ANALYSIS AND DESIGN OF A MULTI-STOREY BUILDING AND ITS FOUNDATION

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Submitted in partial fulfillment of the Degree of

Bachelor of Technology

DEPARTMENT OF CIVIL ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,

WAKNAGHAT, SOLAN (H.P.)

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this report, ***"ANALYSIS AND DESIGN OF A MULTI-STOREY BUILDING AND ITS FOUNDATION"*** in partial fulfillment of the requirement for the award of B. Tech. degree, submitted to the department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan, is an authentic record of my own work carried out from January 2011 to December 2011 under the guidance of **Dr. S.K. Jain**, Associate Professor and **Mr. Anil Dhiman,** Senior Lecturer in the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan.

I have not submitted the matter embodied in this report for award of any other degree.

Date: 12 DEC 2011

(Ankit Vaid)

CERTIFICATE

This is to certify that the work entitled, ***"ANALYSIS AND DESIGN OF A MULTI-STOREY BUILDING AND ITS FOUNDATION"*** submitted by ***Ankit Vaid***, in partial fulfillment for the award of degree of Bachelors of Technology in Civil Engineering of Jaypee University of Information Technology has been carried out under our supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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ACKNOWLEDGEMENT

The success of any project depends largely on the encouragement and guidelines of many others. Therefore I take this opportunity to express my sincere gratitude to the people who have been instrumental in the successful completion of the project.

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I take this opportunity to express my sincere gratitude to the Head of Department of Civil Engineering, **Dr. Ashok Gupta** for giving me the opportunity to do project on ***Analysis and Design of Multi-Storey building and its Foundation*** so as to develop my understanding of the subjects.

The successful compilation of final year project depends on the knowledge and attitude inculcated in the total length of the course. So I want to express my sincere gratitude to all the faculties who taught me during the four years of B.Tech.

—Ankit Vaid

List of Abbreviations and Symbols

Symbol	Meaning
DL	Dead load
LL	Live Load
EL	Earthquake load/seismic load
WL	Wind Load
A_{st}	Area of tension reinforcement
f_y	Characteristic strength of steel
f_{ck}	Characteristic compressive strength of concrete
e_x	Eccentricity along X axis
e_z	Eccentricity along Z axis
Q_u	Ultimate load bearing capacity of a pile
Q_{pu}	Point load bearing capacity of a pile at the base
Q_f	Friction load bearing capacity of a pile
A_p	Cross-sectional area of the pile toe in cm^2
γ	Effective unit weight of soil
$N\gamma$ & N_q	Bearing capacity factors depending on the angle of internal friction
R	Depth of fixity
Q_m	Load on the end pile

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PART- A *SUPERSTRUCTURE*

PART – B ***SUBSTRUCTURE***

Chapter 1

OVERVIEW OF STRUCTURAL ELEMENTS

STEEL CONCRETE COMPOSITE BEAMS: RCC beams are cast in cement concrete reinforced with steel bars. Beams take up compressive and add rigidity to the structure.

- Beams generally carry vertical gravitational forces but can also be used to carry horizontal loads (i.e., loads due to an earthquake or wind).
- The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. In Light frame construction the joists rest on the beam.

Beams generally carry vertical gravitational forces but can also be used to carry horizontal loads (i.e., loads due to an earthquake or wind). The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. In light frame construction the joists rest on the beam.

Beams are characterized by their profile (the shape of their cross-section), their length, and their material. In contemporary construction, beams are typically made of steel, reinforced concrete, or wood. One of the most common types of steel beam is the I-beam or wide-flange beam (also known as a "universal beam" or, for stouter sections, a "universal column"). This is commonly used in steel-frame buildings and bridges. Other common beam profiles are the C-channel, the hollow structural section beam, the pipe, and the angle.

STEEL CONCRETE COMPOSITE COLUMNS: A column is a compression member, comprising either a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel and is generally used as a load-bearing member in a composite framed structure.

In a composite column both the steel and concrete would resist the external loading by Interacting together by bond and friction. Supplementary reinforcement in the concrete encasement prevents excessive spilling of concrete both under normal load and fire conditions.

With the use of composite columns along with composite decking and composite beams it is possible to erect high rise structures in an extremely efficient manner.

The ***advantages*** of composite columns are:

- Increased strength for a given cross sectional dimension.
- Increased stiffness, leading to reduced slenderness and increased buckling resistance.
- Good fire resistance in the case of concrete encased columns.
- Corrosion protection in encased columns.

STEEL CONCRETE COMPOSITE SLABS: A **concrete slab** is a common structural element of modern buildings. Horizontal slabs of steel reinforced concrete, typically between 10 and 50 centimeters thick, are most often used to construct floors and ceilings, while thinner slabs are also used for exterior paving.

In high rise buildings and skyscrapers, thinner, pre-cast concrete slabs are slung between the steel frames to form the floors and ceilings on each level.

Reinforcement design of slabs:

- A *one way slab* needs moment resisting reinforcement only in its short-direction. Because, the moment along long axes is so small that it can be neglected. When the ratio of the length of long direction to short direction of a slab is greater than 2 it can be considered as a one way slab.
- A *two way slab* needs moment resisting reinforcement in both directions. If the ratio of the lengths of long and short side is less than one then moment in both directions should be considered in design.

For a suspended slab, there are a number of designs to improve the strength-to-weight ratio. In all cases the top surface remains flat, and the underside is modulated:

- *Corrugated*, usually where the concrete is poured into a corrugated steel tray. This improves strength and prevents the slab bending under its own weight. The corrugations run across the short dimension, from side to side.

- A *ribbed slab*, giving considerable extra strength on one direction.
- A *waffle slab*, giving added strength in both directions.

Slab Construction:

A concrete slab may be prefabricated or in site. Prefabricated concrete slabs are built in a factory and transported to the site, ready to be lowered into place between steel or concrete beams. They may be pre-stressed (in the factory), post-stressed (on site), or unstressed. It is vital that the supporting structure is built to the correct dimensions, or the slabs may not fit.

In situ concrete slabs are built on the building site using formwork - a type of boxing into which the wet concrete is poured. If the slab is to be reinforced, the rebar is positioned within the formwork before the concrete is poured in. Plastic tipped metal, or plastic bar chairs are used to hold the rebar away from the bottom and sides of the form-work, so that when the concrete sets it completely envelops the reinforcement. For a *ground slab*, the form-work may consist only of sidewalls pushed into the ground. For a *suspended slab*, the form-work is shaped like a tray, often supported by a temporary scaffold until the concrete sets.

Chapter 2

LOADS

DEAD LOADS :

Dead Loads are those loads which are considered to act permanently; they are "dead," stationary, and unable to be removed. The self-weight of the structural members normally provides the largest portion of the dead load of a building. This will clearly vary with the actual materials chosen. Permanent non-structural elements such as roofing, flooring, pipes, ducts, interior partition walls, Environmental Control Systems machinery, elevator machinery and all other construction systems within a building must also be included in the calculation of the total dead load. Office equipment or furniture which might be presumed to be permanent in the user's eyes is not part of the dead load calculations. The total dead load on a building is determined by adding together all of the various dead loads of the building's elements.

The unit weights may be taken from IS: 875 (Part 1)/1987 or ascertained from the manufacturer.

IMPOSED FLOOR LOADS :

IS 875 (Part 2)/1987 deals with the imposed loads on roofs, floors, stairs, balconies, etc., for various occupancies.

Live Loads are those loads which are transient and can change in magnitude. They include all items found within a building during its life (people, sofas, pianos, safes, books, cars, computers, machinery or stored materials) as well as external environmental effects such as loads due to the sun, earth or weather. Wind and earthquakes loads are put into the special category of **lateral live loads** due to the severity of their action upon a building and their potential to cause failure.

The magnitudes of live loads are difficult to determine with the same degree of accuracy that is possible with dead loads. The probable maximum value of live loads has been determined by research and is included in national building codes. These are usually a minimum design load per unit area. Building codes also provide for load reductions under certain conditions. As an example, full live loads will most likely not occur on every floor of a multi-story building at the same time. Therefore, the design live load for some of the columns and the foundation can be reduced. Building codes around the world do not concur on the magnitude of the appropriate design live load values. It is critical that the designer take the time to determine the values set down in the local building codes.

EARTHQUAKE LOADS :

An earthquake is a sudden, rapid shaking of the Earth caused by the breaking and shifting of rock beneath the Earth's surface. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface move slowly over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free causing the ground to shake. Most earthquakes occur at the boundaries where the plates meet; however, some earthquakes occur in the middle of plates.

Ground shaking from earthquakes can collapse buildings and bridges; disrupt gas, electric, and phone services; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis). Buildings with foundations resting on unconsolidated landfill and other unstable soil, and trailers and homes not tied to their foundations are at risk because they can be shaken off their mountings during an earthquake. When an earthquake occurs in a populated area, it may cause deaths and injuries and extensive property damage.

The dynamic response of building to earthquake ground motion is the most important cause of earthquake-induced damage to buildings. The damage that a building suffers primarily depends not upon its displacement, but upon acceleration. Whereas displacement is the actual distance the ground and building may move during an earthquake, acceleration is a measure of how quickly they change speed as they move. The conventional approach to earthquake resistant design of buildings depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great to withstand a given level of earthquake-generated force. This is generally accomplished through the selection of an appropriate structural configuration and the carefully detailing of structural members, such as beams and columns, and the connections between them. For working out the earthquake loading on a building frame, the dead load and imposed load and weights are to be lumped at each column top on the basis of contributory areas.

The imposed load is to be reduced as specified in IS: 1893 (Part1)-2002 for seismic load determination.

WIND LOADS :

Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The radiation effects are primarily responsible for convection either upwards or downwards. The wind generally blows horizontal to the ground at high wind speeds. Since vertical components of atmospheric motion are relatively small, the term 'wind' denotes almost exclusively the horizontal wind, vertical winds are always identified as such. The wind speeds are assessed with the aid of anemometers or anemographs which are installed at meteorological observatories at heights generally varying from 10 to 30 metres above ground.

Design Wind Speed (V_z) - The basic wind speed (V_b) for any site shall be obtained from IS 875 Part 3 Fig.1 and shall be modified to include the following effects to get design wind velocity at a height for the chosen structure:

a) Risk level;

b) Terrain roughness, height and size of structure; and

c) Local topography.

It can be mathematically expressed as follows:

$V_z = V_b k_1 k_2 k_3$

Where;

V_z = design wind speed at any height z in m/s;

k_1 = probability factor (risk coefficient)

k_2 = terrain, height and structure size factor

k_3 = topography factor

NOTE - Design wind up to 10m height from mean ground level shall be considered constant.

Chapter 3

MATERIALS

CEMENT :

Ordinary Portland cement conforming to IS 269 - 1976 shall be used along with fly ash after carrying out the design mix from approved consultant.

REINFORCEMENT :

Cold twisted high yield strength deformed bars grade Fe 415 conforming to IS: 1786-1985, or preferably TMT bars of standard manufacturer e.g. TATA Steel, SAIL or equivalent shall be used.

SPECIFICATIONS OF CONCRETE :

The following grades of concrete mix may be adopted or as required for safe design:

(a) For RCC columns: M25

(b) For beams, slabs, staircase etc.: M25

(c) Max. Water cement Ratio: 0.45

(d) Minimum cement content: 300 kg/m3 of concrete.

