ANALYSIS OF TWO-STOREY RCC FRAME AND DESIGN OF ITS FOUNDATION BY I.S. CODE METHOD

Enrollment number – 101680

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- Mr. Lav Singh

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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

DECLARATION BY THE CANDIDATE

I hereby declare that the work presented in the project entitled **“Analysis of two-storey RCC frame and Design of its foundation by using I.S. Code 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 bonafide project work carried out by me under the guidance of Dr. S.K Jain.

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

Signature of the student

Name of student Sahil Kashyap

Date

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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 I.S. Code method"** submitted by **"Sahil Kashyap"** 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	Signature of supervisor	Signature of supervisor
(Prof. Dr. Ashok K Gupta)	(Dr.S.K.Jain)	(Mr. Lav Singh)
Date :	Date:	Date:

ACKNOWLEDGEMENT

First and foremost, I have to thank my project supervisor Dr. S.K Jain. Without his assistance and dedicated involvement in every step throughout the project, this project would have never been accomplished. I would like to thank you very much for your continous support and understanding over past one year.

I would like to share my gratitude to Mr. Lav Singh for clearing all our queries regarding the design part of the project. He had been very helpful.

I would especially like to thank faculty and the staff members of the Civil Engineering Department, JUIT, Waknaghat who has always been supportive and made this project possible.

I would like to thank my group members Tshering Pelden and Choki Dorjee for their support and help whenever I needed.

Most importantly none of this could have happened without my family and friends.

Signature of the student

Name of student Sahil Kashyap

Date:

SUMMARY

Our project that is “Designing of two storey building with its foundation” 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 we created soil profiles along three different sections. We then created an idealized soil profile by combining and averaging the values such as depth of various sections, the densities of each section etc. For the idealized soil profile we found out different soil properties like c, ø etc.

After that we progressed to modeling of the building on STAAD PRO and analyzing it so that we can get the reactions at the base. This way we can get the actual load that would be coming on the foundation.

Thereafter different components of the building like beam, column, slab and foundation were designed. The designing was 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 and we are doing so by firstly looking into all the conditions and picking the worst case scenario. We are designing for that scenario and that section would be provided for all other parts too and this will ensure that our structure is safe on all parts.

LIST OF FIGURES:

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 two 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 two storey building by assuming data like the clear height between floors, dimension of elements and their quantity. The building is designed on STAADPRO and 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

2.1Materials

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

2.2Methods 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

3.1Idealized 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.

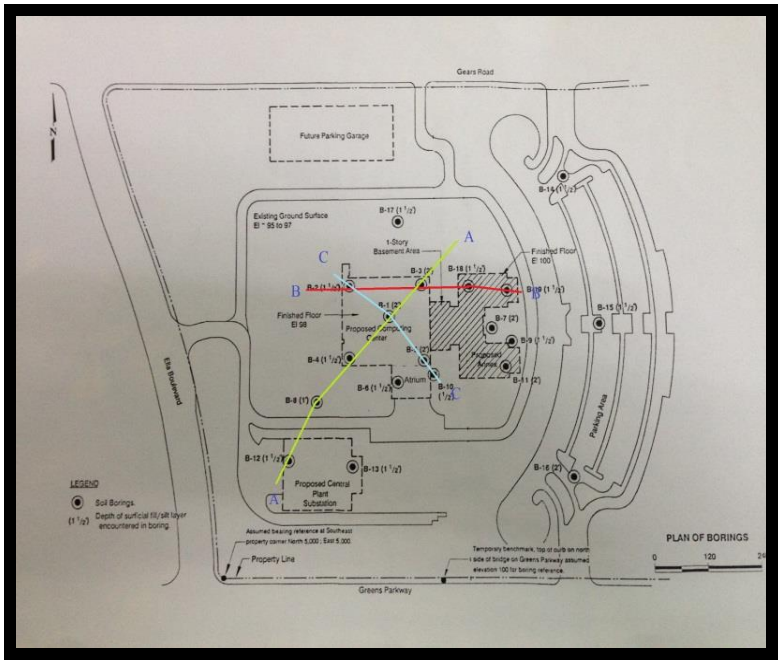


Figure 1: Plan of borings

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.

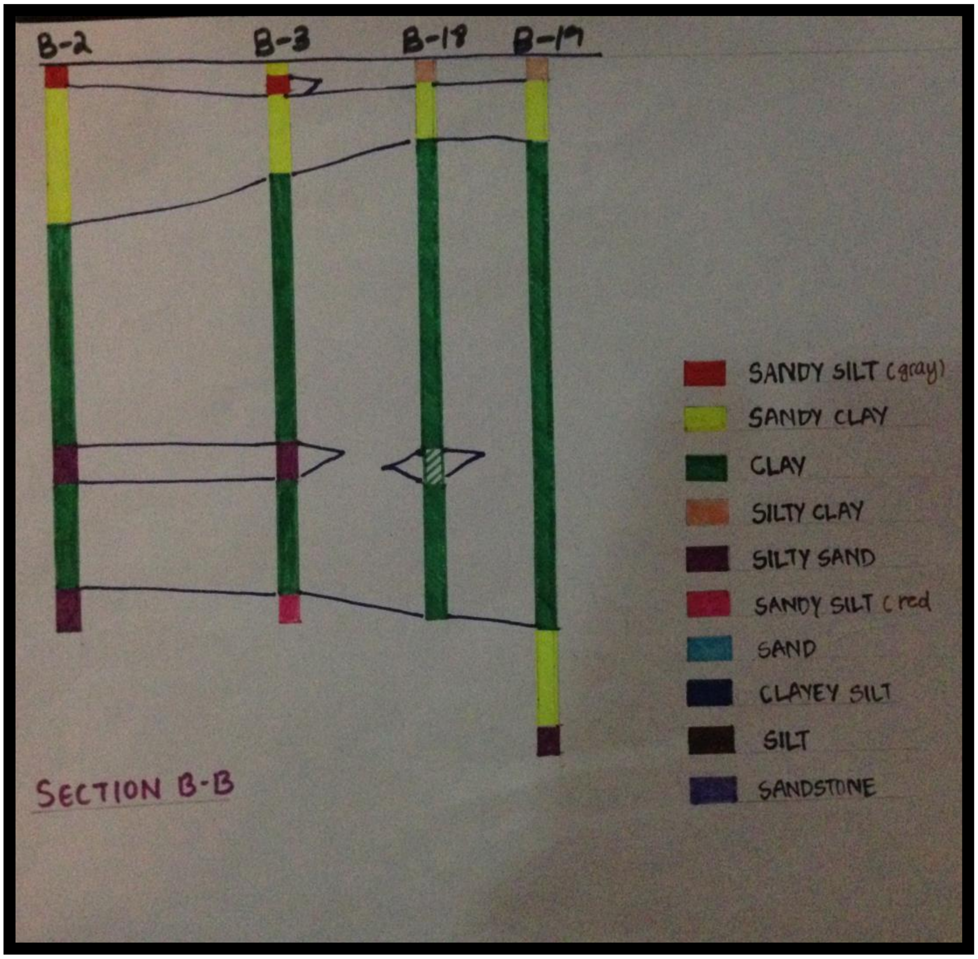


Figure 2: Soil profile of Section B-B

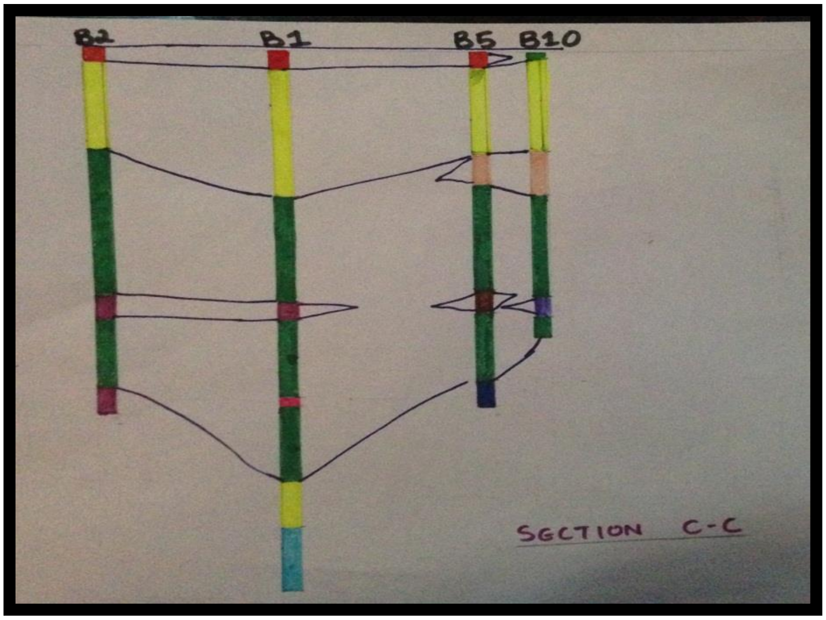


Figure 3: Soil profile of section C-C

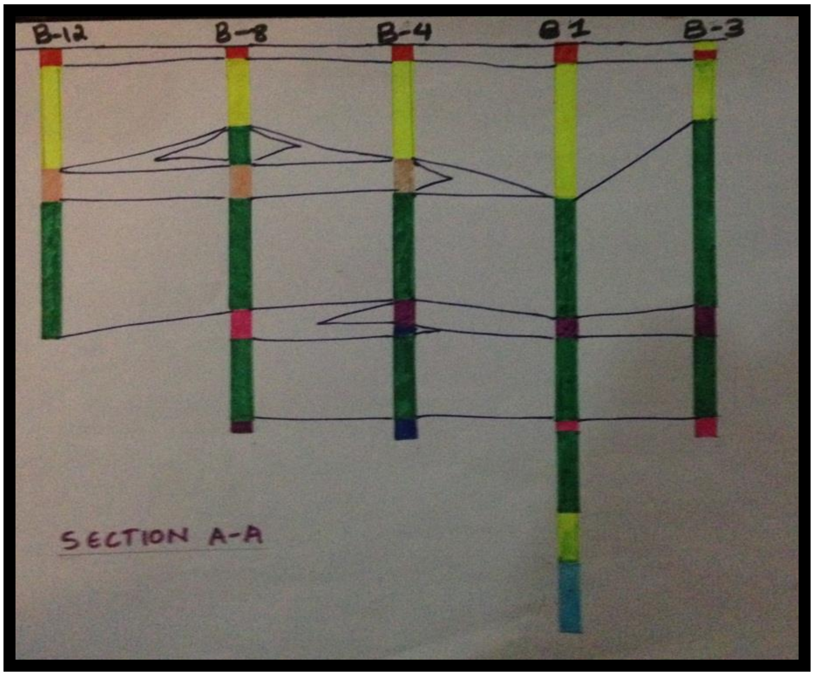


Figure 4: Soil profile of section A-A

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.

