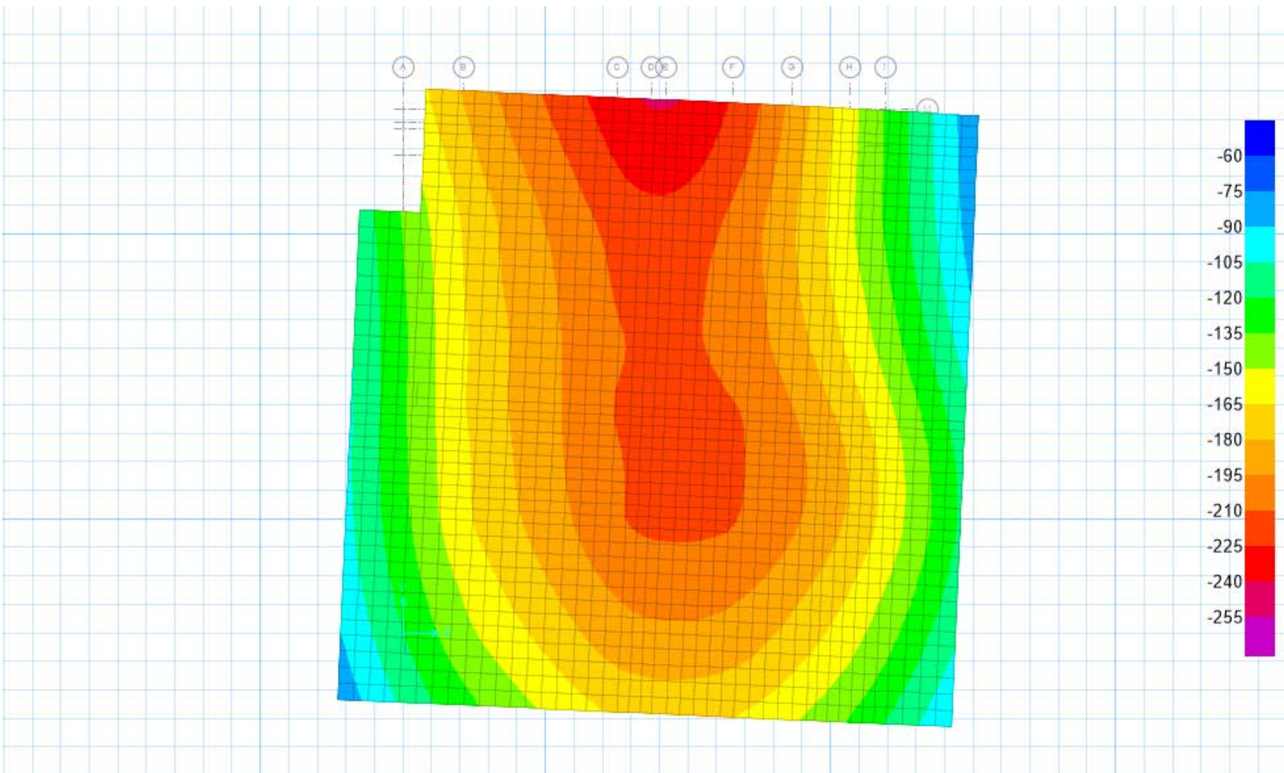


Fig.6.24

Case 3 Size of Raft (42.65m x 45.11m) SBC given 75 kN/m2

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	Punching
600	87.3	272.7	Fail
900	80.7	252.0	Fail
1200	77.3	241.6	Fail
1500	75.6	236.3	Pass
1800	74.9	234.1	Pass
2100	74.9	235.1	Pass
2500	75.7	236.5	Pass
3000	77.5	242.2	Pass
3500	80.0	250	Pass

