ANALYSIS OF TWO-STOREY RCC FRAME AND DESIGN OF ITS FOUNDATION BY SKEMPTON'S METHOD

Enrollment number – 101625

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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

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CERTIFICATE

This is to certify that the work titled **"Analysis of two-storey RCC frame and Design of its foundation by using Skempton's method"** submitted by **"Tshering Pelden"** in partial fulfillment for the award of degree of B. Tech in Civil Engineering program 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 HOD	
Name of HOD	Prof. Dr. Ashok Kumar Gupta
Designation	Professor and Head
Date	

Signature of Supervisor	
Name of Supervisor	Dr. S.K Jain
Designation	Associate Professor
Date	

Signature of Supervisor	
Name of Supervisor	Mr. Lav Singh
Designation	Assistant Professor
Date	

DECLARATION BY THE CANDIDATE

I hereby declare that the project entitled **"Analysis of two-storey RCC frame and Design of its foundation by using Skempton's method"** submitted by me to Jaypee University of Information Technology, Waknaghat in partial fulfillment of the Degree of Bachelor of Technology in Civil Engineering is a record of bona fide project work carried out by me under the guidance of Dr. S.K Jain. The information submitted herein is true and original.

Signature of the student

Name of student Tshering Pelden

Date

ACKNOWLEDGEMENT

I would like to take this opportunity to express my heart filled gratitude to all the people who has directly or indirectly helped in the successful completion of this project. I would like to especially thank the entire faculty and staff members of the Civil Engineering Department, JUIT, Waknaghat without whose support and encouragement this project would not have been possible.

I would like to thank my project guide Dr. S. K Jain for firstly giving us such a noble opportunity to do a project on a topic which would be very beneficial for not only us but all other civil engineers and I would like to thank sir for guiding us throughout the whole journey of the project.

I would like to express my gratitude to Mr. Lav Singh for his hand in the project especially in the structural aspects of the building that we are designing. I would to thank sir for answering all our queries.

I would also like to thank my family, friends and my group mates for their continuous support.

Signature of the student

Name of student Tshering Pelden

Date

SUMMARY

This project that is "Analysis of two-storey RCC frame and Design of its foundation by using Skempton's method" basically deals with the designing of a two storey building along with the design of its foundation. To carry out the project, we were given with different data like:

Plan of boring

Boring logs

Laboratory test data

In situ test data

Firstly considering the test data soil profiles along three different sections are created. Then an idealized soil profile is created by combining and averaging the values such as depth of various sections, the densities of each section etc. For the idealized soil profile we find out different soil properties like c, ø etc.

Then we make the model of the building on STAAD PRO and analyze it to get the reactions at the base. This way the actual load that would be coming on the foundation can be determined.

Thereafter different components of the building like beam, column, slab and foundation are designed. The designing is done according to design procedures given in IS 456: 2000 taking the loads as specified in IS 875. The designing would be done inclining more towards safety rather than economy. Firstly look into all the conditions and pick the worst case scenario and design of that. The final design for that worst scenario would be provided for all other parts too and this will ensure that our structure is safe on all parts.

Signature of Student		Signature of Supervisor	
Name	Tshering Pelden	Name	Dr. S.K Jain
Date		Date	

LIST OF FIGURES:

SYMBOLS:

Symbol	Description	Units
w_n	Water content	%
w_L	Liquid limit	%
w_P	Plastic limit	%
I_P	Plasticity index	-
γ_d	Unit dry weight	kN/m^3
c_u	Un-drained shear strength	kN/m^2
D	Depth of foundation	m
B	Width of foundation	m
V_z	Design wind speed at any height z	m/s
k_1	Probability factor	-
k_2	Terrain height and structure size factor	-
k_3	Topography factor	-
V_b	Basic wind speed	m/s
P_z	Wind pressure	kN/m^2
Nc	Bearing capacity factor	-
q_{nu}	Net ultimate bearing capacity	kN/m^2
q_{ns}	Safe bearing capacity	kN/m^2
P	Column load	kN
d	Effective depth of footing	m
L	Length of foundation	m
V_{u1}	Factored one way shear force	kN
V_{c1}	One-way shear resistance	kN

V_{u2}	Factored two way shear force	kN
V_{c2}	Two-way shear resistance	kN
M_u	Ultimate moment	kN.m
P_t	Percentage reinforcement	%
Ast	Area of steel	mm^2
s	Spacing	mm

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 or vice versa. 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. This project is such a work in which not only a building is designed but its foundation is also designed using the loads computed, that is knowledge of more than one subject is incorporated in this project.

Yet this project is a very simple one that is to construct a two storey building frame in STAAD PRO and designing its foundation. The data in hand like bore log data, consolidation data, etc. are studied and then a soil profile is created on which the building will stand. Then various soil parameters are found. Based on these soil parameters found the bearing capacity and settlement criterion are found. Design the two storey building is proceeded by assuming data like the clear height between floors, dimension of elements and their quantity.

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 of a place in Houston, Texas has been provided. The site investigation involved geotechnical drilling, sampling and laboratory testing.

Data provided:

Plan of boring

Boring logs

Laboratory test data

In situ test data

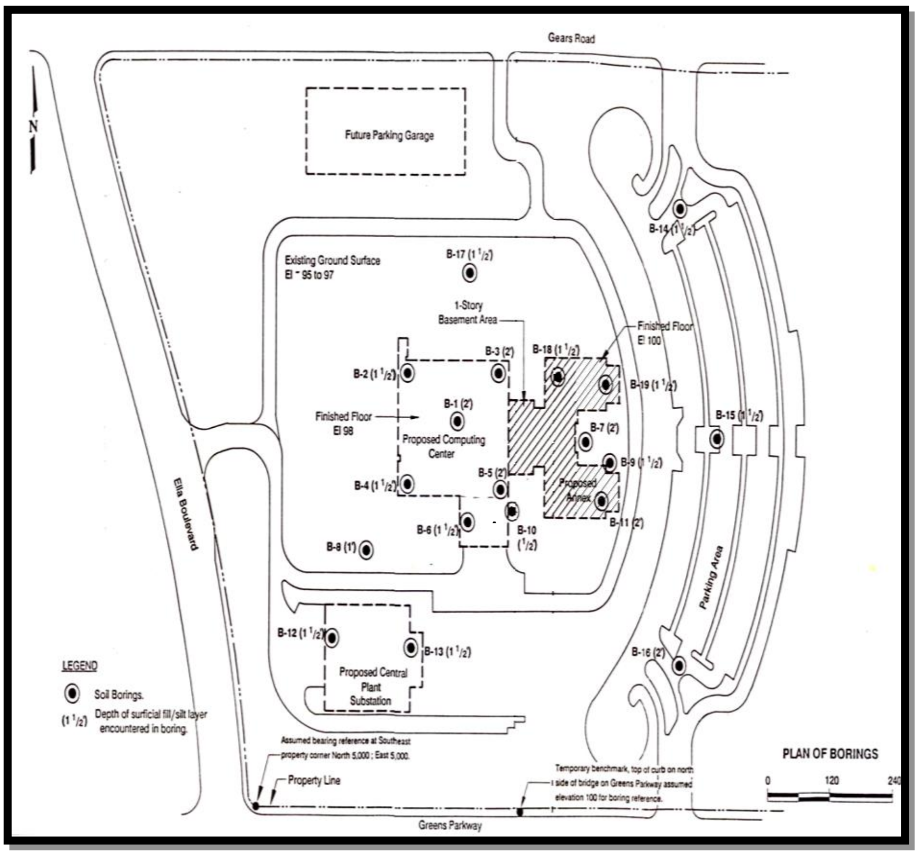


Figure 2.1: Plan of boring

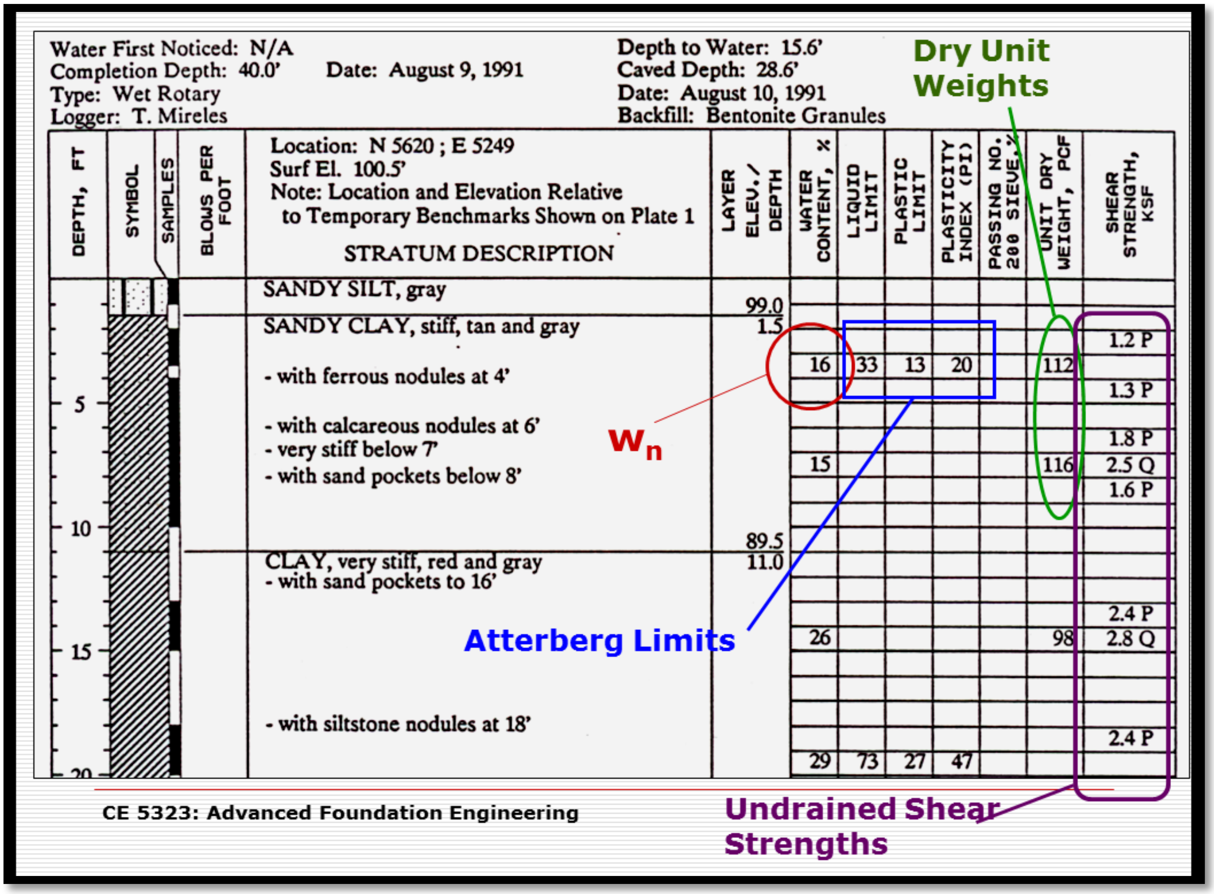


Figure 2.2: Bore log data

Various parameters of soil are given alongside the depth of soil. The data given above is for one particular bore hole. The same bore log data for the other boreholes are given in the appendix.

Some of the parameters of the soil are defined below: [R2.1]

- **Water content**, w_n also called moisture content is defined as the ratio of weight of water to the weight of solids in a given mass of soil.
- **Atterbergs limit**:
  Liquid limit, w_L is the water content at which soil is practically in a liquid state but has an infinitesimal resistance against flow.
  Plastic limit, w_P is defined as the water content at which a soil would just begin to crumble when rolled into a thread of approximately 3mm diameter.
  Plasticity index, I_P is the range of moisture content over which a soil exhibits plasticity.
- **Unit dry weight**, γ_d is the weight of solid per unit of total volume.
- **Un-drained shear strength**, c_u is the property of saturated clay(ϕ_u=0) to resist shearing stress.

In the given data the values of different parameters defined above at different depth are given. The letters ‘P’ and ‘Q’ mentioned together with un-drained shear strength value symbolizes the type of in-situ test used to determine the value i.e. pocket penetrometer test and unconsolidated un-drained tri-axial test respectively.

For more detail on the bore log data and various test used to get the soil parameters refer to appendix.

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, three soil profiles were created by analyzing for various features like depth, water table, stratum description and other information. Step by step procedure is given below:

1. Selecting the section for which the soil profile is to be made

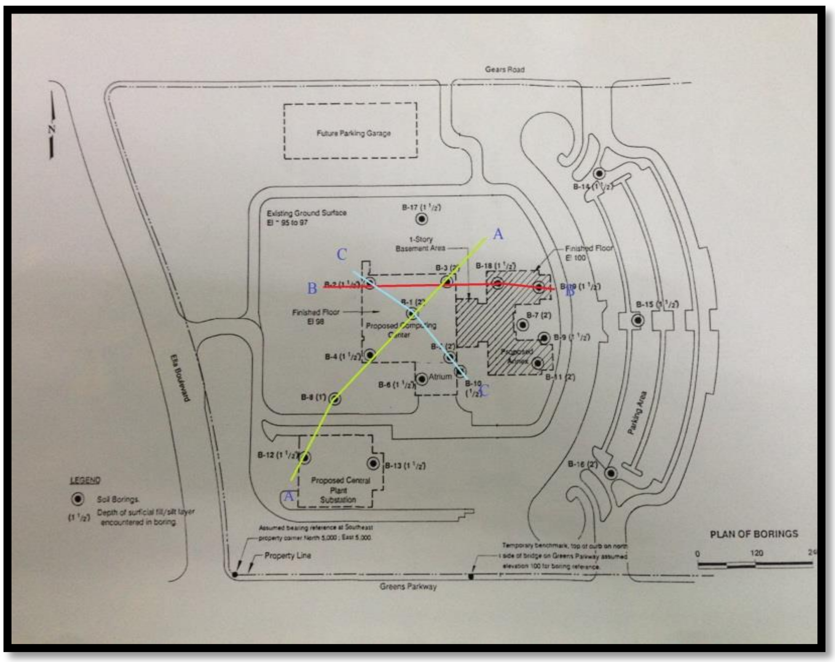


Figure 3.1: Plan of boring marked with sections of soil profile

   The sections marked A-A, B-B and C-C for making the soil profile as it covers most of the area on which the building is to be placed.