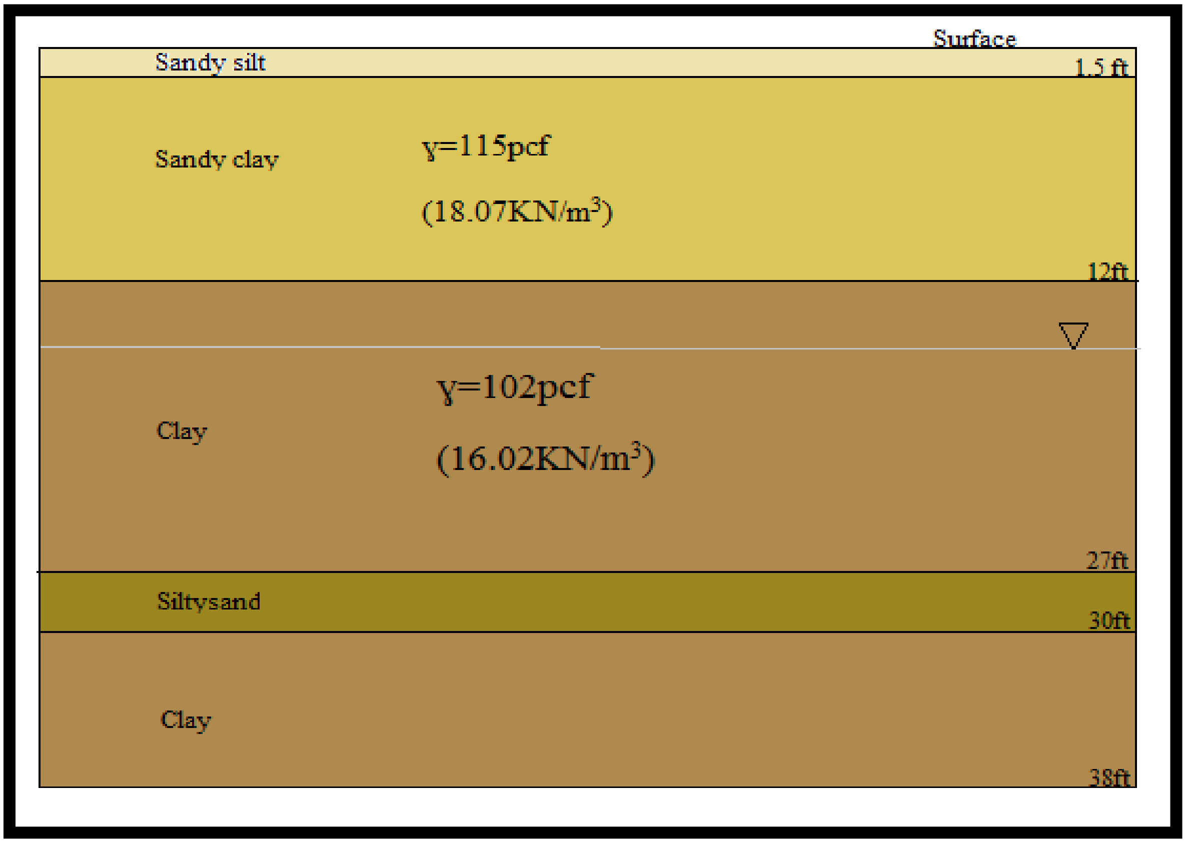
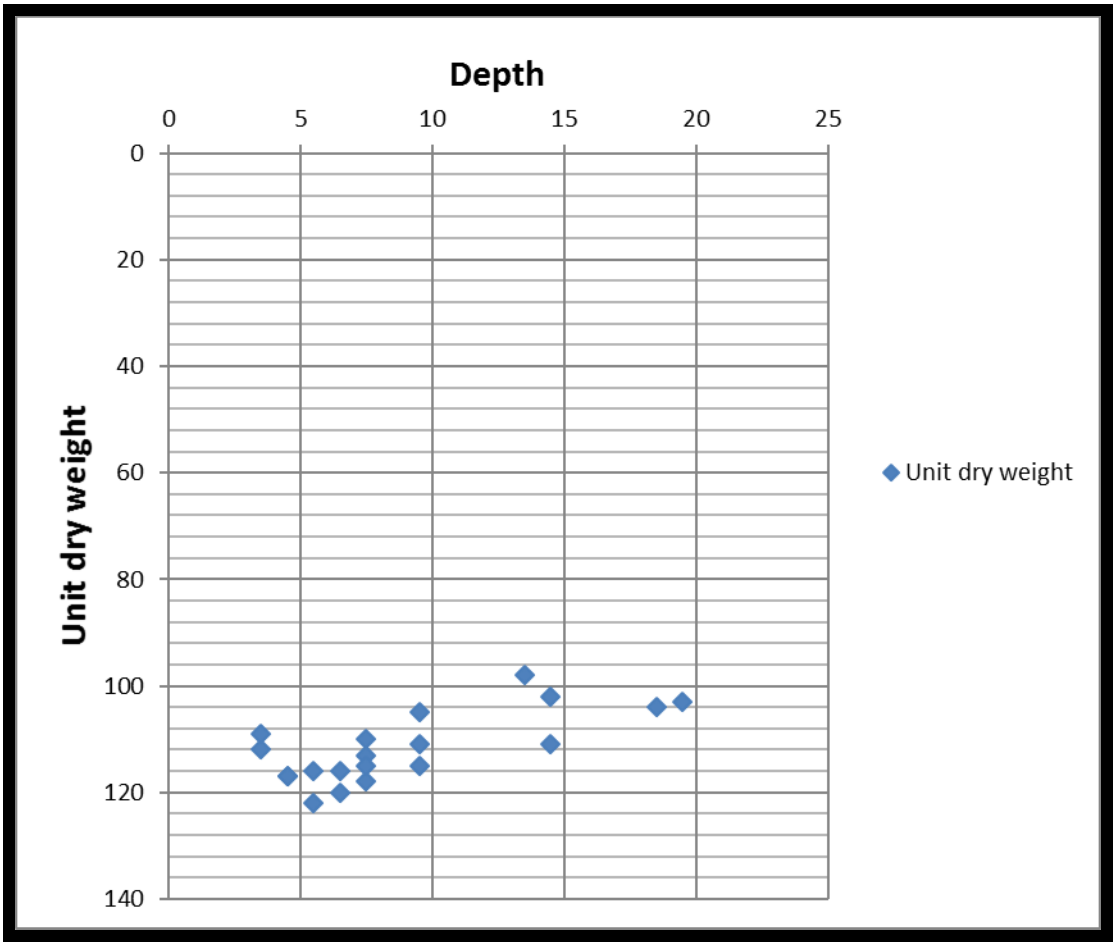


Figure 5: Idealized soil profile

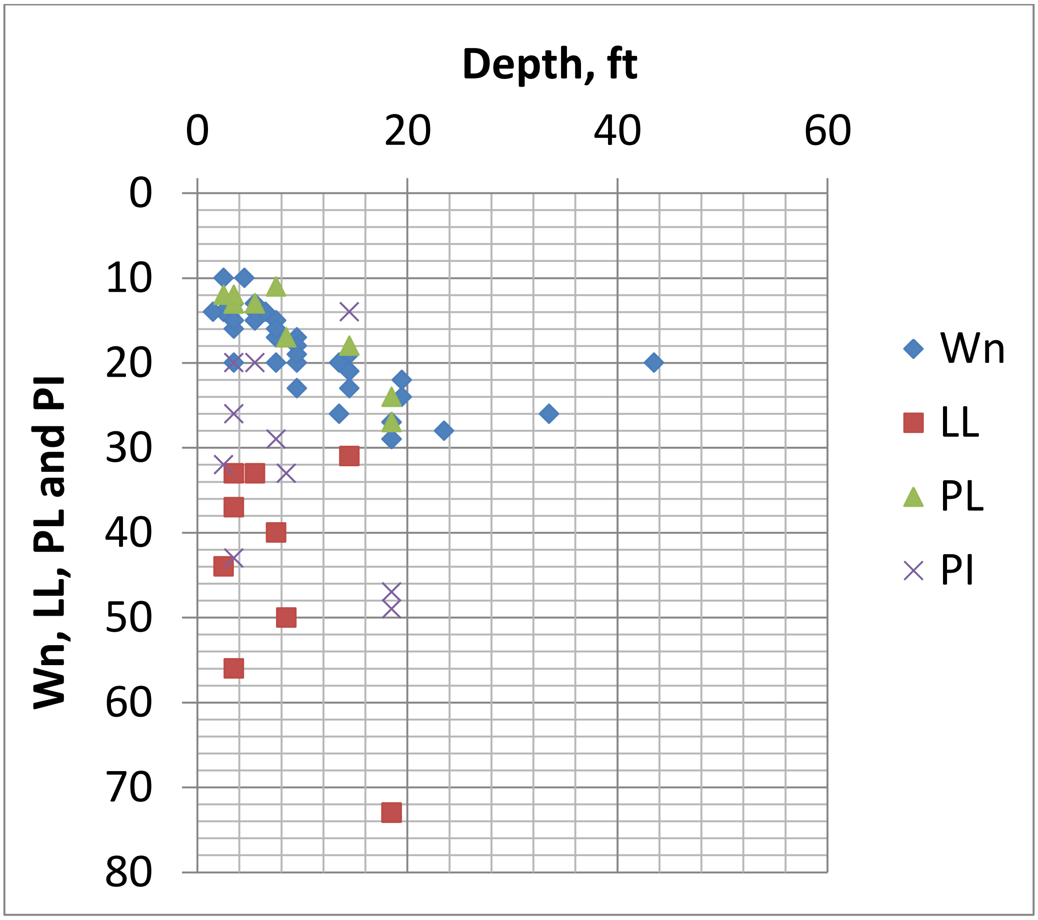
9. The depth of each layer is found by arithmetically averaging all the similar layers in each section. Some of the matchless soil layers and lenses are ignored.

3.2Soil Parameters:

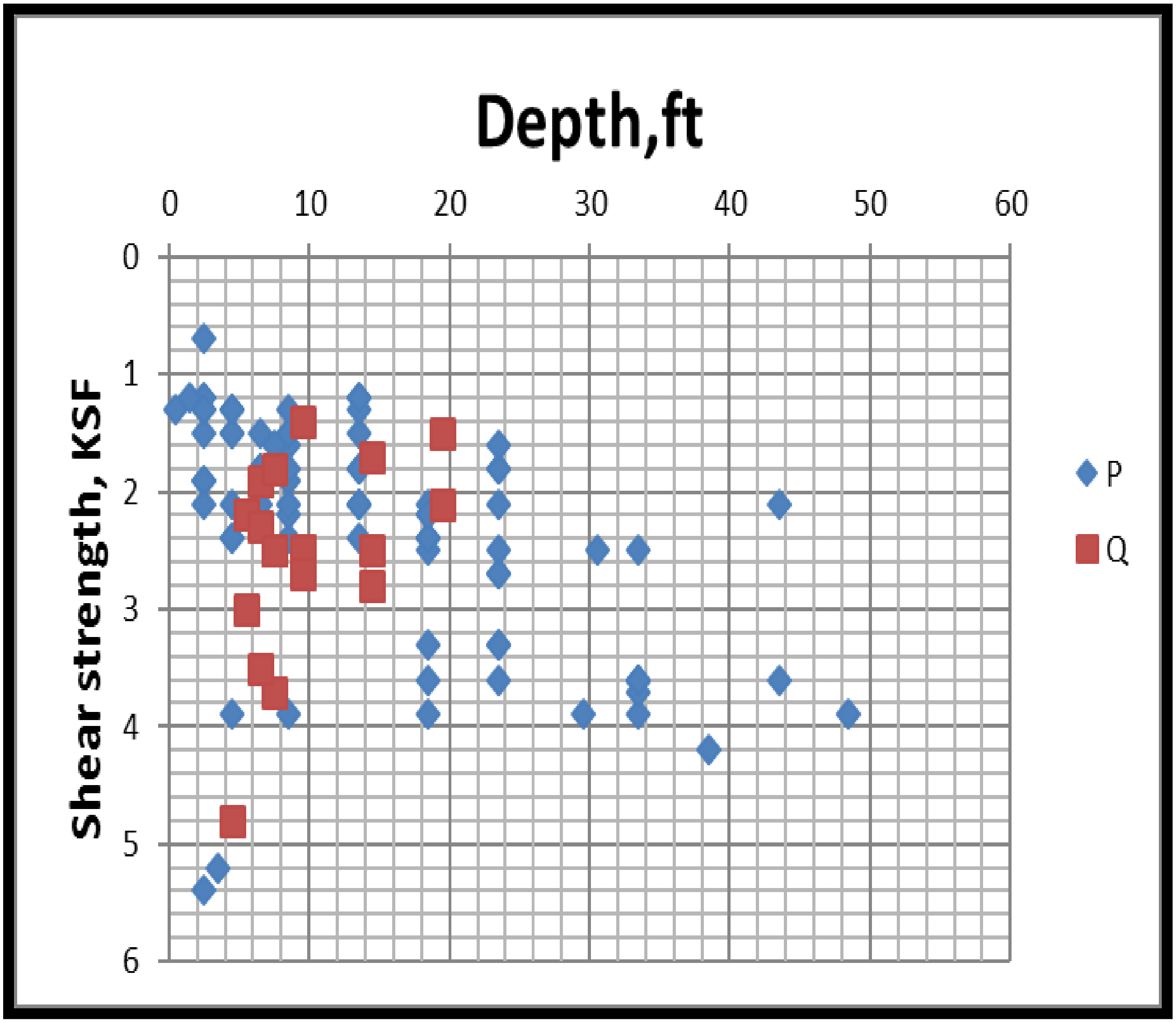
The computations of soil parameters are done by drawing the graph of each parameter against depth. After the graph is drawn, the value of different soil parameters like density, liquid limit, shear strength, etc. for each layer in the idealized soil profile are found by drawing the best fit line.