Settlement(only Raft)1350 70.5mm

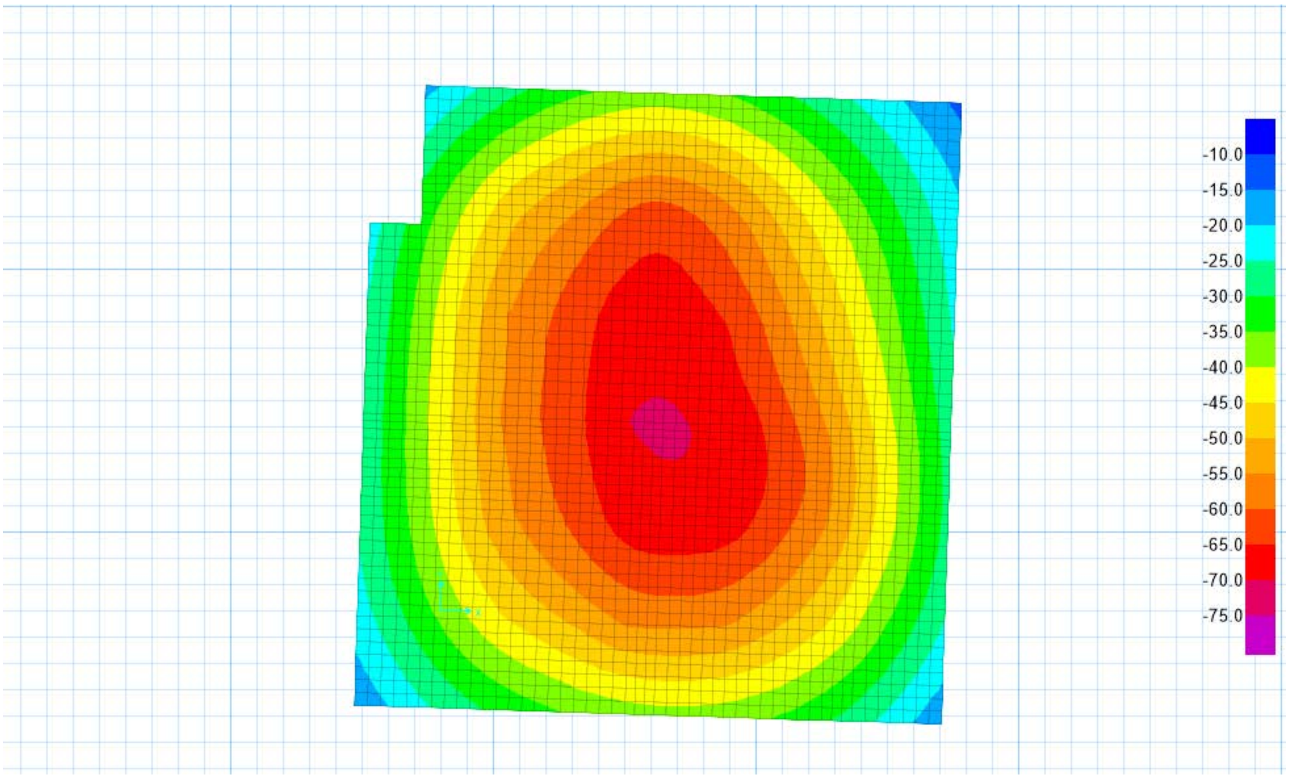


Fig.6.25

Soil Pressure(only Raft)1350 220.4kn/mm2

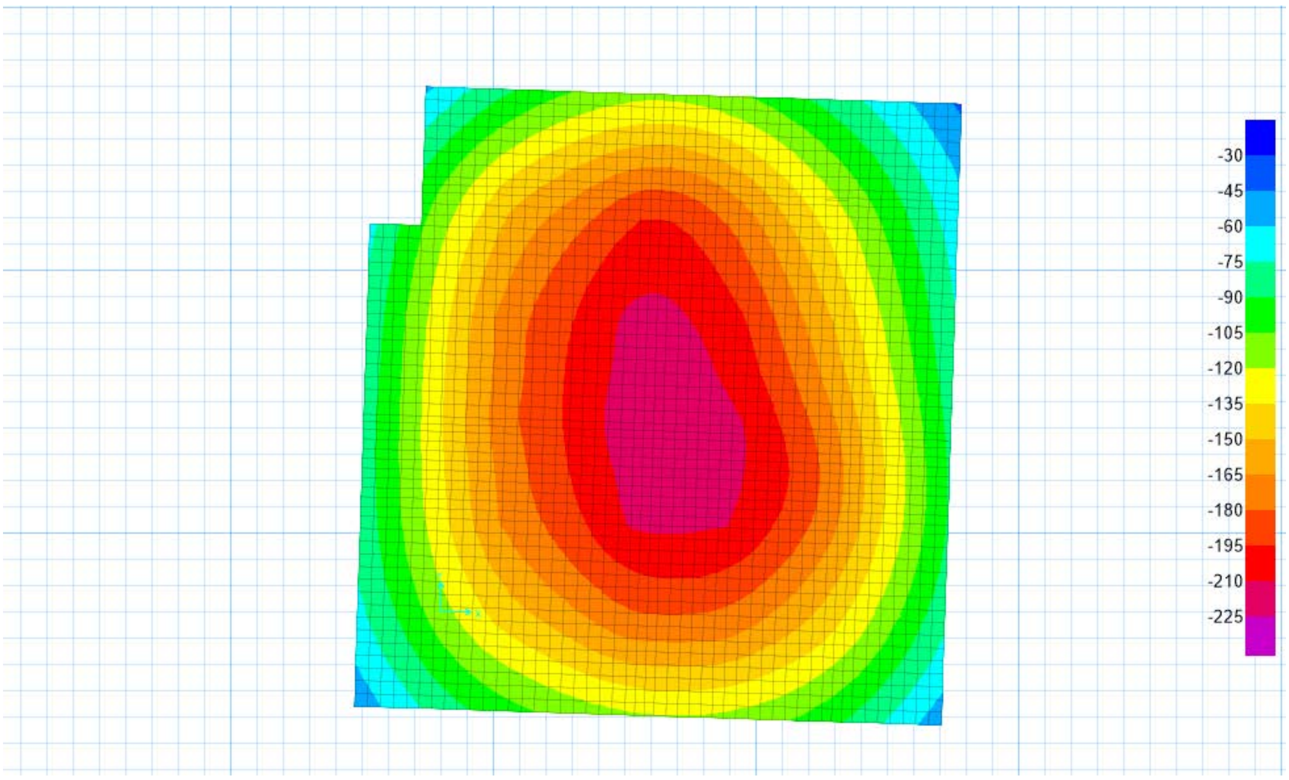


Fig.6.26

6.4 Piled Raft Settlements and Soil Pressure under Raft (Raft 32.65m x 35.0m)

Piles are added to Raft foundation so as to satisfy design criteria of foundation. Piles are mainly settlement reducers and also in this case soil pressure reducers by observing different cases. To Study the behaviour of piled raft foundation many researchers have carried out the parametric study and proves that the piled raft is considered as economical alternatives to pile foundations.

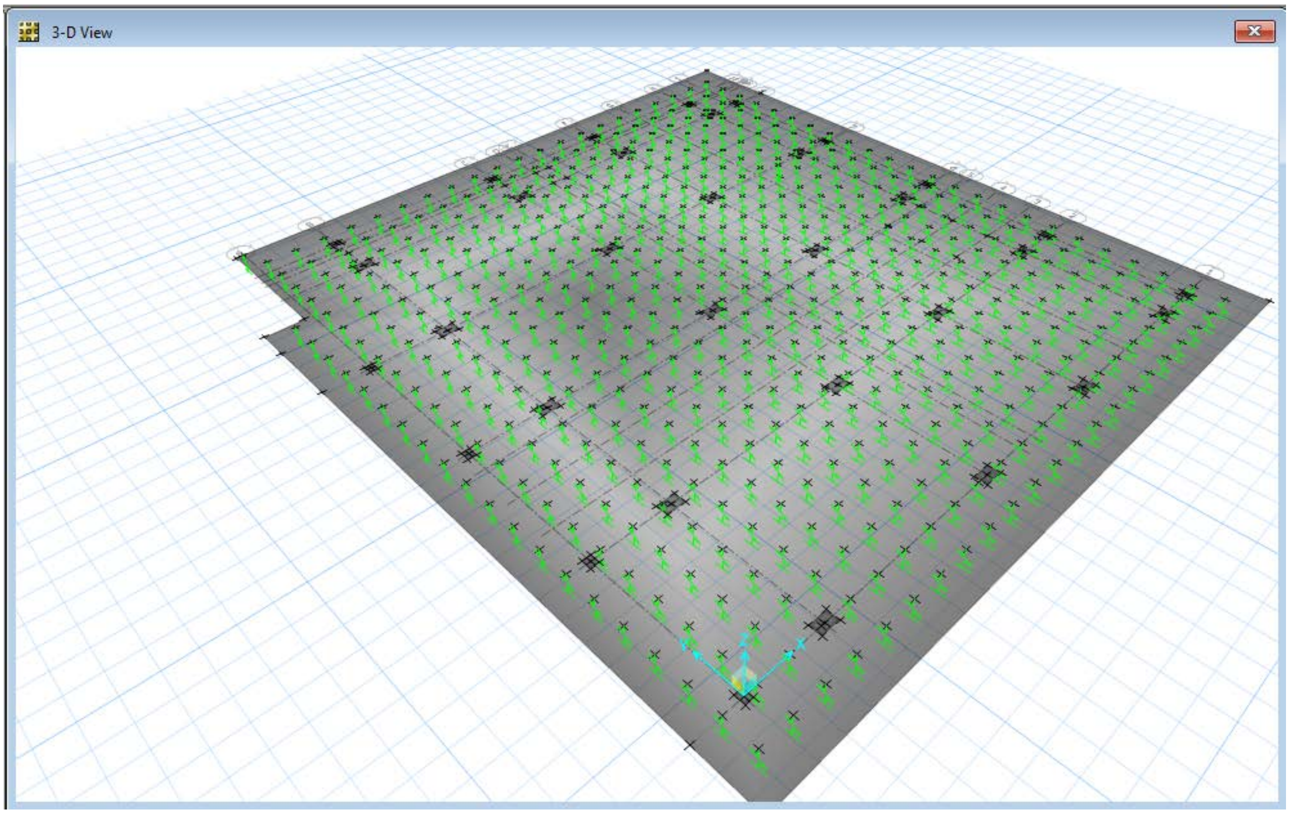


Fig.6.27 Piled Raft R01 (1350) 3D view Piles as spring

The load from superstructure is taken partially by raft and partially by piles. the load from piles is transferred to soil partially by skin friction and partially by end bearing action. we analyzed the piled raft with different spacing configuration of piles and determined the max. settlement and soil pressure under different length of piles. The case are following :-

Case 1 SUR Pile Spacing at 1.875m at both Horizontal and vertical ways

Case2 DUR Pile Spacing at 1.875m at both Horizontal and vertical ways

Case 3 SUR Pile Spacing at 1.500m at both Horizontal and vertical ways

Case4 DUR Pile Spacing at 1.500m at both Horizontal and vertical ways

Case5 DUR Pile Spacing at 1.65m in Horizontal Dirction and 1.80m in Vertical direction (1st Final Proposal)

Case6 DUR Pile Spacing at 1.80m in Horizontal Dirction and 1.65m in Vertical direction (2nd Final Proposal)

