Major Project

on

Software for Analysis & Design of Pile Foundation

By

Rajani Kunal P.
(05MCL019)

DEPARTMENT OF CIVIL ENGINEERING
Ahmedabad 382481

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Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Rajani Kunal P.
(05MCL019)

Guide

Dr. G. N. Gandhi **Prof. N.C.Vyas**

DEPARTMENT OF CIVIL ENGINEERING
Ahmedabad 382481
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CERTIFICATE

This is to certify that the Major Project entitled "Software for analysis and design of Pile Foundation" submitted by Mr. Rajani Kunal P. (05MCL019), towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

(1) Dr. G. N. Gandhi (2) Prof. N. C. Vyas
Guide,
Professor,
Department of Civil Engineering,
Institute of Technology,
Nirma University.
Ahmedabad.

Prof. P. H. Shah
Professor and Head,
Department of Civil Engineering,
Institute of Technology,
Nirma University.
Ahmedabad.

Prof. A. B. Patel
Director,
Institute of Technology,
Nirma University,
Ahmedabad

Examiner

Examiner

Date of Examination

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Rajani Kunal P.
Roll No.05MCL019

ABSTRACT

Software has always satisfied almost all the needs of the user, and nowadays the use of computer has been done for all such applications and needs.

The work includes the study of static analysis of pile foundation considering the different types of soils such as clays with different consistency, sand with different density having different angle of internal friction and layers of sand and clay. It also includes different pile parameters such as shape (circular, square & rectangular), length, installation of the pile, spacing of piles in groups and pattern of the pile group. In addition to this the study also includes the analyses of pile foundation for different types of loads such as co-centric, eccentric and lateral loads. The analysis and design of single pile & group of pile considering the variation in parameters as above is also included. The design of single pile and pile group is also been included in this study. The pile cap analysis and design is also included in this study.

A computer program using C++ language is prepared to handle the various combinations of soil parameters and loads as described above. The programs give the skin resistance for each layer, base resistance and the ultimate bearing capacity of the pile and pile group for the given soil condition. The analysis & design program gives the number of piles, dimension of the pile, and spacing of piles in the pile group for various soil conditions. The study also includes & shows the reinforcement details for individual pile & pile group.

The validity of the program is checked with the manual calculations.

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ABBREVIATION NOTATION AND NOMENCLATURE

A_p	Sectional area of pile at base level;
A_s	Surface area of the pile;
a_q	Shape factor;
A	Area enclosing all the piles in the group;
A_g	Area of the pile group within the perimeter;
A_g	Sectional area of pile group;
A_{pc}	Area of the pile cap;
B_g	Width of the group;
b	Shorter Dimension of a rectangular column;
C_c	Compression index;
C	Unit Cohesion of soil;
C_u, C_P	Average cohesion at pile tip;
$\overline{C}$, $\overline{C}_u$	Average cohesion throughout the length of pile;
c_i	Unit cohesion of individual soil layer enclosing the pile;
d	Effective Depth;
D_f	Depth of pile;
D	Stem (pile) diameter;
d'	Depth of compressive reinforcement from the highly compressed face;
E	Young's modulus of pile material;
e_x	Eccentricity along x-axis;
e_y	Eccentricity along y-axis;
$e_o(i)$	Initial void ratio for i^{th} layer;
$\Delta e(i)$	Change of void ratio caused by the stress increase;
f	Shear resistance of soil along the vertical surface of the block;
f_s	Average ultimate friction of soil/unit area;
F_{ng}	Skin Friction of pile group;

f_{ck}	Characteristic cube compressive strength of the concrete;
H_i	Thickness of ith layer;
I	Influence factor ($1-L/8B_g$);
I_{xx}	Moment of inertia about x-axis;
I_{yy}	Moment of inertia about y-axis;
K	Lateral earth pressure coefficient;
K_1 & K_2	Constants from table 3.1 and 3.2, as per I.S 2911;
L	Depth of pile;
L_e	Length of pile embedment in soil;
L_c	Length of pile on which skin friction acts;
L_f	Free outstanding length of pile;
L_i	Thickness of the individual soil layer enclosing the pile;
L_1	Equivalent cantilever length;
M_u	Factored Moment;
m	Number of columns of piles in a group;
m_1	Reduction factor;
M_x	Total moment about x-axis $= Q * e_y$;
M_y	Total moment about y-axis $= Q * e_x$;
n	Number of rows;
n_1	No. of piles in the group;
N	SPT-N value;
$\overline{N}$	Averaged N value over the embedded depth D_f of the pile;
N_c, N_q, N_γ	Bearing capacity factors;
N_1	Corrected standard penetration number within the seat of settlement (apprx. = B_g below the tip);
P_g	Perimeter of the group;
P	Perimeter of area enclosing all the piles in the group;
P_u	Factored vertical load;
P_D	Effective overburden pressure at pile toe;

P_{Di}	Effective overburden pressure for the ith layer;
Q_l	Lateral load;
Q	The total vertical load acting on the pile cap;
Q_{ug}	Upper limit of pile group capacity, not exceeding the ultimate capacity of a single pile times the number of piles in the group;
q_{ult}	Ultimate bearing capacity of soil at the level of pile tip;
Q_{gu}	Ultimate load carrying capacity of pile group by block action;
Q_u	Ultimate bearing capacity of single pile;
Q_p	Total Point Bearing Resistance;
Q_s	Total Skin Friction Resistance;
q_p	Ultimate bearing capacity of soil;
q	Load intensity (Q_g/A_g);
Q_g	Load acting on the pile group;
$\overline{q}_0$	The average effective over-burden pressure acting along the embedded length;
R	Axial force in the pile under consideration;
s	Spacing of piles;
S_g	Settlement of group;
x	Distance from the centroid of the pile cap to pile about y axis;
y	Distance from the centroid of the pile cap to pile about x axis;
x_1	Distance of the considered pile from y-axis;
y_1	Distance of the considered pile from x-axis;
$\sum x_1^2$	Sum of the squares of the distances of all the piles from y-axis;
$\sum y_1^2$	Sum of the squares of the distances of all the piles from x-axis;
Z_i	The distance from the level of application of the load to the middle of clay layer i;
γD_f	Effective overburden pressure at the bottom;

γ	Effective unit weight of soil;
ϕ	Angle of internal friction;
α	Adhesion co-efficient;
δ	Angle of friction between the piles surface and the surrounding soil;
γ_1	Unit weight of soil within the block;
σ_o	Effective pressure;
$\Delta\overline{\sigma}_o$	Increase in effective pressure;
σ	Combined stress;
θ	$\tan^{-1}(d/s)$ in degrees;

1. INTRODUCTION

1.1 GENERAL

Foundation is that part of structure which transmits the load of the structure to the ground. It is the supporting part of the structure. It acts a connecting link between the structure and ground.

It is derived from the Latin word “fundare” (meaning to set or ground on something solid). It is required for distributing the loads of superstructure on a large area and it should be designed such that

- Soil below does not fail in shear.
- Settlement is within the allowable limit.

There are two types of foundations namely,

Shallow Foundation

Deep Foundation

The pile foundation is a type of deep foundation. A complete pile design project involves determination of pile capacity for given soil conditions to fix the diameter, length and judicious grouping of piles to transfer the upcoming load to soil below for safe functioning of the foundation system throughout its operating life and finally covering the pile with the properly design pile cap. Apart from their ability to transmit foundation loads to underlying strata, piles are also widely used as a means of controlling settlement and differential settlement. For the design of the pile, the designer has to come up with best possible option for the given conditions of the soil by considering the aspects such as bearing capacity, group action and design. The computer analysis of pile foundation seems to be the best option for it, because it can handle the combination of various soil conditions and pile parameters and load combinations. Therefore there exists the need for a software package which could analyze and design the pile foundation.

Current project aims to fulfill the above software requirement.

1.2 HISTORY AND DEVELOPMENT OF PILES

The first historical reference to piling was done by Herodotus, the Greek writer and traveler, who lived in the fourth century B.C. and is sometimes referred as "Father of History". According to his record, it was an African tribe called Peonions, lived in dwellings, erected on lofty piles driven into a lake bed. The piles were driven under some kind of communal arrangement, but later law had been made that when a man wished to marry, he had first to drive three piles.

Greek and Roman engineers used piles for shore works at the Mediterranean coast. In Britain, a Roman bridge spanned the Tyne at Corbridge, about 20 miles west of Newcastle on Tyne, using piles to support the construction. The piles used in this were block oak and were 3mts in length.

Amsterdam was founded about 1000 years ago, was build almost entirely on pile foundations of 15-20 meters of length. The Romans capped their piles with a mixture of stone rubble and concrete. Creasy (An Encyclopedia of Civil Engineering 1861) says that in Holland piling and capping by planking was still in use, with rough stones rammed between the planks. [1]

1.3 TERMINOLOGY

The terms are defined as per IS: 2911(Part I/Sec I) -1979. [2]

1.3.1 **Ultimate Load Capacity:-** The maximum load which a pile can carry before failure of ground (when the soil fails by shear as evidence from the load settlement curves) or failure of pile materials.

1.3.2 **Safe load carrying capacity:** - It is the load derived by applying a factor of safety on the ultimate load capacity of the pile or as determined in the pile load test.

1.3.3 **Factor of Safety:** - It is the ratio of the ultimate load capacity of a pile to the safe load of a pile.

1.3.4 **Allowable Capacity:-** The load which maybe applied to a pile after taking into account its ultimate load capacity, pile spacing, overall bearing capacity of the ground below the pile, the allowable settlement, negative skin friction and the loading conditions including reversal of loads.

1.3.5 Test Pile: - A pile which is selected for load testing and which is subsequently loaded for that purpose. The test pile may form a working pile itself if subjected to routine load test up to one and a half times the safe load.

1.3.6 Trial Pile: - One or more piles, which are not working piles, that may be installed initially to assess the load-carrying capacity of the piles are called trial piles. These piles are tested either to their ultimate bearing capacity or twice the estimated safe load.

1.3.7 Bearing Pile: - A pile formed in the ground for transmitting the load of a structure to the soil by the resistance developed at its tip and/or along its surface. It may be formed either vertically or at an inclination and may be required to take uplift.

1.4 CLASSIFICATION OF FOUNDATION:-

1.4.1 Shallow Foundation - According to Terzaghi [3], it is the one whose width is greater than depth. These are located just below the lowest part of the wall/column which they support. As per IS 6403:1981 it is a foundation whose width is greater than its depth is termed as a shallow foundation. The shearing resistance of the soil in the sides of the foundation is generally neglected

There are different types of shallow foundation:-

1.4.1.1 Spread/Isolated Footing: - A spread footing is provided to support an individual column. It might be circular, square, rectangular slab of uniform thickness.

1.4.1.2 Strip Footing: - It is provided for load bearing wall (continuous footing).

1.4.1.3 Mat/Raft Foundation: - It is large slab supporting a number of columns and walls under the entire structure, used to reduce the differential settlement on non-homogeneous soils.

1.4.1.4 Strap/Cantilever Footing: - It consists of two isolated footings connected with a structural strap or a lever.

1.4.1.5 Combined Footing: - This type of footing is provided when two columns are so closely spaced to each other that their individual footings would overlap. It is also provided when the property line is close to one column that a spread footing would be eccentrically loaded when it is kept within the property line. [3]

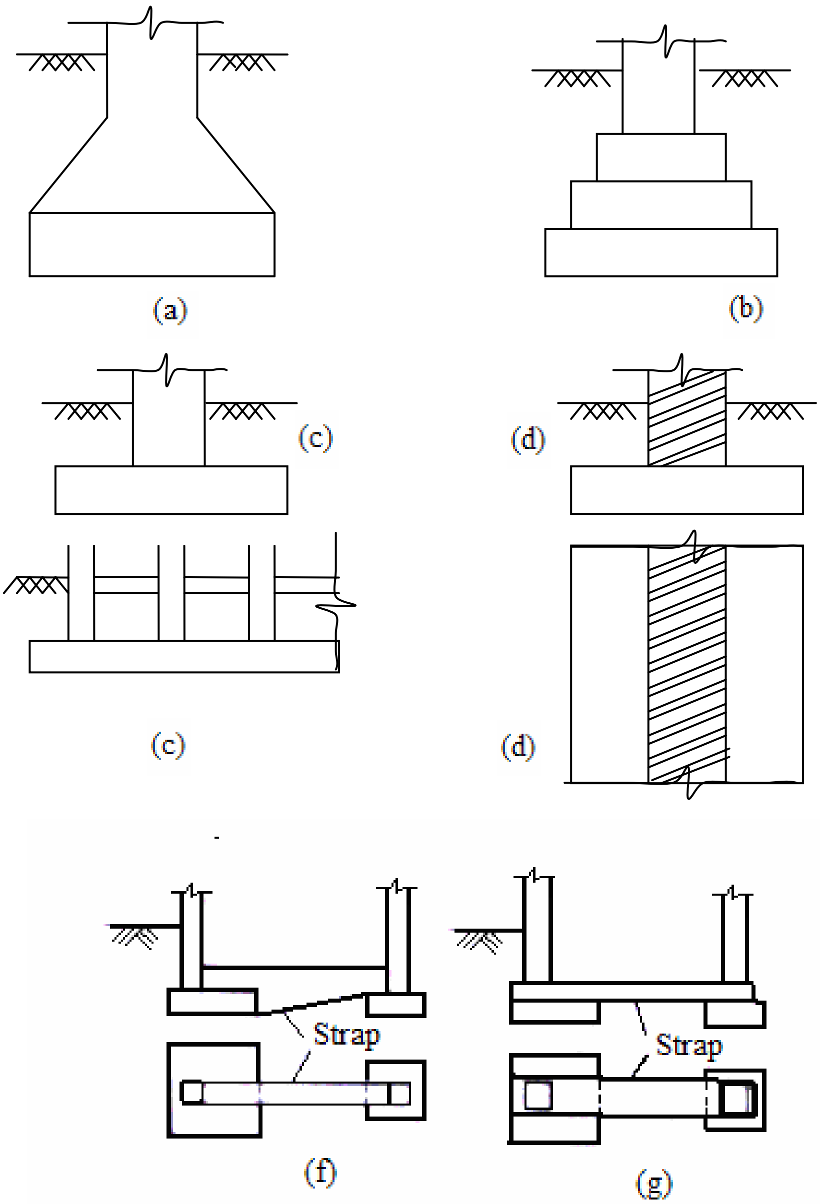


Fig 1.1 Types of shallow foundation: (A, B, C) Spread or Isolated footing, (D) Strip footing, (E) Mat/Raft foundation, (F, G) Strap foundation

1.4.2 Deep Foundation: - When the soil at/or near ground surface is not capable of supporting a structure, deep foundations are required to transfer the loads to deeper strata. As per Terzaghi, it is defined as foundation whose depth is greater that its width. [3]

Following are the different types of deep foundation:-

1.4.2.1 Piles: - It is slender structural member. It is either driven into soil (or) formed in-situ by excavating and filling it with concrete.

1.4.2.2 Piers: - It is a vertical column of relatively large cross-section than pile. A Cast in-situ pile greater than 0.6 m diameter is called pier.

1.4.2.3 *Caissons:* - Its shape is of hollow prismatic box type, which is built above the ground level and then sunk to required depth as a single unit. [3]

1.5 NECESSITY OF PILE FOUNDATION:-

- ❖ When the strata just below the ground surface is highly compressible and very weak to support the load.
- ❖ When the plan of structure is irregular to it's outline and load distribution. It would cause non-uniform settlement.
- ❖ When horizontal forces in addition to vertical loads are to be resisted.
- ❖ When soil layer immediately below the structure are subjected to scour.
- ❖ When structure is subjected to uplift, overturning moments.
- ❖ Where expansive soils, such as black cotton soil exist, which swells or shrink due to change in water content. [3]

1.6 CLASSIFICATION OF PILES: -

1.6.1 According to material used :-

1.6.1.1 *Steel Piles:* - They are either in the form of thick pipes or rolled steel H-sections. They are driven into the ground with their ends open or closed. [3].

1.6.1.2 *Concrete Piles:* - These types of piles are pre-cast or cast in-situ, Cased/uncased. Pre-cast concrete piles are prepared in a factory or a casting yard. Pre-cast piles can also be pre-stressed using high strength steel pre-tensioned cables. Cased piles are constructed by driving a steel casing into the ground and filling it with concrete and reinforcement. Uncased pile is constructed by driving the casing to the desired depth and gradually withdrawing casing when fresh concrete is filled. [3].

1.6.1.3 *Timber Piles:* - They are made of tree trunk. Steel shoes are provided to prevent damage during driving. To avoid damage to the top of the pile, metal band/cap is provided. Splicing of timber piles is done using a piped sleeve/metal straps and bolts. They were used in China, as far back as 200 B.C. by the bridge builders of the Han Dynasty. Timber piles subjected to wetting and drying cycles are much less durable in comparison of the permanently submerged piles. Where permanent submergence was not possible, the piles above water are coated with tar. Iron shoes were also fitted to piles where driving is involved into stony layers. [3,4].

1.6.1.4 *Composite Piles:* - It is made up of two types of materials. Lower portion is of steel and upper portion is of cast in-situ concrete. These are rarely used, due to improper joint between the two dissimilar materials. [3]

1.6.2 Based on Mode of Transfer of Loads:-

1.6.2.1 *End Bearing Piles:* - They transfer the load through their bottom tips in the weak material to a firm stratum below acting as a column. These types of piles are also known as point-bearing piles.`

1.6.2.2 *Friction Piles:* - They transfer the load through skin friction developed between the embedded surface of the pile and the surrounding soil. In clayey soils the load is transferred by adhesion and not friction along the surface of pile shaft. These types of piles are also called "floating piles". When a tapered pile is used for friction load transfer it results in an increased normal pressure in comparison to the pile without taper, which consequently increases the frictional component of the shearing resistance. So tapered piles are very effective is sands, but in clay there is a marginal difference between the capacities of prismatic and tapered piles, as the adhesion component of shearing resistance in independent of the normal pressure. (Fig 1.2)

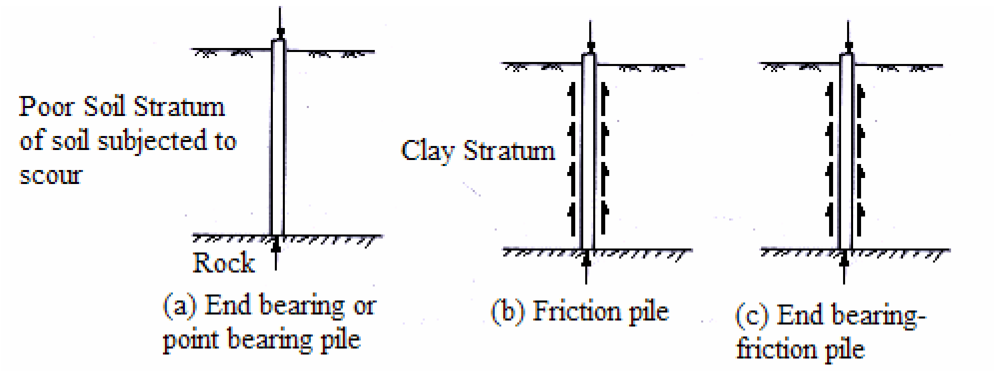


Fig 1.2 Types of pile according to the mode of transfer of load

1.6.2.3 Combined End Bearing and Friction Piles: - Load is transferred by the combination of end bearing at the bottom of the pile and friction along the surface of the pile shaft. [3]

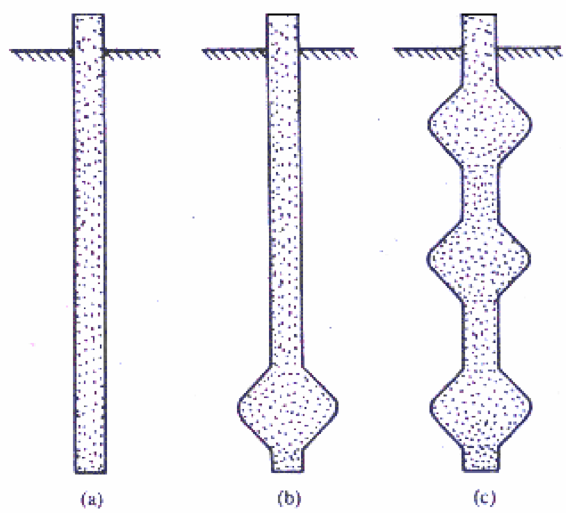
1.6.3 Based on Method of Installation: -

1.6.3.1 Driven Piles: - These piles are driven into soil by applying blows of heavy hammer. [3]. Steam powered hammer had first been used to the driving of piles in Britain by John Rennie in 1801 at the bell docks at the entrance of London Docks. In 1846, compressed-air hammer was proposed by Clarke, freeman and varley. In about 1870 pile driven by gun powder was launched. Currently most piles are driven by steam or diesel hammers. [1]

1.6.3.2 Driven and Cast in-situ Piles: - This method was developed by R.J. Beale in 1903, in which piles are formed by driving a casing with a closed bottom end into the soil. The casing is later filled with concrete (Fig 1.3)

1.6.3.3 Bored and Cast in-situ Piles: - Drilling a hole into the ground and then filling it with concrete in presence of reinforcement. This idea was brought by A. A. Raymond in 1897. It is called Raymond pile system.

1.6.3.4 Screw Piles: - It was first used in the foundation of maplin sands lighthouse in Thames Estuary in 1838. These type of piles are screwed into the soil. [3]



A. *Cast-in-situ* (a) straight bored, (b) single bulb, and (c) multi bulb piles.

Fig 1.3 Cast –in-situ piles

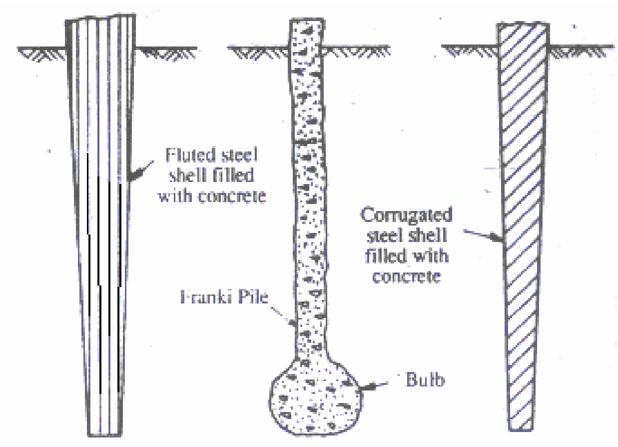


Fig 1.4 Driven and cast-in-situ pile.

1.6.4 Based on Use: -

1.6.4.1 *Load Bearing Piles:* - Used to transfer the load of a structure to a suitable stratum by end bearing, or by friction or by both.

1.6.4.2 *Compaction Piles:* - Driven into loose granular soils to increase the relative density. The bearing capacity of the soil is increased due to densification caused by vibrations (Fig 1.5).

1.6.4.3 *Tension Piles:* - They are used to anchor down structures subjected to hydrostatic uplift forces/overturning forces (Fig 1.5) e.g. for Chimneys, Water Towers etc.

1.6.4.4 *Sheet Piles:* - They form a continuous wall which is used for retaining earth.

1.6.4.5 *Fender Piles:* - They are sheet piles used to protect water front structures from impact of ships and vessels.

1.6.4.6 *Anchor Piles:* - These piles are used to provide anchorage to sheet piles. These piles provide resistance against, horizontal pull for a sheet pile wall. [3]

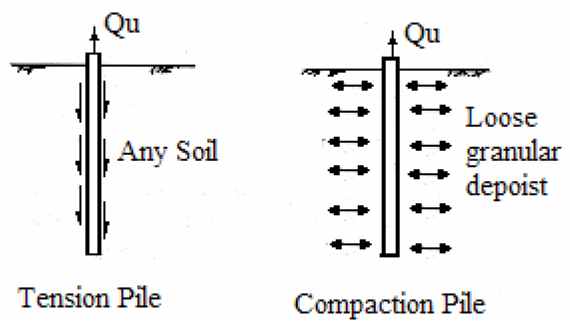


Fig 1.5 Tension and Compaction pile

1.6.5 Special Types of Piles :-

1.6.5.1 Under-reamed Piles: - Piles bored into materials other than bed rock are often enlarged near the bottom to act as anchor against uplift due to swelling pressure (Fig 1.3b, 1.3c, & 1.4b). They also increase the bearing area. These piles are commonly referred to as Belled Piers. The greatest advantage of under-reamed pile is that the resistance against uplift will not be affected by loss of friction in zone unaffected by wetting. The disadvantage of the under-reamed pile is the uncertainty of its bulb hole diameter and difficulty in full clean out and inspection of the bulb.

1.6.5.2 Granular Piles: - Granular piles or stone columns are made of stone aggregates or gravel 12-75mm in size by deep vibratory methods. These piles have been successfully used for strengthening of soft clayey soil deposits either single or in small groups to support large rafts or embankments. These types of piles are well known in France as early as in 1930. They were used first for heavy foundations of iron works at the artillery arsenal in Bayonne.

1.6.5.3 Skirted Granular Piles: - This consists of cast in-situ concrete footing placed on a soil plug. The soil plug in turn is reinforced by granular piles which is subsequently confined by a rigid diaphragm walled called skirt.

1.6.5.4 Bored Pre-cast Piles: - As the name implies they are the pre-cast piles installed in pre-bored holes. Piles of this type combine the advantages of bored and pre-cast piles.

1.6.5.5 Pedestal Piles: - Pedestal piles have been introduced by CBRI, India as a substitute of under-reamed piles, for light structures and buildings. They are specially recommended for foundation on expansive clays.

1.6.5.6 Micro Piles: - It is drilled and grouted pile with centrically placed steel reinforcing member consisting of single or multiple bars. This method uses an outer pipe casing to stabilize the drill hole and an inner drill rod for cleaning out the casing or drilling further into harder ground. After placing the centric rein-forcing element, single or multiple bars and filling the casing with cement grout, the casing is slowly pulled under constant pressure grouting and partly left in the ground to prevent grout loss in grounds with large voids. These piles are ideally suited for piling in restricted area and/or low headroom and close to the existing structures such as in case of under-pinning.

1.6.5.7 *Lime Piles:* - It was first developed in Sweden. In these, mechanical augers makes a bore hole in the ground and simultaneously dry unslaked lime, is introduced through the drill rod, mixing it thoroughly with the soils as the auger advances forward. The lime improves the load carrying capacity of the column through ion exchange.

1.6.5.8 *Expander Body Piles:* - This type of pile is similar to micro-pile and was used in Sweden for underpinning. It uses a folded thin steel sheet which is rapped around the lower part of the pile. The sheet can be inflated in the ground after the pile has been driven /placed in a drilled bore-hole. The piles are placed in holes drilled through the outside rubble/masonry walls for which percussion drilling is normally required. After expansions of the base and filling of the pile shaft with cement grout, the shafts are grouted to the rubble wall.

1.7 BEHAVIOR OF THE PILE UNDER LOAD: -

The calculation of load capacity is based on the load carrying capacity of pile available short time after installation. The reliability of these calculations is assessed by a loading test which is again made at a relatively short time after installation. When a pile is subjected to a successive compressive loading at a rapid/moderately rapid rate of application, the resulting load-settlement curve is formed (Fig. 1.6 a). Initially the pile-soil system behaves elastically. There is straight-line relationship up to some point A on the curve and if the load is released beyond point A on the curve and if the load is released at any stage up to this point the pile head will rebound to its original level. When the load is increased beyond point A there is yielding at, or close to, the pile-soil interface and slippage occurs until point B is reached, when the maximum skin friction on the pile shaft would have been mobilized. If the load is released at this stage the pile head will rebound to point C, the amount of permanent set being the distance 'OC'. The moment required to mobilize the maximum skin fiction is quite small and is only of the order of 0.3-1% of the pile diameter. The base resistance of pile requires a greater downward movement for its full mobilization, and the amount of moment depends on the diameter of the pile. It may be in the range of 10-20% of base diameter. When the stage of full mobilization of the base resistance is reached (point D in Fig 1.6a) the pile plunges downward without any further increase of load or small increases in load produce increasingly large settlements. [5]

The transfer of load from the pile to soil at each stage of loading can be seen in the (Fig 1.6b) in which strain gauges are installed at various points along the pile shaft to deduct the compressive load at each level. When Q_1 load acts on the pile head, the axial load at ground level is also Q_1 which is distributed as friction load within a length of pile L_1. The lower section A_1B of pile will not be affected by this load. When the load is increased to Q_2, the whole load is carried by skin friction of the pile and there is very little or no transfer of load to the toe of the pile (Fig 1.7). When the load is further increased than Q_2, pile shaft has carried maximum of its skin friction and the pile toe will be carrying some load (Fig 1.7). There is no increase in the load transferred in skin friction say at some load Q_m but the base load will still go on increasing till the soil fails by punching shear failure (Fig 1.7). [6]

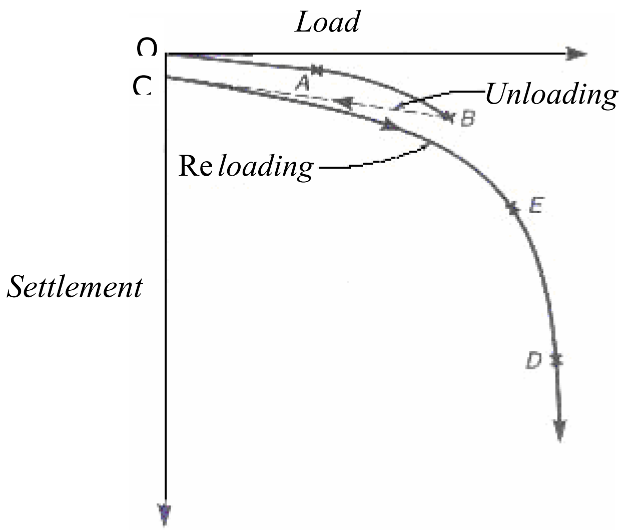


Fig 1.6a Load-settlement curve for compressive load to failure on pile [5]

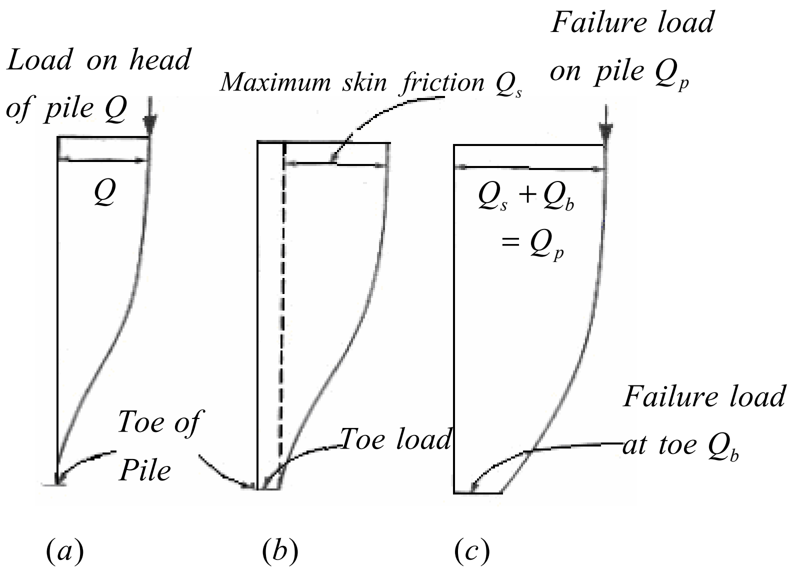


Fig 1.6b: Transfer of load from the pile to soil

(a) At point A in load-settlement curve in fig 1.6a

(b) At point A in load-settlement curve in fig 1.6a

(c) At point D in load-settlement curve in fig 1.6a [5]

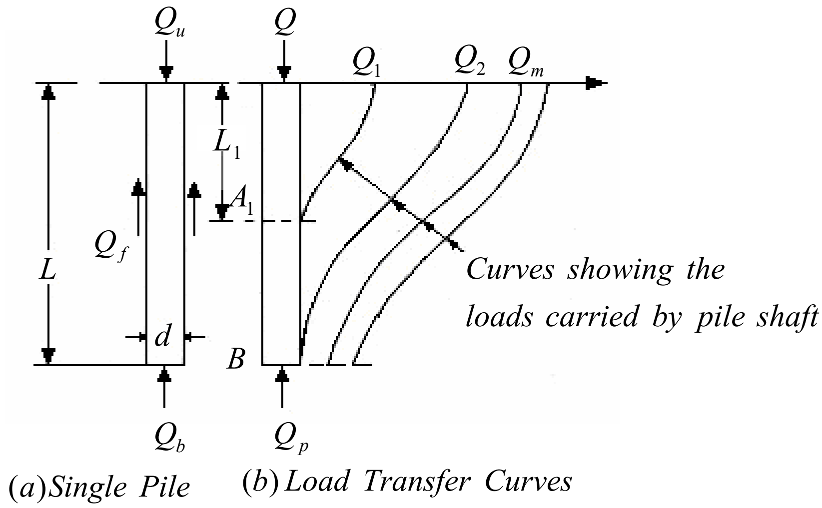


Fig 1.7 Load transfer mechanism [6]

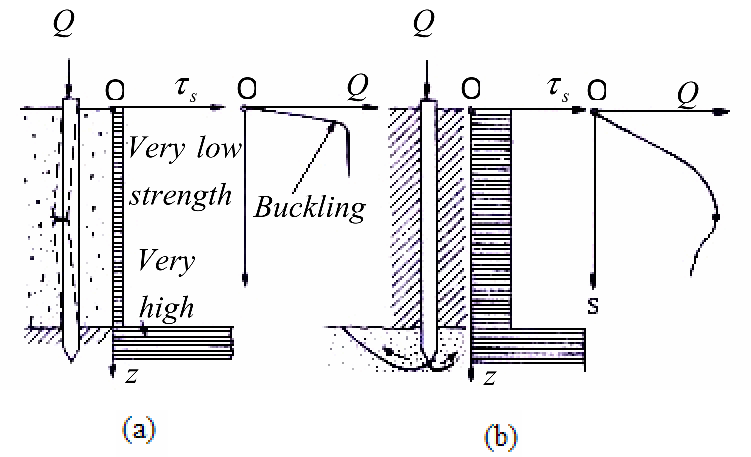
The type of load-settlement curve for a pile depends on the relative strength values of the surrounding and underlying soil. The following are the four types of failures.

- When the soil around the soil is too weak to exert any confining pressure or lateral resistance: In such cases, the pile fails like a compressed, a slender column of the same material; after a more or less elastic compression buckling occurs (Fig 1.8a).

- When the pile penetrates through layers of soil having low shear strength down to a layer having a high strength and the layer extending sufficiently below the tip of the pile: At the ultimate load, there will be base general shear failure at the tip of pile, since the upper layer does not prevent the formation of failure surface. The effect of the shaft friction is rather less, since the lower dense layer prevents the occurrence of excessive settlements. Therefore, the degree of the mobilization of shear stresses along the shaft is low. The load settlement diagram is of the shape typical for a shallow footing on the dense soil (Fig 1.8b)

- When the shear strength of the surrounding soil is fairly uniform, there are chances of punching failure to occur (Fig 1.8c). In this there is no vertical tangent in the diagram and also there is no definite failure load. The load will be carried by point resistance as well as by skin friction. According to Vesic 1967, there occurs only punching shear failure in the deep foundations irrespective of the density of the soil so long the depth-width ratio L/B is greater than 4.

- This is the very rare case where the lower layer is weaker. In such cases, the load will be carried mainly by shaft friction, and the point resistance is almost zero. The load-settlement curve (Fig 1.8d) shows a vertical tangent which represents the load when the shaft friction has been fully mobilized.



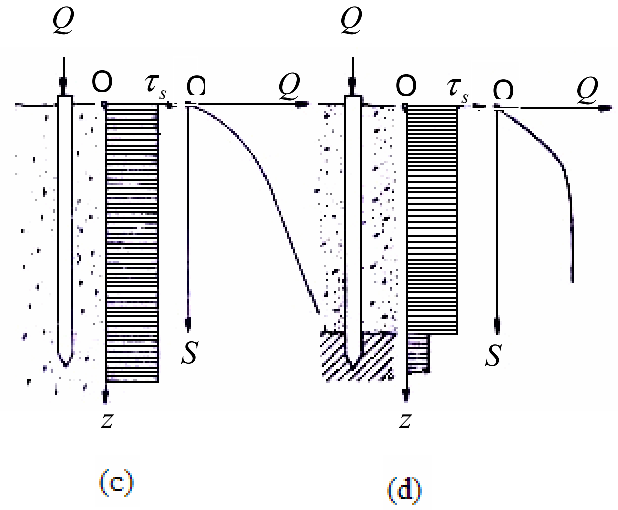


Fig 1.8 Types of failure of pile [6]

1.8 THE ULTIMATE BEARING CAPACITY:-

Soil mechanics theory postulate that the skin friction on a pile shaft can be determined by a simple relationship between the coefficient of earth pressure at rest, the effective over-burden pressure and the drained angle of shearing resistance of the soil. Similarly the end-bearing resistance of the pile can be calculated by soil mechanics theory based on the undisturbed shearing resistance of the soil surrounding it.

1.8.1 Static or soil mechanics approach

1.8.1.1 General Theory

The net ultimate Load Q_u is shown below

$$Q_u = Q_p + Q_s \quad \text{... (1.1)}$$

$$= q_p A_o + f_s A_s \quad \text{... (1.2)}$$

where,

q_p = Tip-point unit resistance of pile;

A_p = Sectional area of pile at base level;

f_s = Avg. ultimate friction of soil/unit area;

A_s = Surface area of the pile.

1.8.1.2 Determination of q_p :-

1.8.1.2.1 *Bearing Capacity Equation*

$$q_p = CN_c + \gamma D_f N_q + .5B\gamma N_\gamma \quad \text{... (1.3)}$$

where,

C = Cohesion of soil;

D_f = Depth of Pile;

B = Width/Diameter of Pile;

$\gamma\ D_f$ = Effective overburden pressure at the bottom;

$N_c, N_q,\ N_\gamma$ = Bearing capacity factors.

as for sand C = 0 ,

$$q_p = \gamma\ D_f\ N_q\ + 0.5B\gamma N_\gamma \quad \text{... (1.4)}$$

Since for piles, B is very small and D is large, contribution of term $0.5B\gamma N_\gamma$ will be very small and can be neglected. The value for the N_q depends on angle of internal friction (ϕ) value and it can be taken from (Fig 1.10). The values given by Berezantzev (Fig. 1.12) are quite dependable and are generally used [3].