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

SOIL PARAMETERS

Depth (ft)	Depth (m)	ɣ (pcf)	Wn	LL	PL	PI	Shear strength	
							P	Q
1.5-12	0.36-3.66	115	14	44	13	31	1.8	2.8
12-27	3.66-8.23	102	24	50	15	33	2.1	2.2
27-30	8.23-9.14		20	50	15	33	2.2	2.5
30-38	9.14-11.5		18	50	15	33	2.4	2.5

CHAPTER 4

TYPES AND SELECTION OF FOUNDATION

4.1Types 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 shallow foundation because it's only two storey high and shallow 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.

4.2General 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.

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 :

```
//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.

5.1Dimension

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

5.2Various loads acting on the superstructure

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

5.2.1Imposed 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 isa commercial building.

From IS 875-part 2, we took the imposed load for commercial building as $\underline{5kN/m^2}$.

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.)

5.2.2Dead 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: 25x section of element

5.2.3Wind 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:

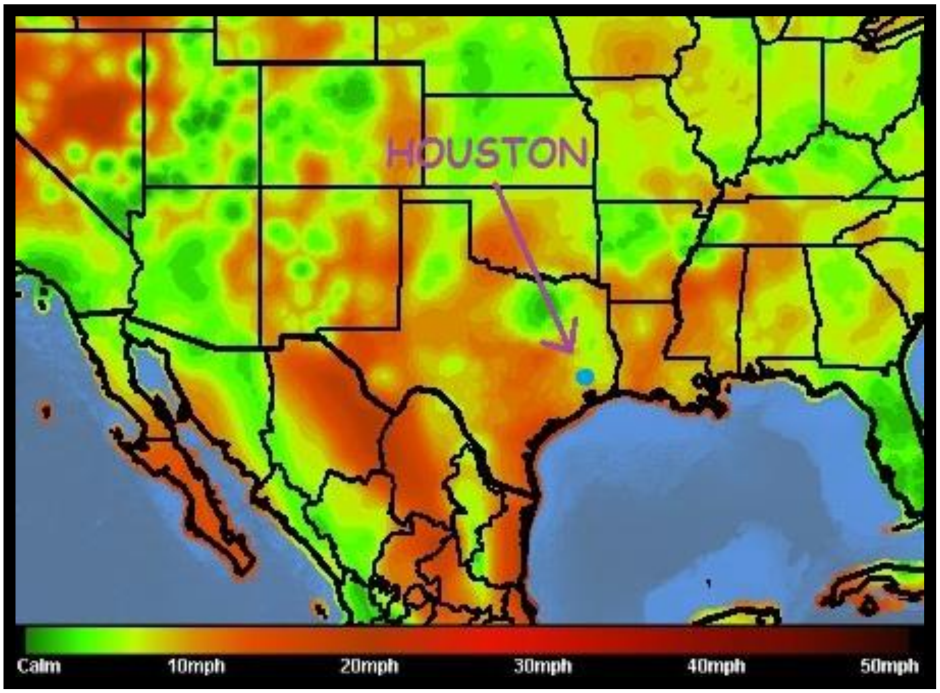


Figure 6: Wind speed map of Texas

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:

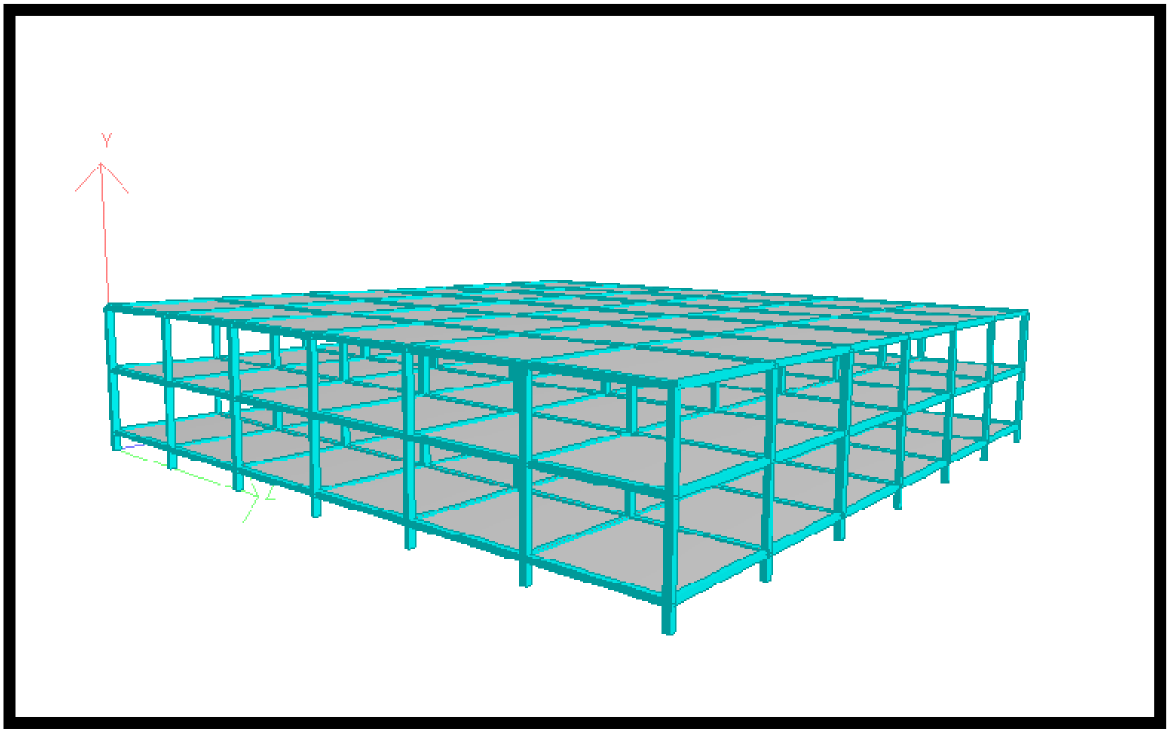


Figure 7: 3D model of the 2 storey building

Different loadings given on the building

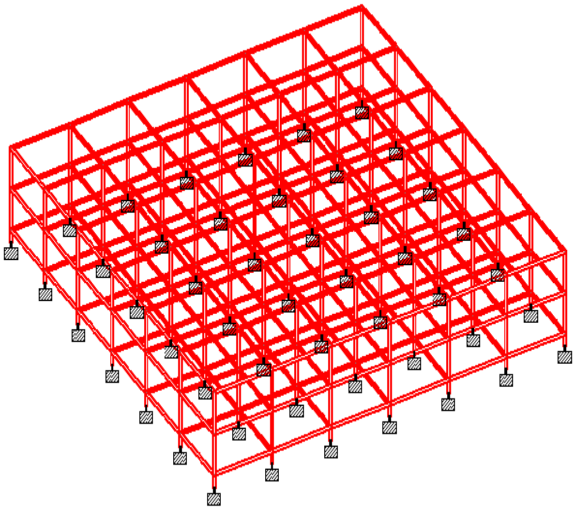


Figure 8: Dead load

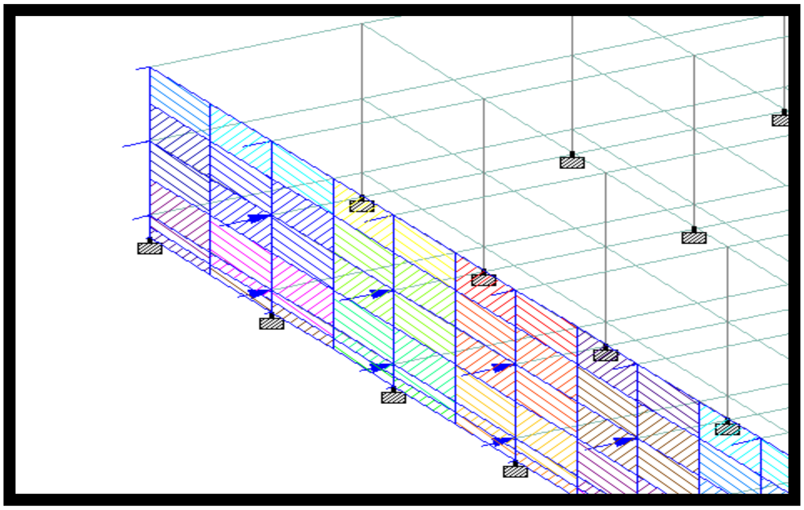


Figure 9: Wind load

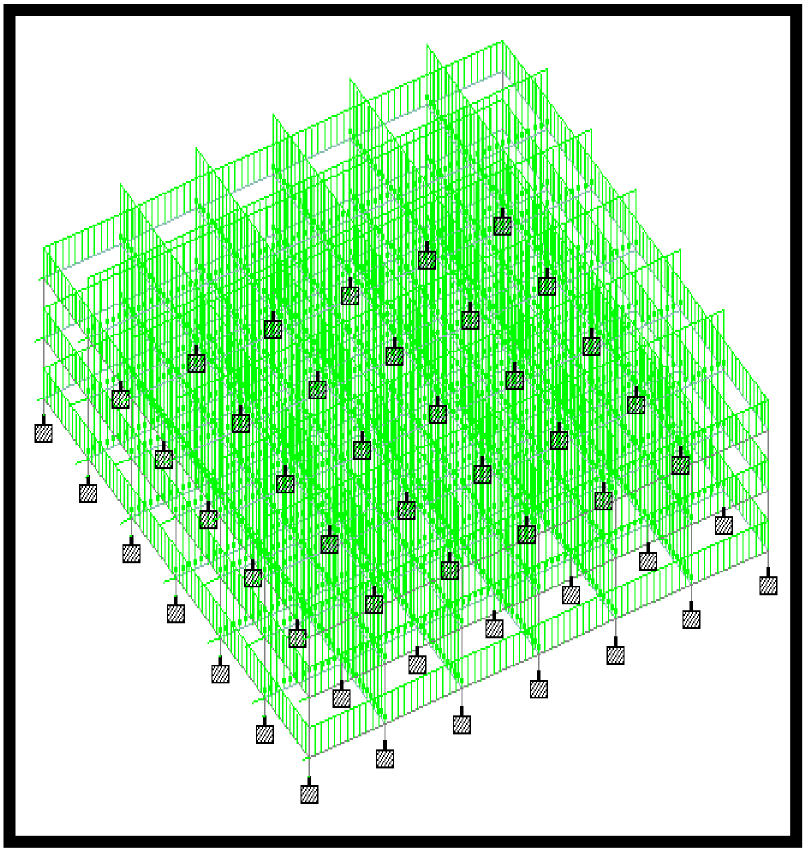
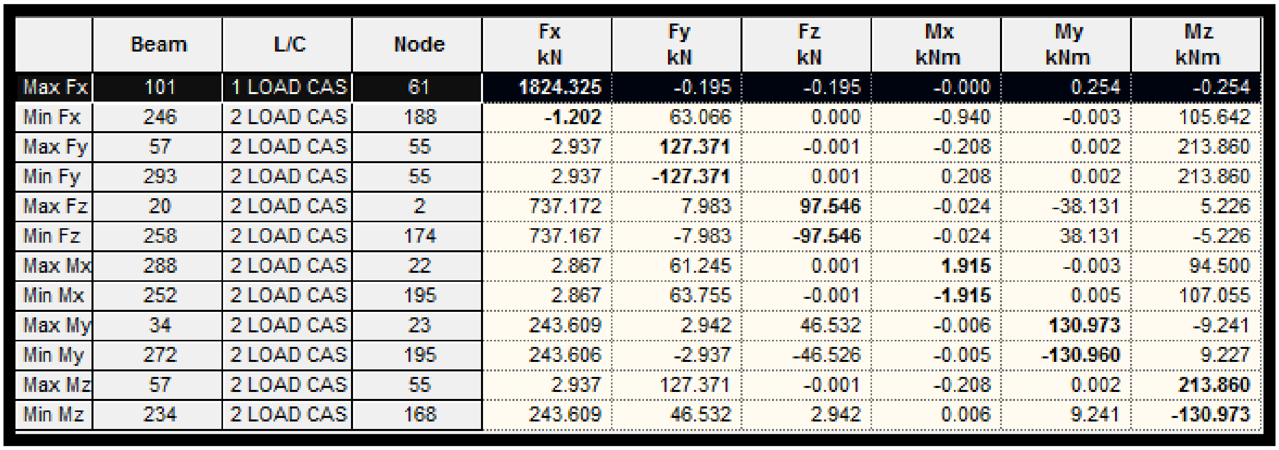


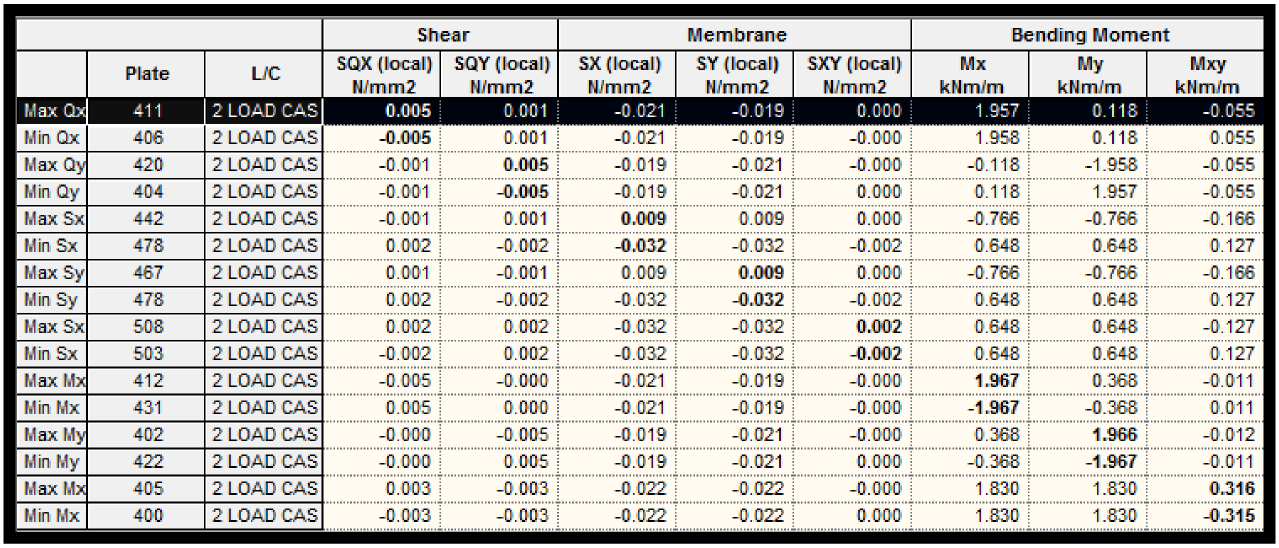
Figure 10: Combined load

Summary of beam analysis (Both horizontal and vertical):



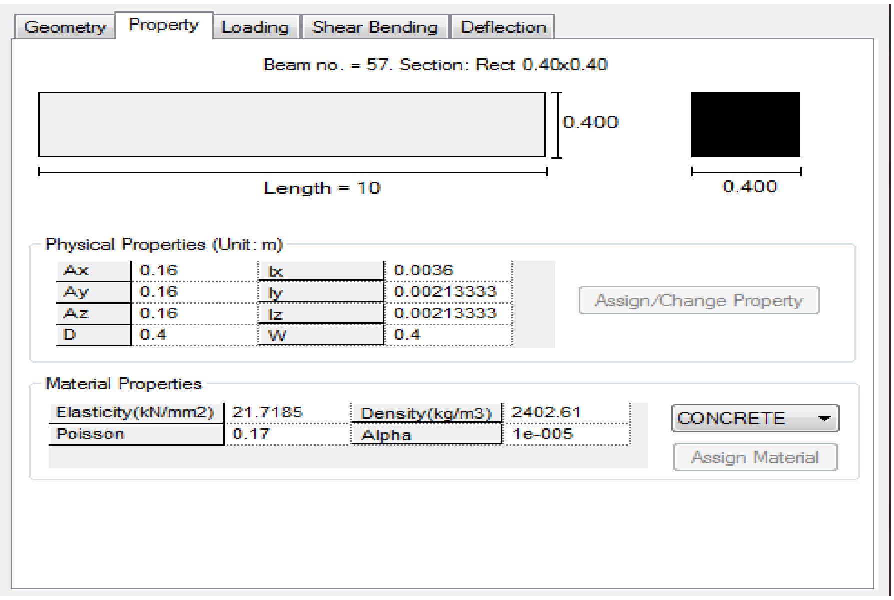
	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	101	1 LOAD CAS	61	**1824.325**	-0.195	-0.195	-0.000	0.254	-0.254
Min Fx	246	2 LOAD CAS	188	**-1.202**	63.066	0.000	-0.940	-0.003	105.642
Max Fy	57	2 LOAD CAS	55	2.937	**127.371**	-0.001	-0.208	0.002	213.860
Min Fy	293	2 LOAD CAS	55	2.937	**-127.371**	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)



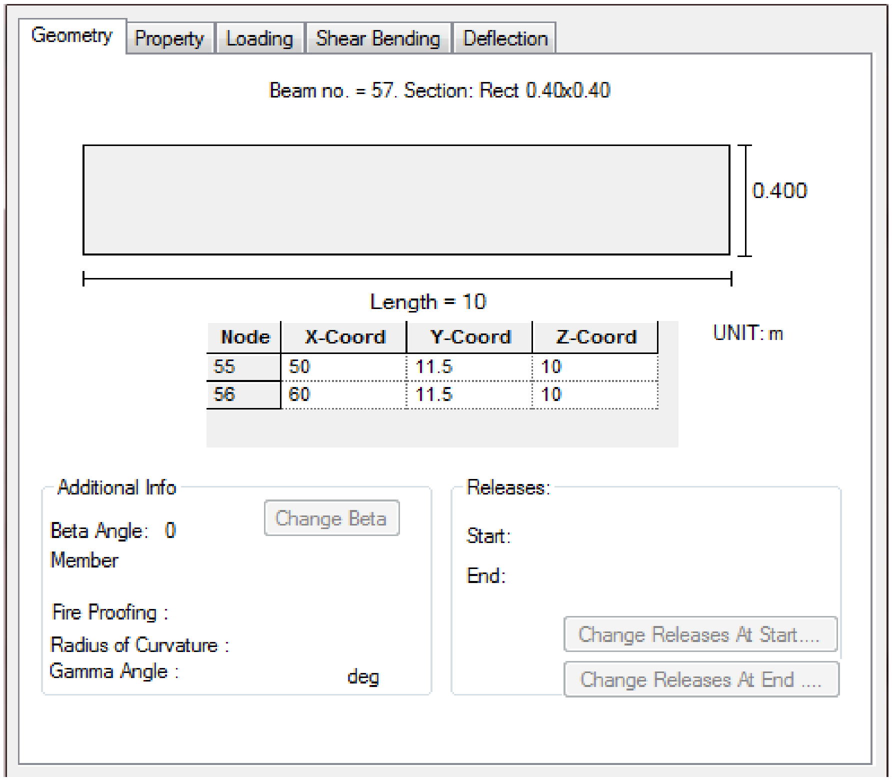
Beam no. = 57. Section: Rect 0.40x0.40

Physical Properties (Unit: m)

Ax	0.16	Ix	0.0036
Ay	0.16	Iy	0.00213333
Az	0.16	Iz	0.00213333
D	0.4	W	0.4

Material Properties

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



Beam no. = 57. Section: Rect 0.40x0.40

Node	X-Coord	Y-Coord	Z-Coord
55	50	11.5	10
56	60	11.5	10

Additional Info

Beta Angle: 0

Member

Fire Proofing :

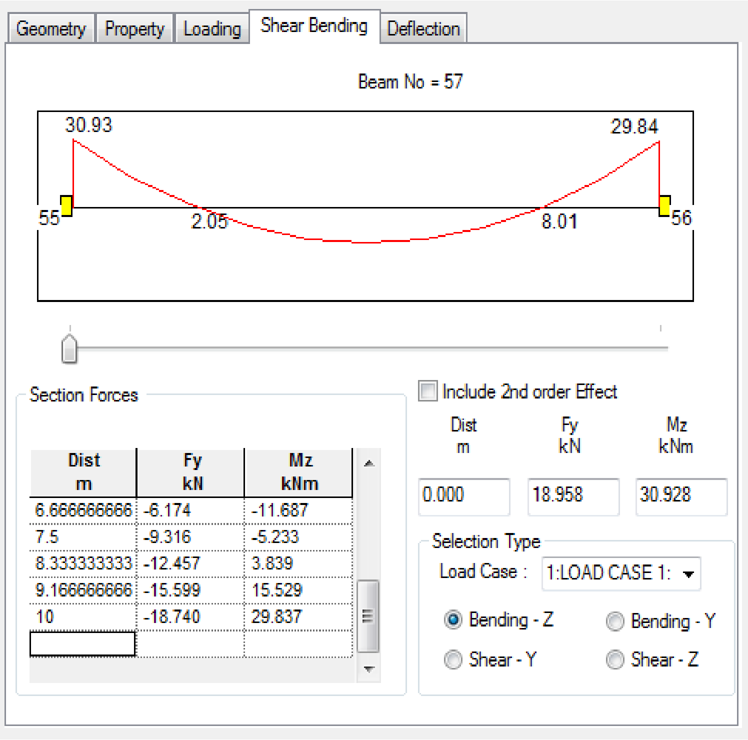
Radius of Curvature :

Gamma Angle : deg

Releases:

Start:

End:



Dist m	Fy kN	Mz kNm
6.666666666	-6.174	-11.687
7.5	-9.316	-5.233
8.333333333	-12.457	3.839
9.166666666	-15.599	15.529
10	-18.740	29.837

☐ Include 2nd order Effect

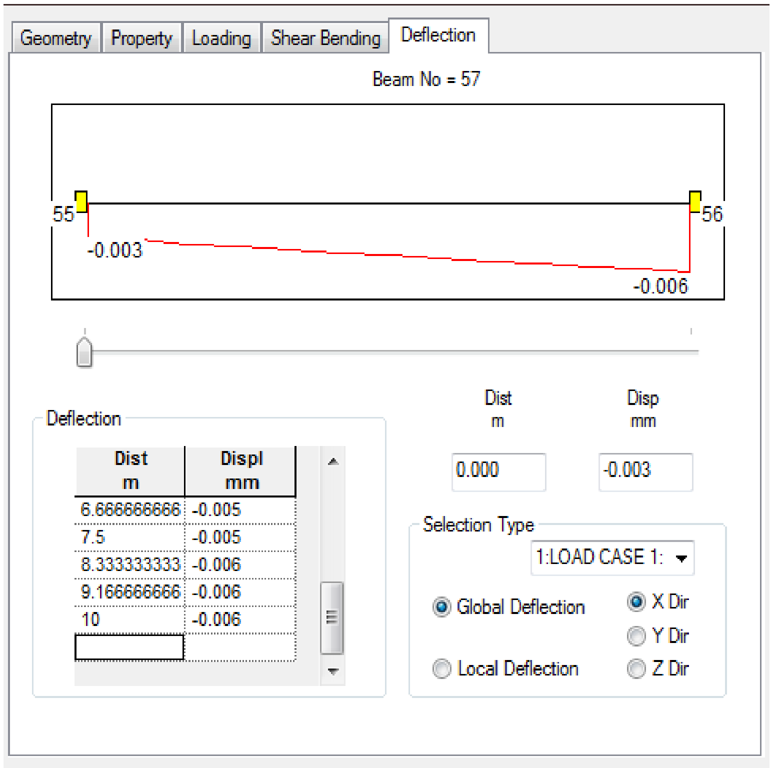
Dist m	Fy kN	Mz kNm
0.000	18.958	30.928

Selection Type

Load Case : 1:LOAD CASE 1:

● Bending - Z ○ Bending - Y

○ Shear - Y ○ Shear - Z



Dist m	Displ mm
6.666666666	-0.005
7.5	-0.005
8.333333333	-0.006
9.166666666	-0.006
10	-0.006

Dist m	Disp mm
0.000	-0.003

Selection Type

1:LOAD CASE 1:

● Global Deflection ● X Dir

○ Y Dir

○ Local Deflection ○ Z Dir

Figure: Shear bending and deflection

Design of slab(No.412):