Case 1 SUR Pile Spacing at 1.875m at both Horizontal and vertical ways

(a) **SUR Pile Length 7.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 182.8 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 182.8 / 12 = 15.233 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/m2	L/d ratio
600	47.1	147.2	18.75
900	42.8	133.6	18.75
1200	40.4	126.2	18.75
1500	39.0	121.8	18.75
1800	38.2	119.25	18.75

(Pile Spacing at 1.875m c/c)

(b) **SUR Pile Length 10.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 238.0 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 238 / 12 = 19.83 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	L/d ratio
600	41.3	129.1	26.25
900	37.1	116.1	26.25
1200	35.1	109.8	26.25
1500	33.9	106.0	26.25
1800	33.2	103.9	26.25

(Pile Spacing at 1.875m c/c)

Settlement (Piled Raft 1350) 34.5mm for 10.5 m length

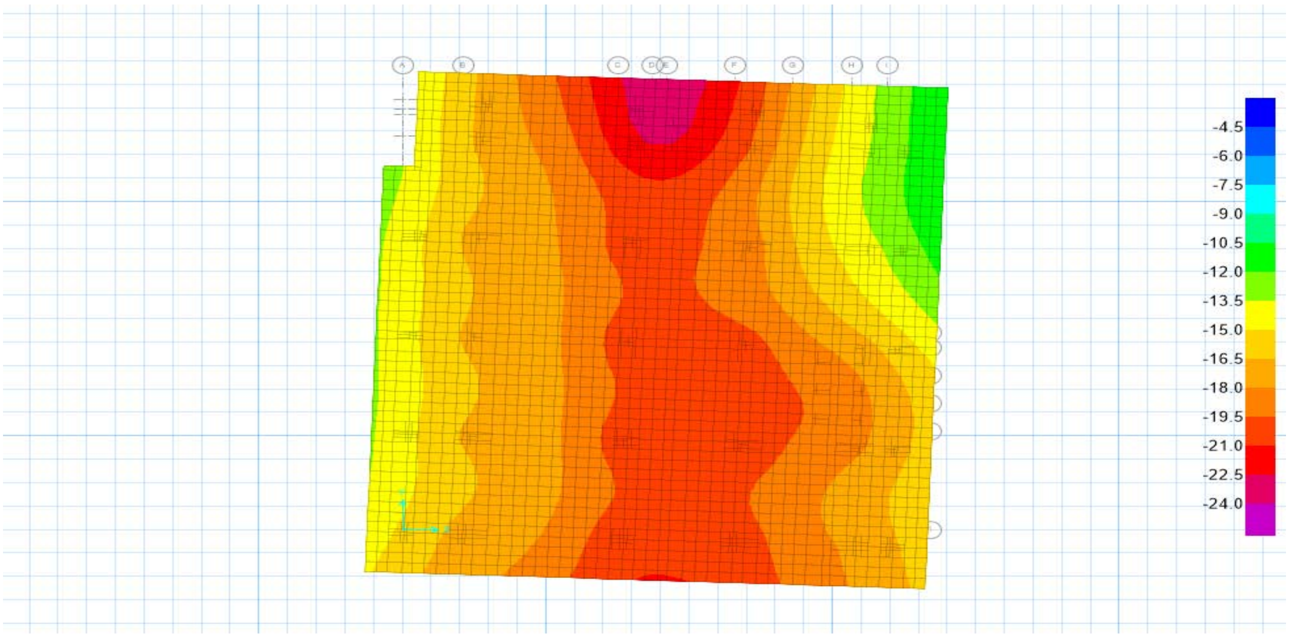


Fig.6.28

Soil Pressure (Piled Raft 1350)108.0kN/m2 for 10.5 m length

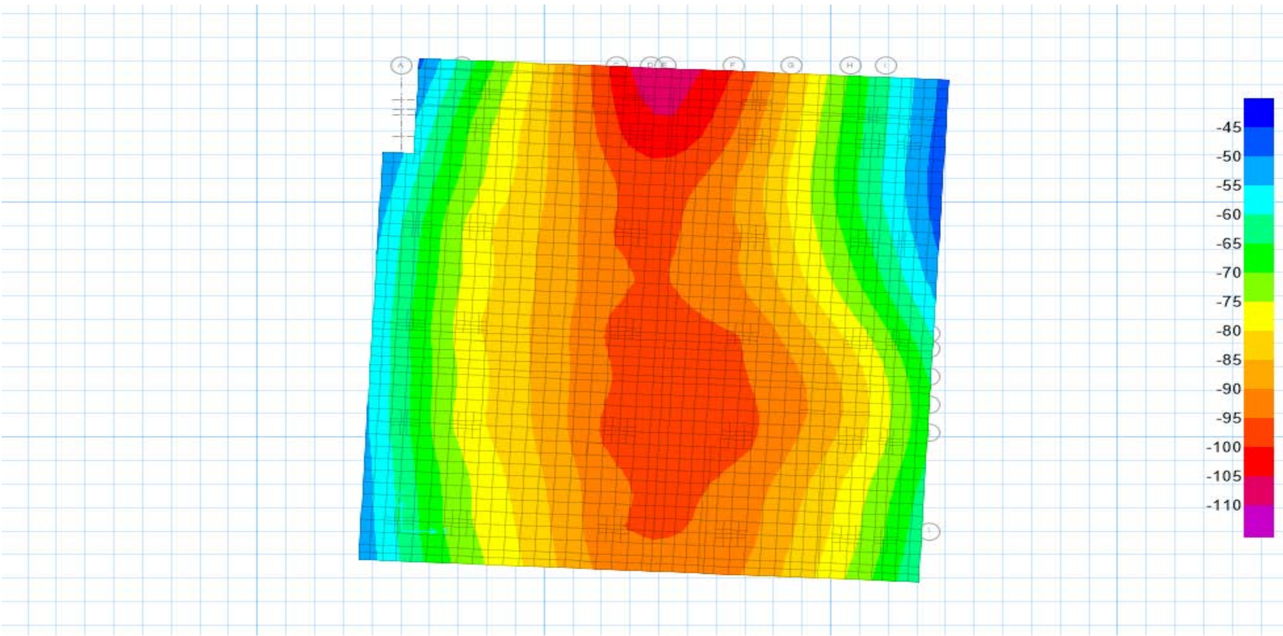


Fig.6.29

Case2 DUR Pile Spacing at 1.875m at both Horizontal and vertical ways

(a) **DUR Pile Length 7.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 279.5 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 279.5 / 12 = 22.875 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	L/d ratio
600	38.3	119.7	18.75
900	34.2	106.8	18.75
1200	32.4	101.1	18.75
1500	31.3	97.7	18.75
1800	30.6	95.8	18.75

(Pile Spacing at 1.875m c/c Both ways)

(b) **DUR Pile Length 10.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 315.2 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 315.2 / 12 = 26.27 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/m2	L/d ratio
600	35.5	110.9	26.25
900	31.4	98.2	26.25
1200	29.8	93.0	26.25
1500	28.8	89.9	26.25
1800	28.2	88.2	26.25

(Pile Spacing at 1.875m c/c Both ways)