2. The distance between two consecutive bore holes along the chosen section is measured using a ruler.
3. Referring to the scale given in the plan and the actual distance between the bore holes are determined.
   - ❖ Scale for the given plan:
     1 cm = 70.58ft
     1 cm = 21.51m

4. For drawing the soil profile an appropriate scale (both horizontal and vertical) may be chosen for the drawing sheet.
    - ❖ Scale for our drawing sheet
    - Vertical scale

      1cm = 2ft
    - Horizontal scale

      1cm =10ft
5. The bore log data is plotted on the sheet.
6. After all data has been plotted, some rough indication of the profile will come into picture. Since three sections were chosen there will be three soil profiles.

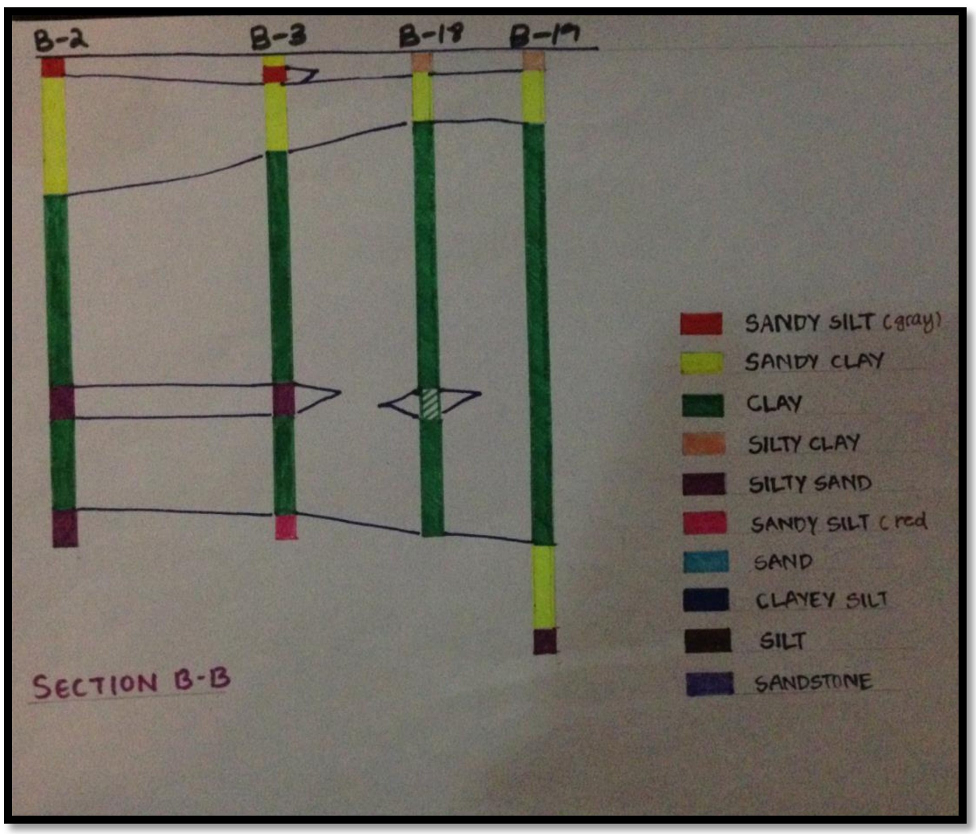


Figure 3.2: Soil profile of Section B-B

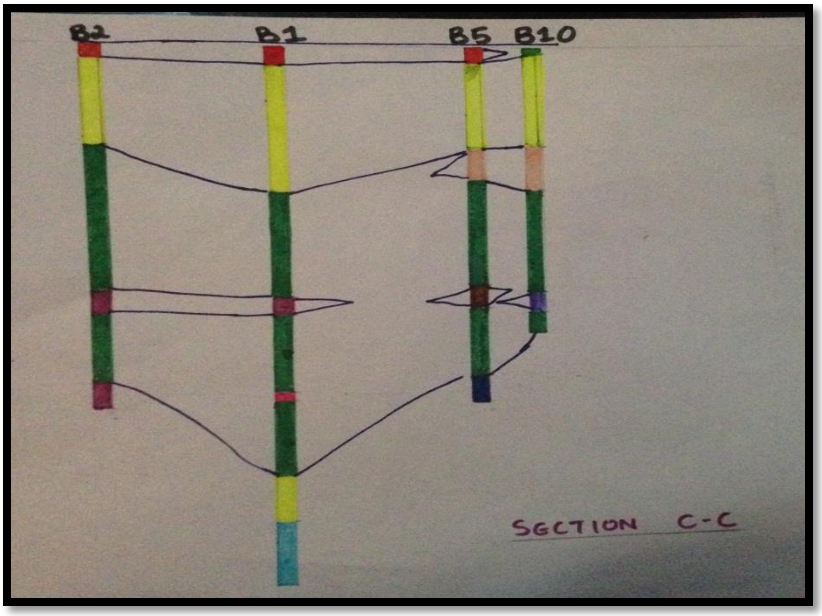


Figure 3.3: Soil profile of section C-C

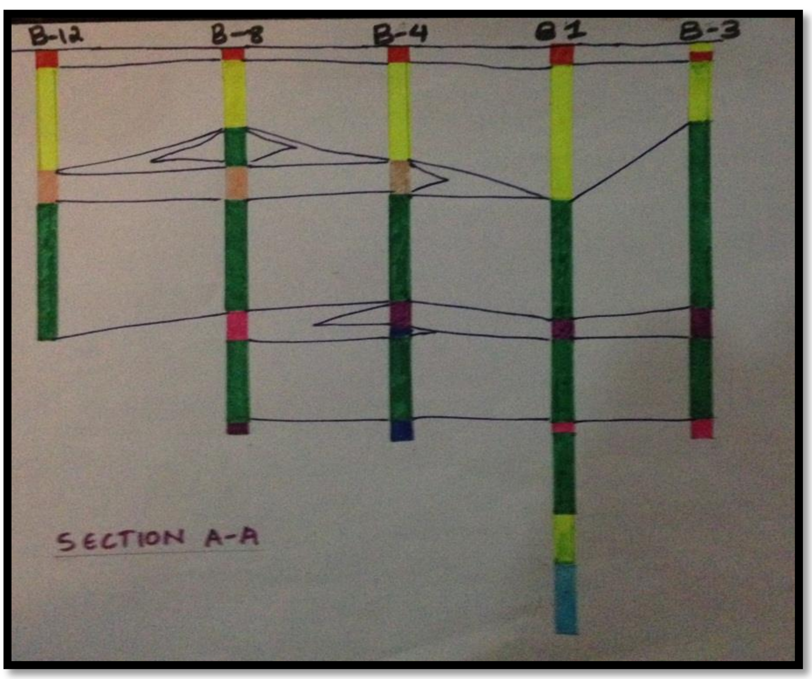


Figure 3.4: Soil profile of section A-A

7. Joinall the layers having same soil type and create lenses for soil types which is present at a section of one or two bore holes only. This is done for all the three sections that have been 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.

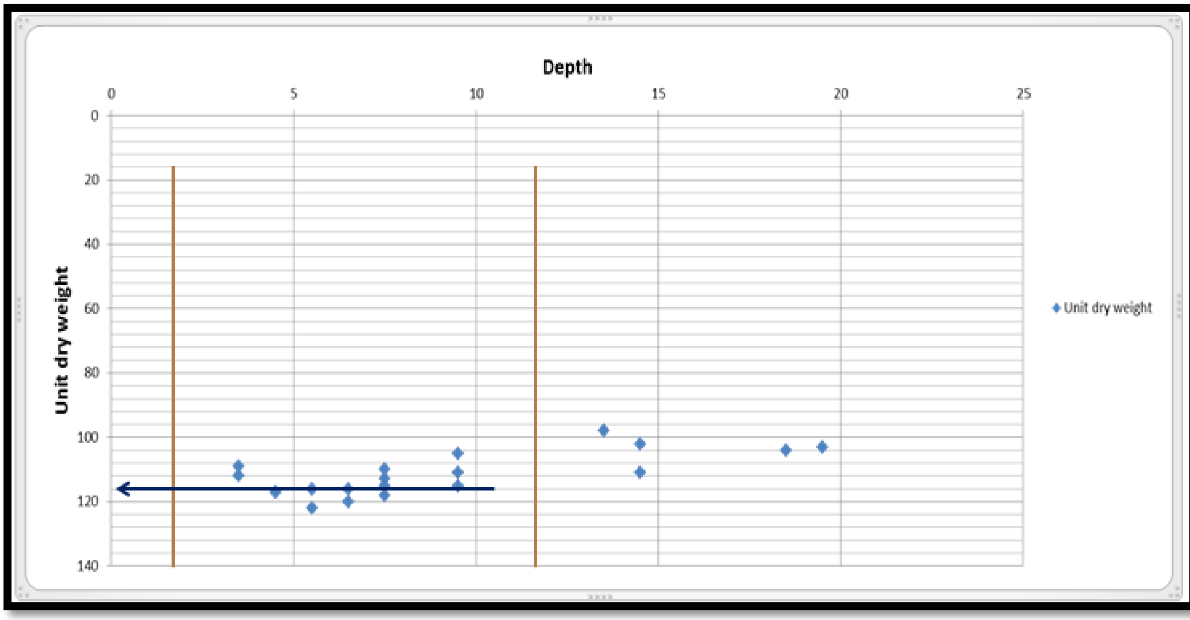
Figure 3.5: Idealized soil profile

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.

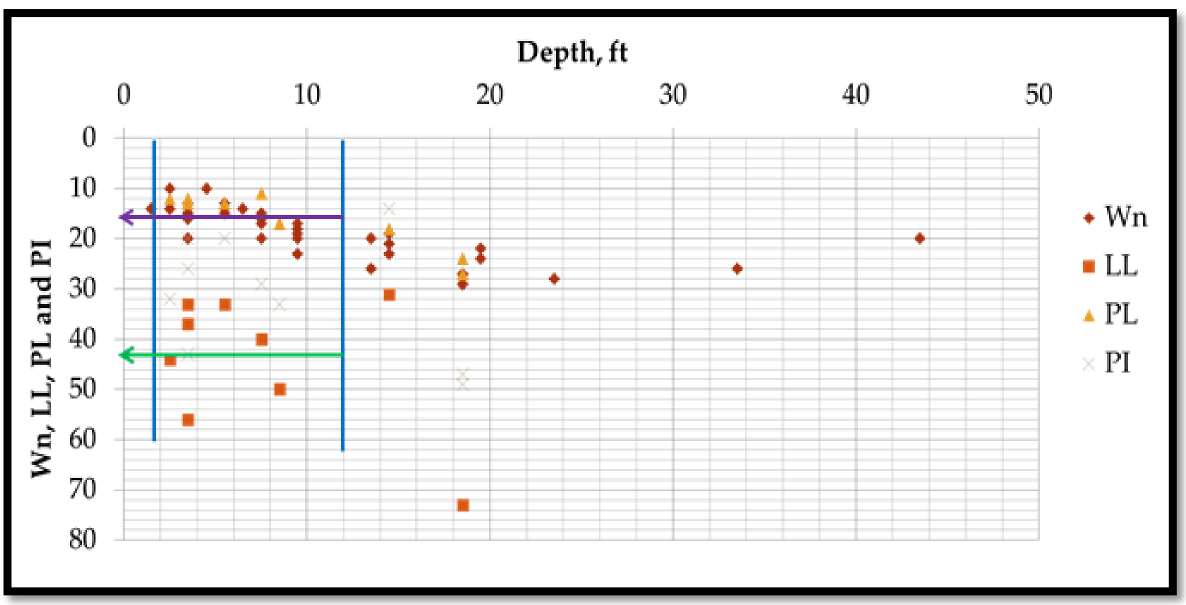
Soil Parameters:

The computations of soil parameters are done by following steps:

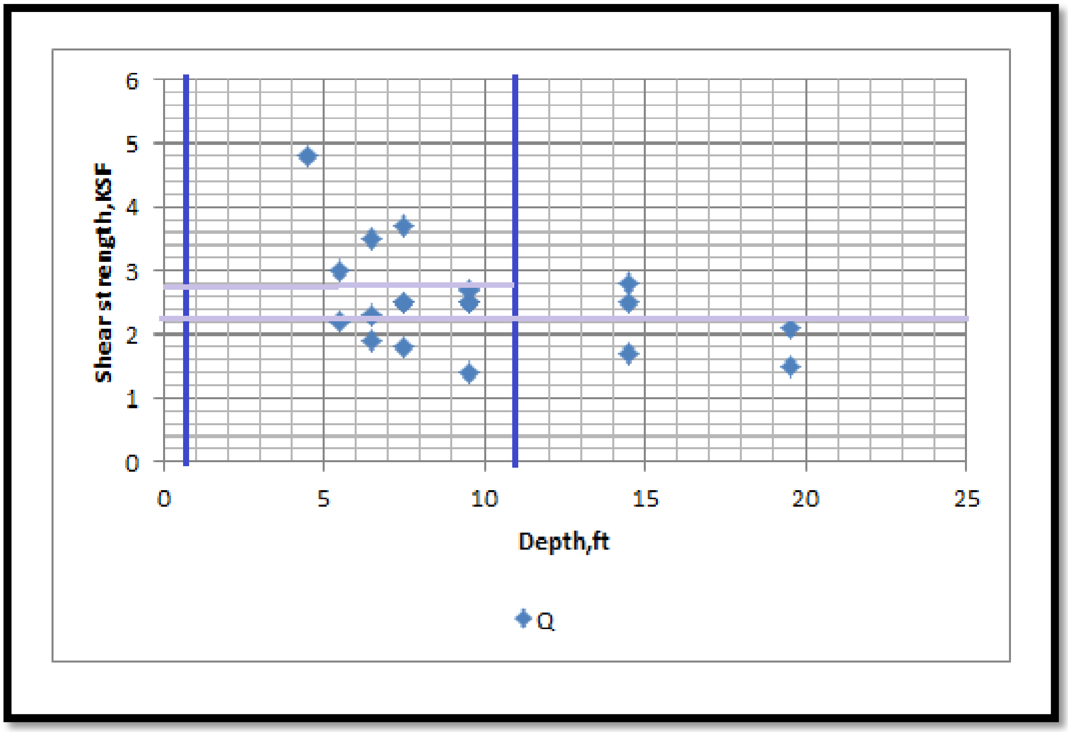
- Plot the graph of each parameter against depth
- Mark the various soil layer depth
- The value of different soil parameters like density, liquid limit, shear strength, etc. for each layer in the idealized soil profile are found by drawing the best fit line in respective layer



Graph 3.1: Unit dry weight v/s depth



Graph 3.2: Depth v/s liquid limit, plastic limit, plasticity index and water content



Graph 3.3: Depth v/s shear strength

Depth(ft)	Depth(m)	ɣ(pcf)	ɣ(kN/m^3)	W_n (%)	LL	PL	PI	Shear strength(kN/m^2) Q
1.5-12	0.36-3.66	115	18.07	14	44	13	31	134.06
12-27	3.66-8.23	102	16.02	24	50	15	33	105.34
27-30	8.23-9.14			20	50	15	33	
30-38	9.14-11.58			18	50	15	33	

Table 3.1: Average value of various soil parameters at different depth

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.

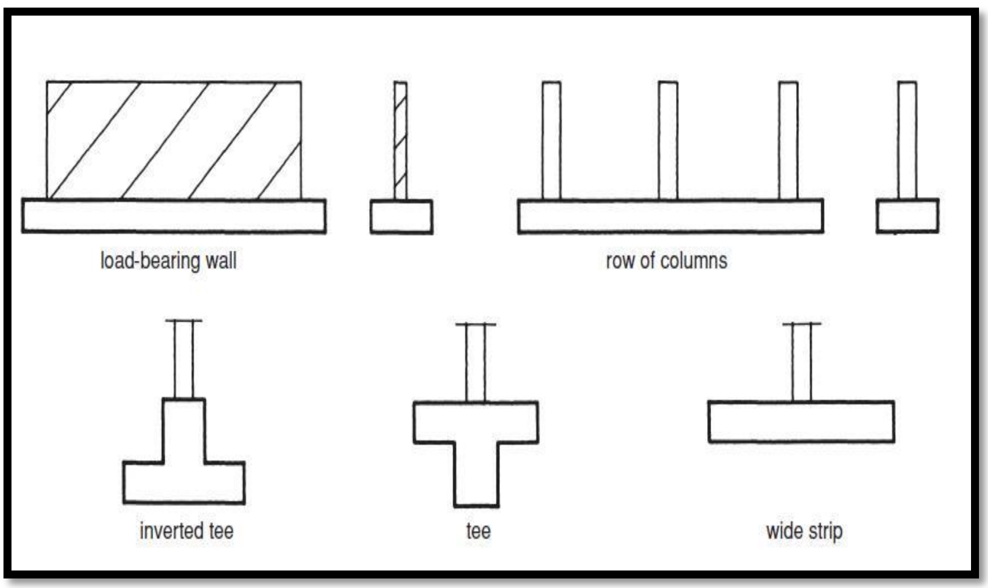


Figure 4.1: Various types of foundation

For a two storey building, shallow foundation will most probably 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 [R4.1]

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.

For calculating the bearing capacity for our idealized soil profile, a program in C was made based on the formulas given in IS: 6403. The code is as given below:

```
//Program to compute Bearing capacity//
#include<stdio.h>
#include<conio.h>
void main()
{
ints,tof;
floatc,qd,nc,nq,b,ny,q;
clrscr();
printf("\n Type of soil:\n");
printf("\n For cohesive soil press 0\n");
printf("\n For non-cohesive soil press any key other than 0\n");
scanf("%d",&s);
printf("\n Enter the type of soil failure\n");
printf("\n For local failure press 0\n");
printf("\n For general failure press any key other than 0\n");
scanf("%f",&tof);
```

```
printf("\n Enter the value of c\n");
scanf("%f",&c);
printf("\n Enter the value of nc\n");
scanf("%f",&nc);
printf("\n Enter the value of q\n");
scanf("%f",&q);
printf("\n Enter the value of nq\n");
scanf("%f,&nq");
printf("\n Enter the value of ny\n");
scanf("%f,&ny");
printf("\n Enter the value of b\n");
scanf("%f",&b);
if (s!=0 &&tof!=0)
{
qd=(c*nc)+(q*(nq-1))+(0.5*b*ny);
printf("\n The valueof of ultimate bearing capacity qd is:%f",qd);
}
if (s!=0 &&tof==0)
{
qd=(0.67*c*nc)+(q*(nq-1))+(0.5*b*ny);
printf("\n The value of ultimate bearing capacity qd is:%f",qd);
}
if(s==0 &&tof==0)
{
qd=(q*(nq-1))+(0.5*b*ny);
printf("\n The value of ultimate bearing capacity qd is: %f",qd);
}
getch();
}
```

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: 5m
- Plinth level: 1.5m
- Cross section of the beam (Used in STAAD PRO) : 400x400mm
- Cross section of the column(Used in STAAD PRO): 500x500mm

Various loads acting on the superstructure [R5.1]

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 is taken on the basis of occupancy and the building in this case is assumed to be a commercial building.

From IS 875-part 2, an imposed load $\underline{5kN/m^2}$ is taken for commercial building.

NOTE: (The snow and rain load is not taken into account, so to compensate these loads and to accommodate processes like expansion of concrete etc. the same maximum value of imposed load has been taken even for 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 the following method is used:

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:

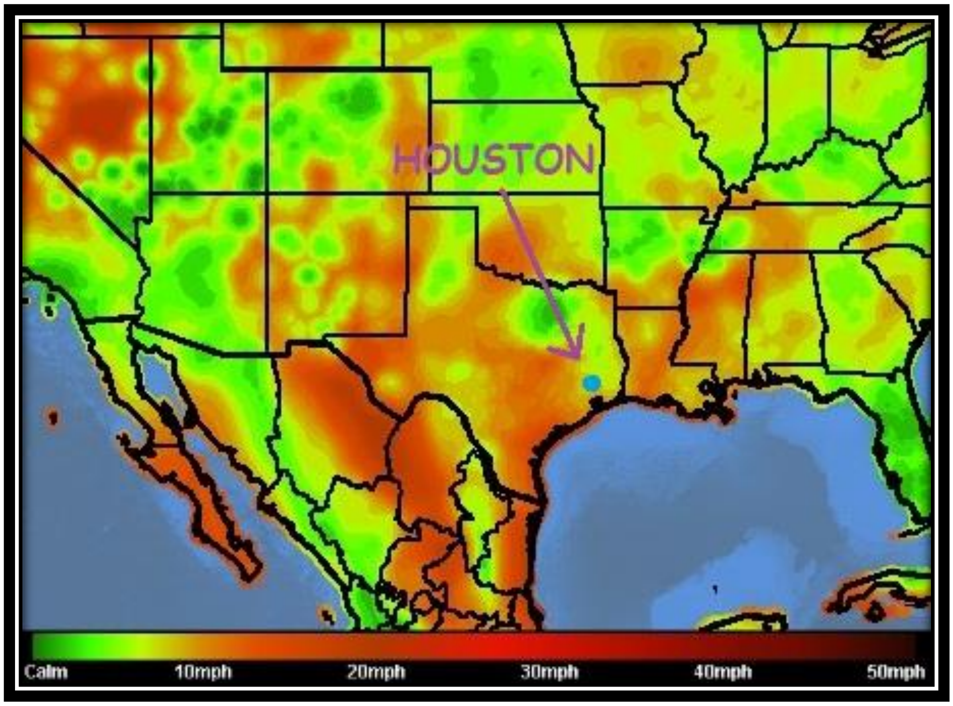


Figure 5.1: Wind speed map of Texas [R5.2]

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

Taking the Terrain Category as 3 and Class as C and the wind intensity for various heights calculated in an excel sheet is 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

Table 5.1: Wind speed at different height

Design and analysis on STAAD PRO:

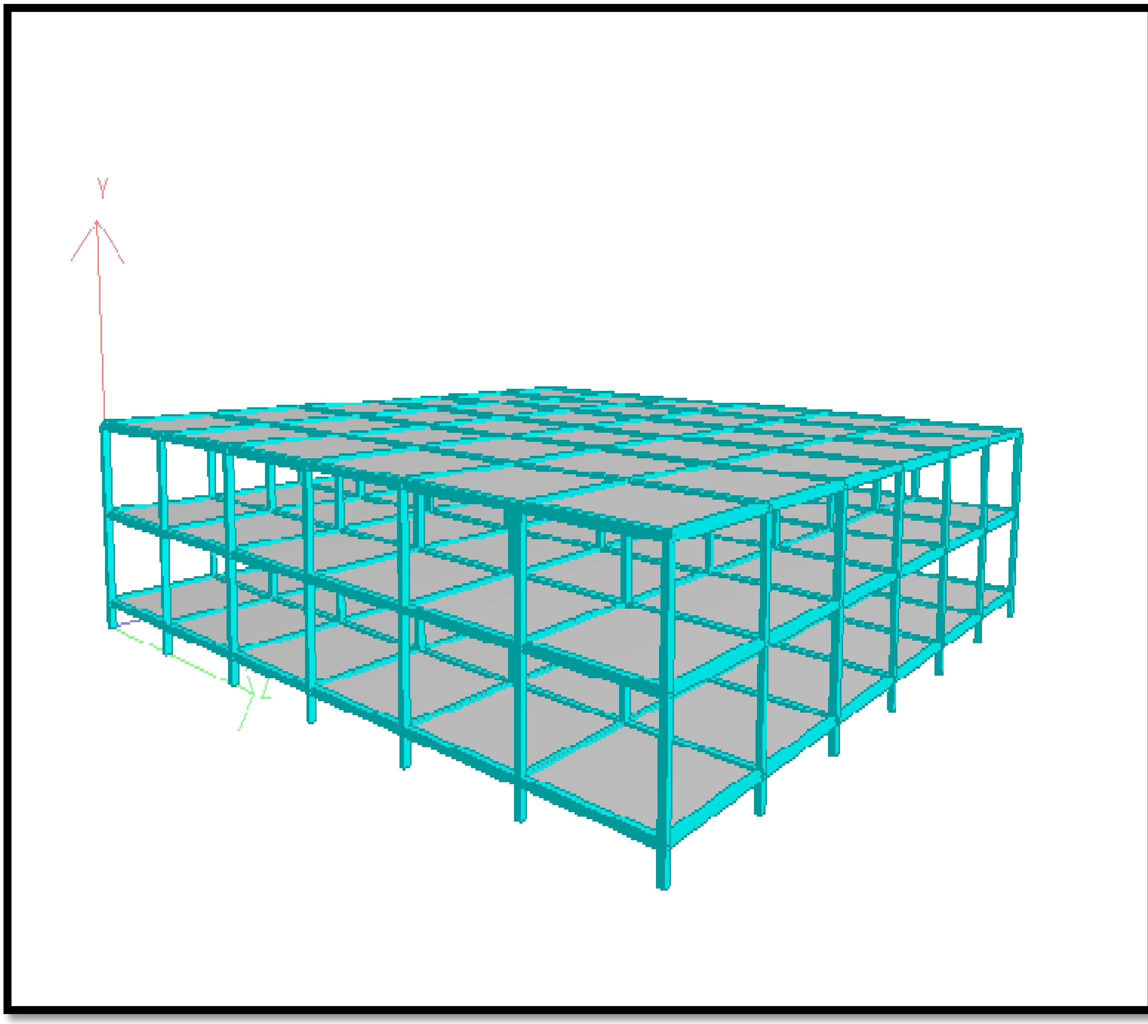


Figure 5.2: 3D model of the 2 storey building

Different loadings given on the building:

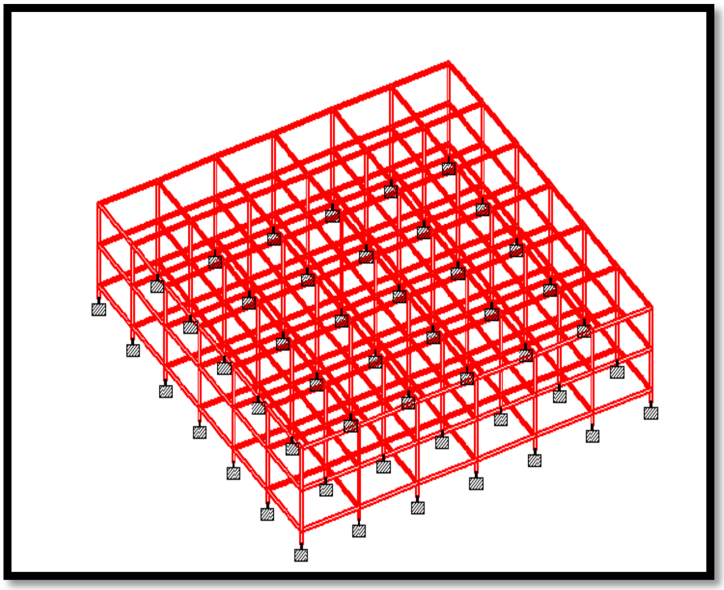


Figure 5.3: Dead load

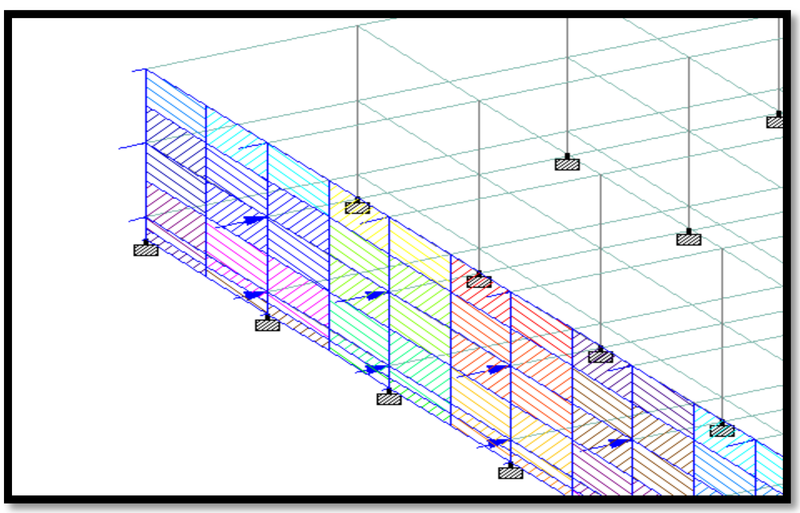


Figure 5.4: Wind load

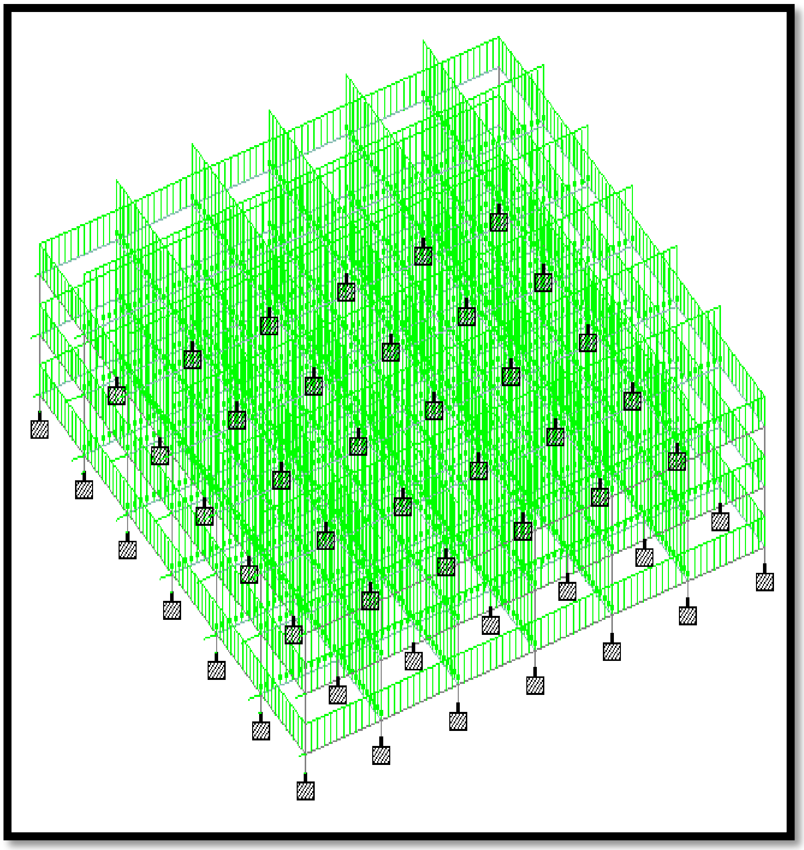


Figure 5.5: Combined load

After loading the building with various loads mentioned, the building was analyzed on and some of the elements were designed on STAAD PRO itself. Few of the STAAD PRO result are shown on the pages that follow.

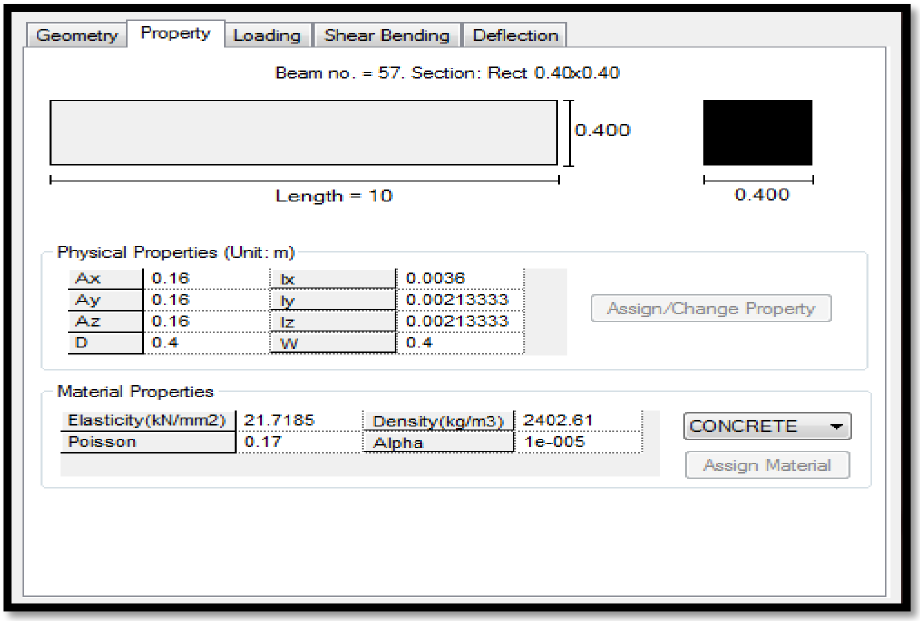
Summary of beam analysis (Both horizontal and vertical beams):

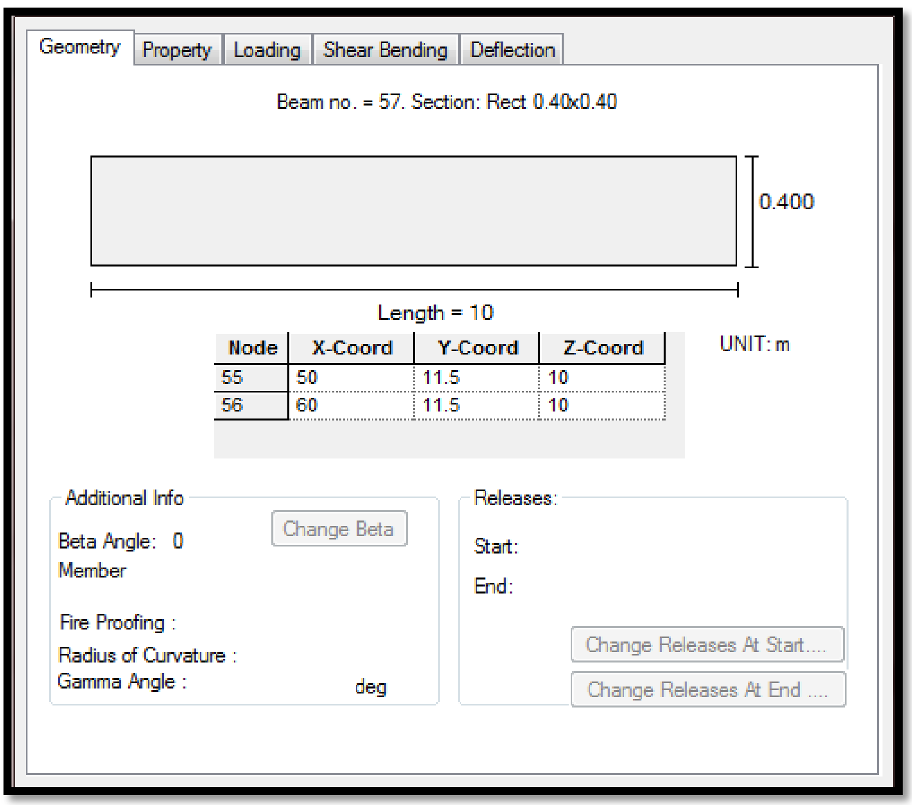
	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	101	1 LOAD CAS	61	1824.325	-0.195	-0.195	-0.000	0.254	-0.254
Min Fx	246	2 LOAD CAS	188	-1.202	63.066	0.000	-0.940	-0.003	105.642
Max Fy	57	2 LOAD CAS	55	2.937	127.371	-0.001	-0.208	0.002	213.860
Min Fy	293	2 LOAD CAS	55	2.937	-127.371	0.001	0.208	0.002	213.860
Max Fz	20	2 LOAD CAS	2	737.172	7.983	97.546	-0.024	-38.131	5.226
Min Fz	258	2 LOAD CAS	174	737.167	-7.983	-97.546	-0.024	38.131	-5.226
Max Mx	288	2 LOAD CAS	22	2.867	61.245	0.001	1.915	-0.003	94.500
Min Mx	252	2 LOAD CAS	195	2.867	63.755	-0.001	-1.915	0.005	107.055
Max My	34	2 LOAD CAS	23	243.609	2.942	46.532	-0.006	130.973	-9.241
Min My	272	2 LOAD CAS	195	243.606	-2.937	-46.526	-0.005	-130.960	9.227
Max Mz	57	2 LOAD CAS	55	2.937	127.371	-0.001	-0.208	0.002	213.860
Min Mz	234	2 LOAD CAS	168	243.609	46.532	2.942	0.006	9.241	-130.973

Summary of slab analysis:

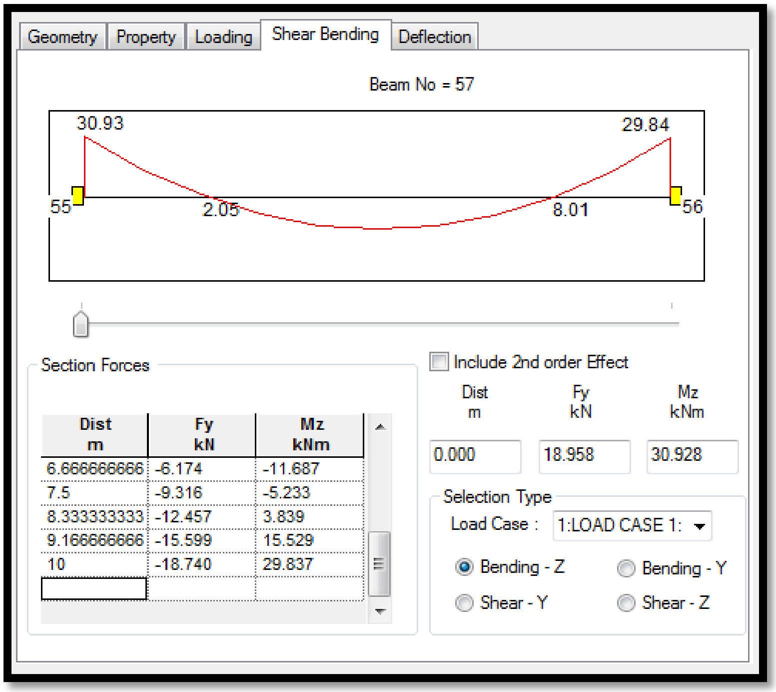
			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	411	2 LOAD CAS	0.005	0.001	-0.021	-0.019	0.000	1.957	0.118	-0.055
Min Qx	406	2 LOAD CAS	-0.005	0.001	-0.021	-0.019	-0.000	1.958	0.118	0.055
Max Qy	420	2 LOAD CAS	-0.001	0.005	-0.019	-0.021	-0.000	-0.118	-1.958	-0.055
Min Qy	404	2 LOAD CAS	-0.001	-0.005	-0.019	-0.021	0.000	0.118	1.957	-0.055
Max Sx	442	2 LOAD CAS	-0.001	0.001	0.009	0.009	0.000	-0.766	-0.766	-0.166
Min Sx	478	2 LOAD CAS	0.002	-0.002	-0.032	-0.032	-0.002	0.648	0.648	0.127
Max Sy	467	2 LOAD CAS	0.001	-0.001	0.009	0.009	0.000	-0.766	-0.766	-0.166
Min Sy	478	2 LOAD CAS	0.002	-0.002	-0.032	-0.032	-0.002	0.648	0.648	0.127
Max Sx	508	2 LOAD CAS	0.002	0.002	-0.032	-0.032	0.002	0.648	0.648	-0.127
Min Sx	503	2 LOAD CAS	-0.002	0.002	-0.032	-0.032	-0.002	0.648	0.648	0.127
Max Mx	412	2 LOAD CAS	-0.005	-0.000	-0.021	-0.019	-0.000	1.967	0.368	-0.011
Min Mx	431	2 LOAD CAS	0.005	0.000	-0.021	-0.019	-0.000	-1.967	-0.368	0.011
Max My	402	2 LOAD CAS	-0.000	-0.005	-0.019	-0.021	-0.000	0.368	1.966	-0.012
Min My	422	2 LOAD CAS	-0.000	0.005	-0.019	-0.021	0.000	-0.368	-1.967	-0.011
Max Mx	405	2 LOAD CAS	0.003	-0.003	-0.022	-0.022	-0.000	1.830	1.830	0.316
Min Mx	400	2 LOAD CAS	-0.003	-0.003	-0.022	-0.022	0.000	1.830	1.830	-0.315