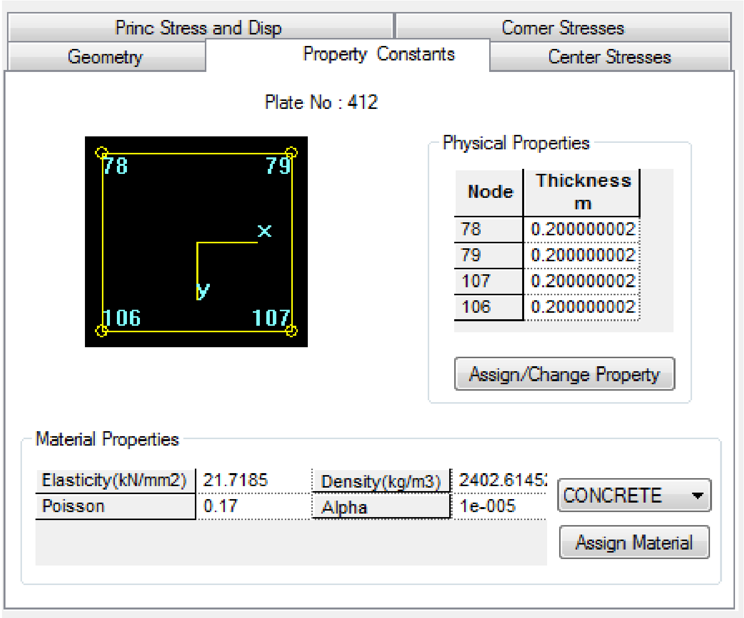


Plate No : 412

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

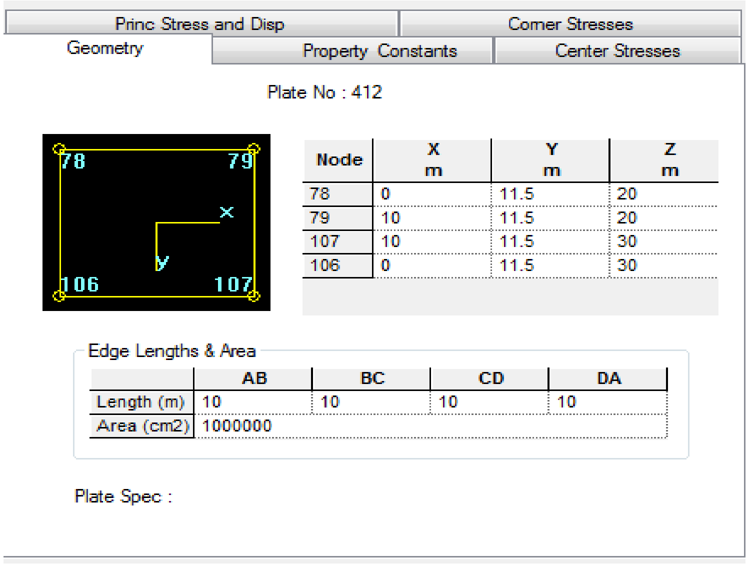


Plate No : 412

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 :

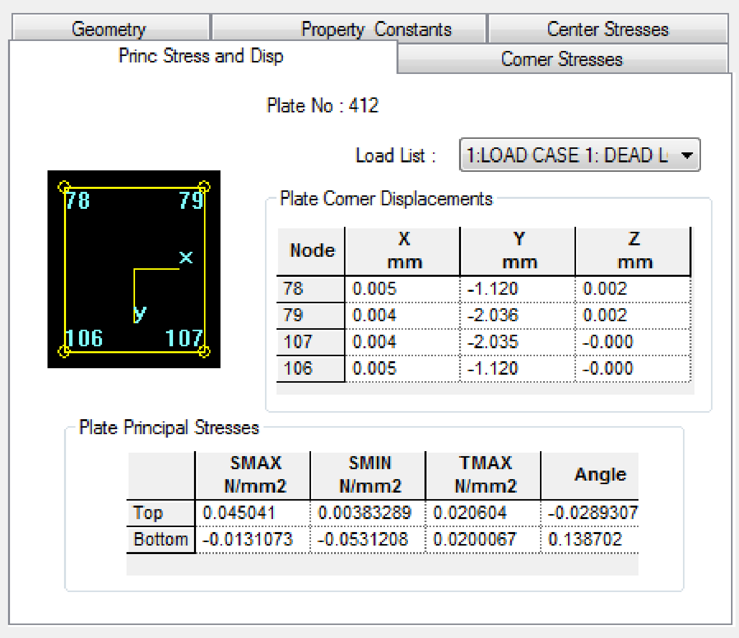


Plate No : 412

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

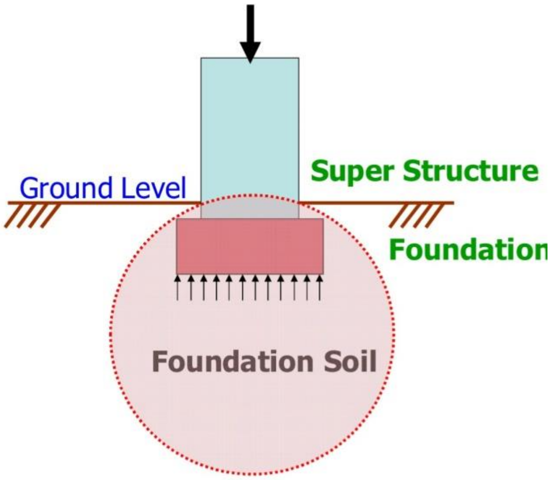
CHAPTER-6

DESIGN OF SUB-STRUCTURE

Design of sub-structure is basically done in two parts:

6.1 Calculation of Net Ultimate Bearing Capacity of soil.

6.2 Design of Footing.



6.1Calculation of Net Ultimate Bearing Capacity of soil

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

There are three modes of failure that limit bearing capacity: general shear failure, local shear failure, and punching shear failure.

6.1.1Definitions

Bearing capacity is the power of foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement. Foundation soil is that portion of ground which is subjected to additional stresses when foundation and superstructure are constructed on the ground. The following are a few important terminologies related to bearing capacity.

Ultimate bearing capacity (q_u) : It is the maximum pressure that a foundation soil can withstand without undergoing shear failure.

Net ultimate bearing capacity (q_{nu}) : It is the maximum extra pressure (in addition to initial overburden pressure) that a foundation soil can withstand without undergoing shear failure.

$$q_{nu} = q_u - \gamma D_f$$

Here, γD_f represents the overburden pressure at foundation level and where γ is the unit weight of soil and D_f is the depth to foundation bottom from Ground Level.

Safe bearing capacity (q_{ns}) : It is the safe extra load the foundation soil is subjected to in addition to initial overburden pressure. F represents the factor of safety.

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

Allowable bearing pressure (q_a) : It is the maximum pressure the foundation soil is subjected to considering both shear failure and settlement.

6.1.2Calculation of ultimate bearing capacity using is code recommendations

IS:6403-1981 recommends that for the computation of the ultimate bearing capacity of a shallow foundation in general shear failure is given by:

$$q_{nu}= cN_c s_c d_c i_c + q(N_q-1)s_q d_q i_q + 0.5\Upsilon B N_\Upsilon s_\Upsilon d_\Upsilon i_\Upsilon W'$$

where s, d ,i are shape, depth and inclination factor respectively.

W' is a factor which takes in to account the effect of water table.

$N_{c,}N_{,}N_\Upsilon$ are the bearing capacity factors.

For cohesive soil, the net ultimate capacity of a footing is given by equation:

$$q_{nu}= cN_c s_c d_c i_c$$

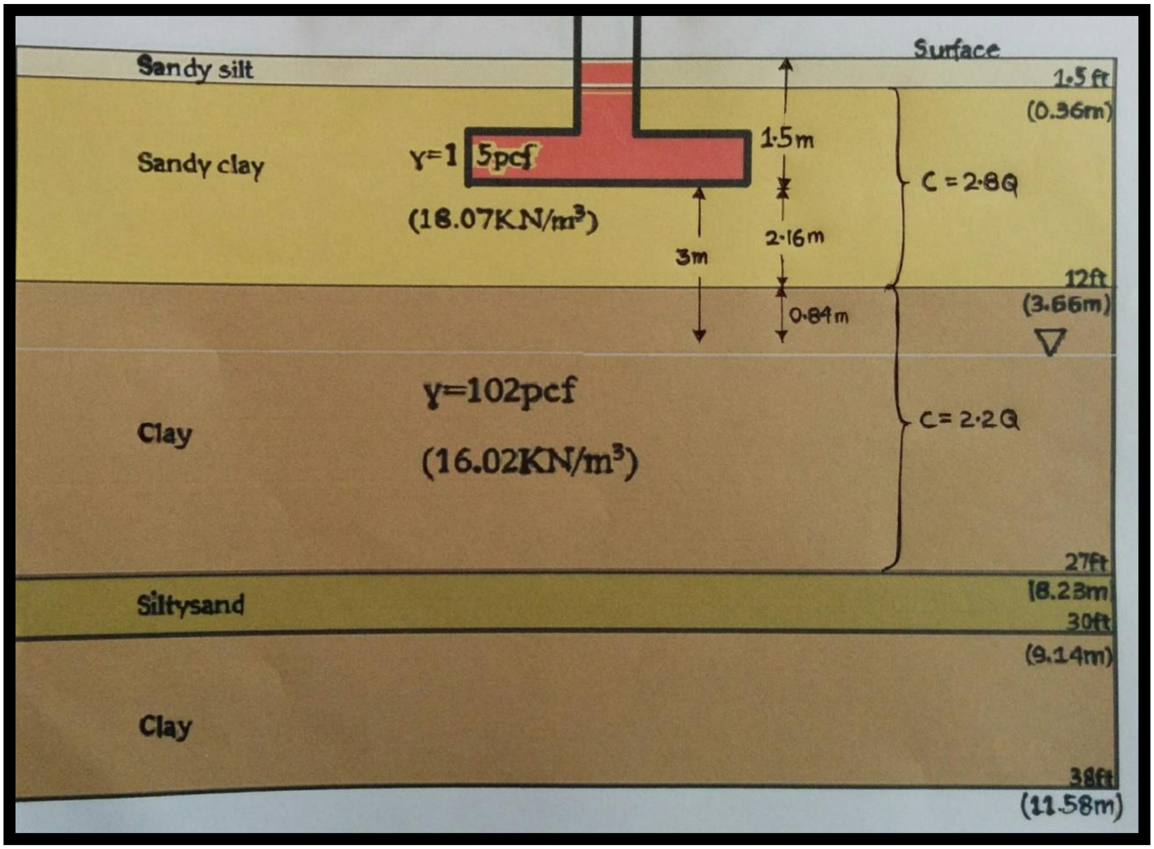


Figure11.Footing placed in idealiszed soil profile

$q_{nu}= cN_c s_c d_c i_c + q(N_q-1)s_q d_q i_q + 0.5\Upsilon BN_\Upsilon s_\Upsilon d_\Upsilon i_\Upsilon W'$

$$c_{u\ avg} = \frac{c_1 H_1 + c_2 H_2 + \ldots}{\Sigma H}$$

$$c_{u\ avg} = \frac{(2.8x2.16) + (0.84x2.2)}{(2.16 + 0.84)}$$

$q_{nu} = cN_c s_c d_c i_c$

$c_{u\ avg} = 126.02\ kN/m^2$

$N_c = 5.14$

$S_c = 1.3$

$d_c = 1.12$

$i_c = 1$

q_{nu}= 126.02 x 5.14 x 1.3 x 1.12 x 1

= 943.11kN/m^2

Factor of Safety (F) = 3

Safe Bearing Capacity= q_{nu} / F = 943.11/3 =314.37 kN/m^2

6.2 Design of Footing

6.2.1Introduction