Settlement (Piled Raft)1350 29.3 mm for 10.5 m length

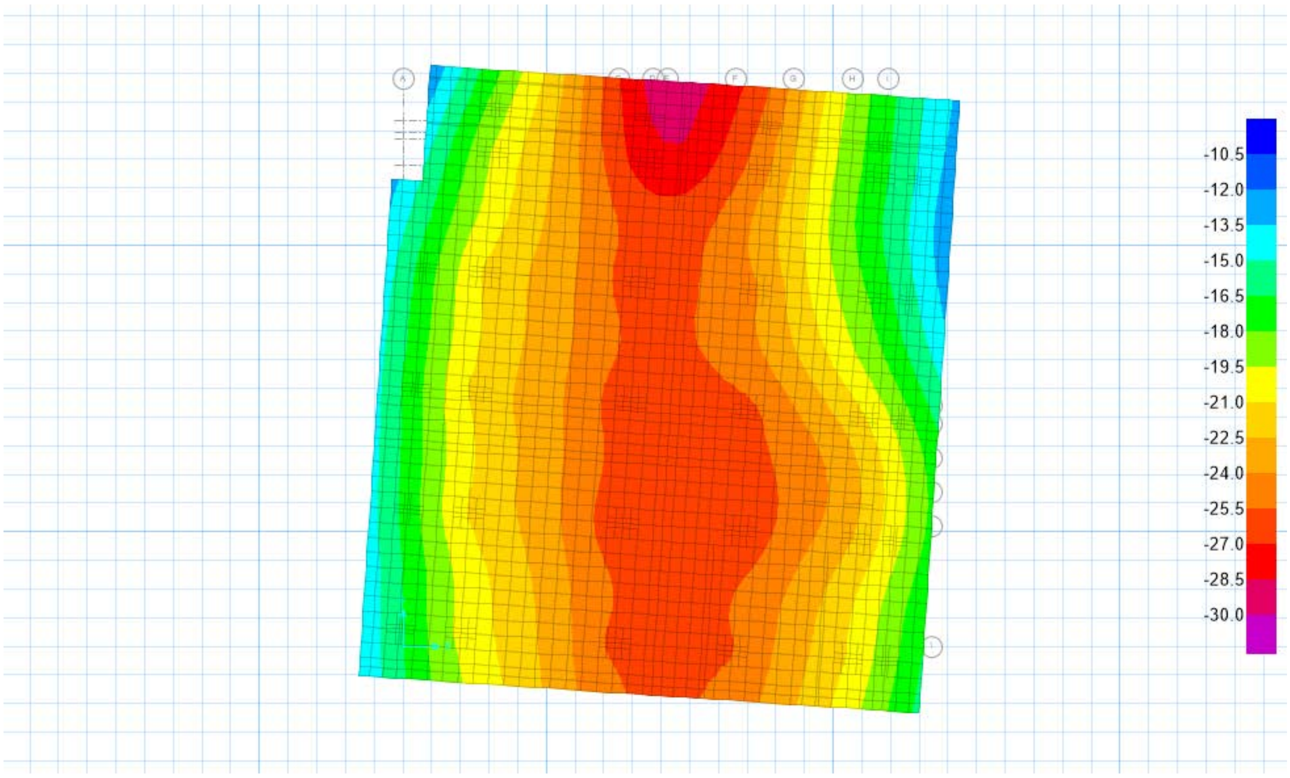
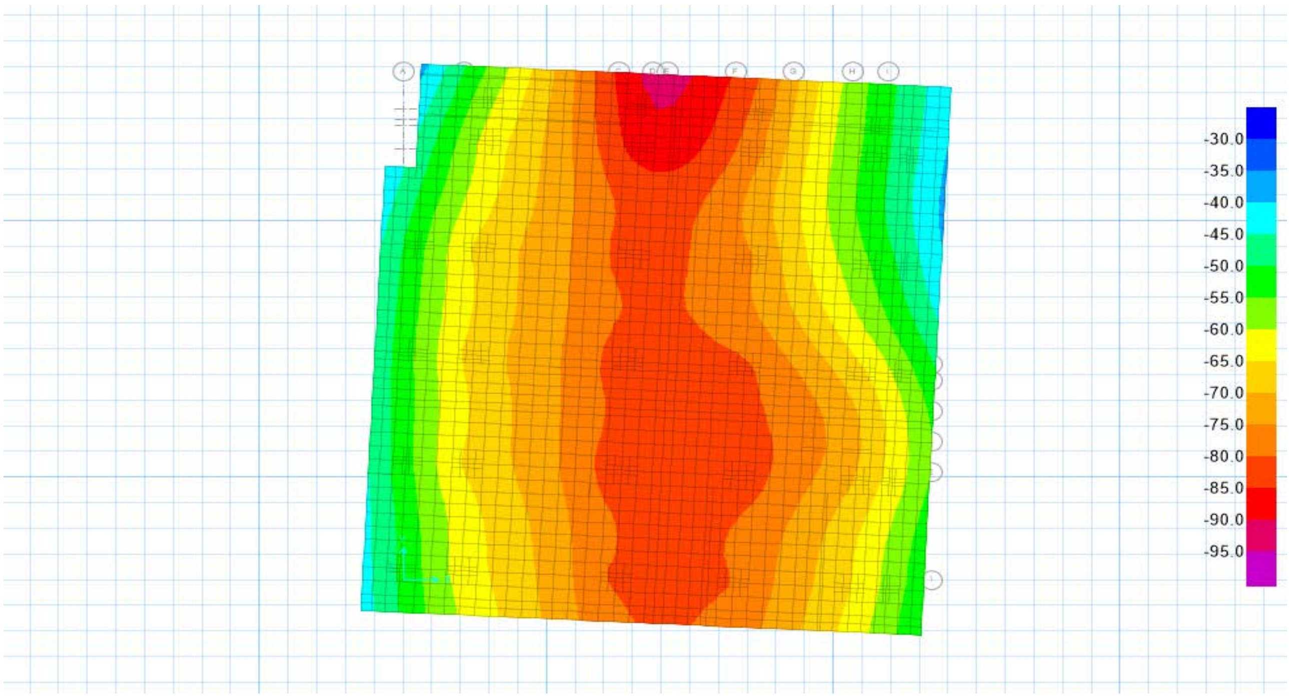


Fig.6.30

Soil pressure (Piled Raft)1350 91.6kN/m2 for 10.5 m length



Case 3 SUR Pile Spacing at 1.500m at both Horizontal and vertical ways

(a) **SUR Pile Length 7.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 182.8 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 182.8 / 12 = 15.233 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	L/d ratio
600	39.0	121.9	18.75
900	33.7	105.4	18.75
1200	32.1	100.4	18.75
1500	31.5	98.5	18.75
1800	31.2	97.5	18.75

(Pile Spacing at 1.50m c/c)

(b) **SUR Pile Length 10.5 m** , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 238.0 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 238 / 12 = 19.83 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/mm2	L/d ratio
600	34.4	107.4	26.25
900	29.5	92.2	26.25
1200	28.0	87.4	26.25
1500	27.4	85.6	26.25
1800	27.3	84.6	26.25

(Pile Spacing at 1.50m c/c Both ways)

