Design of a Multi Storeyed Building and its Pile Foundation

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Bachelor of Technology

DEPARTMENT OF CIVIL ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT

CANDIDATE'S DECLARATION

I hereby declare that the work presented in the project entitled "**Design of a multi storeyed building and its pile foundation"** submitted towards the completion of project in eighth semester at **Jaypee University of Information Technology, Waknaghat**, is an authentic record of my original work carried out under the guidance of Dr. S.K.JAIN, Associate Professor, **Jaypee University of Information Technology.**

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

Signature:

Name: Paras Girdher

Roll no. : 101614

Place: Waknaghat

Date:

CERTIFICATE

This is to certify that the work titled "**Design of a multi storeyed building and its pile foundation**" submitted by **Paras Girdher** in partial fulfillment for the award of degree of B.Tech Civil Engineering of **Jaypee University of Information Technology, Waknaghat** has been carried out under my 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.

Signature of Supervisor…………….………. Signature of Supervisor …..……………..

Name of Supervisor …………………….. Name of Supervisor ……………………..

Designation …………………….. Designation ……………………..

Date …………………….. Date ……………………..

Signature of Head of Department ………………………...

Name of Head of Department ………………………..

Designation ………………………..

Date ………………………..

ACKNOWLEDGEMENT

I express sincere gratitude to **Dr. S.K. JAIN** and **Mr. LAV SINGH** (Assistant Professor), **Department of Civil Engineering** , **Jaypee University of Information Technology, Waknaghat** under whose supervision and guidance this work has been carried out .His whole hearted involvement, advice, guidance, support and constant encouragement throughout, have been responsible for carrying out this project work with confidence . I am really thankful to him for showing confidence in me to take up this project. It was due to his planning and guidance that I am able to complete this project in time.

I am sincerely grateful to **Dr. ASHOK KUMAR GUPTA**, Professor and **Head of Department of Civil Engineering**, **Jaypee University of Information Technology, Waknaghat** for providing all the necessities for the successful completion of my project.

Signature of the student ……………………..

Name of Student ……………………..

Date ……………………..

LIST OF ABBREVIATION AND SYMBOLS

A_b = c/s area of pile.

A_s = surface area of pile.

A_c = area of compressive steel

A_{sc} = area of longitudinal steel

C_u = undrained cohesion.

C_r = reduction factor.

D_p = diameter of pile.

E = efficiency of pile.

F_s = skin friction.

F_{ck} = characteristic compressive stress.

F_y = characteristic strength of steel.

K = coefficient of earth pressure.

K_1 = probability factor.

K_2 = terrain height and size factor.

K_3 = topography factor.

N_c = bearing capacity factor.

N_q = bearing capacity factor depends on angle of internal friction.

P_u = Ultimate load.

Q_u = ultimate bearing capacity.

Q_{pu} = ultimate end bearing resistance.

Q_f = ultimate skin friction.

q_{pu} = point bearing resistance.

q = effective vertical stress.

V_z = design wind speed at any height z in m/sec.

V_b = basic wind speed.

ϒ = unit weight of soil.

α = adhesion factor.

Ø = angle of internal friction.

∂ = angle of wall friction between the pile and soil, in degrees.

INDEX

CHAPTER 1

INTRODUCTION

For a civil engineer or civil engineering student, designing building may be his cup of tea but often problems occur when the same engineer has to deal with the geological part that is designing of foundation of the same building. Such problems mainly occur because in colleges, even though all the aspects of civil engineering such as building bridges, constructing buildings, making highways, designing foundation etc. are taught, students tend to incline towards one particular course. Moreover students take particular electives which they think they might excel in. There is nothing wrong in doing so but students tend to face difficulties later when expertise in one course is not enough. Our project is such a work in which we not only design a building but also its foundation using the loads computed that is knowledge of more than one subject is incorporated in our project.

Yet our project is a very simple one that is to build a five storey building with its foundation. We firstly study the data we have in hand. We were provided with data like bore log data, consolidation data, etc. Then we create a soil profile on which our building will stand. We then find different soil parameters. Based on these soil parameters we have to find the bearing capacity and settlement criterion and later on, check whether our designed foundation is sufficient or not.

We design the five storey building by assuming data like the clear height between floors, dimension of elements and their quantity. The building is designed on STAADPRO and manual calculations are done to verify the sufficiency of the design.

In short the project mainly revolves around designing different elements of the building and verifying their adequacy by means of various methods and methodologies.

CHAPTER 2

MATERIALS, METHODS AND METHODOLOGIES

Materials

The detailed site investigation data has been provided. The site investigation involved geotechnical drilling, sampling and laboratory testing.

Data provided (Refer to appendix):

Plan of boring

Boring logs

Laboratory test data

In situ test data

Methods and Methodologies

For the design of superstructure, software like STAAD PRO and Auto cad are most likely to be used. The design method would basically be limit state method. The load computations will be done automatically by these soft wares, if not other methods may be applied.

To find bearing capacity of soil, various properties of soil are to be looked into and an idealized soil profile is be created. The formulas supplied by IS code for bearing capacity and settlement of foundation is to be programmed on C to make the calculations easier.

The soil profile and drawings such as that of reinforcement placements are to be drawn by hand on charts. Comparison between manual calculations and STAAD PRO results will also be made.

The type of foundation to support the building would be determined by rough approximate methods and if shallow foundations are recommended, design charts would be developed for sizing the spread footings for various column load ranges.

CHAPTER 3

SOIL PROFILES AND SOIL PARAMETERS

Idealized soil profile

Soil profile refers to the layers of soil horizon such as the top soil, subsoil and bed rock layer but from a geotechnical engineers perspective it is a much detailed illustration of different layers formed by different type of soil such as clay, silt, sand etc.

Looking into the data of bore logs given, we created three soil profiles by analyzing for various features like depth, water table, stratum description and other information. We took step by step procedure as follows:

1. Selecting the section for which we are going to make the soil profile.

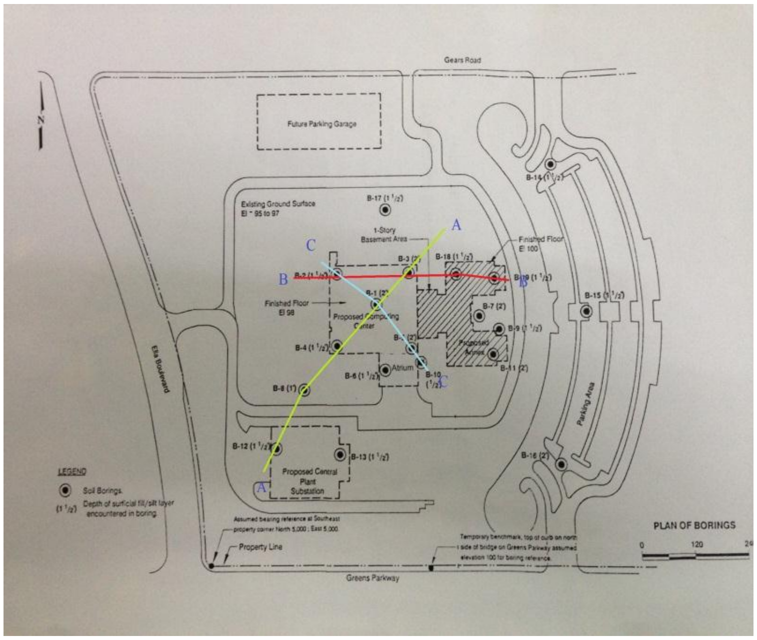


Figure 1: Plan of borings

2. Using a ruler to measure the distance between two consecutive bore holes along the section that we have chosen.
3. Taking the scale given in the plan and finding the exact distance between the bore holes.
   - ❖ Scale for the given plan:
     1 cm = 70.58ft
     1 cm = 21.51m

4. Choosing an appropriate scale (both horizontal and vertical) for our drawing sheet.
   - ❖ Scale for our drawing sheet
     - Vertical scale
       1cm = 2ft
     - Horizontal scale
       1cm =10ft
5. Drawing the bore log data on the sheet.
6. After all data has been plotted, some rough indication of the profile will come into picture.

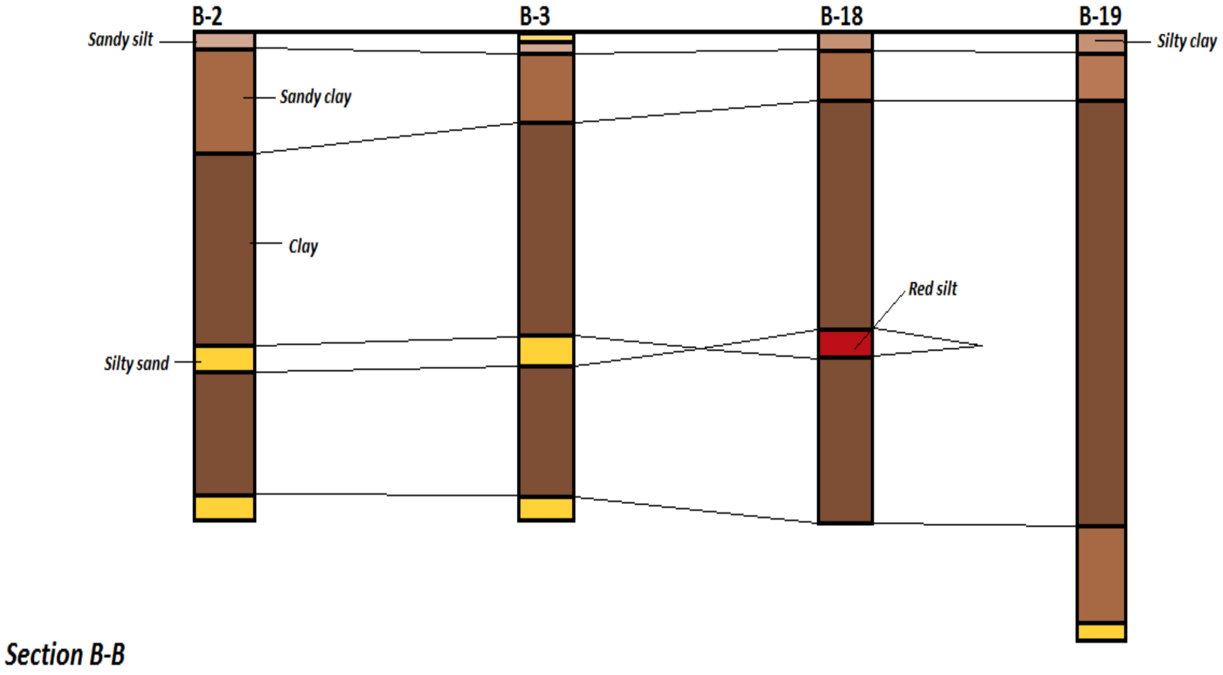


Figure 2: Soil profile of Section B-B

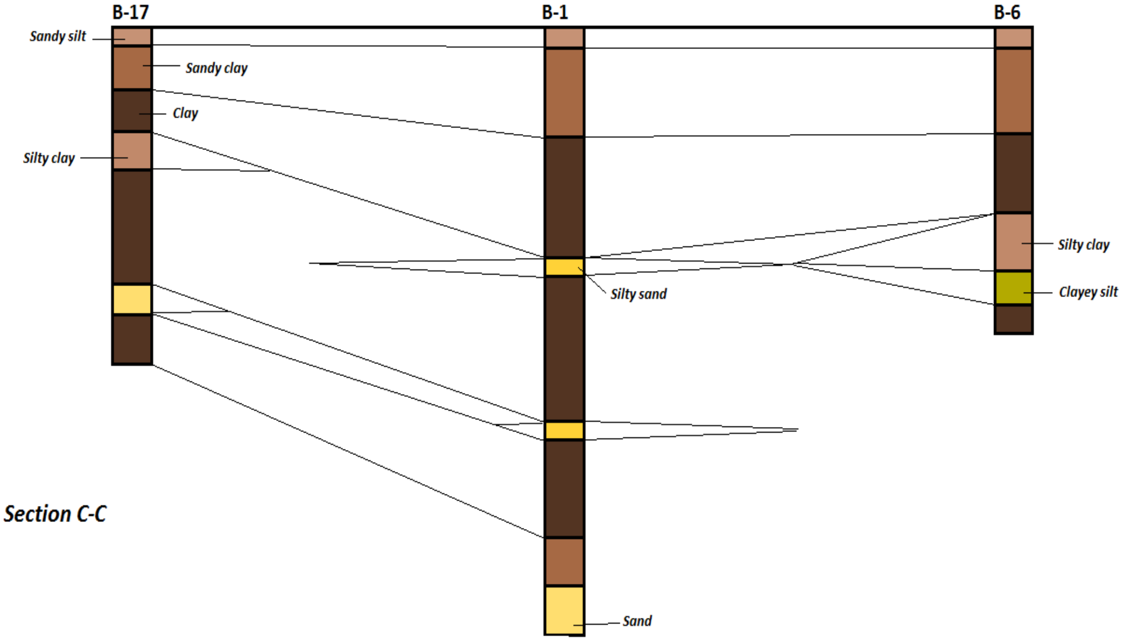


Figure 3: Soil profile of section C-C

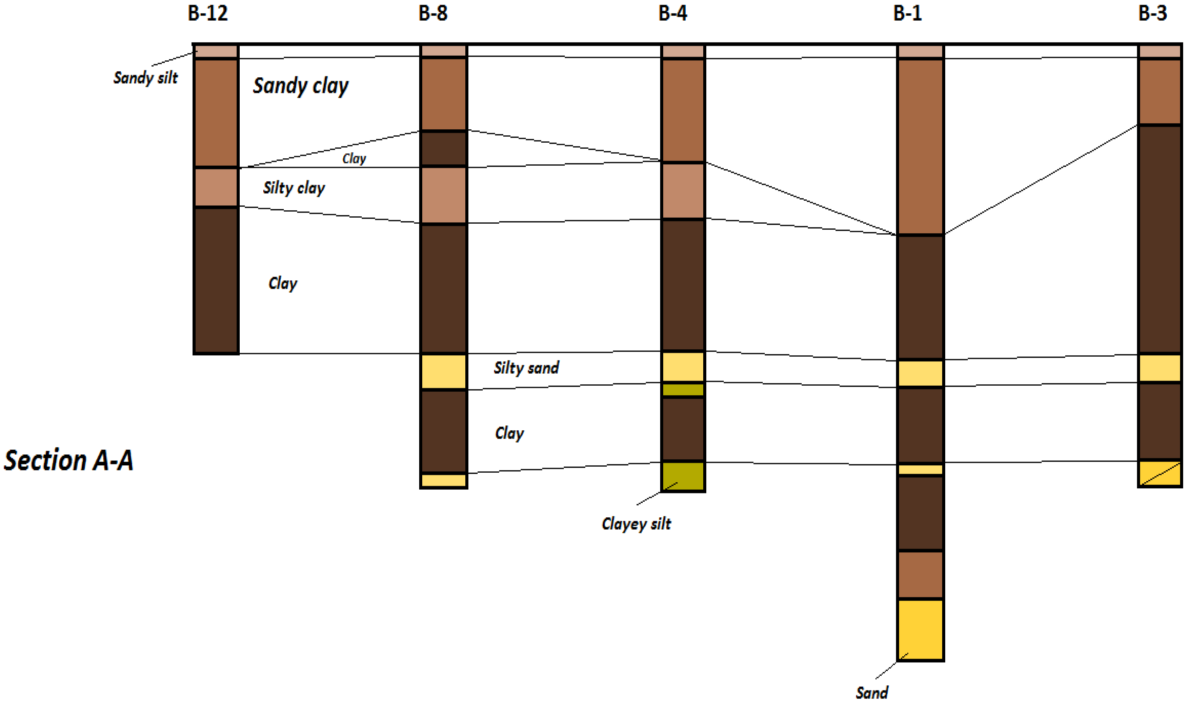


Figure 4: Soil profile of section A-A

7. Joining all the layers having same soil type and creating lenses too. This was done for all the three sections that we have chosen.
8. When all the three sections are done, an idealized soil profile is created by comparing and averaging the values of depth in each section and ignoring all the insignificant layers like lenses and all.

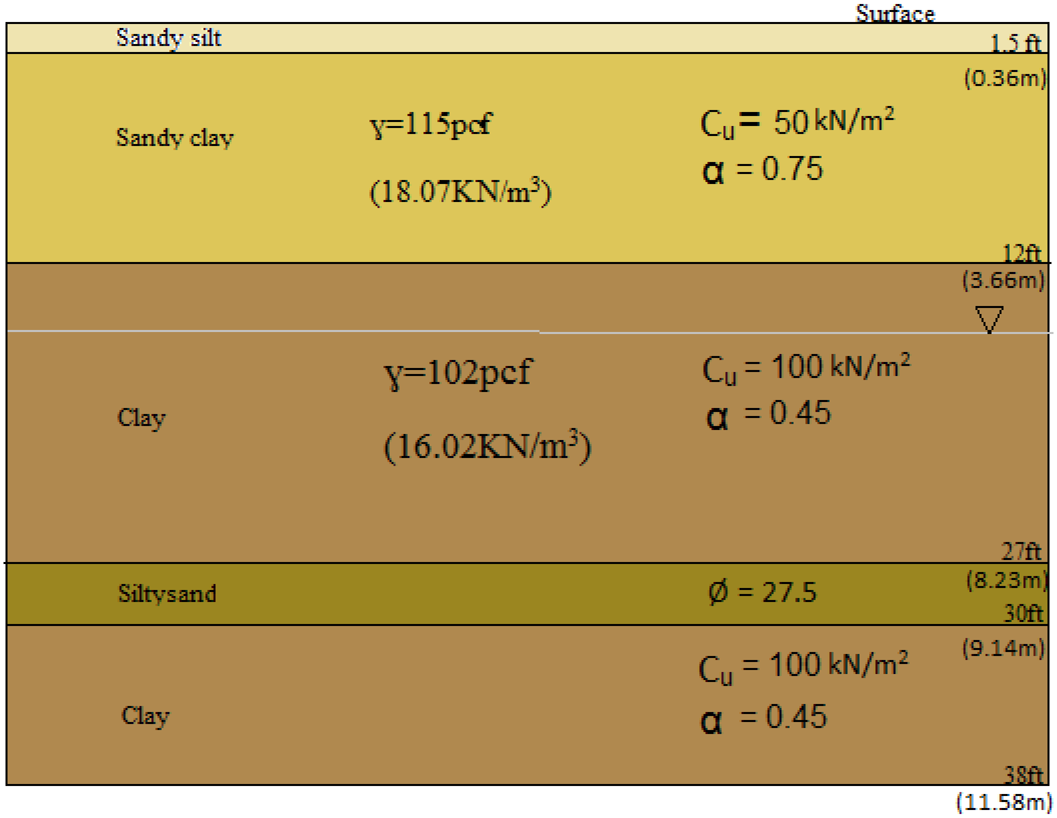
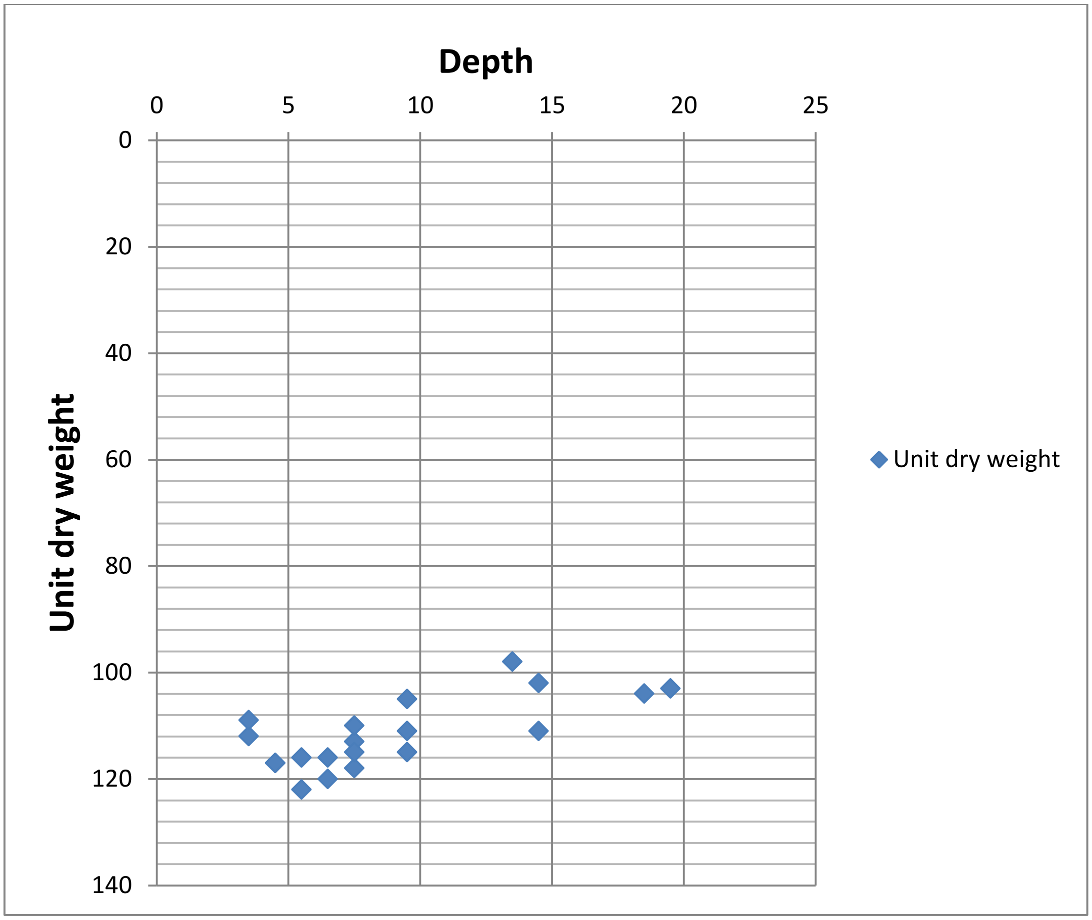