The factor N_q determined by terzaghi are applicable to Shallow foundations and can't be applied to deep piles because D_f >B. Berezantzev, Khristoforv, and Golubkov (1961) have developed some empirical values, depending on ϕ and D_f/B ratio, for evaluating this factor N_q for driven piles, as given in Table 1.1

Table 1.1 Value of N_q for driven pile

ϕ in degrees	Values of N_q	
	For D_f /B = 25	For D_f /B = 50
28	12	9
30	7	14
32	25	22
34	40	37
36	58	56
38	89	88
40	137	136

For Clay (ϕ=0)

$$q_p = CN_c + 0.5B\gamma N'_\gamma \qquad \text{... (1.5)}$$

where,

N_c = bearing capacity factor, generally taken as 9.

$$q_p = CN_c + 0.5B\gamma(N_\gamma - 1) \qquad \text{... (1.6)}$$

1.8.1.2.2 Terzaghi's Equation:-

For Sand

$$q_p = a_q \gamma D_f N_f \qquad \text{... (1.7)}$$

where,

a_q = shape factor = 1.3

Thus,

$$q_p = 1.3\gamma D_f N_q \qquad \text{... (1.8)}$$

Here N_q is calculated considering the ϕ.

ϕ<28° = General shear condition.

ϕ=28°-36°= Mix shear condition.

ϕ>36° = Local shear condition.

1.8.1.2.3 Vesic Equation:-

For Sand

$$q_p = a_q \gamma_f N_q \qquad \text{... (1.9)}$$

where,

a_q = shape factor = 3

$$q_p = 3\gamma_f N_q \qquad \text{... (1.10)}$$

Here in this equation N_q is calculated according to the equation

$$N_q = e^{\{3.8\phi \tan\phi)}[\tan^2(45+\phi/2)] \qquad \text{... (1.11)}$$

Where, ϕ in exponential next to the numeric value has to be taken in radian and other values are to be taken in degrees.

1.8.1.2.4 Meyerhof's method:-

For Sand

The point bearing capacity q_p of a pile generally increases with the depth of embedment in the bearing stratum. Pile is considered as circular foundation. It reaches a maximum value at an embedment ratio of (D_f /B) $_{cr.}$ Beyond the critical value of (D_f /B)$_{cr}$ the value of q_p remains constant, equal to the limiting q_l . The critical ratio (D_f /B)$_{cr}$ depends on upon the soil friction angle (ϕ). [3]

Once the value of ratio has been determined, the following procedure is used to estimate bearing capacity.

i. Determine the actual (D_f /B) ratio for the pile.

ii. Determine N_q for (D_f /B) ratio from the Fig. 1.9

iii. Determine the point resistance Q_p

$$Q_p = A_p \gamma D_f N_q <= A_p q_l \qquad \text{... (1.12)}$$

$$q_l = 50 N_q \tan\phi \qquad \text{... (1.13)}$$

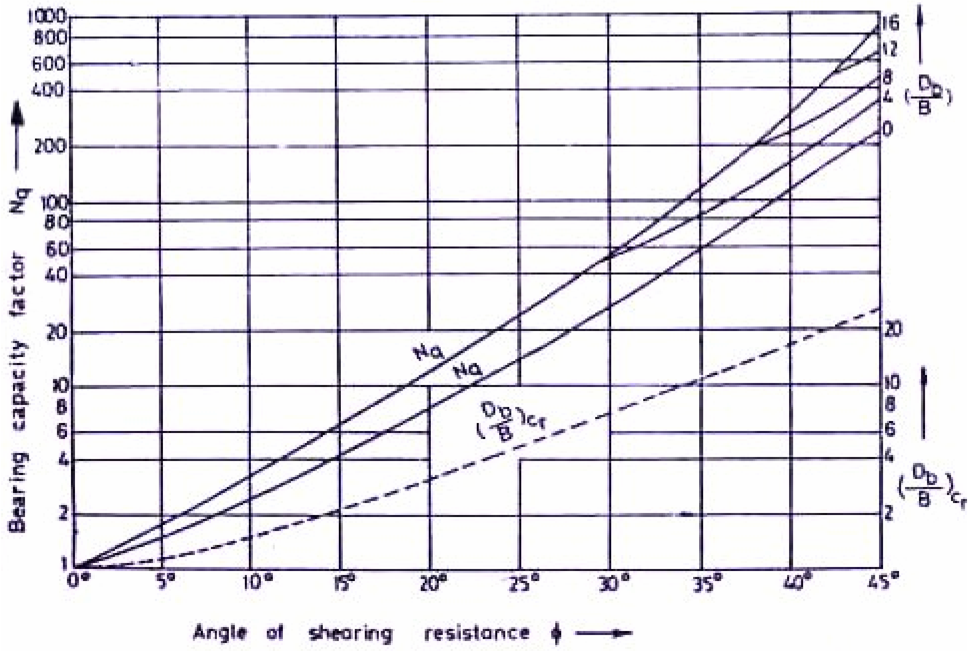


Fig 1.9 N_Q Value by meyerhof [3]

The bearing capacity factor N_q, is a function of ϕ. There is a great variation in the values of N_q derived by different investigators as shown in the (Fig 1.10). comparisons of observed base resistance of piles by Nordlund (1963) and Vesic (1964) have shown that N_q values established by Berezantsev (1961) shown in (Fig 1.10b), which take into account the depth to width ratio of the pile most nearly conform to the practical criteria of pile failure.

For Clay (ϕ = 0)

Driving of piles in clay stratum causes the lateral as well as vertical movement of the soil surrounding it. The upward movement of the soil causes the ground surface to heave around the top of the pile. This reduces the bearing capacity of the neighboring pile. The soil gets completely remoulded due to the driving action. The load is transferred to the soil pores as pore pressure in clay.

The dissipation of the pore pressure will take few months and hence the load carrying capacity of the pile in clay increases with the passage of time. There will be consequently increase in Φ and in skin friction due to the dissipation of the pore pressure.

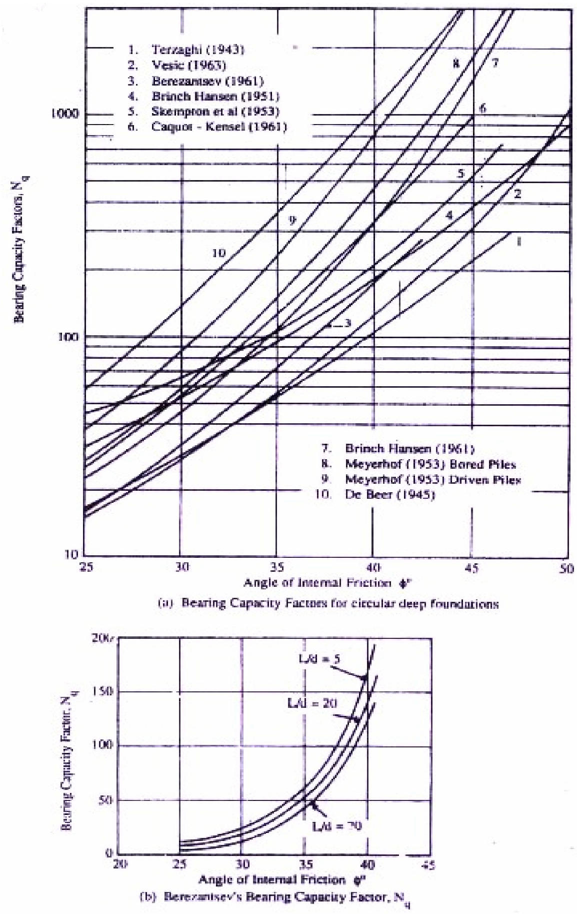


Fig 1.10 Bearing capacity factor N_q by various investigators

for deep foundations [6]

In bored piles, very small layer about 1 cm will get remoulded during boring. Due to the seepage of the pore water flowing from soil towards the hole, there will be softening of the surrounding soil and also the wet concrete poured in the hole causes wetting and softening of the contact soil. Thus soil reduces its shear strength, which will reduce the skin friction and hence reducing the load carrying capacity.

Due to such soil behavior during pile installation, it is very difficult to precisely estimate the load carrying capacity analytically. However a rough estimate can be made on the basis of the equations worked out by investigators, supported by empirical factors.

Ultimate Bearing Capacity

$$q_p = C_u N_c \qquad \text{... (1.14)}$$

Where,

N_c = 9 for piles in clay, skemp0ton's N_c value for (D/B) > 4

C_u = Average cohesion at pile tip.

N_c = 5.7 to 8.2 for expansive clays,

N_c = 7.4 to 9.3 for insensitive clays

Limitation of the above method: -

- The equations (1.12, 1.13 & 1.14) are valid only till D_f is less than a certain maximum value. Roughly equaling to 15B-20B, below this value the values of q_f and f_s won't change. This is caused to the arching of the soil around the lower part of pile.
- Live load of pile cannot be determined with above two equations.
- These equations are used for the driven piles to smaller depth of (10B -15B).

1.8.1.3 Determination of f_s :-

1.8.1.3.1 Bearing capacity equation

For clay

$$f_s = \alpha .\overline{C_u} \quad \text{... (1.15)}$$

where,

α **=** coefficient called adhesion

$\overline{C_u}$ = is the undrained shear strength (cohesion) of the clay, average over the entire depth of the pile. The biggest difficulty in using this equation is the real difficulty faced in precisely evaluating $\overline{C_u}$, because it varies considerably over the entire depth of pile. [8].

For Sand

$$f_s = K \ \overline{q}_0 \tan \delta \quad \text{... (1.16)}$$

where,

$\overline{q}_0$ **=** the average effective over-burden pressure acting along the embedded length. (γD_f /2)

δ = angle of friction between the piles surface and the surrounding sand, and can empirically be taken as equal to 0.75ϕ for concrete piles. [8]

K = Lateral earth pressure *coefficient*.

1.8.1.3.2 Tomlinson's α-Method.

For clay

See equation (1.15)

Tomlinson has given the values of ɑ in relation to $\overline{C_u}$ for three types of cases. They are.

Case 1 : Piles driven through sands or sandy gravels into stiff clay strata.

Case 2 : Piles driven through soft clay into stiff clay strata.

Case 3 : Piles driven into a firm to stiff clay without any overlying strata.

The values of ɑ vary with C_u with L/d ratios [6]

It must be emphasized that the above graph shows design curves which can take into account all the uncertainties in the method of calculation and variation in the adhesion factor that are known to occur in identical piles on the same site. The adhesion factors in the above graph are applicable to tapered piles, where the tendency is to close up the gap around the upper part of the shaft and to increase the consolidation of a dragged-down soft clay skin. [5].

The value of α depends upon the consistency of the clay. For normally consolidated clays, the value of α is taken as unity.

The ultimate bearing capacity of the piles in different soils is as follows:-

For Sand,

$$Qu = A_p \gamma D N_q + K\overline{q}_o \tan \delta A_s \qquad \text{... (1.17)}$$

For Clay,

$$Qu = A_p . N_c . C_u + \alpha . \overline{C}_u . A_s \qquad \text{... (1.18)}$$

For piles in clays, it is customary to adopt two different values of safety factors for base resistance (say F1) and for shaft resistance (say F2). Generally, a higher value, say 3 is adopted for the base resistance, and 1-1.25 for the shaft resistance. Higher value of factor of safety for base resistance than that for shaft resistance is chosen, since the shaft resistance gets fully mobilized at smaller deformation.

1.8.1.4 I.S. Code Method

1.8.1.4.1 Piles in Granular Soils

According to IS: 2911 – 1979 the value of δ, may be taken equal to ϕ . For driven pile in loose to medium sands, the recommended value of K is between 1 and 3 and the N_q factor value has to be taken from the graph (Fig 1.11) recommended by Vesic. N_γ Can be taken for general shear failure according to IS: 6403-1971. These values are given in Table 1.2.

As per IS: 2911 – 1979 ultimate bearing capacity can be determined by following formula:

$$Qu = A_p(0.5D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} K P_{Di} \tan\delta \qquad \text{... (1.19)}$$

where,

A_p = Cross-sectional area of pile toe in cm^2;

D = Stem diameter in cm;

γ = Effective unit weight of soil at pile toe in kg/cm^3;

P_D = Effective overburden pressure at pile toe in kgf/cm^2;

N_q = Bearing capacity factor depending upon the angle of internal friction ϕ at toe (Fig1.11);

N_γ = Bearing capacity factor taken from Table 1.2

$\sum_{i=1}^{n}$ = Summation for n layers in which pile is installed;

K = Coefficient of earth pressure;

P_{Di} = Effective overburden pressure in kgf/cm^2 for the ith layer where i varies from 1 to n;

δ = Angle of wall friction between pile and soil, in degrees (may be taken equal to ϕ); and

A_{si} = Surface area of pile stem in cm^2 in the ith layer where i varies from 1 to n.

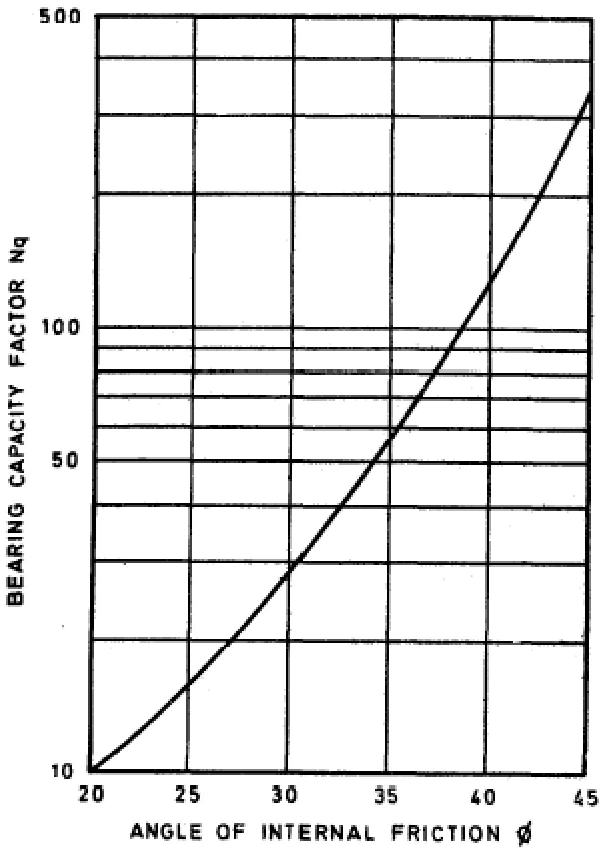


Fig 1.11 Bearing capacity factor N_q

1.8.1.4.2 Piles in Cohesive Soils

As per **IS: 2911 – 1979** ultimate bearing capacity (Q_u) in cohesive soil can be determined by following formula:

$$Qu = A_p C_p N_c + A_s \alpha \overline{C} \qquad \dots (1.20)$$

where,

A_p = Cross-sectional area of pile toe in cm^2;

N_c = Bearing capacity factor from Table 1.2, usually taken as 9;

C_P = Average cohesion at pile tip in kgf/cm^2;

α = Reduction factor;

$\overline{C}$ = Average cohesion throughout the length of pile in kgf/cm^2;

A_s = Surface area of pile shaft in cm^2.

The values of α may be taken depending upon the consistency of the soils, which are shown in the Table 1.3. Generally the value of α is taken according the value of cohesion.

Table 1.2 Bearing capacity factors (N_c , N_γ) [7]

ϕ (Degrees)	N_γ	N_c
0	0.00	5.14
5	0.45	6.48
10	1.22	8.35
15	2.65	10.98
20	5.39	14.83
25	10.88	20.72
30	22.40	30.14
35	48.03	46.12
40	109.41	75.31
45	271.76	133.88
50	762.89	266.89

Table 1.3 Adhesion factors

Consistency	C $Value$ Kg/cm^2	N $Value$	$Value$ of α
Soft to very soft	<0.5	< 4	1
Medium	0.5-1.0	4 to 8	0.7
Stiff	1.0-2.0	8 to 15	0.4
Stiff to hard	>2.0	> 15	0.3

For working out safe load a minimum factor of safety 2.5 should be used. α may be taken to vary from 0.5 to 0.3, depending upon the consistency of the soil. Higher values up to 1 may used for softer soils, provided the soil is not sensitive.

1.8.1.5 Standard Penetration Test N value:-

The values of q_p and f_s are determined by using the empirical correlation developed by Meyerhof (1976) between them and the SPT-N values.

For Driven Piles

$$q_p = 40N(D/B) \quad \text{... (1.21)}$$

$$f_s = 2\overline{N} \quad \text{... (1.22)}$$

Where,

N = SPT-N value in the vicinity of the pile base.

$\overline{N}$ = It is the averaged value over the embedded depth D_f of the pile.

For Bored Piles

The value of q_p and f_s from equation (1.21) should be multiplied $(1/3)$ and (1/2) respectively. [8]

1.9 PILE GROUP

Pile is not used singularly beneath a column or a wall, because it is extremely difficult to drive the pile absolutely vertical and to place the foundation exactly over its centre line. If eccentric loading results, the connection between the pile and column may break (or) the pile may fail structurally because of bending stresses. In real practice, structural loads are supported by several piles acting as a group. The settlement of the group will therefore be greater than that of single pile. It is common to term it as “Efficiency” (or) “Settlement ratio” of groups.

Efficiency = It is the ratio average load per pile to load at failure of comparable single pile.

Settlement Ratio = It is the ratio settlement of group to settlement of single pile.

For walls, piles are installed in a staggered arrangement on both sides of its centre line. The loads are usually transferred to the pile group through a reinforced concrete slab, structurally tied to the pile tops such that piles act as on unit. The slab is known as pile cap. The load carrying capacity of pile group is not necessarily equal to the sum of the capacity of individual piles. When the piles are spaced at a sufficient distance apart, the group capacity may approach nearly to the individual capacities. On the other hand, if the piles are closely spaced, the stresses may reduce the load-carrying capacity of piles. [3]

I.S. 2911(Part I/Sec I) -1979 recommends a min spacing of 2.5 times the shaft diameter for point bearing. A minimum of 3 times the shaft diameter for friction piles. In case of piles of non-circular cross-section the diameter of the circumscribed circle shall be adopted. A good practice is to drive piles from the centre of the group towards the edges. The centre to centre spacing of piles should be considered from two aspects:

a) Practical aspects of installing the piles, and
b) The nature of the load transfer to the soil and possible reduction in the bearing capacity of a group of piles thereby. [2]

The spacing of piles in a group depends on many factors such as length, size & shape of piles, soil characteristics & magnitude & type of loads. When the piles are spaced closely, the soil is highly stressed and it may cause the shear failure of soil (or) excessive settlement of the pile group. Pile group consist of different number of piles. There are different patterns of the arrangement of piles in the group. Similarly there are four, five, six and nine number of piles arranged together to form a group. [Fig 1.12]

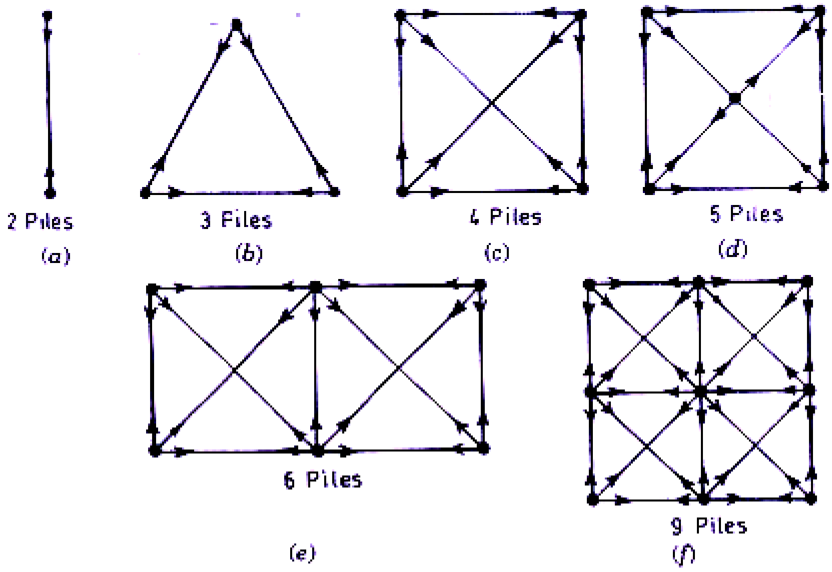


FIG 1.12 Arrangement of pile in pile group [8]

The spacing of the pile in the pile group also depends on factors such as cost of foundation, method of installation and efficiency of the pile group. When the piles are spaced closely, the soil is highly stressed in the zones of overlapping of pressures. Large spacing lead to higher costs of pile caps [Fig 1.13]. Generally, the spacing for point bearing piles can be mush less than the friction piles. The spacing for straight uniform diameter piles may vary from 2 to 6 times the diameter of the shaft. [6]

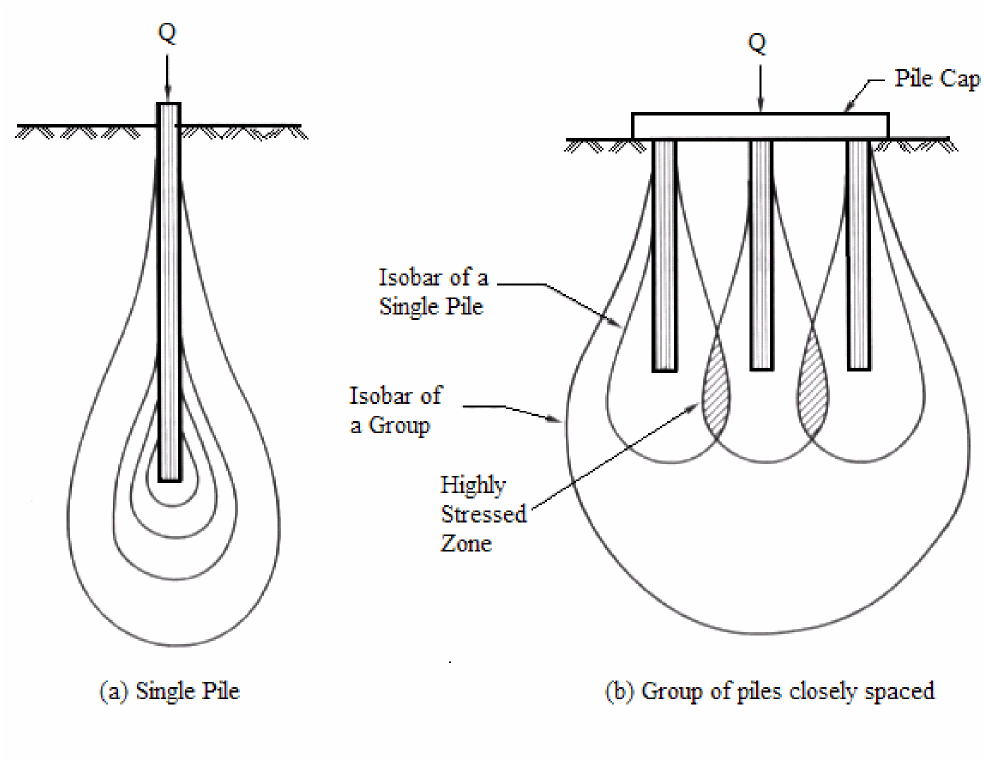


Fig 1.13 Stress of the individual pile(a) and group of pile(b)

Pile tops are connected together with a R.C.C pile cap. It is designed as an individual footing subjected to column load plus weight of the pile cap and soil above the cap. Wherever the conditions permit, the piles should be arranged in the most compact geometric form in order to keep the stresses in the pile cap to a minimum. [9]

1.9.1 Pile Group Efficiency

The Pile Group Efficiency E_g is expressed as

$$E_g = \frac{Q_{gu}}{\sum Q_u} \qquad \text{... (1.23)}$$

where,

Q_{gu} = Ultimate load bearing capacity of a pile group.

Q_u = Ultimate load bearing capacity of a single pile.

Vesic (1967) carried out tests on 4 and 9 pile groups driven into sand under controlled conditions. Piles with spacings 2, 3, 4, and 6 times pile diameter. Those tests were conducted in homogenous, and medium dense sand and he concluded the point efficiency of all the tests were unity. The skin efficiency increases with the increase in the pile spacing. The Connverse-Labarre formula is one of the most widely used group-efficiency equations which is expressed as,

$$E_g = 1 - \frac{\theta(n-1)m + (m-1)n}{90mn} \qquad \text{... (1.24)}$$

where,

m = Number of columns of piles in a group;

n = Number of rows;

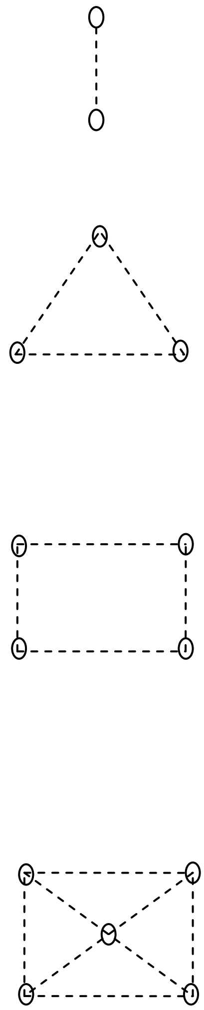
θ = $\tan^{-1}(d/s)$ in degrees;

d = Diameter of pile;

s = Spacing of piles.

There is not sufficient experimental evidence to determine efficiency of piles in clay soils. [6]

When a small number of piles are used in a pile group the efficiency of the pile group can be determined by Felds rule. According to this rule, the value of each pile is reduced by $\frac{1}{16}$ due to the effect of the nearest pile in each straight or diagonal row. [Fig 1.14] [13]



1. *Two Pile Group*

$$E_g = 1 - \frac{1}{16} = \frac{15}{16}$$
$$= 93.75\%$$

2. *Three Pile Group*

$$E_g = 1 - \frac{1}{16} - \frac{1}{16} = \frac{7}{8}$$
$$= 87.5\%$$

3. *Four Pile Group*

$$E_g = 1 - \frac{1}{16} - \frac{1}{16} - \frac{1}{16} = \frac{13}{16}$$
$$= 81.25\%$$

4. *Five Pile Group*

$$for\ 4\ Piles = 1 - \frac{1}{16} - \frac{1}{16} - \frac{1}{16} = \frac{13}{16}$$
$$for\ 1\ Pile = 1 - \frac{1}{16} - \frac{1}{16} - \frac{1}{16} - \frac{1}{16} = \frac{12}{16}$$
$$Average\ E_g = \frac{4 * \frac{13}{16} + 1 * \frac{12}{16}}{5} = 83.46\%$$

Fig 1.14 Efficiency of pile group by feld's rule [13]

1.9.2 Bearing Capacity of Pile Group

1.9.2.1 Pile Group in Sand

If piles are driven into loose to medium dense sands, the soil around the piles up to about 3 times the diameter is supposed to get compacted. The efficiency of the pile group will be greater than unity. However, it is conventional practice to assume

$$Q_{gu} = nQ_u \qquad \text{… (1.25)}$$

where,

Q_{gu} = Ultimate load carrying capacity of a pile group with n piles;

Q_u = the ultimate load capacity of a single pile.

In case of bored pile, the soil gets loosened during the boring and efficiency of the pile group decreases and will never be greater than unity. The load bearing capacity of a single bored-and cast-in-situ pile will be very much less than that of a driven pile, thus the above equation also applies to bored piles. But here in this work the formula used for the group capacity is:

$$Q_{gu} = E_g (nQ_u) \qquad \text{... (1.26)}$$

where,

n = no. of piles in the group. [6]

1.9.2.2 Pile Group in Clay

The bearing capacity of a pile group may be either of the following:

a) Equal to the bearing capacity of individual piles multiplied by the number of piles in a group (this is true mostly for bearing piles only)
b) For friction piles in soft clay, the group capacity will be the frictional capacity along the perimeter of the column of soil enclosed by the pile group together with the end bearing of the above column. [Fig 1.15] [2][14]

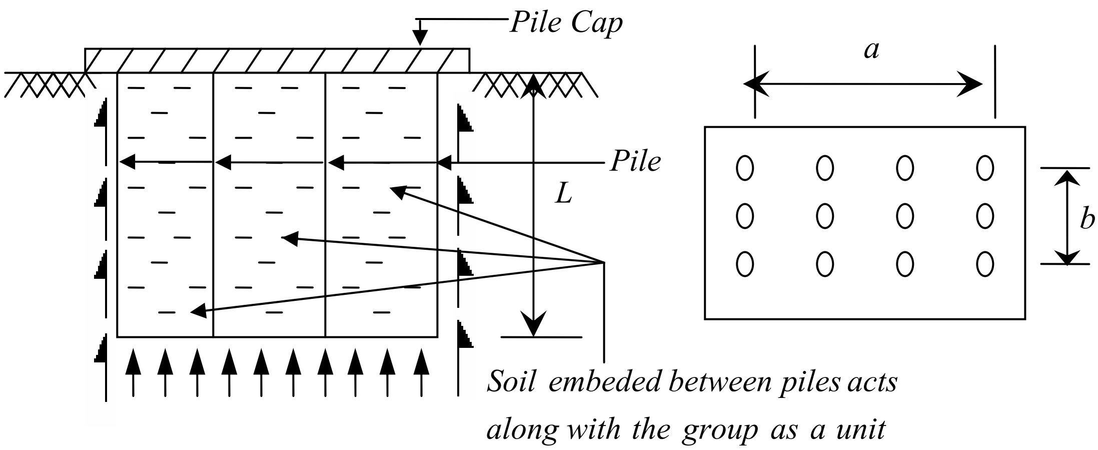


Fig 1.15 Pile group acting as a block (column enclosed by piles) [14]

When piles are spaced at closer intervals, the soil contained between the piles move downward with the piles and at failure, piles and soil move together to give the typical *"block failure".* This type of failure occurs when piles are placed within 2 to 3 times the pile diameter, but for wider spacings the piles fail individually.

The equation for block failure may be written as:

$$Q_{gu} = cN_c A_g + P_g \sum L_i c_i \qquad \text{... (1.27)}$$

where,

Q_{gu} = Ultimate load carrying capacity of pile group by block action;

c = Unit cohesion of clay beneath the pile group;

N_c = Bearing capacity factor usually taken as 9;

A_g = Sectional area of pile group ($a * b$);

P_g = Perimeter of pile group;

L_i = Thickness of the individual soil layer enclosing the pile;

c_i = unit cohesion of individual soil layer enclosing the pile.

Bearing capacity of a pile group on the basis of individual pile failure is same as equation (1.25), Terzaghi and Peck recommended that bearing capacity of a pile group is normally taken as the smaller of the two above equations. [6]

Terzaghi & Peck (1967) the pile group may fail as a unit. The recommended equation for the calculating ultimate bearing capacity of pile group is:

$$Q_{ug} = fLP + q_{ult} A + \gamma_1 L_e A \qquad \text{... (1.28)}$$

Where,

Q_{ug} = Upper limit of pile group capacity, not exceeding the ultimate capacity of a single pile times the number of piles in the group;

f = Shear resistance of soil along the vertical surface of the block;

L_e = Length of pile embedment in soil;

P = Perimeter of area enclosing all the piles in the group;

q_{ult} = Ultimate bearing capacity of soil at the level of pile tip;

A = Area enclosing all the piles in the group;

γ_1 = Unit weight of soil within the block.

Skin Friction

$$F_{ng} = C_u L_c P_g + \gamma_1 L_c A_g \qquad \text{... (1.29)}$$

where,

F_{ng} = Skin Friction of pile group;

C_u = Average cohesion at pile tip;

P_g = Perimeter of the group;

γ_1 = Unit weight of soil within the block;

L_c = Length of pile on which skin friction acts;

A_g = Area of the pile group within the perimeter. [9]

1.10 NEGATIVE SKIN FRICTION

When a fill is placed in a compressible soil deposit, consolidation of the compressible material will occur. When a pile is driven through the compressible material before consolidation is complete, the soil will move downward relative to the pile. This relative movement will develop skin friction between the piles and moving soil is termed as "*negative skin friction*" [Fig 1.16].

The principal effect of negative skin resistance is to increase the axial load in the lower fixed portion of the pile. It may also result in increased pile settlements due to the axial shortening and/or additional point penetration of the pile under the increased axial load. It causes large tension stresses when the effect is from expansive soils, especially if no or insufficient gap is left between soil and pile cap, the soil expands against both the pile and the cap. It is caused due to the lowering of the groundwater table with resulting ground subsidence. Pile driving produces negative stresses in the upper shaft when the load is released and the pile shaft expands upward. [10]

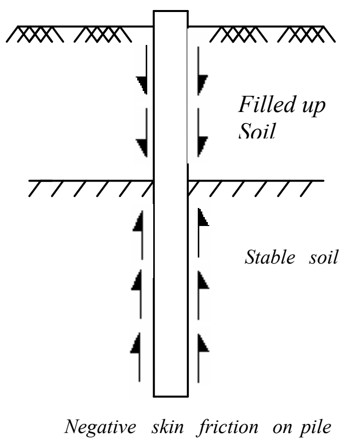


Fig 1.16 Negative skin friction acting on the pile [10]

1.11 LATERALLY LOADED PILES

Piles are sometimes to subjected to lateral loads due to wind pressure, water pressure, earth pressure etc. When the horizontal component of the load is small in comparison with the vertical (<20%), it is generally assumed to be carried by vertical piles and no special provision for lateral load is made. [3] Although the usual application of a pile foundation results primarily in axial loading, there exist numerous situations in which components of load at the pile head produce significant lateral displacements as well as bending moments and shears. Unlike axial loads, which only produce displacements parallel to the axis of the pile (one-dimensional system), lateral loads may produce displacements in any direction. Unless the pile cross section is circular, the laterally loaded pile/soil system represents a three-dimensional problem. Most of the research on the behavior of laterally loaded piles has been performed on piles of circular cross section in order to reduce the three-dimensional problem to two dimensions. Little work has been done to investigate the behavior of noncircular cross section piles under generalized loading. [19]

If horizontal load is large, inclined piles called “Raking Piles” or “Batter Piles” are provided to take the horizontal load. These piles have high resistance to lateral loads, as a large portion of the horizontal component of the load is carried axially by the pile. Batter piles, along with the vertical piles, are provided in situations where the horizontal loads are significant, such as wharves, jetties, bridge, trestles, retaining wall and tall chimneys. [3]

Reese and Matlock were the first to recommended, in 1956, non-dimensional analysis for lateral resistance of vertical piles. As in beams in elastic foundations they adopted a non-dimensional quantity called *Relative Stiffness Factor* to predict the behaviour of piles. Based on the above work and also that of Davisson, the ACI Committee recommended in 1972 the quantities R and T to determine the relative stiffness factor for the following cases:

- Where the modulus of horizontal subgrade reaction is constant along the depth as in over consolidated clays they recommended factor R.

- Where the modulus of horizontal subgrade reaction increases with depth as in sand deposits and in normally consolidated clays, they recommended factor T

Based on the principles described above and depending on the constraints at the top of the piles, I.S: 2911-1979 Part I/Sec 3 –Appendix D classifies piles as follows (This is similar to Broms method)

- Free headed pile (piles unrestrained at the top)
- Fixed headed piles or restrained pile connected to pile caps at the top. [14]

1.12 SCOPE OF WORK

The work includes the study of static analysis of pile foundation considering the different types of soils such as clays with different consistency, sand with different density having different angle of internal friction and layers of sand and clay. It will also include different pile parameters such as diameter, length, spacing of piles in groups and pattern of the pile group. The scope also includes analyzing the pile foundation for different types of loads such as co-centric, eccentric and lateral load. The study will be carried by using the method prescribed in Indian Standard Code.

A computer program using C++ language will be developed to handle various combinations of soils, parameters of piles, and loads as described above. The validity of the program will be checked by sample manual calculations. Thereafter design of pile is done according to the codal provisions. The software will be prepared which can be used for the static analysis and design of pile foundations by inputting the basic parameters of soils and pile.

1.13 ORGANISATION OF PROJECT

The present thesis report is divided in five chapters. Chapter-2, includes a brief introduction to the different types of piles, analysis of it according to the different methods suggested by different investigators. In addition it covers the details of the software reviewed for the preparation of the software for the pile foundation. Chapter-3, deals with the analysis and design of the piles which is followed by code provisions. Chapter-4 deals with the analysis and design of pile group with complete detailing of the pile group. Parametric study for different types of pile shape of varying sizes in three different type of soil condition is also included. It also includes the parametric study of the pile group considering different shapes of pile cap and different pile shape. Chapter-5 includes the summary of the work done, and future scope of work.

2. LITERATURE SURVEY

2.1 GENERAL

In the literature study, study of various papers related to pile foundation is presented. The study covers the details and information of topics related to single pile and pile group analysis which is then used in the design of it.

2.2 LITERATURE REVIEW

The load carrying capacity calculation formula for single pile for different soil conditions are taken from **IS: 2911 [2].** Code gives the useful information for the design consideration for the bored pile, driven pile and pile cap for the pile group. Spacing, behaviour of the pile in the pile group and reinforcement specifications for the pile group are used as per recommended by the code. The lateral resistance of the single pile is calculated using the code method. Bearing capacity factor N_q and reduction factor α is taken from the code.

K. R. Arora [3] gives a good idea about the classification of the different types of piles. General theories for the analysis of the single pile and brief knowledge of the pile group are also taken from this reference. **M.J. Tomlinson [5]** and **V. N. S. Muthy [6]** gives a good idea for the understanding of the behaviour of pile under load. Murthy also gives a good sense of understanding for the failure of the single pile for specific type of soil and method of analysis for the pile group.

N_γ and N_c values are taken from **I.S.: 6403 – 1981 [7]** as suggested by IS 2911.

Negative skin friction theory is very well explained by **J. E. Bowles [10].**

N. Krishna Raju [12] has explained a good concept of the design of pile cap by truss analogy method and bending theory.

S. Ramamurtham [13] gives a good example of the design for three pile group i.e. triangular shape pile cap.

P.C. Varghese [14] gives a good knowledge about the lateral resistance of the single pile as suggested in IS 2911 code.