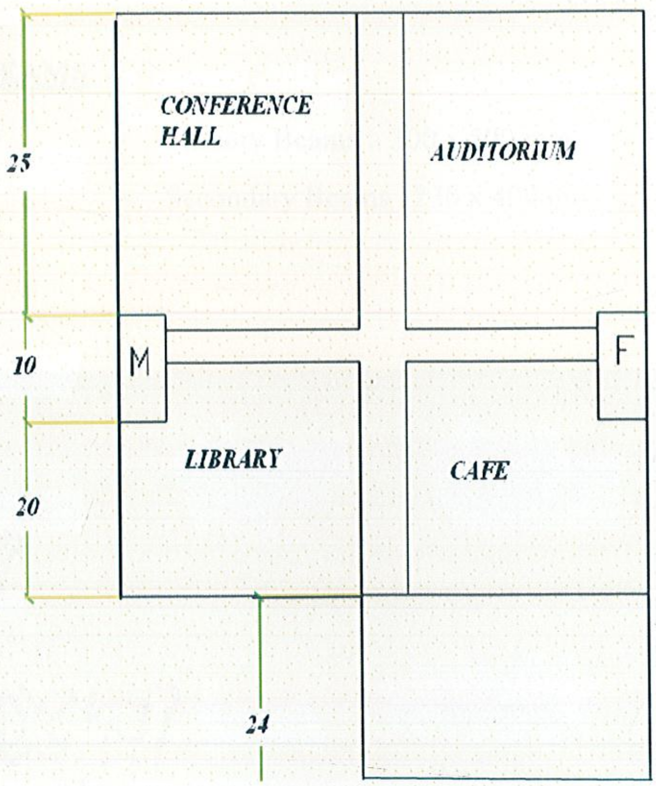
(e) Admixtures of approved brand may be used as per mix design

Chapter 4

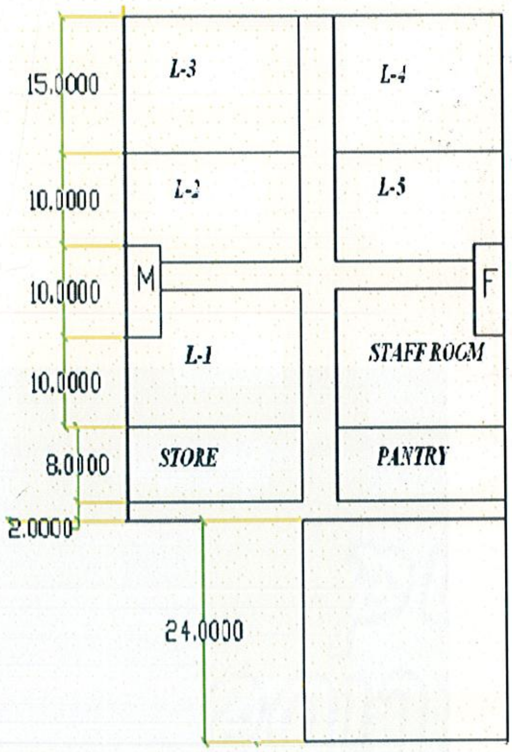
INTRODUCTION TO PROJECT

PLAN OF BUILDING:

Plan of the building has been made using **AUTOCAD.** Proposed building consists of three storeys with top two storeys having computer labs and in first floor we will have auditorium, conference hall, library and cafe.



1st Floor



2nd & 3rd floor

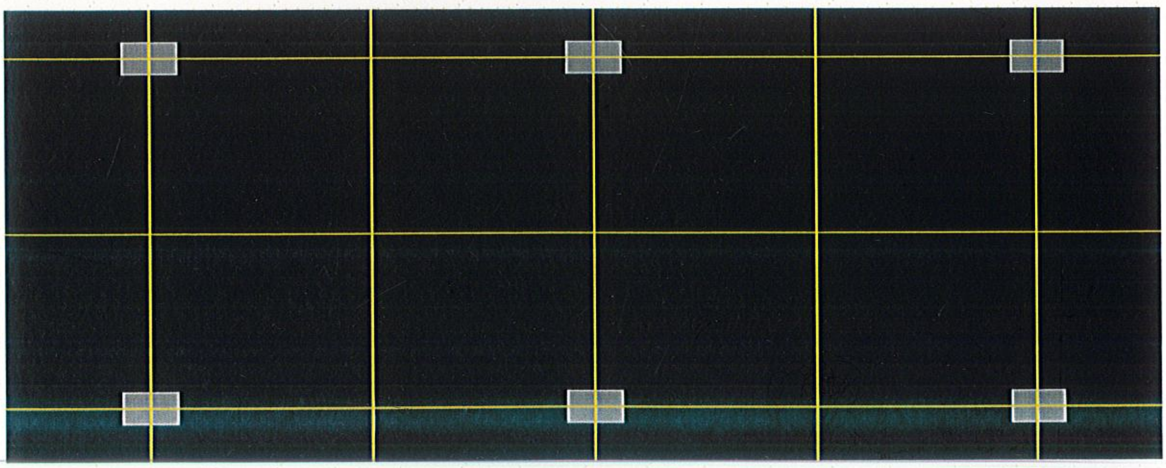
FUNDAMENTAL DATA REGARDING PROJECT:

The material properties, framed section and wall/slab connection.

- Height of the building (3 x 3.5 = 10.5 m)
- Concrete : M25
- Steel : Fe 415
- Primary Beam : 300x500 mm
- Secondary Beam : 230x400 mm
- Column : 450x600 mm
- Slab Thickness : 150 mm

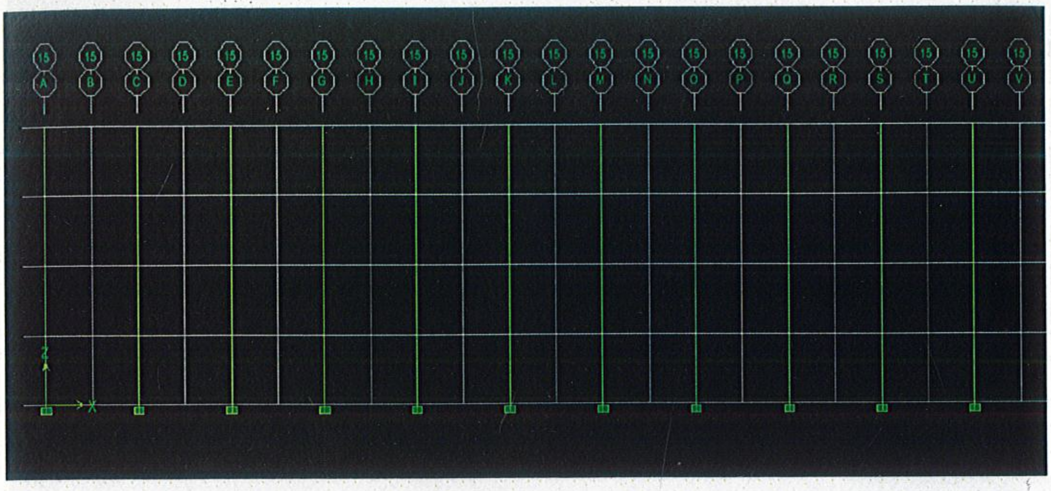
BEAMS

- Primary Beams : 300 x 500 mm
- Secondary Beams : 230 x 400 mm



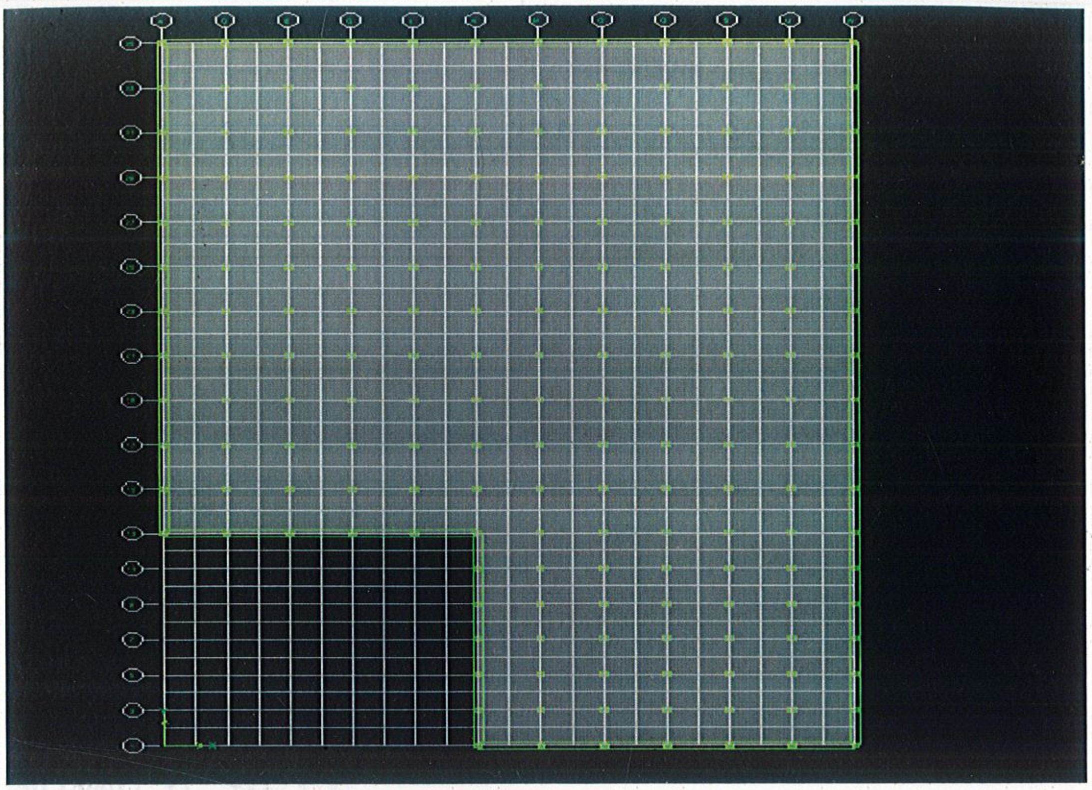
COLUMNS :

- Columns : 450 x 600 mm



SLABS :

- Slabs : 150 mm



LOADING:

- Dead Load
- Live Load
- ELX (Earthquake Load in X direction)
- ELY (Earthquake Load in Y direction)
- WLX (Wind Load in X direction)
- WLY (Wind Load in Y direction)

Dead Load: Dead load of 1.5 kN/m^2 has been provided in gravity direction for the whole structure.

Live load: It is based on IS 875 Part II- 1987. Values are given in the table below:

Live Load Table.