Figure 5: Idealized soil profile

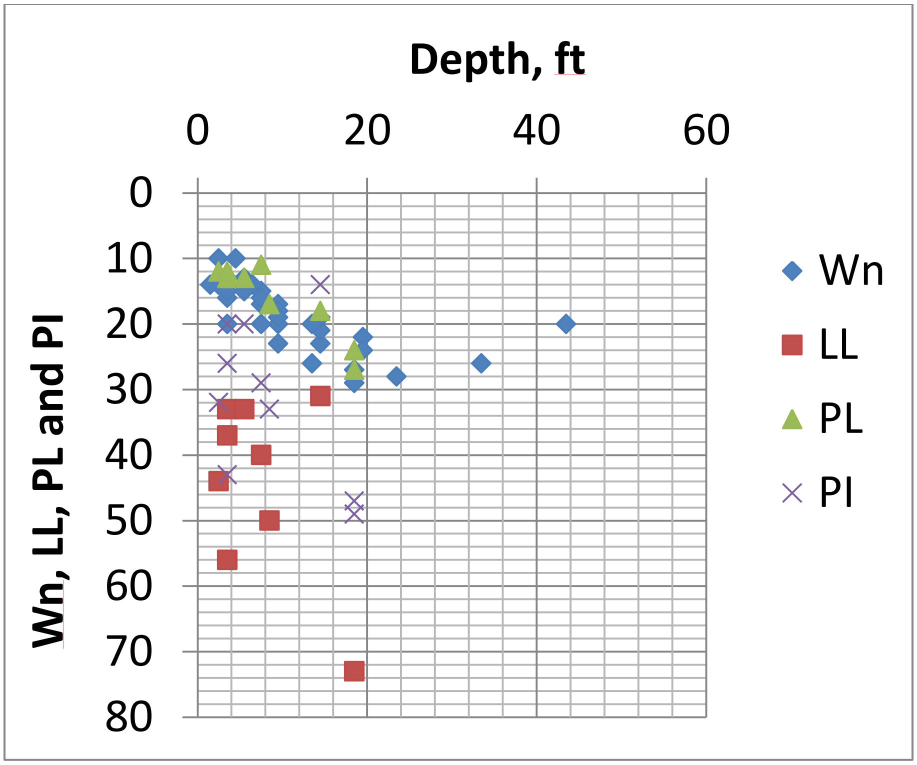
9. The depth of each layer is found by arithmetically averaging all the similar layers in each section. Some of the matchless soil layers and lenses are ignored.

Soil Parameters:

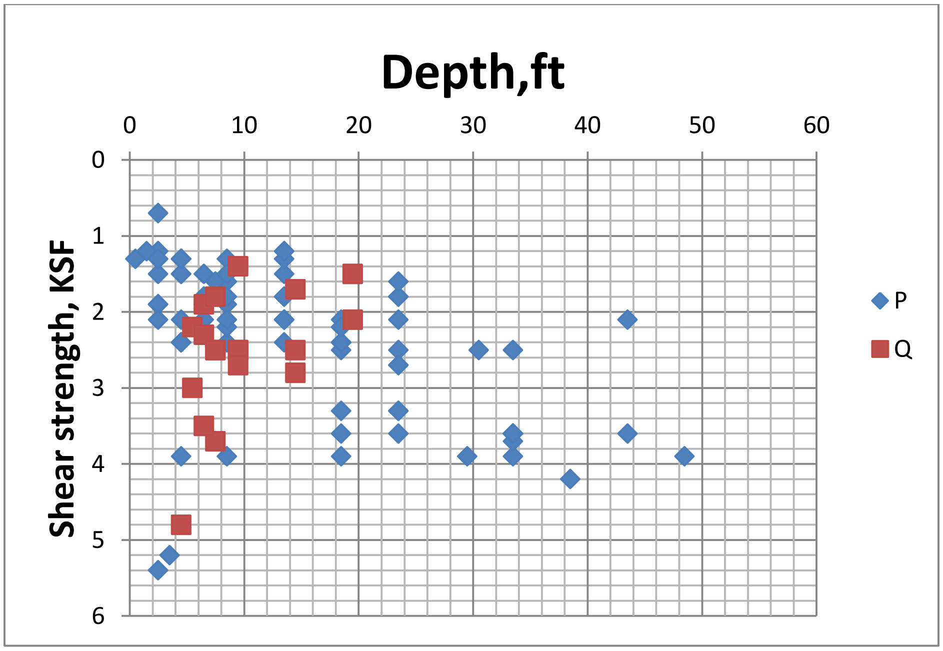
The computations of soil parameters are done by drawing the graph of each parameter against depth. After the graph is drawn, the value of different soil parameters like density, liquid limit, shear strength, etc. for each layer in the idealized soil profile are found by drawing the best fit line.



Graph 1: Depth v/s depth



Graph 2: Depth v/s liquid limit, plastic limit, plasticity index and water content



Graph 3: Depth v/s shear strength

CHAPTER 4

TYPES AND SELECTION OF FOUNDATION

Types of Foundation

Foundations can be classified into two general categories:

1. Shallow foundation

   When the D/B ratio is less than 2

2. Deep foundation

   When the D/B ratio is more than 2

There are further many other types or subdivisions of both shallow and deep foundations based on different functions, method of building, shape, etc.

In case of our building we are going with a pile foundation because it’s only five storey high and pile foundation will suffice to support the loads coming on it. But checks will be done to make sure the foundation provides enough safety and is able to bear the load of superstructure effectively.

General requirements of foundations

Foundations have to satisfy three basic criteria for a satisfactory performance. They are:

a) Location and depth criterion
b) Shear failure criterion or bearing capacity criterion
c) Settlement criterion

Location and depth criterion

The location and depth of foundation is taken such that there is no adverse effect because of factors such as lateral expulsion of soil from beneath the foundation, seasonal volume changes like due to freezing and thawing and presence of adjoining structure.

The depth of our foundation is initially being taken as 1.5m so that the foundation lies in the clay layer and gets enough bearing and friction from it.

Changes can be made if the depth was found to be inadequate.

Shear failure criterion or bearing capacity criterion

The foundation is provided with adequate factor of safety against shear failure or soil rupture.

Allowable bearing pressure is the maximum intensity of loading that can be imposed on the soil with no possibility of shear failure or the possibility of excessive settlement. The Indian Standard Code (IS: 6403-1981) refers to allowable bearing pressure by the name allowable bearing capacity.

CHAPTER 5

DESIGN OF SUPERSTRUCTURE

The project is continued with the design of superstructure .Basically, it will be a two-storey building that will be modeled and analyzed using STAAD PRO.

Dimension

The building will have following dimension:

- Cross section of the building: 60x60m
- Length of the beam:10m
- Height of the column: 2.9m
- Plinth level: 1.5m
- Cross section of the beam (Used in STAAD PRO) : 600x300mm
- Cross section of the column(Used in STAAD PRO): 600x600mm

Various loads acting on the superstructure

1. Imposed load or Live Load
2. Dead Load
3. Wind Load

Imposed load/Live load

Imposed loads are the minimum loads which should be taken into consideration for the purpose of structural safety of the building. This load is assumed to be produced by the intended use or the occupancy of the building including weight of the movable partition, distributed and concentrated loads, loads due to impact and vibration and dust load but excluding wind load, seismic load, snow load etc.

Imposed load in our case is taken on the basis of occupancy. Our building is a commercial building.

From IS 875-part 2, we took the imposed load for commercial building as 35kN/m.

NOTE: (We have not taken snow and rain load, so to compensate these loads and to accommodate processes like expansion of concrete etc. we have taken the same maximum value of imposed load even on the roof top.)

Dead load

Dead load includes the weight of all the permanent components of the building including walls, partitions, columns, floors, roofs, finished and fixed permanent equipment and fittings that are integral part of the building. Unit weight of the building materials is taken in accordance with IS:875-part 1.

Regarding input of dead load in STAAD PRO, it can be done automatically but for the manual considerations we use the following method:

Unit weight of concrete: 25kN/m^3

Dead load of an element: 25 x section of element

Wind load

Wind load is applied to take in account the static and dynamic effects of wind forces on the structures. Wind load will be estimated taking in account the variation in the wind speed with time. The effect of wind on the structure is determined by the combined action of external and internal pressures acting upon it.

Wind load is calculated in accordance to the IS:875-part3.Firstly,design wind speed is calculated using the following formula:

$$V_z = V_b * k_1 * k_2 * k_3$$

Where,

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

k_1=probability factor;

k_2=terrain height and structure size factor;

k_3=topography factor;

V_b= basic wind speed.

Using above formula and evaluating the values of k2,k2 ,k3 and Vb, the value of design speed can be calculated. The wind pressure is given by

$$P_z=0.6\ V_z^2$$

The plan of boring given to us is from Houston, Texas. The wind map of Houston is as shown below:

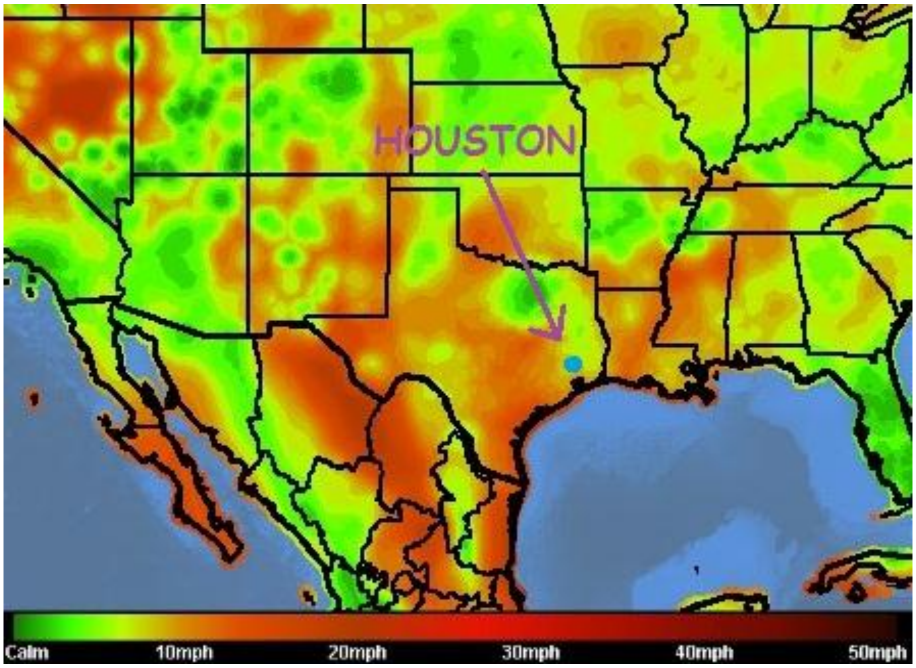


Figure 6: Wind speed map of Texas

From the figure we got the average wind speed of Houston as around 8mph which is 3.575 m/s.

We took the Terrain Category as 3 and Class as C and we computed the wind intensity in excel sheet as follows:

Height(m)	K_1	K_2	K_3	V_b(m/s)	V_z(m/s)	P_z(kN/m2)
10	1	0.82	1	3.575	2.932	0.0052
15	1	0.88	1	3.575	3.146	0.0059
20	1	0.91	1	3.575	3.253	0.0064
25	1	0.96	1	3.575	3.432	0.0071

The above mentioned loads were taken and a building was modeled, analyzed and some elements designed on STAAD PRO.

Design and analysis on STAAD PRO:

Different loadings given on the building

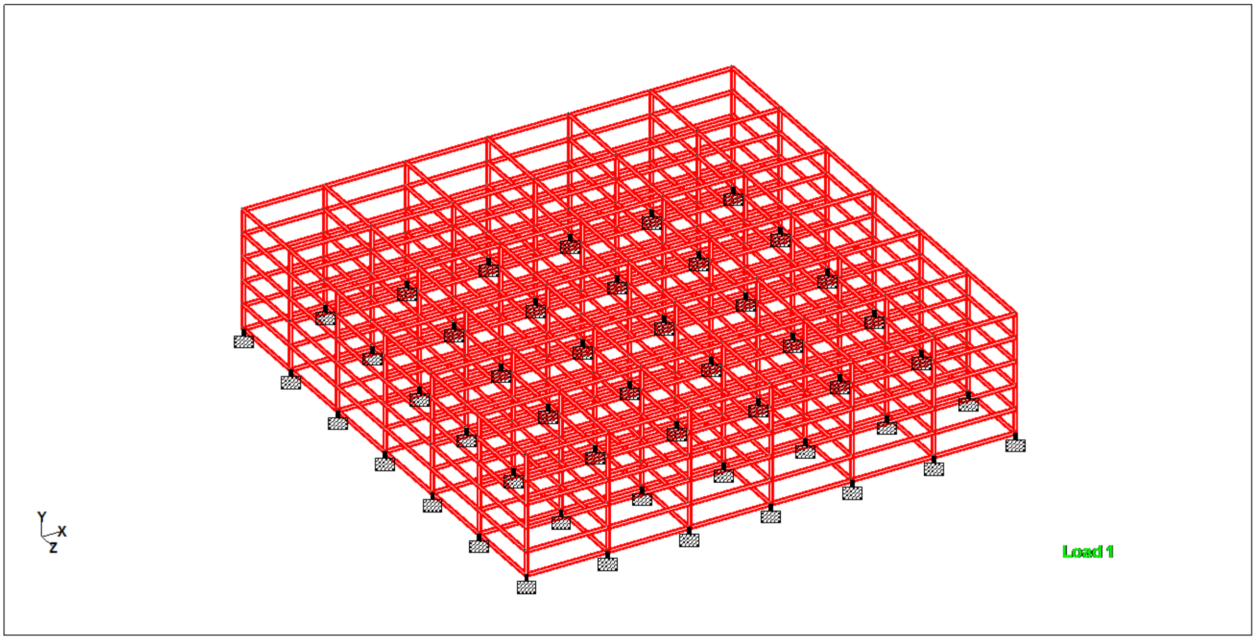


Figure 8: Dead load

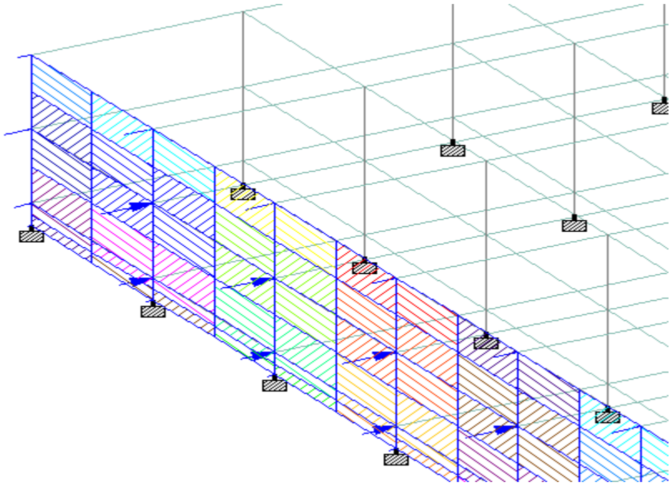


Figure 9: Wind load

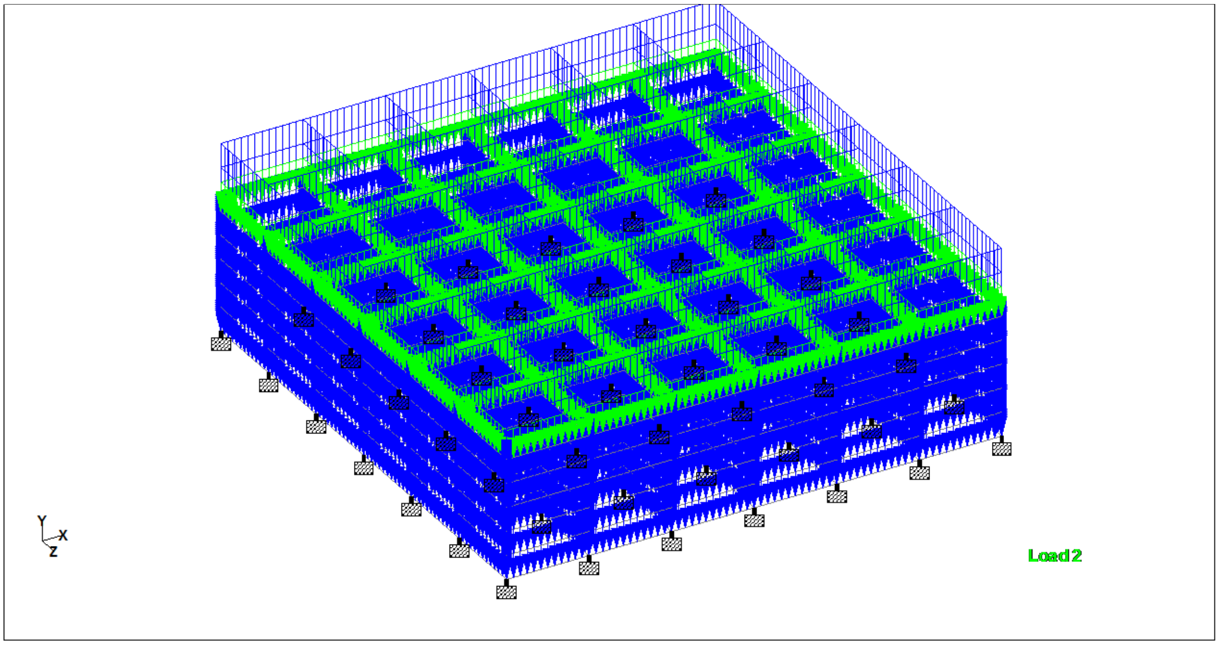
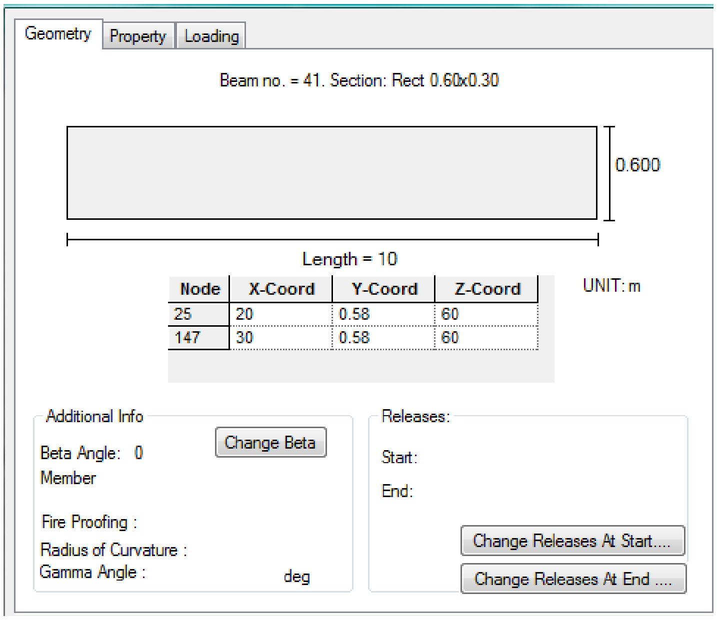