In this study, work carried out by **S. C. Gupta [15]** was on the analysis method for calculating the bending moment of piles and results of it were supported by finite element analysis on computers. Most of the methods available for analysis of piles are given in standard books and Indian codes, are for single pile. The behaviour of pile under combined axial and lateral loads is not defined in codes and in general literature. Most of the design engineers are designing piles based on length of fixity charts as given in IS 2911 Part 1. Further the work also includes the drawbacks for the moment calculation on the pile as per I.S. code and other formulas from which the code has suggested the method. To prove this drawback true, a pile group model was prepared with the help of finite element and STAAD Pro software. The general theory for the calculating the length of fixity suggested by code was the main concern for this study.
The method for moment calculation on the single pile was suggested by the author and possible checks for the analysis were also included. The piles designed by the suggested method were not only economical but also safer. To prove this statement a case study on a real bridge design was considered, which were earlier designed based on the length of fixity calculation as per IS: 2911 and were crossed checked by the recommended method. This study concludes that the recommended method by not only economies the design by more than 30 percent in terms of flexural reinforcement but also reduces the overall length of the pile.

S. K. Bose [16] carried out the design of pile cap considering the case study of rajagarden flyover which is situated in Delhi. The designing of the pile cap was done using the bending theory and truss analogy method. Various load combinations including seismic, longitudinal and transverse loads were considered. Reinforcement details for each method were included. The load combinations considered for design of pile cap were the total vertical load, total longitudinal moment and total transverse moment. Load on pile cap had been calculated considering the maximum effects from normal case, seismic longitudinal case and seismic transverse case. In this paper the analysis was done by the bending theory and truss analogy method for the different pile caps under the flyover and maximum area of steel calculated by either of the method was provided.

Tridibesh Indu [17] had carried out the analysis work for different types of pile caps having different number of piles under it. Principles for the analysis were suggested and an illustration for a 4 pile rectangular cap under biaxially eccentric column load had been done, this principle was utilized for a few types of caps in respect of the application and scope of truss method. The paper includes the method to analysis for three pile group, hexagonal pile group and rectangular pile group. This paper was prepared and presented as the information on the application of the truss method for the design of the pile caps is scarce. The paper concludes that the approach provides conceptually elegant solutions for triangle, hexagonal and rectangular pile group, but then beam method should continue to be used as a safe general procedure for all types of pile caps until the and extensive study is done for the application of the suggested method.

2.3 SUMMARY

Concepts of analysis and design of the single pile and group of pile including the pile cap were understood in this chapter from the paper and books referred. These concepts are useful to understand the behavior of pile under different soil condition. The detailed study of all these information collected is discussed in the next chapter.

3. COMPUTER PROGRAM FOR ANALYSIS & DESIGN OF A SINGLE PILE

3.1 ANALYSIS METHOD

Here, I. S. Code Method is used for the analysis of the pile. The code referred for this analysis is **I.S. 2911 (Part I/Sec I) 1979.**

3.1.1 Piles in Granular Soils

According to **IS: 2911 – 1979** the value of δ**,** may be taken equal to ϕ **.** For driven pile in loose to medium sands, the recommended value of K is between 1 and 3 and the bearing capacity factor N_q value has to be taken from chapter 1 (Fig 1.12) recommended by Vesic, and N_γ value is given in chapter 1 (Table 1.2)

$$Q_u = A_p(0.5D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} K P_{Di} \tan\delta \qquad \text{... (3.1)}$$

where,

Q_u = Ultimate Bearing Capacity of the pile.

A_p = Cross-sectional area of pile toe in cm^2;

D = Stem diameter in cm;

γ = Effective unit weight of soil at pile toe in kg/cm^3;

P_D = Effective overburden pressure at pile toe in kgf/cm^2;

N_q, N_γ = Bearing capacity factors depending upon the angle of internal friction ϕ at toe;

$\sum_{i=1}^{n}$ = Summation for n layers in which pile is installed;

K = Coefficient of earth pressure;

P_{Di} = Effective overburden pressure in kgf/cm^2 for the ith layer where i varies from 1 to n;

δ = Angle of wall friction between pile and soil, in degrees (may be taken equal to ϕ); and

A_{si} = Surface area of pile stem in cm^2 in the ith layer where i varies from 1 to n.

3.1.2 Piles in Cohesive Soils

As per **IS: 2911 – 1979** ultimate bearing capacity (Q_u) in cohesive soil can be determined by following formula:

$$Q_u = A_p C_i N_c + \sum_{i=1}^{n} A_{si} \alpha_i C_i \qquad \text{... (3.2)}$$

where,

A_p = Cross-sectional area of pile toe in cm^2;

N_c = Bearing capacity factor usually taken as 9;

C_i = Unit Cohesion of the ith layer where i varies from 1 to n in kgf/cm^2;

α_i = Reduction factor for the ith layer where i varies from 1 to n.

A_{si} = Surface area of pile stem in cm^2 in the ith layer where i varies from 1 to n.

The values of α, are to be taken depending upon the consistency of the soils, which are shown in chapter 1 (Table 1.2). For working out safe load, a minimum factor of safety 2.5 should be used. α may be taken to vary from 0.5 to 0.3, depending upon the consistency of the soil. Higher values up to 1 may used for softer soils, provided the soil is not sensitive. For the calculation C value is taken as weighted average for cohesion. In the present study, the value of cohesion as it is for each layer are considered and according to that the value of α is taken from the table.

3.1.3 Piles in $C-\phi$ Soils

$$Q_u = A_p (CN_c + 0.5 D \gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} K P_{Di} \tan \delta + \sum_{i=1}^{n} As_i \alpha_i C_i \qquad \text{... (3.3)}$$

where,

A_p = Cross-sectional area of pile toe in cm^2;

D = Stem diameter in cm;

γ = Effective unit weight of soil at pile toe in kg/cm^3;

P_D = Effective overburden pressure at pile toe in kgf/cm^2;

N_q, N_γ = Bearing capacity factors depending upon the angle of internal friction ϕ at toe (Fig 2.13);

$\sum_{i=1}^{n}$ = Summation for n layers in which pile is installed;

K = Coefficient of earth pressure;

P_{Di} = Effective overburden pressure in kgf/cm^2 for the ith layer where i varies from 1 to n;

δ = Angle of wall friction between pile and soil, in degrees (may be taken equal to ϕ); and

A_{si} = Surface area of pile stem in cm^2 in the ith layer where i varies from 1 to n.

N_c = Bearing capacity factor usually taken as 9;

C_i = Unit Cohesion the ith layer where i varies from 1 to n in kgf/cm^2;

α_i = Reduction factor for the ith layer where i varies from 1 to n.

N_q is calculated from the Vesic equation, which is,

$$N_q = e^{\{3.8\phi\tan\phi\}}[\tan^2(45+\phi/2)] \quad \text{... (3.4)}$$

N_γ & N_c are calculated from the Vesic equation, which is

$$N\gamma = 2(Nq+1)\tan\phi \quad \text{... (3.5)}$$

$$Nc = (Nq-1)\cot\phi \quad \text{... (3.6)}$$

Here N_q for equation (3.5 & 3.6) is calculated by,

$$Nq = e^{\pi\tan\phi}[\tan^2(45+\phi/2)] \quad \text{... (3.7)}$$

3.2 LATERAL RESISTANCE OF PILE

I.S: 2911-1979 has recommended a method for calculating the depth of fixity, maximum moment of laterally loaded piles and lateral deflection of the pile cap. This method assumes that the pile is fixed at an arbitrary depth below the ground surface and then to calculate its deflection as per simple cantilever either free or fixed at the head but with freedom to translate.

To determine the depth of fixity and hence the equivalent length of the cantilever is calculated using the graph [Fig 3.1] according to **Amendment No.3, Sep'1987, Section I in I.S. : 2911-1979.**

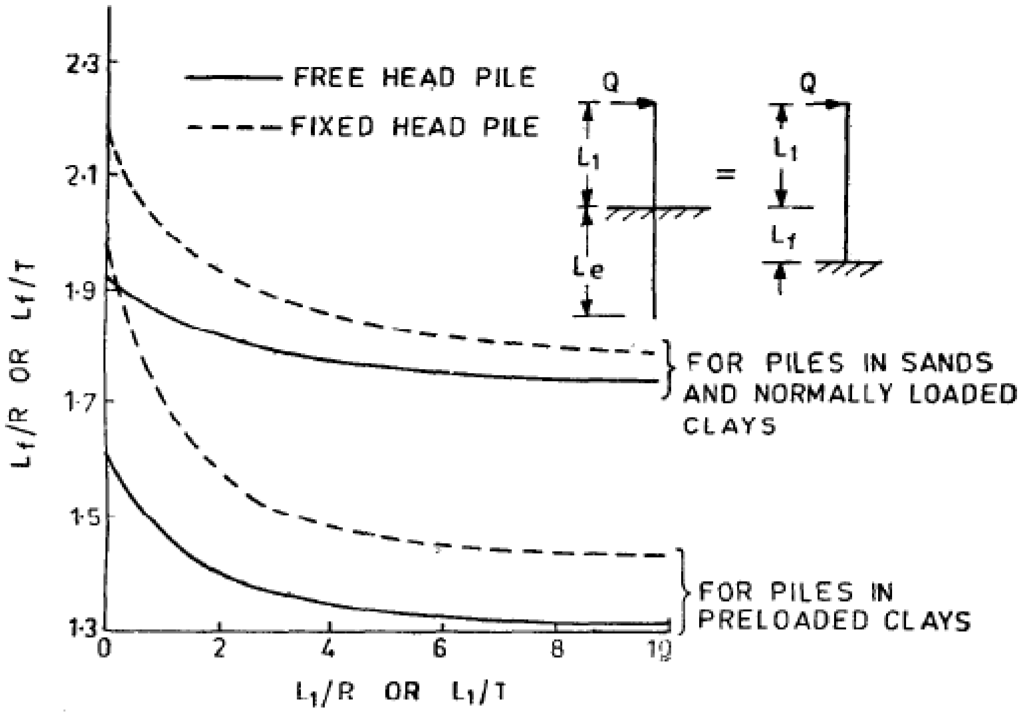


Fig 3.1 Determination of depth fixity [2]

Here firstly the stiffness factor T or R are calculated,

$$T = \sqrt[5]{\frac{EI}{K_1}} \qquad \text{... (3.8)}$$

$$R = \sqrt[4]{\frac{EI}{K_2}} \qquad \text{... (3.9)}$$

Where,

K_1 & K_2 = constants from table 3.1 and 3.2, as per I.S 2911;

E = young's modulus of pile material in kg/cm^2;

I = moment of inertia of the pile cross-section;

L_e = embedded length in cm;

L_f = free outstanding length of pile cm;

L_1 = equivalent cantilever length cm.

Note: Fig 3.1 is valid for long flexible piles where the embedded length L_e is ≥4R or 4T.

Table 3.1 Values of constant K_1 (kg/cm^2)

Type of soil	Dry	Submerged
Loose sand	0.260	0.146
Medium sand	0.773	0.525
Dense sand	2.075	1.245
Very loose sand under repeated loading or normally loading clays	-	0.040

Table 3.2 Values of constant K_2 (kg/cm^2)

Unconfined compressive strength (kg/cm^2)	Value
0.2 to 0.4	7.75
1 to 2	48.80
2 to 4	97.75
more than 4	195.5

Knowing the length of the equivalent cantilever the pile head deflection (Y) shall be computed using the following equations:

$$Y_{(cm)} = \frac{Q_l(L_1 + L_f)^3}{3EI} \quad \text{... For free head pile} \quad \text{... (3.10)}$$

$$Y_{(cm)} = \frac{Q_l(L_1 + L_f)^3}{12EI} \quad \text{...For fixed head pile} \quad \text{... (3.11)}$$

Where,

Q_l = lateral load in kg.

The fixed end moment of the equivalent cantilever is higher than the actual maximum moment of the pile. The actual maximum moment is obtained by multiplying the fixed end moment of the equivalent cantilever by a reduction factor, from graph [Fig 3.2] as per I.S. 2911. Horizontal load can also be calculated by the formulas given below by assuming some moment. The fixed end moment of the equivalent cantilever is given by:

$$M_f = Q(L_1 + L_f) \quad \text{... For free head pile} \quad \text{... (3.12)}$$

$$M_f = \frac{Q(L_1 + L_f)}{2} \quad \text{...For fixed head pile} \quad \text{... (3.13)}$$

The actual maximum moment (M) $= m(M_f)$.

Where,

m = reduction factor.

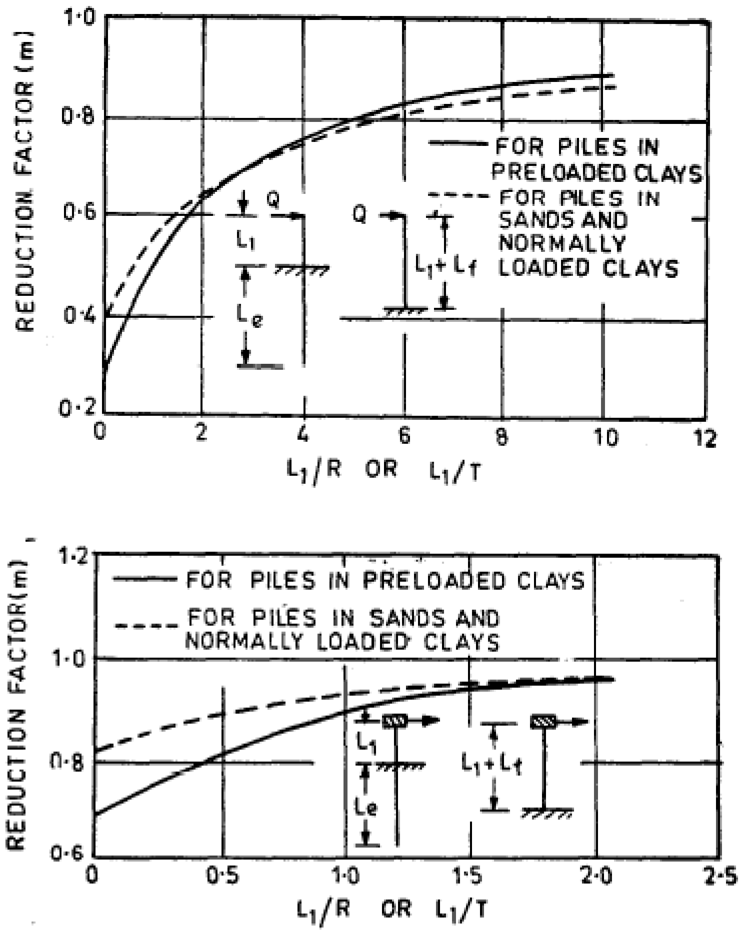


Fig 3.2 Determination of reduction factor for Computation of maximum moment in pile. [2]

3.3 DESIGN STEPS OF PILE

Pile foundations shall be designed in such a way that the load from the structure it supports, can be transmitted to the soil without causing any soil failure and without causing such settlement differential or total under permanent transient loading as may result in structural damage and/or functional distress. The pile shaft should have adequate structural capacity to withstand all loads (vertical, axial or otherwise) and moments which are to be transmitted to the subsoil. Piles are generally very long in their length and they are designed as long column. The design of pile is done according to the type of installation which is generally,

1. Bored Pile
2. Driven Pile

These two types of the piles are designed according to the code specification.

For the bored piles the following are the aspect that has to kept in mind while designing it.

- Minimum Longitudinal Reinforcement within the pile shaft should be 0.4% of the sectional area, with a minimum clear cover of 40mm according to IS: 2911-1979 (Part I/ Sec II).

- Minimum Lateral ties diameter should be of 6mm with spacing not exceeding 150mm according to IS: 2911-1979 (Part I/ Sec II).

Bored Pile is designed as follows:-

1. P_u is the factored vertical load, $m_{ux1}, m_{ux2}, m_{uy1}$ & m_{uy2} are the initial moments acting on the columns at top and bottom along x and y axis.
2. L/D & L/b ratios are calculated, according to the IS: 456-2000 code clause 25.1.2, if the ratio is more than or equal to 12 than it has to be designed as long column otherwise it has to designed as short column.
3. Calculate eccentricity by using the following formulas.

$$e_x = \frac{D}{2000}\left(\frac{l_{ex}}{D}\right)^2 \quad e_y = \frac{b}{2000}\left(\frac{l_{ey}}{b}\right)^2 \qquad \text{... (3.14)}$$

4. Additional moments are calculated by the following formulas:

$$m_{ux} = P_u e_x \quad m_{uy} = P_u e_y \qquad \text{... (3.15)}$$

5. The above calculated additional moments are to be reduced by multiplying with the multiplication factors (k_x & k_y).

6. To calculate the multiplication factors, percentage of steel (p) should be known, if not then assume some value of it. According to IS: 2911-1979 (Part I/ Sec I), minimum percentage of steel should be 0.4%. Calculate the gross area of the section (A_g).

7. Get the value of P_{uz} / A_g from the chart 63 of SP: 16, considering the values of f_{ck}, f_y and % of steel. Calculate the value of P_{uz} from the above ratio.

8. Calculate the axial load (P_b) corresponding to the condition of maximum compressive strain of 0.0035 in concrete and tensile strength of 0.002 in the outermost layer of tension steel. The value of axial load is calculated in both the directions, which depends upon arrangement of reinforcement, cover ratio ($d^{'} / D$), in addition to the grade of concrete and steel. Where $d^{'}$ is the addition of clear cover and half the diameter of bar assumed. P_b can be calculated by the following formula:

$$P_b = \left(k_1 + k_2 \frac{p}{f_{ck}} \right) f_{ck} bD \qquad \text{... (3.16)}$$

9. The value of co-efficient k_1 & k_2 for various cases are given in Table 3.3 and Table 3.4.

Table 3.3 Values of k_1 for design purpose

Section	$d^{'} / D$			
	0.05	0.10	0.15	0.20
Rectangular	0.219	0.207	0.196	0.184
Circular	0.172	0.160	0.149	0.138

Table 3.4 Values of k_2 for design purpose

Section	f_y N/mm^2	d'/D			
		0.05	0.10	0.15	0.20
Rectangular, reinforcement on two opposite sides	250	-0.045	-0.045	-0.045	-0.045
	415	0.096	0.082	0.0.46	-0.022
	500	0.213	0.173	0.104	-0.001
Rectangular, reinforcement on four sides	250	0.215	0.145	0.061	-0.011
	415	0.424	0.328	0.203	0.028
	500	0.545	0.425	0.256	0.040
Circular	250	0.193	0.148	0.077	-0.020
	415	0.410	0.323	0.201	0.036
	500	0.543	0.443	0.291	0.056

10. Multiplication factors k_x & k_y are calculated using following formula:

$$k_x = \frac{P_{uz} - P_u}{P_{uz} - P_{bx}}, \; k_y = \frac{P_{uz} - P_u}{P_{uz} - P_{by}} \quad \text{... (3.17)}$$

11. In case of a braced column without any transverse loads occurring in its height, the additional moment shall be added to an initial moment equal to sum of $0.4m_{u1}$ and $0.6m_{u2}$, where m_{u2} is the larger end moment and m_{u1} is the smaller end moment (assume negative if the column bent in double curvature). In no case shall the initial moment be less than $0.4m_{u1}$ nor the total moment including the initial moment be less than m_{u2}. For unbraced columns, the additional moment shall be added to the end moments
12. Unbraced compressive members, at any given level or storey, subject to lateral load are usually constrained to deflect equally. In such cases slenderness ratio for each column may be taken as the average for all columns acting in the same direction.
13. Now the modified actual moments should be compared with those calculated from eccentricity consideration and the greater value from them should be taken as the initial moments for adding with additional moments. To calculate the eccentricity the following

formula should be used.

$$e_x = \frac{l}{500} + \frac{D}{30}, \; e_y = \frac{l}{500} + \frac{b}{30} \qquad \text{... (3.18)}$$

14. If calculated e_x & e_y are less than 20mm, then according to the clause 25.4 of I.S. 456: 2000. Moment calculation is to be done considering the equation (3.15).

15. $M_u / f_{ck}bd^2$ ratio value is calculated from the graph of SP: 16 considering the specific d'/D ratio & grade of steel for $P_u / f_{ck}bd$ & p / f_{ck} value. The moments calculated from the ratio are the maximum moment capacity.

16. The value of $\frac{m_{ux}}{m_{ux1}}$ ratio is calculated from the chart 64 of SP: 16 considering the ratio of $\frac{P_u}{P_{uz}}$ & $\frac{m_{uy}}{m_{uy1}}$, where m_{ux} & m_{uy} are moments about x and y axes due to design loads and m_{ux1} m_{uy1} are maximum biaxial moment capacity for an axial load P_u, bending about x and y axes respectively. The graph value is compared with the original ration of $\frac{m_{ux}}{m_{ux1}}$ if the graph value is greater than the original value, then the percentage of steel assumed is satisfactory or else one has to increase the percentage of steel.

17. Lateral Reinforcement consists of two types of reinforcement. One is lateral ties in which one has to assume the diameter of lateral tie and spacing of it should be minimum of minimum lateral dimension, 16 times the diameter of the main bar or 300mm. Second is helical reinforcement in which the strength of the compressive member can support 1.05 times the load of similar member with lateral ties. Thus the axial load becomes $P_u = 1.05 * P_u$.

18. Assume some diameter of the helical reinforcement with some cover, the minimum diameter of helical reinforcement is 8 mm.

19. The pitch of the helical reinforcement is calculated by the following formula [18]:

$$p = \frac{4a_{sp}}{\left(0.36\left[\frac{A_g}{A_{cr}} - 1\right]\frac{f_{ck}}{f_y}\right)(D_c)} \qquad \text{... (3.19)}$$

where,

a_{sp} = area of the diameter assumed for helical reinforcement.

A_g = Gross area of the section.

A_{cr} = area of the core of the helically reinforced column measured to the outside of the diameter of helix.

D_c = diameter of the core.

p = pitch for the helical reinforcement, which should be

$<$75 mm

$<$ (D_c/6)

$>$25mm.

If the calculate pitch value is greater than 25 mm and less than (D_c/6) consider the calculated value.

For the Driven piles the following are the aspect that has to kept in mind while designing it.

- Minimum Longitudinal Reinforcement within the pile shaft should be 1.25% of the sectional area for piles having length upto 30 times the least later dimension according to IS: 2911-1979 (Part I/ Sec III).
- Minimum Longitudinal Reinforcement within the pile shaft should be 1.5% of the sectional area for piles having length between 30 to 40 times the least lateral dimension IS: 2911-1979 (Part I/ Sec III).
- Minimum Longitudinal Reinforcement within the pile shaft should be 2.0% of the sectional area for piles having length more than 40 times the least lateral dimension according to IS: 2911-1979 (Part I/ Sec III).
- The lateral reinforcement (link or ties) of not less than 6mm should not be used and spacing between them should no exceed 150mm according to IS: 2911-1979 (Part I/ Sec III).

Driven Pile is designed as follows:-

1. L/D ratio is calculated and accordingly the design on pile is differentiated. According to the IS: 456-2000 code clause 25.1.2, if the ratio is more than or equal to 12 than it has to be designed as long column otherwise it has to designed as short column. Where L is the effective length of the column in respect to the major axis and D is the depth in respect to the major axis.
2. Area of steel is calculated by the following formula $P = \sigma_{cc} A_{cc} + \sigma_{sc} A_{sc}$. Here the first term is the vertical load acting on the pile. Second term is the permissible stress in concrete. Third term is the total area of the section including the area of steel and concrete. Fourth term is the permissible stress in steel and the last the term is the area of steel. Calculated area is checked with the minimum value and maximum of them is considered and then accordingly the numbers of bars are calculated.
3. Lateral reinforcement for the central section of the pile is 0.2% of the gross volume. Spacing of the lateral ties is calculated by the following formula $Volume\,of\ one\ tie = Volume\,of\ \ pile\ per\ pitch\ length$ not exceeding (D/2) c/c.
4. Spiral reinforcement is provided near the pile head for a length of the three times the greater dimension of the section. Volume of spiral is 0.6% of the gross volume. Volume of spiral per mm length is calculated. Spacing of the spiral reinforcement is calculated by the following formula $Spacing = \dfrac{Circumference\,of\ Spiral}{Volume\,of\ spiral\ per\,mm\ length}$ some of the bars are to be provided inside the spiral so as to hold the spiral in position and they also run through the same length till spiral.
5. Lateral reinforcement at the both the ends of the pile for a length of the three times the greater dimension of the section with the spacing calculated from the following formula $Volume\,of\ one\ tie = Volume\,of\ ties$, where volume of ties is 0.6% of the gross volume.
6. Spacer bars are provided to hold the longitudinal bars in position.

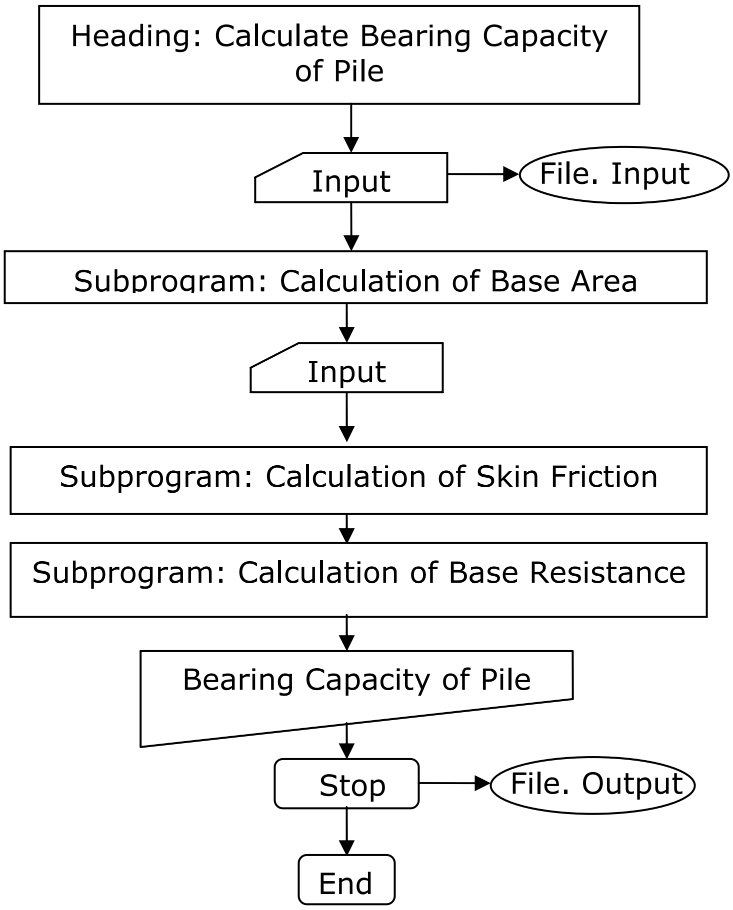
Programs are prepared for the analysis and design on the single pile using C++ language. Brief idea of all the programs, their working is explained below.

3.4 FLOW OF ALL PROGRAMS

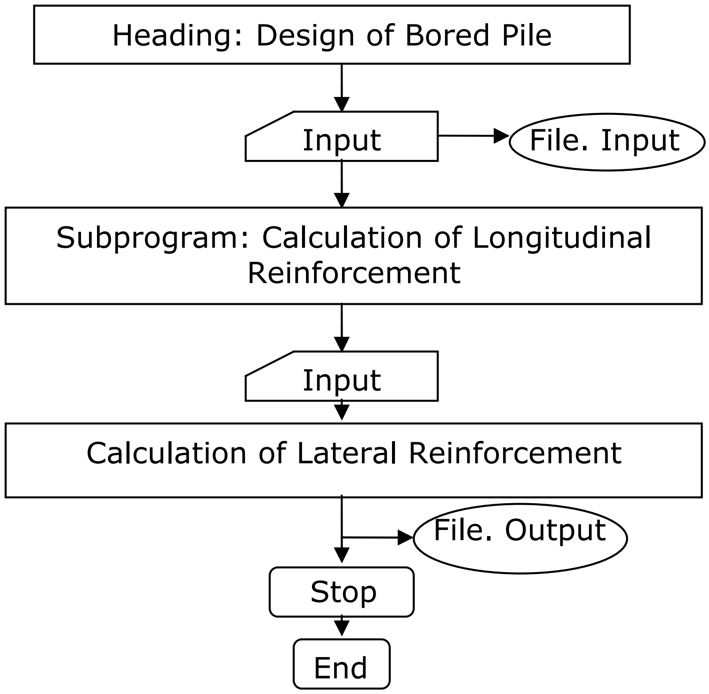
(1) Program for the analysis of single pile.

(2) Program for the design of bored pile.

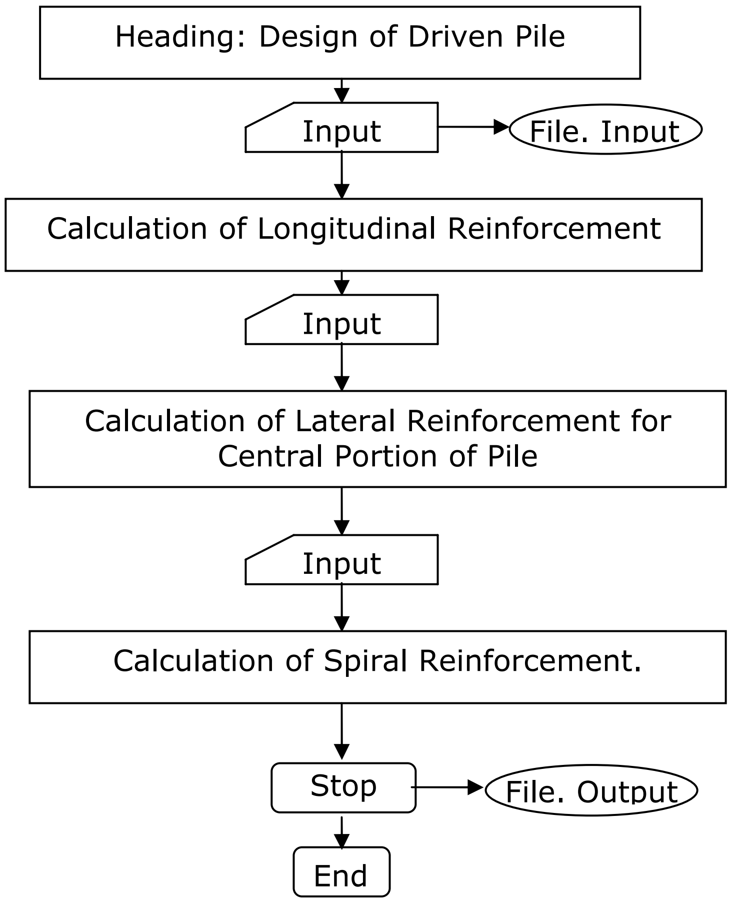
(3) Program for the design of driven pile.



Flow of Program for Analysis of Pile



Flow of Program for Design of Bored Pile



Flow of Program for Design on Driven Pile

3.5 INPUT AND OUTPUT OF THE PROGRAMS

The Input Data for the Analysis Program is as follows:-

1. Shape of pile.
2. The Dimensions of the section.
3. Type of Installation of Pile.
4. The Length of the Pile.
5. No. of Layers.
6. Type of the soil Pile is surrounded to.
7. Concerned values of the soil parameters for particular type of soil layer selected.

Note: -

- All The Values Should be entered in the same unit.
- If water table is present at some level, it should be considered as a different layer and the corresponding final value of Effective Unit Weight must be entered by the user.

Case C: - Analysis of the single pile

Input Data taken as per supplied by Adani Group (Page 58, Table 3.5a)

1. Shape of pile. = Circular
2. The Dimensions of the section. = 60 cm
3. Type of Installation of Pile. = Driven
4. The Length of the Pile. = 1200 cm
5. No. of Layers. = 9
6. Type of the soil Pile is surrounded to. = $C-\phi$
7. Concerned values of the soil parameters for particular type of soil layer selected.

Water Table is present at the second layer.

Length of the Pile = 1650 cm

No. of Layers are = 9

Layer 1 thickness = 100 cm

Layer 2 thickness = 50 cm

Layer 3 thickness = 150 cm

Layer 4 thickness = 150 cm

Layer 5 thickness = 150 cm

Layer 6 thickness	=	150 cm
Layer 7 thickness	=	150 cm
Layer 8 thickness	=	150 cm
Layer 9 thickness	=	150 cm

LAYER 1 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0016 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0

LAYER 2 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0016 kg/cm^3
Value of submerged unit weight	=	0.0006 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0

LAYER 3 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0016 kg/cm^3
Value of submerged unit weight	=	0.0006 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0
Unit Cohesion for this layer	=	0.11 kg/cm^2
Alpha α	=	0.7

LAYER 4 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.00172 kg/cm^3
Value of submerged unit weight	=	0.00072 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0

LAYER 5 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.00172 kg/cm^3

Value of submerged unit weight	=	0.00072 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.5
Value of angle of internal friction	=	28°

LAYER 6 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0021 kg/cm^3
Value of submerged unit weight	=	0.0011 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0

LAYER 7 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0021 kg/cm^3
Value of submerged unit weight	=	0.0011 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.5
Value of angle of internal friction	=	31°

LAYER 8 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0021 kg/cm^3
Value of submerged unit weight	=	0.0011 kg/cm^3
Value of coefficient of earth pressure (K)	=	0
Value of angle of internal friction	=	0

LAYER 9 INPUT PROPERTIES:-

Value of Effective unit weight	=	0.0021 kg/cm^3
Value of submerged unit weight	=	0.0011 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.5
Value of angle of internal friction	=	31°

Factor of safety is = 2.5

Here in this analysis the reference data was provided in kN/m^2, but for the program analysis these data were converted into Kg/cm^2 this can been seen in page 58 and 59.

Output Data as per reference (Page 58, table 3.5a)

Total Ultimate load carrying capacity of the pile (without 25% increase)	=	1702 kN
Safe load carrying capacity of pile (Without 25% increase)	=	681 kN
Total Ultimate load carrying capacity of the pile (with 25% increase)	=	2128 kN
Safe load carrying capacity of pile (with 25% increase)	=	851 kN

Output of the program (Page 59 table 3.5b)

Total Ultimate load carrying capacity of the pile (without 25% increase)	=	1486 kN
Safe load carrying capacity of pile (With 25% increase)	=	594 kN
Total Ultimate load carrying capacity of the pile (without 25% increase)	=	1858 kN
Safe load carrying capacity of pile (With 25% increase)	=	743 kN

The value difference between the reference and program is about 1.14%. This is because the value calculated for the total over burden pressure as per the reference comes to be 135.40 kN/m^2, while the value calculated by the program comes to 115.6 kN/m^2. For the calculation of skin friction the effective over-burned pressure of individual layer is to be considered and for the the calculation of the base resistance the total over burden pressure is to be considered, but in the reference the total over burden pressure value is considered, which is not correct. For this analysis an excel sheet was also prepared to cross check the program values. The comparison of the reference value and program is tabulated in Table 3.5 from the table, it can be concluded that the program values are reliable. Thus the validity of the programs is checked. The excel sheet is placed after the table.

Table 3.5 Comparison of axial load carrying capacity of single pile (reference value and program value)

Reference value					Output of Program			
Layer	Soil Pressure kN/m^2	Effective Over burden pressure kN/m^2	Skin Friction kN	Base Resistance kN	Soil Pressure kN/m^2	Effective Over burden pressure kN/m^2	Skin Friction kN	Base Resistance kN
1	16	8	0	0	16	8	0	0
2	3	17.5	0	0	3	17.5	0	0
3	9	23.5	21.77	0	9	23.5	21.77	0
4	10.8	33.4	0	0	10.8	33.4	0	0
5	10.8	44.2	99.67	0	10.8	44.2	99.67	0
6	16.5	57.85	0	0	16.5	57.85	0	0
7	16.5	74.35	189.47	0	16.5	74.35	189.47	0
8	16.5	90.85	0	0	16.5	90.85	0	0
9	16.5	107.35	335.79	1055.42	16.5	107.35	273.55	901.26
		135.4	646.7			115.6	584.46	
Total ultimate Vertical load carrying capacity	=(1055.42 + 646.7)		1702.12		Total ultimate Vertical load carrying capacity	=(901.26 + 584.46)		1485.72
25 % increase	=(0.25* 1702.12)		425.53		25 % increase	=(0.25* 1485.72)		371.43
			2127.65					1857.15
	Total ultimate Vertical load carrying capacity with 25% increase		2128	kN		Total ultimate Vertical load carrying capacity with 25% increase	1858	kN
	Safe load carrying capacity	(2128/ 2.5)	851	kN		Safe load carrying capacity	(1858/ 2.5)	743 kN

Axial Load Carrying Capacity of a Single Vertical Pile In Layered Soil — Upto Max 9 Layers + Water Table

Note :- If water table is present, consider the starting of the water table as additional layer including the normal layers.

DATA : -

Shape of Pile	=	**Circular**	
Diameter of the Pile	=	**0.6**	m
Cross-Sectional Area of Pile at Tip A_p	=	**0.282735**	m^2
Is Water Table Present	=	**Present**	
Enter the depth of H20 Level From Top Layer	=	**1**	m
No. of Soil Layer	=	**9**	
Unit Weight of Water	=	**10**	kN/m^3
ϕ Value for Last Layer	=	**19**	
N_q of n^{th} Layer	=	**26.8000**	Manually
N_c of n^{th} Layer	=	**9.0000**	Manually
N_γ of n^{th} Layer	=	**27.5300**	Manually
Factor of Safety	=	**2.5**	
Type of Instalaltion	=	**Driven**	
α value to be taken according to	=	**C value**	

Formula's

$$Q_p = A_p(CN_c + 0.5D\gamma N_\gamma + P_D\ N_q)$$

$$Q_s = \sum_{i=1}^{n} A_{si} KP_{Di} \tan\delta + \sum_{i=1}^{n} As_i \alpha_i C_i$$

$$Q_u = A_p(CN_c + 0.5D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} KP_{Di} \tan\delta + \sum_{i=1}^{n} As_i \alpha_i C_i$$

$$Q_u = Q_s + Q_p$$

$$Q_{safe} = Q_u / F.O.S$$

Layer No.	Thickness of soil layer L m	Unit wt of soil γ kN/m^3	Submerged Unit Wt. of Soil γ_{sub} kN/m^3	Angle of Internal Friction ϕ Degree	Unit Cohesion c kN/m^2	Co-Efficient of Earth Pressure K	N Value	Value of Reduction Factor α From C value	Value of Reduction Factor α From N value	Angle of wall Friction δ Degree	Soil Pressure $Pd = (\gamma \times L)$ kN/m^2	Eff. Over Burden Pressure for ith layr Pd_i kN/m^2	Area of Skin Friction A_s m^2	Skin Friction Resistance Q_s kN	Total End Bearing Resistance Q_p kN
1	1	16	-	0	0	0	No Use	0	Not Applicable	0	16	8	1.8849	0	-
2	0.5	16	6	0	0	0	No Use	0	Not Applicable	0	3	17.5	0.94245	0	-
3	1.5	16	6	0	11	0	No Use	0.7	Not Applicable	0	9	23.5	2.82735	21.770595	-
4	1.5	17.2	7.2	0	0	0	No Use	0	Not Applicable	0	10.8	33.4	2.82735	0	-
5	1.5	17.2	7.2	28	0	1.5	No Use	0	Not Applicable	28	10.8	44.2	2.82735	99.67069	-
6	1.5	21	11	0	0	0	No Use	0	Not Applicable	0	16.5	57.85	2.82735	0	-
7	1.5	21	11	31	0	1.5	No Use	0	Not Applicable	31	16.5	74.35	2.82735	189.4635	-
8	1.5	21	11	0	0	0	No Use	0	Not Applicable	0	16.5	90.85	2.82735	0	-
9	1.5	21	11	31	0	1.5	No Use	0	Not Applicable	31	16.5	107.35	2.82735	335.79	1055.42
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														646.69478	1055.42

12 m

Total Effective Pressure 135.4 kN/m^2

	Total Skin Friction	**646.69478**	kN
	Total End Bearing Resistance	**1055.42**	kN
Without 25% increase	Total Ultimate Pile Load Carrying Capacity	**1702**	kN
	Total Safe Pile Load Carrying Capacity	**681**	kN
With 25% increase	Total Ultimate Pile Load Carrying Capacity	**2128**	kN
	Total Safe Pile Load Carrying Capacity	**851**	kN

Axial Load Carrying Capacity of a Single Vertical Pile In Layered Soil — Upto Max 25 Layers + Water Table

Note :- If water table is present, consider the starting of the water table as additional layer including the normal layers.