Occupancy Type	UDL (kN/m^2)
Conference Hall	3
Auditorium	4
Library	8.6
Cafeteria	3
Labs	3
Store Room	5
Staff Room	2.5
Corridors/Passage	4
Toilets	2

Earthquake Load :

Seismic Zone Factor 0.24

Soil Type (medium) II

Importance Factor 1.5

Wind Load : $V_z = V_b k_1 k_2 k_3$

$V_b = 47$ m/s (From Fig.1 IS 875 Part III)

$k_1 = 1.07$

Structure Class C (As greatest dimension > 50 m)

Topography 1

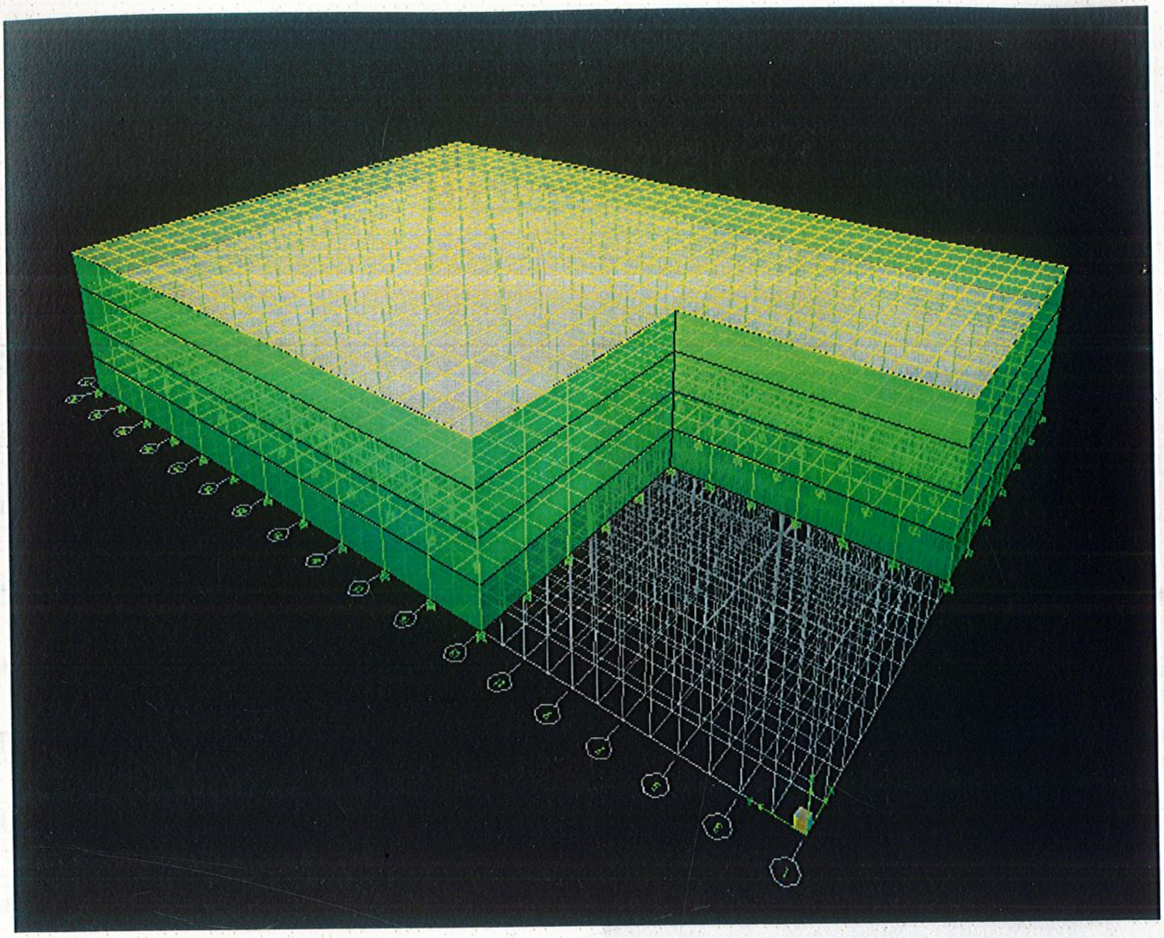
Terrain Category 3

$k_2 = 0.825$

$k_3 = 1$

$V_z = 47 \times 1.07 \times 0.825 \times 1 = 41.24$ m/s

Wind pressure = $0.6 \times V_z^2 = 0.6 \times 41.24^2 = 1020.44$ N/m^2



Chapter 5

MANUAL DESIGN

Design of Columns :

Size of Column = 450 x 600 mm

Grade of Concrete = M25

Grade of Steel = Fe415

Factored Load (P_u) = 858.55 kN

M_{ux} = 152.67 kN-m

M_{uy} = 167.38 kNm

Assume the Reinforcement = 0.85%

$P_u / f_{ck} = 0.048$

Uniaxial Moment Capacity about x-x axis

$d'/D = 0.0625$

$P_u / f_{ck} bd = (858.55 \times 10^3) / (25 \times 450 \times 600)$

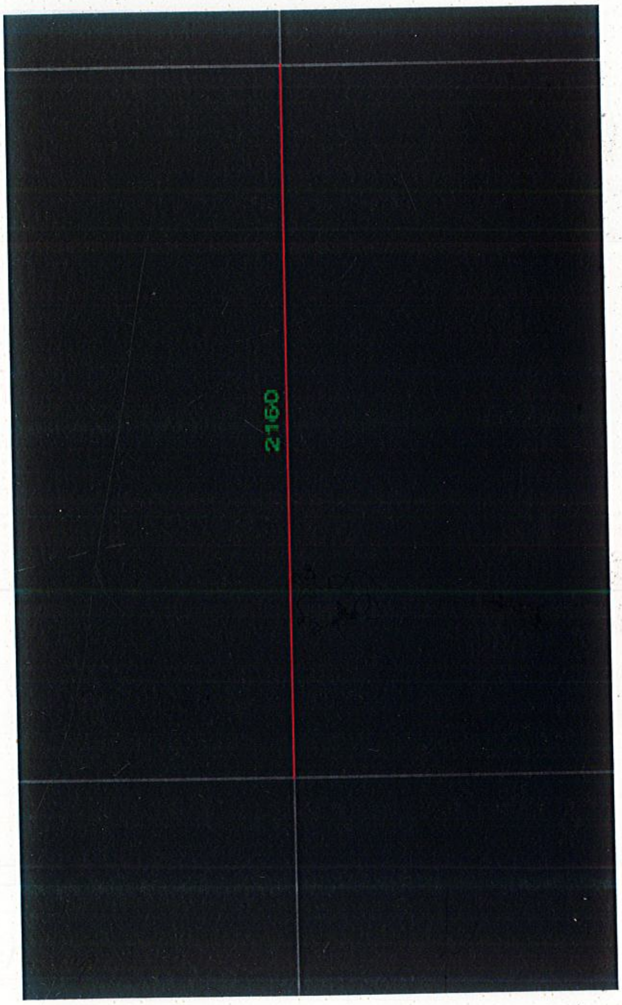
$= 0.0127$

From Chart 44 of SP-16

$M_u / f_{ck} bd^2 = 0.11$

$M_{ux1} = 0.11 \times 24 \times 450 \times 600^2$

$= 445$ kNm



Area of steel in columns given by ETABS

Uniaxial Moment Capacity about y-y axis

$d'/D = 0.83$

From Chart 45 of SP-16

$M_u/ f_{ck} bd^2 = 0.1$

$M_{uy1}= 1 \times 25 \times 600 \times 450^2$

Calculation of P_{uz}

Referring to Chart 63 corresponding to $P = 0.85$, $F_y = 415$, $f_{ck} = 25$;

$P_{uz} / A_g = 16 \text{ N/ mm}^2$

$P_{uz} = 4320 \text{ kN}$

$P_u / P_{uz} = 858.55 / 4320$

$= 0.199$

$M_{ux} / M_{ux1} = 152.67 / 445$

$= 0.419$

$M_{uy} / M_{uy1} = 167.33 / 303$

$= 0.699$

Referring to Chart 64 the permissible value of M_{ux} / M_{ux1} corresponding to the value of M_{uy}/M_{uy1} and P_u/P_{uz}

$M_{ux} / M_{ux1} = 0.43$

Actual Value of $M_{ux} / M_{ux1} = 0.419$

Hence, section is OK.

Design of Beam :

Beam 2856

Size of Beam = 300 x 500 mm

Concrete Mix = M 20

Characteristic strength of Steel = 415 N/mm^2

Design Moment = 170.58 kN-m

Assuming 25 mm bars with 25 mm clear cover.

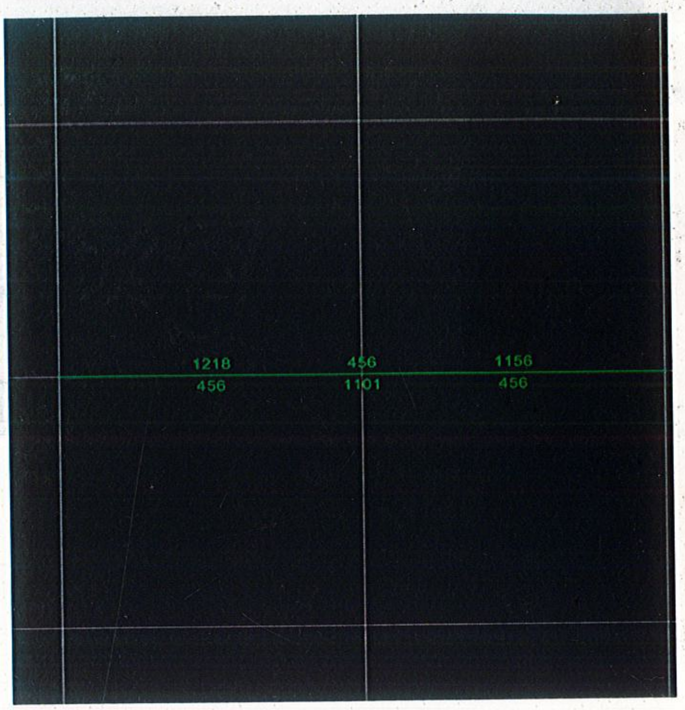
Effective depth (d) = 500 – 25 – (25/2)

= 462.5 mm

For Fe 415 and f_{ck} = 20

$M_{ulim} / bd^2 = 2.76$ N / mm^2

$M_{ulim} = 2.76 \times 0.3 \times 0.4625^2 \times 10^3 = 177.1$ kN-m



Area of steel in Beam 2856 given by ETABS

Moment < M_{ulim}

Section will be singly reinforced rectangular section.

Therefore, $M_u / b = (170 / 0.3) = 567$ kN-m per m width

Referring to Chart 6 of SP16, corresponding to $M_u / b = 567$ kN-m per m width and d = 462.5 mm

Percentage of Steel, $p_t = (100A_s / bd)$

= 0.88

$A_s = 0.88$ bd / 100

= 1221 mm^2

Beam 2461

Size of Beam = 300 x 500 mm

Concrete Mix = M 20

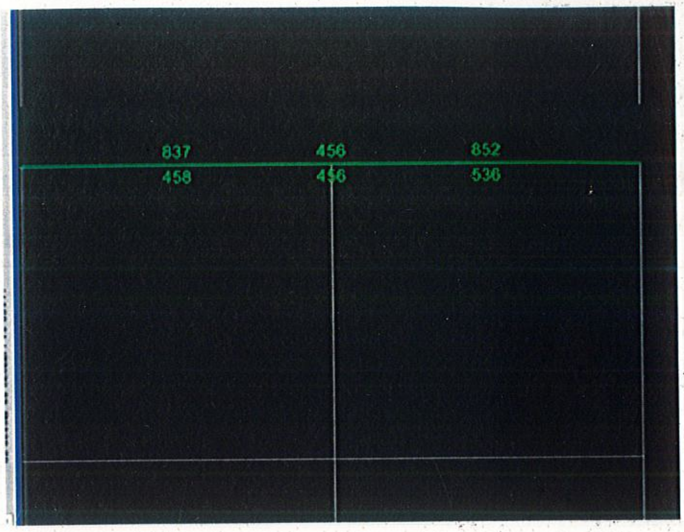
Characteristic strength of Steel = 415 N/mm^2

Design Moment = 125.03 kN-m

Assuming 25 mm bars with 25 mm clear cover.

Effective depth (d) = 500 – 25 – (25/2)

= 462.5 mm



Area of steel in Beam 2461 given by ETABS

For Fe 415 and f_{ck} = 20

$M_{ulim} / bd^2 = 2.76$ N / mm^2

$M_{ulim} = 2.76 \times 0.3 \times 0.4625^2 \times 10^3 = 177.1$ kN-m

Moment < M_{ulim}

Section will be singly reinforced rectangular section.