Settlement (Piled Raft)1350 26.3 mm for 10.5 m length

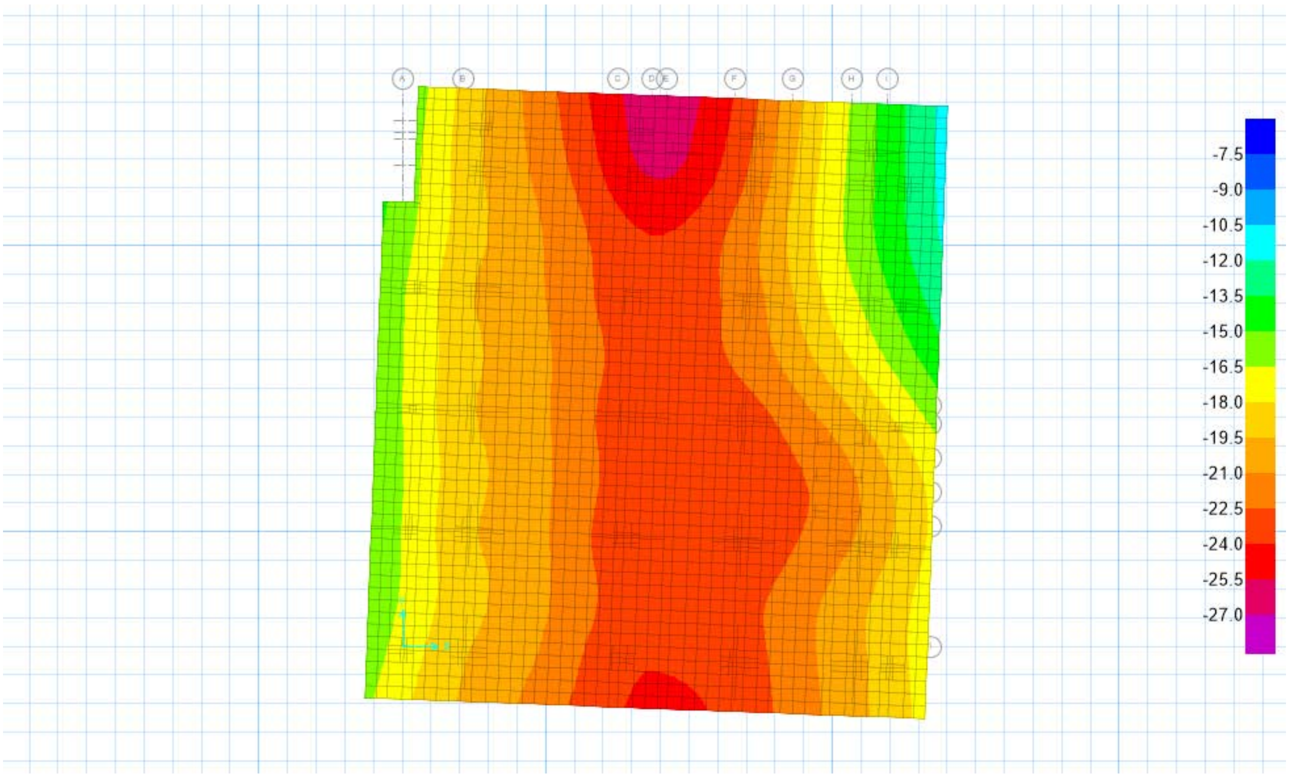


Fig.6.31

Soil pressure (Piled Raft)1350 81.2kN/m2 for 10.5 m length pile

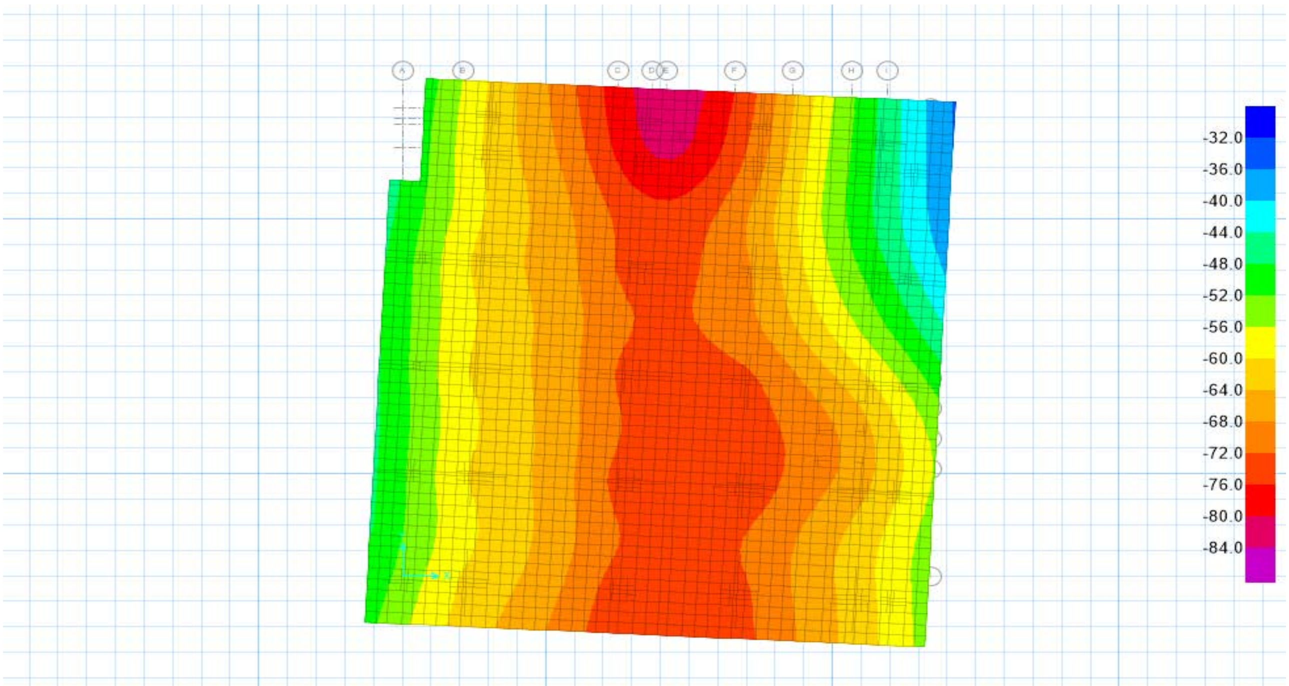


Fig.6.32

Case4 DUR Pile Spacing at 1.500m at both Horizontal and vertical ways

(a) DUR Pile Length 7.5 m , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 279.5 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 279.5 / 12 = 22.875 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/m2	L/d ratio
600	31.7	99.1	18.75
900	27.2	85.1	18.75
1200	25.8	80.5	18.75
1500	25.2	78.8	18.75
1800	24.9	77.8	18.75

(Pile Spacing at 1.50m c/c Both ways)

(b) DUR Pile Length 10.5 m , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 315.2 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 315.2 / 12 = 26.27 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/m2	L/d ratio
600	29.5	92.2	26.25
900	24.3	78.5	26.25
1200	**23.2**	**74.0**	26.25
1500	23.2	72.4	26.25
1800	22.9	71.5	26.25

(Pile Spacing at 1.50m c/c Both ways)