Figure 10: live load

Design of beam (No.41)



Beam no. = 41. Section: Rect 0.60x0.30

Node	X-Coord	Y-Coord	Z-Coord
25	20	0.58	60
147	30	0.58	60

UNIT: m

Additional Info

Beta Angle: 0

Member

Fire Proofing :

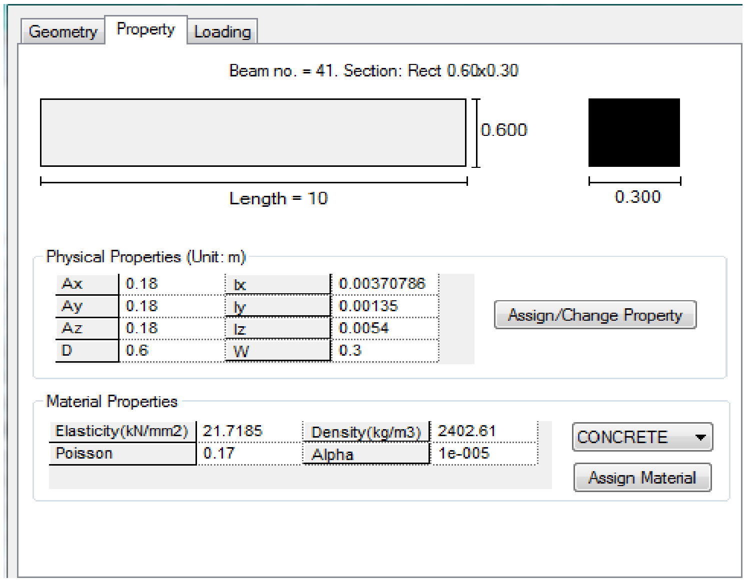
Radius of Curvature :

Gamma Angle : deg

Releases:

Start:

End:



Beam no. = 41. Section: Rect 0.60x0.30

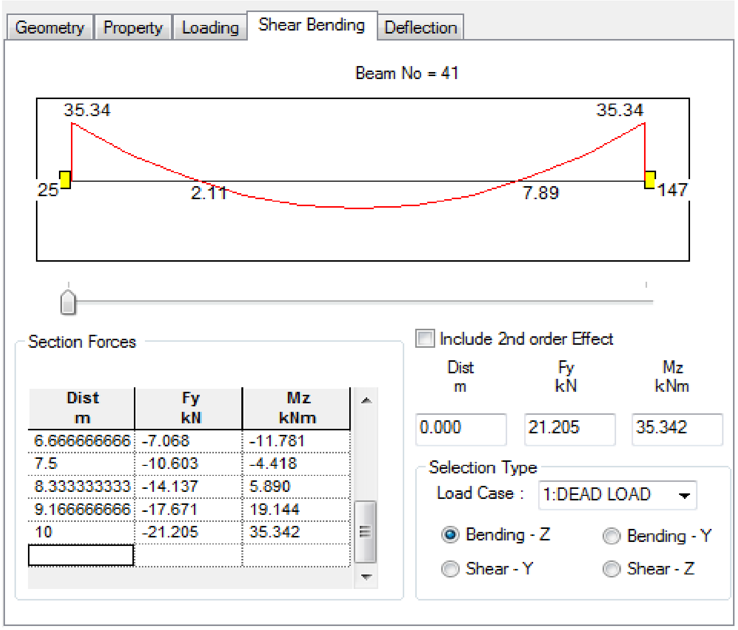
Physical Properties (Unit: m)

Ax	0.18	Ix	0.00370786
Ay	0.18	Iy	0.00135
Az	0.18	Iz	0.0054
D	0.6	W	0.3

Material Properties

Elasticity(kN/mm2)	21.7185	Density(kg/m3)	2402.61
Poisson	0.17	Alpha	1e-005

CONCRETE



Beam No = 41

Section Forces

Dist m	Fy kN	Mz kNm
6.666666666	-7.068	-11.781
7.5	-10.603	-4.418
8.333333333	-14.137	5.890
9.166666666	-17.671	19.144
10	-21.205	35.342

☐ Include 2nd order Effect

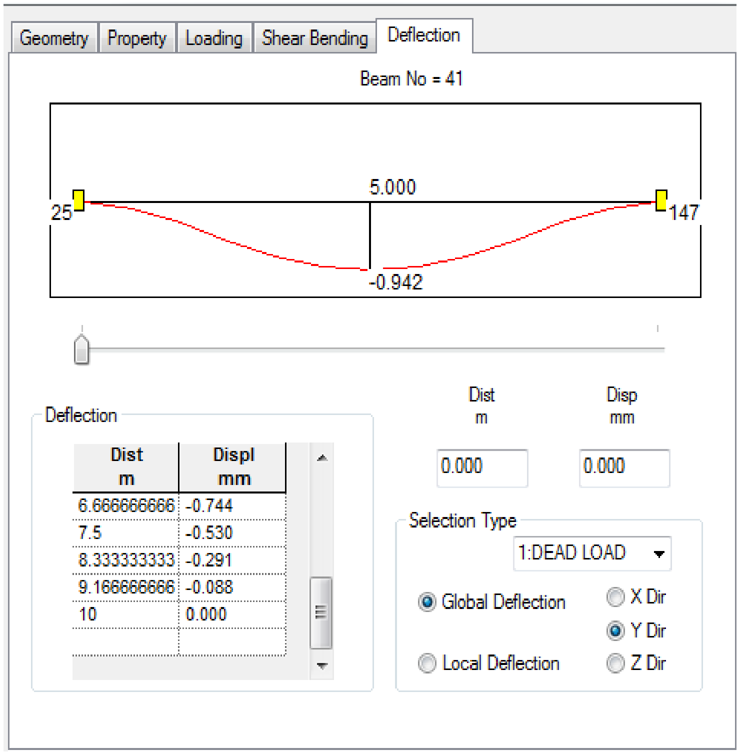
Dist m	Fy kN	Mz kNm
0.000	21.205	35.342

Selection Type

Load Case : 1:DEAD LOAD

● Bending - Z ○ Bending - Y

○ Shear - Y ○ Shear - Z



Beam No = 41

Deflection

Dist m	Displ mm
6.666666666	-0.744
7.5	-0.530
8.333333333	-0.291
9.166666666	-0.088
10	0.000

Dist m: 0.000

Disp mm: 0.000

Selection Type: 1:DEAD LOAD

● Global Deflection

○ Local Deflection

○ X Dir

● Y Dir

○ Z Dir

Figure: Shear bending and deflection

Design of slab (No.412):

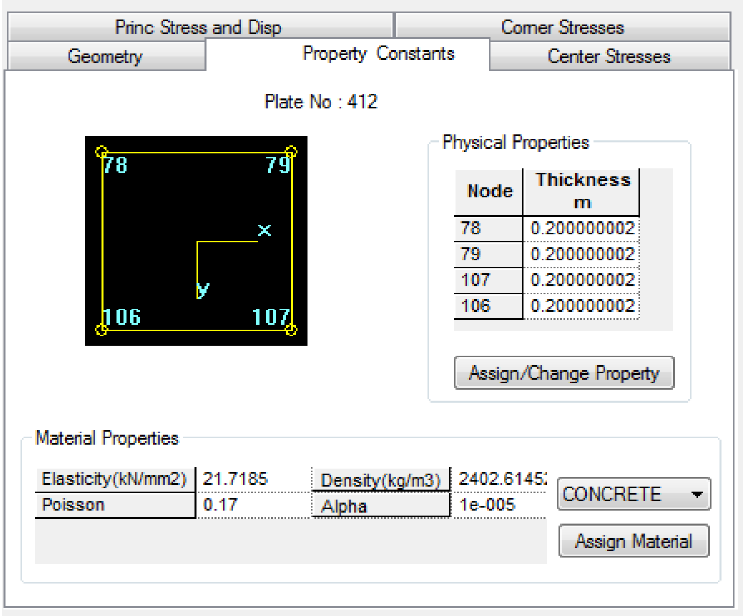


Plate No : 412

Physical Properties

Node	Thickness m
78	0.200000002
79	0.200000002
107	0.200000002
106	0.200000002

Material Properties

Elasticity(kN/mm2)	21.7185	Density(kg/m3)	2402.6145:
Poisson	0.17	Alpha	1e-005

CONCRETE

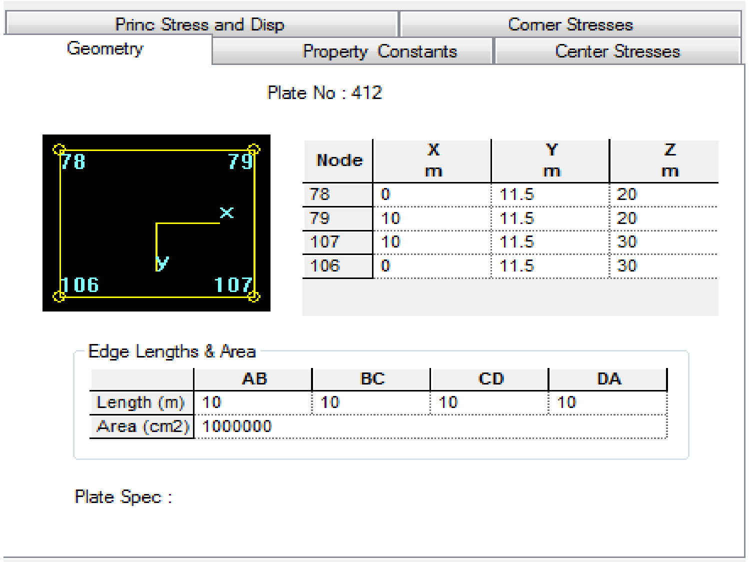


Plate No : 412

Node	X m	Y m	Z m
78	0	11.5	20
79	10	11.5	20
107	10	11.5	30
106	0	11.5	30

Edge Lengths & Area

	AB	BC	CD	DA
Length (m)	10	10	10	10
Area (cm2)	1000000			

Plate Spec :

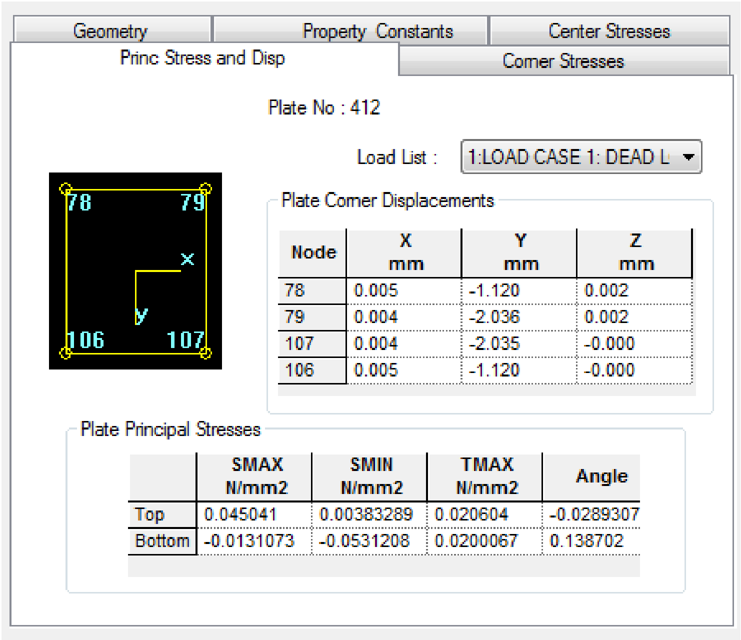


Plate No : 412

Load List : 1:LOAD CASE 1: DEAD L

Plate Corner Displacements

Node	X mm	Y mm	Z mm
78	0.005	-1.120	0.002
79	0.004	-2.036	0.002
107	0.004	-2.035	-0.000
106	0.005	-1.120	-0.000

Plate Principal Stresses

	SMAX N/mm2	SMIN N/mm2	TMAX N/mm2	Angle
Top	0.045041	0.00383289	0.020604	-0.0289307
Bottom	-0.0131073	-0.0531208	0.0200067	0.138702

CHAPTER 6

FOUNDATION

PILE FOUNDATION:

INTRODUCTION

Pile foundations are the part of a structure used to carry and transfer the load of the structure to the bearing ground located at some depth below ground surface.

Soil at shallow depths – strong; provide shallow foundation.
Soil at shallow depths – poor; provide deep foundation.

TYPES OF PILES:

Piles can be classified in several ways:

A. Classification based on function and mode of load transfer:
   1. End bearing piles.
   2. Friction piles
   3. Compaction piles
   4. Tension piles or uplift piles.
   5. Anchor piles.
   6. Batter piles.
   7. Sheet piles. Etc..

B. Classification based on materials and the methods of installation:
   1. Concrete piles.
      a) Precast.
      b) Cast – in – situ
         - Driven shell : cased or uncased
         - Bored piles: with or without base enlargement.

   2. Timber piles
   3. Steel piles
      a) H – Piles.
      b) Pipe piles : open ended or closed ended
      c) Sheet piles.

END BEARING PILES:

These piles transfer their load on to a firm stratum located at a considerable depth below the base of the structure and they derive most of their carrying capacity from the penetration resistance of the soil at the toe of the pile (see figure 1.1). The pile behaves as an ordinary column and should be designed as such. Even in weak soil a pile will not fail by buckling and this effect need only be considered if part of the pile is unsupported, i.e. if it is in either air or water. Load is transmitted to the soil through friction or cohesion. But sometimes, the soil surrounding the pile may adhere to the surface of the pile and causes "Negative Skin Friction" on the pile. This, sometimes have considerable effect on the capacity of the pile. Negative skin friction is caused by the drainage of the ground water and consolidation of the soil. The founding depth of the pile is influenced by the results of the site investigate on and soil test.

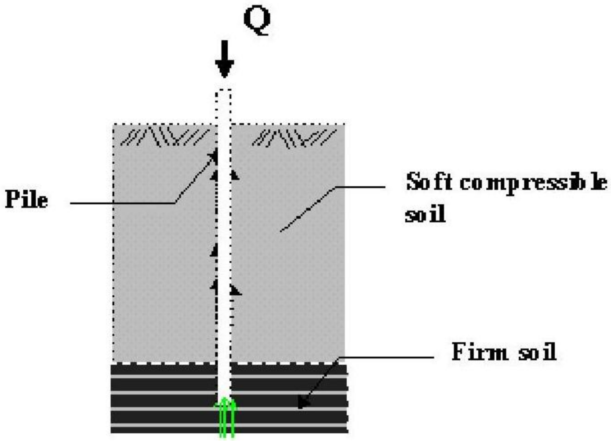


Figure 11: End bearing pile

FRICTION PILE

Carrying capacity is derived mainly from the adhesion or friction of the soil in contact with the shaft of the pile (see fig 1.2).

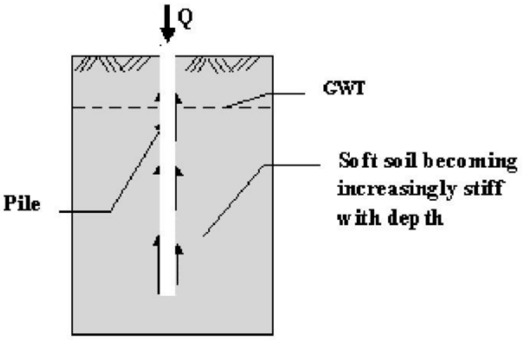


Figure 12: Friction piles

FRICTION AND COHESION LESS PILES

An extension of the end bearing pile when the bearing stratum is not hard, such as a firm clay. The pile is driven far enough into the lower material to develop adequate frictional resistance. A farther variation of the end bearing pile is piles with enlarged bearing areas. This is achieved by forcing a bulb of concrete into the soft stratum immediately above the firm layer to give an enlarged base. A similar effect is produced with bored piles by forming a large cone or bell at the bottom with a special reaming tool. Bored piles which are provided with a bell have a high tensile strength and can be used as tension piles (see fig.1-3).

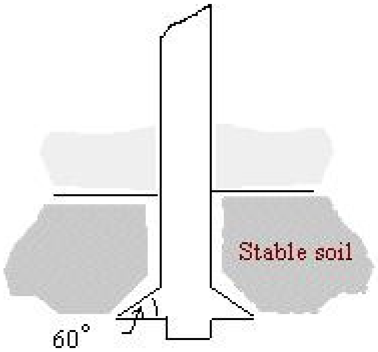


Figure 13: Under-reamed base enlargement to a bore-and-cast-in-situ pile

CHAPTER 7

LOAD CARRYING CAPACITY OF SINGLE PILE

The load carrying capacity of piles can be estimated by several methods which may be grouped into following categories:

a) Static pile load formulae
b) Pile load test
c) Pile driving formulae
d) Correlations with penetration test data

But I will be using static pile load formulae for calculating load carrying capacity of pile.

STATIC PILE LOAD FORMULAE

When a compressive load is applied on pile, the will tend to move in downward direction relative to surrounding soil. This will cause shear stress to develop between the soil and the surface of the shaft. Then applied load is distributed as friction load along some certain length of pile. This ultimate skin friction is known as ultimate skin friction resistance of pile, Q_f .and the resistance offered by tip of pile is known as point bearing, Q_{pu} .

The maximum load which the pile can support through the combined action of skin friction and point bearing is known as the ultimate load carrying capacity, Q_u of the pile.

$$Q_u = Q_{pu} + Q_f \quad \ldots\ldots (1)$$

If,

$Q_f << Q_{pu}$, then the pile may be called as ‘end bearing’ pile

If,

$Q_f >> Q_{pu}$, then the pile may be called as ‘friction’ pile.

$$Q_u = Q_{pu} + Q_f$$

$$\text{Or, } Q_u = q_{pu} * A_b + f_s * A_s \ldots\ldots(2)$$

Where, q_{pu} = point bearing resistance, A_b = c/s area of pile,

f_s = skin friction, A_s = surface are of pile.