DATA : -

Shape of Pile	=	**Circular**	
Diameter of the Pile	=	**60**	cm
Cross-Sectional Area of Pile at Tip A_p	=	**2827.35**	cm^2
Is Water Table Present	=	**Present**	
Enter the depth of H20 Level From Top Layer	=	**100**	cm
No. of Soil Layer	=	**9**	
Unit Weight of Water	=	**0.001**	kg/cm^3
ϕ Value for Last Layer	=	**19**	
N_q of n^{th} Layer	=	**26.8000**	Manually
N_c of n^{th} Layer	=	**9.0000**	Manually
N_γ of n^{th} Layer	=	**27.5300**	Manually
Factor of Safety	=	**2.5**	
Type of Instalaltion	=	**Driven**	
α value to be taken according to	=	**C value**	

Formula's

$$Q_p = A_p(CN_c + 0.5D\gamma N_\gamma + P_D N_q)$$

$$Q_s = \sum_{i=1}^{n} A_{si} KP_{Di} \tan\delta + \sum_{i=1}^{n} As_i \alpha_i C_i$$

$$Q_u = A_p(CN_c + 0.5D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} KP_{Di} \tan\delta + \sum_{i=1}^{n} As_i \alpha_i C_i$$

$$Q_u = Q_s + Q_p$$

$$Q_{safe} = Q_u / F.O.S$$

Layer No.	Thickness of soil layer L cm	Unit wt of soil γ kg/cm^3	Submerged Unit Wt. of Soil γ_{sub} kg/cm^3	Angle of Internal Friction ϕ Degree	Unit Cohesion c kg/cm^2	Co-Efficient of Earth Pressure K	N Value	Value of Reduction Factor α From C value	Value of Reduction Factor α From N value	Angle of wall Friction δ Degree	Soil Pressure $Pd = (\gamma \times L)$ kg/cm^2	Eff. Over Burden Pressure for ith layr Pd_i kg/cm^2	Area of Skin Friction A_s cm^2	Skin Friction Resistance Q_s kg	Total End Bearing Resistance Q_p kg
1	100	0.0016	-	0	0	0	No Use	0	Not Applicable	0	0.16	0.08	18849	0	-
2	50	0.0016	0.0006	0	0	0	No Use	0	Not Applicable	0	0.03	0.175	9424.5	0	-
3	150	0.0016	0.0006	0	0.11	0	No Use	0.7	Not Applicable	0	0.09	0.235	28273.5	2177.0595	-
4	150	0.00172	0.00072	0	0	0	No Use	0	Not Applicable	0	0.108	0.334	28273.5	0	-
5	150	0.00172	0.00072	28	0	1.5	No Use	0	Not Applicable	28	0.108	0.442	28273.5	9967.069	-
6	150	0.0021	0.0011	0	0	0	No Use	0	Not Applicable	0	0.165	0.5785	28273.5	0	-
7	150	0.0021	0.0011	31	0	1.5	No Use	0	Not Applicable	31	0.165	0.7435	28273.5	18946.35	-
8	150	0.0021	0.0011	0	0	0	No Use	0	Not Applicable	0	0.165	0.9085	28273.5	0	-
9	150	0.0021	0.0011	31	0	1.5	No Use	0	Not Applicable	31	0.165	1.0735	28273.5	27355.624	90162.1841
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	1200													58446.102	90162.1841

Total Effective Pressure 1.156 Kg/cm^2

	Total Skin Friction	**58446.102**	kg		
	Total End Bearing Resistance	**90162.184**	kg		
Without 25% increase	Total Ultimate Pile Load Carrying Capacity	**148608**	kg	**1486**	kN
	Total Safe Pile Load Carrying Capacity	**59443**	kg	**594**	kN
With 25% increase	Total Ultimate Pile Load Carrying Capacity	**185760**	kg	**1858**	kN
	Total Safe Pile Load Carrying Capacity	**74304**	kg	**743**	kN

Single Pile Analysis

Case 1a to 3b

Different cases considered for the analysis of the pile are as per [Fig 3.3].

Here the constant terms for this particular problem are soil parameters, number of layers, thickness of each layer & length of the pile. Water table is present at 900cm below from the ground. The soil here is $C-\phi$ type.

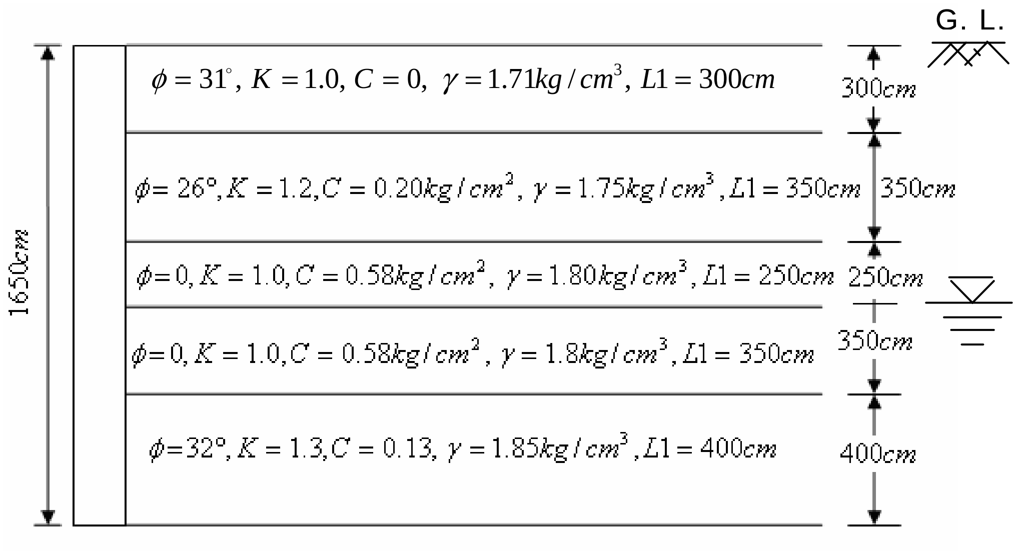


Fig 3.3 Soil Parameter for the analysis of pile

Study is for the $C-\phi$ soil type. The data used here are the assumed ones and are the same for all the cases 1a to 3b, Input data for the program of soil properties and length of the pile.

Length of the Pile	=	1650 cm
No. of Layers are	=	5
Layer 1 thickness	=	300 cm
Layer 2 thickness	=	350 cm
Layer 3 thickness	=	250 cm
Layer 4 thickness	=	350 cm
Layer 5 thickness	=	400 cm

LAYER 1 INPUT PROPERTIES:-

Ist layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	1.71 kg/cm^3

Value of coefficient of earth pressure (K)	=	1.0
Value of angle of internal friction	=	31°

LAYER 2 INPUT PROPERTIES:-

II nd layer is $C-\phi$ type Soil

Alpha value selected is based on C value	=	1
Value of Effective unit weight	=	1.75 kg/cm^3
The value of Angle of Internal Friction	=	26°
Unit Cohesion for this layer	=	0.2 kg/cm^2
Value of coefficient of earth pressure (K)	=	1.2

LAYER 3 INPUT PROPERTIES:-

III rd layer is CLAY (C type of Soil)

Alpha value selected is based on C value

α	=	0.7
Value of Effective unit weight	=	1.8 kg/cm^3
Unit Cohesion for this layer is	=	0.58 kg/cm^2
Value of coefficient of earth pressure (K)	=	1.0

LAYER 4 INPUT PROPERTIES (Water Table Starts from here):-

IV th layer is CLAY (C type of Soil)

α	=	0.7
Value of Effective unit weight	=	1.8 kg/cm^3
Value of submerged unit weight	=	0.8 kg/cm^3
Unit Cohesion for this layer is	=	0.58 kg/cm^2
Value of coefficient of earth pressure (K)	=	1.0

LAYER 5 INPUT PROPERTIES:-

V th layer is $C-\phi$ type Soil

α Value selected is from C value	=	1
Value of Effective unit weight	=	1.85 kg/cm^3
Value of submerged unit weight	=	0.8 kg/cm^3
The value of Angle of Internal Friction	=	32°

Unit Cohesion for this layer	=	0.13 kg/cm^2
Value of coefficient of earth pressure (K)	=	1.3

Input data of pile for the program.

CASE: 1a

Shape of the Pile	=	**Circular.**
The diameter of Pile is	=	25 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to C-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c are calculated as per equation (3.5, 3.6 & 3.7)

Output of the Program

CASE: 1a Circular Driven Pile, $C-\phi$ type soil.

Skin Resistance for the 1st layer is	=	3.63138 $x\,10^6$ kg
Skin Resistance for the 2nd layer is	=	1.31862 $x\,10^7$ kg
Skin Resistance for the 3rd layer is	=	7971.79 kg
Skin Resistance for the 4th layer is	=	11160.5 kg
Skin Resistance for the 5th layer is	=	5.16951 $x\,10^7$ kg
The total value of Skin Resistance	=	6.85317 $x\,10^7$ kg
The value of Point Resistance is	=	3.9794 $x\,10^7$ kg

Ultimate Bearing Capacity of Pile is	=	1.08326 $x\,10^8$ kg

The input and output files.

Input File

CASE Ia

Type of pile is CIRCULAR

The diameter of pile is : 25

It is a Driven Pile

The Length of the Pile is : 1650 cm

No. of Layer are : 5

Layer 1 thickness is : 300 cm

****

Layer 2 thickness is : 350 cm

****

Layer 3 thickness is : 250 cm

****

Layer 4 thickness is : 350 cm

****

Layer 5 thickness is : 400 cm

****

LAYER 1 INPUT PROPERTIES

****

Value of Effective unit weight for the layer 1 is : 1.71 kg/cm3

Value of coefficient of earth pressure (K) for the layer 1 is : 1

The selected layer is SAND (Phi type Soil)

Value of angle of internal friction for the layer 1 is : 31

****

LAYER 2 INPUT PROPERTIES

****

Value of Effective unit weight for the layer 2 is : 1.75 kg/cm3

The selected layer is C-Phi type Soil

The value of Angle of Internal Friction is : 26

Unit Cohesion for this layer is : 0.2 kg/cm2

Alpha value selected is from C value

****

LAYER 3 INPUT PROPERTIES

****

Value of Effective unit weight for the layer 3 is : 1.8 kg/cm3

The selected layer is CLAY (C type of Soil)

Unit Cohesion for this layer is : 0.58 kg/cm2

Alpha value selected is based on C value

Here in this layer Ny is Zero

Here in this layer Nq is Zero

****

LAYER 4 INPUT PROPERTIES

****

Value of Effective unit weight for the layer 4 is : 0.8 kg/cm3

The selected layer is CLAY (C type of Soil)

Unit Cohesion for this layer is : 0.58 kg/cm2

Alpha value selected is based on C value

Here in this layer Ny is Zero

Here in this layer Nq is Zero

****

LAYER 5 INPUT PROPERTIES

****

Value of Effective unit weight for the layer 5 is : 0.85 kg/cm3

The selected layer is C-Phi type Soil

The value of Angle of Internal Friction is : 32

Unit Cohesion for this layer is : 0.13 kg/cm2

Alpha value selected is from C value

****

The Value of Nq is taken from the Vesic Equation, which matches with the Graph value of Code I.S. 2911:1979 (PART I/SEC I) and the equation is Nq=(3*((exp(3.8*Phi*tan(Phi)))*(pow(tan(45+(Phi/2)),2))))

Ny Value is taken from the Vesic Equation
and the equation (2*(((exp(PIE*tan(Phi)))*(pow(tan(45+(Phi/2))2))) + 1)*(tan(Phi)))

Nc Value is taken from the Vesic Equation and the equation is Nc =((((exp(PIE*tan(Phi)))*(pow(tan(45+(Phi/2)),2))) - 1)*(cot(Phi)))

Factor of safety Inputted is : 2.5

Output file

CASE Ia

The area of pile at base is 490.874

LAYER 1 VALUE

****

The selected layer is SAND (Phi type Soil)

C=0

alpha=0

Nc=0

Value of Delta for Driven Pile is : 31

The average effective overburden pressure for the 1th layer is : 256.5

The area of the skin friction is : 23561.9

The skin resistance for the 1 th layer is : 3.63138e+06

****

LAYER 2 VALUE

****

The selected layer is C-Phi type Soil

Alpha value for this layer is : 1

Value of Delta for Driven Pile is : 26

The average effective overburden pressure for the 2th layer is : 819.25

The area of the skin friction is : 27488.9

The skin resistance for the 2 th layer is : 1.31862e+07

****

LAYER 3 VALUE

****

The selected layer is CLAY (C type of Soil)

Angle of internal friction is zero in this layer

Alpha value for this layer based on C value is : 0.7

Value of Delta for Driven Pile is : 0

The average effective overburden pressure for the 3th layer is : 1350.5

The area of the skin friction is : 19635

The skin resistance for the 3 th layer is : 7971.79

****

LAYER 4 VALUE

****

The selected layer is CLAY (C type of Soil)

Angle of internal friction is zero in this layer

Alpha value for this layer based on C value is : 0.7

Value of Delta for Driven Pile is : 0

The average effective overburden pressure for the 4th layer is : 1715.5

The area of the skin friction is : 27488.9

The skin resistance for the 4 th layer is : 11160.5

****

LAYER 5 VALUE

****

The selected layer is C-Phi type Soil

Alpha value for this layer is : 1

Value of Delta for Driven Pile is : 32

The average effective overburden pressure for the 5th layer is : 2025.5

The area of the skin friction is : 31415.9

The skin resistance for the 5 th layer is : 5.16951e+07

Nq value calculated from the Vesic Equation is : 36.7762

Ny value calculated from the Vesic Equation is : 30.2146

Nc value calculated from the Vesic Equation is : 35.4902

****

The effective overburden pressure at pile toe is : 2195.5

The total value of Base Resistance Qp is : 3.9794e+07

The total value of Skin Resistance Qs is : 6.85317e+07

****

The ultimate bearing capacity Qu is : 1.08326e+08

****

The safe load carrying capacity of the pile is : 4.33303e+07

Input data of pile for the program for Case1b to 3b.

CASE: 1b

Shape of the Pile	=	**Circular.**
The diameter of Pile is	=	25 cm

It is a **Bored Pile** (δ =.67ϕ)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to N-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c values are taken by the program from the table suggested in chapter1 Table (1.2). Here N values are assumed values, for IInd layer N is taken as 5, for IIIrd layer it is taken as 7, for IVth layer it is taken as 8 and for Vth layer it is taken as 3.

CASE: 2a

Shape of the Pile	=	**Square**
One side of the square	=	15 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to C-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c are calculated as per equation (3.5, 3.6 & 3.7)

CASE: 2b

Shape of the Pile	=	**Square**
The diameter of Pile is	=	15 cm

It is a **Bored Pile** (δ =.67ϕ)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to N-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c values are taken by the program from the table suggested in chapter1 Table (1.2). Here N values are assumed values, for IInd layer N is taken as 5, for IIIrd layer it is taken as 7, for IVth layer it is taken as 8 and for Vth layer it is taken as 3.

CASE: 3a

Shape of the Pile	=	**Rectangular**
The Longer side of the rectangular is	=	30 cm
The short side of the rectangular is	=	20 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to C-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c are calculated as per equation (3.5, 3.6 & 3.7)

CASE: 3b

Shape of the Pile	=	**Rectangular**
The Longer side of the rectangular is	=	30 cm
The short side of the rectangular is	=	20 cm

It is a **Bored Pile** ($\delta = .67\phi$)

The soil selected is $C-\phi$ type soil.

α value is taken by program according to N-value

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c values are taken by the program from the table suggested in chapter1 Table (1.2). Here N values are assumed values, for IInd layer N is taken as 5, for IIIrd layer it is taken as 7, for IVth layer it is taken as 8 and for Vth layer it is taken as 3.

Output of the Program

CASE: 1b Circular Bored Pile, $C-\phi$ type soil.

Skin Resistance for the 1st layer is	=	2.29214 $x\,10^6$ kg
Skin Resistance for the 2nd layer is	=	8.48313 $x\,10^6$ kg
Skin Resistance for the 3rd layer is	=	7971.79 kg
Skin Resistance for the 4th layer is	=	11160.5 kg

Skin Resistance for the 5th layer is	=	$3.24895 \; x\, 10^7$ kg
The total value of Skin Resistance	=	$4.32839\, x\, 10^7$ kg
The value of Point Resistance is	=	$3.98068 \; x\, 10^7$ kg

Ultimate Bearing Capacity of Pile is	=	$0.830907\, x\, 10^8$ kg

CASE: 2a Square Driven Pile, $C-\phi$ type soil

Skin Resistance for the 1st layer is	=	$2.77417 \; x\, 10^6$ kg
Skin Resistance for the 2nd layer is	=	$1.00735 \; x\, 10^7$ kg
Skin Resistance for the 3rd layer is	=	6090 kg
Skin Resistance for the 4th layer is	=	8526 kg
Skin Resistance for the 5th layer is	=	$3.94921 \; x\, 10^7$ kg
The total value of Skin Resistance	=	$5.23544 \; x\, 10^7$ kg
The value of Point Resistance is	=	$1.82113 \; x\, 10^7$ kg

Ultimate Bearing Capacity of Pile is	=	$0.705657\, x\, 10^8$ kg

CASE: 2b Square Bored Pile, $C-\phi$ type soil

Skin Resistance for the 1st layer is	=	$1.75107 \; x\, 10^6$ kg
Skin Resistance for the 2nd layer is	=	$6.48064 \; x\, 10^7$ kg
Skin Resistance for the 3rd layer is	=	6090 kg
Skin Resistance for the 4th layer is	=	8526 kg
Skin Resistance for the 5th layer is	=	$2.46976 \; x\, 10^7$ kg
The total value of Skin Resistance	=	$3.29439 \; x\, 10^7$ kg
The value of Point Resistance is	=	$1.80433 \; x\, 10^7$ kg

Ultimate Bearing Capacity of Pile is	=	$0.509872 \; x \; 10^8$ kg

CASE: 3a Rectangular Driven Pile, $C-\phi$ type soil

Skin Resistance for the 1st layer is	=	$4.62362 \; x\, 10^6$ kg
Skin Resistance for the 2nd layer is	=	$1.67891 \; x\, 10^7$ kg
Skin Resistance for the 3rd layer is	=	10150 kg
Skin Resistance for the 4th layer is	=	14210 kg
Skin Resistance for the 5th layer is	=	$6.58202 \; x\, 10^7$ kg

The total value of Skin Resistance	=	$8.72573 \; x \, 10^7$ kg
The value of Point Resistance is	=	$4.86021 \, x \, 10^7$ kg

Ultimate Bearing Capacity of Pile is	=	$1.35859 \; x \, 10^8$ kg

CASE: 3b Rectangular Bored Pile, $C-\phi$ type soil

Skin Resistance for the 1st layer is	=	$2.91845 \; x \, 10^6$ kg
Skin Resistance for the 2nd layer is	=	$1.08011 \; x \; 10^7$ kg
Skin Resistance for the 3rd layer is	=	10150 kg
Skin Resistance for the 4th layer is	=	14210 kg
Skin Resistance for the 5th layer is	=	$4.13669 \; x \, 10^7$ kg
The total value of Skin Resistance	=	$5.51107 \; x \, 10^7$ kg
The value of Point Resistance is	=	$4.86021 \; x \, 10^7$ kg

Ultimate Bearing Capacity of Pile is	=	$1.03713 \; x \, 10^8$ kg

The first three cases results are tabulated in Table 3.7.

Case 4 to 6

Different cases considered for the analysis of the pile are as per [Fig 3.4]. Here the constant terms for this particular problem are soil parameters, number of layers, thickness of each layer & length of the pile. The soil here is ϕ type. The data here are the assumed ones and are same for the case 4, case 5 and case 6. Input data for the program of soil properties and length of the pile.

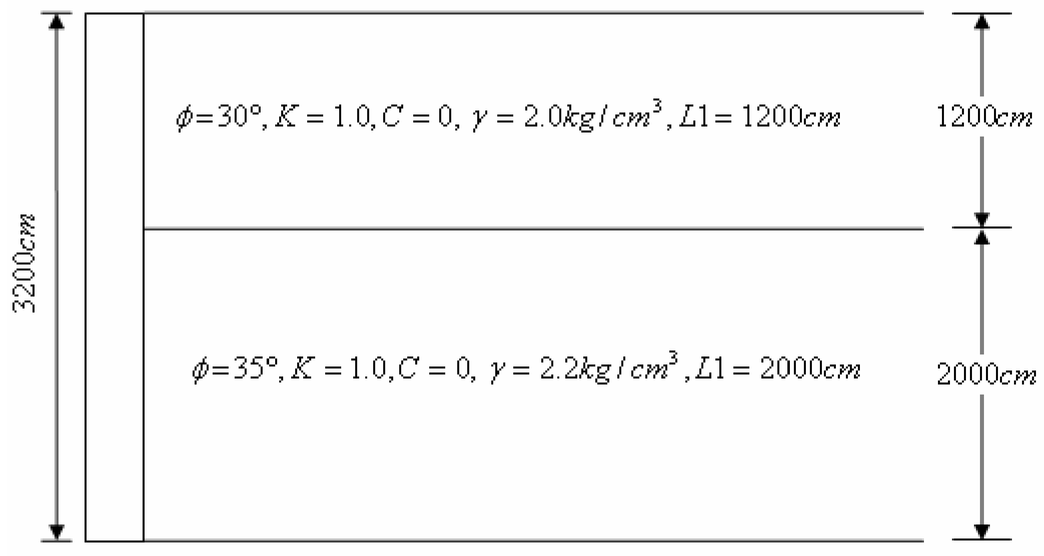


Fig 3.4 Soil parameters of sand for the analysis of pile

LAYER 1 INPUT PROPERTIES:-

I^st layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	2.0 Kg/cm^3
Value of coefficient of earth pressure (K)	=	1.0
Value of angle of internal friction	=	30°

LAYER 2 INPUT PROPERTIES:-

I^st layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	2.2 Kg/cm^3
Value of coefficient of earth pressure (K)	=	1.0
Value of angle of internal friction	=	35°

Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ, N_c are calculated as per equation (3.5, 3.6 & 3.7)

Input of pile for the program for case 4 to 6.

CASE: 4

Shape of the Pile	=	**Circular**
Length of the Pile	=	3200 cm
No. of Layers are	=	2
Layer 1 thickness is	=	1200 cm
Layer 2 thickness is	=	2000 cm
The diameter of Pile is	=	25 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is ϕ type soil.

CASE: 5

Shape of the Pile	=	**Square**
Length of the Pile	=	3200 cm
No. of Layers are	=	2
Layer 1 thickness is	=	1200 cm
Layer 2 thickness is	=	2000 cm
The diameter of Pile is	=	15 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is ϕ type soil.

CASE: 6

Shape of the Pile	=	**Rectangular**
Length of the Pile	=	3200 cm
No. of Layers are	=	2
Layer 1 thickness is	=	1200 cm
Layer 2 thickness is	=	2000 cm
The Longer side of the rectangular is	=	30 cm
The short side of the rectangular is	=	20 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is ϕ type soil.

Output of the program

CASE: 4 Circular Driven Pile, ϕ type soil.

Skin Resistance for the 1st layer is	=	$6.52968 \, x \, 10^6$ Kg
Skin Resistance for the 2nd layer is	=	$5.05946 \, x \, 10^7$ Kg
The total value of Skin Resistance	=	$5.71243 \, x \, 10^7$ Kg
The value of Point Resistance is	=	$1.88382 \, x \, 10^7$ Kg

Ultimate Bearing Capacity of Pile is	=	$0.759625 \, x \, 10^8$ Kg

CASE: 5 Square Driven Pile, ϕ type soil

Skin Resistance for the 1st layer is	=	$4.98831 \, x \, 10^6$ Kg
Skin Resistance for the 2nd layer is	=	$3.86515 \, x \, 10^7$ Kg
The total value of Skin Resistance	=	$4.36398 \, x \, 10^7$ Kg
The value of Point Resistance is	=	$8.62289 \, x \, 10^6$ Kg

Ultimate Bearing Capacity of Pile is	=	$0.522627 \, x \, 10^8$ Kg

CASE: 6 Rectangular Driven Pile, ϕ type soil

Skin Resistance for the 1st layer is	=	$9.14523 \, x \, 10^6$ Kg
Skin Resistance for the 2nd layer is	=	$6.77801 \, x \, 10^7$ Kg
The total value of Skin Resistance	=	$7.69253 \, x \, 10^7$ Kg
The value of Point Resistance is	=	$2.38201 \, x \, 10^7$ Kg

Ultimate Bearing Capacity of Pile is	=	$1.00745 \, x \, 10^8$ Kg

The results of cases 4, 5 and 6 are tabulated in table 3.9.

Case 7 to 9

Different cases considered for the analysis of the pile are as per [Fig 3.5]. Here the constant terms for this particular problem are soil parameters, number of layers, thickness of each layer & length of the pile. The soil here is C type. The data here are the assumed ones and are same for the case 7, case 8 and case 9. Input data for the program of soil properties and length of the pile

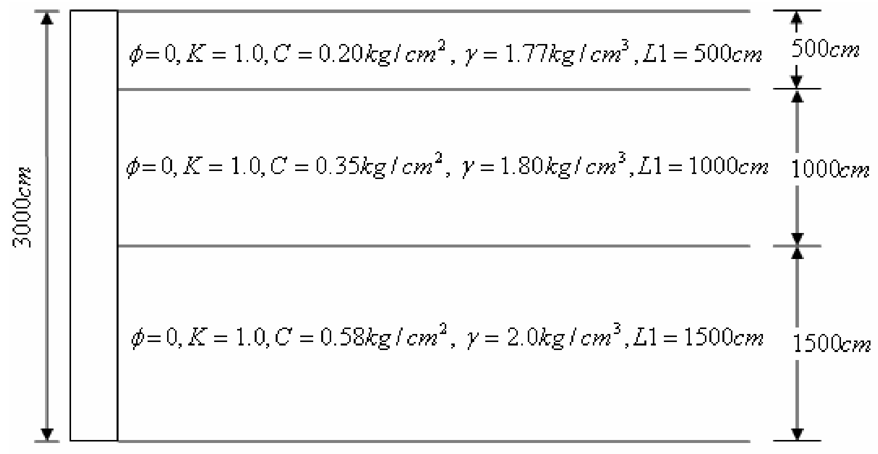


Fig 3.5 Soil parameters of clay for analysis of pile

LAYER 1 INPUT PROPERTIES:-

I[st] layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	1.77 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.0
Unit Cohesion for this layer	=	0.20 kg/cm^2

LAYER 2 INPUT PROPERTIES:-

I[st] layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	1.80 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.0
Unit Cohesion for this layer	=	0.35 kg/cm^2

LAYER 3 INPUT PROPERTIES:-

I[st] layer is SAND (ϕ type Soil)

Value of Effective unit weight	=	2.00 kg/cm^3
Value of coefficient of earth pressure (K)	=	1.0

Unit Cohesion for this layer = 0.58 kg/cm^2

Here in this the bearing capacity factor N_c is calculated as per equation (3.6 & 3.7)

Input data of pile for the program for case 4 to 6.

CASE: 7

Shape of the Pile	=	**Circular**
Length of the Pile	=	3000 cm
No. of Layers are	=	3
Layer 1 thickness is	=	500 cm
Layer 2 thickness is	=	1000 cm
Layer 3 thickness is	=	1500 cm
Diameter of the Pile	=	25 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is C type soil.

α value is taken by program according to C-value

CASE: 8

Shape of the Pile	=	**Square**
Length of the Pile	=	3000 cm
No. of Layers are	=	3
Layer 1 thickness is	=	500 cm
Layer 2 thickness is	=	1000 cm
Layer 3 thickness is	=	1500 cm
One side of Square	=	15 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is C type soil.

α value is taken by program according to C-value

CASE: 9

Shape of the Pile	=	**Rectangular**
Length of the Pile	=	3000 cm
No. of Layers are	=	3
Layer 1 thickness is	=	500 cm
Layer 2 thickness is	=	1000 cm

Layer 3 thickness is	=	1500 cm
The Longer side of the rectangular is	=	30 cm
The short side of the rectangular is	=	20 cm

It is a **Driven Pile** ($\delta = \phi$)

The soil selected is C type soil.

α value is taken by program according to C-value

Output of the program

CASE: 7 Circular Driven Pile, C type soil

Skin Resistance for the 1st layer is	=	7853.98 kg
Skin Resistance for the 2nd layer is	=	27488.90 kg
Skin Resistance for the 3rd layer is	=	47830.7 kg
The total value of Skin Resistance	=	83173.7 kg
The value of Point Resistance is	=	2793180.0 kg

Ultimate Bearing Capacity of Pile is	=	2876353.7 kg

CASE: 8 Square Driven Pile, C type soil

Skin Resistance for the 1st layer is	=	6000 kg
Skin Resistance for the 2nd layer is	=	21000 kg
Skin Resistance for the 3rd layer is	=	36540 kg
The total value of Skin Resistance	=	63540 kg
The value of Point Resistance is	=	1280300 kg

Ultimate Bearing Capacity of Pile is	=	1343840 kg

CASE: 9 Rectangular Driven Pile, C type soil

Skin Resistance for the 1st layer is	=	10000 kg
Skin Resistance for the 2nd layer is	=	35000 kg
Skin Resistance for the 3rd layer is	=	60900 kg
The total value of Skin Resistance	=	105900 kg
The value of Point Resistance is	=	34141.3 kg

Ultimate Bearing Capacity of Pile is	=	3520030.0 kg

The results of cases 4, 5 and 6 are tabulated in table 3.11.

Laterally Loaded Piles

The Input Data for calculating (I.S. 2911-1979) the Depth of Fixity and Moment acting on the pile for the given Horizontal load:

1. Shape of pile.
2. Dimension of the pile.
3. Horizontal load acting on the pile.
4. Free outstanding length of the pile.
5. Embedded Length of the pile.
6. Condition of the pile head.
7. Soil condition and its respective Parameters.
8. Grade of Concrete.

Input for the program

Case A: Circular Pile

Shape of the pile	=	Circular
Diameter of the pile	=	60cm
Horizontal load acting on the pile	=	8700 kg
Free Outstanding length of the pile	=	0 cm
Embedded Length of the pile	=	1200 cm
Pile Head Condition	=	Fixed
Type of Soil	=	Sand
Unconfined Compressive Strength	=	1 kg/cm^2
Grade of Concrete	=	40 N/mm^2

The Out Put Value of the above input is:-

1. Young's Modulus (E)
2. Moment of inertia (I)
3. EI
4. Stiffness factor
5. Depth of Fixity
6. Fixed End Moment
7. Actual Maximum Moment

Output of the program

Case A: Circular Pile

Young's Modulus	=	3 kg/cm^2
Moment of inertia	=	636173 cm4
EI	=	1.90852e+06 kg/cm^2
Stiffness factor	=	14.0627 cm
Depth of Fixity	=	30.938 cm
Fixed End Moment	=	134580 kgcm
Reduction Factor	=	0.82 (From graph)
Actual Maximum Moment	=	137945 kgcm

Design programs (1) Bored Pile (Case AD)

(2) Driven Pile (Case BD)

The Input Data for the Design Program of Bored Pile is as follows:

1. Shape of pile.
2. Enter The Dimensions of the section.
3. Loads Acting on the Pile.
4. Grade of Concrete and Steel
5. Assuming the percentage of steel.
6. Clear cover for the section
7. Diameter of the bar for longitudinal
8. The Value of $M_u / f_{ck}bd^2$ from SP 16.
9. Diameter of the bar Helix reinforcement.
10. The value of p / f_{ck} from SP 16.
11. The value of M_{ux} / M_{ux1} from chart 64 of SP 16.

Input for the program (Assumed data)

CASE: AD Circular Bored Pile

Shape of pile	=	**Circular**
The diameter of Pile	=	450 mm
The Length of the Pile	=	15 m
The Vertical Load on the Pile	=	245 kN
The Moment acting on the Pile about x axis	=	10.5 kNm
The Moment acting on the Pile about y axis	=	15 kNm
Grade of Concrete	=	25 N/mm^2
Grade of Steel	=	415 N/mm^2
Assumed percentage of steel	=	3 %
Clear Cover for the reinforcement	=	40 mm
Assumed diameter of bar for longitudinal Reinforcement	=	32 mm
Value of $(M_u / \sigma_{ck}bd^2)_x$ from the chart of SP 16	=	0.0905
Value of $(M_u / \sigma_{ck}bd^2)_y$ from the chart of SP 16	=	0.0905
Assumed diameter of bar for helix		

Reinforcement = 8 mm

The Out Put Value of the circular bored pile is:-

1. L/D
2. Additional Moments
3. Total moment for which the pile has to design.
4. Moment for which the column has to be designed.
5. Moments calculated from the Graph of SP 16.
6. No. of bars for the Longitudinal Reinforcement
7. Spacing for the lateral reinforcement.

Output of the program

CASE: AD Circular Bored Pile

L/D ratio is = 33.333

As the L/D ratio for the pile exceeds the value 12 so it has to be designed as Long Column

Additional Moments about x axis = 78.033 kNm

Additional Moments about y axis = 78.066 kNm

The value of d'/D about x axis = 0.15

The value of d'/D about y axis = 0.15

Moments M_{ux} for which the column

has to be designed = 93.033

Moments M_{uy} for which the column

has to be designed = 89.058

Moment M_{ux} from graph = 206 kNm

Moment M_{uy} from graph = 206 kNm

Longitudinal Reinforcement = Provide 6 bars of 32 mm dia

Lateral Reinforcement = Provide 8 mm helix at a pitch of 40 mm c/c

Reinforcement details are given in Fig 3.6.

The Input Data for the Design Program of Driven Pile is as follows:-

1. Shape of pile.
2. Enter The Dimensions of the section.
3. Loads Acting on the Pile.
4. Grade of Concrete and Steel
5. The Length of the Pile.
6. Clear cover for the section
7. Diameter of the bar for longitudinal
8. Diameter of the bar for lateral reinforcement for central potion of pile.
9. Diameter of the bar for lateral reinforcement as spiral near the pile head.
10. Diameter of the bar for lateral reinforcement for both the ends (top & bottom) of the Pile.

Input data for the program from reference [12]

CASE: BD Square Driven Pile

Shape of pile	=	**Square**
One side of square is	=	300 mm
The Vertical Load on the Pile	=	600 kN
Grade of Concrete	=	20 N/mm^2
Grade of Steel	=	415 N/mm^2
The Length of the Pile	=	6.6 m
Clear Cover for the reinforcement	=	40 mm
Assumed diameter of bar for longitudinal Reinforcement	=	20 mm
Assumed diameter of bar for lateral Reinforcement for central portion	=	8 mm
Assumed diameter of bar for lateral Reinforcement for spiral near pile head	=	8 mm
Assumed diameter of bar for lateral Reinforcement for both (top & bottom) ends of Pile	=	8 mm

The Out Put Value of the square driven pile is

1. L/D
2. No. of bars for the Longitudinal Reinforcement

3. Spacing of Lateral Reinforcement at the Central Portion.
4. Spacing of Lateral Reinforcement as spiral near the pile head
5. Spacing of lateral reinforcement for both the ends (top & bottom) of the Pile.

Output of the reference [12]

L/D ratio is = 22

As the L/D ratio for the pile exceeds the value 12 so it has to be designed as Long Column.

Longitudinal Reinforcement	= 4 bars of 20 mm diameter
Spacing of Lateral Reinforcement at the Central Portion.	= 8 mm bars @ 150 mm c/c
Spacing of Lateral Reinforcement as spiral near the pile head	= 8 mm bars @ 45 mm c/c for a length of 900 mm
Spacing of lateral reinforcement for both the ends (top & bottom)	= 8 mm bars @ 70 mm c/c for a length of 900 mm

Output of the program

CASE: BD Square Driven Pile

L/D ratio is = 22

As the L/D ratio for the pile exceeds the value 12 so it has to be designed as Long Column.

Longitudinal Reinforcement	= 8 bars of 20 mm diameter
Spacing of Lateral Reinforcement at the Central Portion.	= 8 mm bars @ 150 mm c/c
Spacing of Lateral Reinforcement as spiral near the pile head	= 8 mm bars @ 50 mm c/c for a length of 900 mm
Spacing of lateral reinforcement for both the ends (top & bottom) of the Pile.	= 8 mm bars @ 80 mm c/c for a length of 900 mm

Reinforcement details are given in fig 3.7.