Footings are structural elements that transmit column or wall loads to the underlying soil below the structure. Footings are designed to transmit these loads to the soil without exceeding its safe bearing capacity, to prevent excessive settlement of the structure to a tolerable limit, to minimize differential settlement, and to prevent sliding and overturning. The settlement depends upon the intensity of the load, type of soil, and foundation level. Where possibility of differential settlement occurs, the different footings should be designed in such away to settle independently of each other.

Foundation design involves a soil study to establish the most appropriate type of foundation and a structural design to determine footing dimensions and required amount of reinforcement.

Because compressive strength of the soil is generally much weaker than that of the concrete, the contact area between the soil and the footing is much larger than that of the columns and walls.

The type of footing chosen for a particular structure is affected by the following:

1. The bearing capacity of the underlying soil.

2. The magnitude of the column loads

3. The position of the water table.

4. The depth of foundations of adjacent buildings.

6.2.2Types of foundations

Based on the position with respect to ground level, footings are classified into two types;

1. Shallow Foundations

2. Deep Foundations

Shallow Foundations are provided when adequate SBC is available at relatively short depth below ground level. Here, the ratio of D_f / B < 1, where $D_f$is the depth of footing and B is the width of footing

Deep Foundations are provided when adequate SBC is available at large depth below ground level. Here the ratio of D_f / B >= 1.

Types of Shallow Foundations

The different types of shallow foundations are as follows:

- **Isolated Footing**
- Combined footing
- Strap Footing
- Strip Footing
- Mat/Raft Foundation
- Wall footing

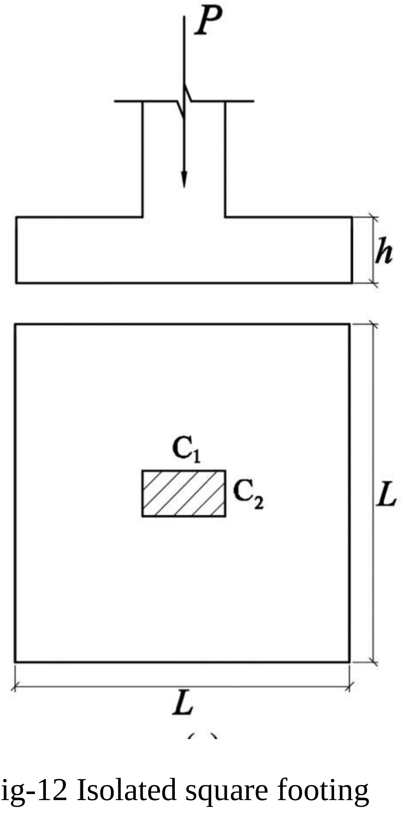


Fig-12 Isolated square footing

6.2.3DESIGN OF AN ISOLATED SQUARE FOOTING

Taking Node 86 from the Plan of the Building.

DATA PROVIDED:

Load on the column= 1826kN

Column size= 500x500mm

Safe Bearing Capacity= 314.37kN/m^2

Assuming M_{20} and Fe_{415}

Node	**F_x (kN)**	**F_y (kN)**	**F_z (kN)**	**M_x (kN-m)**	**M_y (kN-m)**	**M_z (kN-m)**
86	-15.93	1826	-0.00	0.00	0.00	9.061

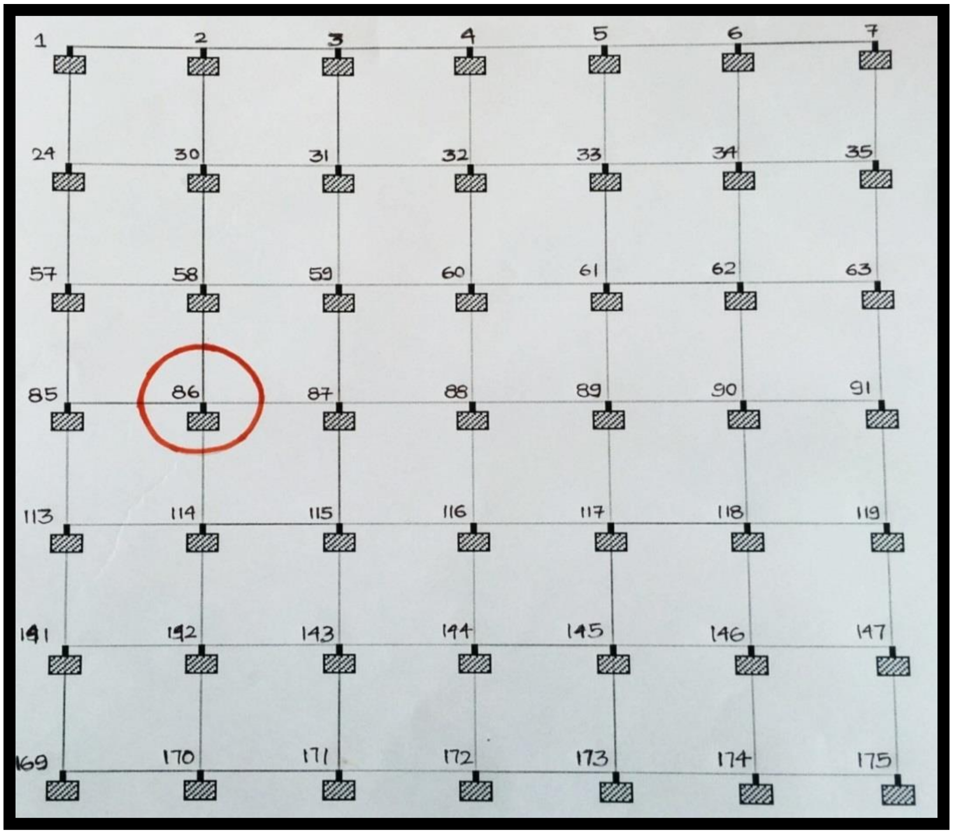


Figure-13.Plan of the building showing respective nodes

SIZE OF THE FOOTING:

Assuming the weight of footing + Back Fill= 10% of load

Total load=1.1x1826=2008.6kN

Base Area required= Total load/Safe Bearing Capacity=2008.6/314.37=6.389m^2

For a square footing,

Minimum size of the square footing=√A

=2.57m

Hence , provide a footing of size 3m x 3m

Net upward pressure in soil,p= 2008.6/(3x3)= 223.17< 314.37kN/m^2

Factored upward pressure of soil= 1.5 x223.17=334.76 kN/m^2

Factored vertical load,P=2008.6 x1.5= 3013kN

TWO WAY SHEAR

Assume an uniform overall thickness of footing,D= 750mm

Assuming 16ϕ bars of main steel, cover = 75mm

Effective Thickness, d= 750-75-16 =659mm

Critical section for two way shear/Punching shear occurs at a distance of d/2 from face of the column.

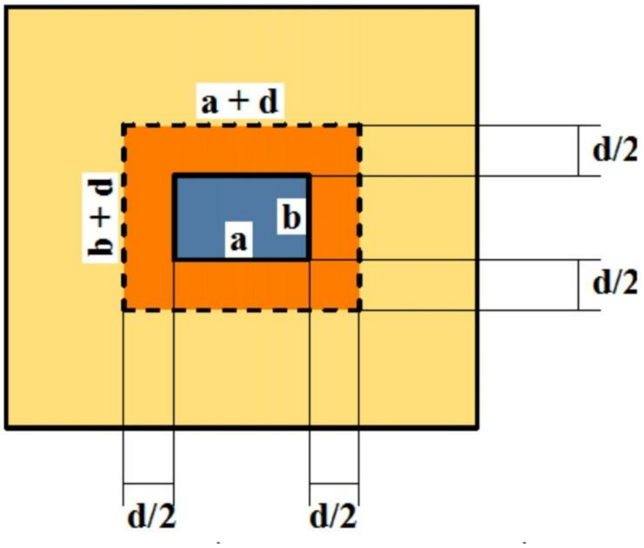


Fig-14.Critical section for two way shear.

Punching area of the footing = $(500+d)^2$ =$(500+659)^2$=1.343m^2

Punching Shear Force= Factored Load-(Factored upward pressure x Punching area of footing)

= 3013 –(334.37 x 1.343)

Perimeter of critical section = 4(550+d)=4(500+659)=4636mm

$$\text{Nominal Shear Stress in Punching},\tau_v = \frac{\text{Punching Shear Force}}{\text{Perimeter x Effective Thickness}}$$