RESISTANCE DUE TO END BEARING

- ✓ For granular soils, (c = 0)

  $Q_{pu} = q(N_q - 1)*A_p$……… (3)

  - ➢ q=effective vertical stress kN/m^2,
  - ➢ Nq=bearing capacity factors depending on angle of internal friction,
  - ➢ Ap = c/s area of pile

- ✓ For clayey soils, (Ø = 0)

  $Q_{pu}= C*(N_C)$………………. (4)

  - ➢ C = undrained cohesion.
  - ➢ N_c=bearing capacity factor

RESISTANCE DUE TO SKIN FRICTION

- ✓ For granular soils,(c=0)

  $Q_f =\sum^n_{i=1} K \sigma_v \tan \delta (A_{si})$….. (5)

  - ➢ K = coefficient of earth pressure.
  - ➢ ∂ = angle of wall friction between the pile and soil, in degrees.
  - ➢ A_{si} = surface area of pile stem in m^{2}in the ith layer, I varies from 1 to n.

- ✓ For clayey soils,(Ø = 0)

  $Q_f =\sum^n_{i=1} \alpha C_u A_{si}$………………. (6)

  - ➢ A_{si}=surface area of pile stem in m^2
  - ➢ α=adhesion factor.
  - ➢ C_u=cohesion kN/m^2

References (basic and applied soil mechanics by Raman and Rao)

CALCULATION OF VARIOUS SOIL PARAMETERS

For clayey soil

Adhesion factor, α can be estimated from the table given below

Referred from IS 2911 part 1 sec 1

Undrained shear strength C_u is computed from, averaging all shear strength values given in bore hole data (refer appendix 1.0).

Then, value of adhesion factor, α is carried from graph given below.

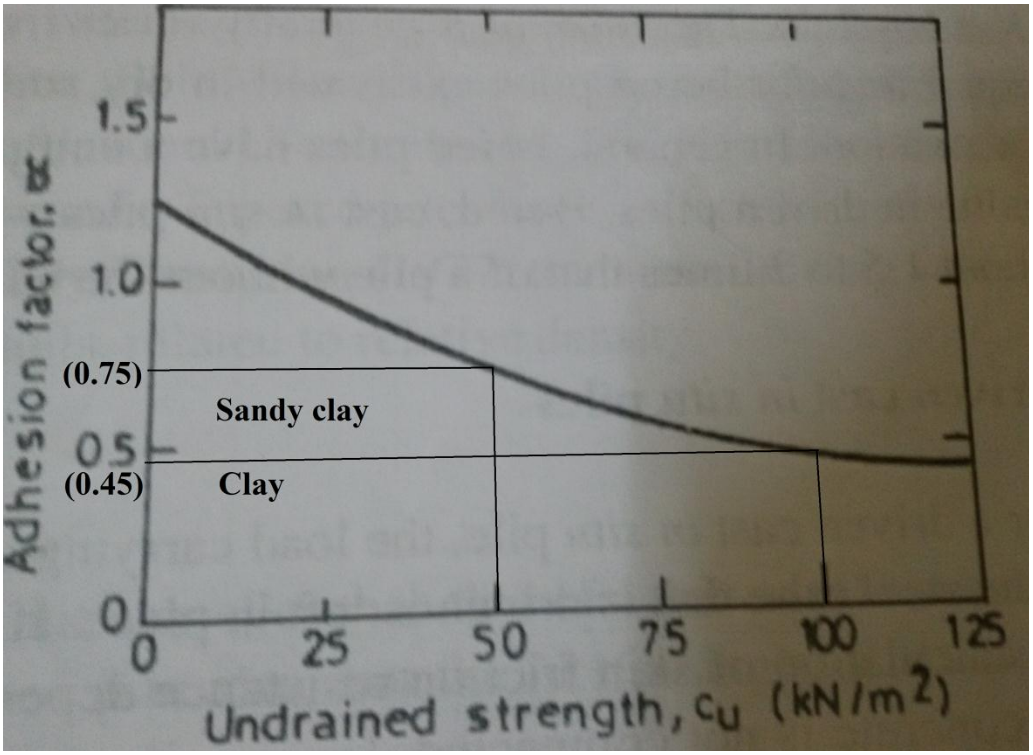


Figure 14

Value of N_c = 9 (for pile foundation, IS 2911 part 1 sec 1)

N_q value is computed from graph ‘bearing capacity factor for bored piles’ given in is code

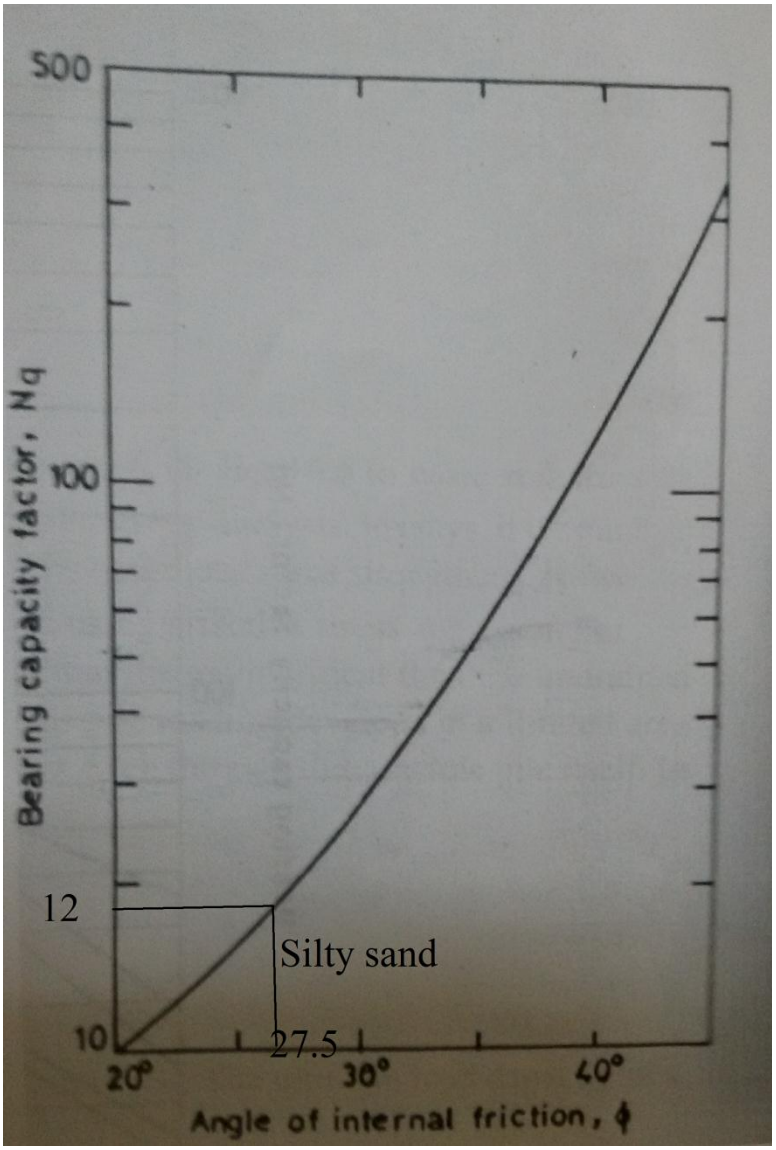


Figure 15

Selecting column for calculating load carrying capacity of pile under single column

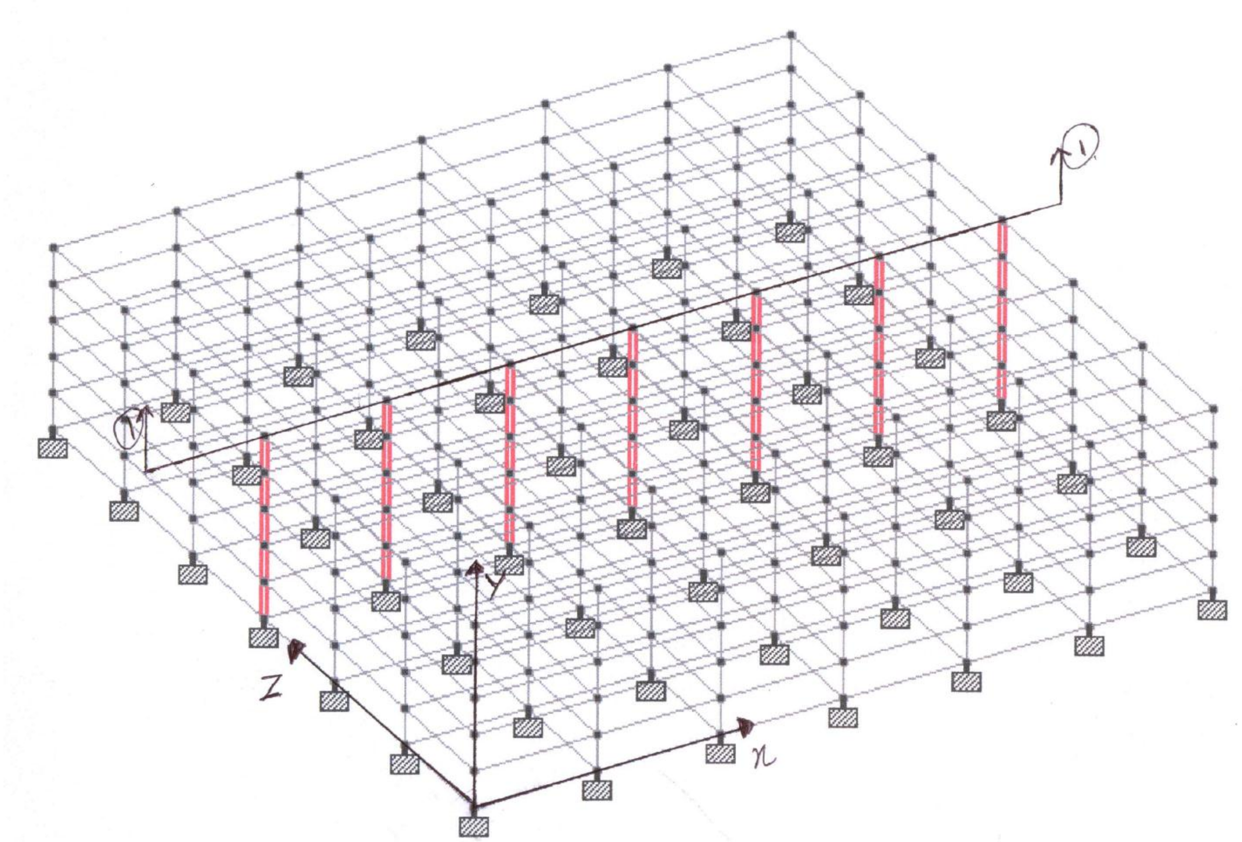


Figure 16: Isometric view of building

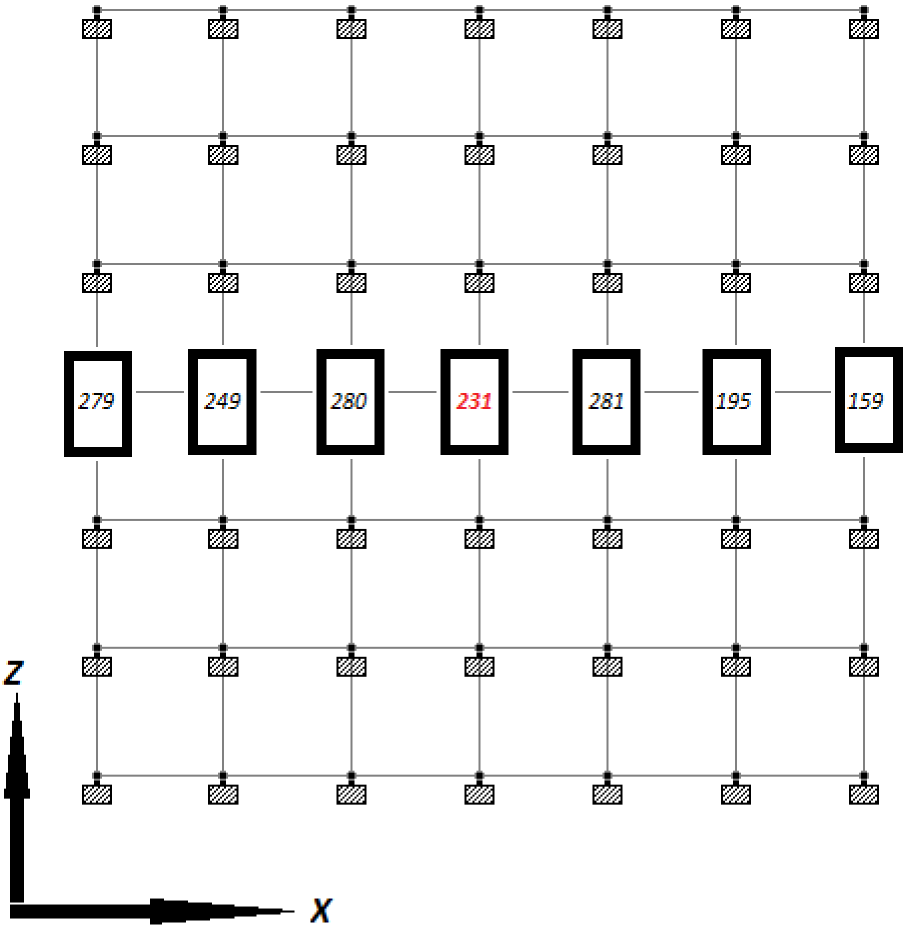


Figure 17: Top view

Axial load on columns

Selecting Centre column for design purpose due to maximum load

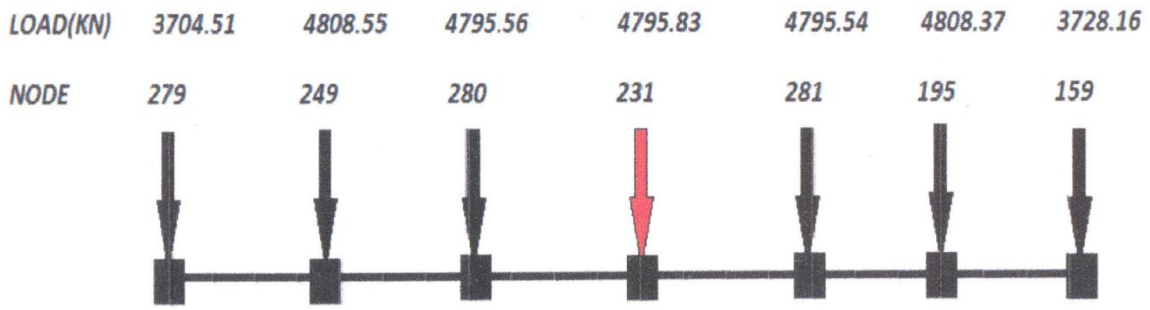


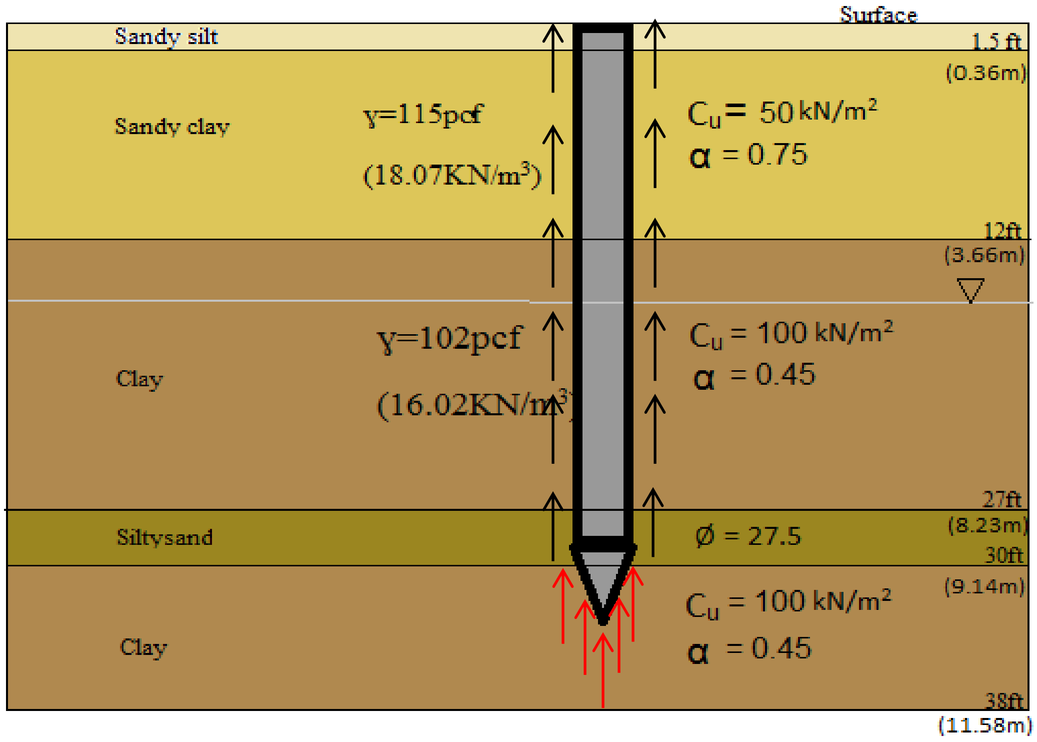
Figure 17: load on selected column

COMPUTATIONS FOR LOAD CARRYING CAPACITY OF SINGLE PILE

Assuming diameter of pile = 300mm.

Hard stratum to be achieved at the depth of 10m from top surface.

NOTE: neglecting first layer of soil profile i.e. sandy silt, for pile cap.



A. Cohesive soils (Ø = 0)

a) Sandy clay (layer 1**)**

Depth, L = 3.3 m

Unit weight, Υ = 18 KN/m^3

Undrained shear strength, C_u = 50 KN/m^2

Adhesion factor, α = 0.75

Bearing capacity factor, N_c = 9 (for pile foundation)

- ✓ **END BEARING:**

$Q_U = q_{pu} * A_b$ $\quad \{ A_b = \frac{\pi}{4} * 0.3^2 = 0.07\ m^2$

$= C*N_C* A_b$

$= 50*9*0.07$

$= 31.5$ KN.

- ✓ **SKIN FRICTION:**

$Q_f = \alpha C_u A_{si}$ $\quad \{ A_{si} = \pi*0.3*3.3 = 3.11\ m^2$

$= 0.75*50*3.11$

$= 116.63$ KN.

From equation **(1)**

Load capacity, Q_u = 148.43 KN. ………. (a)

b) Clays (layer 2**):**

Υ = 16 KN/m^3

C_u = 100 KN/m^2

α = 0.45

L = 4.57 m

(Layer 4):

Υ = 16 KN/m^3

C_u = 100 KN/m^2

α = 0.45

L = 0.86 m

From equation (1)

..i.e. $Q_u = Q_{pu} + Q_f$

$= Q_{pu(2)} + Q_{pu(4)} + Q_{f(2)} + Q_{f(4)}$

$= (C*N_C* A_b)_2+(C*N_C* A_b)_4+(\alpha C_u A_{si})_2+(\alpha C_u A_{si})_4$

= 356.8 KN

SO,. Q_u = 356.8KN.

c) Silty sand:

$Ø = 27.5^o$
N_q = 12 (IS: 2911 part – 1, 1979)
$ϒ = 15$ KN/m^3
K = 2 (table 16.3, Ranjan and Rao)
$\partial = 0.75* Ø$
$\partial = 20.6^o$
D = 0.91 m
$A = \pi * D * L = 0.857\ m^2$
$A_b = 0.07\ m^2$

From eqn…. (1)
Q_u = 31.2 KN.