Settlement (Piled Raft 1350mm) 23.4 for 10.5 m length

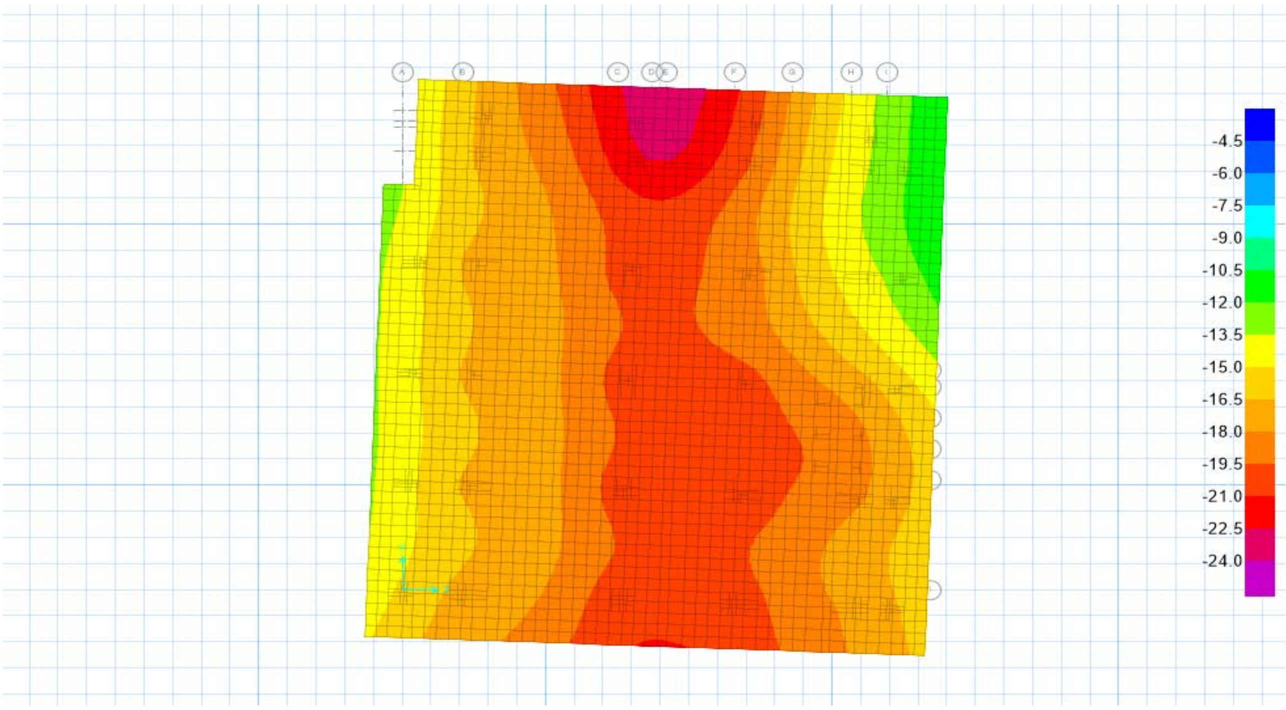


Fig.6.34

Soil pressure (Piled Raft 1350) 73.13kN/m2 for 10.5 m length

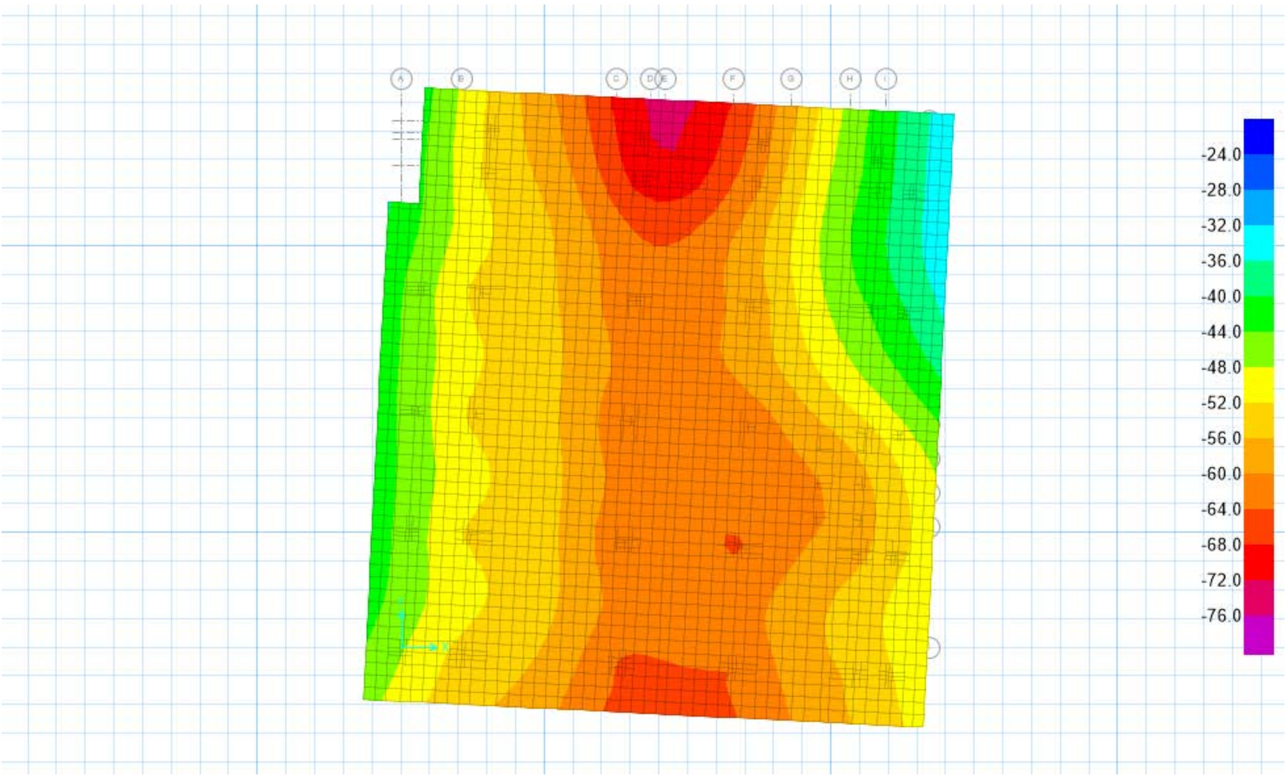


Fig.6.35

Case5 (Raft 1350mm) DUR Pile Spacing at 1.65m in Horizontal Direction and 1.80m in Vertical direction

DUR Pile Length 10.5 m , Pile Dia = 400mm, SBC = 75 kN/m2

Pile capacity = 315.2 kN , Allowable Settlement of pile = 12 mm

Point Spring Value for Pile = 315.2 / 12 = 26.27 kN/mm

Raft Thickness mm	Settlement mm	Soil Pressure kN/m2	L/d ratio
1350	23.4	73.05	26.25