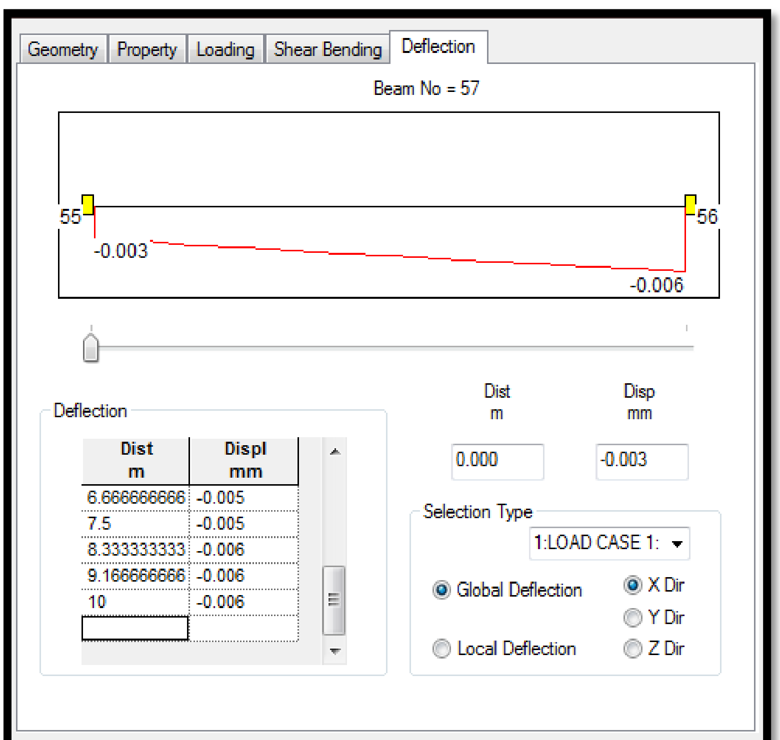
Design of beam (No.57)



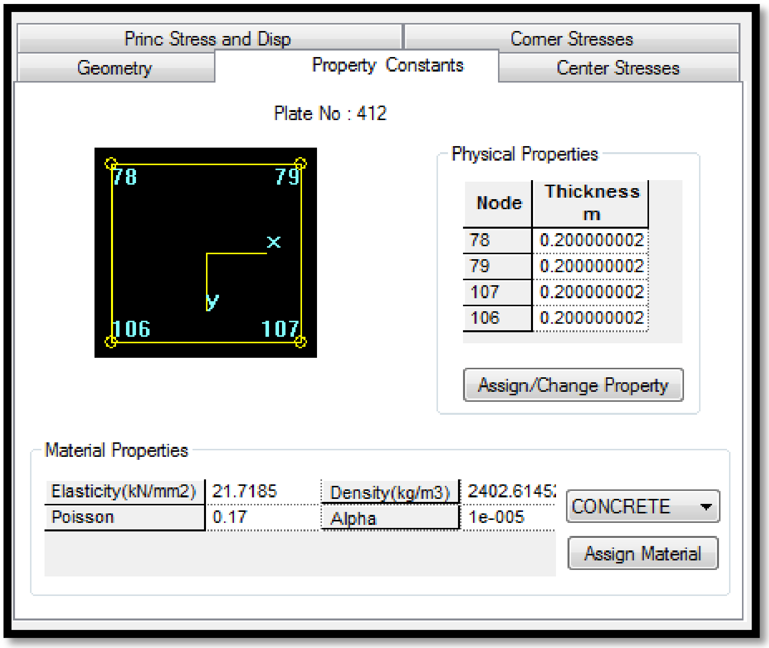


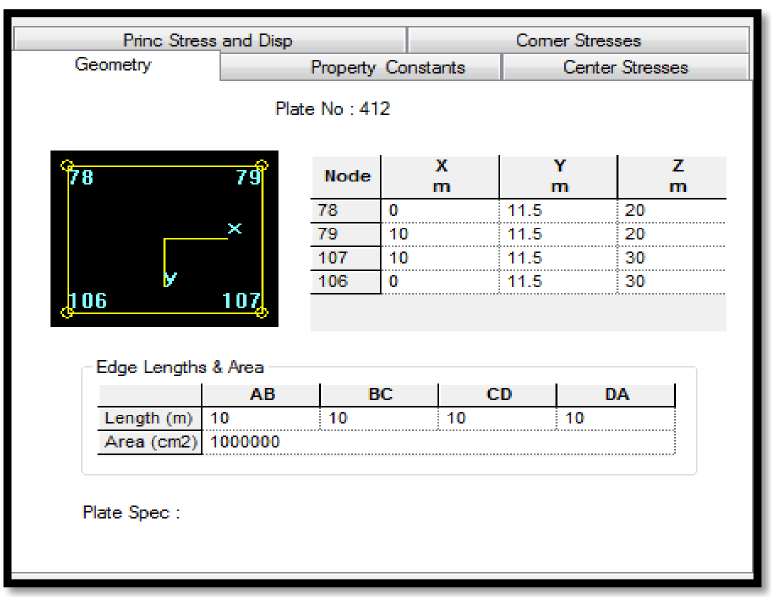
Shear bending and deflection of beam no. 57





Design of slab (No.412):





Geometry | Property Constants | Center Stresses

Princ Stress and Disp | Corner Stresses

Plate No : 412

Load List : 1:LOAD CASE 1: DEAD L

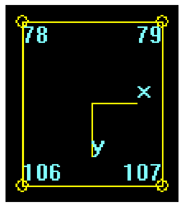


Plate Corner Displacements

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

BEARING CAPACITY

Shallow foundation will suffice for our RCC frame as stated earlier in Chapter 4. As mentioned in ‘Principles of foundation engineering’ by BM Das; to perform satisfactorily, shallow foundations must have two main characteristics:

1. They have to be safe against overall shear failure in the soil that supports them.
2. They cannot undergo excessive displacement, or settlement.

The load per unit area of the foundation at which shear failure in soil occurs is called the ultimate bearing capacity. [R6.1]

There are various methods or theories to find the bearing capacity such as the following:

1. Terzaghi
2. Skempton
3. Meyerhoff
4. IS Code

These methods are pretty much same except for the values of various parameters that are taken.

Skempton’s Bearing capacity analysis for clay soils

Skempton’s (1951) analysis is applicable for a saturated clay soil for which øu=0. The bearing capacity factor Nc is given by Skempton on the basis of theory, laboratory test and field observations. N_c is seen to increase with the ratio of D_f/B. Skempton proposed the following expressions for N_c. [R6.2]

For strip footings: $N_c= 5(1+0.2\ D_f/B)$, with a maximum limiting value of 7.5

For circular and square footings: $N_c= 6(1+0.2\ D_f/B)$, with a maximum limiting value of 9

For rectangular footings: $N_c= 5(1+0.2\ D_f/B)(1+0.2B/L)$ for $D_f/B \leq 2.5$

$N_c= 7.5(1+0.2B/L)$ for $D_f/B>2.5$

For øu=0 condition, the net ultimate bearing capacity is given by

$$q_{nu}=c_uN_c$$

The plan of the foundation of the building is shown in the figure below and selecting the center column i.e. column no.88 and designing an isolated square footing for it.

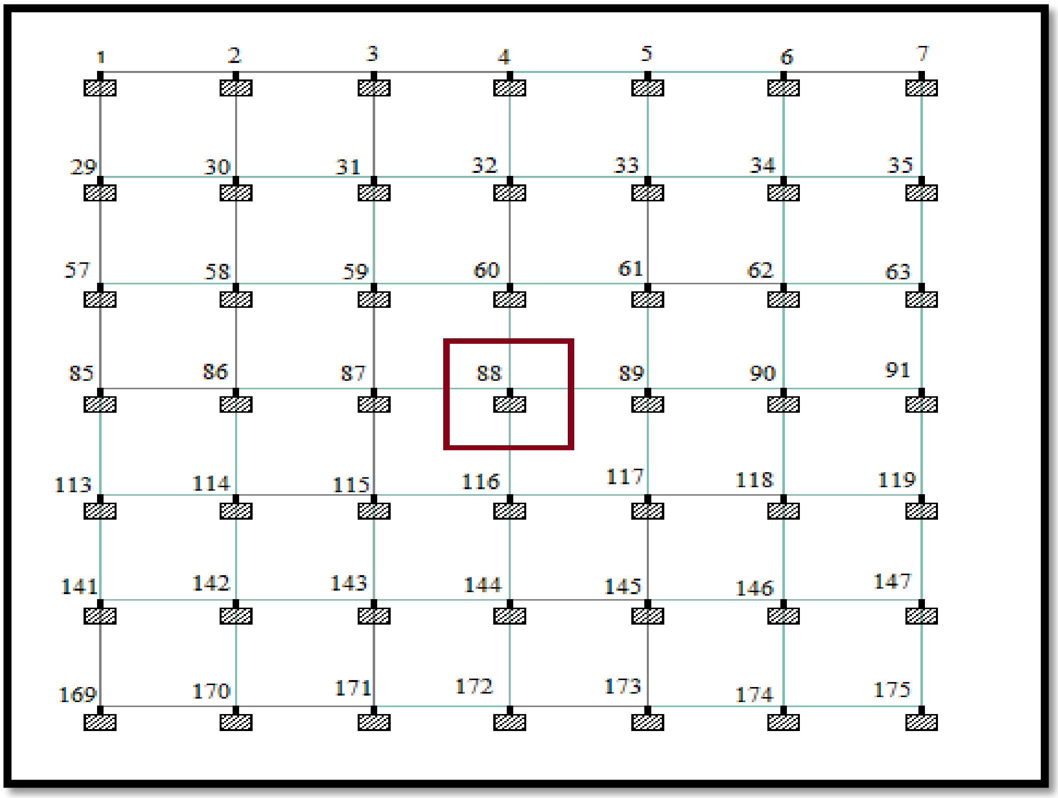
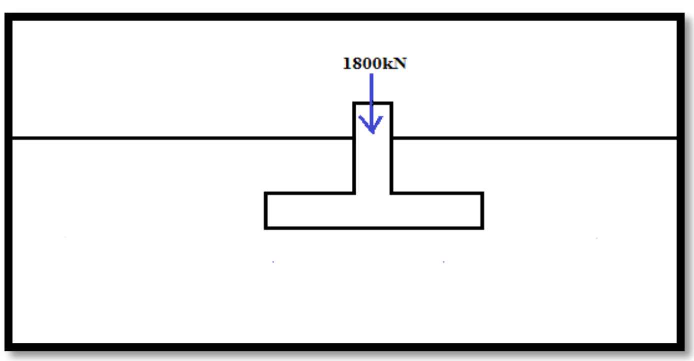


Figure 6.1: Plan of foundation of the building

The loads coming on center column that is corresponding to footing no.88can be found from our STAAD Pro result and is shown below: [Refer appendix for more loads]



On the center column only the vertical load in the Y- direction is significant and the other loads are as small as .003kN so can be ignored.

Calculation of bearing capacity

Assuming depth of footing, D_f as 1.5m and width of footing, B as 3m then zone of shear would also be 3m below the base of footing as shown in figure

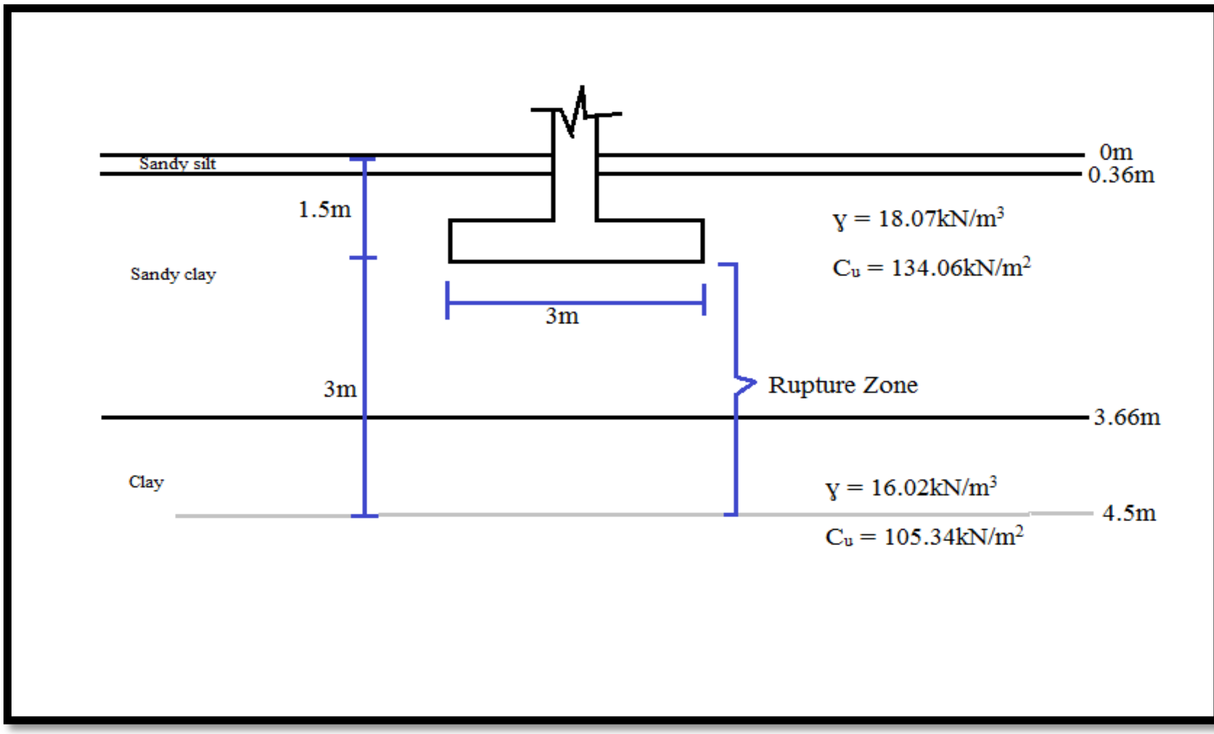


Figure 6.2: Foundation on idealized profile along with the rupture zone of shear

The average value of cohesion for different layers of soil lying in the rupture zone can be approximated by using following equation:

$$c_{av} = (c_1H_1+c_2H_2+\ldots+c_nH_n)/\sum H_i \qquad [R6.3]$$

In our case

- c_1= 134.06kN/m^2
- H_1= 2.16m
- c_2= 105.34kN/m^2
- H_2= 0.84m

Therefore c_{av}= 126.02kN/m^2

Now using Skempton's equation

$N_c = 6\ (1+0.2D_f/B)$

$N_c = 6.6$

We got both c_u and N_c

Therefore, $q_{nu} = c_u N_c$

$= 832\ kN/m^2$

And taking FOS=2.5

$q_{ns} = q_{nu}/FOS$

$= 333 kN/m^2$

$= 33.96 tons/m^2$

CHAPTER 7

RCC DESIGN OF ISOLATED FOOTING

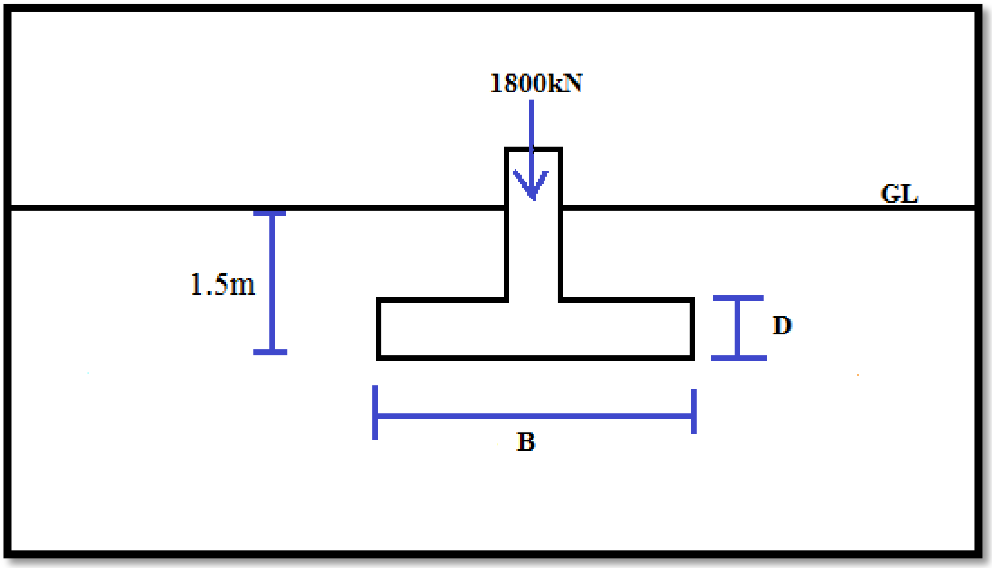


Figure 7.1: Section of foundation with assumed dimensions and loads

1. Data we have

   - Column size = 500 x 500 mm
   - Load, P = 1800 kN
   - Safe bearing capacity, q_a=333 kN/m^2
   - M 20 and Fe 415
   - Cover = 50mm
   - R/F Bar ø = 20mm

2. Size of footing

   Assuming 10% allowance for weight of backfill

   Total load = P+ ΔP

   =1.1 * 1800

   = 1900 kN

   Required area, A_{reqd} = P+ΔP / q_a [R7.1]

= 1900/333

= 5.95 m2

Minimum size of square footing, B = $\sqrt{A_{reqd}}$

= $\sqrt{5.95}$

= 2.43m

Therefore assuming base of footing as 3m X 3m

3. Thickness of footing slab

Assuming load factor as 1.5

Net soil pressure at ultimate loads, q_u= 1.5P/A

= (1800 * 1.5) /(3*3)

= 300kN/m^2

= 0.3 N/mm^2

a) One way shear
The critical section of one way shear is at a distance d from the column face.

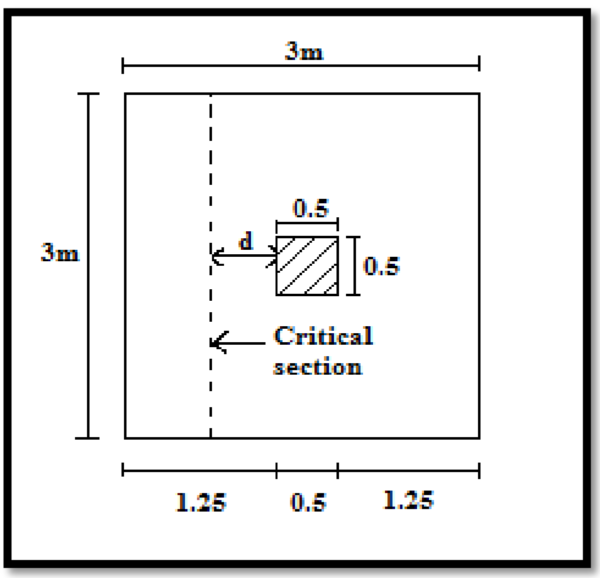
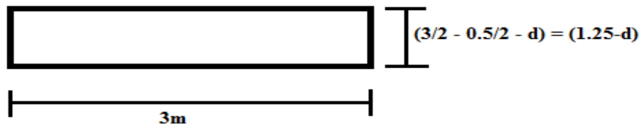


Figure 7.2: Critical section for one-way shear



Factored shear force, V_{u1}= q*area

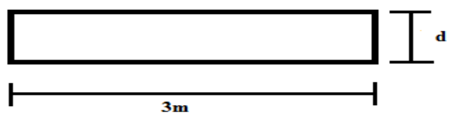
= q_u* L * (lever arm – d)

= 0.3 * 3000 * (1250 - d)

= (1125000 - 900d) mm

Assuming τ_c= 0.36MPa i.e. for M20 concrete with say P_t=0.25 [R7.2]

One-way shear resistance, $V_{c1} = \tau_c$ *A



V_{c1} = 0.36 * 3000 * d

= 1080 d

For safety, $V_{u1} \leq V_{c1}$

Therefore, d ≥568mm

b) Two way shear

The critical section of two way shear is at a distance d/2 from the column face

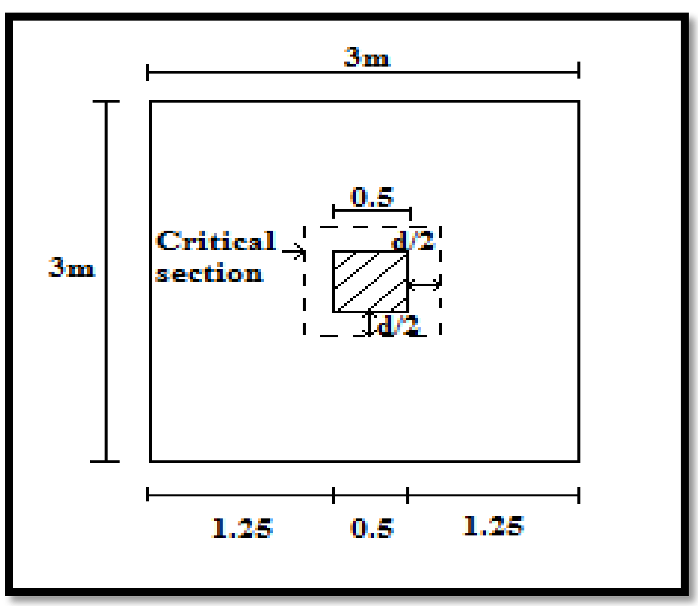


Figure 7.3: Critical section for two-way shear

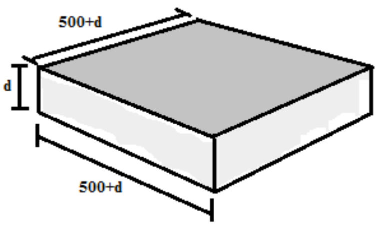
Factored shear force, $V_{u2}= q_u * [L^2 - (a + d)^2]$

$=0.3 * [3000^2 - (500 + d)^2]$ mm

Taking the depth which we got from one way shear i.e. d=568mm

$V_{u2}= 2357.8 * 10^3$ N

Two-way shear resistance, $V_{c2} = k_s * \tau_c * A$ [R7.3]



$V_{c2} = k_s * \tau_c * (\text{perimeter} - d)$

From clause 31.6.3.1 of IS 456 2000

$k_s = 500/500 + 1 = 1.5$ and $k_{s,\, max}=1$

$\tau_c = 0.25* \sqrt{20} =1.118$MPa

$V_{c2} = 1* 1.118 * [4 * (500+d) * d]$

$= 2336d + 4.472\, d^2$

For safety $V_{u2} \leq V_{c2}$

Therefore, $d \geq 517.94$ mm

One-way shear governs the thickness.

Therefore total thickness, D = 568 + 50 + 20 = 638 mm

≈ 650 mm

Taking final D=650

Then, d_1 = 650 – 50 – 20/2 = 590 mm and

d_2 = 650 – 50 – 20 - 20/2=570mm

4. Design of flexural reinforcement
   Calculation of maximum bending moment
   The critical section for moment is at the face of the column.

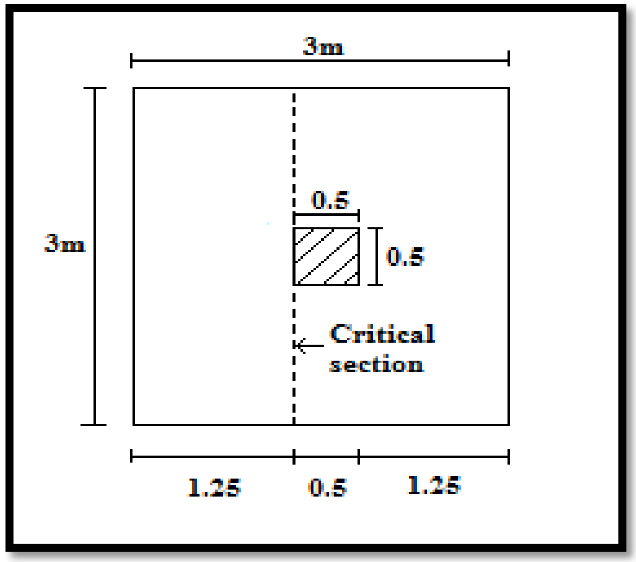
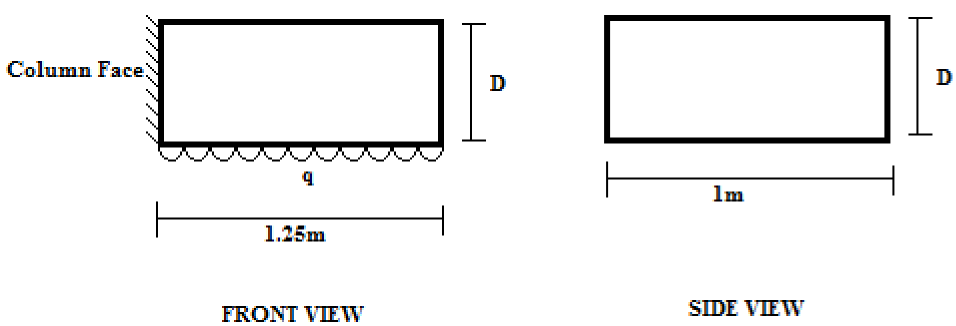


Figure 7.4: Critical section for moment

Taking the moment for 1m strip



$M_u = (wl^2)/2$ {Maximum bending moment for cantilever}

$= 0.3*1250^2/2$

$= 234.375$kN.m

$Mu=0.87f_yA_{st}\,d\{1- (A_{st}f_y/bdf_{ck})\}$ [R7.4]

Taking d=d1=590mm

$234.375 * 10^6= 0.87 * 415 *A_{st1} *590 *\{1-(A_{st1}*415) / (1000*590*20)\}$

$A_{st1} = 1146.4mm^2$

Ast_{min} = 0.12/100 * BD

= 0.0012 * 1000 * 650

= 780 mm^2 < A_{st1} (Okay)

But we assumed P_t =0.25 for one way shear, so

$Ast_{required}$ = (0.25 * 1000 * 590) /100

= 1475mm^2

Using 20mm bars, no. of bars required = 1475/($\frac{\pi}{4}$ * 20^2)

= 4.695

But this number is for 1m strip only. Our footing base is 3m long so

No. of bars = 3*4.695

≈15 bars

Spacing, s = effective width/(no. of bars -1)

= (3000 – (50*2) -20)/ (15-1)

= 205.71 mm

Provide 15 numbers of 20mm diameter bar at 200mm c/c

A_{st2} = (0.25 * 1000 * 570) /100

= 1425mm^2

Using 20mm bars, no. of bars required = 1425/($\frac{\pi}{4}$ * 20^2)

= 4.536

But for 3m width

No. of bars = 3*4.536

≈14 bars

Spacing, s = effective width/(no. of bars -1)

= (3000 – (50*2) -20)/ (14-1)

= 221.5 mm

Provide 14 numbers of 20mm diameter bar at 220mm c/c

Required development length, $L_d = ø*\sigma_s/4*\tau*d$ [R7.5]

$L_d = \{(20*0.87*415)/(4*1.2*1.6)\}$

$= 940mm$

Length available = 1250-50 =1200mm > 940mm Hence Okay

5. Transfer of force at column

   Max. Bearing stress, $f_{br,max}=0.45*fck*\sqrt{A1}/A2$ [R7.6]