Therefore, $M_u / b = (125.03 / 0.3) = 416.7$ kN-m per m width

Referring to Chart 6 of SP16, corresponding to M_u/b= 416.7 kN-m per m width and d=462.5 mm

Percentage of Steel, $p_t = (100A_s / bd)$

= 0.6

$A_s = 0.6\ bd / 100$

= 832.5 mm^2

Design of Slab :

$L_x = 5$ m

Cover for mild exposure = 15 mm

Span is large and loading is heavy assume a span depth ratio of 25

d = 5000/ 25 = 200 mm

h = 200 + 5 + 15 =220 mm

Design load :

DL 0.22 x 25 x 1 = 5.5 KN /m^2

LL 8.6 KN/ m^2

Design load 1.5 (DL +LL)

= 1.5 x 8.6 x 5.5

=21.2 KN/ m^2

Max factored moment and check for depth :

$L_y / L_x = (5/5) = 1 < 2$

Hence slab is a two way slab

From Table 26 (IS 456:2000)

$\alpha_x = 0.047$

$\alpha_y = 0.047$

$M_x = \alpha_x W L_x^2$

$= 0.047 \times 21.2 \times 5^2 = 24.91$ KN-m

$M_y = \alpha_y W L_x^2$

= 24.91 KN-m

Check depth for max bending moment

$M_{u\,max}$ =0.138 f_{ck} bd

d = (24.91 x 10^6)/ (0.138 x 25 x 1000)

= 84.97 mm < 200 mm therefore safe

Check for shear:

For L_y / L_x = 1

γ_x in L_y direction = 0.33

γ_y in L_x direction = 0.33

Max design shear = $\gamma_x W L_x$

= 0.33 x 21.2 x 5

= 34.98 KN

τ_v = V/ bd

= (34.98 x 10^3) / (1000 x 199)

=0.176 N / mm^2

τ_c = 0.32 N / mm^2 (from table 19 of IS 456)

$\tau_v < \tau_c$ hence slab is safe in shear

Area of steel:

For steel in short direction

d= 199 mm

M / bd^2 = 24.91 x 10^6 / 1000 x 199^2

= 0.629

Percent of steel (p_t) = 0.18

A_s = 0.18 x 1000 x 199 / 100

= 358.2 mm^2 per m width

Using 12 mm bars with c/c spacing of 280 mm < 3d or 300 mm

Check for deflection:

Basic span depth ratio = 20

p_t = 0.18

F_1 = 1.7 from (IS 456 fig 4)

Allowable L/d ratio = basic x F_1

= 20 x 1.74

=34

Actual L/d = 25.12 < 34

Hence assumed L/d enough to control deflection.

Chapter 6

PILE FOUNDATION

INTRODUCTION :

A shallow foundation is usually provided when the soil at a shallow depth has adequate capacity to support the load of a superstructure. However in situations where the soil at shallow depths is poor, in order to transmit the load safely, the depth of foundation has to be increased till a suitable soil stratum is met. In view of increased depth, such foundations are called *deep foundations* or *pile foundations*.

A pile is a relatively small diameter shaft, which is driven into the ground by suitable means. The piles are usually driven in groups to provide foundation for structures. The pile group may be subjected to vertical loads, horizontal loads or a combination of both.

Pile foundation consists of long, slender, prefabricated structure members driven or inserted into the ground. Engineers use piles both on land and in the sea to support many kinds of structures. Piles are made from variety of materials and in different diameters and length according to the needs of each project.

Pile transfers the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity.

Piles are usually useful in transferring load through poor soil or water to a suitable bearing stratum by means of end bearing. Such piles are called *end bearing piles* or *point bearing piles*. When the piles are installed in soft soils such that the loads are transferred through friction along the length of the piles, they are called *frictional piles*.

When to use Pile Foundation:

Pie foundation is generally used in place of shallow foundation when:-

a) Upper soils are weak, structure loads are high.

b) Upper soils are subjected to scour or undermining.

c) Foundation must penetrate through water.

d) Need large uplift capacity.

e) Need large lateral load capacity.

Purpose of Pile Foundation:

The purpose of pile foundation is to transfer a foundation load to a solid ground and to resist vertical and uplift load acting on the foundation.

A structure can be founded on piles if the soil immediately beneath its basë does not have adequate bearing capacity, if the results of the site investigation show that the shallow soil is unstable and weak or if the estimated settlement is not acceptable, a pile foundation may be considered. Further a cost estimated may indicate that a pile foundation may be cheaper than any other compared ground improvement costs.

In case of heavy construction, it is likely that the bearing capacity of shallow soil will not be satisfactory and the construction should be built on the pile foundation. Piles are convenient method of foundation for works over water, such as jetties or bridge piers.

TYPES OF PILES

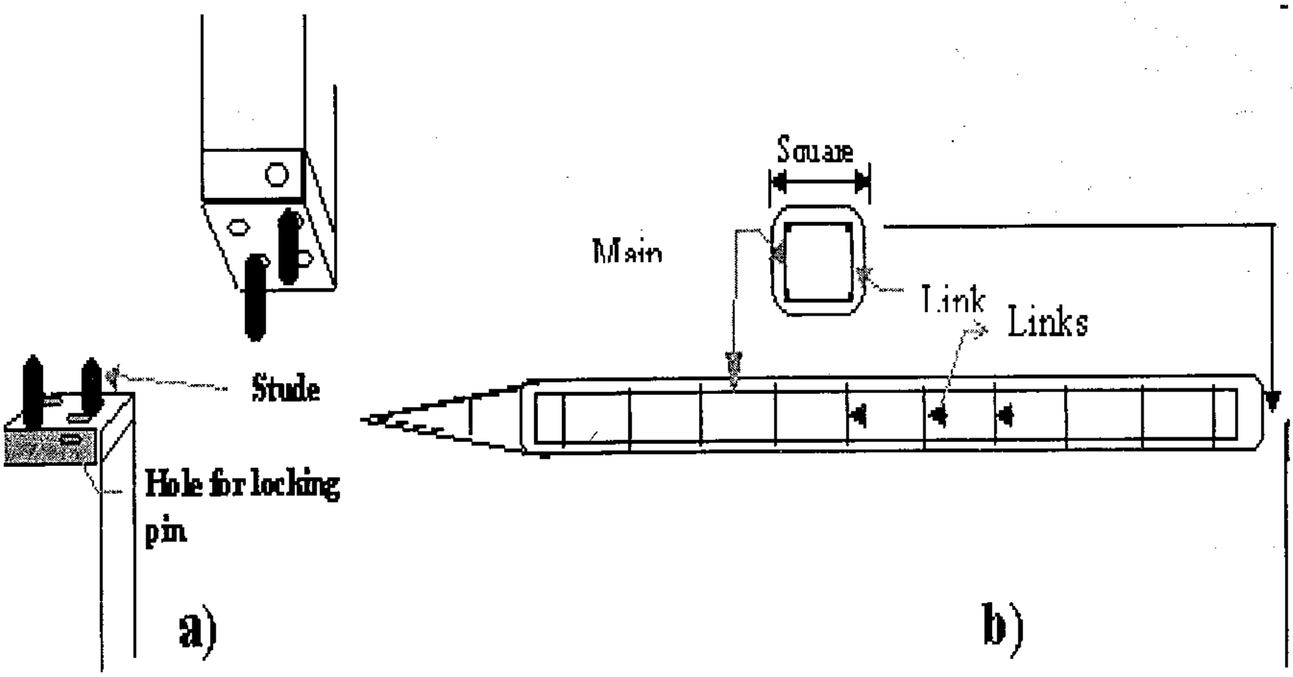
Piles are classified using different criteria. Some of these criteria are:-

- Material of construction: e.g. timber, steel, concrete etc.
- Cross section: e.g. cylindrical, tapered, under reamed etc.
- Shape: e.g. circular, square, hexagonal, I section, H section, pipe etc.
- Mode of load transfer: e.g. bearing, friction, tension etc.
- Method of forming: e.g. precast , prestressed, cast in-situ etc
- Method of installation: e.g. driven, bored, vibrated, jetted etc.

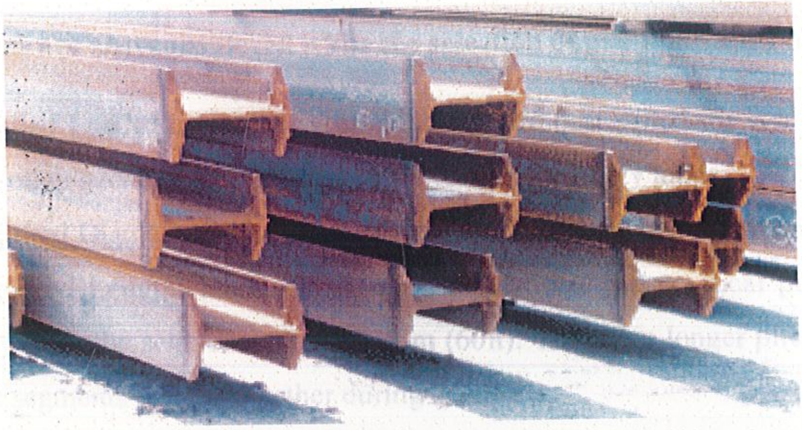
However, the best way of classifying the pile is on the basis of the effect of installation of pile on the soil. Based on this criterion, piles can be considered to fall into two main classes: *displacement piles* and *non displacement piles.*

If during the installation of the pile, a large volume of soil is displaced laterally and upwards, such a pile is called *displacement pile*. Driven and cast-in-place, driven precast or prestressed concrete piles, timber piles etc. are example of displacement piles.

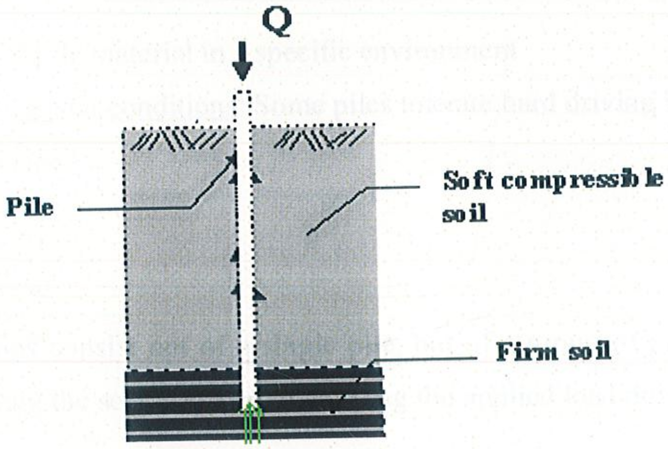
Non displacement piles are those piles whose installation does not lead to any displacement of soil at all. Bored cast in situ and bored precast piles are example of non displacement piles.



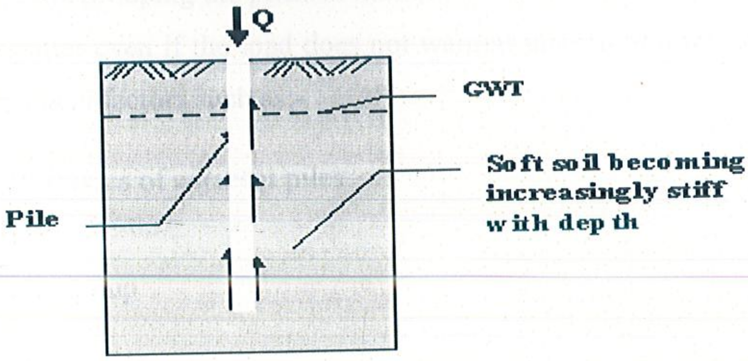
Concrete piles



Steel piles



End Bearing Pile



Friction Pile

Following factors are also considered while the selection of pile types such as:

a) The Applied Load: Some piles, such as timber are best suited for low to medium loads whereas other such as steel, may be cost effective for heavy loads.

b) The Required Diameter: Most pile types are available only in certain diameter.

c) The Required Length: Highway shipping regulations and practical pile driver heights generally limit the segments to about 18m (60ft). Therefore longer piles must consist of multiple segments spliced together during driving.

d) The Local Availability of each pile type: Some pile
Types may be abundant in certain geographical areas whereas other may be scarce. This can significantly affect the cost of each pile type.

e) The durability of pile material in a specific environment

f) The anticipated driven conditions: Some piles tolerate hard driving while others are more likely to be damaged.