So.net load carrying capacity of single pile, Q_u = 148.43+356.8+31.2
Q_u = 536.43 KN

Allowable load carrying capacity of single pile, Q = 536.43/2.5 = 214.572 KN.

Grouping of piles:

In a group of pile no. of piles is decided by axial load coming on foundation from single column as selected above.

Load on foundation due selected column, Q_{ug} = 4795.83 KN

Ultimate load capacity of single pile, Q_u = 536.43 KN

No. of piles in a group = $\frac{\text{Qug}}{\text{Qu}}$

$= \frac{4795.83}{536.43}$

= 9 piles in a group. (See fig.19 for Top view of pile group)

Spacing of piles in a group:

1. If capacity of pile is due to both skin friction and end bearing then spacing is given by 2.5*D
2. If capacity of pile is mainly due to skin friction spacing is given by 3.0*D

So from clause 2 spacing of pile given by:

S = 3.0*D

= 3*0.35 = 1.05 m c/c

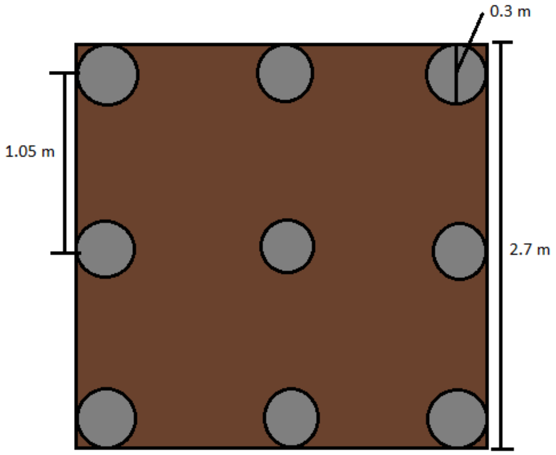


Figure 19: Pile in group

Efficiency of pile group:

By, converse – labarre formulae:

$$E = \frac{1-\theta(n-1)*m+(m-1)*n}{90*m*n}$$

Where,

m = no. of columns in a pile group.

n = no. of rows in a pile group.

$\theta = \tan^{-1}\frac{d}{s}$

d = Diameter of pile

s = c/c spacing

$$E = \frac{1-\tan^{-1}\left(\frac{0.3}{1.05}\right)*(3-1)*3+(3-1)*3}{90*3*3}$$

E = 1-0.12

So,

Group efficiency, E = 0.88

CHAPTER 8
R.C.C DESIGN OF PILE

Reinforcement detailing of pile:

- A reinforced pile is designed as a column, considering it fixed at one end hinged at other end, the effective length of the pile is taken as $2/3^{rd}$ 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 the 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 5 mm 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 the three times the least lateral dimension, lateral reinforcement should not be less than 0.6% 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 form of helix.
- The cover to reinforcement including binding wire shall not be less than 40 mm and for piles exposed to seawater or other corrosive content his has to be increased to 50 mm.

DESIGNING:

Material to be used for constructing a pile
Grade of Concrete = M_{20}
Grade of steel = Fe_{415}
Length of pile = 10 m
Load coming on pile from central column = 4795.83 KN.

For M_{20} concrete, $F_{ck} = 20$ N/mm^2,
For Fe $_{415}$ steel, $F_y = 415$ N/mm^2

Main reinforcement:

Total length of pile = 10m,

Size of pile = $A = \frac{\pi r^2}{4}$

L/D ratio = 26.7>12 (long column)

Reduction factor, C_r = 1.25-(L_{eff}/48*D) (eqn by R.C.C design by B.C Punmia)

C_r = 0.55

Design load for column, P_u = (1.5*532.87/0.55)

P_u = 1453.28 KN

Effective length of pile = 0.6*10 = 6 m

Min. eccentricity = Greater of

1) = 20 mm

2) = L_e/500 + b/30

= 6000/500 + 300/30

= 12+10

= 22 mm

Min eccentricity = 22 mm

Ultimate load for pile is given by:

$P_u = 0.4*f_{ck}*A_c + 0.67*f_y*A_{sc}$

$1453.287*10^3 = 0.4*20*(70685.83-A_{sc}) +0.67*415*A_{sc}$

A_{sc}= 3287.51 mm^2……….. (2)

Min r/f provided should be 1.5 % of c/s area of pile = 0.015*70685.83

Min r/f, c/s area = 1060.28 mm^2

Providing 8 steel bars of diameter 22 mm

$A_{sc} = \pi * 22^2 * 8/4$ = 3041.061 mm^2 < 3287.51 mm^2 from eqn (2) (hence Safe)

Lateral reinforcement in the body of the pile:

R/F should be provided in the form of links of not less than 5 mm diameter taking 40 mm cover

Adopting 8 mm diameter bars

Diameter of lateral bars required = 300-80-8 = 212 mm

Volume of pile per pitch length = 70685.83*p mm^3

Volume of one tie = $\frac{\pi * d * \pi * 8 * 8}{4}$ == 33477.7 mm^3

Calculating pitch, p of ties

$= \frac{0.2 * 70685.83 * p}{100} = 33477.7$

p = 237 mm

Max permissible pitch, p = 0.5*D_{pile}

= 0.5*300

p = 150 mm < 237 mm hence provide 150 mm.

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

Lateral reinforcement near pile head:

Near pile head, special spiral reinforcement is to be provided for length of 3*30 = 900 mm

Volume of spiral, @ 0.6% of gross volume per mm length = $\frac{0.6 * \pi * 300 * 300}{4 * 100}$

= 424 mm^3

Pitch, p = $\frac{33478}{424}$

p = 79 mm.

Hence provide 75 mm c/c, 8 mm dia. Spiral bars through length of 900 mm.

Lateral r/f at pile end:

Volume of tie s per mm length, @ 0.6 % gross volume = 424 mm^3

Volume of tie = 33478 mm^3

Pitch, p = 33478/424

p = 79 mm

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

Plan of pile detailing:

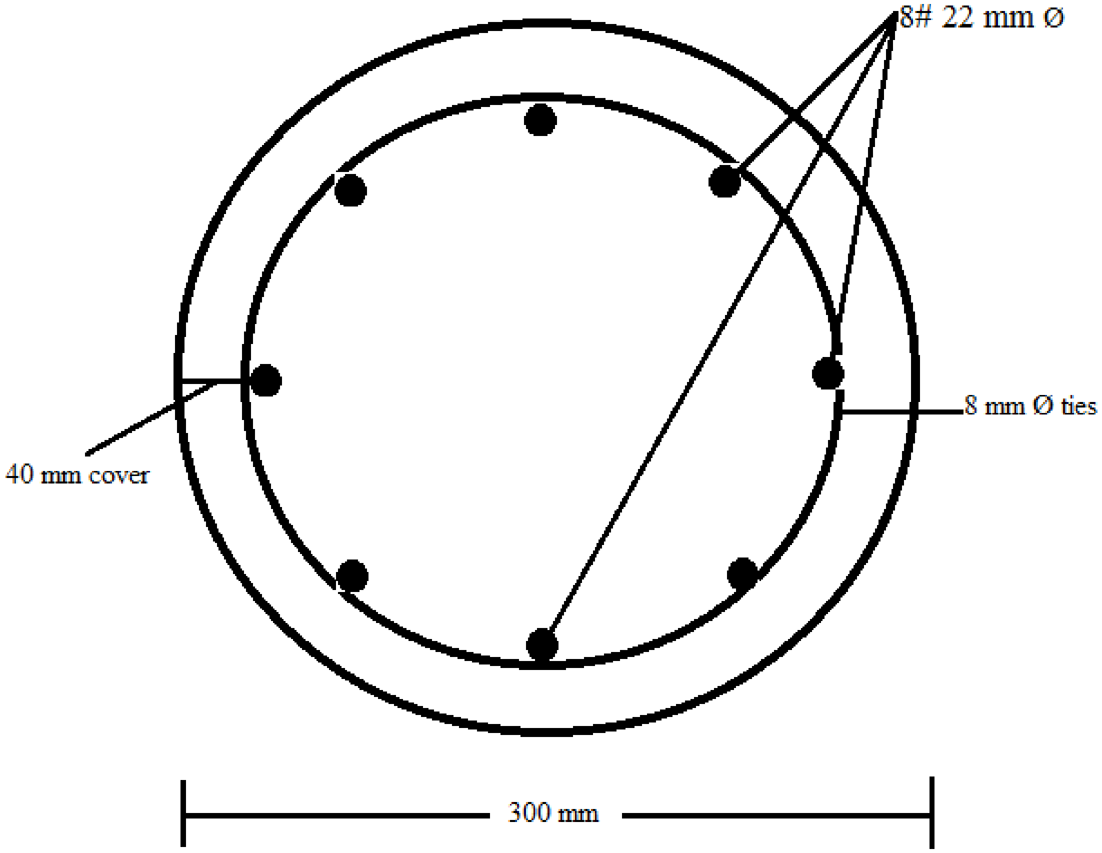


Figure 20: plan of pile detailing

Detailing of pile body:

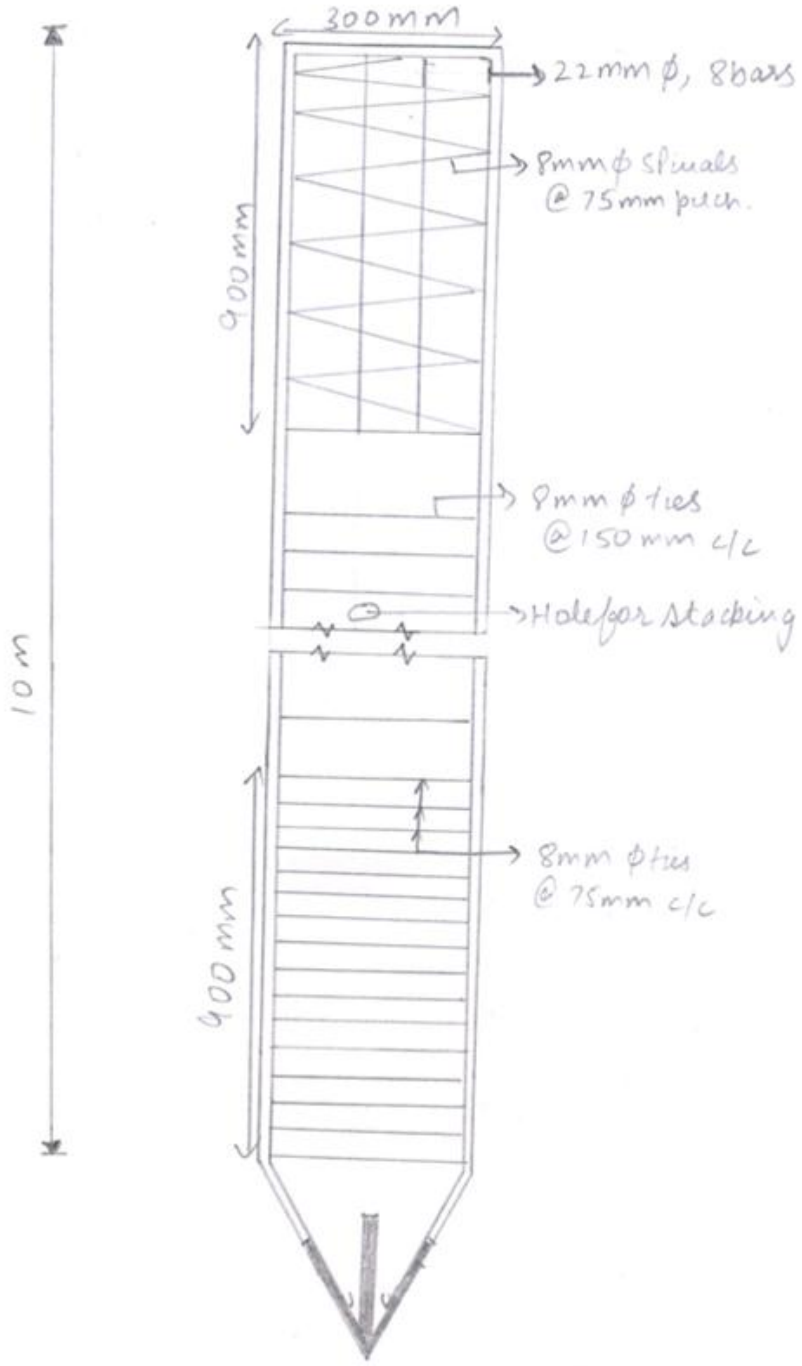


Figure 21: detailing of pile body

CHAPTER 9
R.C.C structure of pile cap

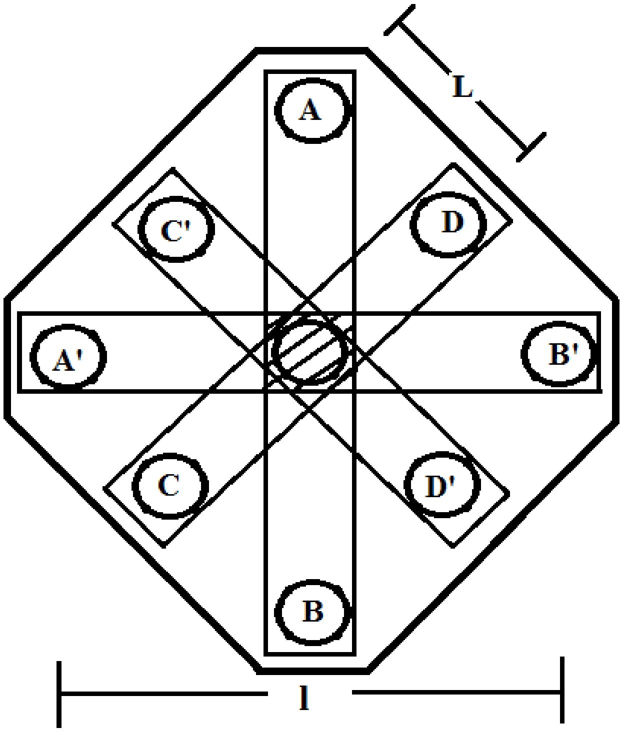


Figure 22: Pile cap for nine piles

Dimension of pile cap:

Centre to centre spacing of piles = L = 1.05 m

Keeping 200 mm clear projection of the cap beyond pile face. Overall length of the cap along the direction AB = 2.1*$\sqrt{2}$ +0.3+0.2 = 3.47 m.

Length of beam CD = 2*L = 2.01 m.

So ..length of cap in the direction DC = 2.01 + 0.3 + 0.2 = 2.51 m.

Design of beam (AB, A'B'):

load on each pile = $W/_9$ = $^{4795.83}/_9$ = 532.87 KN

let the width of beam = width of column = 600mm so …. B.M due to load = 532.87*2.1*$\sqrt{2}$ = 1582.54 KN-m = 1582.54*10^6 N-mm.

In order to claculate the bending moment due to self weight of the beam plus weight of part of slab , let us assume total thickness of slab to be 800 mm , the self weight of the beam is calculated on the assumption that weight of slab equal to two times the width of the beam acts with the beam.

$$w = \frac{3\times600\times800}{106}\times1\times25000 = 36000 \text{ N/m.}$$

length of beam l = 2*L*$\sqrt{2}$ = 2.96 m.

total load =2.96*36000 = 106898.4 N

reaction at A = 106898.4/3 = 35632.8 N

Distance of point of appplication of column load = l/2 = 2.1/$\sqrt{2}$ = 1.48 m

B.M at the centre of column , due to self weight is = (35632.8*1.48) - ($\frac{36000}{2}$*1.48^2)

= 13.3*10^6 N-mm.

Total B.M = 13.3*10^6 + 1582.54 * 10^6

= 1595.14 * 10^6 N-mm

$$d = \sqrt{\frac{1595\times106}{0.914\times600}} = 1705.5 \text{ mm}$$

$$A_{st} = \frac{1595.14*106}{230*0.904*1700} = 4499.24 \text{ mm}^2$$

No. of 25 mm Ø bars = $\frac{4499.24}{490.8}$ = 10

So… provide 10 bars of 25mm Ø

Actual area of steel provided = 10*490.8 = 4908 mm^2.

Design of beam (CD, C'D'):

Span, l = 2.01m

B.M due to load from column = 532.43* 1.05 = 535.5 KN-m.

Load due to to self weight = 36000 N/m

Length of beam = 2.01 m

Reaction at C = 24120 KN .

B.M at the centre of column , due to self weight = (24120 * 1.05) – ($\frac{36000}{2}$*1.05^2)

$= 5.4 * 10^6$ N-mm.

Total B.M = 5.4+535.5

$= 540.9 *10^6$ N-mm

The reinforcment in direction of CD will be placed below the reinforcement of AB.

Hence available d = 1700+25 = 1725mm.

So…..$A_{st} = \frac{540.9*106}{230*0.904*1725} = 1505.6$ mm^2

Hence provide 4 no. of 25 mm Ø bars

Secondary Reinforcement:

Area of secondary reinforcement running round each pile head = 0.2*4499.24

= 899.848 mm^2

Using 20 mm Ø bars , $A_{Ø}$ = 314.4 mm^2

No. of bars = 4 .