Settlement (Piled Raft 1350mm) 23.4mm for 10.5 m length

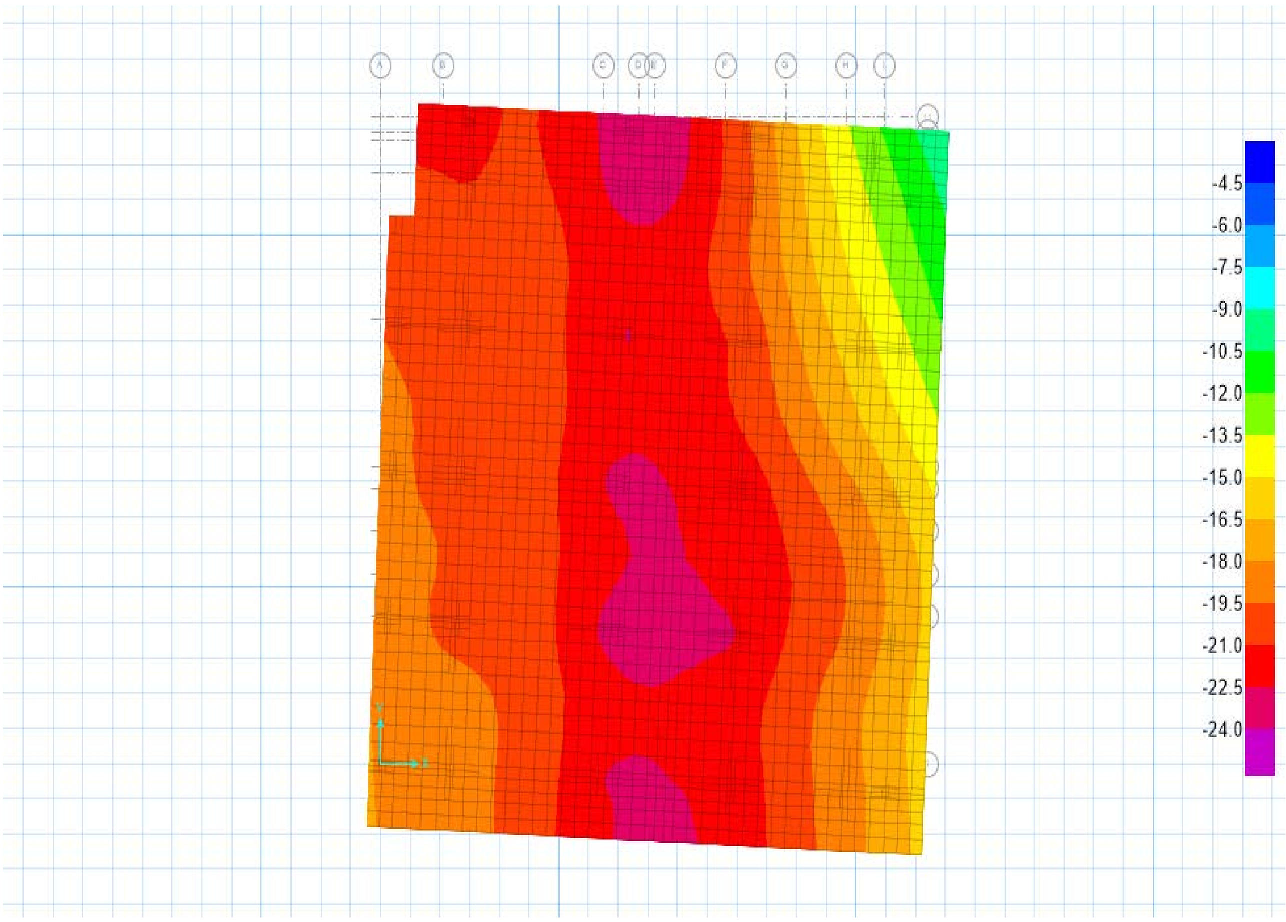


Fig.6.36 (Settlement)

Soil Pressure (Piled Raft 1350mm) 73.05 kN/m2 for 10.5 m length

Fig.7.37

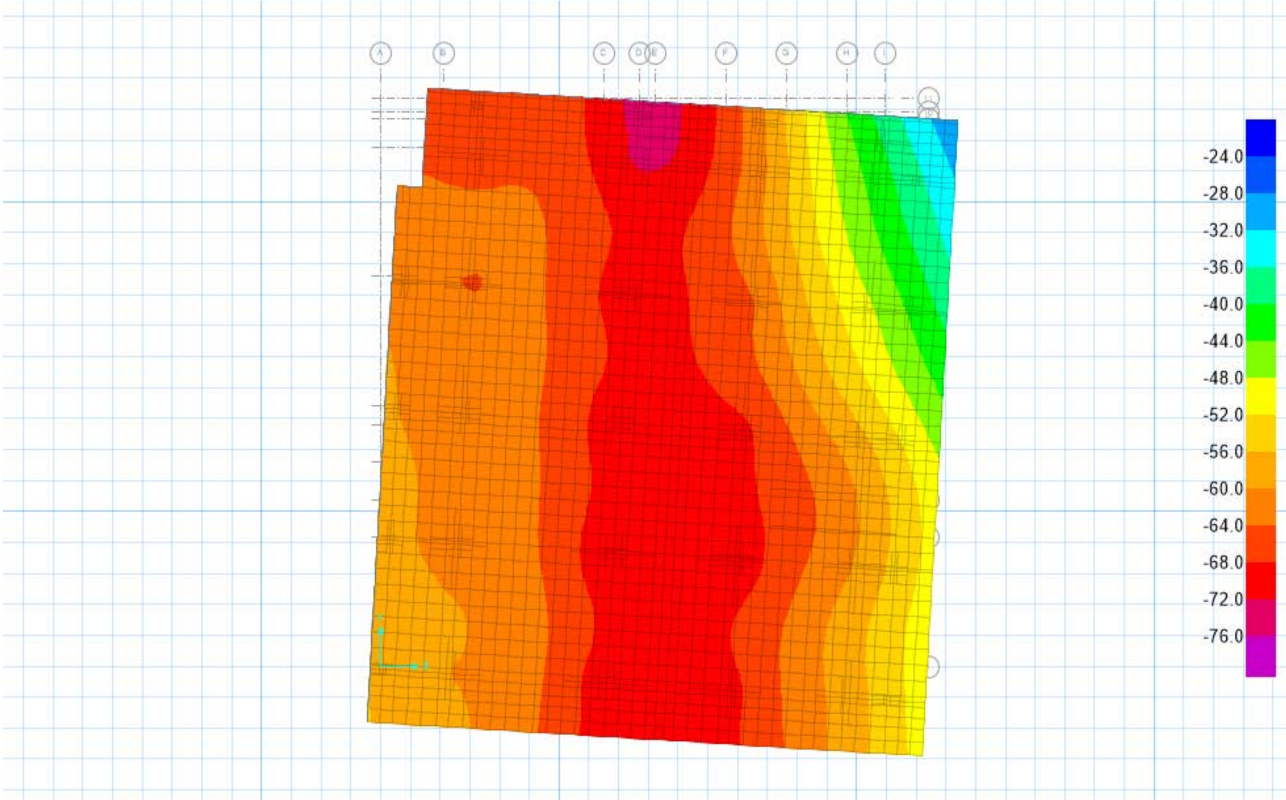


Fig.6.38 (Soil Pressure)

6.5 Result & Discussions

The Study indicate that piled raft Foundation concept has been significant advantages in comparison to conventional foundation for suitable soil. As settlement is one of the major criteria to decide type of foundation and piles can be used as settlement reducers. the settlement of raft and piled raft has been studies in this project. in this given problem the soil bearing capacity is very low , so we also study the effect of different type of piles (Single under reamed and Double under reamed piles) on soil pressure under the raft. we use pile resistance under raft as point spring resistance .The load sharing between raft and piles also has been studies by settlement of raft and it is found that the part of load shared by raft goes on decreasing with increasing pile capacity and length of pile, hence depending on the depth of piles.

In this study we also observed that for different pile configuration settlement is observed in SAFE software and utilities of piles has been observed.

In design office where computer facilities are available, rafts are being analysed by flexible approach considering the stiffness of the raft alone. The piles are being assumed to be equally loaded and hence piles of equal safe load capacity are provided throughout the raft. All other assumption of designing the raft only for vertical loads, neglecting the seismic effects, are being made.

This study has shown that the variation of moments in the rafts, while these factors are considered, are very substantial and the raft design, neglecting these factors, would not be safe. Even the piles will be subjected to loads much higher than their safe carrying capacity and consequently affect the structure.

However, it would be necessary to analyse the raft for all conditions of loading without making any assumption pointed out above and design the raft for worst values of moments also. It is clear that the practice of designing the raft on flexible approach and simultaneously making the assumption being made in conventional design is not a safe practice.