Grouping of Piles:

Most of pile foundations consist not of a single pile, but of a group of piles, which act in the double role of reinforcing the soil, and also of carrying the applied load down to deeper, stronger soil strata.

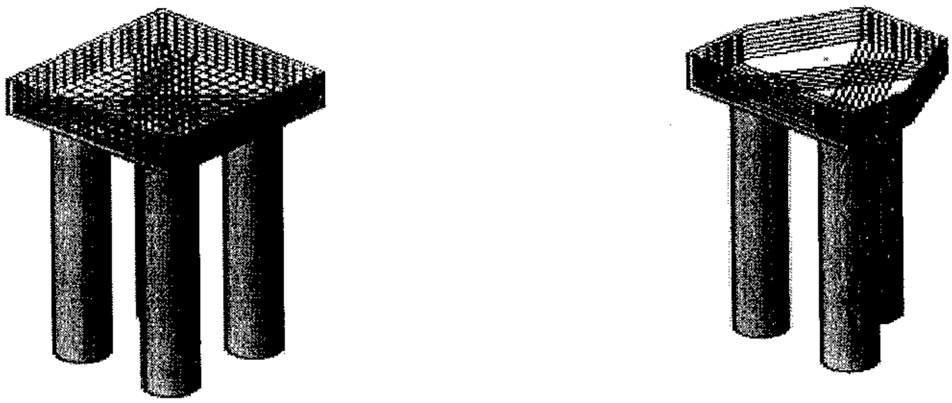
The pile group is often joined at the ground surface by a concrete slab such as pile cap sufficient spacing is providing while grouping the piles. A minimum number of three piles are used under a column of triangular patter even if the load does not warrant the use of three piles. The spacing of piles depends upon many factors such as:-

- Overlapping of stresses of adjacent piles
- Cost of foundation
- Efficiency of pile group
- Type of Soil

PILE CAP

The pile cap distributes the applied load to the individual piles which in turn, transfer the load to the bearing ground.

The stiffness of pile cap will influence the distribution of structural loads to the individual piles. The thickness of pile cap must be at least four times the width of an individual pile to cause a significant influence on the stiffness of the foundation. The individual piles are spaced and connected to the pile cap or tie beams and trimmed in order to connect the pile to the structure at cut-off level



Pile Cap

Chapter 7

PROJECT WORK

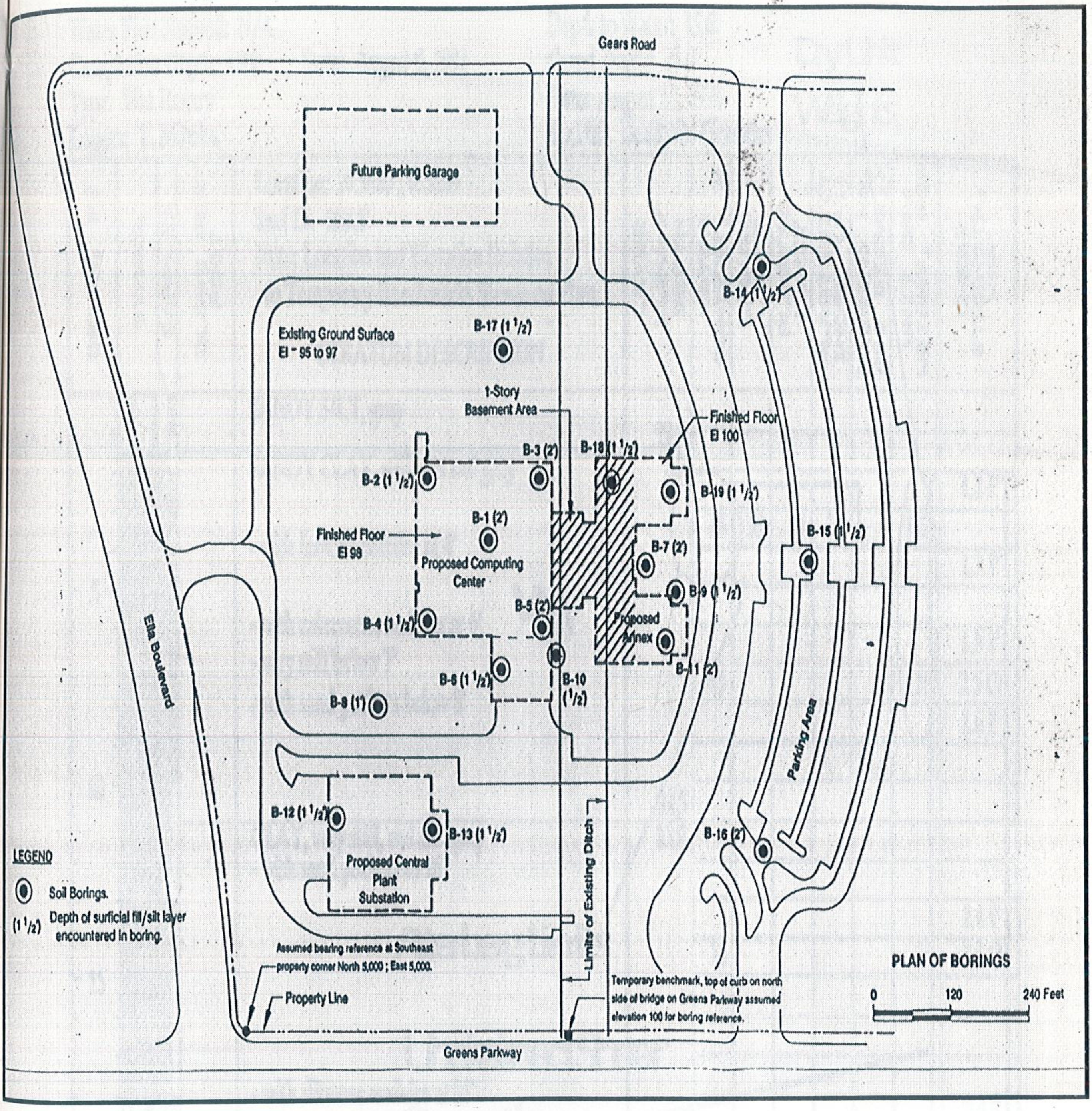
DESIGN SOIL PROFILE :

A design soil profile shows the general site stratigraphy at the site. It identifies each layer, layer boundaries (top and bottom), depth to water table and properties (such as unit weight, shear strengths) for each layer.

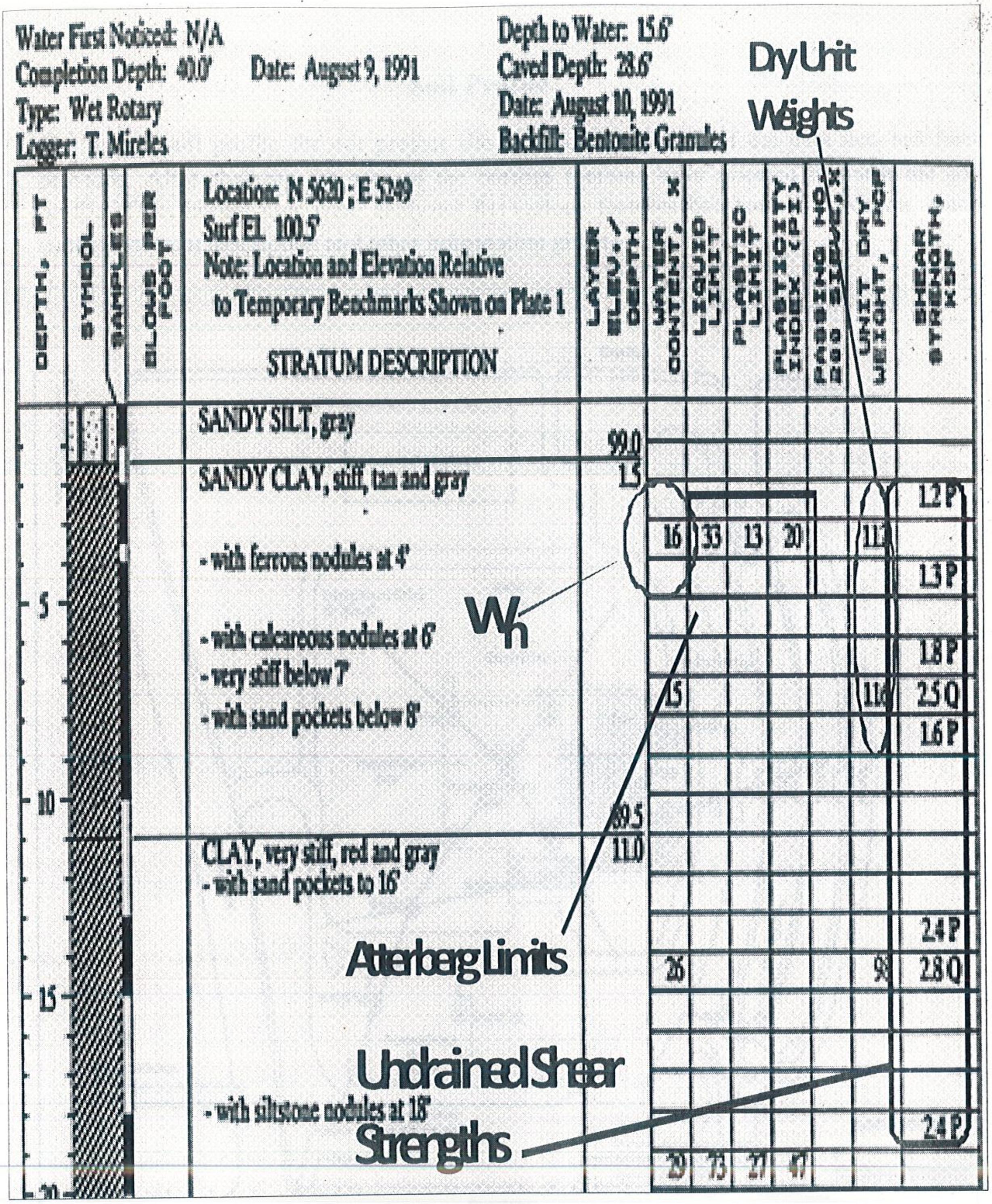
General soil profile has been made from the data provided by geotechnical engineering consultants. They completed a detailed site investigation (geotechnical drilling, sampling and laboratory testing). We have been provided with the data collected during the above site investigation.