Detailing of pile cap is given in fig. 24(next page)

Detailing of pile cap:

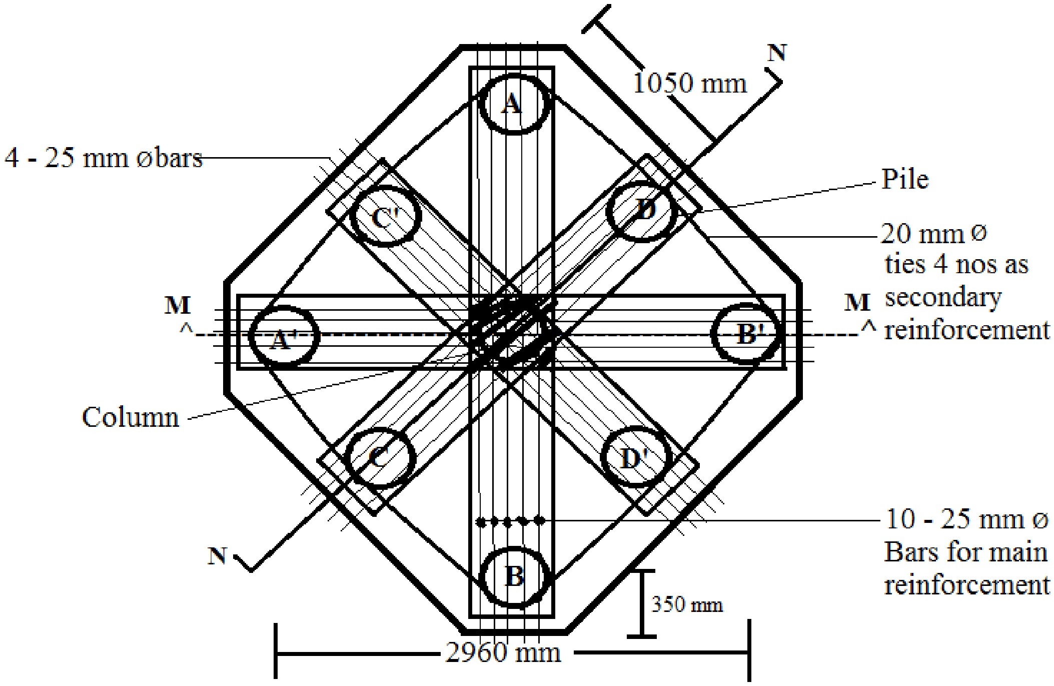


Figure 23: Sectional plan of pile cap

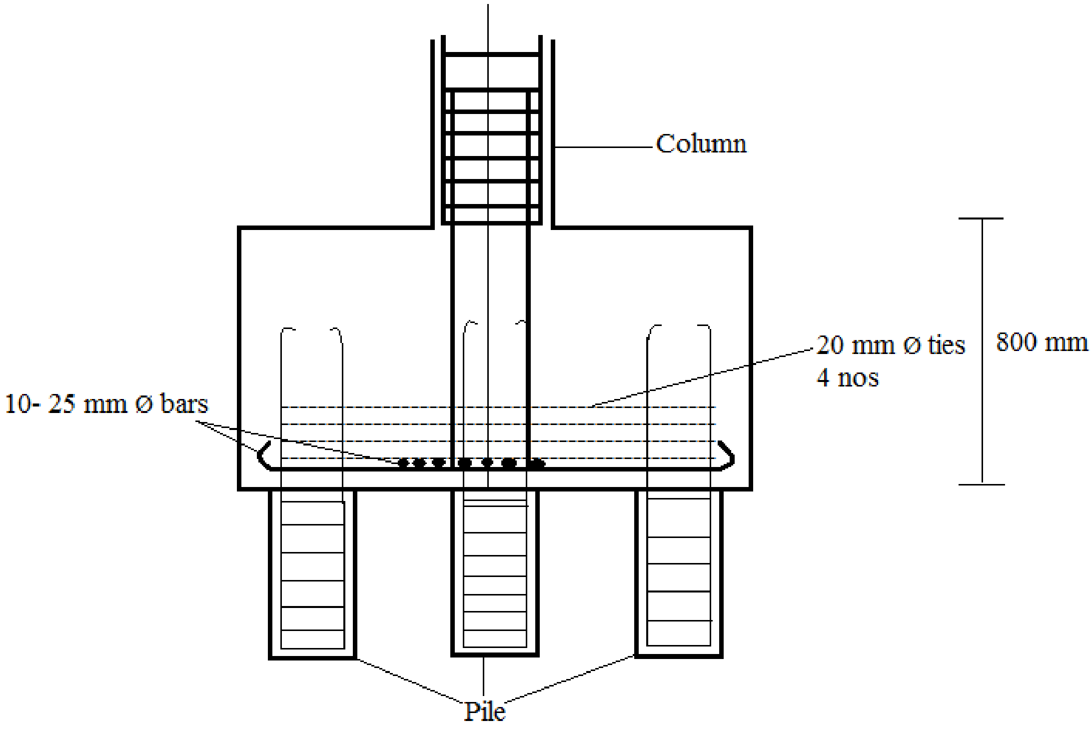
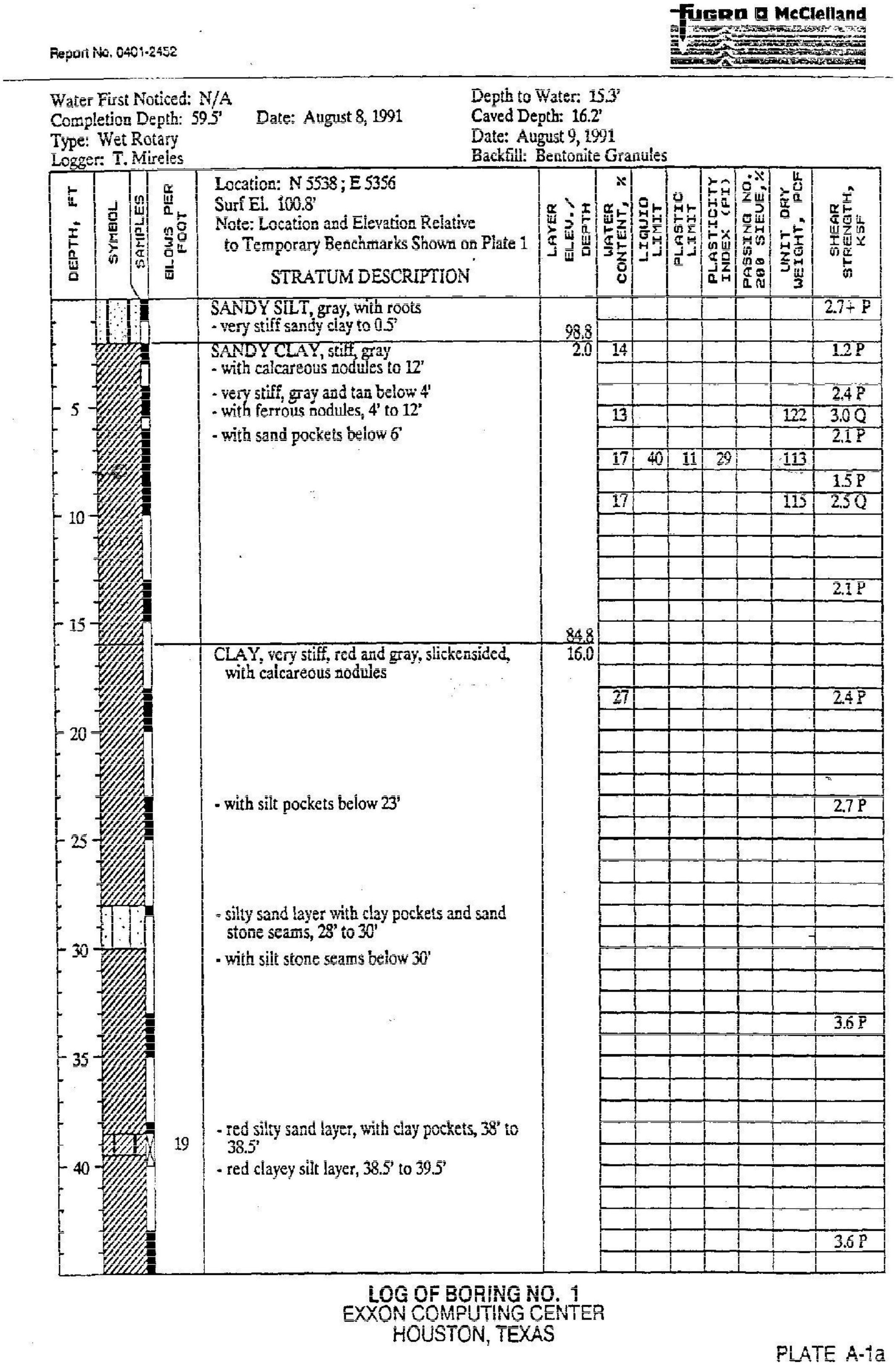


Figure 24: Section at M-M

(Reference: - R.C.C design by B.C Punmia)

APPENDIX (Bore logs)



Fugro McClelland

Report No. 0401-2452

Water First Noticed: N/A
Completion Depth: 59.5' Date: August 8, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.3'
Caved Depth: 16.2'
Date: August 9, 1991
Backfill: Bentonite Granules

Location: N 5538 ; E 5356
Surf El. 100.8'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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, with roots - very stiff sandy clay to 0.5'								2.7+ P
				SANDY CLAY, stiff, gray - with calcareous nodules to 12'	98.8 2.0	14						1.2 P
				- very stiff, gray and tan below 4'								2.4 P
5				- with ferrous nodules, 4' to 12'		13					122	3.0 Q
				- with sand pockets below 6'								2.1 P
						17	40	11	29		113	
												1.5 P
						17					115	2.5 Q
10												
												2.1 P
15												
				CLAY, very stiff, red and gray, slickensided, with calcareous nodules	84.8 16.0							
						27						2.4 P
20												
				- with silt pockets below 23'								2.7 P
25												
				- silty sand layer with clay pockets and sand stone seams, 28' to 30'								
30				- with silt stone seams below 30'								
												3.6 P
35												
			19	- red silty sand layer, with clay pockets, 38' to 38.5'								
40				- red clayey silt layer, 38.5' to 39.5'								
												3.6 P

LOG OF BORING NO. 1
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-1a

Water First Noticed: N/A
Completion Depth: 59.5' Date: August 8, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.3'
Caved Depth: 16.2'
Date: August 9, 1991
Backfill: Bentonite Granules

Location: N 5538 ; E 5356
Surf El. 100.8'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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
				CLAY, very stiff, red, slickensided	53.3 47.5							
50				SANDY CLAY, very stiff, red and gray	48.3 52.5							3.9 P
55			50/11"	SAND, very dense, tan, fine - with silt to 55'								
60			50/8"		41.3 59.5							
65												
70												
75												
80												
85												

LOG OF BORING NO. 1

EXXON COMPUTING CENTER
HOUSTON, TEXAS

Water First Noticed: N/A
Completion Depth: 40.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

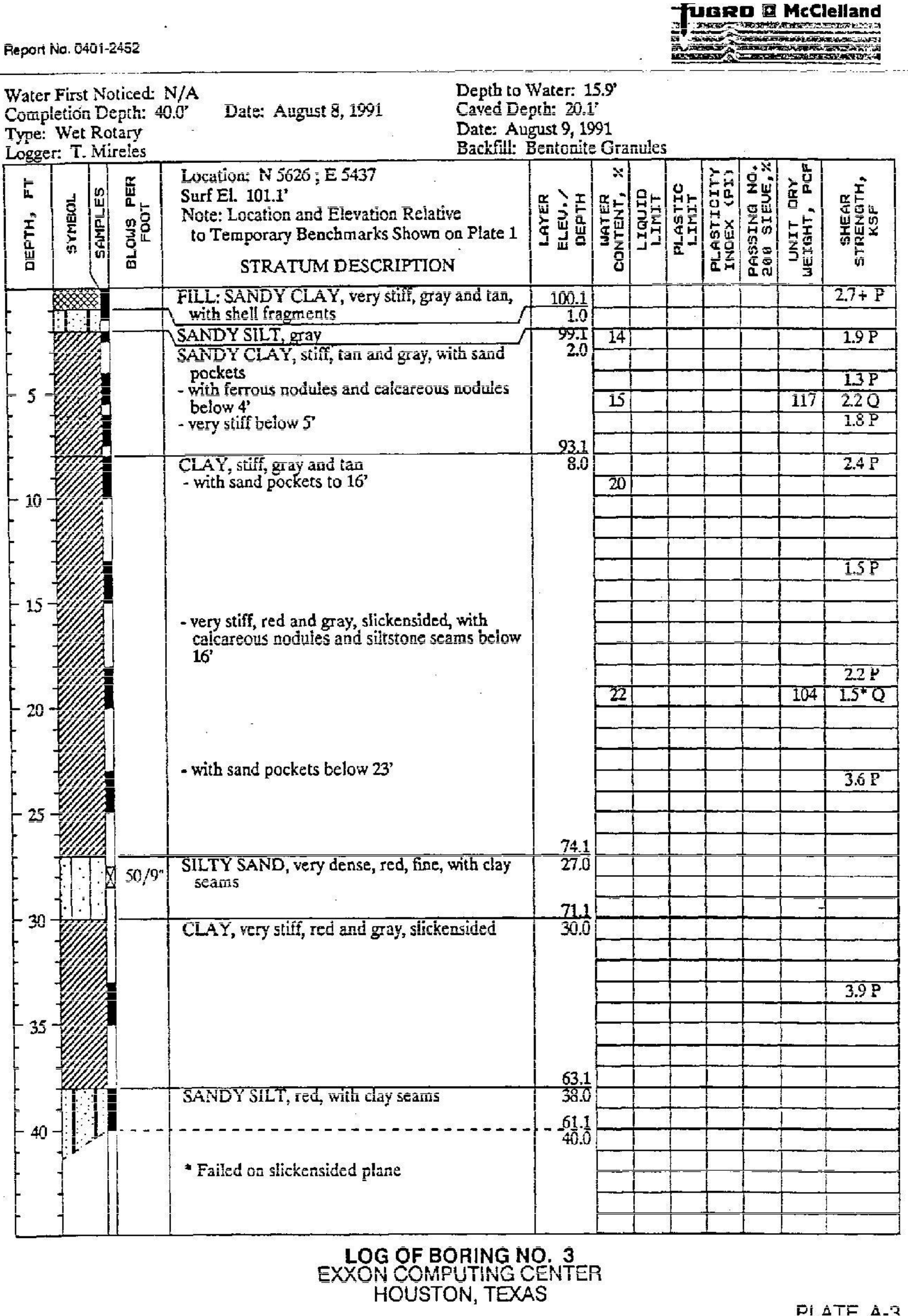
Depth to Water: 15.6'
Caved Depth: 28.6'
Date: August 10, 1991
Backfill: Bentonite Granules

Location: N 5620 ; E 5249
Surf El. 100.5'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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 1.5							
				SANDY CLAY, stiff, tan and gray								1.2 P
						16	33	13	20		112	
				- with ferrous nodules at 4'								1.3 P
5												
				- with calcareous nodules at 6'								1.8 P
				- very stiff below 7'		15					116	2.5 Q
				- with sand pockets below 8'								1.6 P
10					89.5 11.0							
				CLAY, very stiff, red and gray - with sand pockets to 16'								
												2.4 P
						26					98	2.8 Q
15												
				- with siltstone nodules at 18'								2.4 P
						29	73	27	47			
20												
				- with silt pockets below 23'								2.5 P
25												
					73.5 27.0							
				SILTY SAND, very dense, red, with sand stone seams								
			50/1.5"		71.0 29.5							3.9 P
30				CLAY, very stiff, red and gray, slickensided - with siltstone nodules to 33'								
												3.6 P
35												
					63.5 37.0							
				SILTY SAND, very dense, red, fine								
			50/6"									
40					60.5 40.0							

LOG OF BORING NO. 2
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-2



Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 40.0' Date: August 8, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.9'
Caved Depth: 20.1'
Date: August 9, 1991
Backfill: Bentonite Granules

Location: N 5626 ; E 5437
Surf El. 101.1'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

BLOWS PER FOOT	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
	FILL: SANDY CLAY, very stiff, gray and tan, with shell fragments	100.1 1.0							2.7+ P
	SANDY SILT, gray	99.1 2.0	14						1.9 P
	SANDY CLAY, stiff, tan and gray, with sand pockets								1.3 P
	- with ferrous nodules and calcareous nodules below 4'		15					117	2.2 Q
	- very stiff below 5'								1.8 P
	CLAY, stiff, gray and tan	93.1 8.0							2.4 P
	- with sand pockets to 16'		20						
									1.5 P
	- very stiff, red and gray, slickensided, with calcareous nodules and siltstone seams below 16'								2.2 P
			22					104	1.5* Q
	- with sand pockets below 23'								3.6 P
50/9"	SILTY SAND, very dense, red, fine, with clay seams	74.1 27.0							
	CLAY, very stiff, red and gray, slickensided	71.1 30.0							3.9 P
	SANDY SILT, red, with clay seams	63.1 38.0							
		61.1 40.0							

* Failed on slickensided plane

LOG OF BORING NO. 3
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-3

Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 40.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.2'
Caved Depth: 27.2'
Date: August 10, 1991
Backfill: Bentonite Granules

Location: N 5461 ; E 5261
Surf El. 100.4'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

	DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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
1.5					SANDY SILT, gray	98.9 1.5							
					SANDY CLAY, stiff, tan and gray		14						1.9 P
					- very stiff, with calcareous and ferrous nodules below 4'								2.4 P
	5												1.9 P
10							15					118	3.7 Q
													1.9 P
	10					88.9 11.5							
3.5					SILTY CLAY, stiff, red and gray, with sand pockets								1.3 P
						85.4 15.0	23					102	1.7 Q
	15				CLAY, very stiff, red and gray, slickensided, with calcareous nodules								
													3.3 P
11	20												
					- with silt pockets below 23'								3.3 P
	25					74.4 26.0							
2.5					SILTY SAND, red, fine - with sandstone 27' to 28.5'								
1				17	- red, clayey silt layer, 28.5' to 29.5'	70.9 29.5							
	30				CLAY, very stiff, red and gray, slickensided, with siltstone nodules								
8.5													3.6 P
	35					62.4 38.0							
2				19	CLAYEY SILT, medium dense, red	60.4 40.0							
	40												

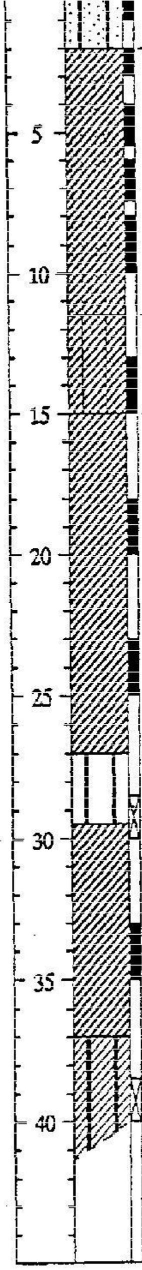
LOG OF BORING NO. 4
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-4

Water First Noticed: N/A
Completion Depth: 40.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.4'
Caved Depth: 19.0'
Date: August 10, 1991
Backfill: Bentonite Granules

Location: N 5470 ; E 5444
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1



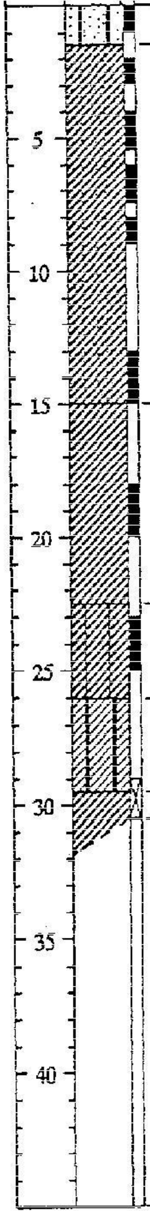
BLOWS PER FOOT	STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX (PI)	PASSING NO. 200 SIEVE,%	UNIT DRY WEIGHT, PCF	SHEAR STRENGTH, KSF
	SANDY SILT, gray								
	- very stiff sandy clay to 0.5'	98.7							
	SANDY CLAY, stiff, gray and tan, with calcareous nodules	2.0							1.5 P
			15						
	- very stiff, tan and gray, with ferrous nodules below 4'								1.5 P
			14	33	13	20		120	2.3 Q
									1.8 P
									1.8 P
			18					112	2.5 Q
		89.2							
	SILTY CLAY, stiff, red and gray	11.5							
									1.2 P
		85.7	21						
	CLAY, very stiff, red and gray, slickensided, with siltstone nodules	15.0							
									3.6 P
	- with silt pockets below 23'								3.3 P
		73.7							
	SILT, medium dense, red, with siltstone seams	27.0							
18		71.2							
	CLAY, very stiff, red and gray, slickensided	29.5							
	- with siltstone seams, 32' to 33.5'								
									3.7 P
		63.7							
	CLAYEY SILT, medium dense, red	37.0							
20		60.7							
		40.0							

LOG OF BORING NO. 5
EXXON COMPUTING CENTER
HOUSTON, TEXAS

Water First Noticed: N/A
Completion Depth: 30.5' Date: August 10, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 13.9'
Caved Depth: 20.3'
Date: August 12, 1991
Backfill: Bentonite Granules

Location: N 5402 ; E 5380
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1



BLOWS PER FOOT	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, light gray - very stiff sandy clay to 0.5'	99.2 1.5							
	SANDY CLAY, very stiff, gray, with sand pockets								2.7+ P
			13						3.9 P
	- tan and gray, below 6'								3.3 P
			14					117	4.6 Q
	- with ferrous nodules at 8'								3.0 P
									2.2 P
	CLAY, very stiff, red and gray, slickensided	85.7 15.0							
	- with calcareous nodules below 18'		33					89	0.88* Q
									2.2 P
	SILTY CLAY, stiff, red and gray	78.2 22.5							
									1.2 P
	CLAYEY SILT, red - with sandstone seams below 27'	74.7 26.0							
									3.3 P
20	CLAY, very stiff, red and gray, slickensided	71.2 29.5							
		70.2 30.5							