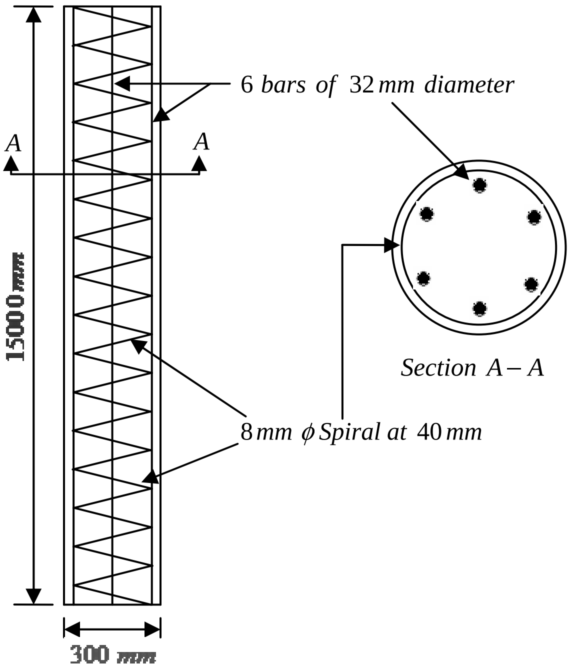


Fig 3.6 Detailing of bored pile for case AD

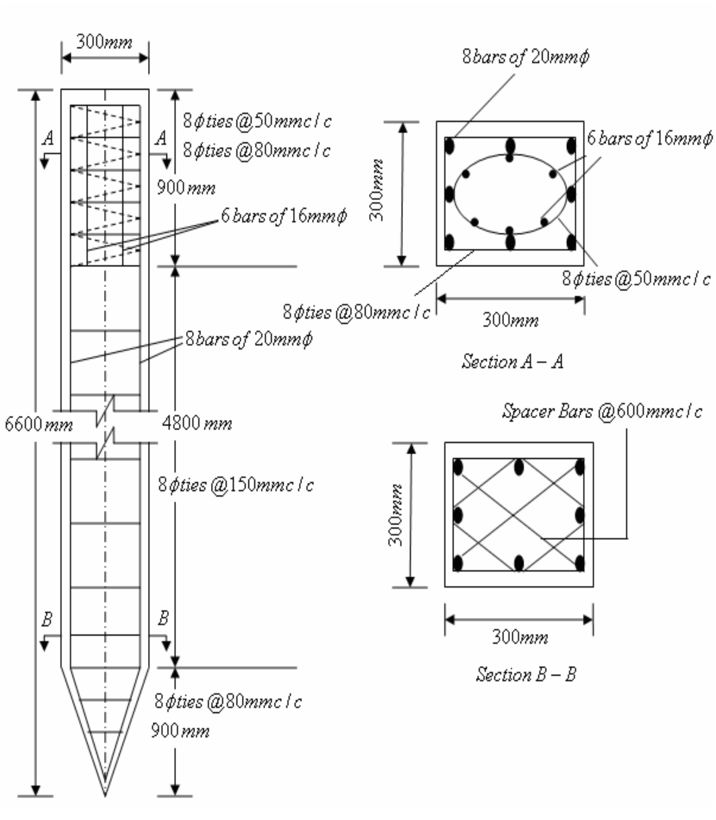


Fig 3.7 Detailing of driven pile for case BD

Summary of input and output values of design program is given in Table 3.12

3.6 RESULTS

Input & Output Values of Analysis of pile for Different Cases:-

Cases 1a, 1b, 2a, 2b, 3a, 3b.

Table 3.6 Soil input parameters for case 1a, 1b, 2a, 2b, 3a & 3b.

Sr. No.	Layer Thickness cm	Type of Soil	Soil Parameters	Water Table
1	300	Sand	$\phi = 31^\circ$, $K = 1$, $C = 0$, $\gamma = 1.71 kg / cm^3$	Not present
2	350	Sand & clay	$\phi = 26^\circ$, $K = 1.2$, $C = 0.20 kg / cm^2$, $\gamma = 1.75 kg / cm^3$	Not present
3	250	Clay	$\phi = 0$, $K = 1$, $C = 0.58 kg / cm^2$, $\gamma = 1.80 kg / cm^3$	Not present
4	350	Clay	$\phi = 0$, $K = 1$, $C = 0.58 kg / cm^2$, $\gamma = 1.80 kg / cm^3$, $\gamma' = 0.80 kg / cm$	Present
5	400	Sand & clay	$\phi = 32^\circ$, $K = 1.3$, $C = 0.13 kg / cm^2$, $\gamma = 1.85 kg / cm^3$, $\gamma' = 0.85 kg / cm$	Present

Table 3.7 Input & output values of analysis of piles for case 1a, 1b, 2a, 2b, 3a & 3b.

Pile Parameters	INPUT Parameters	OUTPUT Ultimate Bearing Capacity of Pile
(Circular) Pile:- Dia = 25cm Length = 1650cm Soil:- $C - \phi$ type 5 layers, water table present at 3rd layer.	Case 1 a N_q , N_γ , N_c calculated from vesic equation. $\delta = \phi$,(Driven Pile), α value from C-value	$1.08326 \, x \, 10^8$ kg
	Case 1 b N_q ,calculated from vesic equation. N_γ , N_c from table given in IS 6403 1981 $\delta = .67\phi$,(Bored Pile) α value from N-value	$0.830907 \, x \, 10^8$ kg

Table 3.7 Continue

(Square) Pile:- Side = 15cm Length = 1650cm Soil:- $C-\phi$ type 5 layers, water table present at 3rd layer.	Case 2 a N_q, N_γ, N_c calculated from vesic equation. $\delta = \phi$,(Driven Pile), α value from C-value	$0.705657\, x\, 10^8$ kg
	Case 2 b N_q ,calculated from vesic equation. N_γ, N_c from table given in IS 6403 1981 $\delta = .67\phi$,(Bored Pile) α value from N-value	$0.509872\, x\, 10^8$ kg
(Rectangular) Pile:- Longer Side = 30cm Shorter Side = 20cm Length = 1650cm Soil:- $C-\phi$ type 5 layers, water table present at 3rd layer.	Case 3 a N_q, N_γ, N_c calculated from Vesic equation. $\delta = \phi$,(Driven Pile), α value from C-value	$1.35859\, x\, 10^8$ kg
	Case 3 b N_q ,calculated from vesic equation. N_γ, N_c from table given in IS 6403 1981 $\delta = .67\phi$,(Bored Pile) α value from N-value	$1.03713\, x\, 10^8$ kg

Cases 4, 5, 6.

Table 3.8 Soil input parameters for case 4, case 5 & case 6

Sr. No.	Layer Thickness cm	Type of Soil	Soil Parameters	Water Table
1	1200	Sand	$\phi = 30^{\circ}$, $K = 1$, $C = 0$, $\gamma = 2.0\,kg/cm^3$	Not present
2	2000	Sand	$\phi = 35^{\circ}$, $K = 1.2$, $C = 0$, $\gamma = 2.2\,kg/cm^3$	Not present

Table 3.9 Input & output values of analysis of piles for case4, case5 & case6.

Pile Parameters	INPUT Parameters	OUTPUT Ultimate Bearing Capacity of Pile
(Circular) Pile:- Soil:- ϕ type 2 layers	Case 4 Dia = 25cm Length = 3200 cm N_q , N_γ calculated from Vesic equation. $\delta = \phi$,(Driven Pile)	0.759625 x 10^8 kg
(Square) Pile:- Soil:- ϕ type 2 layers	Case 5 Side = 15cm Length = 3200cm N_q , N_γ calculated from vesic equation. $\delta = \phi$,(Driven Pile)	0.522627 x 10^8 kg
(Rectangular) Pile:- Soil:- ϕ type 2 layers	Case 6 Longer Side = 30cm Shorter Side = 20cm Length = 3200cm N_q , N_γ calculated from vesic equation. $\delta = \phi$,(Driven Pile),	1.00745 x 10^8 kg

Cases 7, 8, 9.

Table 3.10 Soil input parameters for case 7, case 8 & case 9

Sr. No.	Layer Thickness cm	Type of Soil	Soil Parameters	Water Table
1	500	Clay	$\phi = 0$, $K = 1$, $C = 0.20 kg/cm^2$, $\gamma = 1.77 kg/cm^3$	Not present
2	1000	Clay	$\phi = 0$, $K = 1$, $C = 0.35 kg/cm^2$, $\gamma = 1.80 kg/cm^3$	Not present
3	1500	Clay	$\phi = 0$, $K = 1$, $C = 0.58 kg/cm^2$, $\gamma = 2.0 kg/cm^3$	Not present

Table 3.11 Input & output values of analysis of piles for case7, case8 & case9

Pile Parameters	INPUT Parameters	OUTPUT Ultimate Bearing Capacity of Pile
VIIth (Circular) Pile:- Soil:- C type 3 layers	Case 7 Dia = 25cm Length = 3000 cm N_c is Calculated from vesic equation. $\delta = \phi$,(Driven Pile)	$2.876354 \, x \, 10^6$ kg
VIIIth (Square) Pile:- Soil:- C type 3 layers	Case 8 Side = 15cm Length = 3000cm N_c is Calculated from vesic equation. $\delta = \phi$,(Driven Pile)	$1.34384 \, x \, 10^6$ kg
IXth (Rectangular) Pile:- Soil:- C type 3 layers	Case 9 Longer Side = 30cm Shorter Side = 20cm Length = 3000cm N_c is Calculated from vesic equation. $\delta = \phi$,(Driven Pile)	$3.520030 \, x \, 10^6$ kg

Table 3.12 Input & output values of design of bored and driven piles

Cases	INPUT Parameters	OUTPUT Longitudinal & Lateral Reinforcement
I[st] Circular Dia =450 mm Length = 15 m BORED PILE	Vertical load= 245 kN Moment about x axis = 10.5 kNm Moment about y-axis = 12 kNm f_{ck} = 25 N/mm^2 f_y = 415 N/mm^2 Clear cover = 40mm Diameter of bar for longitudinal reinforcement = 32 mm Assumed % of steel = 3 $(M_u/\sigma_{ck}bd^2)_x$ =0.0905 $(M_u/\sigma_{ck}bd^2)_y$ =0.0905 Diameter of bar for helix reinforcement = 8 mm	L/D= 33.33 Design as a Long Column Additional moment about x-axis =78.033 kNm Additional moment about x-axis =78.066 kNm $(d'/D)_x$ = 0.15 $(d'/D)_y$ = 0.15 Moment Mux from graph = 206 kNm Moment Muy from graph =206 kNm Longitudinal Reinforcement = Provide 6 bars of 32 mm dia Lateral Reinforcement = Provide 8 mm bars at a pitch of 40 mm c/c
I[st] Square Side length = 300 mm Length = 15 m DRIVEN PILE	Vertical load= 1000 kN f_{ck} = 20 N/mm^2 f_y = 415 N/mm^2 Clear cover = 40mm Diameter of bar for longitudinal reinforcement = 20 mm Lateral Reinforcement Diameter of :- Bar in central portion = 8 mm Bar near pile head = 8 mm Bar at both the ends of pile (top & Bottom) = 8 mm	L/D= 22 Design as a Long Column Longitudinal Reinforcement = Provide 12 bars of 20 mm diameter. Lateral Reinforcement = @ Central portion = Provide 8 mm bars at a pitch of 165 mm c/c Near Pile Head = 8 mm bars at a pitch of 45 mm c/c for a length of 1500mm Both Ends (top & Bottom) 8 mm bars at a pitch of 55 mm c/c for a Length of 1500 mm

3.7 SUMMARY

The soil input parameters for case 1a to 3b, case 4-6 & case 7-9 are specified in table 3.6, table 3.8 & table 3.10 respectively. The following table gives the summary of load carrying capacity of single pile under different soil condition.

Table 3.13 Summary of the analysis of different types of piles.
Load Carrying capacity

Cases	Type of Soil	Type of pile	Shape of Pile	Bearing Capacity
1a	$C-\phi$ type	Driven	Circular	$1.08326\ x\,10^8$ kg
1b		Bored	Circular	$0.830907\,x\,10^8$ kg
2a		Driven	Square	$0.705657\,x\,10^8$ kg
2b		Bored	Square	$0.509872\,x\,10^8$ kg
3a		Driven	Rectangular	$1.35859\,x\,10^8$ kg
3b		Bored	Rectangular	$1.03713\,x\,10^8$ kg
4	ϕ type	Driven	Circular	$0.759625\,x\,10^8$ kg
5			Square	$0.522627\,x\,10^8$ kg
6			Rectangular	$1.00745\,x\,10^8$ kg
7	C type	Driven	Circular	$2.876354\,x\,10^6$ kg
8			Square	$1.34384\,x\,10^6$ kg
9			Rectangular	$3.520030\,x\,10^6$ kg

Table 3.14 Comparison of the bearing capacity
of the different types piles in different soil conditions

Type of Soil	Shape of pile	Type of Installation	Bearing Capacity kg	Ratio of the Maximum Value* to the lower value
$C-\phi$	Rectangular	Driven	1.3586E+08 *	1
	Circular		1.0833E+08	1.25
	Square		7.0566E+07	1.93
	Rectangular	Bored	1.0371E+08*	1
	Circular		8.3091E+07	1.25
	Square		5.0987E+07	2.03
ϕ	Rectangular	Driven	1.0075E+08*	1
	Circular		7.5963E+07	1.33
	Square		5.2263E+07	1.93
C	Rectangular	Driven	3.5200E+06*	1
	Circular		2.8764E+06	1.22
	Square		1.3438E+06	2.62

3.8 CONCLUSION

1. The results of analysis of single pile in some soil condition were cross-checked with the data provided by the Adani group. Thus the validity of the program is checked. [Table 3.5]
2. The Bearing capacity of Rectangular Driven Pile in $C-\phi$ type of soil is 1.25 times the Bearing Capacity of Circular Driven Pile and 1.93 times the Square Driven Pile.[Table 3.14]
3. The Bearing capacity of Rectangular Bored pile in $C-\phi$ type of soil is 1.248 times the Bearing Capacity of Circular Bored Pile and 2.03 times the Square Bored Pile. [Table 3.14]
4. The Bearing capacity of Rectangular Driven Pile in ϕ type of soil is 1.326 times the Bearing Capacity of Circular Driven Pile and 1.927 times the Square Driven Pile. [Table 3.14]
5. The Bearing capacity of Rectangular Driven Pile in *C type* of soil is 1.22 times the Bearing Capacity of Circular Driven Pile and 2.62 times the Square Driven Pile. [Table 3.14]

4. COMPUTER PROGRAM FOR ANALYSIS & DESIGN PILE GROUP

4.1 ANALYSIS METHOD

I.S. 2911 (Part I/Sec I) 1979 has just suggested some of the parameters for the analysis of pile group i.e. spacing, type of failure of the pile group, reinforcement specifications for pile cap, factor of safety for the static or dynamic formulas. [2]

4.1.1 Pile Group in Granular Soils

The δ, K, and bearing capacity factor value are to be considered as specified in chapter 3 which deals with the analysis of single pile. The bearing capacity formula for the pile group is suggested as follows:

$$Q_{gu} = nQ_u \qquad \text{... (4.1)}$$

where,

Q_{gu} = Ultimate load carrying capacity of a pile group with n piles;

Q_u = the ultimate load capacity of a single pile.

The load bearing capacity of a single bored-and cast-in-situ pile will be very much less than that of a driven pile, thus the above equation also applies to bored piles. But here in this work the formula used for the group capacity is:

$$Q_{gu} = E_g(nQ_u) \qquad \text{... (4.2)}$$

where,

n = no. of piles in the group.

E_g = Pile Group Efficiency.

4.1.2 Pile Group in Clay

The bearing capacity of a pile group may be either of the following:

Equal to the bearing capacity of individual piles multiplied by the number of piles in a group or else it will be the frictional capacity along the perimeter of the column of soil enclosed by the pile group together with the end bearing of the above column.[2][14]

The equation for block failure may be written as:

$$Q_{gu} = cN_c A_g + P_g \sum L_i c_i \quad \text{... (4.3)}$$

where,

Q_{gu} = Ultimate load carrying capacity of pile group by block action;

c = Unit cohesion of clay beneath the pile group;

N_c = Bearing capacity factor usually taken as 9;

A_g = Sectional area of pile group ($a * b$);

P_g = Perimeter of pile group;

L_i = Thickness of the individual soil layer enclosing the pile;

c_i = unit cohesion of individual soil layer enclosing the pile.

Bearing capacity of a pile group on the basis of individual pile failure is same as equation (4.1), Terzaghi and Peck recommended that bearing capacity of a pile group is normally taken as the smaller of the two above equations. [6]

4.1.3 Geometry of the Pile Layout for group of pile.

Load Distribution

The load moment shared by each pile in a pile group should be analysed to safeguard against the possibility of overstressing any portion of the pile group. The simple static analysis is the traditional method commonly used in a practice. Fig 4.1 shows a pile group acted upon by a vertical load Q and a horizontal load H. As long as the resultant r intersects the bottom of the pile cap, the vertical load R on a pile can be computed as given in equation 4.4. Thus, when the total vertical load, centrally placed, is Q, the number of piles is n, then the load transmitted to each pile shall be $\frac{Q}{n}$. When however, the pile cap is eccentrically loaded, as to subject the pile cap to a central vertical load (Q) and additional moment M_x and M_y, then the load transmitted to a pile is given by the equation:

$$R = \frac{Q}{n} + \frac{M_y * x_1}{\sum x_1^2} + \frac{M_x * y_1}{\sum y_1^2} \quad \text{... (4.4)}$$

where,

R = axial force in the pile under consideration;

Q = the total vertical load acting on the pile cap;

n = the number of piles in the group;

M_x = total moment about x-axis $= Q * e_y$;

M_y = total moment about y-axis $= Q * e_x$;

e_x = eccentricity along x-axis;

e_y = eccentricity along y-axis;

x_1 = distance of the considered pile from y-axis;

y_1 = distance of the considered pile from x-axis;

$\sum x_1^2$ = sum of the squares of the distances of all the piles from y-axis;

$\sum y_1^2$ = sum of the squares of the distances of all the piles from x-axis.[8]

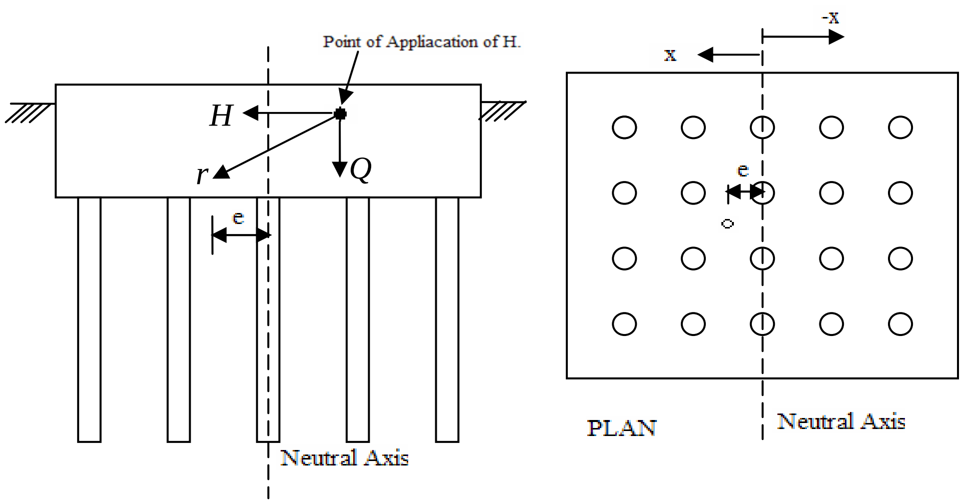


Fig 4.1 Pile Group subjected to vertical and horizontal load.

4.1.4 Types of load:

Different loads considered for the analysis of the pile group are same as used to calculate the load acting on the single pile, they are vertical load, horizontal load and moments coming from the column above the pile cap.

4.1.5 Different shape of pile group:

Here in this study different shape of pile group studied are triangular, square and rectangular, consisting of 3 piles for triangular pile cap, 4 and 9 number of piles for square pile cap and 6 and 12 piles for the rectangular pile cap.

4.1.6 Different shapes of piles under the pile cap:

Three different shapes of piles were studied in this work they are circular type pile, square type pile and rectangular type pile. These 3 types piles were further distinguished in two other forms as per their installation i.e. cast-in-situ (bored) pile and driven pile.

4.1.7 Soil Conditions.

Two types of soil conditions were considered for the analysis of the pile group. They were sandy soil and clayey soil.

4.2 SETTLEMENT OF THE PILE GROUP

The settlement of a pile group is due to the elastic shortening of piles and due to the settlement of the soil supporting the piles. It is assumed that the pile group acts as a single pile large deep foundation, such as a pier or a mat. The total load is assumed to act at a depth equal to two-thirds the pile length in the case of friction piles [Fig 4.2a], in the case of end-bearing piles, the total is assumed to act at the pile tips [Fig 4.2b]. In the case of combined action, the frictional component is assumed to act as 2/3D and the bearing component at the tip.

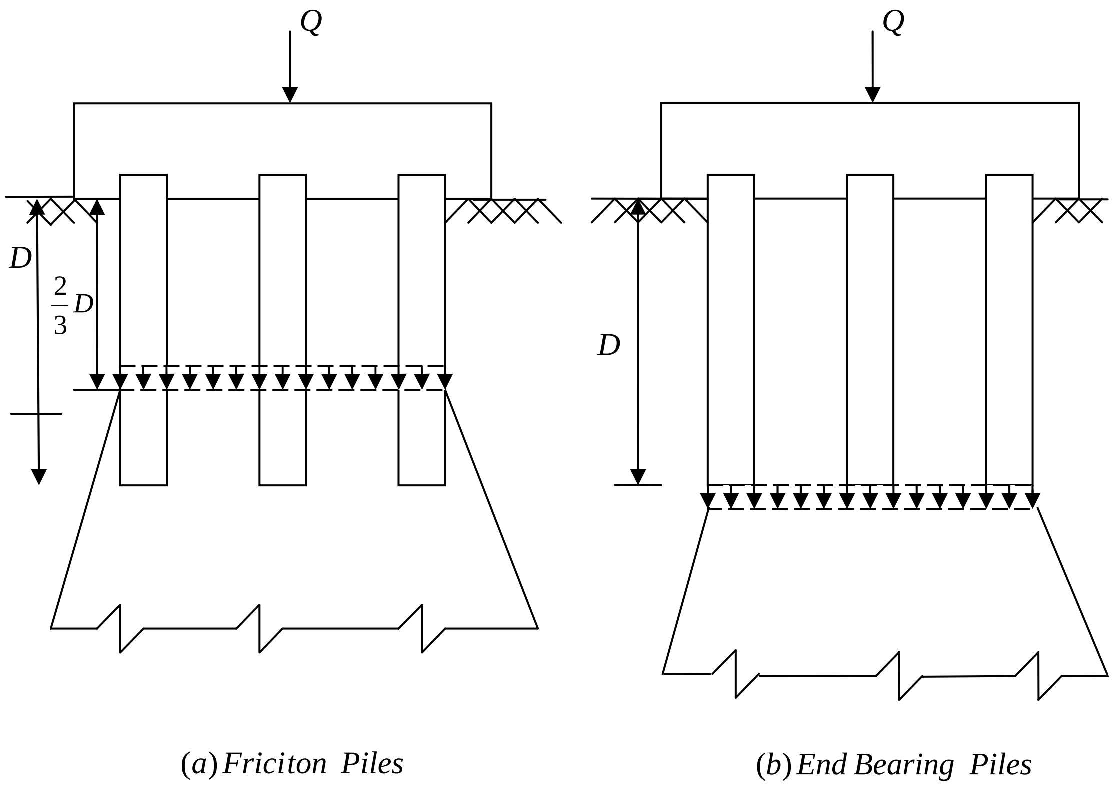


Fig 4.2 Settlement of the pile group.

Meyerhof (1976) suggests the following empirical relation for the elastic settlement of a pile group in sands and gravels.

$$S_g = \frac{9.4q\sqrt{B_g I}}{N_1} \qquad \text{... (4.5)}$$

where,

S_g = settlement of group (mm);

q = load intensity (Q_g/A_g);

Q_g = load acting on the pile group;

A_g = area of the pile group;

B_g = width of the group;

I = influence factor ($1 - L/8B_g$);

L = length of pile;

N_1 = corrected standard penetration number within the seat of settlement (apprx. = B_g below the tip).

The present knowledge is not sufficient to evaluate the settlements of piles and pile groups. It has been found from field observation that the settlement of a pile group is many times the settlement of a single pile at the corresponding working load. there are no equation that would satisfactorily predict the settlements of piles in sand. It is better to rely on load tests for piles in sand.

The consolidation settlement of a pile group in clay can be determined same as shallow foundation. Generally, 2:1 load distribution is assumed from the level at which the load acts. Sometimes, the load is assumed to spread outwards from the edge of the block at an angle 30° to the vertical. The stress increase at the middle of each layer is calculated as

$$q_i = \frac{Q_g}{(B_g + Z_i) + (L_g + Z_i)} \qquad \text{... (4.6)}$$

where,

Z_i = is the distance from the level of application of the load to the middle of clay layer i.

The settlement of each layer caused by the increased stress is given by

$$\Delta s(i) = \frac{\Delta e(i)}{1 + e_o(i)} H_i \qquad \text{... (4.7)}$$

where,

$\Delta e(i)$ = change of void ratio caused by the stress increase;

$e_o(i)$ = initial void ratio for i^{th} layer;

H_i = thickness of i^{th} layer.

Alternatively,

$$\Delta s(i) = \frac{C_c H_i}{1 + e_o(i)} \log\left(\frac{\overline{\sigma}_o + \Delta\overline{\sigma}_i}{\overline{\sigma}_o}\right) \qquad \text{... (4.8)}$$

where,

C_c = compression index;

σ_o = effective pressure;

$\Delta\overline{\sigma}_o$ = increase in effective pressure.

The total settlement is equal to the sum of the settlement of all layers. [3]

$$S_g = \sum \Delta s(i) \qquad \text{... (4.9)}$$

4.3 Pile Cap

Pile caps are structural elements that tie a group of piles, together. Piles caps may support bearing walls, isolated columns and groups of several columns. Piles caps are used to transmit the forces from the columns, or walls to the piles. Plan dimensions of a pile cap depend on the spacing between the piles and their arrangement. When two or more piles are to be provided under a column or pier it is necessary to provide a slab to distribute the load to the individual piles. This slab is called a pile cap. Different types of pile caps are designed for different number of pile in a pile group. Pile caps consist of a rigid deep slab well bonded with longitudinal reinforcement of the piles. The pile caps may be designed by assuming that the load from column is dispersed at 45˚ from the top of the cap up to the mid-depth of the pile cap from the base of the column or pedestal. The reaction from piles may also be taken to be distributed at 45˚ from the edge of the pile up to the mid-depth of the pile cap. On this basis, the maximum bending moment and shear forces should be worked out at critical sections. The overall depth of the pile cap should be such that it provides sufficient bond length for pile reinforcement.

4.3.1 Design of Square and Rectangular Pile Cap

The design of a pile cap is based on the same principles as involved in the design of footings and rafts. Small pile caps may be designed as a reinforced concrete truss as shown in Fig 4.3. Steel acts as tension chord and concrete as diagonal struts.

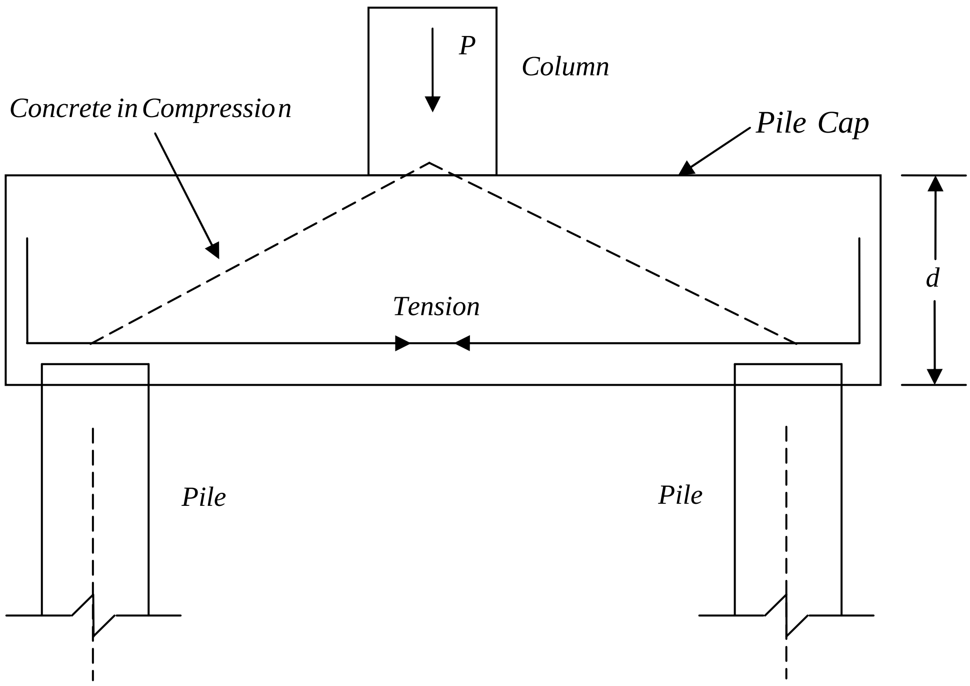


Fig 4.3 Truss action in pile cap.

Pile caps are usually provided with a uniform thickness it is designed by either of the two theories.

1. Truss Theory
2. Bending Theory.

Truss Theory

Referring to Fig 4.4, when the angle of dispersion of load θ is less than 30°, the value of shear span/depth (a_v/d) is less than 0.6. Under this condition, the load is transferred to the piles by strut action shown in Fig 4.3. Experiments have shown that the truss action (similar to deep beams and corbels) is significant for ratios of (a_v/d) = 2. Here it is assumed that the pile cap acts as a truss or a space frame, where the steel reinforcement act as a tension members and concrete acts as the compression member. In the truss theory, the tensile force between the pile heads is assumed to be resisted by the reinforcements similar, to the tie member of a truss and hence special care should be taken in detailing of the tension reinforcements and its anchorage at the ends. [12]. Truss theory is mostly used in for 2, 3, 4 and 5 number of pile groups. [14]. In general practice, the reinforcement calculated by truss theory is checked with the reinforcement calculated by the moment theory and greater of the two is considered for the further calculation.

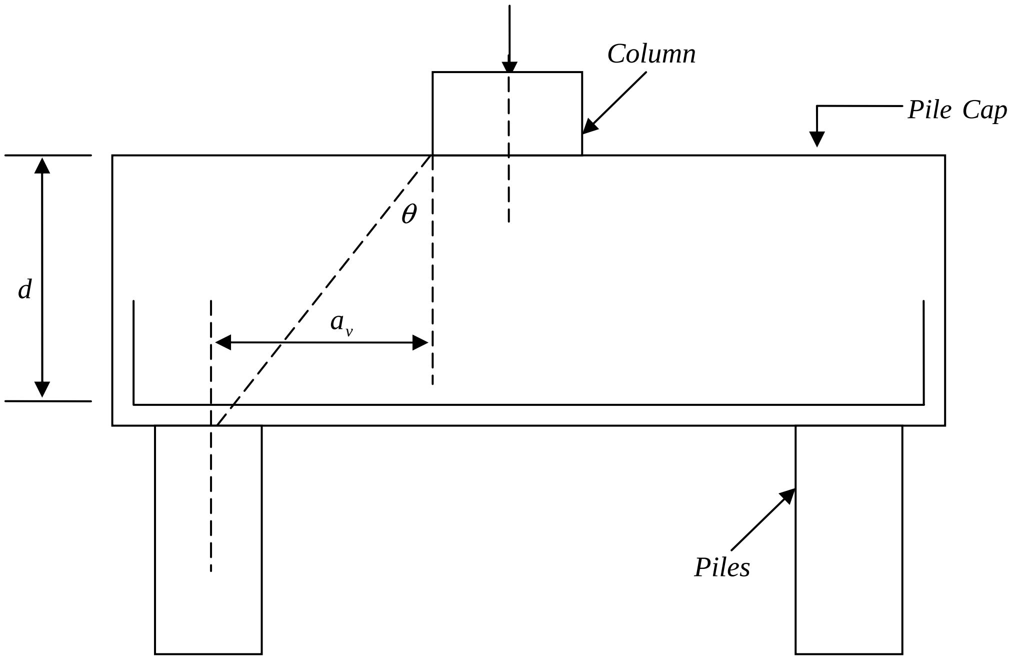


Fig 4.4 Load transfer in thick pile caps

Bending Theory

When the spacing of piles is at greater intervals associated with thinner pile caps in which the shear span (a_v/d) ratio is more than 2, flexural action is more predominant than truss action and hence the tensile reinforcement at the bottom of the pile cap is designed to resist the maximum bending moment as in an ordinary beam. In this method vertical load acting on single pile in a group is calculated by the equation 4.4. Shear check is done for pile cap by considering the load acting on the pile cap. Moment is calculated at the face of the upper column in both the direction considering the vertical load acting on the single pile about both the axis and the distance between the centroid and pile.

General guidelines for the design of square and rectangular shape pile cap:

1. Piles should be arranged so that centroid of the group coincides with the line of action of load.
2. A clear overhang of pile cap beyond the outermost pile should be kept minimum 100mm. This takes into account the no verticality of the piles.
3. The cap is generally cast over 75 mm thick leveling course of concrete. The clear cover for main reinforcement in the cap slab shall not be less than 60 mm.
4. The pile should project 50 mm into the cap concrete.

5. The pile cap should be deep enough to allow for necessary overlap of the column.

6. The formula to calculate the thickness of the pile cap as a function of the dimension of the pile. i.e.

$$D = (2d_p + 100) \;\; mm \;\; for \;\; d_p \; not \;\; greater \;\; than \; 550 \; mm \qquad \text{... (4.10)}$$

$$D = (1/3)(8d_p + 600) \; mm \;\; for \;\; d_p \;\; greater \; than \; or \; equal \; to \; 550 \, mm \qquad \text{... (4.11)}$$

Where,

D = overall thickness of pile cap (mm);

d_p = dimension of pile (mm).

7. Vertical load on single pile in a group is calculated using equation 4.4.

8. As per (shear span/ depth) ratio calculation and number of piles in the group, type of the theory is used for the analysis of the pile cap, i.e. if (a_v/d) ratio is less than 0.6 and if total number of piles in group are more than 5, then bending theory is used for the analysis of the pile cap.

9. If truss theory is predominant than as per fig 4.5, here it is 4 pile group considered, tension in the bottom steel rod is calculated as

$$H.d = \frac{P_u}{4}\left[\frac{L}{2} - \frac{a}{4}\right] \qquad \text{... (4.12)}$$

10. Area of steel is calculated by using the formula given below

$$ast = \frac{H}{0.87 \, fy} \qquad \text{... (4.13)}$$

and percentage of steel is calculated as $p_t = (100 \, ast / b \, d)$. If the value is less than 0.12% than provide minimum of the percentage of steel as 0.12% or else provide the calculated value.

11. Moment is calculated at the face of the column above the pile cap. The area of steel is calculated by using the formula given below.

$$ast = \frac{0.5 \, fck}{fy}\left[1 - \sqrt{1 - \frac{4.6 \, M_u}{fck \, b \, d^2}}\right] bd \qquad \text{... (4.14)}$$

12. Shear reinforcement is calculated according to reference [20] and as per the calculation it is provided i.e. if minimum comes in consideration calculate and provide that or else the extra shear reinforcement is calculated and provided

13. Distribution is calculated as 0.12% of the gross area of the pile cap, where d is the effective depth of the pile cap and b is taken as 1000 mm. The

steel area calculated from these calculations is provided on the top of the pile cap both ways.

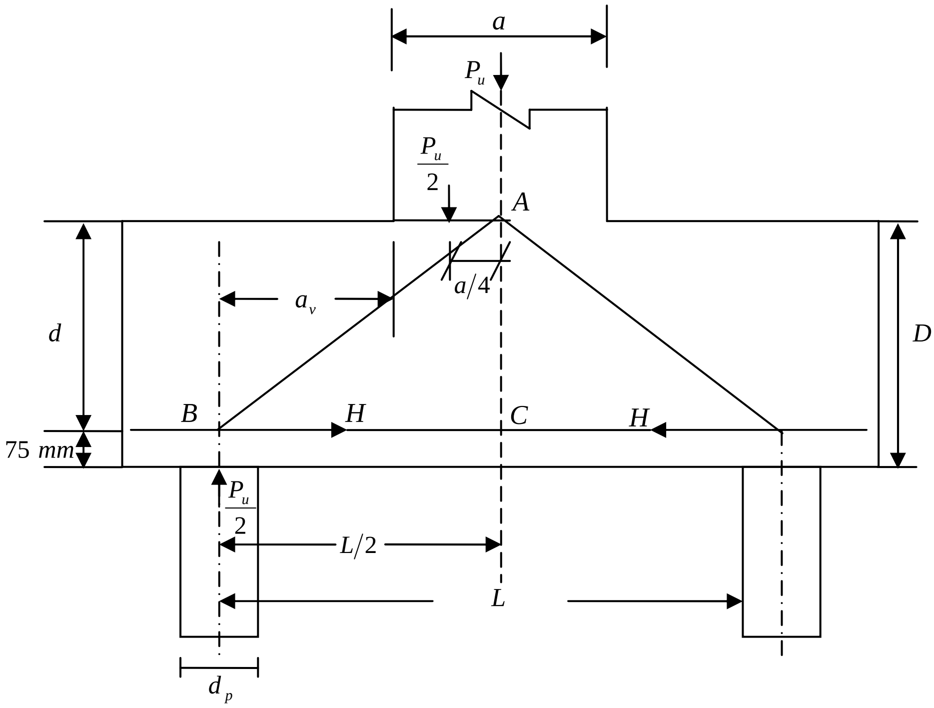


Fig 4.5 Design of pile cap (truss action).

14. Area of steel calculated by moment method is compared with area of steel calculated by truss theory method, and the maximum of the both is considered for calculation of number of bars. In case of moment theory method the area calculated is considered for the further calculation.

15. Secondary reinforcement is considered as 20% of the maximum area of steel selected. The steel calculated here are provided on each face of the pile cap.