Data provided includes:

- Plan of Borings
- Boring logs
- Laboratory Test data: - water content, Atterberg Limits (LL, PL, PI), Undrained shear strength, Consolidation Plots.
- In-situ Test Data (SPT-N)



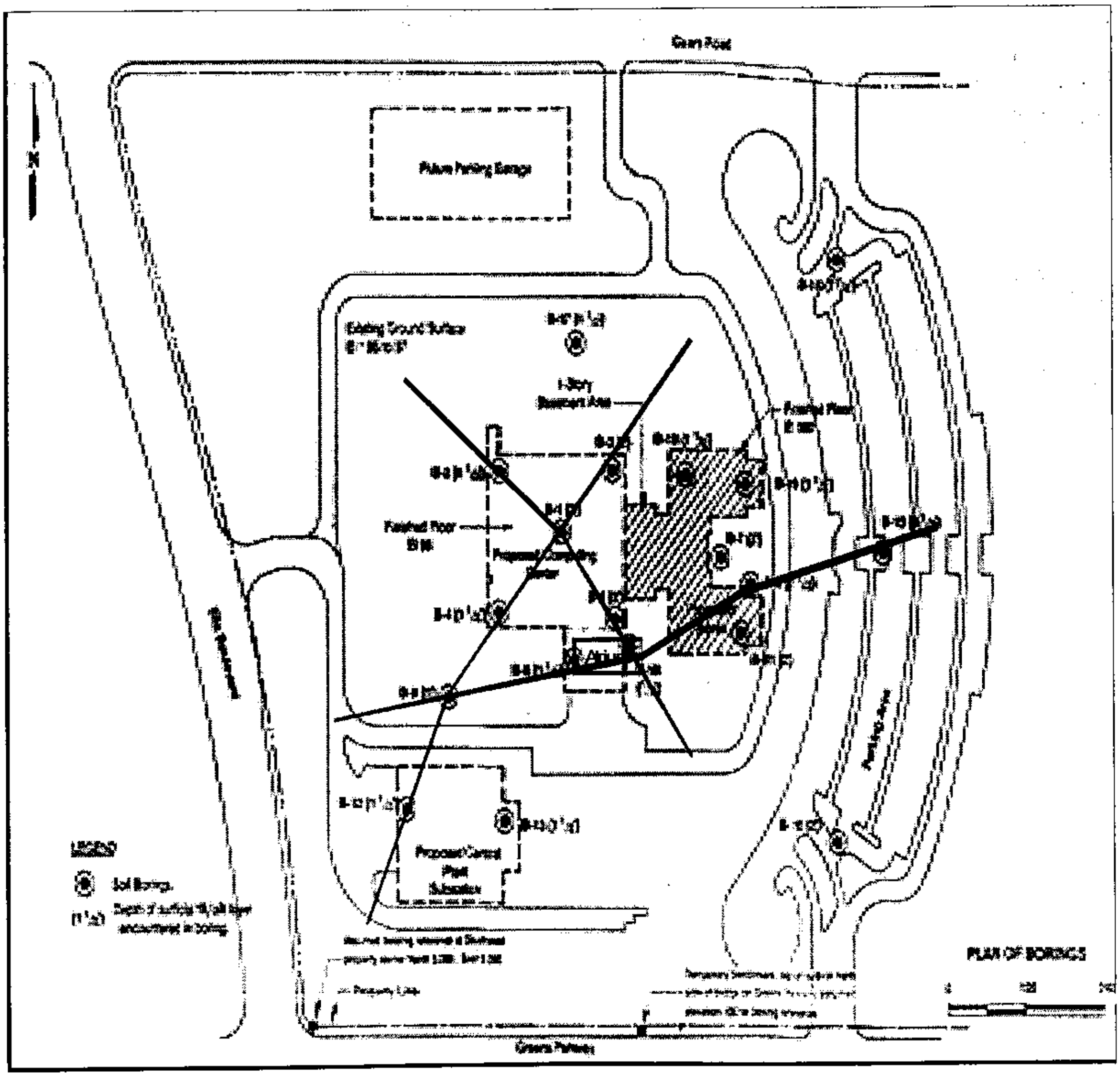
Plan of Borings


Water First Noticed: N/A
Completion Depth: 40.0'
Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles
Depth to Water: 15.6'
Caved Depth: 28.6'
Date: August 10, 1991
Backfill: Bentonite Granules
Dry Unit Weights
DEPTH, FT
SYMBOL
SAMPLES
BLOWS PER FOOT
Location: N 5620 ; E 5249
Surf El. 100.5'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1
STRATUM DESCRIPTION
LAYER ELEV. / DEPTH
WATER CONTENT, %
LIQUID LIMIT
PLASTIC LIMIT
PLASTICITY INDEX (PI)
PASSING NO. 200 SIEVE, %
UNIT DRY WEIGHT, PCF
SHEAR STRENGTH, KSF
SANDY SILT, gray
99.0
SANDY CLAY, stiff, tan and gray
1.5
- with ferrous nodules at 4'
- with calcareous nodules at 6'
- very stiff below 7'
- with sand pockets below 8'
89.5
CLAY, very stiff, red and gray
- with sand pockets to 16'
11.0
- with siltstone nodules at 18'
Wn
Atterberg Limits
Undrained Shear Strengths
5
10
15
1.2 P
16
33
13
20
112
1.3 P
1.8 P
15
116
2.5 Q
1.6 P
2.4 P
26
98
2.8 Q
2.4 P

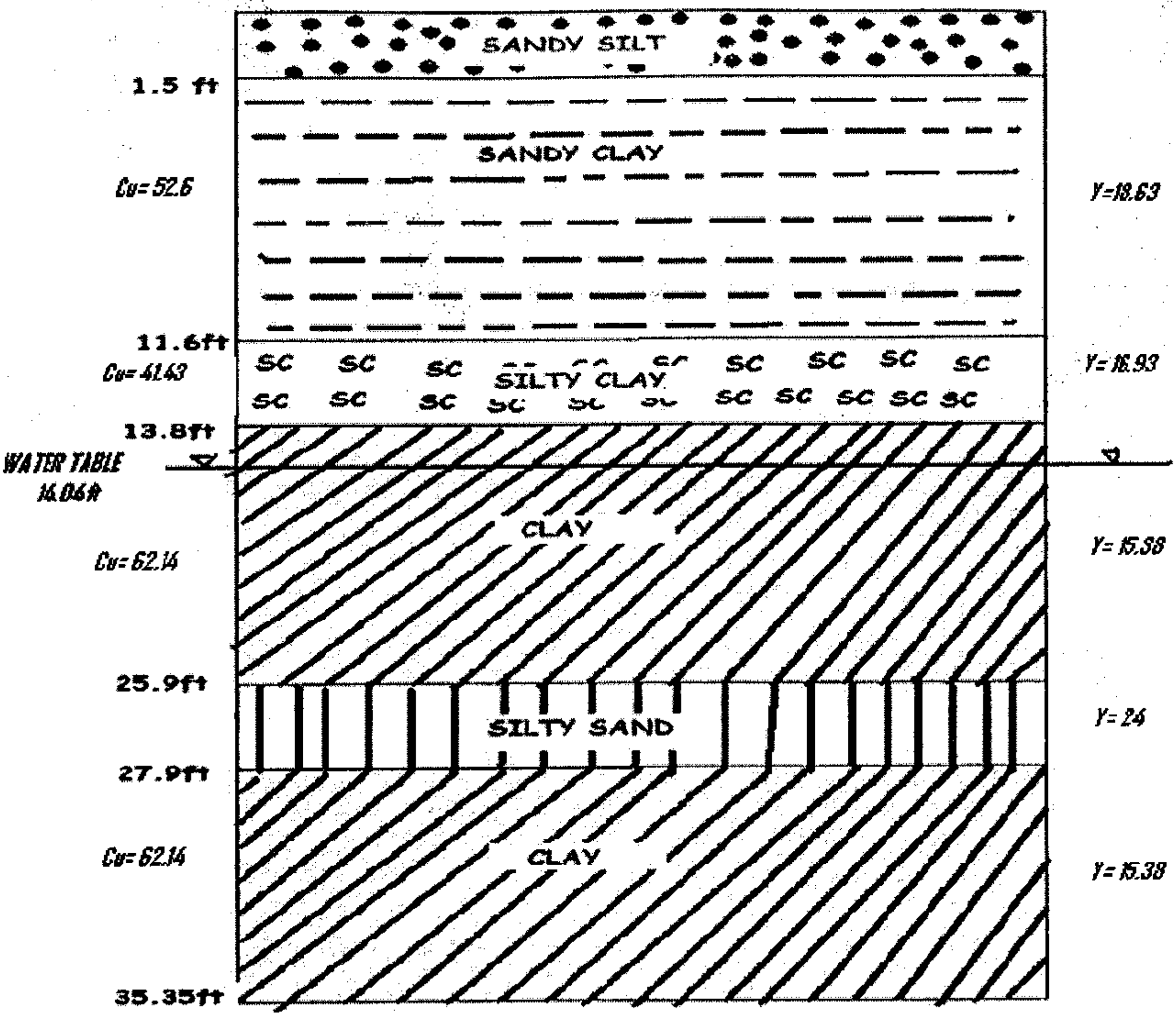
Boring Data

Soil Profile

The design soil profile for our project site is based on review of the data that has been provided. After studying the plan of the borings sections were selected to make the soil profile. Then boring logs were analyzed for various features like surface elevation, water content, stratum description and other information given.



Selected Section



Cu in KN/m²

Y in KN/m³

Final Soil Profile

BEARING CAPACITY :

Bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. *Ultimate bearing capacity* is the theoretical maximum pressure which can be supported without failure; *allowable bearing capacity* is the ultimate bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement.

Bearing capacity of the single pile:

$Q_u = Q_{pu} + Q_f$

$Q_{pu} = \{q\ (N_q\text{-}1) + 0.5\gamma B N_\gamma\}\ Ap$

$Q_f = \sum^{n}_{i=1} K\ \sigma_{av} \tan\delta\ A_{si} + \sum^{n}_{i=1} \alpha C_u A_{si}$

Where,

Q_{pu}= point bearing resistance.

Q_f= ultimate skin friction resistance.

q = effective vertical stress in kN/m^2.

σ_{av} = average effective over burden pressure over the embedded length of pile.

α = adhesion factor.

C_u = cohesion in kN/m^2.

A_p = cross-sectional area of the pile toe in m^2.

γ = effective unit weight of the soil at pile toe in kN/m^3.

N_γ & N_q = bearing capacity factors depending upon the angle of internal friction ø at the toe cap.

$\sum^{n}_{i=1}$ = summation for n layers in which pile is installed.

K = coefficient of earth pressure.

δ = angle of wall friction between the pile & soil, in degrees

A_{si}= surface area of the pile stem in m^2 in the i^{th} layer where i varies from 1 to n.

1. Pile of 250 mm Diameter

D = 250 mm

$q_p = qN_q + 0.5\gamma BN_\gamma$ (value of $0.5\gamma BN_\gamma$ is very small, hence ignored)

$q_p = qN_q$

$q_{pu} = q\,(N_q - 1)$

N_q= 108.75 (for ø = 42)

$q = \sum \gamma D_f = (18.63*3.08) + (6.93*0.67) + (5.38 * 3.68) + (0.5*14)$

$= 96.5 kN/m^2$

q_{pu}= 96.5 (108.75-1)

= 10397.87 kN/m^2

$Q_{pu} = q_{pu} \times A_b$

$= 10397.87 \times (\pi \times 0.25^2) / 4$

= 510.40 kN

$Q_f = \sum^{n}_{i=1} K\, \sigma_{av} \tan\delta\, A_{si} + \sum^{n}_{i=1} \alpha C_u A_{si}$

$\sum^{n}_{i=1}\alpha C_u A_{si}$= (0.5*52.6*π*0.25*3.08) + (0.5*41.43*π*0.25*0.67) + (0.5*62.14*π*0.25*3.68)

$= 164.32$ kN

$K = 1.5$

$\delta = 0.95ø$

$= 39.9$

$A_{si} = \pi*0.25*0.57$

$= 0.448\ m^2$

$\sum^{n}_{i=1} K\ \sigma_{av} \tan\delta\ A_{si} = 1.5*(\tan 39.9)*92.5*0.448$

$= 51.97$ kN

$Q_f = 216.29$ kN

$Q_u = Q_{pu} + Q_f$

$= 510.40 + 216.29$

$= 726.69$ kN

$Q_{safe} = 726.69 /3$

$= 242.23$ kN

2. Pile of 300 mm Diameter

D = 300 mm

$q_p = qN_q + 0.5\gamma BN_\gamma$ (value of $0.5\gamma BN_\gamma$ is very small, hence ignored)

$q_p = qN_q$

$q_{pu} = q\ (N_q - 1)$

$N_q = 108.75$ (for ø = 42)

$q = \sum \gamma D_f = (18.63*3.08) + (6.93*0.67) + (5.38 * 3.68) + (0.5*14)$

$= 96.5 kN/m^2$

$q_{pu} = 96.5\ (108.75-1)$

$= 10397.87\ kN/m^2$

$Q_{pu} = q_{pu} \times A_b$

$= 10397.87 \times (\pi \times 0.3^2) / 4$

$= 734.9 kN$

$Q_f = \sum_{i=1}^{n} K\ \sigma_{av} \tan\delta\ A_{si} + \sum_{i=1}^{n} \alpha C_u A_{si}$