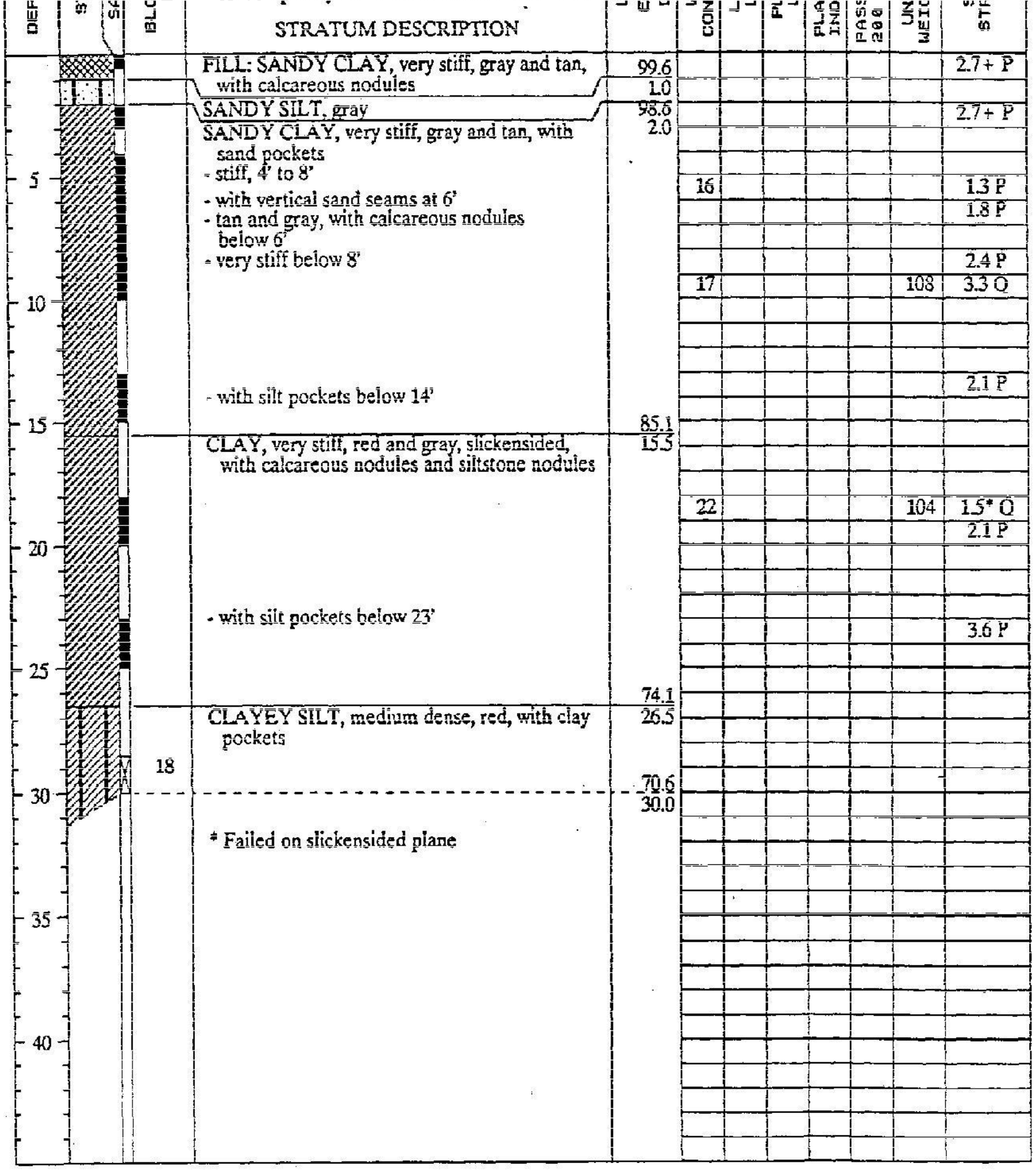
* Failed on a slickensided plane

LOG OF BORING NO. 6
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-6

Water First Noticed: N/A
Completion Depth: 30.0' Date: August 10, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 4.8'
Caved Depth: 9.8'
Date: August 12, 1991
Backfill: Bentonite Granules



DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5539 ; E 5592 Surf El. 100.6' 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
				FILL: SANDY CLAY, very stiff, gray and tan, with calcareous nodules	99.6 1.0							2.7+ P
				SANDY SILT, gray	98.6 2.0							2.7+ P
				SANDY CLAY, very stiff, gray and tan, with sand pockets								
5				- stiff, 4' to 8'		16						1.3 P
				- with vertical sand seams at 6'								1.8 P
				- tan and gray, with calcareous nodules below 6'								
				- very stiff below 8'								2.4 P
						17					108	3.3 Q
10												
												2.1 P
				- with silt pockets below 14'								
15					85.1 15.5							
				CLAY, very stiff, red and gray, slickensided, with calcareous nodules and siltstone nodules								
						22					104	1.5* Q
												2.1 P
20												
				- with silt pockets below 23'								3.6 P
25					74.1 26.5							
				CLAYEY SILT, medium dense, red, with clay pockets								
			18									
30					70.6 30.0							
				* Failed on slickensided plane								
35												
40												

LOG OF BORING NO. 7
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-7

Water First Noticed: N/A
Completion Depth: 39.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

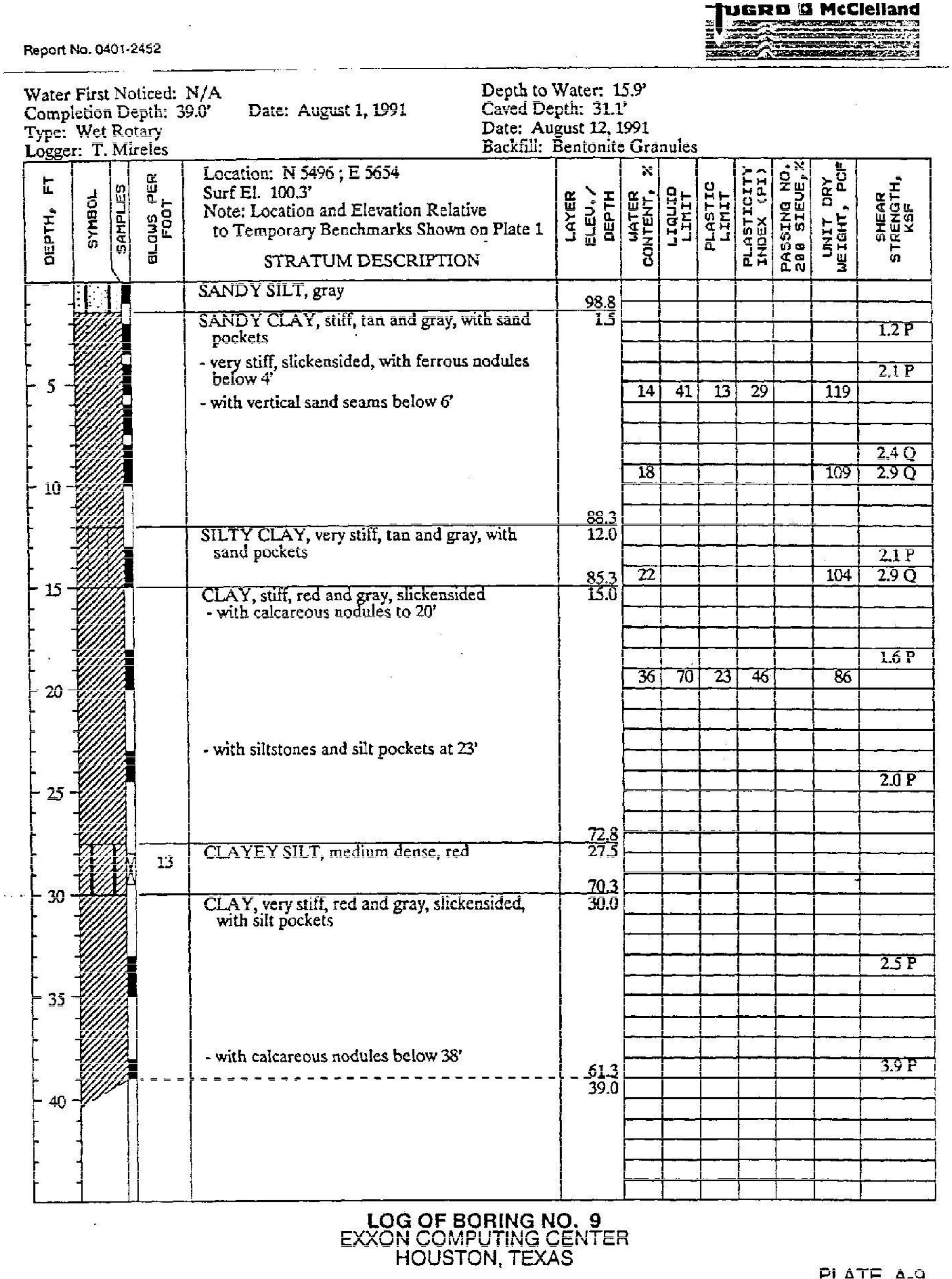
Depth to Water: 14.9'
Caved Depth: 33.6'
Date: August 12, 1991
Backfill: Bentonite Granules

Location: N 5364 ; E 5197
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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	99.7							
				SANDY CLAY, stiff, gray and tan	1.0							
				- with calcareous nodules at 2'								1.3 P
						15						
				- with ferrous nodules at 4'								1.5 P
5						15					116	1.9 Q
				- tan and gray below 6'								1.6 P
					92.7							
				CLAY, stiff, tan and gray, with calcareous nodules and sand pockets	8.0							1.3 P
						23					105	1.4 Q
10												
					88.7							
				SILTY CLAY, stiff, tan and gray, with calcareous nodules and silt pockets	12.0							1.2 P
					85.7							
15				CLAY, very stiff, red and gray, slickensided, with calcareous nodules	15.0							
						29						2.5 P
20												
				- with sand pockets below 23'								2.1 P
25												
					74.2							
			50/6"	SANDY SILT, very dense, red, fine - with sandstone seams below 28'	26.5					60		
					71.2							
30				CLAY, very stiff, red, slickensided	29.5							
				- with sandstone seam at 32'								3.6 P
35												
					62.7							
				SILTY SAND, red, fine, with clay pockets and sandstone nodules	38.0							
					61.7							
40					39.0							

LOG OF BORING NO. 8
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-8



Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 39.0' Date: August 1, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 15.9'
Caved Depth: 31.1'
Date: August 12, 1991
Backfill: Bentonite Granules

Location: N 5496 ; E 5654
Surf El. 100.3'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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	98.8 1.5							
				SANDY CLAY, stiff, tan and gray, with sand pockets								1.2 P
				- very stiff, slickensided, with ferrous nodules below 4'								2.1 P
5				- with vertical sand seams below 6'		14	41	13	29		119	
												2.4 Q
						18					109	2.9 Q
10					88.3 12.0							
				SILTY CLAY, very stiff, tan and gray, with sand pockets								2.1 P
					85.3 15.0	22					104	2.9 Q
15				CLAY, stiff, red and gray, slickensided - with calcareous nodules to 20'								
												1.6 P
						36	70	23	46		86	
20												
				- with siltstones and silt pockets at 23'								
25												2.0 P
					72.8 27.5							
			13	CLAYEY SILT, medium dense, red								
30					70.3 30.0							
				CLAY, very stiff, red and gray, slickensided, with silt pockets								
												2.5 P
35												
				- with calcareous nodules below 38'								3.9 P
					61.3 39.0							
40												

LOG OF BORING NO. 9
EXXON COMPUTING CENTER
HOUSTON, TEXAS

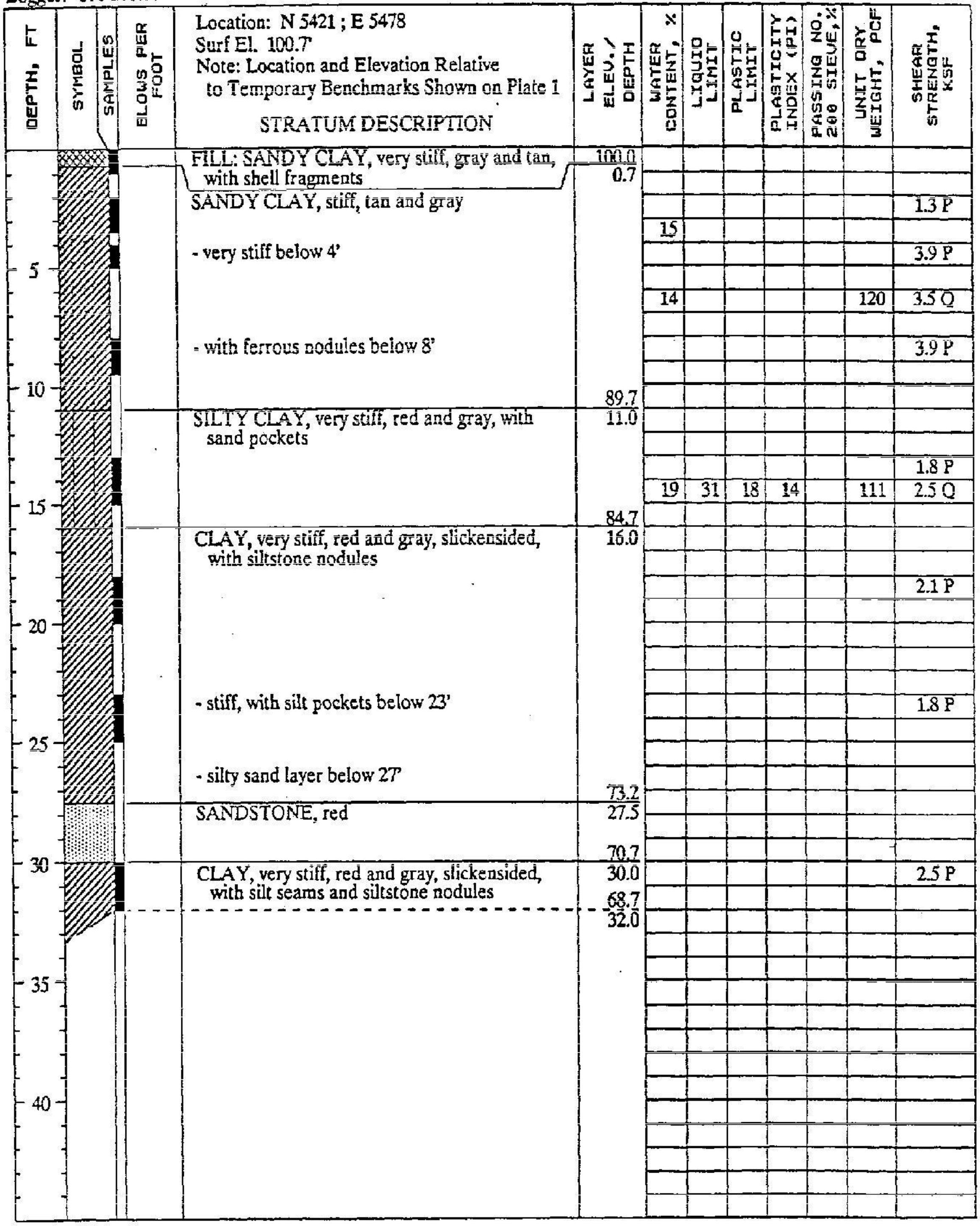
PLATE A-9

Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 32.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 7.8'
Caved Depth: 12.4'
Date: August 10, 1991
Backfill: Bentonite Granules



Location: N 5421 ; E 5478
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

BLOWS PER FOOT	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
	FILL: SANDY CLAY, very stiff, gray and tan, with shell fragments	100.0 0.7							
	SANDY CLAY, stiff, tan and gray								1.3 P
			15						
	- very stiff below 4'								3.9 P
			14					120	3.5 Q
	- with ferrous nodules below 8'								3.9 P
	SILTY CLAY, very stiff, red and gray, with sand pockets	89.7 11.0							
									1.8 P
			19	31	18	14		111	2.5 Q
	CLAY, very stiff, red and gray, slickensided, with siltstone nodules	84.7 16.0							
									2.1 P
	- stiff, with silt pockets below 23'								1.8 P
	- silty sand layer below 27'								
	SANDSTONE, red	73.2 27.5							
	CLAY, very stiff, red and gray, slickensided, with silt seams and siltstone nodules	70.7 30.0							2.5 P
		68.7 32.0							

LOG OF BORING NO. 10
EXXON COMPUTING CENTER
HOUSTON, TEXAS

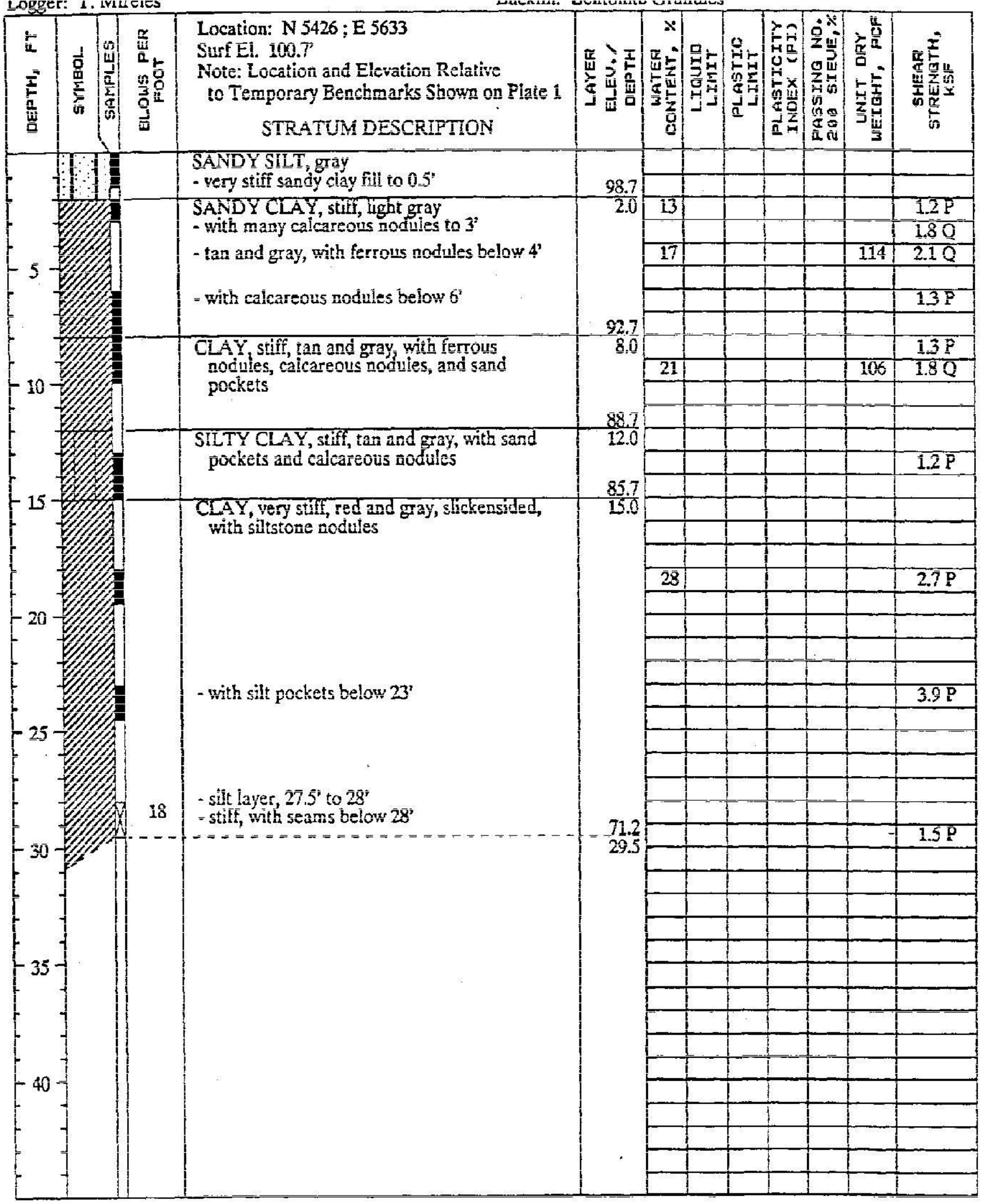
PLATE A-10

Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 29.5' Date: August 10, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 14.3'
Caved Depth: 19.1'
Date: August 12, 1991
Backfill: Bentonite Granules