16. Moment check is done for the pile cap by using the following formula

$$\sigma = \frac{Q}{A_{p_c}} + \frac{M_x y}{I_{xx}} + \frac{M_y x}{I_{yy}} \qquad \text{... (4.15)}$$

where,

σ = combined stress;

Q = the total vertical load acting on the pile cap;

A_{p_c} = area of the pile cap;

M_x = total moment about x-axis;

M_y = total moment about y-axis;

I_{xx} = moment of inertia about x-axis;

I_{yy} = moment of inertia about y-axis;

x = distance from the centroid of the pile cap to pile about y axis;

y = distance from the centroid of the pile cap to pile about x axis;

Combined stress check is to be given as vertical load is acting on the pile cap in addition to the horizontal load and moment. The calculated stress should be less than 1. If the value exceeds 1, than one has to increase the spacing so that length can increase or else one has to increase the depth of the pile cap so that the stresses are within the permissible limits.

15. If moment theory is predominant than the vertical load acting on the single pile is calculated using equation 4.4, considering the vertical load acting on the single pile of the group moments are calculated at the face of the column above the pile cap. The further procedure is same from step 11. [12]

Designing of the pile cap deals with a lot of trial and error procedure to get the accurate result. In this procedure firstly one has to assume some dimension of the pile and analysis of the pile cap is done to get the vertical load acting on single pile, then considering the soil condition and load acting on the single pile, actual dimension of the pile are calculated. Considering the vertical load, pile is designed as per the type of installation and if dimension calculated does no satisfy the design they are revised as per the design or else the assumed dimension is ok. The dimension calculated from the design is then used for the analysis of the pile cap to get the vertical load acting on the single pile. If the vertical load calculated as per new design is less than or equal the old vertical load, then the pile dimensions are ok or else pile dimensions are to be calculated while designing the pile.

After getting the new pile dimension of the pile, design of pile cap is carried out as explained from either of the two theories, whichever is applicable. This method is done where the number of piles is known in a group. In other case where number of piles are not known dimension of the pile are to assumed and as per the soil condition & bearing capacity of the pile is calculated, and from this bearing capacity number of piles are calculated from the load given. The dimensions of the pile are then checked as explained above.

4.3.2 Design of Triangular Pile Cap

General theory for the design of triangular shape pile cap:

For the design of triangular pile cap, the pile cap may be treated as a system of beams even though they take the form of slab of uniform thickness covering all the area occupied by the piles. The width of the beam may be taken as the width of the pile supporting it. Fig 4.6 shows an arrangement of a pile cap provided for three piles which are placed on the corners of an equilateral triangle of side L. The column is located at the centroid of this triangle. For purpose of the design the load P on the column is assumed to be applied on the beam DC of length $(L\sqrt{3})/2$ at a point G at a distance of $L/2\sqrt{3}$ from the end D. The vertical reactions for this beam will be $P/3$ at C and ${}^{2P}\!/_{3}$ at D. The beam DC has one support at C over a pile and the other support on the middle point of the beam AB. The beam AB has a span L and is loaded at its middle point with a load of ${}^{2P}\!/_{3}$. Each vertical reaction for this beam is $P/3$. Secondary reinforcement is provided to prevent the piles from splaying outwards from a pile cap. This reinforcement shall be provided to the following requirements:

a) This reinforcement shall be provided at the bottom of the pile cap running round the longitudinal reinforcement projecting from the piles into the pile cap.

b) There should be a change in direction of the secondary reinforcement at the head of every pile.

The amount of secondary reinforcement changing its direction at the head of each pile shall be not less than 20% of the main tensile reinforcement. [2, 13]

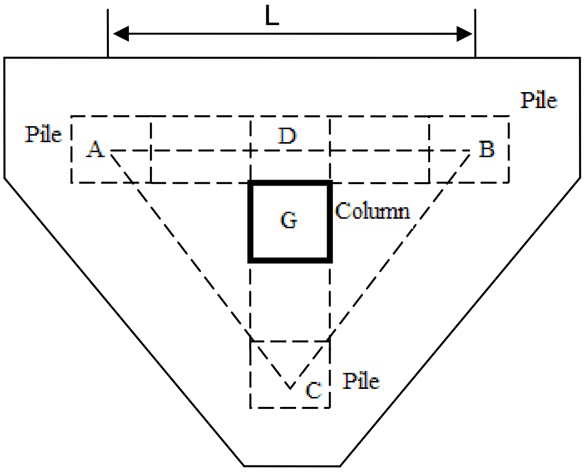


Fig 4.6 Layout of the three pile group (Triangular Pile Cap)

Following are the steps for the design of triangular shape pile cap.

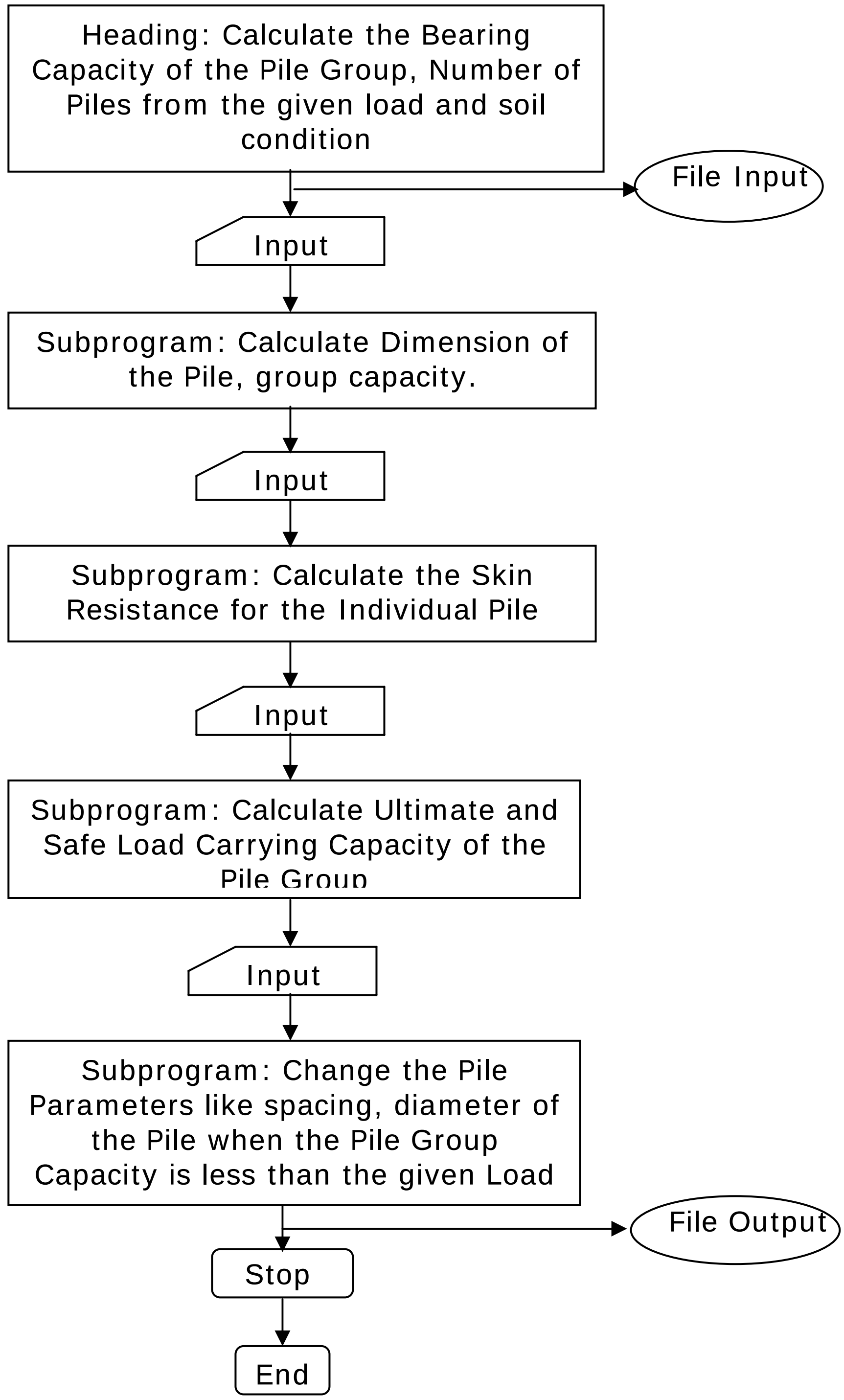
1. Two imaginary beams AB and CD are considered having the width equal to the width of the pile.
2. The depth of the pile cap calculated as per equation 4.10 and 4.11.
3. The load coming from the column is considered in addition to the self weight of the pile cap, acting on the beam CD and moment is calculated on the point G, the reaction of D is acting the centre of the beam AB.
4. Depth check is done for the moment calculated by the formula $M_u = 0.138 f_{ck} b d^2$.
5. Area of the steel is calculated and numbers of bars are calculated for the longitudinal reinforcement of beam CD.
6. Similarly longitudinal reinforcement for the beam AB is calculated considering the reaction of D and self weight of the pile cap as specified above.
7. Secondary reinforcement is calculated as 20 % of the highest longitudinal reinforcement from both the beam.

Programs are prepared for the analysis and design on the pile group using C++ language. Brief idea of all the programs, their working is explained below

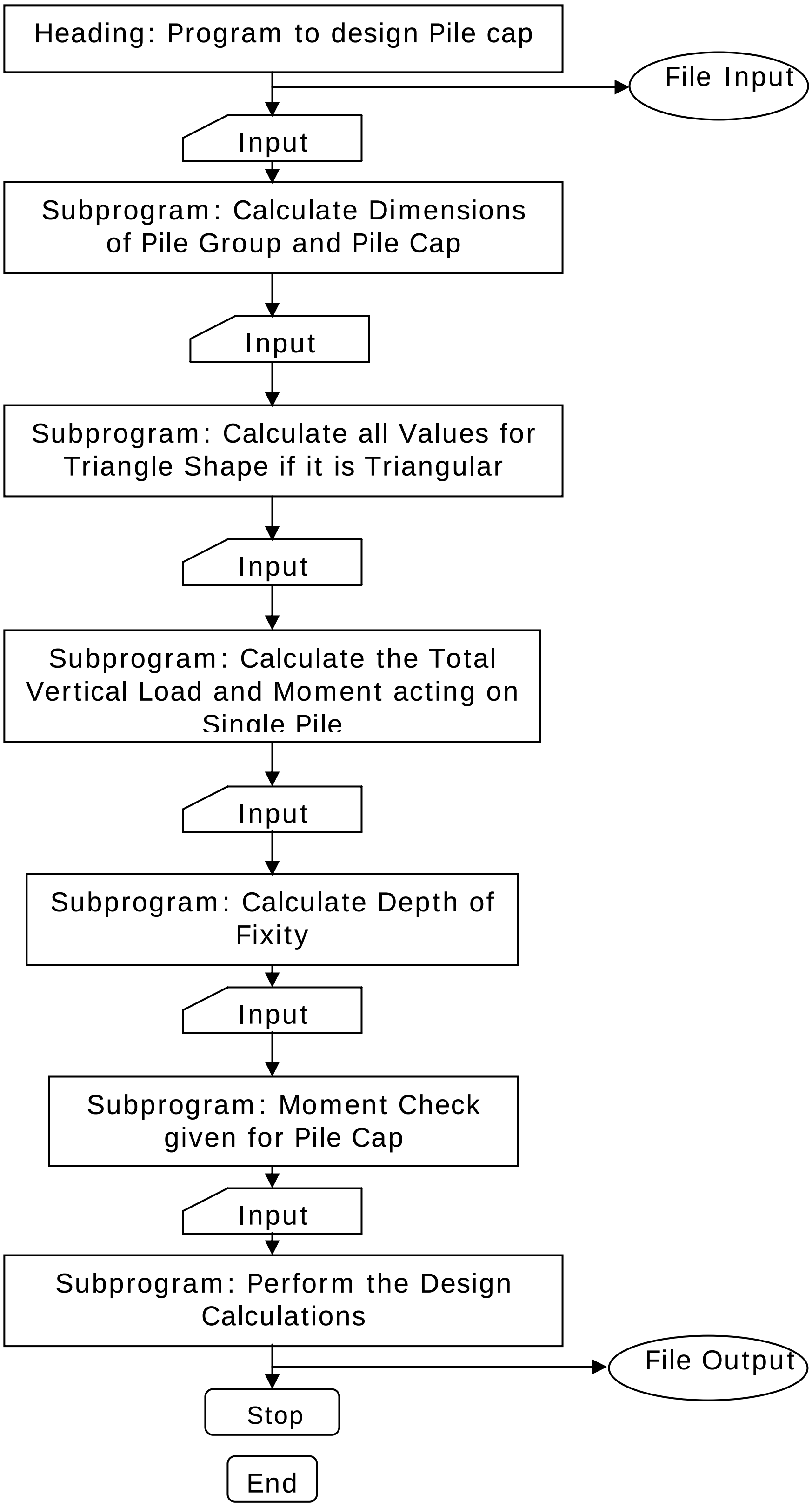
4.4 FLOW OF PROGRAMS

(1) Program for the analysis of pile group.

(2) Program for the pile cap design.



Flow of program for the analysis of pile group



Flow of Programs for pile cap analysis & design

4.5 INPUT AND OUTPUT OF THE PROGRAM FOR PILE GROUP ANALYSIS

Input data for the calculation of no. of pile for the given load and soil condition:

1. Shape of the pile.
2. Dimension of the pile.
3. Length of the pile.
4. Soil parameters.
5. Load acting on the pile group.
6. Factor of safety for the bearing capacity of the pile.
7. Shape of the pile group
8. Number of piles in the group.
9. Spacing between the piles.
10. Factor is safety for the bearing capacity of the pile group.

Out put data of the program:

1. Total resistance of the pile.
2. Safe load carrying capacity of the individual pile.
3. No. of piles required for the corresponding load.
4. Ultimate bearing capacity of the pile group.
5. safe load bearing capacity of the pile group.

Case 1: Calculation of the number of piles and checking the group capacity.

Input data taken from reference [8]

Shape of pile	=	Circular.
One side of the pile	=	600mm
Length of the pile	=	14 m
Clayey soil		
K	=	1
Cohesion value is	=	36 kN/m^2
Load coming from the top	=	3000 kN.
F.O.S for the pile	=	3
Shape of pile group	=	square.

Number of piles in the group	=	25
Spacing between two piles	=	1.8 m
F.O.S for the bearing capacity of pile group	=	3

Output Data as per reference [8]

Total resistance of the pile	=	369.4 kN
Safe load carrying capacity of pile	=	123.1 kN
No. of piles	=	24.37
Ultimate bearing capacity of pile group	=	15288. kN
Safe load carrying capacity of pile group	=	5100 kN

Output of the program

Total resistance of the pile	=	458.515 kN
Safe load carrying capacity of pile	=	152.8 kN
No. of piles	=	20
Ultimate bearing capacity of pile group	=	34452.6 kN
Safe load carrying capacity of pile group	=	11484.2 kN

Here the number of piles from program is less than the actual values; this is because of the negligence of the base resistance in the reference. But the input value for the program for number of pile is taken as 25, to compare the value with the reference. Thus in this type of problem the values are at the higher side as there is increase of the base resistance. The remaining values calculated are almost equal to the value specified in the reference. The analysis for the pile group gives the lower value than the calculated in the reference, which is much more conservative side.

Analysis and design of triangular pile cap

Input data for the design of triangular shape pile cap :-

1. Shape of pile.
2. Enter The Dimensions of the section.
3. Shape and size of column above pile cap.
4. 0ver-hang distance from the last pile.
5. Clear cover
6. Vertical load acting on the pile group
7. Grade of cement and steel.
8. Spacing between the two piles.
9. Diameter of bar for Beam CD.
10. Diameter of bar for Beam AB.
11. Diameter of bar for secondary reinforcement.

Ref Fig [4.6]

Output of the program:-

1. Depth of the pile cap.
2. Reinforcement of the beam CD.
3. Reinforcement of the beam AB.
4. Secondary reinforcement.

Case TD: - Design of Triangular Pile cap.

Data is taken from reference [13].

Input Data:

Shape of pile	=	Square
One side of the square pile	=	300 mm
Shape of the column	=	square
One side of the square column	=	300 mm
Over-hang distance	=	150 mm
Clear cover	=	80 mm
Vertical load	=	600 kN
Grade of cement and steel	=	M15, 415 N/mm^2
Spacing	=	1200 mm
Diameter of bar for beam CD	=	25 mm

Diameter of bar for beam AB	=	25 mm
Diameter for Secondary Reinforcement	=	10 mm

Output Data as per reference

Depth of the pile cap = 750 mm

Reinforcement for beam CD = 4 bars of 25 mm dia

Reinforcement for beam AB = 4 bars of 25 mm dia.

Secondary Reinforcement = 4 bars of 10 mm dia

Output of the program

Depth of the pile cap = 750 mm

Reinforcement for beam CD = 4 bars of 25 mm dia

Reinforcement for beam AB = 4 bars of 25 mm dia.

Secondary Reinforcement = 4 bars of 10 mm dia

This shows that the program gives the accurate result for the data given in the reference [13].

Problem TD1:

Input Data (Assumed one)

Shape of pile	=	Square
One side of the square pile	=	400 mm
Shape of the column	=	square
One side of the square column	=	400 mm
Over-hang distance	=	150 mm
Clear cover	=	80 mm
Vertical load	=	540 kN
Grade of cement and steel	=	M20, 415 N/mm^2
Spacing	=	1200 mm
Diameter of bar for beam DC	=	16 mm
Diameter of bar for beam AB	=	16 mm
Secondary reinforcement	=	10 mm

Output Data

Depth of the pile cap	= 900 mm
Reinforcement for beam CD	= 4 bars of 16 mm dia
Reinforcement for beam AB	= 4 bars of 16 mm dia.
Secondary Reinforcement	= 3 bars of 10 mm dia

The detailing of the above pile cap is given in sheet 1 (page 150).

Analysis and design of square and rectangular pile cap

Input data for the design of square shape pile cap is as follows:-

1. Shape of pile.
2. Enter The Dimensions of the section.
3. Shape and size of column above pile cap.
4. 0ver-hang distance from the last pile.
5. Clear cover
6. Vertical load acting on the pile group
7. Grade of cement and steel.
8. Spacing between the two piles.
9. Diameter of bar for Longitudinal Reinforcement
10. Diameter of bar for Distribution steel.
11. Diameter for the shear reinforcement.
12. Diameter of bar for secondary reinforcement.

Output of the program:-

1. Longitudinal Reinforcement.
2. Distribution steel.
3. shear reinforcement.
4. Secondary reinforcement.

Case SD: - Design of Square Pile cap.

Data is taken from reference [12].

Input Data:

Shape of pile	=	Square
One side of the square pile	=	500 mm
Shape of the column	=	square
One side of the square column	=	300 mm
Over-hang distance	=	100 mm
Clear cover	=	80 mm
Vertical load	=	2000 kN
Grade of cement and steel	=	M20, 415 N/mm^2
Spacing	=	1200 mm

Diameter of bar for longitudinal r/f	=	16 mm
Diameter of bar distribution steel	=	16 mm
Diameter of bar for shear reinforcement	=	4 legged 8mm diameter
Diameter for Secondary Reinforcement	=	10 mm

Output Data as per reference [12]

In this problem, diamond type pile cap is considered.

Longitudinal Reinforcement	= 4 bars o5 25 mm dia for 500 mm width.
Distribution Steel	= 16 mm dia bars at 300 mm c/c.
Secondary Reinforcement	= 12 mm dia at 300 mm c/c.

Output Data of the Program

In the program, square type of pile cap is considered.

Longitudinal Reinforcement	= 16 mm dia bars at 200 mm c/c
Distribution Steel	= 16 mm dia bars at 200 mm c/c.
Shear reinforcement	= 4 legged stirrups 8 mm at 90 mm c/c
Secondary Reinforcement	= 5 bars of 10 mm dia

As due to the shape difference in the pile cap, the values differ slightly. The values calculated from the program are considerable.

The detailing of the values of program for the square pile cap is given in sheet 1 (page 150).

Input data for the design of Rectangular shape pile cap is as follows:-

1. Shape of pile.
2. Enter The Dimensions of the section.
3. Shape and size of column above pile cap.
4. 0ver-hang distance from the last pile.
5. Clear cover
6. Vertical load acting on the pile group
7. Grade of cement and steel.
8. Spacing between the two piles.
9. Diameter of bar for Longitudinal Reinforcement
10. Diameter of bar for Distribution steel.

11. Diameter for the shear reinforcement.
12. Diameter of bar for secondary reinforcement.

Output of the program:-

1. Longitudinal Reinforcement.
2. Distribution steel.
3. Shear reinforcement.
4. Secondary reinforcement.

Case RD: - Design of Rectangular Pile cap.

Data here are assumed one.

Input Data:

Shape of pile	=	Square
One side of the square pile	=	500 mm
Shape of the column	=	square
One side of the square column	=	400 mm
Over-hang distance	=	100 mm
Clear cover	=	80 mm
Vertical load	=	900 kN
Moment acting about X-Axis	=	85 kNm
Grade of cement and steel	=	M20, 415 N/mm^2
Spacing	=	1200 mm
Diameter of bar for longitudinal r/f	=	20 mm
Diameter of bar distribution steel	=	16 mm
Diameter of bar for shear reinforcement	=	4 legged 10 mm diameter
Diameter for Secondary Reinforcement	=	10 mm

Output Data of the Program

Longitudinal Reinforcement	= 20 mm dia bars at 300 mm c/c
Distribution Steel	= 16 mm dia bars at 200 mm c/c.
Shear reinforcement	= 4 legged stirrups 8 mm at 140 mm c/c
Secondary Reinforcement	= 5 bars of 10 mm dia

The detailing of the above pile cap is given in sheet 1 (page 150).

4.6 PARAMETRIC STUDY ON ANALYSIS OF PILE AND PILE GROUP

A parametric study has been carried out to find the maximum bearing capacity of the individual pile and group of pile for two different soil conditions. There is the variation in the shape of the pile, dimension of the pile, type of pile, number of piles in the group and shape of the pile cap. The above variations are as follows:

Soil condition = sandy soil and clayey soil.

Shape of Pile = circular, square and rectangular.

Dimension of different types of pile =

Circular section	= 0.15 m to 0.40m
Square section	= (0.15 *0.15) m^2 to (0.40*0.40) m^2
Rectangular section	= (0.15*0.20) m^2 to (0.40*0.45) m^2

The increment in size of the pile section is taken as 0.05 m.

Type of pile = Cast-in-situ (bored) and Driven.

Number of piles in a group = 3, 4, 6, 9, 12.

Shape of the pile cap = Triangular (3 Piles), Square (4 Piles & 9 Piles) and Rectangular (6 Piles & 12 Piles).

360 cases (i.e. 180 for sandy soil and remaining 180 for clayey soil) were solved to cover up all the above variations of pile, pile group and soil, the details of all the cases are given in Table 4.1. Length of the Pile is assumed as = 15 m for all the cases. Here the soils parameters for the 2 different types of soil considered are purely assumed one.

Sandy Soil

Value of Effective unit weight	=	16 kN/m^3
Value of coefficient of earth pressure (K)	=	1.2
Value of angle of internal friction	=	31°

Single layer of the sand is assumed to be surrounding the pile and pile group. Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ is calculated as per equation (3.5 & 3.7) from chapter 3.

Spacing between two plies in the pile group for this soil condition is taken as 1 m throughout all the 180 cases.

Clayey Soil

Alpha value (α) = 0.7

Value of Effective unit weight = 17 kN/m^3

Unit Cohesion for this layer is = 50 kN/m^2

Value of coefficient of earth pressure (K) = 1.0

Single layer of the clay is assumed to be surrounding the pile and pile group.

Bearing capacity factor N_c value is taken by the program from the table suggested in chapter1 Table (1.2).

Spacing between the two piles in the pile group for this soil condition are as follows

For Circular pile and Square pile ranging from 0.5 m to 0.35 m = 1 m

and for both the pile section having the dimension as 0.4 m = 1.2 m

For Rectangular section ranging from (0.15*0.20) to (0.30*0.35) = 1 m

and for above pile section having dimension (0.35*0.40) & (0.40-0.45) = 1.2 m.

Table 4.1.Variations considered for the analysis of pile group With different shapes of pile.

<table>
<tr><th>Shape of Pile</th><th>Size of the pile in m</th><th>Soil Type</th><th>No of Piles</th><th>Shape of pile cap</th><th>Cases Considering the variation of size & type of installation</th><th>Total No. of cases</th></tr>
<tr><td rowspan="10">Circular
1)Driven
2)Bored</td><td rowspan="10">0.15, 0.20, 0.25, 0.30, 0.35, 0.40</td><td>Sand</td><td rowspan="2">3</td><td rowspan="2">Triangular</td><td>12</td><td rowspan="10">120</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td>Sand</td><td rowspan="2">4</td><td rowspan="2">Square</td><td>12</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td>Sand</td><td rowspan="2">6</td><td rowspan="2">Rectangular</td><td>12</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td>Sand</td><td rowspan="2">9</td><td rowspan="2">Square</td><td>12</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td>Sand</td><td rowspan="2">12</td><td rowspan="2">Rectangular</td><td>12</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td rowspan="4">Square
1)Driven
2)Bored</td><td rowspan="4">0.15, 0.20, 0.25, 0.30, 0.35, 0.40</td><td>Sand</td><td rowspan="2">3</td><td rowspan="2">Triangular</td><td>12</td><td rowspan="4">48</td></tr>
<tr><td>Clay</td><td>12</td></tr>
<tr><td>Sand</td><td rowspan="2">4</td><td rowspan="2">Square</td><td>12</td></tr>
<tr><td>Clay</td><td>12</td></tr>
</table>

Table 4.1 Continue

Shape of Pile	Size of the pile in m	Soil Type	No of Piles	Shape of pile cap	Cases Considering the variation of size & type of installation	Total No. of cases
Square 1)Driven 2)Bored	0.15, 0.20, 0.25, 0.30, 0.35, 0.40	Sand	6	Rectangular	12	72
		Clay			12	
		Sand	9	Square	12	
		Clay			12	
		Sand	12	Rectangular	12	
		Clay			12	
Rectangular 1)Driven 2)Bored	(0.15 * 0.20) (0.20 * 0.25) (0.25 * 0.30) (0.30 * 0.35) (0.35 * 0.40) (0.40 * 0.45)	Sand	3	Triangular	12	120
		Clay			12	
		Sand	4	Square	12	
		Clay			12	
		Sand	6	Rectangular	12	
		Clay			12	
		Sand	9	Square	12	
		Clay			12	
		Sand	12	Rectangular	12	
		Clay			12	
Total No. of cases						360

The following are the graphs are plotted to get the clear idea for the bearing capacity of different types of pile group and pile cap.

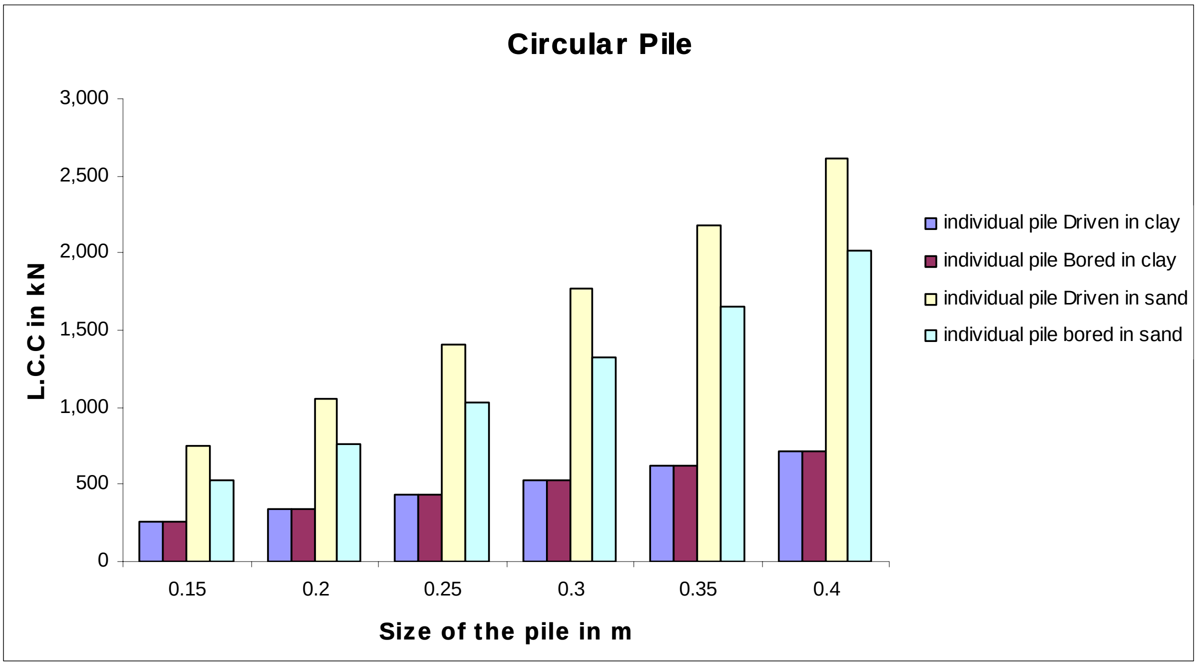


Fig 4.7 Comparison of the individual capacity
of circular pile in clay and sand soil

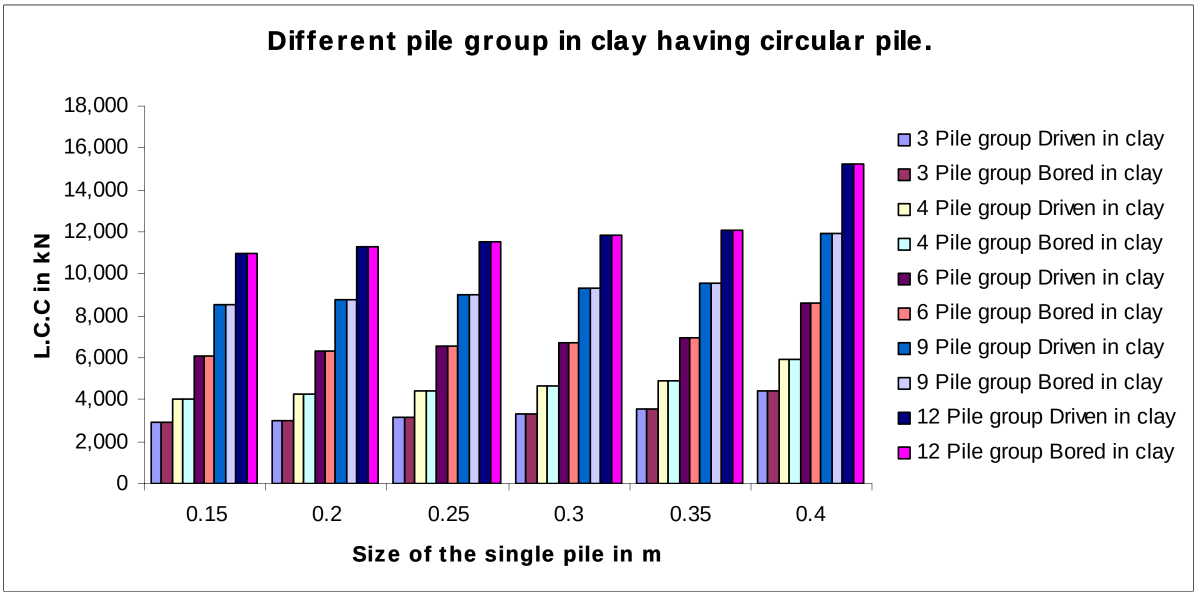


Fig 4.8 Comparison of the different pile group capacity
having circular pile in clay soil

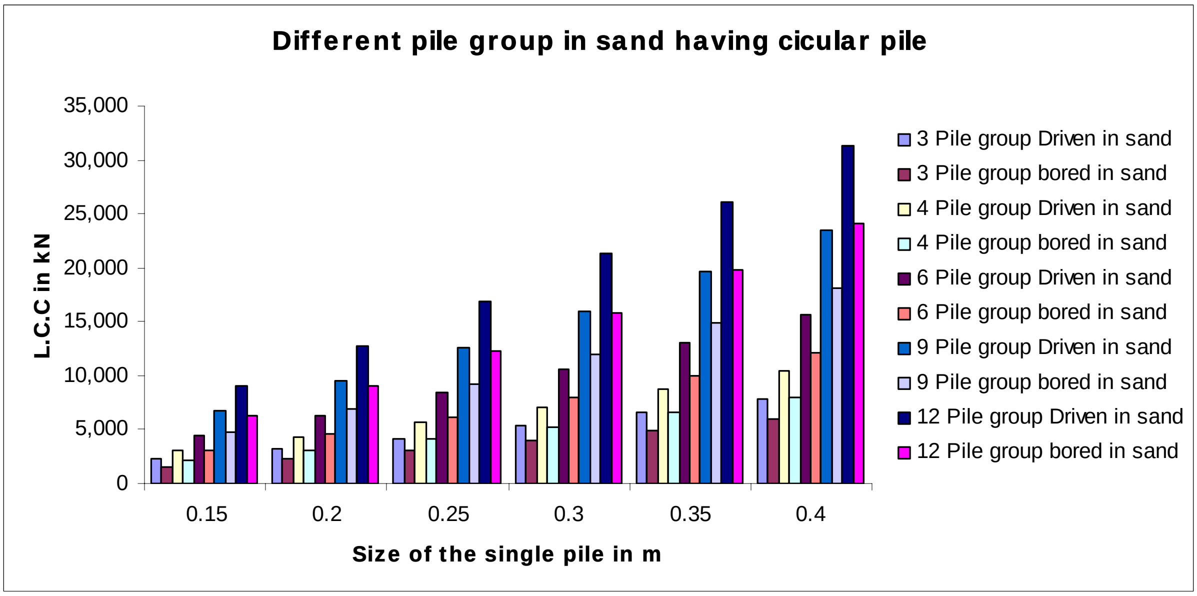


Fig 4.9 Comparison of the different pile group capacity having circular pile in sandy soil

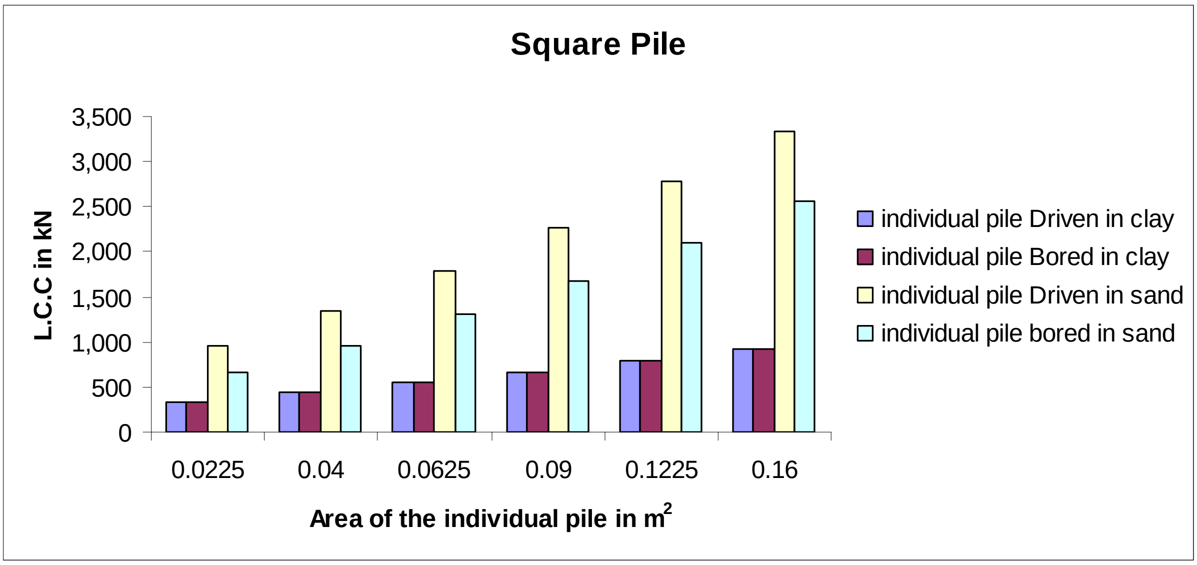


Fig 4.10 Comparison of the individual capacity of square pile in clay and sand soil

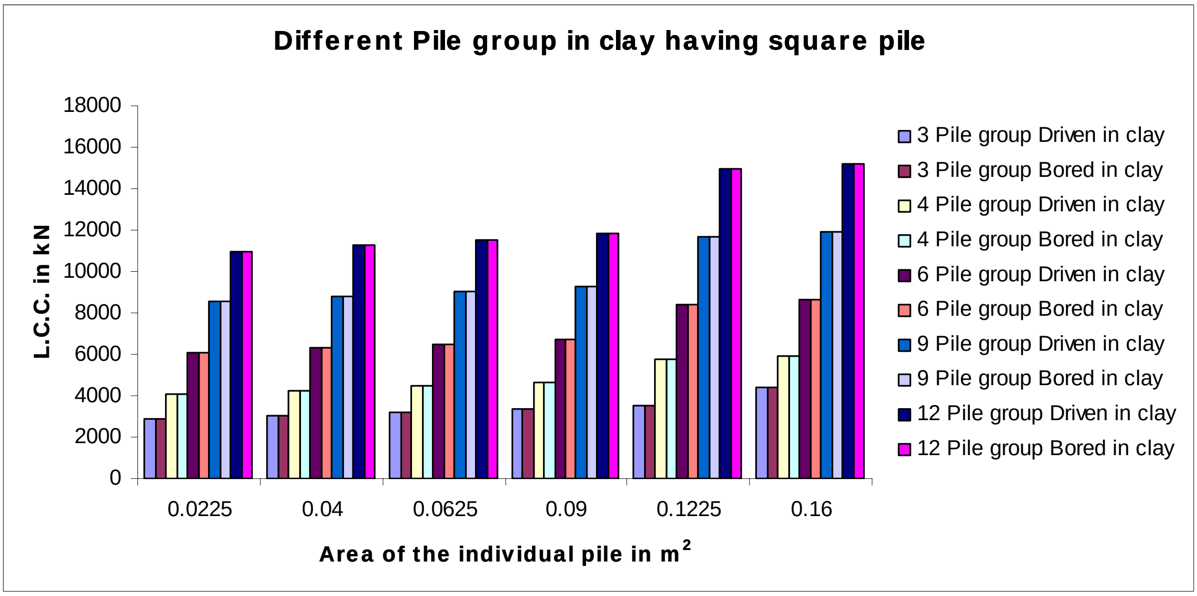


Fig 4.11 Comparison of the different pile group capacity having square pile in clay soil