$\sum_{i=1}^{n} \alpha C_u A_{si} = (0.5*52.6*\pi*0.3*3.08) + (0.5*41.43*\pi*0.3*0.67) + (0.5*62.14*\pi*0.3*3.68)$

$= 197.19 kN$

$K = 1.5$

$\delta = 0.95ø$

$= 39.9$

$A_{si} = \pi*0.3*0.57$

$= 0.54\ m^2$

$\sum_{i=1}^{n} K\ \sigma_{av} \tan\delta\ A_{si} = 1.5*(\tan 39.9)*92.5*0.54$

$= 62.68\ kN$

$Q_f = 259.84\ kN$

$Q_u = Q_{pu} + Q_f$

$= 734.9 + 259.84$

$= 994.74\ kN$

$Q_{safe} = 994.74/3$

$= 331.58\ kN$

Loading of piles under horizontal loads:

Load on the pile group = 2025.95 kN

Moment in x direction = -166.206 kNm

Moment in y direction = -190.64 kNm

Total number of piles = 9

The axial load in any pile m, at a distance x & y from the centroid with eccentricity e_x & e_y is given by:

$$Q_m = Q_g/N \pm (Q_g.e_x)\, x / \sum x^2 \pm (Q_g.e_y)\, y/\sum y^2$$

$= 225.11 - 23.54 - 20.53$

$= 181.04$ kN < 242.23 kN (hence the pile(250 mm) is safe)

$= 181.04$ kN < 331.58 kN (hence the pile(300 mm) is safe)

Deflection in piles:

1. Pile of 250 mm Diameter

$E = 20*10^6 / 98.1$ kg/cm^2

$I = 1.917*10^4$ cm^4

UCS= 2.35kg/cm^2

$K_2 = 97.75$ kg/cm^2

$R = (EI/K_2)^{1/4}$

$= 79.51$ cm

$L_1 = 0$

$L_1/R = 0$

$L_f/R = 2$

$L_f = 159.02$ cm

Length of Fixity = $L_1 + L_f$

Calculation for deflection

$Y = Q (L_1 + L_f)^3 / 12 EI$

Q = the horizontal load acting on the pile. = 85.48 kN

$Y = (8548 \times 159.02^3) / (12 \times 3908256881)$

= 0.732 cm

= 7.32 mm

2. Pile of 300 mm of Diameter

$E = 20 * 10^6 / 98.1$ kg/cm^2

$I = 3.97 * 10^4$ cm^4

UCS= 2.35kg/cm^2

$K_2 = 97.75$ kg/cm^2

$R = (EI/K_2)^{1/4}$

= 95.39 cm

$L_1/R = 0$

$L_f/R = 2$

$L_f = 190.78$ cm

Length of Fixity = $L_1 + L_f$

Calculation for deflection

$Y = Q (L_1 + L_f)^3/12 EI$

Q = the horizontal load acting on the pile. = 85.48 kN

$Y = (8548 \times 190.78^3) / (12 \times 8093781855)$

= 0.611 cm

= 6.11 mm

PILE CAP

Spacing of piles(250mm) = 1.375 m

Spacing of piles(300mm) = 1.35 m

Depth of pile cap = 0.6 m

Dimension = 3x3 m

Reinforcement detailing in pile

- A reinforced pile is designed as a column, considering it fixed at one end and hinged at other end, the effective length of the pile is taken as 2/3rd the length embedded in the soil.
- The longitudinal reinforcement in a pile usually varies from 1.25% to 2% of the gross sectional area of the pile, depending on its length.
- For a length 30 times the least width of the pile, the longitudinal steel is usually 1.25% and the longitudinal steel is increased to 2% for a length above 40 times the least width of the pile.
- Lateral R/C with at least 5mm diameter bars have to be provided in the form of links, and the amount should not be less than 0.2% of the gross volume of the pile and the centre to centre spacing should not exceed half the least width of the pile.
- At ends of the pile for a distance of three times the least lateral dimension, lateral reinforcement should not be less than 0.60% of the gross volume.

- For piles penetrating hard soil, lateral reinforcement at the top of the pile for a distance of three times the width should be in the form of helix.
- The cover to reinforcement including binding wire shall not be less than 40mm and for piles exposed to seawater or other corrosive content this has to be increased to 50mm.

Reinforcement detailing in pile(250mm)

Pile depth = 8m

Diameter of pile = 250 mm

L/D = 32>12 (the pile behaves as long column)

Reduction coeff. $C_r = 1.25 - L_{ef}/48D = 0.53$

Design load for column $P_u = 1.5 \times 181.04 / 0.53 = 512.38$ kN

Load carrying capacity of the column is given by:

$$P_u = 0.4\, f_{ck} A_g + (0.67\, f_y - 0.4\, f_{ck})\, A_{sc}$$

$$512 \times 10^3 = 0.4 \times 30\, (\pi \times 125^2) + (0.67 \times 415 - 0.4 \times 30)\, Asc$$

$$A_{sc} = 289.6 \text{ mm}^2$$

Min. r/f = 1.5% of cross section area of the pile = $(1.5/100)^* \pi r^2$

$= 736.31 \text{ mm}^2$

Hence we provide 4 bars of 16 mm dia in circular arrangement

$A_{sc,\ actual} = 804.25 \text{ mm}^2$

Lateral r/f in the body of the pile :

It should be provided in the form of links of not less than 5mm dia. wires, taking 40 mm cover.

Adopting 8mm dia bars

Diameter of the lateral bar required = (250-80-8) = 162 mm

Hence volume of the bar = 25582.01 mm^3

Volume of r/f needed per mm length = $(0.2 \times 3.14 \times 125^2)/100$

$= 98.125\ mm^3$

Pitch = 260.71 mm

Max. permissible pitch = 0.5 x 250 = 125 mm

Hence provide 8mm dia. bars at 125mm c/c throughout the length of the pile.

Lateral r/f near the pile head:

Special r/f to be provided for a length of = 3 x 250 = 750 mm

Volume of r/f per mm length = $0.6 \times 3.14 \times 125^2/100$

$=294.375 mm^3$

Adopting 8mm dia. spiral pitch = $\pi \times 162 \times \pi \times 4^2 / 424 = 86.9$ mm

Hence provide 8 mm dia. spiral at 80 mm pitch at the top of the pile for a length of 900 mm

Lateral r/f at the pile end:

Volume of ties per mm length @ 0.6% gross volume = 294.375 mm^3

Volume of tie = 25582.01 mm^3

Pitch = 33478 / 424 = 86.9 mm

Hence provide 8mm dia. ties @ 80mm c/c at the bottom of pile for depth of 900 mm.

Reinforcement detailing in pile(300mm)

Pile depth = 8m

Diameter of pile = 300mm

L/D = 26.7>12 (the pile behaves as long column)

Reduction coeff. $C_r = 1.25 - L_{ef}/48D = 0.65$

Design load for column $P_u = 1.5 \times 181.04 / 0.65 = 418$ kN

Load carrying capacity of the column is given by:

$P_u = 0.4\ f_{ck}A_g + (0.67\ f_y - 0.4\ f_{ck})\ A_{sc}$

$418 \times 10^3 = 0.4 \times 30\ (\pi \times 150^2) + (0.67 \times 415 - 0.4 \times 30)$ Asc

$A_{sc} = 1617.102\ mm^2$

Min. r/f = 1.5% of cross section area of the pile = $(1.5/100)^* \pi r^2$

$= 1060\ mm^2$

Hence we provide 8 bars of 16 mm dia in circular arrangement

$A_{sc,\ actual} = 1608.5\ mm^2$

Lateral r/f in the body of the pile :

It should be provided in the form of links of not less than 5mm dia. wires, taking 40 mm cover.

Adopting 8mm dia bars

Diameter of the lateral bar required = (300-80-8) = 212 mm

Hence volume of the bar = 33478 mm^3

Volume of r/f needed per mm length = $(0.2 \times 3.14 \times 150^2)/100$

$=141.3\ mm^3$

Pitch = 237 mm

Max. permissible pitch = 0.5 x 300 = 150 mm

Hence provide 8mm dia. bars at 150mm c/c throughout the length of the pile.

Lateral r/f near the pile head:

Special r/f to be provided for a length of = 3 x 300 = 900 mm

Volume of r/f per mm length = $0.6 \times 3.14 \times 150^2/100$

$=424 mm^3$

Adopting 8mm dia. spiral pitch = $\pi \times 212 \times \pi \times 4^2 / 424 = 79$ mm

Hence provide 8 mm dia. spiral at 75 mm pitch at the top of the pile for a length of 900 mm

Lateral r/f at the pile end:

Volume of ties per mm length @ 0.6% gross volume = 424 mm^3

Volume of tie = 33478 mm^3

Pitch = 33478 / 424 = 79 mm

Hence provide 8mm dia. ties @ 75mm c/c at the bottom of pile for depth of 900 mm.

Design of pile cap:

Design for moment

$M_{umax} = (P_{ua1} + P_{ua2})(S - b/2)$

$P_{ua1} = 1.5$ ((Column load P + self wt of pile cap) / No. of piles + $M_{uy}X/\sum X^2$)

$= 1.5\ [(2025.95 + 103.5)/9 + (-190.64\times 1.35)/(2 \times 3 \times 1.35^2)]$

= 319.67 kN-m

P_{ua2} = 390.21 kN-m

P_{ua3} = 354.9 kN-m

M_{umax} = 1065 kN-m

$$A_{st} = (0.5 fck / f_y)\left[1-\sqrt{1-(4.6 M_{ux} / (f_{ck} b d^2)}\right] bd$$

$= (0.5\times25/415)[1-\sqrt{(1-(4.6\times1065)/25\times600\times600^2)}]\ 600 \times 600$

$= 7540\ mm^2$

$< 0.85Bd/f_y$

$< 3686.74\ mm^2$

$A_{st} = 7540\ mm^2$

Providing 26# 20 mm Dia bars ($A_{st\,(actual)} = 8168\ mm^2$) at bottom in both directions

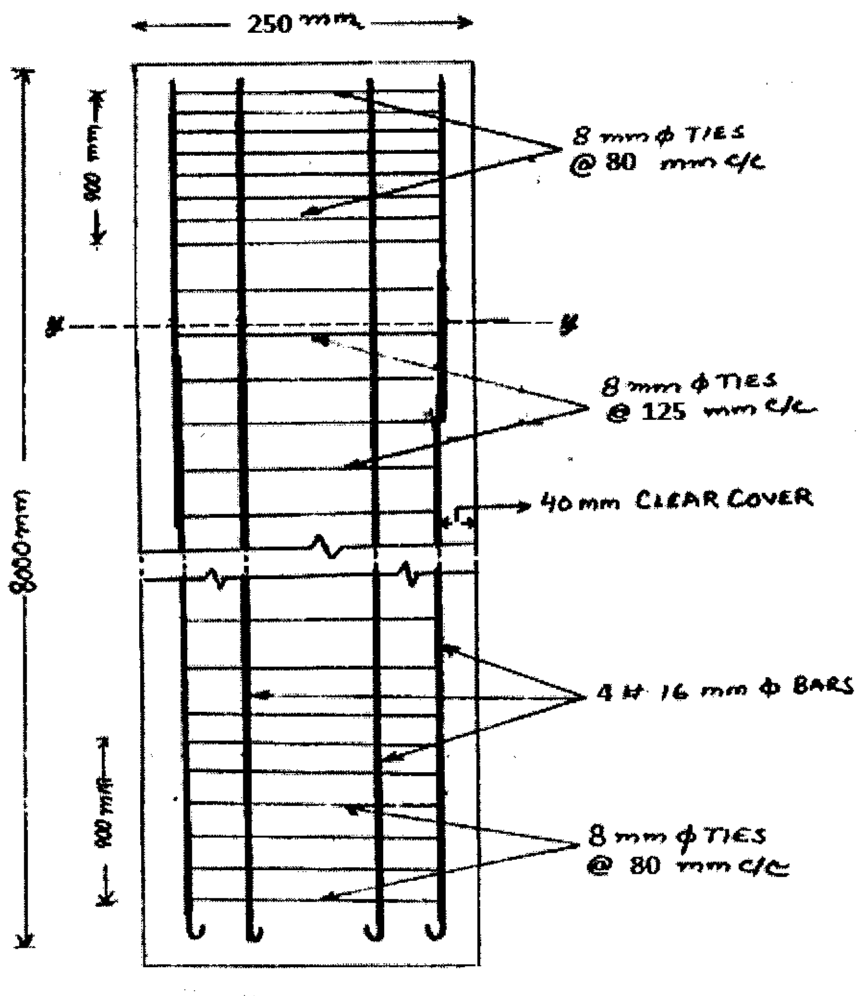
Nominal reinforcement of 13 # 10 mm Ø bars.