CASE 1 :-

(a) SUR Pile length 7.5 m (L/D = 18.75) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1875 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 182.8 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 38.2 mm for raft thickness of 1800 mm which quite high for piled raft and the minimum soil pressure under raft is 119.25 kN/m^2 for same thickness of raft which is far greater than 75 kN/m^2

(b) SUR Pile length 10.5 m (L/D = 26.25) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1875 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 238.0 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 33.2 mm for raft thickness of 1800 mm which is less than 40 mm but thickness of raft is quit higher for piled raft and the minimum soil pressure under raft is 103.9 kN/m^2 for same thickness of raft which is far greater than 75 kN/m^2

CASE 2 :-

(a) DUR Pile length 7.5 m (L/D = 18.75) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1875 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 279.5 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 30.6 mm for raft thickness of 1800 mm but thickness of raft is quit higher side and the minimum soil pressure under raft is 95.8 kN/m^2 for same thickness of raft which is greater than 75 kN/m^2

(b) DUR Pile length 10.5 m (L/D = 26.25) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1875 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 315.2.0 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 28.2 mm for raft thickness of 1800 mm which is less than 40 mm but thickness of raft is more for piled raft provision and the minimum soil pressure under raft is 88.2 kN/mm^2 for same thickness of raft which is greater than 75 kN/m^2

CASE 3 :-

(a) SUR Pile length 7.5 m (L/D = 18.75) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1500 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 182.8 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 31.2 mm for raft thickness of 1800 mm which quite high for piled raft and the minimum soil pressure under raft is 97.5 kN/m^2 for same thickness of raft which is not less than allowing SBC 75 kN/m^2

(b) SUR Pile length 10.5 m (L/D = 26.25) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1500 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 238.0 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 27.3 mm for raft thickness of 1800 mm which is less than 40 mm but thickness of raft is quit higher for piled raft provision and the minimum soil pressure under raft is 84.6 kN/m^2 for same thickness of raft which is far greater than 75 kN/m^2

CASE 4 :-

(a) DUR Pile length 7.5 m (L/D = 18.75) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1500 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 279.5 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 24.9 mm for raft thickness of 1800 mm but thickness of raft is quit higher side and the minimum soil pressure under raft is 77.8 kN/m^2 for same thickness of raft which is greater than 75 kN/mm^2

(b) DUR Pile length 10.5 m (L/D = 26.25) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1500 mm in both X- direction and Y - direction. the piles are of 400 mm diameter and has given capacity is 315.2 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 22.9 mm for raft thickness of 1800 mm which is less than 40 mm but thickness of raft is more for piled raft provision and the minimum soil pressure under raft is 71.5 kN/m^2 for same thickness of raft which is greater than 75 kN/m^2.

In this case we also found out that for 12 mm thickness of raft, the settlement of raft is 23.2 mm and soil pressure under the raft is 74 kN/m^2 which less than allowable limit of soil pressure (75 kN/mm^2).

CASE 5 (Raft 1350 mm):- Pile spacing in X- direction is 1650 mm and in Y - direction 1800 mm

(b) DUR Pile length 10.5 m (L/D = 26.25) In this case the raft size of 32.65m x 34.5m is supported by single under reamed piles at the spacing of 1650 mm in both X- direction and 1800 mm in Y - direction. the piles are of 400 mm diameter and has given capacity is 315.2 kN. the allowable settlement of pile is assumed 12 mm maximum and raft settlement of 40 mm. by observing this case we found that minimum settlement of raft is 23.4 mm for raft thickness of 1350 mm which is less than 40 mm and thickness of raft is quite suitable for piled raft provision and the minimum soil pressure under raft is 73.1 kN/m^2 for same thickness of raft which is less than 75 kN/m^2.

For the increasing numbers of piles of equal diameter, the total soil pressure and total settlement underneath the raft each to be decreasing for a similar loading and same raft and same soil properties. within the analysis of piled raft we tend to conjointly observed that load sharing by piles increasing with increasing of numbers of pile as a result of the soil bearing capability is incredibly low. the overall load on raft is concerning 15520 ton and in first final proposal total load shared by 395 piles is 80%.

6.6 Conclusions

In this study we found that in piled raft, the piles acts as settlement reducers but they also reduce soil pressure marginally in low bearing soils. The final proposal given to the consultant from our study that a raft with thickness of 1350mm and piles with 400mm diameter (DUR 10.5m length) at horizontal spacing 1.65 m and vertically spacing at 1.8 m has a safer side . The approach of piled raft with help of SAFE software carried out for column vertical loads Plus earthquake loads, that may lead more numbers of the piles to satisfy the soil pressure under the raft.

6.7 References

6.7.1 IS 2950 (P-I)-1981, " Indian Standard code of practice for design and construction of raft foundation, " BIS, New Delhi.

6.7.2 H.G. Poulos, " Simplified design procedure for piled raft Foundation." ASCE.

6.7.3.) Apurba Tribedi, Correlation between Soil Bearing Capacities and Modulus of Subgarde reaction," apurba,tribedi@bentley.com

6.7.4.) P.D. Long," Piled Raft - A cost effective Foundation Method for High Rises," Geotechnical Engineering journal of SEAGS & AGSSEA vol.41 no.3 sept2010

6.7.5.) A.M. ibrahim, " Pile raft foundation with piles as settlement reducer,"abdelazimin@yahoo.com

6.7.6.) H.G. Poulos," Piled raft foundation : design and applications," Geotechnique 51 no.2, 95-133 (2001)

6.7.7.) Balakumar V," A Design Method for Piled Raft Foundations," Simplex infrastructure Limited, Chennai, Tamil Nadu, India.

6.7.8.) H.G. Poulos (2001), " Methods of analysis of Piled raft Foundations," Internatoional Society of soil Mechanics and geotechnical Engineering

6.7.9.) S.C. Gupta, " Raft Foundation - Design and analysis with a practical Approach," New Age international, publishers 2012.

6.7.10.) Poulos H. G. and Davis E. H. (1980), Pile foundation analysis and design, John Wiley and Sons, New York

6.7.11.) Poulos H. G. (2001), "Piled raft foundation: design and application", *Geotechnique*, Vol. 51(2.

6.7.12.) Randolph M.F. (1994), " Design methods for pile group and piled-rafts", *Proc.* of the 13th International

6.7.13.) Viggiani, C. (2001). Analysis and Design of Piled Foundations. 1st Arrigo Croce Lecture, Rivista Italiana di Geotecnica, No.1/2001.

6.7.14.) Russo, G. (1998). Numerical Analysis of Piled Rafts International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 22, No. 6.

6.7.15.) Russo, G. and Viggiani, C. (1998). Factors Controlling Soil-Structure Interaction for Piled Rafts. Darmstadt Geotechnics, Darmstadt Univ. of Technology, No. 4.

6.7.16.) Poulos, H.G., Small, J.C., Ta, L.D., Sinha, J. and Chen, L. (1997). Comparison of some Methods for Analysis of Piled Rafts. In Proceedings of the 14th International Conference on Soil Mechanics and Foundation Engineering, Hamburg, Vol. 2.

6.7.17.) Randolph, M.F. (1983). Design of Piled Raft Foundations. Recent Developments in Laboratory and Field Tests and Analysis of Geotechnical Problems, Bangkok.

6.7.18.) Randolph, M.F. (1994). Design Methods for Pile Groups and Piled Rafts. In the Proceedings of the 13th International Conference on Soil Mechanics and Foundation Engineering, New Delhi, Vol. 5.

6.7.19.) Randolph, M.F. and Wroth, C.P. (1978). Analysis of Deformation of Vertically Loaded Piles. Journal of the Geotechnical Engineering Division, Vol. 104, No. 12, pp. Randolph, M.F. and

6.7.20.) Wroth, C.P. (1979). An Analysis of the Vertical Deformation of Pile Groups. Geotechnique, Vol. 29, No. 4.

6.7.21.) Randolph, M.F. and Clancy, P. (1994). Design and Performance of a Piled Raft Foundation. Geotechnical Special Publication No. 40, Yeung, A.T. and Felio, G.Y.