   And $\{\sqrt{A1}/A2\}_{max} =2$

a) For column face, f_{ck} =25MPa , A1=A2=$(500)^2mm^2$

   $f_{br, max-col}$=0.45*25*1 =11.25 MPa

b) For footing face, f_{ck} =25MPa , A1= $(3000)^2$ mm^2

   A2= $(500)^2$ mm

   $\sqrt{A1}/A2 = \sqrt{(3000)^2/(500)^2}$

   =6 but max is 2

   $f_{br, max-ftg}$=0.45*25*2 =18 MPa

   The column face governs and $f_{br, max}$=11.25 MPa

   Limiting bearing pressure = 11.25 * 500^2

   = 2812.5kN > P_u =1.5*1800=2700KN

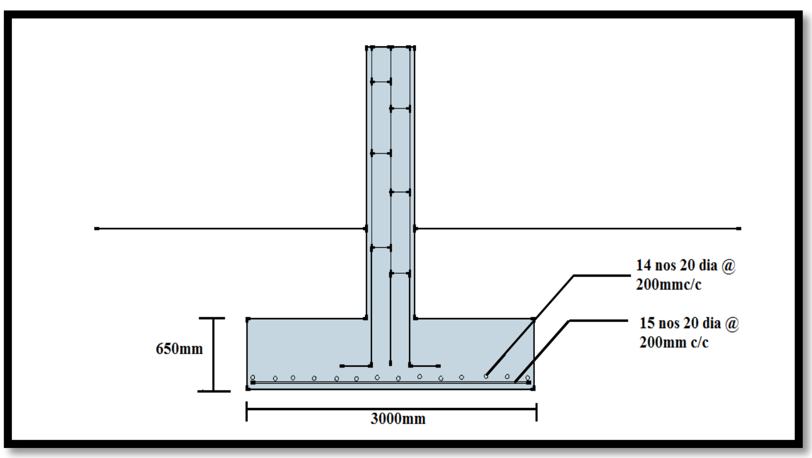


Figure 7.5: Reinforcement detailing in footing

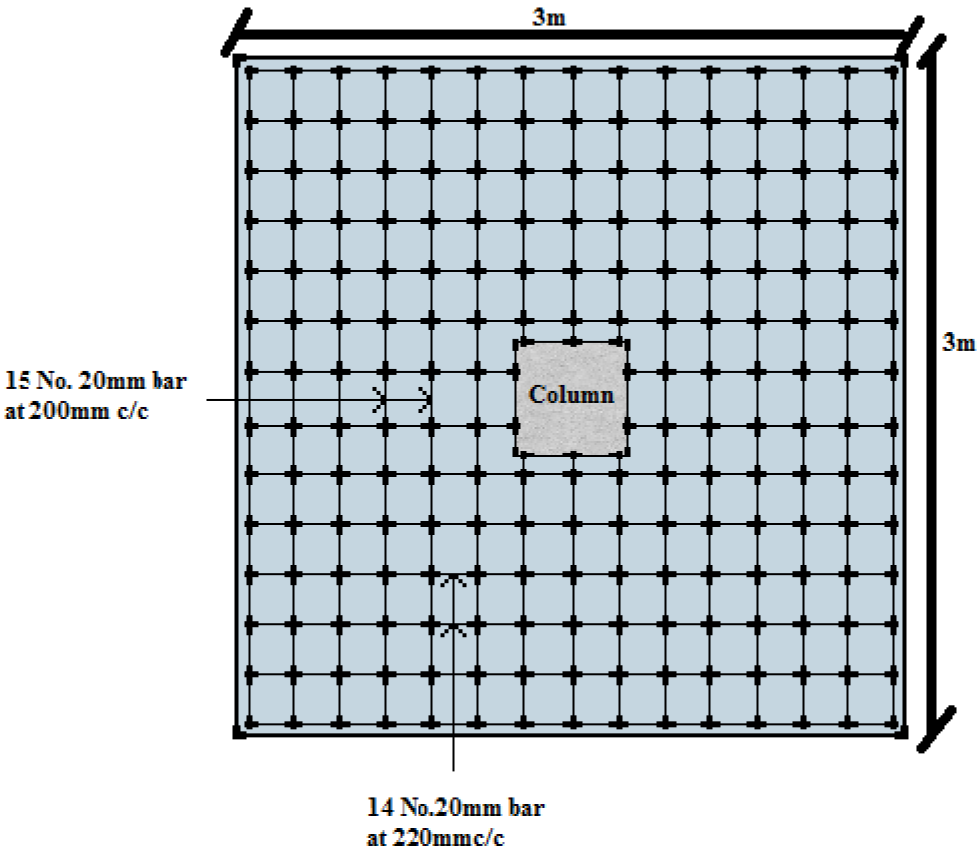


Figure 7.6: Plan of footing with reinforcement detailing

APPENDIX

Bore log data:

Report No. 0401-2452

FUGRO McClelland

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								2.7+ P
				- very stiff sandy clay to 0.5'	98.8							
				SANDY CLAY, stiff, gray	2.0	14						1.2 P
				- with calcareous nodules to 12'								
				- 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					84.8							
				CLAY, very stiff, red and gray, slickensided, with calcareous nodules	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

Report No. 0401-2452

TUGRO McClelland

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

PLATE A-1b

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: 15.6'
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

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
	- with calcareous nodules at 6'								
	- very stiff below 7'								1.8 P
	- with sand pockets below 8'		15					116	2.5 Q
									1.6 P
		89.5 / 11.0							
	CLAY, very stiff, red and gray - with sand pockets to 16'								
									2.4 P
			26					98	2.8 Q
	- with siltstone nodules at 18'								2.4 P
			29	73	27	47			
	- with silt pockets below 23'								2.5 P
		73.5 / 27.0							
	SILTY SAND, very dense, red, with sand stone seams								
50/1.5"		71.0 / 29.5							3.9 P
	CLAY, very stiff, red and gray, slickensided - with siltstone nodules to 33'								
									3.6 P
		63.5 / 37.0							
	SILTY SAND, very dense, red, fine								
50/6"		60.5 / 40.0							

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

PLATE A-2

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

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
0		FILL: SANDY CLAY, very stiff, gray and tan, with shell fragments	100.1 / 1.0							2.7+ P
1		SANDY SILT, gray	99.1 / 2.0	14						1.9 P
2		SANDY CLAY, stiff, tan and gray, with sand pockets - with ferrous nodules and calcareous nodules below 4' - very stiff below 5'	93.1 / 8.0							1.3 P
5				15					117	2.2 Q
										1.8 P
8		CLAY, stiff, gray and tan - with sand pockets to 16'								2.4 P
				20						
										1.5 P
15		- very stiff, red and gray, slickensided, with calcareous nodules and siltstone seams below 16'								2.2 P
20				22					104	1.5* Q
		- with sand pockets below 23'	74.1 / 27.0							3.6 P
27	50/9"	SILTY SAND, very dense, red, fine, with clay seams	71.1 / 30.0							
30		CLAY, very stiff, red and gray, slickensided	63.1 / 38.0							3.9 P
38		SANDY SILT, red, with clay seams	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	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	98.9 / 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
				15					118	3.7 Q
										1.9 P
10			88.9 / 11.5							
		SILTY CLAY, stiff, red and gray, with sand pockets								1.3 P
15			85.4 / 15.0	23					102	1.7 Q
		CLAY, very stiff, red and gray, slickensided, with calcareous nodules								3.3 P
20										
		- with silt pockets below 23'								3.3 P
25			74.4 / 26.0							
		SILTY SAND, red, fine - with sandstone 27' to 28.5'								
	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								
										3.6 P
35			62.4 / 38.0							
	19	CLAYEY SILT, medium dense, red	60.4 / 40.0							
40										

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

PLATE A-4

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: 15.4'
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

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, 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
5				14	33	13	20		120	2.3 Q
										1.8 P
										1.8 P
				18					112	2.5 Q
10			89.2							
		SILTY CLAY, stiff, red and gray	11.5							
										1.2 P
			85.7	21						
15		CLAY, very stiff, red and gray, slickensided, with siltstone nodules	15.0							
										3.6 P
20										
		- with silt pockets below 23'								3.3 P
25			73.7							
		SILT, medium dense, red, with siltstone seams	27.0							
	18		71.2							
30		CLAY, very stiff, red and gray, slickensided	29.5							
		- with siltstone seams, 32' to 33.5'								
										3.7 P
35			63.7							
		CLAYEY SILT, medium dense, red	37.0							
	20		60.7							
40			40.0							

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

PLATE A-5

FUGRO McClelland

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

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 - very stiff sandy clay to 0.5'	99.2 / 1.5							
		SANDY CLAY, very stiff, gray, with sand pockets								2.7+ P
5				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
10										
			85.7 / 15.0							2.2 P
15		CLAY, very stiff, red and gray, slickensided								
		- with calcareous nodules below 18'		33					89	0.88* Q
										2.2 P
20										
		SILTY CLAY, stiff, red and gray	78.2 / 22.5							
										1.2 P
25		CLAYEY SILT, red - with sandstone seams below 27'	74.7 / 26.0							
30	20	CLAY, very stiff, red and gray, slickensided	71.2 / 29.5							3.3 P
			70.2 / 30.5							
35										
40										

* 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

Location: N 5539 ; E 5592
Surf El. 100.6'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

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
		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										
		- with silt pockets below 14'								2.1 P
15		CLAY, very stiff, red and gray, slickensided, with calcareous nodules and siltstone nodules	85.1 / 15.5							
				22					104	1.5* Q
										2.1 P
20										
		- with silt pockets below 23'								3.6 P
25		CLAYEY SILT, medium dense, red, with clay pockets	74.1 / 26.5							
	18									
30			70.6 / 30.0							
35										
40										

* Failed on slickensided plane

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

PLATE A-7

Report No. 0401-2452 | FUGRO McClelland

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	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
0		SANDY SILT, gray	99.7 / 1.0							
1		SANDY CLAY, stiff, gray and tan								
2		- with calcareous nodules at 2'								1.3 P
3				15						
4		- with ferrous nodules at 4'								1.5 P
5				15					116	1.9 Q
6		- tan and gray below 6'								1.6 P
8		CLAY, stiff, tan and gray, with calcareous nodules and sand pockets	92.7 / 8.0							1.3 P
9				23					105	1.4 Q
12		SILTY CLAY, stiff, tan and gray, with calcareous nodules and silt pockets	88.7 / 12.0							
13										1.2 P
15		CLAY, very stiff, red and gray, slickensided, with calcareous nodules	85.7 / 15.0							
18				29						2.5 P
23		- with sand pockets below 23'								2.1 P
26.5	50/6"	SANDY SILT, very dense, red, fine	74.2 / 26.5							
28		- with sandstone seams below 28'						60		
29.5		CLAY, very stiff, red, slickensided	71.2 / 29.5							
32		- with sandstone seam at 32'								
33										3.6 P
38		SILTY SAND, red, fine, with clay pockets and sandstone nodules	62.7 / 38.0							
39			61.7 / 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'
Type: Wet Rotary
Logger: T. Mireles

Date: August 1, 1991

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

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
	- with vertical sand seams below 6'		14	41	13	29		119	
									2.4 Q
			18					109	2.9 Q
		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
	CLAY, stiff, red and gray, slickensided - with calcareous nodules to 20'								
									1.6 P
			36	70	23	46		86	
	- with siltstones and silt pockets at 23'								
									2.0 P
		72.8 / 27.5							
13	CLAYEY SILT, medium dense, red	70.3 / 30.0							
	CLAY, very stiff, red and gray, slickensided, with silt pockets								
									2.5 P
	- with calcareous nodules below 38'								3.9 P
		61.3 / 39.0							

LOG OF BORING NO. 9

EXXON COMPUTING CENTER
HOUSTON, TEXAS

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

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
	89.7 / 11.0							
SILTY CLAY, very stiff, red and gray, with sand pockets								1.8 P
		19	31	18	14		111	2.5 Q
	84.7 / 16.0							
CLAY, very stiff, red and gray, slickensided, with siltstone nodules								2.1 P
- stiff, with silt pockets below 23'								1.8 P
- silty sand layer below 27'	73.2 / 27.5							
SANDSTONE, red	70.7 / 30.0							
CLAY, very stiff, red and gray, slickensided, with silt seams and siltstone nodules	68.7 / 32.0							2.5 P

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	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 - with many calcareous nodules to 3'	2.0	13						1.2 P
										1.8 Q
5		- tan and gray, with ferrous nodules below 4'		17					114	2.1 Q
		- with calcareous nodules below 6'	92.7							1.3 P
		CLAY, stiff, tan and gray, with ferrous nodules, calcareous nodules, and sand pockets	8.0							1.3 P
10			88.7	21					106	1.8 Q
		SILTY CLAY, stiff, tan and gray, with sand pockets and calcareous nodules	12.0							1.2 P
15		CLAY, very stiff, red and gray, slickensided, with siltstone nodules	85.7 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

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

	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
1.5			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	
	5		- stiff, tan and gray below 4'								1.3 P
											1.5 P
					20					110	1.8 Q
10.5											1.5 P
	10										
			SILTY CLAY, stiff, red and gray, with silt pockets	88.7 / 12.0							
3.5											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
14			- 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

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				- very stiff, tan and gray, with ferrous nodules below 6'		19					109	1.7 Q
												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							

DEPTH, FT: 5, 10, 15, 20, 25, 30, 35, 40

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

DEPTH, FT	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	99.1 / 1.5							1.3 P
	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
5		95.1 / 5.5	10					117	4.8 Q
	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
10	- slickensided below 10'		19					111	2.7 Q
	- 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