τ_v= 2563.87 x 10^3/(4636 x 659) = 0.84N/mm^2

Allowable Shear Stress = $k_s\tau_c$ (***ref. to sec 31.6.3 IS 456:2000***)

τ_c=0.25$\sqrt{fck}$ =.25 u 20 =1.12N/mm^2

k_s= (0.5+ $ß_c$)=(0.5 + 0.5/.5)= 1

Allowable Shear Stress =$k_s\tau_c$ = 1 x 1.12 = 1.12N/mm^2

Allowable Shear Stress > Punching Shear Stress

Therefore, assumed thickness is sufficient to resist Punching Shear Force.

DESIGN FOR FLEXURE

The critical section of flexure occurs at the face of column.

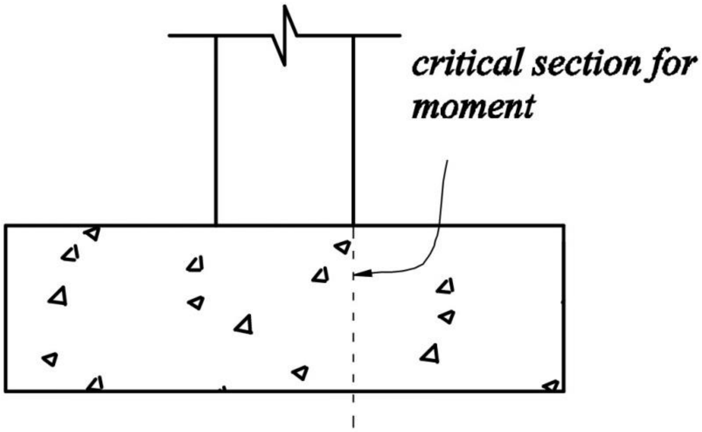


Fig-15. Critical section for moment.

Factored upward soil pressure, p_u=334.5kN/m^2

Let projection of footing beyond column face=l=(3000-500)/2=1250mm

Bending Moment at critical section, $M_u = p_u l^2 b/2$ (***ref. to sec 34.2.3 IS456:2000***)

$$M_u = \frac{334.76 \times 1.25^2 \times 3}{2}$$

M_u= 784.59kN-m

$$M_u = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{b\, d\, f_{ck}} \right)$$ ***(ref.to Annex G-1.1 of IS 456:2000)***

Calculating A_{st} from above equation and on solving ,A_{st} = 3420mm^2

% area of steel, p_t = 0.172

ONE WAY SHEAR

The critical section of one way shear occurs at a distance of ‘d’at the face of column.

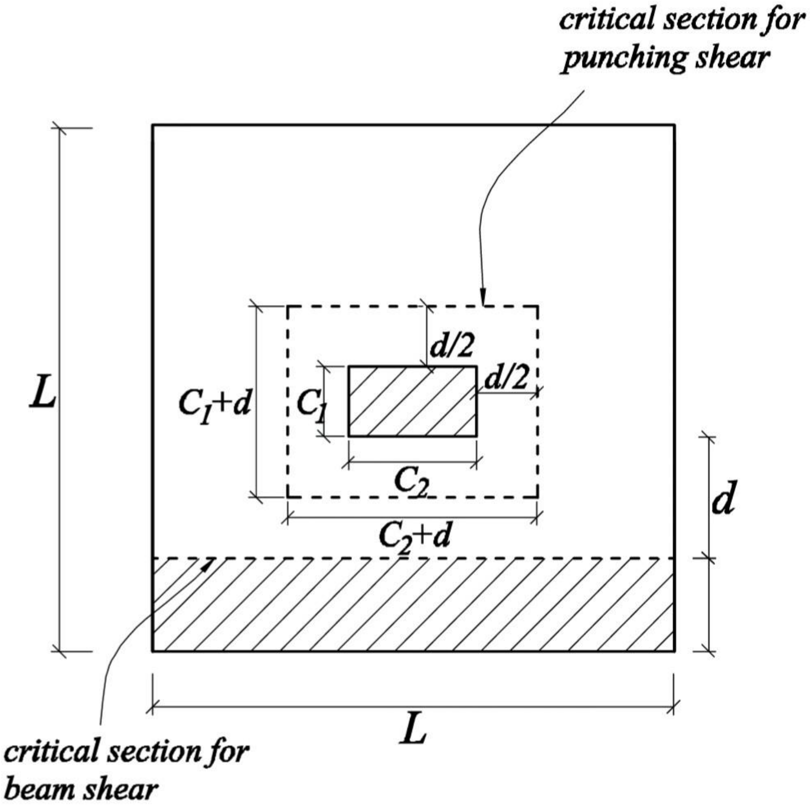


Fig-16.Critical section for one way shear.

$V_u = p_u(l\text{-}d)B$

$V_u = 334.76(1.25 – 0.659)3$

V_u=827.27kN

τ_v=0.41N/mm^2

Referred to Table 61 of SP-16, τ_c=0.41,f_{ck}=20N/mm^2

p_t= 0.36

Comparing p_t from flexure and one way criterion,

Provide p_t= 0.36(larger of the two)

Hence, Area of steel required ($A_{st\ req.}$) = $\frac{p_t .\ B\ .d}{100}$

$A_{st\ req}$= 7117.2mm^2

No. of bars= $\frac{A_{streq}}{\pi/4 \times 16^2}$ = 36 bars

Spacing = 80 mm c/c both ways.

$A_{st\ provided} = 36 \times \pi/4 \times 16^2 = 7236mm^2$

$A_{st\ provided} > A_{st\ required}$ (o.k.)

Provide 36 bars of 16ϕ at spacing of 80mm c/c.

CHECK FOR DEVELOPMENT LENGTH

Required development length = $L_d = \frac{\phi(0.87f_y)}{\tau_{bd}}$ ***(ref. to Cl. 26. 2 .1 of IS 456:2000)***

For M_{20} and Fe_{415}, $L_d = 47\phi$

For 16ϕ bars, $L_d = 47 \times 16 = 752m$

Total length available =1250-75=1175>752 (o.k.)

CHECK FOR BEARING STRESS

Let A_1= area of footing = 3 x 3 = $9m^2$

A_2= area of column=0.500 x 0.500 =$0.25m^2$

$\sqrt{(A1/A2)} = 6 > 2$

Limit the value of $\sqrt{(A1/A2)}$ =2

Permissible bearing stress = $0.45\ f_{ck}\sqrt{(A1/A2)} = 18N/mm^2$

Actual bearing stress = $\frac{\text{Factored Load}}{\text{Area of column}} = \frac{1000 \times 3031}{500 \times 500} = 12.21N/mm^2$

Therefore, Actual Bearing Stress < Permissible Bearing Stress (o.k.)

R/F DETAILING

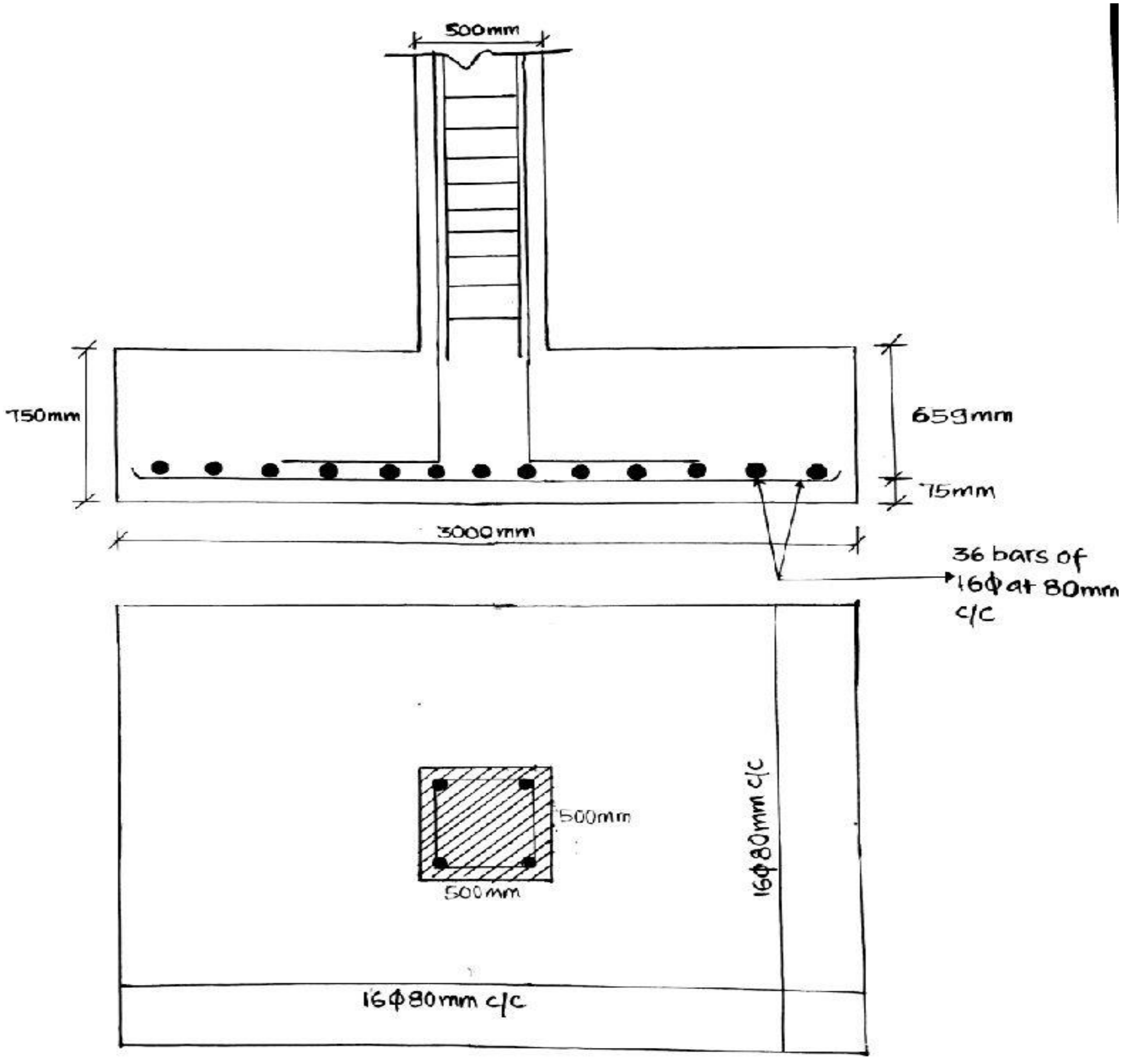
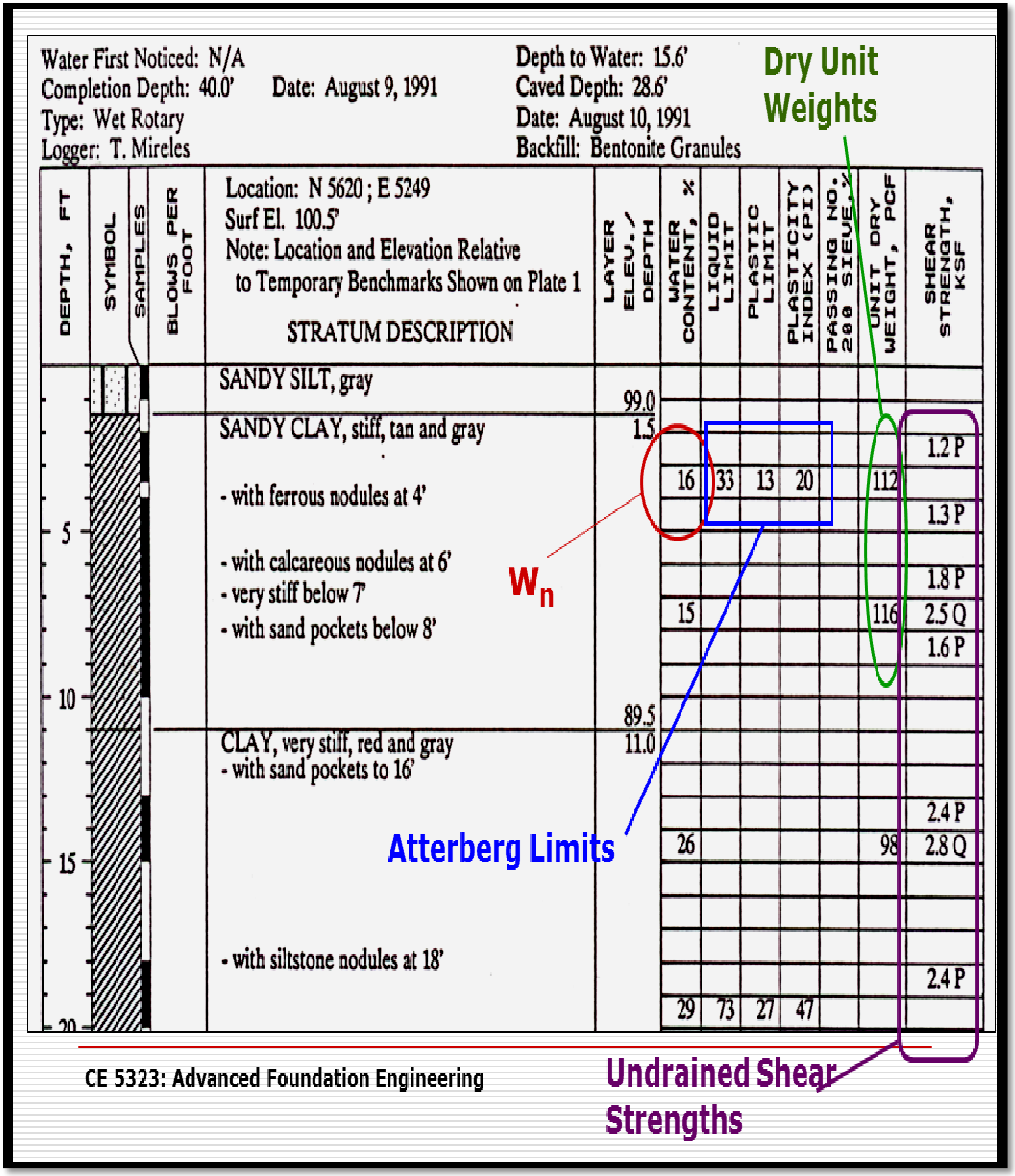


Figure-17 R/f detailing of Isolated Square Footing

APPENDIX (Bore logs)



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

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5620 ; E 5249 Surf El. 100.5' Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1 STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX (PI)	PASSING NO. 200 SIEVE,%	UNIT DRY WEIGHT, PCF	SHEAR STRENGTH, KSF
				SANDY SILT, gray	99.0							
				SANDY CLAY, stiff, tan and gray	1.5							1.2 P
				- with ferrous nodules at 4'		16	33	13	20		112	
5												1.3 P
				- 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							
				CLAY, very stiff, red and gray - with sand pockets to 16'	11.0							
												2.4 P