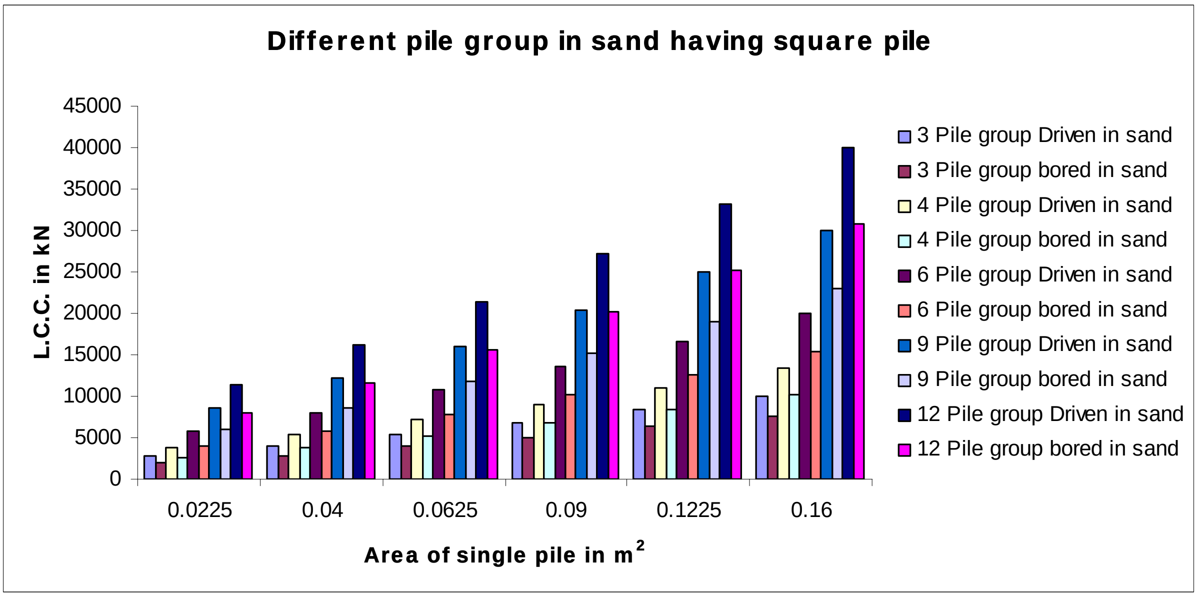


Fig 4.12 Comparison of the different pile group capacity having square pile in sandy soil

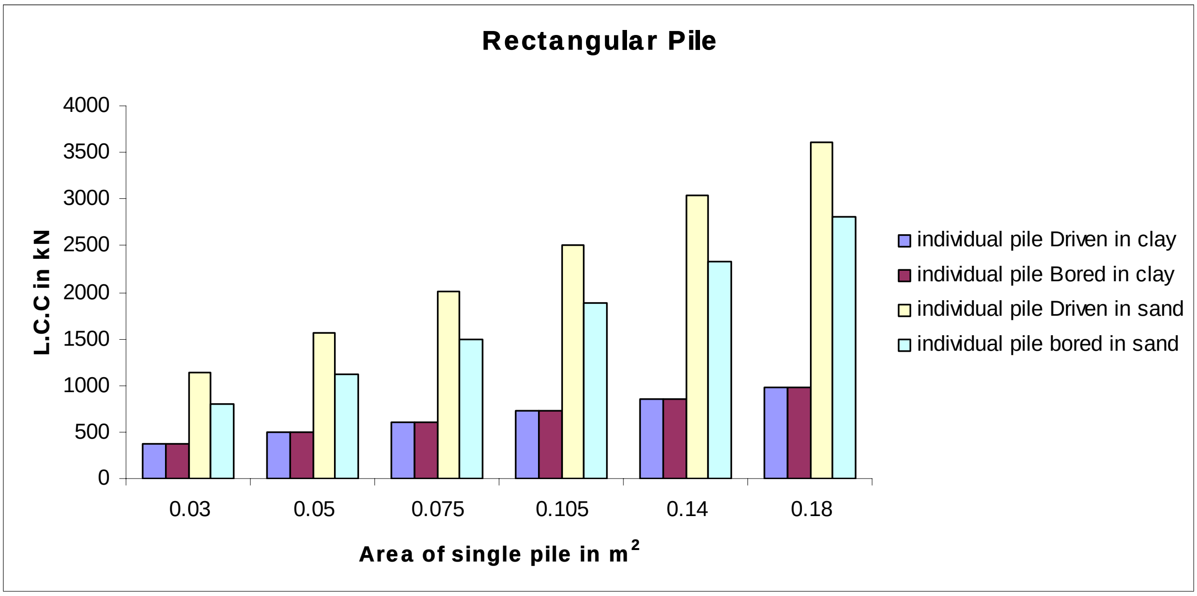


Fig 4.13 Comparison of the individual capacity of rectangular pile in clay and sand soil

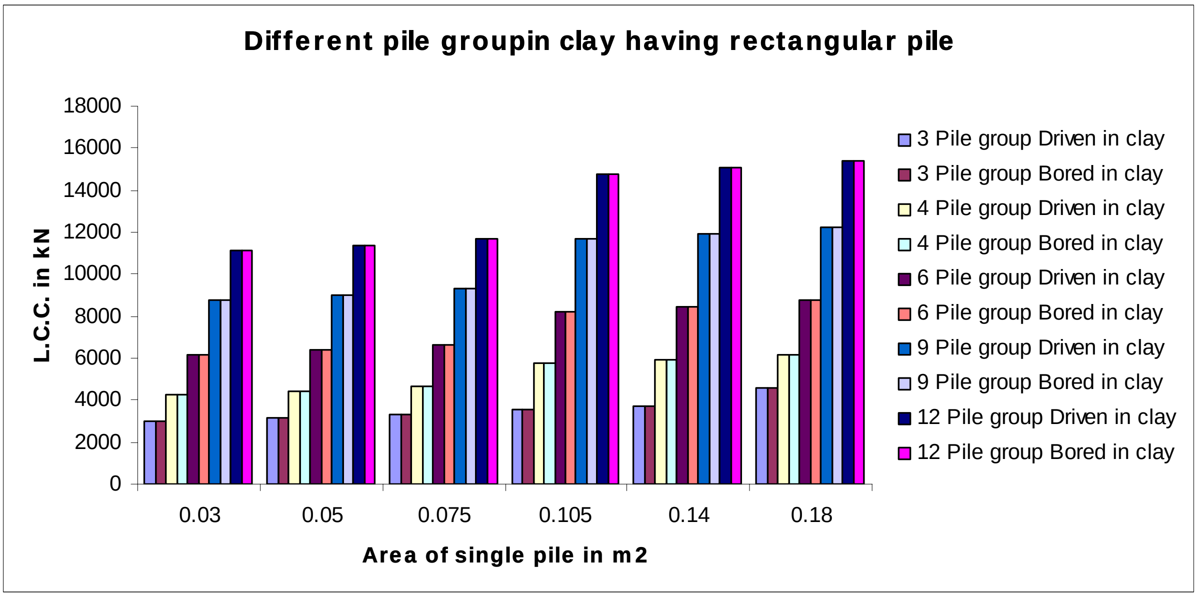


Fig 4.14 Comparison of the different pile group capacity having rectangular pile in clay soil

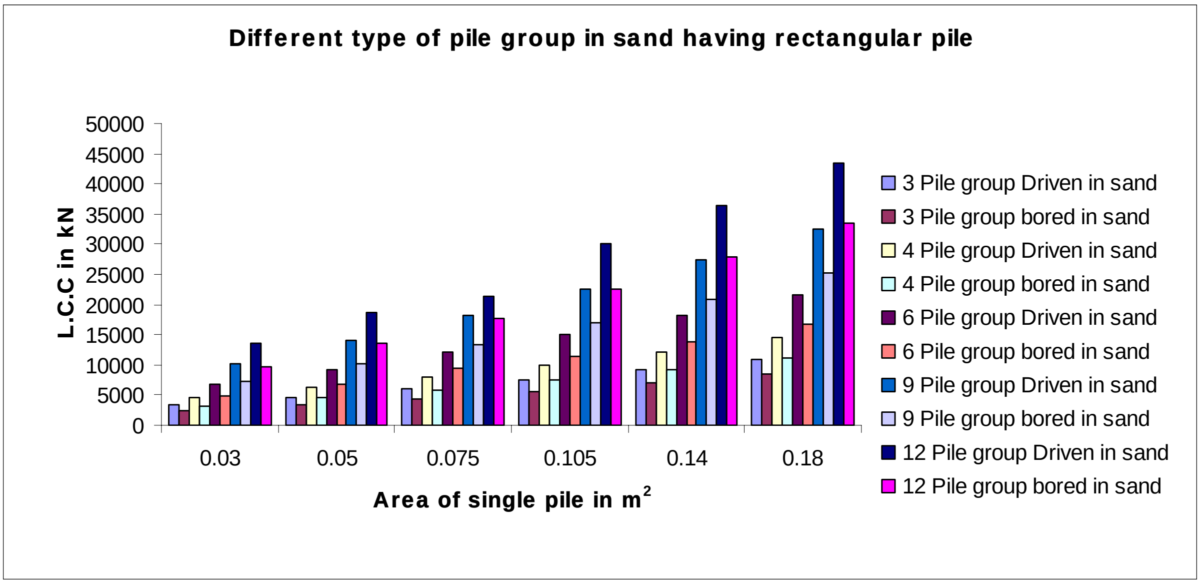


Fig 4.15 Comparison of the different pile group capacity having rectangular pile in sandy soil

The points that can be interpreted from this parametric study are:

1. The values of bearing capacity of bored and driven single pile in clayey soil having circular section have the same values. This goes exactly same with the square section and rectangular section case. Driven single pile in sand gives more bearing capacity than bored single pile in sand for all the shapes of pile. [Fig 4.7, Fig 4.10, Fig 4.13]
2. Group capacities of different pile group having different number of piles, driven and bored in clay type of soil, having circular section give the same value. This result also holds good for the square section and rectangular section of pile. [Fig 4.8, Fig 4.11, Fig 4.14]
3. Group capacity having driven piles beneath it, gives more bearing capacity value in sand condition in comparison to the bored pile in sandy soil. This result matches for all the different shape of pile i.e. circular, square and rectangular. [Fig 4.9, Fig 4.12, Fig 4.15]
4. The analysis for the pile group gives the lower value than the calculated in the reference, which is much more conservative side. [Case 1, page 107]
5. The value of the design of the triangular pile cap from the program is almost same as per the reference. [Case TD, page 110]

6. As the shape of the pile cap was different in the reference i.e. in reference the shape considered was diamond, while in the program it was considered as square pile cap, the reinforcement details for both the pile cap, the values differ slightly. The values calculated from the program are considerable.[Case SD, page 113]

4.7 PARAMETRIC STUDY ON DIFFERENT TYPES OF PILE CAP

In this parametric study the most economical pile group is to be calculated for two different soil condition i.e. sandy soil and clayey soil. The variation for this analysis and design are as follows:

Soil condition = sandy soil and clayey soil.
Shape of Pile = circular, square and rectangular.
Type of pile = Cast-in-situ (bored) and Driven.
Number of piles in a group = 4, 6, 9, 12.
Shape of the pile cap = Square (4 piles, 9 piles) and Rectangular (6 piles, 12 piles).
The dimension of the pile are calculated as per the soil condition and they are checked while designing, if the dimension falls short, one has to increase the dimension of the pile of corresponding shape.

48 cases (i.e. 24 for sandy soil and remaining 24 for clayey soil) were solved to cover up all the above variations of pile, pile group and soil. Length of the Pile is assumed as = 15 m for all the cases. Here are the soils parameters for the 2 different types of soil considered are purely assumed for the sake of the analysis.

Sandy Soil

Layer 1

Value of Effective unit weight	= 0.00171 kg/cm^3
Value of coefficient of earth pressure (K)	= 1
Value of angle of internal friction	= 31°

Layer 2

Value of Effective unit weight	= 0.00185 kg/cm^3
Value of coefficient of earth pressure (K)	= 1.3
Value of angle of internal friction	= 32°

Two layer of the sand is assumed to be surrounding the pile and pile group. Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ is calculated as per equation (3.5 & 3.7) from chapter 3.

Spacing between two plies in the pile group for this soil condition varies according to its size. Generally it is kept 3 times the maximum dimension of the pile.

Clayey Soil

Layer 1

Value of Effective unit weight = 0.00171 kg/cm^3

Value of angle of internal friction = 0°

Unit Cohesion = 0.11 kg/cm^2

Alpha value selected is based on C value as per I.S. code

Layer 2

Value of Effective unit weight = 0.00185 kg/cm^3

Value of angle of internal friction = 0°

Unit Cohesion = 0.2 kg/cm^2

Alpha value selected is based on C value as per I.S. code

Two layer of the sand is assumed to be surrounding the pile and pile group.

Bearing capacity factor N_c value is taken by the program from the table suggested in chapter1 Table (1.2).

Spacing between two plies in the pile group for this soil condition varies according to its size. It is kept 3 times the maximum dimension of the pile.

Load data and other assumed data:

In all the 48 cases it is assumed that there is a circular column on all the pile caps is having diameter 500 mm. Total number of cases are tabulated in Table 4.2 and the main cases divided in sub-cases are tabulated in Table 4.3.

The length of the pile assumed is totally embedded length, free outstanding length of the pile is zero.

Vertical Factored load acting on the pile cap is = 2000 kN

Excluding the self weight of the pile cap.

Horizontal Load is acting in both the direction

Horizontal load acting along X-Axis is = 30 kN

Horizontal load acting along Y-Axis is = 25 kN

Moment acting about X-Axis = 55 kNm

Moment acting about Y-Axis = 75 kNm

Pile Head is fixed.

Unconfined Compressive Strength = 1 Kg/cm^2

Sand & Normally Loaded Clay type of soil this is used for calculation of the depth of fixity on the pile and moment acting on the pile.

Here for the above pile cap design, the vertical load acting on the single pile is calculated by assuming some dimension of the pile to get this load for this study for 4 pile group (square pile cap) circular pile is assumed having the diameter of the pile as 500mm. The load calculated from this analysis was 620 kN, considering this load and given soil condition dimension of the pile was calculated, which came as 252 mm for bored pile in sandy soil. Similarly the dimension of the pile was calculated in clay soil which came as 835 mm for both driven and bored pile. Circular pile having the dimension 252 mm was designed for the load and moment calculated from the pile cap analysis, in which it got failed and thus keeping the percentage of steel constant to 3% and then different dimensions where assumed for the pile, the dimension in which all the column checks were satisfied that dimension was considered. Taking that new dimension of the pile, pile cap analysis is done to get actual vertical load acting on the single pile. The load calculated from the new dimension were less, thus the new dimension calculated is o.k. Design example is given at page 129.

This procedure is done in each and every pile cap design and for each and every pile shape considered for the study. Table 4.4 shows, dimension of different shape of pile for different pattern of the pile cap, which are calculated as per the soil condition and vertical load acting on the single pile for different types of pile group.

Table 4.5 shows, the dimension of the pile calculated as per the design, keeping the percentage of steel as 3% for the bored pile. These values were then entered to get the new vertical load acting on each single pile. The calculation showed some of the new value of the vertical load were less in some cases and were almost equal to the original calculated vertical load.

After the calculation of the design of the column the dimension of the pile section is calculated, and considering those dimension of the pile section pile cap is designed for the given load condition. Estimation of the cost of different shapes of pile cap having different type of pile section under them in different type of soil condition is done. The estimated cost is shown in Table 4.6a (Clayey soil) and Table 4.6b (Sandy soil). Cost of lowest cost for each group is tabulated in the Table 4.7 and Table 4.8 gives the most economical section for the given load condition. The estimation cost of pile group is shown in Fig 4.22 (Clayey soil) and Fig 4.23 (Sandy soil). Here below the cases are divided to get a better idea of the study.

Table 4.2 Variations considered for pile cap design

Shape of Pile	Soil Type	No of Piles	Shape of pile cap	Cases	Total No. of cases
Circular (Driven & Bored)	Sand	4	Square	2	16
	Clay			2	
	Sand	6	Rectangular	2	
	Clay			2	
	Sand	9	Square	2	
	Clay			2	
	Sand	12	Rectangular	2	
	Clay			2	
Square (Driven & Bored)	Sand	4	Square	2	16
	Clay			2	
	Sand	6	Rectangular	2	
	Clay			2	
	Sand	9	Square	2	
	Clay			2	
	Sand	12	Rectangular	2	
	Clay			2	
Rectangular (Driven & Bored)	Sand	4	Square	2	16
	Clay			2	
	Sand	6	Rectangular	2	
	Clay			2	
	Sand	9	Square	2	
	Clay			2	
	Sand	12	Rectangular	2	
	Clay			2	
Total No. of cases					48

Table 4.3 Cases for the different types of pile group having different types of pile cap

Cases	Shape of Pile cap	Shape of pile	Soil type	Type of installation
Case 1 a	4 pile group having square pile cap	Circular	Clay	Bored
		Square		
		Rectangular		
Case 1 b		Circular	Sand	Bored
		Square		
		Rectangular		
Case 2 a		Circular	Clay	Driven
		Square		
		Rectangular		
Case 2 b		Circular	Sand	Driven
		Square		
		Rectangular		
Case 3 a	6 pile group having rectangular pile cap	Circular	Clay	Bored
		Square		
		Rectangular		
Case 3 b		Circular	Sand	Bored
		Square		
		Rectangular		
Case 4 a		Circular	Clay	Driven
		Square		
		Rectangular		
Case 4 b		Circular	Sand	Driven
		Square		
		Rectangular		
Case 5 a	9 Pile group having square pile cap	Circular	Clay	Bored
		Square		
		Rectangular		
Case 5 b		Circular	Sand	Bored
		Square		
		Rectangular		
Case 6 a		Circular	Clay	Driven
		Square		
		Rectangular		
Case 6 b		Circular	Sand	Driven
		Square		
		Rectangular		
Case 7 a	12 pile group having rectangular pile cap	Circular	Clay	Bored
		Square		
		Rectangular		
Case 7 b		Circular	Sand	Bored
		Square		
		Rectangular		
Case 8 a		Circular	Clay	Driven
		Square		
		Rectangular		
Case 8 b		Circular	Sand	Driven
		Square		
		Rectangular		

Design Example:

Data as per described above for the 48 cases.

Vertical Factored load acting on the pile cap is Q = 2000 kN

Excluding the self weight of the pile cap.

Horizontal Load is acting in both the direction

Horizontal load acting along X-Axis is = 30 kN

Horizontal load acting along Y-Axis is = 25 kN

Moment acting about X-Axis = 55 kNm

Moment acting about Y-Axis = 75 kNm

Pile Head is fixed.

Unconfined Compressive Strength = 1 kg/cm^2

Sand & Normally Loaded Clay type of soil is used for calculation of the depth of fixity on the pile and moment acting on the pile.

Soil parameters

Sandy Soil

Layer 1

Value of Effective unit weight = 0.00171 kg/cm^3

Value of coefficient of earth pressure (K) = 1

Value of angle of internal friction = 31°

Layer 2

Value of Effective unit weight = 0.00185 kg/cm^3

Value of coefficient of earth pressure (K) = 1.3

Value of angle of internal friction = 32°

Two layer of the sand is assumed to be surrounding the pile and pile group. Here in this the bearing capacity factor N_q, is calculated as per equation (3.4) and N_γ is calculated as per equation (3.5 & 3.7) from chapter 3.

Here, the design example is of square pile cap having 4 circular (Bored) piles under it.

Dimension calculation of the pile cap

Firstly here some dimension of the pile is assumed to get the vertical load acting on the single pile from column above pile cap. Assume the diameter of the pile as 500 mm.

The clear cover for the pile cap is taken as 80 mm.

Thus as per the equation 4.10, the depth of pile comes to

D= (2*500) +100 = 1100 mm (overall depth of the pile cap)

d=1100-80 = 1020 mm

n=4 (number of piles)

The over-hang from the last pile is 100 mm,

Spacing between two piles is 1500 mm, spacing is considered as 3D (3 times the diameter of the pile),

Length of the pile cap is : 1500+500+100+100 = 2200 mm

Here as the pile cap is square length is equal to breadth.

Grade of concrete is: M-25,

Grade of steel is: Fy-415,

Factored Load is: 2200 kN (considering 10% as the self wt of the pile cap) (Q)

Moment about x-axis calculated from the horizontal load = 30*1.1(depth)

= 33 kNm

Moment about x-axis calculated from the horizontal load = 25*1.1(depth)

= 27.5 kNm

Total moment acting on the pile cap including the horizontal moments are

M_{uy} = 88 kNm (33 + 55)

M_{ux} = 102.5 kNm (27.5 +75)

ex =0.0466 (102.5/2200)

ey = 0.04 (88/2200)

x=y= 1500/2= 750 mm

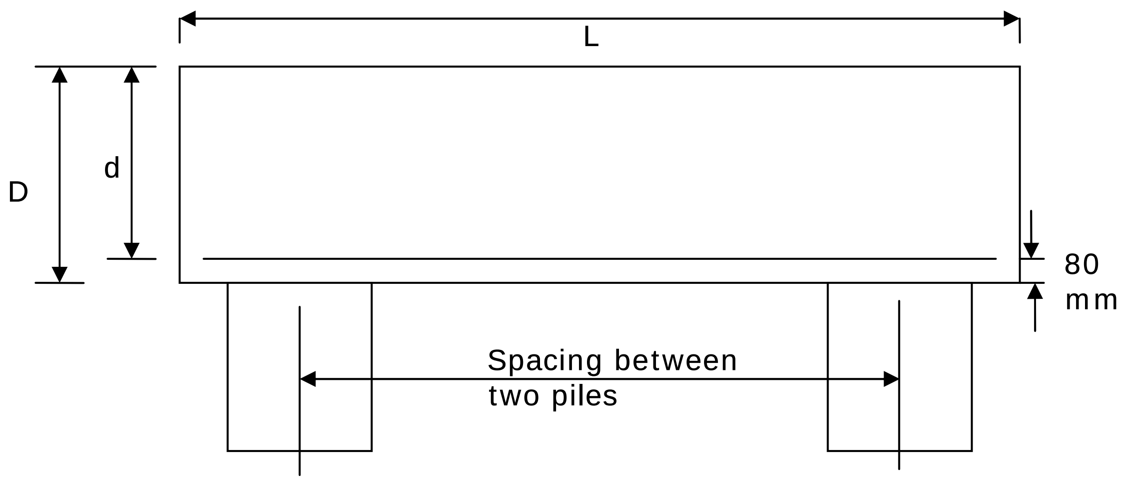


Fig 4.16 Diagram of square pile cap.

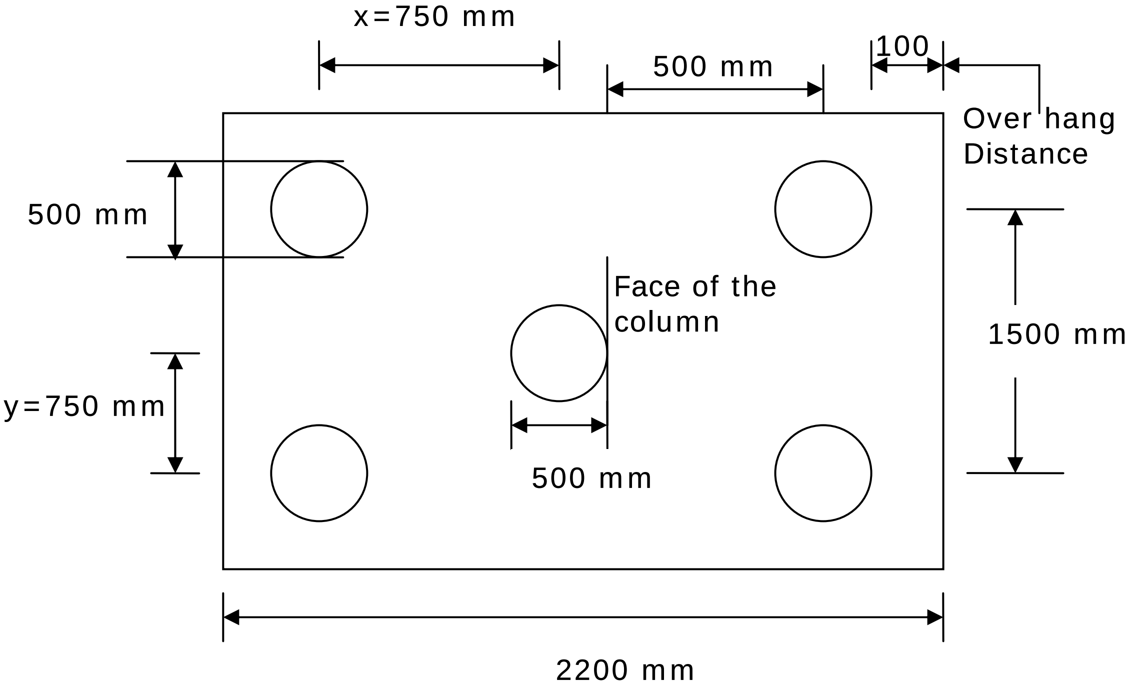


Fig 4.17 Dimension layout of the square pile cap

$$R = \frac{2200}{4} + \frac{88*0.75_1}{4*0.75^2} + \frac{102.5*0.75}{4*0.75^2}$$

Substituting above values in equation 4.4, the vertical load acting on the single pile comes to = 614 kN

Pile Dimension calculation

Considering the vertical load as 620 kN (taken more value to be on safer side), dimension of the pile is calculated using the equation 3.1 and 3.2 of chapter 3, here the length of the pile, is kept constant to 15 mt. The soil data is given as the data and The calculation of the pile dimension is done as per the equation described below:

$$614 * 10^6 = A_p(0.5D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} A_{si} K P_{Di} \tan\delta$$

The dimension of the circular comes to 252.5 mm.

Column Design (detailing as explained in chapter 3, page 83)

Considering this dimension, design of the bored pile is done as explained in chapter 3 (page 45). The area of steel calculated is more than 4%, so increasing the dimension of the pile while restricting the area of steel to 3%. The dimension for the 3% reinforcement for the given load condition comes to about 530 mm.

Taking into account the new dimension of the pile as per the above calculation, vertical load acting on the single pile is again calculated. The vertical load acting on the single considering the new dimension comes to 613.25 kN, as done previously at (page), which is smaller as compared the considered value. Thus the dimension is safe for the load coming.

The reinforcement of the pile is 8 bars or 32 mm diameter and having the helix of 8mm diameter at 40 mm pitch. Thus the pile dimensions are fixed under the pile cap for the given load and soil condition. The clear cover for the single pile is as 50 mm.

Pile cap Design

Now the pile cap is designed considering the new pile dimension, after entering all the load values firstly the moment check is given to the pile cap from equation 4.15.

The clear cover for the pile cap is taken as 80 mm.

Thus as per the equation 4.10, the depth of pile comes to

D= (2*530) +100 = 1160 mm (overall depth of the pile cap)

d=1100-80 = 1080 mm

The over-hang from the last pile is 100 mm,

Spacing between two piles is 1500 mm, spacing is considered as 3D (3 times the diameter of the pile),

Length of the pile cap is : 1500+530+100+100 = 2230 mm

Here as the pile cap is square length is equal to breadth

Area of the pile cap= 4.9729e+06mm^2 (L*B)

Ixx is: 2.34096e+11 mm^4 (bd^3/12) = ((2230*(1080)^3)/12)

Iyy is: 2.34096e+11 mm^4

Moment about x-axis calculated from the horizontal load = 30*1.16(depth)

= 34.8 kNm

Moment about x-axis calculated from the horizontal load = 25*1.16(depth)

= 29 kNm

Total moment acting on the pile cap including the horizontal moments are

M_{uy} = 89.8 kNm (55(given) + 34.8)

M_{ux} = 104 kNm (75(given)+29)

The combined stress is calculated as per the equation 4.15. The values used in the formula are defined above, the undefined terms here are x and y, which are distance from the centroid of the pile cap to the last pile about y-axis and x-axis respectively. x=750 mm, y=750 mm.

$$\sigma = \frac{2230*10^3}{4.9729*10^6} + \frac{104*10^6*750}{2.34096*10^6} + \frac{89.8*10^6*750}{2.34096*10^6}$$

= 0.442308+0.333+0.287702

= 1.06 >1

Thus increasing the depth of the pile cap, till the value comes less than 1, this is an iterative method.

As the depth increases the moment of inertia in both the axes increases and thus the stress comes under the permissible limits. The stress comes to 0.95 at an overall depth of 1240 mm and effective depth of 1160 mm.

Calculation for the depth of fixity for the given load is calculated as explained in chapter 3 (page 42).

Calculation of Main bars for the pile cap (at bottom)

Now here as per the truss theory the ratio of the shear span to depth ration is: [fig 4.4]

av/d = 500/1160= 0.431 < 2 Thus truss theory is predominant.

Now as the vertical load acting on the single pile is known, considering that load tension in the steel is calculated as per equation 4.12 and Fig 4.5. The value comes to

H=296 kN = [550*((1.500/2)-(0.500/4))/(1.160)]

Ast=(296*10^3/0.87*415)

Area of steel is calculated as per equation 4.13. This comes to 820 mm^2

Percentage of steel is calculated as per $p_t = (100\,ast/b\,d)$ which comes to 0.031% which is less than 0.12%, where b is the breadth of the pile cap.

$$p_t = (100*820/(2230*1160))$$

= 0.03173% <0.12%

Thus considering minimum value which comes to 3104.26 mm^2 . Assuming the diameter of the bar as 25 mm, thus spacing for the 25 mm bars comes to 352.72, but the maximum spacing to provide is 300 mm so providing 25 mm diameter at 300 m c/c both ways at bottom. No. of bars calculated at the bottom comes to 16 bars. Thus area provided is 3927 mm^2. [Fig 4.18]

Calculation of the Distribution bars (at top of pile cap)

Distribution steel is provided at the top of the pile cap, which is calculated as the gross area of the pile cap. here d is 1160 mm and b is 1000 mm. this area comes to (0.12*1000*1160/100), which comes to 1392 mm. Considering 12 mm diameter bar, the spacing comes to 180 mm c/c. Thus numbers of bars at the top are 25. [fig 4.18]

Check for Shear

Considering the vertical load acting on the pile cap (2200 kN), nominal shear stress comes to τ_v =0.4424, and τ_c for 0.1518 is 0.28, thus shear reinforcement is necessary. [20]

Vus= (2200-((0.28*2230*1160)/100))

= 1475.696 kN.

Assuming 4 legged 10 mm diameter (area=314.159 mm^2)

Spacing calculated as : (314,159*0.87*415*1160/1475.696e+03)

= 89.16 mm

Provide 4 legged 8 mm diameter at 85 mm c/c. [fig 4.18]

Check for the moment action:

Checking for the moment action, considering the vertical load acting on the single pile, moment is calculated at the face of the column (fig 4.17) which comes to 613kN.

Moment at the face of the column= (613*0.5+613*0.5) =613kNm

Here 613kN is the vertical load acting on single pile (page 132)

Now as per equation 4.14, area of steel calculated

$$ast = \frac{0.5*25}{415}\left[1-\sqrt{1-\frac{4.6*613*10^6}{25*2230*1160^2}}\right]2230*1160$$

as 1478.40 mm^2 which is less than the provided value of 3927 mm^2. Thus provided area of steel is o.K.

Secondary Reinforcement (at each face of the pile cap)

Secondary reinforcement is calculated as 20 % of the maximum of the area of steel calculated, this is 785.4 mm^2, and considering 12 mm diameter and thus 7 no. of bars are to be provided on each face of the pile cap. Thus total numbers of the bars to be provided are 28. [fig 4.18]

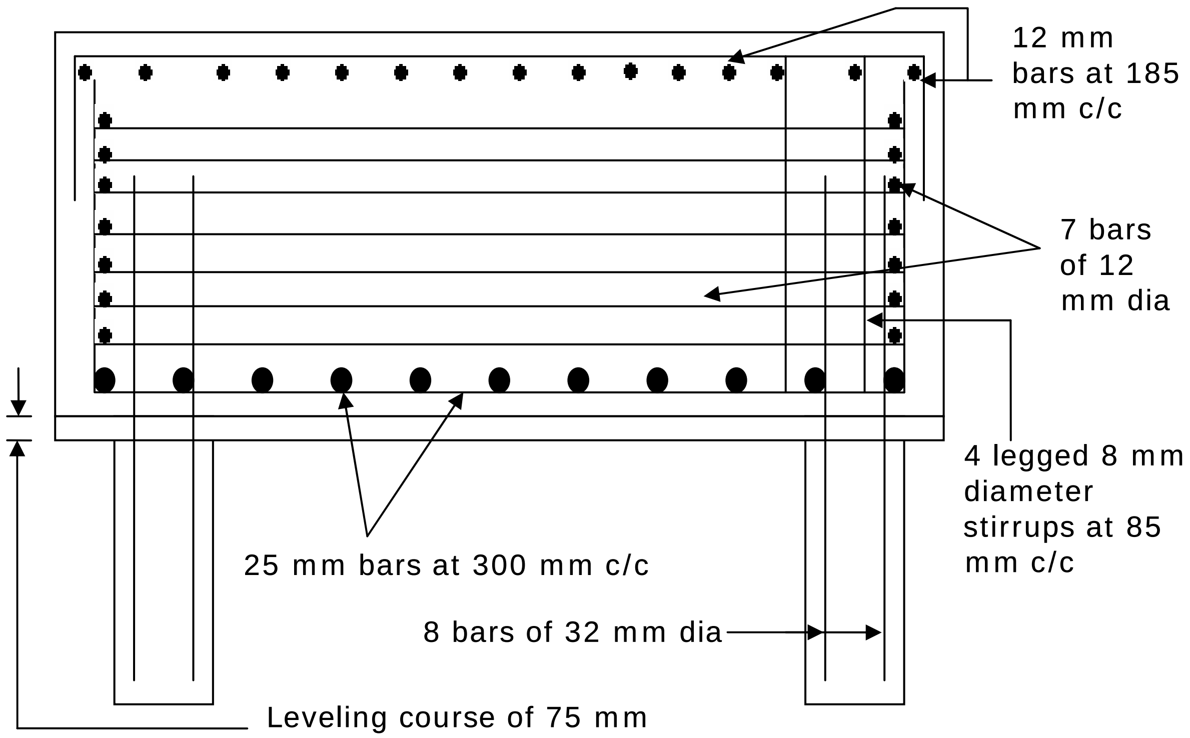


Fig 4.18 Detailing of the square pile cap

Total weight of steel calculation for the pile group (pile cap and pile)

25 mm diameter bars 16 in number at the bottom both ways having the length as (2230-160+1160-80-12-12-50) mm, 3076 mm. Here 50 mm is the extra length.

Distribution steel 25 no. of bars having the diameter of 12 mm. and length (2230-160+100). Here 100 mm is the extra length.

No. of Stirrups calculated are 27. 4 legged 10 mm diameter. (1160-80) effective depth minus clear cover (1080*2+1000) =3160 mm

Secondary reinforcement have about 25 number of the 12 mm bars. Length of the bar is (2230-80-80) = 2070 mm

Pile reinforcement is 8 bars of 32 mm diameter and the length is 15 m

Here 7850 Kg/m^3 is the density of the steel.

Weight of the steel from the main steel for the pile cap is:
(Area of the bar*no. of bar*length of bar*density of the steel)
: (490.87/e+06)*16*(3.076)*7850

= 189.645 Kg

Weight of the steel from the distribution steel is:
: (113.1/e+06)*25*2.170*7850

= 48.15 Kg

Weight of the steel from the shear reinforcement is:
: (78.54/e+06)*27*7850*3.160

= 52.60 Kg

Weight of the steel from the secondary reinforcement is:
(113.1/e+06)*25*7850*2.070

= 46 kg.

Weight of steel from the single pile reinforcement is:
(804.42/e+06*8*15*7850)

= 757.60 Kg

4 no. of piles thus the quantity of steel is: 757.70 * 4 =3031.05 Kg

Number of Helix is: 375, having 8 mm diameter, thus cost for the shear reinforcement is: (530-100) subtracting the clear cover in the pile. Thus the area of the helix is:

3.1416*(430/1000)*((3.1416*8*8)/4*1000*1000)*7850*375

= 199.89 Kg

Total weight of steel is: (189.645 + 48.15 + 52.60 + 46+3031.054+199.89)

= 3567.34 Kg

= 3570 Kg

Cost estimation of the total steel for the pile group (pile cap and pile)

The cost of steel per Kg is taken Rs. 30/Kg

Thus the total cost of steel for the pile cap is : (3570*30) = 1, 07,100 Rs.

Cost estimation of the total concrete for the pile group (pile cap and pile)

For concrete the area of the pile cap is:

: (2.230*2.230*1.240)

= 6.1663 m^3

For each pile the concrete to be used is :

: 0.7854*(530/1000)*(530/1000)*15

= 3.309 m^3

4 no. of piles thus concrete volume becomes to: 3.309 * 4 = 13.2336 m^3

Leveling course is of 75 mm thus, concrete for this work is:
((2230/1000)*(2230/1000)*(75/1000))

=0.373 m^3

Thus the total quantity of the concrete is:

(6.1663+13.2336+0/373) = 19.773 m^3

The cost of concreting is taken as 3000/ m^3

The total cost of concreting for the pile cap comes to: 19.773 *3000

= 59,319 Rs.

Thus the total cost of the Square pile group having bored circular pile comes to

= 1, 07,100 + 59,319

= 1, 66,419 Rs/-

Table 4.4 Dimensions of pile calculated using program having different type of pile caps, soil conditions and loads.