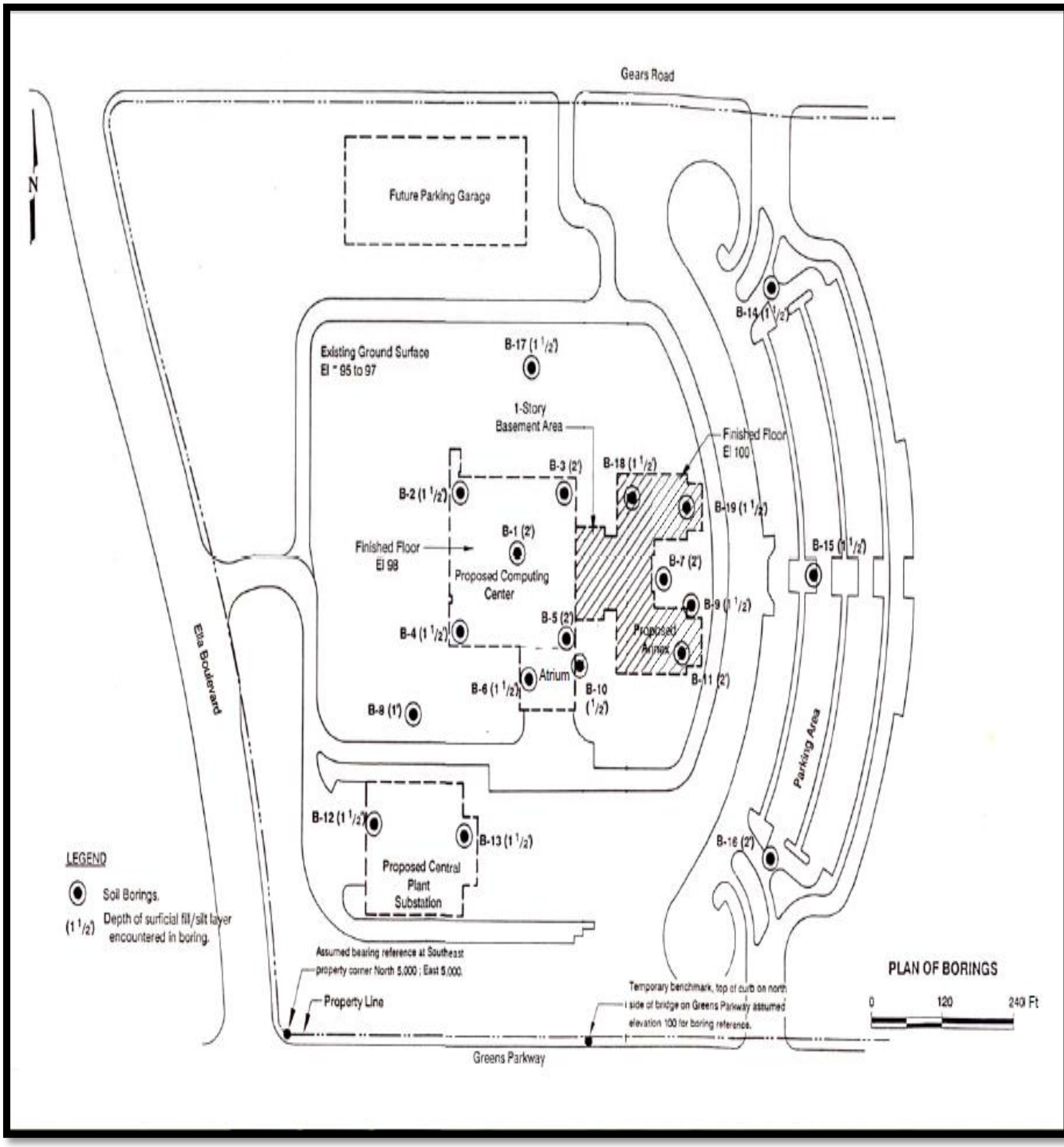
Location: N 5634 ; E 5712
Surf El. 100.4'
Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1

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
					52.4 / 48.0							
			27	SILTY SAND, medium dense, light gray and tan, fine, with sandy clay pockets	50.4 / 50.0					37		
50												
55												
60												
65												
70												
75												
80												
85												

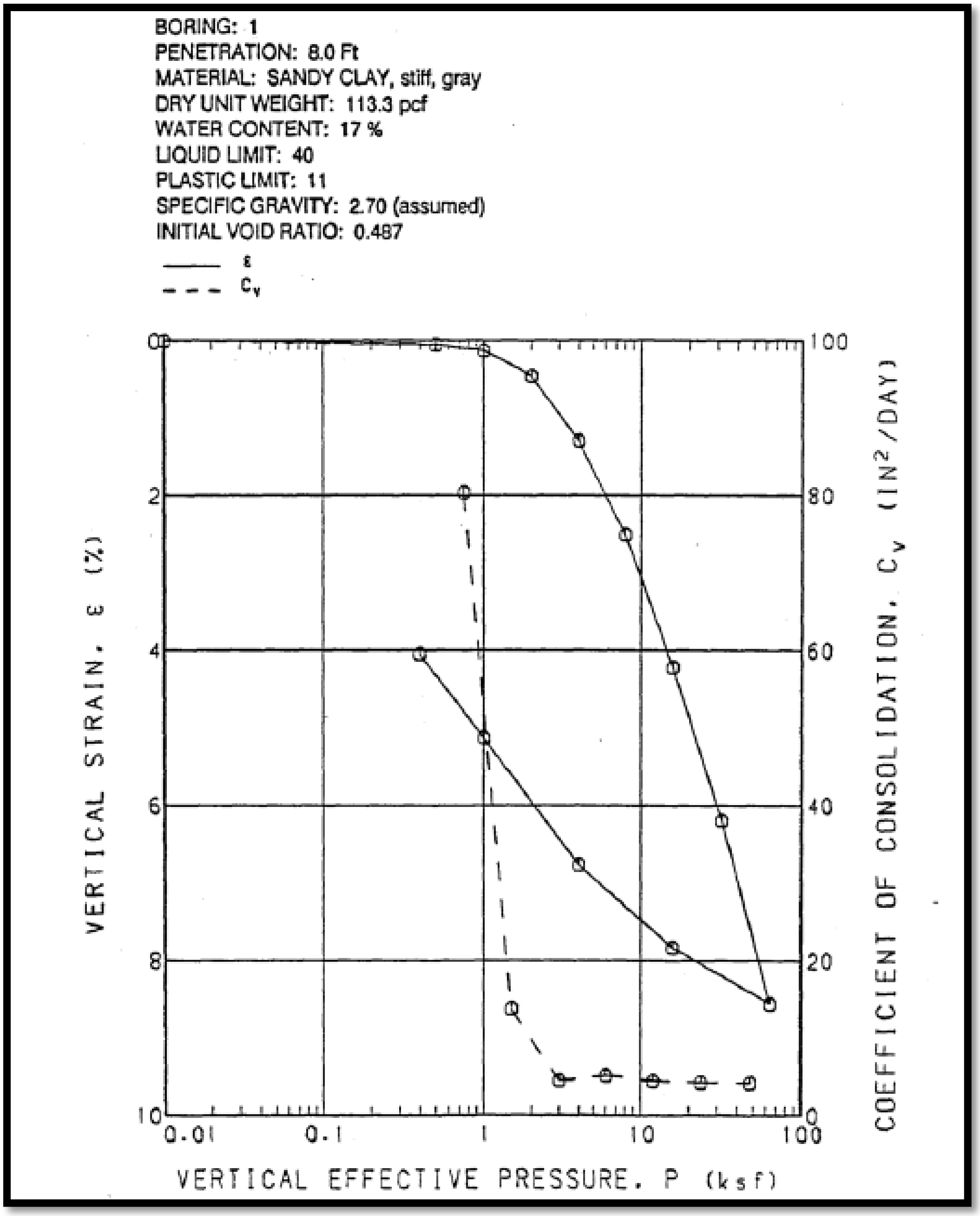
LOG OF BORING NO. 19
EXXON COMPUTING CENTER
HOUSTON, TEXAS

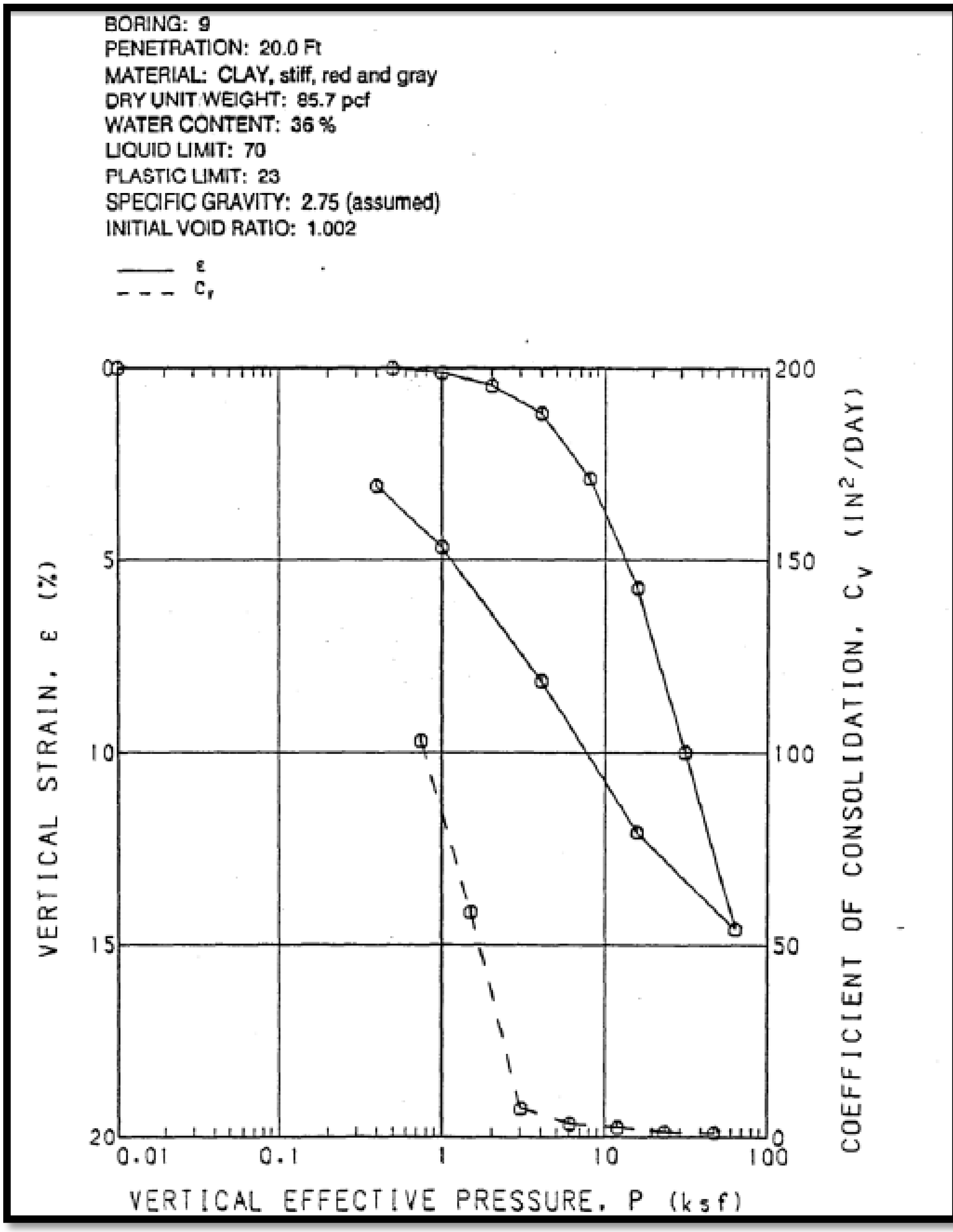
PLATE A-19b

Plan of boring



Consolidation data:




BORING: 9
PENETRATION: 20.0 Ft
MATERIAL: CLAY, stiff, red and gray
DRY UNIT WEIGHT: 85.7 pcf
WATER CONTENT: 36 %
LIQUID LIMIT: 70
PLASTIC LIMIT: 23
SPECIFIC GRAVITY: 2.75 (assumed)
INITIAL VOID RATIO: 1.002
ε
C_v
VERTICAL STRAIN, ε (%)
0
5
10
15
20
0.01
0.1
1
10
100
200
150
100
50
0
COEFFICIENT OF CONSOLIDATION, C_v (IN^2/DAY)
VERTICAL EFFECTIVE PRESSURE, P (ksf)

Loads on footing:

Node	F_x (kN)	F_y (kN)	F_z (kN)	M_x (kN.m)	M_y (kN.m)	M_z (kN.m)
85	108.66	960.805	0.000	0.000	0.000	-42.269
86	-15.930	1825.432	-0.000	0.000	0.000	9.061
87	-1.549	1791.060	0.002	0.001	0.000	1.826
88	-0.076	1797.039	-0.007	-0.003	0.000	0.099
89	1.383	1791.059	0.004	0.002	-0.000	-1.622
90	15.751	1825.432	-0.000	0.000	0.000	-8.850
91	-108.805	960.906	0.001	0.000	0.000	42.452
4	-0.057	960.859	108.763	42.370	-0.000	0.091
32	-0.085	1825.440	-15.832	-8.948	-0.000	0.103
60	-0.087	1791.056	-1.463	-1.721	0.000	0.104
116	-0.084	1791.061	1.462	1.721	0 .000	0.102
144	-0.085	1825.424	15.834	8.949	0.000	0.103
172	-0.057	960.854	-108.762	-42.369	0.000	0.091

REFERENCES

[R2.1] Basic and Applied Soil mechanics by Gopal Ranjan and A.S.R. Rao

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