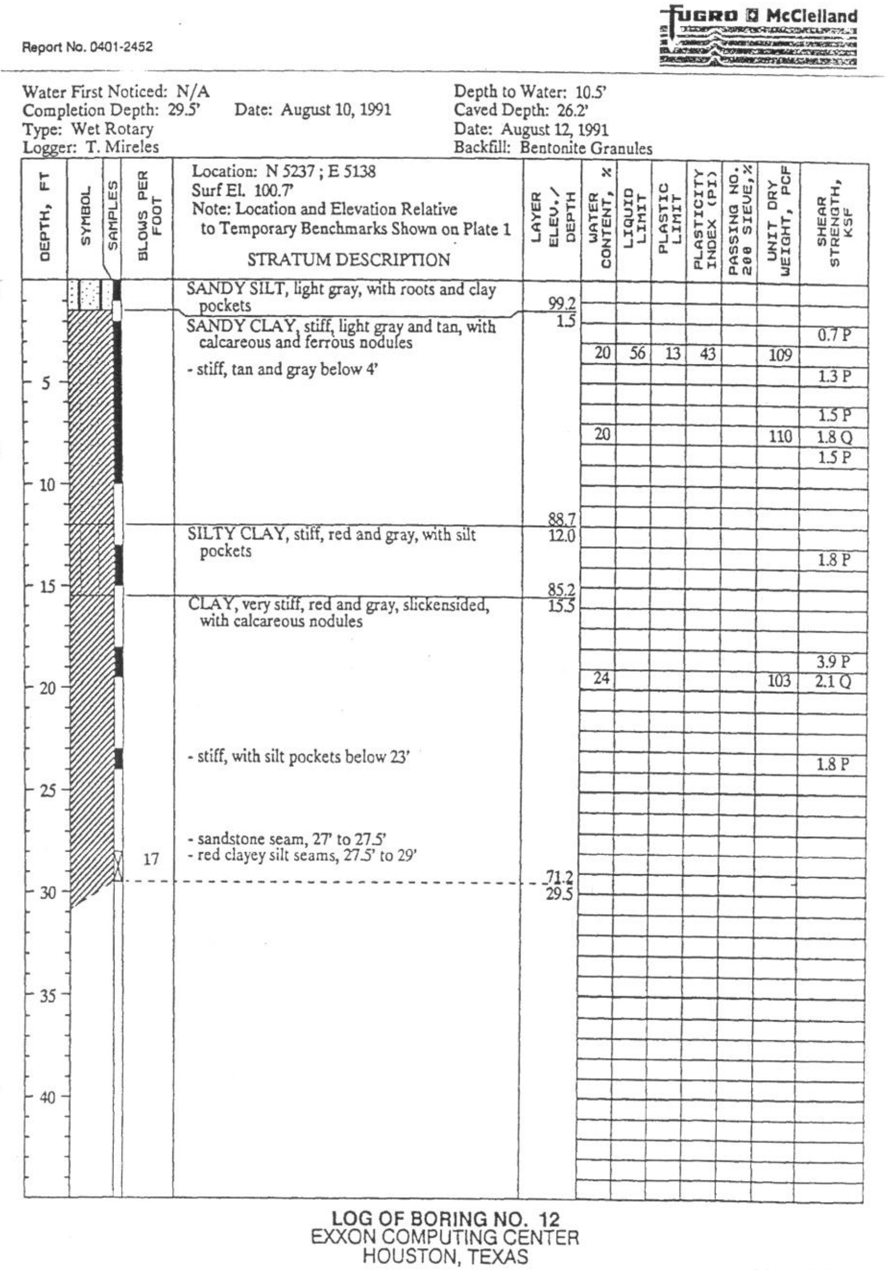


Location: N 5426 ; E 5633
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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 - very stiff sandy clay fill to 0.5'	98.7							
				SANDY CLAY, stiff, light gray	2.0	13						1.2 P
				- with many calcareous nodules to 3'								1.8 Q
				- tan and gray, with ferrous nodules below 4'		17					114	2.1 Q
5												
				- with calcareous nodules below 6'								1.3 P
					92.7							
				CLAY, stiff, tan and gray, with ferrous nodules, calcareous nodules, and sand pockets	8.0							1.3 P
						21					106	1.8 Q
10												
					88.7							
				SILTY CLAY, stiff, tan and gray, with sand pockets and calcareous nodules	12.0							1.2 P
					85.7							
15				CLAY, very stiff, red and gray, slickensided, with siltstone nodules	15.0							
						28						2.7 P
20												
				- with silt pockets below 23'								3.9 P
25												
			18	- silt layer, 27.5' to 28' - stiff, with seams below 28'								
					71.2 29.5							1.5 P
30												
35												
40												

LOG OF BORING NO. 11
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-11



Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 29.5' Date: August 10, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 10.5'
Caved Depth: 26.2'
Date: August 12, 1991
Backfill: Bentonite Granules

Location: N 5237 ; E 5138
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

1.5

10.5

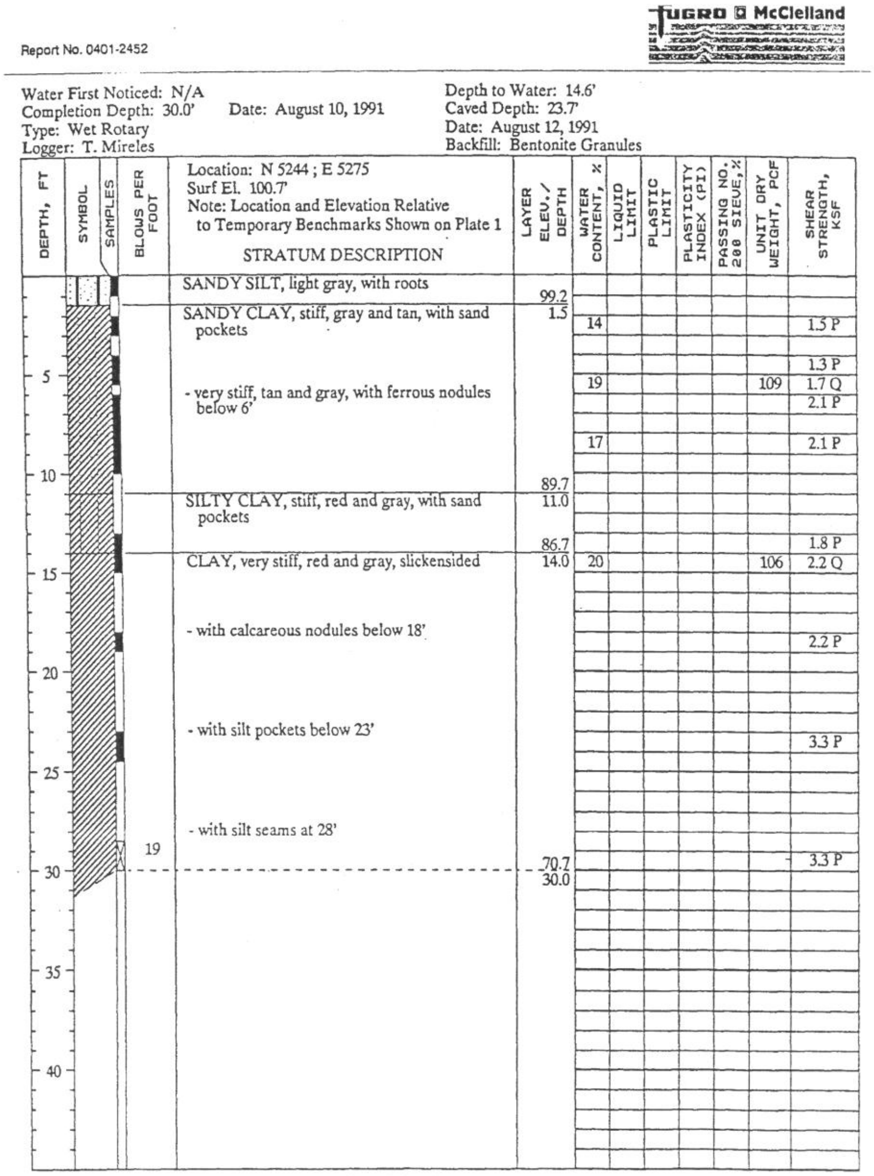
3.5

14

DEPTH, FT	BLOWS PER FOOT	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, light gray, with roots and clay pockets	99.2 1.5							
		SANDY CLAY, stiff, light gray and tan, with calcareous and ferrous nodules								0.7 P
				20	56	13	43		109	
		- stiff, tan and gray below 4'								
5										1.3 P
										1.5 P
				20					110	1.8 Q
										1.5 P
10										
		SILTY CLAY, stiff, red and gray, with silt pockets	88.7 12.0							
										1.8 P
15		CLAY, very stiff, red and gray, slickensided, with calcareous nodules	85.2 15.5							
										3.9 P
20				24					103	2.1 Q
		- stiff, with silt pockets below 23'								1.8 P
25										
	17	- sandstone seam, 27' to 27.5' - red clayey silt seams, 27.5' to 29'								
30			71.2 29.5							
35										
40										

LOG OF BORING NO. 12
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-12



Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 30.0' Date: August 10, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 14.6'
Caved Depth: 23.7'
Date: August 12, 1991
Backfill: Bentonite Granules

Location: N 5244 ; E 5275
Surf El. 100.7'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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, light gray, with roots	99.2 1.5							
				SANDY CLAY, stiff, gray and tan, with sand pockets		14						1.5 P
												1.3 P
5						19					109	1.7 Q
				- very stiff, tan and gray, with ferrous nodules below 6'								2.1 P
						17						2.1 P
10					89.7 11.0							
				SILTY CLAY, stiff, red and gray, with sand pockets	86.7 14.0							1.8 P
15				CLAY, very stiff, red and gray, slickensided		20					106	2.2 Q
				- with calcareous nodules below 18'								2.2 P
20												
				- with silt pockets below 23'								3.3 P
25												
			19	- with silt seams at 28'								3.3 P
30					70.7 30.0							
35												
40												

LOG OF BORING NO. 13
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-13

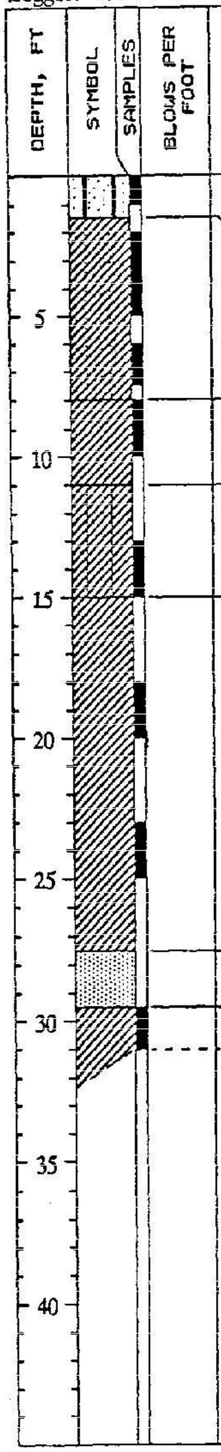
Report No. 0401-2452

FUGRO McClelland

Water First Noticed: N/A
Completion Depth: 31.0' Date: August 9, 1991
Type: Wet Rotary
Logger: T. Mireles

Depth to Water: 14.9'
Caved Depth: 18.4'
Date: August 10, 1991
Backfill: Bentonite Granules

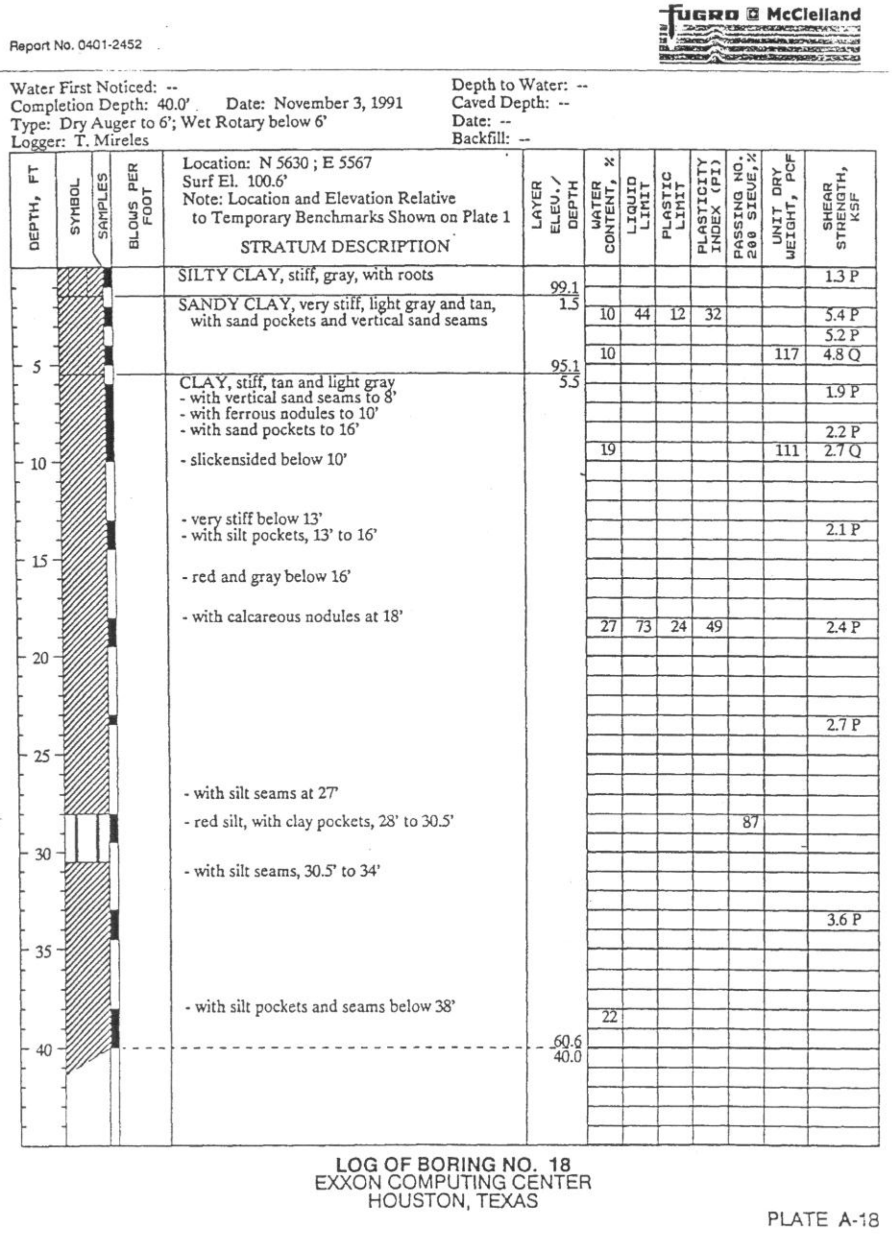
Location: N 5777 ; E 5371
Surf El. 101.1'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1



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 - very stiff sandy clay fill to 0.5'	99.6 1.5							
SANDY CLAY, stiff, tan and gray, with sand pockets and calcareous nodules								1.3 P
		14					119	2.8 U
- very stiff, 4' to 6'								3.9 P
- stiff, with ferrous nodules below 6'		20						1.6 P
CLAY, stiff, tan and gray, with sand pockets and calcareous nodules	93.1 8.0							1.2 P
		18					108	1.2 Q
SILTY CLAY, stiff, tan and gray, with silt pockets	90.1 11.0							
								1.8 P
CLAY, very stiff, red and gray, slickensided, with siltstone nodules	86.1 15.0							
								3.6 P
								3.9 P
- silty sand layer, 27' to 27.5'								
SANDSTONE, red, with silt seams	73.6 27.5							
CLAY, very stiff, red, slickensided, with silt pockets and siltstone nodules	71.6 29.5							3.7 P
	70.1 31.0							

LOG OF BORING NO. 17
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-17



Report No. 0401-2452

FUGRO McClelland

Water First Noticed: --
Completion Depth: 40.0' Date: November 3, 1991
Type: Dry Auger to 6'; Wet Rotary below 6'
Logger: T. Mireles

Depth to Water: --
Caved Depth: --
Date: --
Backfill: --

Location: N 5630 ; E 5567
Surf El. 100.6'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

0.75 -1.5

2 4

11.25 22.5

1.25 - 2.5

4.75 - 9.5

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	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
				SILTY CLAY, stiff, gray, with roots								1.3 P
					99.1 1.5							
				SANDY CLAY, very stiff, light gray and tan, with sand pockets and vertical sand seams		10	44	12	32			5.4 P
												5.2 P
						10					117	4.8 Q
5					95.1 5.5							
				CLAY, stiff, tan and light gray - with vertical sand seams to 8' - with ferrous nodules to 10' - with sand pockets to 16'								1.9 P
												2.2 P
						19					111	2.7 Q
10				- slickensided below 10'								
				- very stiff below 13' - with silt pockets, 13' to 16'								2.1 P
15												
				- red and gray below 16'								
				- with calcareous nodules at 18'		27	73	24	49			2.4 P
20												
												2.7 P
25												
				- with silt seams at 27'								
				- red silt, with clay pockets, 28' to 30.5'						87		
30				- with silt seams, 30.5' to 34'								
												3.6 P
35												
				- with silt pockets and seams below 38'		22						
40					60.6 40.0							

LOG OF BORING NO. 18
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-18

Report No. 0401-2452

FUGRO McClelland

Water First Noticed: --
Completion Depth: 50.0' Date: November 3, 1991
Type: Dry Auger to 10'; Wet Rotary below 10'
Logger: T. Mireles

Depth to Water: --
Caved Depth: --
Date: --
Backfill: Bentonite Granules

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5634 ; E 5712 Surf El. 100.4' 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
	▨				52.4 48.0							
50		☒	27	SILTY SAND, medium dense, light gray and tan, fine, with sandy clay pockets	50.4 50.0					37		
55												
60												
65												
70												
75												
80												
85												

LOG OF BORING NO. 19
EXXON COMPUTING CENTER
HOUSTON, TEXAS

PLATE A-19b

REFERNCES

- Idealized soil profile, bore log data.
- Load carrying capacity of pile group, Ranjan, Gopal and Rao, A.S.R. basic and applied soil mechanics: 4835/24, Ansari road, daryaganj, new delhi-110002.
- R.C.C design of pile body and pile cap, Dr.B.C. Punmia, Err. Ashok Kumar Jain, Dr. Arun K.Jain. R.C.C. Designs: Golden house, Daryaganjand new delhi-110002.
- Geotechnical engineering by Gulati and Dutta.
- I.S codes: IS 2911_part 1_sec – 1
  IS 2911_part 1_sec – 2
  IS 875_3 (wind speed, loading on building).
  IS 8009 part –2
- Foundation design, Principles and practices, Donald P. Coduto.