Type of Group	Soil Condition	No. of piles	Type of pile below the pile cap	Length of the pile in m	Type of installation	Dimension of the pile In mm
Square	Sand	4	Circular	15	Driven	180
					Bored	235
			Square		Driven	150 * 150
					Bored	200 * 200
			Rectangular		Driven	80 * 135
					Bored	125* 160
	Clay	4	Circular	15	Driven	835
					Bored	835
			Square		Driven	690 * 690
					Bored	690 * 690
			Rectangular		Driven	200* 410
					Bored	200 * 410
Rectangular	Sand	6	Circular	15	Driven	155
					Bored	200
			Square		Driven	130 * 130
					Bored	170 * 170
			Rectangular		Driven	80 * 110
					Bored	100* 146
	Clay	6	Circular	15	Driven	860
					Bored	860
			Square		Driven	710 * 710
					Bored	710 * 710
			Rectangular		Driven	250 * 350
					Bored	250 * 350
Square	Sand	9	Circular	15	Driven	105
					Bored	140
			Square		Driven	100 * 100
					Bored	120 * 120
			Rectangular		Driven	50 * 80
					Bored	80* 100

Table 4.4 continue

Square	Clay	9	Circular	15	Driven	590
					Bored	590
			Square		Driven	490 * 490
					Bored	490 * 490
			Rectangular		Driven	180 * 300
					Bored	180 * 300
Rectangular	Sand	12	Circular	15	Driven	95
					Bored	125
			Square		Driven	80 * 80
					Bored	110 * 110
			Rectangular		Driven	50 * 80
					Bored	80* 100
	Clay	12	Circular	15	Driven	535
					Bored	535
			Square		Driven	440 * 440
					Bored	440 * 440
			Rectangular		Driven	170 * 280
					Bored	170 * 280

Table 4.5 Dimension of pile calculated as per design.

Type of Group	Soil Condition	No. of piles	Type of pile below the pile cap	Length of the pile in m	Type of installation	Dimension of the pile
Square	Sand	4	Circular	15	Driven	200
					Bored	530
			Square		Driven	200 * 200
					Bored	500 * 500
			Rectangular		Driven	210 *150
					Bored	550* 450
	Clay	4	Circular	15	Driven	835
					Bored	835
			Square		Driven	690 * 690
					Bored	690 * 690
			Rectangular		Driven	200* 410
					Bored	550 * 400

Table 4.5 Continue

Type of Group	Soil Condition	No. of piles	Type of pile below the pile cap	Length of the pile in m	Type of installation	Dimension of the pile in mm
Rectangular	Sand	6	Circular	15	Driven	200
					Bored	500
			Square		Driven	200 * 200
					Bored	450 * 450
			Rectangular		Driven	200 * 150
					Bored	550* 450
	Clay	6	Circular	15	Driven	750
					Bored	750
			Square		Driven	590 * 590
					Bored	590* 590
			Rectangular		Driven	250 * 350
					Bored	500 * 400
Square	Sand	9	Circular	15	Driven	200
					Bored	400
			Square		Driven	200 * 200
					Bored	400 * 400
			Rectangular		Driven	200 * 150
					Bored	500*400
	Clay	9	Circular	15	Driven	590
					Bored	590
			Square		Driven	490 * 490
					Bored	490 * 490
			Rectangular		Driven	180 * 300
					Bored	450*350
Rectangular	Sand	12	Circular	15	Driven	200
					Bored	450
			Square		Driven	200 * 200
					Bored	400 * 400
			Rectangular		Driven	200 * 150
					Bored	500* 400
	Clay	12	Circular	15	Driven	535
					Bored	535
			Square		Driven	440 * 440
					Bored	440 * 440
			Rectangular		Driven	170 * 280
					Bored	450*350

Table 4.6a Cost estimated values of pile cap for clayey soil

Type of soil	Shape of the pile cap	No of piles in the group	Shape of the pile	Type of installation of the pile	Estimated cost in Rs.
Clay	Square	4	Circular	Driven	371607
				Bored	543151
			square	Driven	310087
				Bored	452452
			Rectangular	Driven	111643
				Bored	229835
	Rectangular	6	Circular	Driven	403009
				Bored	628286
			square	Driven	357686
				Bored	536461
			Rectangular	Driven	122368
				Bored	242412
	Square	9	Circular	Driven	354618
				Bored	516720
			square	Driven	257263
				Bored	323608
			Rectangular	Driven	119558
				Bored	280025
	Rectangular	12	Circular	Driven	397581
				Bored	603833
			square	Driven	362303
				Bored	452403
			Rectangular	Driven	122827
				Bored	398106

Table 4.6b Cost estimated values of pile cap for sandy soil

Type of soil	Shape of the pile cap	No of piles in the group	Shape of the pile	Type of Installation of the pile	Estimated cost in Rs.
Sand	Square	4	Circular	Driven	164275
				Bored	174507
			Square	Driven	76517
				Bored	209648
			Rectangular	Driven	136553
				Bored	199205

Table 4.6b Continue

Type of soil	Shape of the pile cap	No of piles in the group	Shape of the pile	Type of Installation of the pile	Estimated cost in Rs.
Sand	Rectangular	6	Circular	Driven	97743
				Bored	257532
			square	Driven	142971
				Bored	237197
			Rectangular	Driven	155384
				Bored	267016
	Square	9	Circular	Driven	139418
				Bored	190128
			square	Driven	132706
				Bored	260192
			Rectangular	Driven	140244
				Bored	359744
	Rectangular	12	Circular	Driven	184377
				Bored	404189
			square	Driven	208269
				Bored	372181
			Rectangular	Driven	176994
				Bored	501053

Table 4.7 Lowest value of all the four types of pile group in different soil.

Pile Group	Type of Pile Cap	Type of Soil	Shape of Pile	Type of Installation	Cost in Rs.
4 Pile Group	Square	Sand	Square	driven	76517
6 Pile Group	Rectangular		Circular	driven	97743
9 Pile Group	Square		Square	driven	132706
12 Pile Group	Rectangular		Rectangular	driven	176994
4 Pile Group	Square	Clay	Rectangular	driven	111643
6 Pile Group	Rectangular		Rectangular	driven	122368
9 Pile Group	Square		Rectangular	driven	119558
12 Pile Group	Rectangular		Rectangular	driven	122827

Table 4.8 Economical section for the given load condition

Type of Pile group	Type of pile	Type of soil	Min Cost in Rs.
4 Pile Group	Square	Clay	111643
4 Pile Group	Rectangular	Sand	76517

The following are the graphs are plotted to get the clear idea of the cost of each pile group having different pile cap and piles under it.

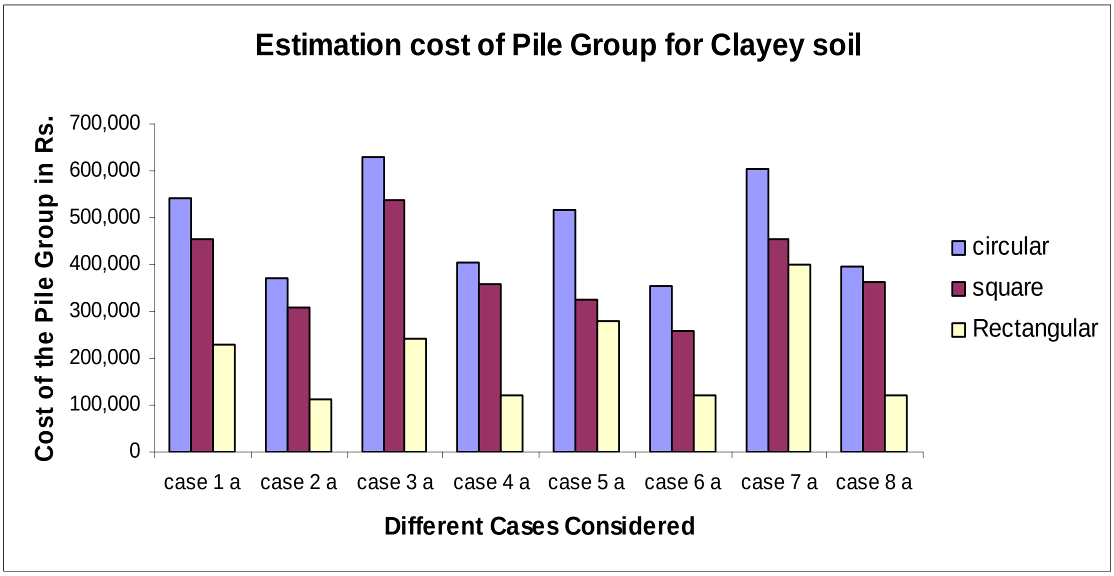


Fig 4.19 Graph of comparison of cost estimation of different pile group in clayey soil

*case 1a, case 2a, etc. as per Table 4.3

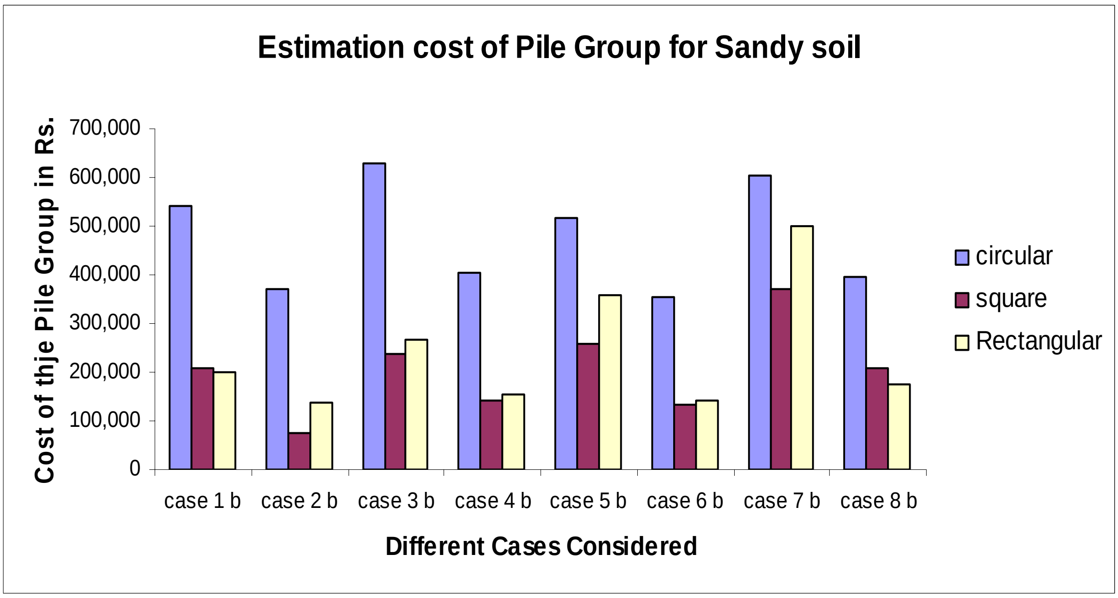


Fig 4.20 Graph of comparison of cost estimation of different pile group in sandy soil

*case 1b, case 2b, etc. as per Table 4.3

Note : in this estimation boring of soil and pile driving hammer's price are not included.

Table 4.9 Scheduling of all the pile cap cases for clayey type of soil

Type of pile group	Type of Pile cap	Type of pile	Pile Cap Reinforcement				Pile Reinforcement		
			Longitudinal Bars at bottom (in Both Direction)	Distribution Steel at top (both ways)	Shear Reinforcement	Secondary Reinforcement on each face	Longitudinal Bars	Lateral Reinforcement	
4 Pile Group	Square	Circular Bored	16 mm bars at 250 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 260mm c/c	7 bars of 10 mm diameter	20 bars of 32 mm dia	8 mm dia Helix at 42 mm pitch	
		Circular Driven	16 mm bars at 250 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 260mm c/c	7 bars of 10 mm diameter	22 bars of 20 mm dia	8 mm bars at 105 mm c/c pitch	central portion
								8 mm bars at 30 mm c/c pitch	at pile head for 2505 mm
								8 mm bars at 35 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 255 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 130 mm c/c	6 bars of 10 mm diameter	18 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 255 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 130 mm c/c	6 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm bars at 150 mm c/c pitch	central portion
								8 mm bars at 25 mm c/c pitch	at pile head for 2070 mm
								8 mm bars at 40 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	16 mm bars at 235 mm c/c	16 mm bars at 235 mm c/c	4 Legged 8 mm at 85 mm c/c	5 bars of 10 mm diameter	9 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 150 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 102 mm c/c	4 bars of 10 mm diameter	10 bars of 16 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 20 mm c/c pitch	at pile head for 1230 mm
								8 mm bars at 90 mm c/c pitch	at top and bottom of pile
6 Pile Group	Rectangular	Circular Bored	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 300 mm c/c	5 bars of 10 mm diameter	18 bars of 32 mm dia	8 mm dia Helix at 42 mm pitch	
		Circular Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 300 mm c/c	5 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm bars at 115 mm c/c pitch	central portion
								8 mm bars at 35 mm c/c pitch	at pile head for 2250 mm
								8 mm bars at 35 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 140 mm c/c	5 bars of 10 mm diameter	19 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 255 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 140 mm c/c	5 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm bars at 125 mm c/c pitch	central portion
								8 mm bars at 25 mm c/c pitch	at pile head for 2130 mm
								8 mm bars at 40 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	20 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	4 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 150 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 85 mm c/c	3 bars of 10 mm diameter	8 bars of 16 mm dia	8 mm bars at 125 mm c/c pitch	central portion
								8 mm bars at 35 mm c/c pitch	at pile head for 1050 mm
								8 mm bars at 80 mm c/c pitch	at top and bottom of pile

Table 4.9 Continue

Type of pile group	Type of Pile cap	Type of pile	Pile Cap Reinforcement				Pile Reinforcement		
			Longitudinal Bars at bottom (in Both Direction)	Distribution Steel at top (both ways)	Shear Reinforcement	Secondary Reinforcement on each face	Longitudinal Bars	Lateral Reinforcement	
9 Pile Group	Square	Circular Bored	16 mm bars at 300 mm c/c	12 mm bars at 245 mm c/c	4 Legged 8 mm at 160mm c/c	7 bars of 10 mm diameter	11 bars of 32 mm dia	8 mm dia Helix at 42 mm pitch	
		Circular Driven	16 mm bars at 300 mm c/c	12 mm bars at 245 mm c/c	4 Legged 8 mm at 160mm c/c	7 bars of 10 mm diameter	12 bars of 20 mm dia	8 mm bars at 145 mm c/c pitch	central portion
								8 mm bars at 40 mm c/c pitch	at pile head for 2505 mm
								8 mm bars at 45 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 295 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 85 mm c/c	7 bars of 10 mm diameter	19 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 295 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 85 mm c/c	7 bars of 10 mm diameter	12 bars of 20 mm dia	8 mm bars at 170 mm c/c pitch	central portion
								8 mm bars at 35 mm c/c pitch	at pile head for 1470 mm
								8 mm bars at 55 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	16 mm bars at 300 mm c/c	12 mm bars at 235 mm c/c	4 Legged 8 mm at 75 mm c/c	3 bars of 10 mm diameter	9 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	4 bars of 10 mm diameter	10 bars of 16 mm dia	8 mm bars at 90 mm c/c pitch	central portion
								8 mm bars at 25 mm c/c pitch	at pile head for 900 mm
								8 mm bars at 90 mm c/c pitch	at top and bottom of pile
12 Pile Group	Rectangular	Circular Bored	32 mm bars at 300 mm c/c	12 mm bars at 285 mm c/c	4 Legged 8 mm at 200mm c/c	9 bars of 16mm diameter	10 bars of 32 mm dia	8 mm dia Helix at 60 mm pitch	
		Circular Driven	32 mm bars at 300 mm c/c	12 mm bars at 285 mm c/c	4 Legged 8 mm at 200mm c/c	9 bars of 16mm diameter	10 bars of 20 mm dia	8 mm bars at 155 mm c/c pitch	central portion
								8 mm bars at 45 mm c/c pitch	at pile head for 1605 mm
								8 mm bars at 50 mm c/c pitch	at top and bottom of pile
		Square Bored	20 mm bars at 150 mm c/c	12 mm bars at 230 mm c/c	4 Legged 8 mm at 100 mm c/c	7 bars of 16 mm diameter	19 bars of 20 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	20 mm bars at 150 mm c/c	12 mm bars at 230 mm c/c	4 Legged 8 mm at 100 mm c/c	7 bars of 16 mm diameter	16 bars of 16 mm dia	8 mm bars at 185 mm c/c pitch	central portion
								8 mm bars at 40 mm c/c pitch	at pile head for 1320 mm
								8 mm bars at 60 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	32 mm bars at 300 mm c/c	12 mm bars at 230 mm c/c	4 Legged 8 mm at 120 mm c/c	7 bars of 16 mm diameter	16 bars of 20 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	20 mm bars at 165 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	7 bars of 12 mm diameter	6 bars of 20 mm dia	8 mm bars at 85 mm c/c pitch	central portion
								8 mm bars at 20 mm c/c pitch	at pile head for 840 mm
								8 mm bars at 85 mm c/c pitch	at top and bottom of pile

Table 4.10 Scheduling of all the pile cap cases for sandy type of soil

Type of pile group	Type of Pile cap	Type of pile	Pile Cap Reinforcement: Longitudinal Bars at bottom (in Both Direction)	Pile Cap Reinforcement: Distribution Steel at top (both ways)	Pile Cap Reinforcement: Shear Reinforcement	Pile Cap Reinforcement: Secondary Reinforcement on each face	Pile Reinforcement: Longitudinal Bars	Pile Reinforcement: Lateral Reinforcement	
4 Pile Group	Square	Circular Bored	16 mm bars at 225 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 85mm c/c	5 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm dia Helix at 40 mm pitch	
		Circular Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	4 bars of 10 mm diameter	12 bars of 32 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 30 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 205 mm c/c	16 mm bars at 205 mm c/c	4 Legged 8 mm at 90 mm c/c	5 bars of 10 mm diameter	10 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 185 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 70 mm c/c	4 bars of 10 mm diameter	4 bars of 16 mm dia	8 mm bars at 75 mm c/c pitch	central portion
								8 mm bars at 25 mm c/c pitch	at pile head for 450 mm
								8 mm bars at 75 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	16 mm bars at 235 mm c/c	16 mm bars at 235 mm c/c	4 Legged 8 mm at 85 mm c/c	5 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 165 mm c/c	16 mm bars at 165 mm c/c	4 Legged 8 mm at 80 mm c/c	4 bars of 10 mm diameter	9 bars of 32 mm dia	8 mm bars at 75 mm c/c pitch	central portion
								8 mm bars at 15 mm c/c pitch	at pile head for 630 mm
								8 mm bars at 75 mm c/c pitch	at top and bottom of pile
6 Pile Group	Rectangular	Circular Bored	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 80 mm c/c	4 bars of 10 mm diameter	9 bars of 32 mm dia	8 mm dia Helix at 40 mm pitch	
		Circular Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	2 bars of 10 mm diameter	6 bars of 20 mm dia	8 mm bars at 78 mm c/c pitch	central portion
								8 mm bars at 50 mm c/c pitch	at pile head for 465 mm
								8 mm bars at 78 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 300 mm c/c	12 mm bars at 215 mm c/c	4 Legged 8 mm at 70 mm c/c	4 bars of 10 mm diameter	20 bars of 16 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 65 mm c/c	2 bars of 10 mm diameter	6 bars of 20 mm dia	8 mm bars at 65 mm c/c pitch	central portion
								8 mm bars at 20 mm c/c pitch	at pile head for 390 mm
								8 mm bars at 65 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	20 mm bars at 275 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 75 mm c/c	5 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 150 mm c/c	20 mm bars at 165 mm c/c	4 Legged 8 mm at 90 mm c/c	2 bars of 10 mm diameter	7 bars of 32mm dia	8 mm bars at 75 mm c/c pitch	central portion
								8 mm bars at 15 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 75 mm c/c pitch	at top and bottom of pile

Table 4.10 Continue

Type of pile group	Type of Pile cap	Type of pile	Pile Cap Reinforcement				Pile Reinforcement		
			Longitudinal Bars at bottom (in Both Direction)	Distribution Steel at top (both ways)	Shear Reinforcement	Secondary Reinforcement on each face	Longitudinal Bars	Lateral Reinforcement	
9 Pile Group	Square	Circular Bored	16 mm bars at 300 mm c/c	12 mm bars at 195 mm c/c	4 Legged 8 mm at 75mm c/c	5 bars of 10 mm diameter	10 bars of 20 mm dia	8 mm dia Helix at 42 mm pitch	
		Circular Driven	16 mm bars at 300 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 60mm c/c	2 bars of 10 mm diameter	18 bars of 16 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 60 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
		Square Bored	16 mm bars at 295 mm c/c	12 mm bars at 195 mm c/c	4 Legged 8 mm at 75mm c/c	5 bars of 10 mm diameter	16 bars of 20 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	16 mm bars at 295 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 60mm c/c	2 bars of 10 mm diameter	10 bars of 20 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 40 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	16 mm bars at 300 mm c/c	12 mm bars at 235 mm c/c	4 Legged 8 mm at 75 mm c/c	3 bars of 10 mm diameter	8 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	16 mm bars at 300 mm c/c	16 mm bars at 260 mm c/c	4 Legged 8 mm at 55 mm c/c	2 bars of 10 mm diameter	6 bars of 16 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 45 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
12 Pile Group	Rectangular	Circular Bored	20 mm bars at 150 mm c/c	12 mm bars at 240 mm c/c	4 Legged 8 mm at 100mm c/c	7 bars of 16mm diameter	6 bars of 32 mm dia	8 mm dia Helix at 40 mm pitch	
		Circular Driven	16 mm bars at 245 mm c/c	12 mm bars at 150 mm c/c	4 Legged 8 mm at 60mm c/c	4 bars of 16mm diameter	16 bars of 16 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 60 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
		Square Bored	20 mm bars at 150 mm c/c	12 mm bars at 210 mm c/c	4 Legged 8 mm at 95 mm c/c	7 bars of 16 mm diameter	20 bars of 16 mm dia	8 mm dia at 300 mm c/c	
		Square Driven	20 mm bars at 225 mm c/c	16 mm bars at 150 mm c/c	4 Legged 8 mm at 85 mm c/c	6 bars of 16 mm diameter	10 bars of 20 mm dia	8 mm bars at 100 mm c/c pitch	central portion
								8 mm bars at 40 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 100 mm c/c pitch	at top and bottom of pile
		Rectangular Bored	32 mm bars at 300 mm c/c	12 mm bars at 255 mm c/c	4 Legged 8 mm at 140 mm c/c	8 bars of 16 mm diameter	8 bars of 32 mm dia	8 mm dia at 300 mm c/c	
		Rectangular Driven	20 mm bars at 225 mm c/c	12 mm bars at 215 mm c/c	4 Legged 8 mm at 85 mm c/c	4 bars of 12 mm diameter	16 bars of 16 mm dia	8 mm bars at 75 mm c/c pitch	central portion
								8 mm bars at 15 mm c/c pitch	at pile head for 600 mm
								8 mm bars at 75 mm c/c pitch	at top and bottom of pile

The points that can be interpreted from this parametric study are:

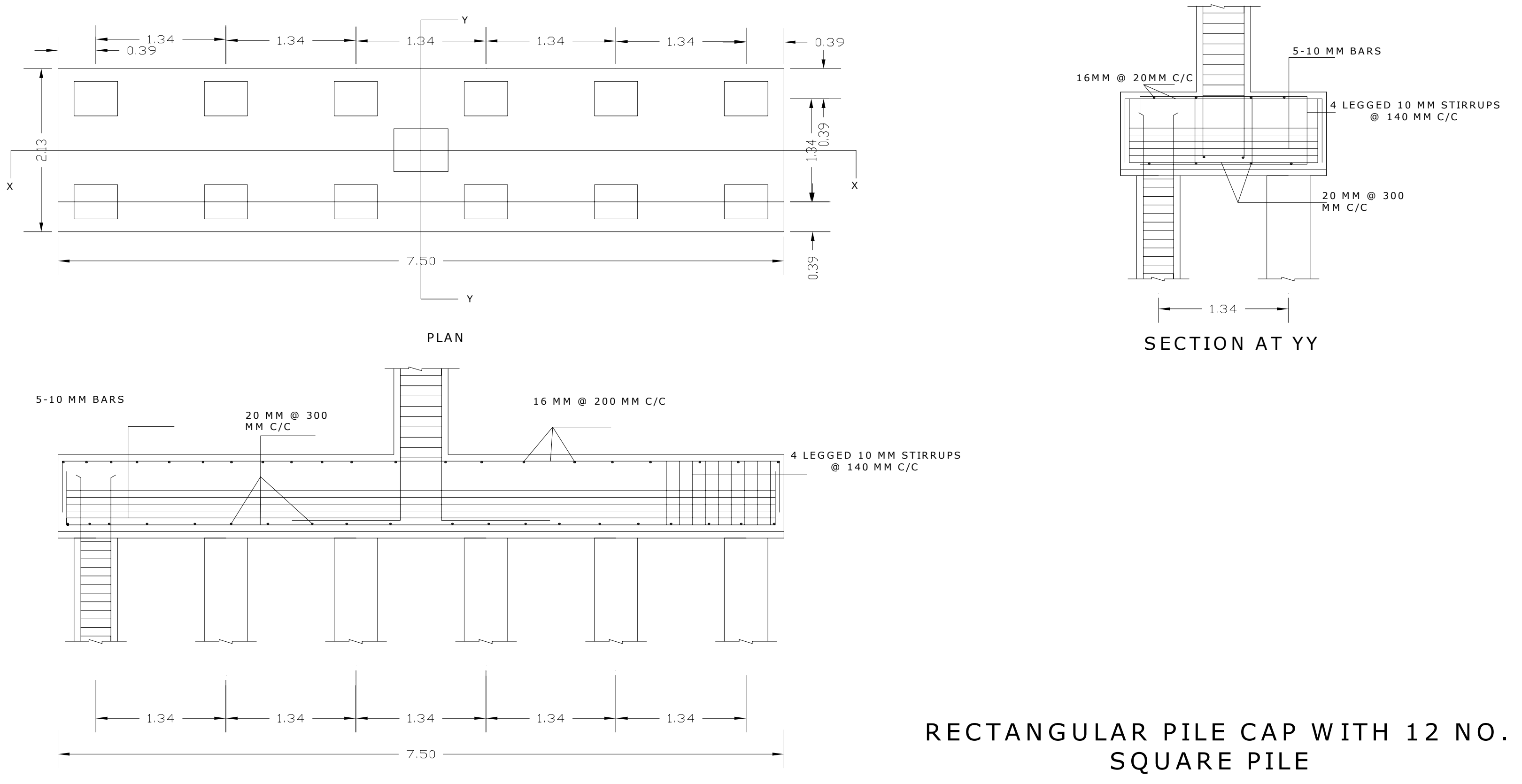
1. For the clayey soil, considering all the given inputs, the most economical pile group with minimum cost is square pile cap having four square (driven) piles under it. [Table 4.8]
2. For the clayey soil, considering all the above inputs, the most economical pile group with minimum cost is square pile cap having four rectangular (driven) piles under it. [Table 4.8]
3. The dimensions of the driven pile are much less that bored pile for the same load and same soil condition. [Table 4.4, 4.5]

4.8 CONCLUSION

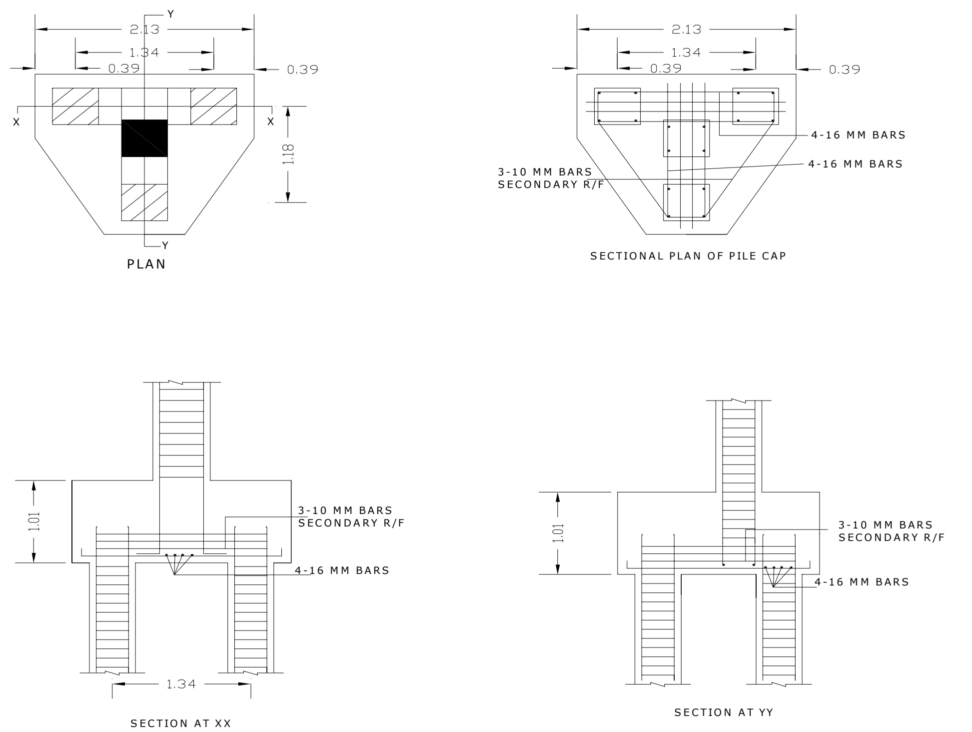
1. The analysis for the pile group gives the lower value than the calculated in the reference, which is much more conservative side. [Case 1, page 107]
2. The value of the design of the triangular pile cap from the program is almost same as per the reference. [Case TD, page 110]
3. As the shape of the pile cap was different in the reference i.e. in reference the shape considered was diamond, while in the program it was considered as square pile cap, the reinforcement details for both the pile cap, the values differ slightly. The values calculated from the program are considerable. [Case SD, page 113]
4. The values of bearing capacity of bored and driven single pile in clayey soil having circular section have the same values. This goes exactly same with the square section and rectangular section case. Driven single pile in sand gives more bearing capacity than bored single pile in sand for all the shapes of pile. [Fig 4.7, Fig 4.10, Fig 4.13]
5. Group capacities of different pile group having different number of piles, driven and bored in clay type of soil, having circular section give the same value. This result also holds good for the square section and rectangular section of pile. [Fig 4.8, Fig 4.11, Fig 4.14]
6. Group capacity having driven piles beneath it, gives more bearing capacity value in sand condition in comparison to the bored pile in sandy soil. This

result matches for all the different shape of pile i.e. circular, square and rectangular. [Fig 4.9, Fig 4.12, Fig 4.15]

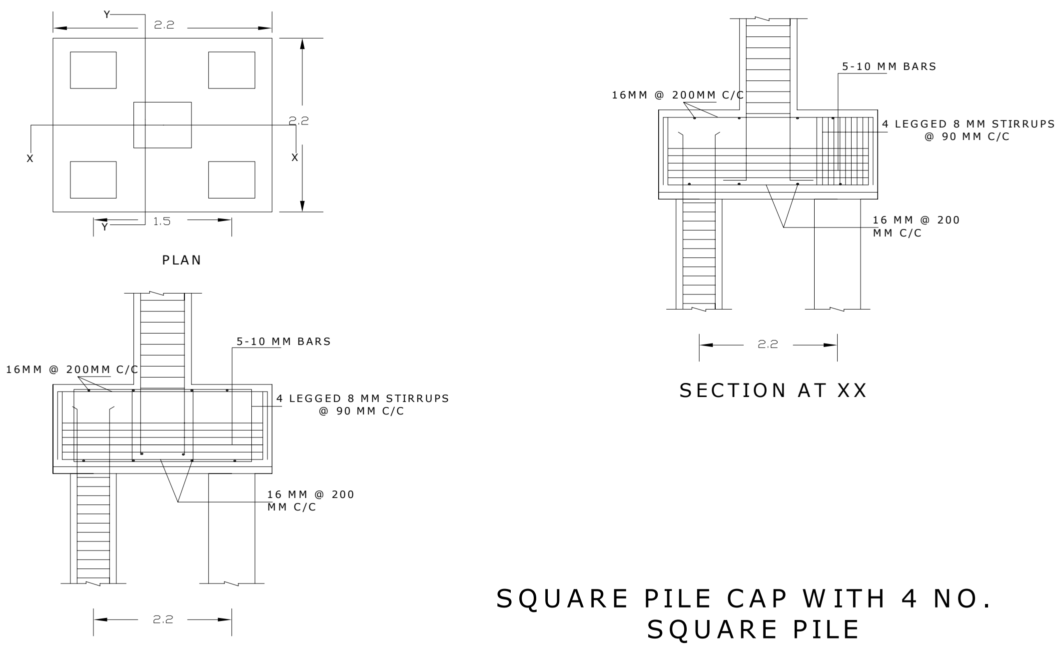
7. The dimensions of the driven pile are much less that bored pile for the same load and same soil condition. [Table 4.4, 4.5]
8. For the clayey soil, considering all the given inputs, the most economical pile group with minimum cost is square pile cap having four square (driven) piles under it. [Table 4.8]
9. For the clayey soil, considering all the above inputs, the most economical pile group with minimum cost is square pile cap having four rectangular (driven) piles under it. [Table 4.8]



RECTANGULAR PILE CAP WITH 12 NO.
SQUARE PILE



TRIANGULAR PILE CAP WITH 3 NO.
SQUARE PILE



SQUARE PILE CAP WITH 4 NO.
SQUARE PILE

NOTE : ALL DIMENSIONS ARE IN METER

CIVIL DEPARTMENT INSTITUTE OF TECHNOLOGY, NIRMA UNIVERSITY
TITLE : DETAILING OF DIFFERENT TYPEOF PILE CAP
PROJECT : SOFTWARE FOR ANALYSIS AND DESIGN OF PILE FOUNDATION
CLIENT :
DWG. NO : SHEET 1 DRAWN BY : KUNAL CHECK BY :
DATE : 29/04/2007 SCALE : 1:1 REVISION : Ro

DETAILING OF DIFFERENT TYPE OF PILE CAP

SHEET I

5. SUMMARY AND FUTURE SCOPE OF WORK

5.1 SUMMARY

1. A complete analysis of single pile for its load bearing capacity, considering the different types of soils such as clays with different consistency, sand with different density having different angle of internal friction and layers of sand and clay is carried out it also includes different pile parameters such as diameter, length and type of installation of it. The analysis is done with the IS 2911: 1979 code provisions.
2. Computer program using C++ language is prepared for the analysis of the single pile which gives the load bearing capacity of the pile. (Program I)
3. The analysis program gives dimensions of the individual pile as per the soil data and given load.
4. Design program of the Bored and Driven single pile is also prepared in C++ language, which gives its reinforcement. (Program IIa, Program IIb).
5. Nine cases where solved for the evaluation of the bearing capacity of the individual pile considering different pile shapes i.e. circular, square & rectangular for different types of the soil condition i.e. sand, clay and sand- clay both present. The results are tabulated in table 3.13.
6. Pile group analysis of different shapes mainly triangular, square & rectangular consisting of the different number of shapes is done. This analysis is carried out by using the prepared program, in which two type of soil are considered i.e. sand and clay. (Program III)
7. Program III, which is the analysis program for the pile group gives the ultimate bearing capacity of pile group by group action and by individual action, number of piles as per the soil condition and given load.
8. To get the idea of load carrying capacity of the pile group, different number of piles in a group were considered with pile having mainly 3 shapes i.e. circular, square and rectangular (bored and driven) varying in the size from 0.15 m to 0.40 m in two different types of soil conditions (sand and clay). Considering these variations about 360 cases for single pile and pile group capacity were solved.
9. Program for the design of the different pile cap geometry having different shapes of piles under it is prepared giving the reinforcement detail,

considering the different type of loads i.e. vertical load, horizontal load and moment acting on the pile cap (Program IV).

10. To know the most economical pile group for some given constant load conditions, 48 different cases were solved, considering the variation in number of piles in a group, shape of pile, type of installation and soil conditions. The result of this work is shown in table 4.6a and 4.6b.

5.2 CONCLUSION

1. The results of analysis of single pile in some soil condition were cross-checked with the data provided by the Adani group. Thus the validity of the program is checked. [Table 3.5]
2. The Bearing capacity of Rectangular Driven Pile in $C-\phi$ type of soil is 1.25 times the Bearing Capacity of Circular Driven Pile and 1.93 times the Square Driven Pile.[Table 3.14]
3. The Bearing capacity of Rectangular Bored pile in $C-\phi$ type of soil is 1.248 times the Bearing Capacity of Circular Bored Pile and 2.03 times the Square Bored Pile. [Table 3.14]
4. The Bearing capacity of Rectangular Driven Pile in ϕ type of soil is 1.326 times the Bearing Capacity of Circular Driven Pile and 1.927 times the Square Driven Pile. [Table 3.14]
5. The Bearing capacity of Rectangular Driven Pile in *C type* of soil is 1.22 times the Bearing Capacity of Circular Driven Pile and 2.62 times the Square Driven Pile. [Table 3.14]
6. The analysis for the pile group gives the lower value than the calculated in the reference, which is much more conservative side. [Case 1, page 107]
7. The value of the design of the triangular pile cap from the program is almost same as per the reference. [Case TD, page 110]
8. As the shape of the pile cap was different in the reference i.e. in reference the shape considered was diamond, while in the program it was considered as square pile cap, the reinforcement details for both the pile cap, the values differ slightly. The values calculated from the program are considerable. [Case SD, page 113]
9. The values of bearing capacity of bored and driven single pile in clayey soil having circular section have the same values. This goes exactly same with

the square section and rectangular section case. Driven single pile in sand gives more bearing capacity than bored single pile in sand for all the shapes of pile. [Fig 4.7, Fig 4.10, Fig 4.13]

10. Group capacities of different pile group having different number of piles, driven and bored in clay type of soil, having circular section give the same value. This result also holds good for the square section and rectangular section of pile. [Fig 4.8, Fig 4.11, Fig 4.14]
11. Group capacity having driven piles beneath it, gives more bearing capacity value in sand condition in comparison to the bored pile in sandy soil. This result matches for all the different shape of pile i.e. circular, square and rectangular. [Fig 4.9, Fig 4.12, Fig 4.15]
12. The dimensions of the driven pile are much less that bored pile for the same load and same soil condition. [Table 4.4, 4.5]
13. For the clayey soil, considering all the given inputs, the most economical pile group with minimum cost is square pile cap having four square (driven) piles under it. [Table 4.8]
14. For the clayey soil, considering all the above inputs, the most economical pile group with minimum cost is square pile cap having four rectangular (driven) piles under it. [Table 4.8]

5.3 FUTURE SCOPE OF WORK

1. Prepare the program for the analysis and design of the hexagonal shape pile cap.
2. Analysis and design of the pile group in $C-\phi$ condition.
3. Study the dynamic analysis of single pile and group of piles with different shapes of pile and different soil conditions.
4. Dynamic analysis of pile cap.

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