15						26					98	2.8 Q
				- with siltstone nodules at 18'								2.4 P
20						29	73	27	47			

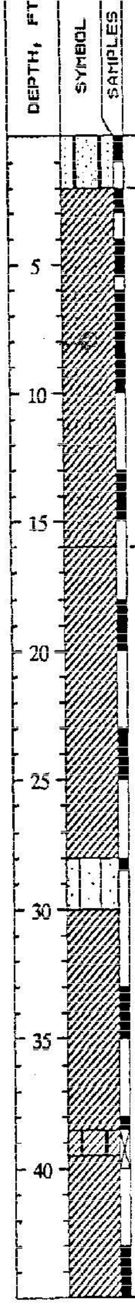
Report No. 0401-2452

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



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
	- 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
									2.1 P
		84.8							
	CLAY, very stiff, red and gray, slickensided, with calcareous nodules	16.0							
			27						2.4 P
	- with silt pockets below 23'								2.7 P
	- silty sand layer with clay pockets and sand stone seams, 28' to 30'								
	- with silt stone seams below 30'								
									3.6 P
19	- red silty sand layer, with clay pockets, 38' to 38.5'								
	- 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

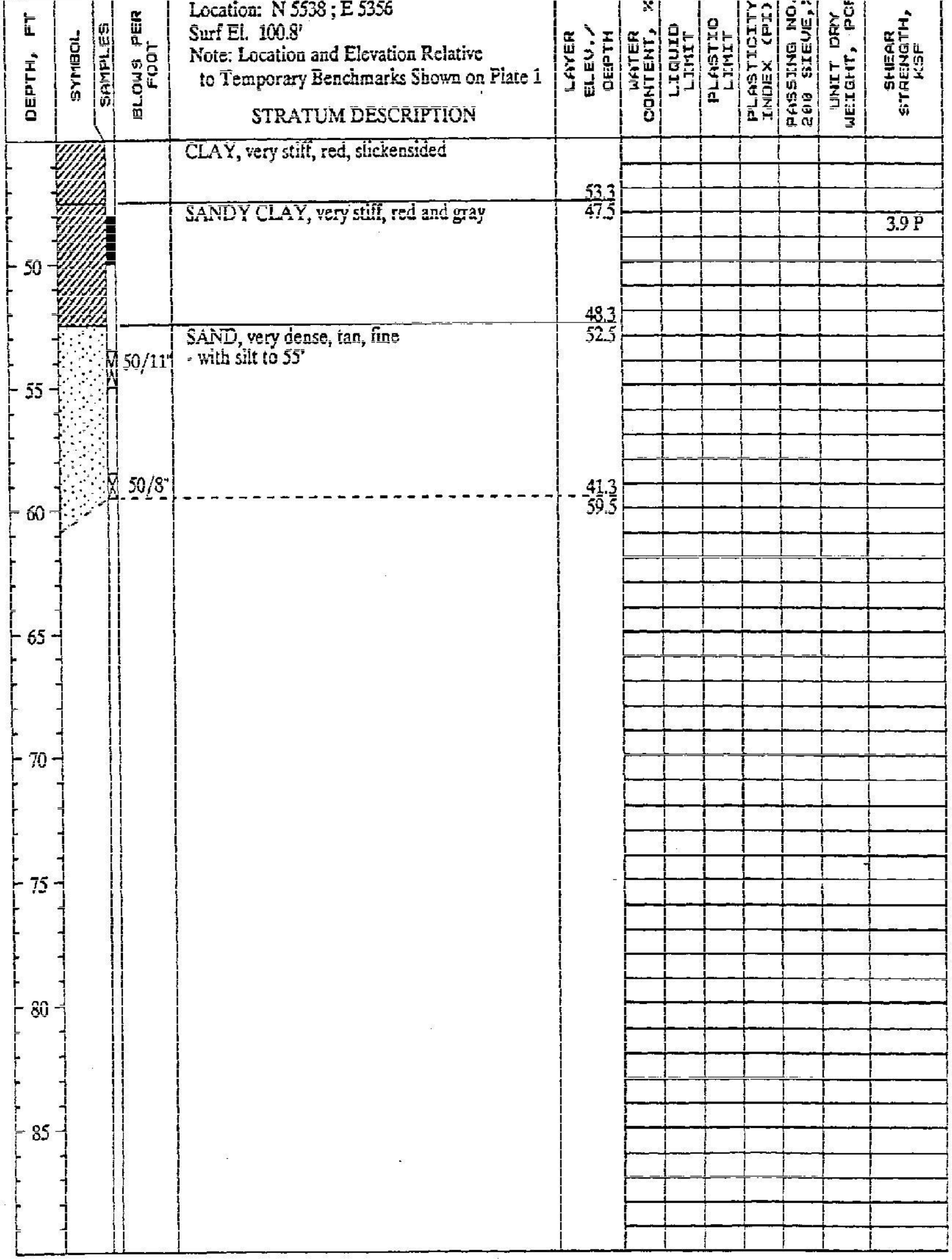
aaaa

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
				CLAY, very stiff, red, slickensided	53.3 47.5							
				SANDY CLAY, very stiff, red and gray								3.9 P
					48.3 52.5							
			50/11"	SAND, very dense, tan, fine - with silt to 55'								
			50/8"		41.3 59.5							

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'								
5												1.3 P
				- 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
15						26					98	2.8 Q
				- with siltstone nodules at 18'								2.4 P
20						29	73	27	47			
				- with silt pockets below 23'								2.5 P
25					73.5 27.0							
			50/1.5"	SILTY SAND, very dense, red, with sand stone seams	71.0 29.5							
30				CLAY, very stiff, red and gray, slickensided - with siltstone nodules to 33'								3.9 P
35												3.6 P
					63.5 37.0							
			50/6"	SILTY SAND, very dense, red, fine	60.5 40.0							
40												

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

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
				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								
				- with ferrous nodules and calcareous nodules below 4'								1.3 P
5				- very stiff below 5'		15					117	2.2 Q
												1.8 P
				CLAY, stiff, gray and tan	93.1 8.0							2.4 P
				- with sand pockets to 16'		20						
10												
												1.5 P
15												
				- very stiff, red and gray, slickensided, with calcareous nodules and siltstone seams below 16'								
												2.2 P
						22					104	1.5* Q
20												
				- with sand pockets below 23'								3.6 P
25												
			50/9"	SILTY SAND, very dense, red, fine, with clay seams	74.1 27.0							
30				CLAY, very stiff, red and gray, slickensided	71.1 30.0							
												3.9 P
35												
				SANDY SILT, red, with clay seams	63.1 38.0							
40					61.1 40.0							
				* Failed on slickensided plane								

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

PLATE A-3

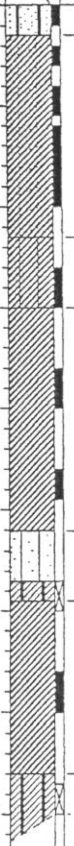
Report No. 0401-2452

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
	15					85.4 15.0	23					102	1.7 Q
					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								
	40					60.4 40.0							

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

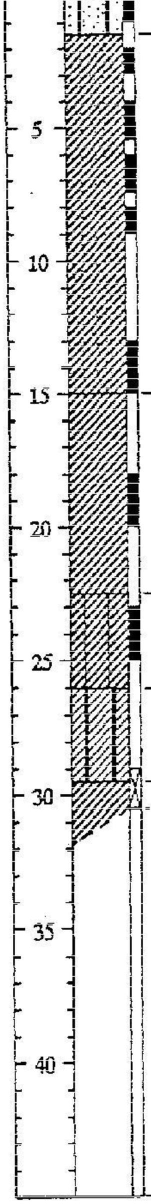
Depth to Water: 15.4'
Caved Depth: 19.0'
Date: August 10, 1991
Backfill: Bentonite Granules

DEPTH, FT	BLOWS PER FOOT	Location: N 5470 ; E 5444 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
		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

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



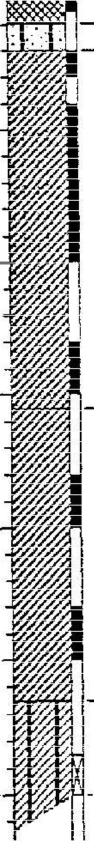