REINFORCEMENT DETAILING AND DRAWINGS

Reinforcement detailing of piles(250mm) :

Grade of concrete M-25

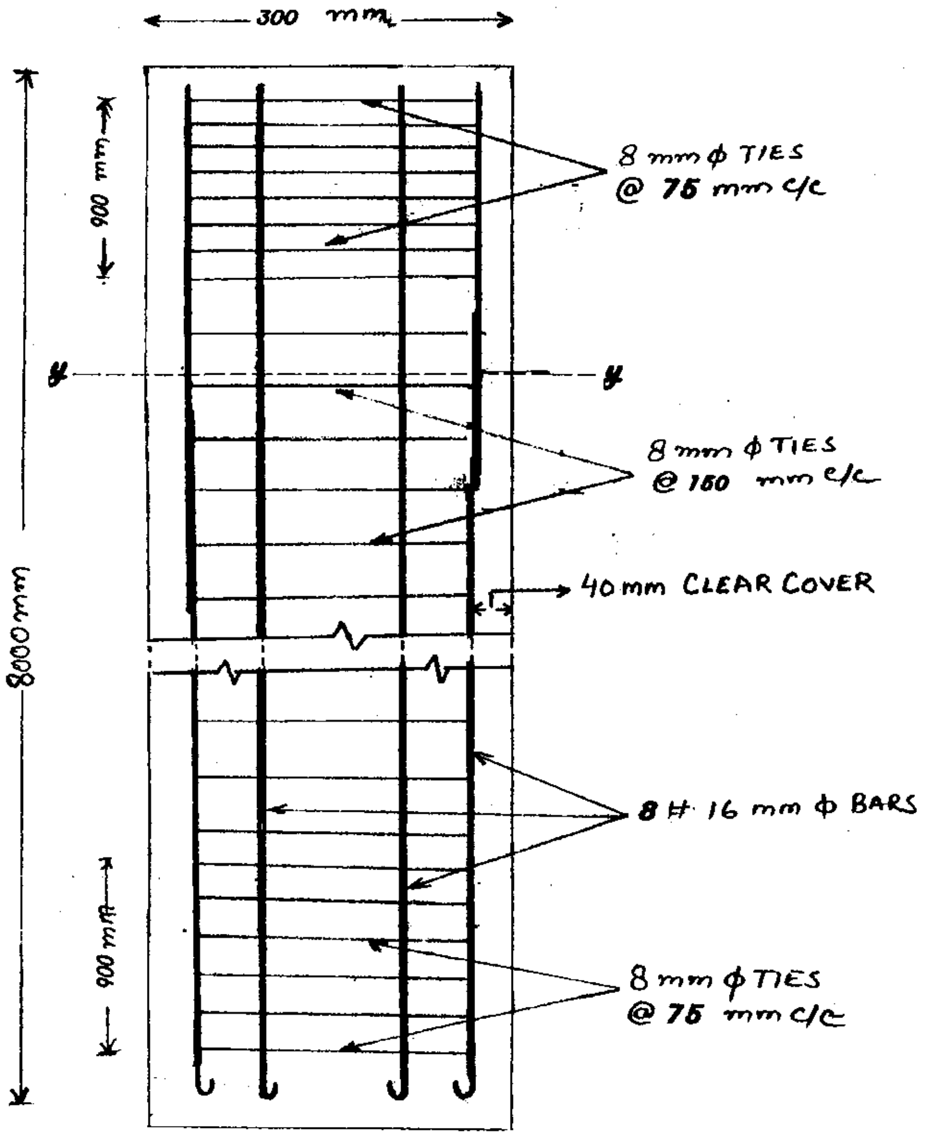
Grade of steel Fe-415



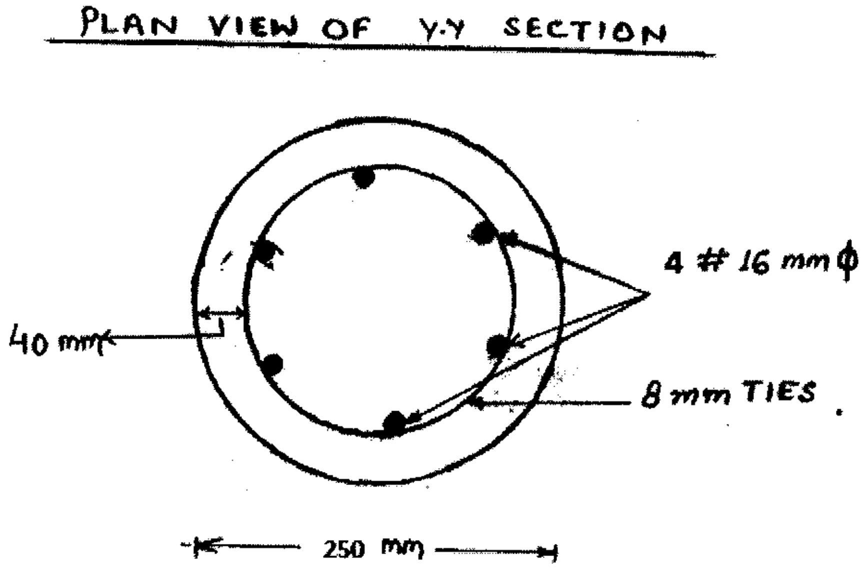
Reinforcement detailing of piles(300mm) :

Grade of concrete M-25

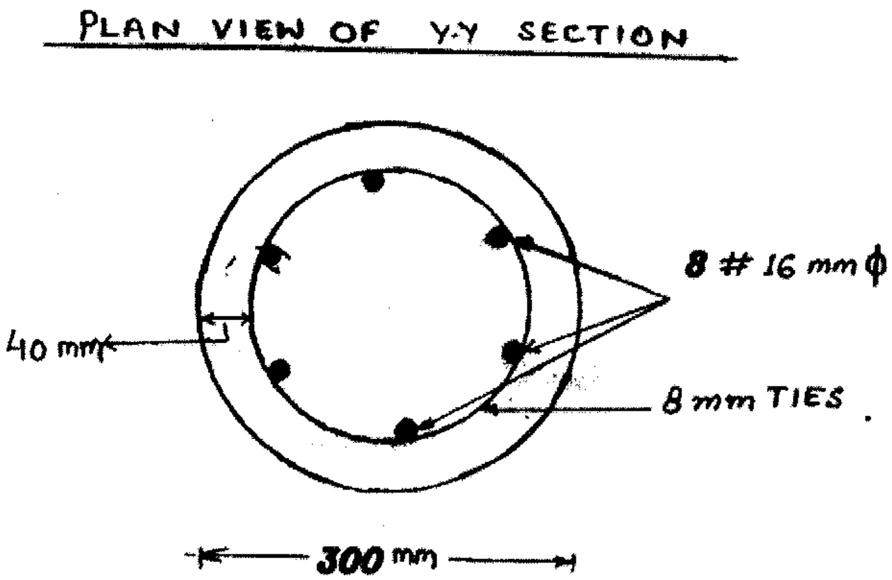
Grade of steel Fe-415



Plan view of pile(250mm) detailing :



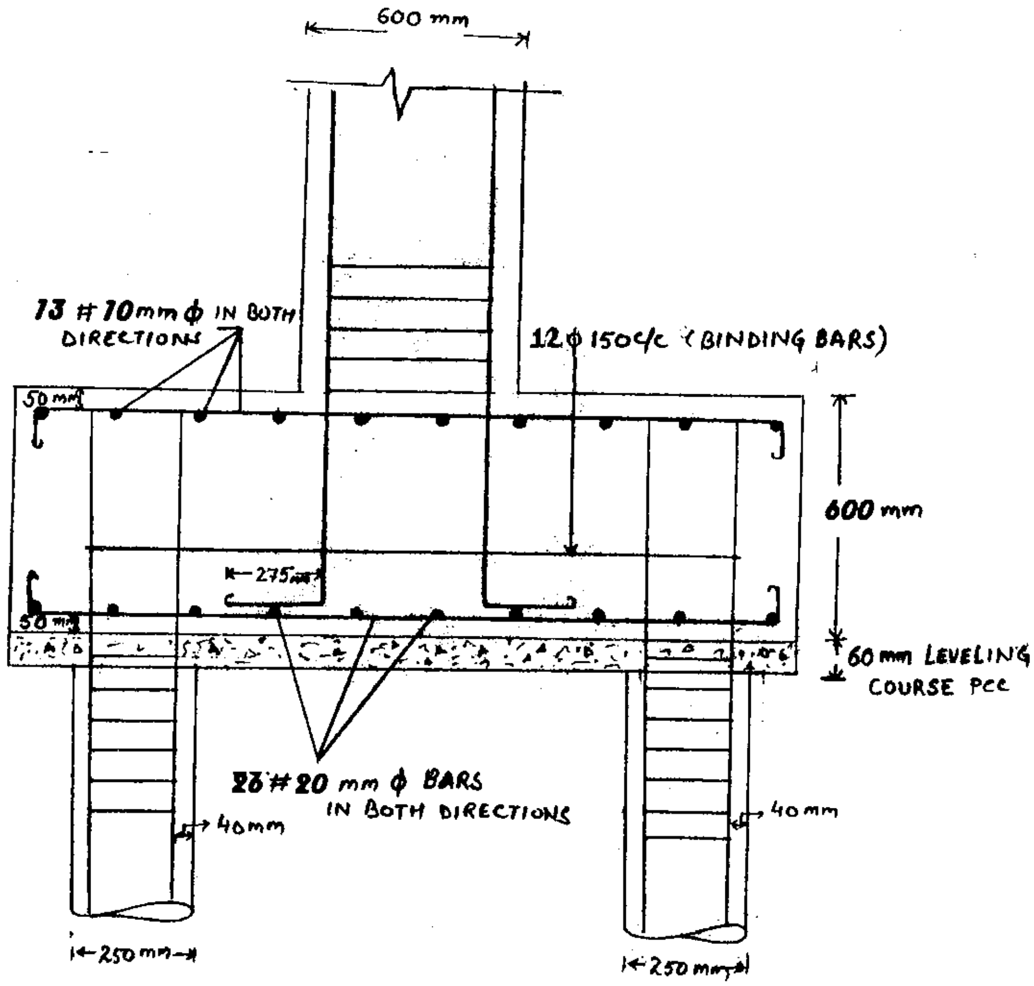
Plan view of pile(300mm) detailing :



Grade of concrete M-25

Grade of steel Fe-415

Reinforcement detailing of pile cap :



Plan of pile cap detailing :