BLOWS PER FOOT	Location: N 5402 ; E 5380 Surf El. 100.7' Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1 STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX (PI)	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	SHEAR STRENGTH, KSF
	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
		85.7 15.0							2.2 P
	CLAY, very stiff, red and gray, slickensided								
	- 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							
		71.2 29.5							3.3 P
20	CLAY, very stiff, red and gray, slickensided	70.2 30.5							
	* Failed on a slickensided plane								

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

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								
		- stiff, 4' to 8'								
5				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							
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	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

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

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5496 ; E 5654 Surf El. 100.3' 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								
				SANDY CLAY, stiff, tan and gray, with sand pockets	98.8 1.5							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
10						18					109	2.9 Q
				SILTY CLAY, very stiff, tan and gray, with sand pockets	88.3 12.0							2.1 P
						22					104	2.9 Q
15				CLAY, stiff, red and gray, slickensided - with calcareous nodules to 20'	85.3 15.0							
												1.6 P
20						36	70	23	46		86	
				- with siltstones and silt pockets at 23'								
25												2.0 P
			13	CLAYEY SILT, medium dense, red	72.8 27.5							
30				CLAY, very stiff, red and gray, slickensided, with silt pockets	70.3 30.0							
												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

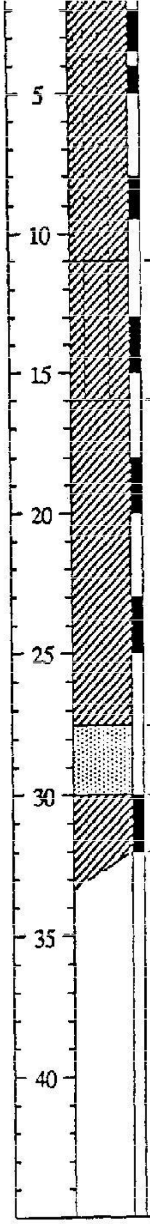
PLATE A-9

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



BLOWS PER FOOT	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								2.5 P
		68.7 32.0							

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

PLATE A-10

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	8.0							1.3 P
				nodules, calcareous nodules, and sand		21					106	1.8 Q
10				pockets								
					88.7							
				SILTY CLAY, stiff, tan and gray, with sand	12.0							
				pockets and calcareous nodules								1.2 P
					85.7							
15				CLAY, very stiff, red and gray, slickensided,	15.0							
				with siltstone nodules								
						28						2.7 P
20												
				- with silt pockets below 23'								3.9 P
25												
				- silt layer, 27.5' to 28'								
			18	- stiff, with seams below 28'								
					71.2							1.5 P
30					29.5							
35												
40												

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

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	
5		- stiff, tan and gray below 4'								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

DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5244 ; E 5275 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
				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												
				- with silt seams at 28'								
			19									3.3 P
30					70.7 30.0							
35												
40												

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

PLATE A-13

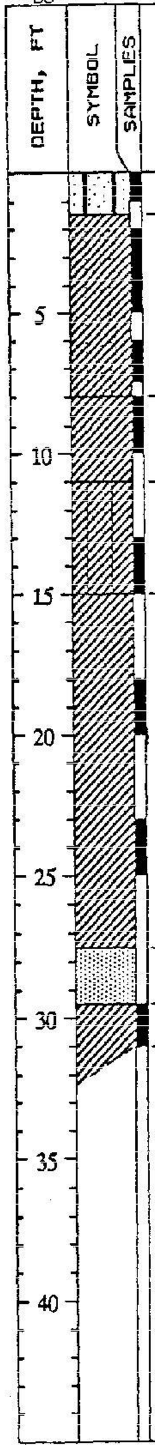
Report No. 0401-2452

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



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'	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

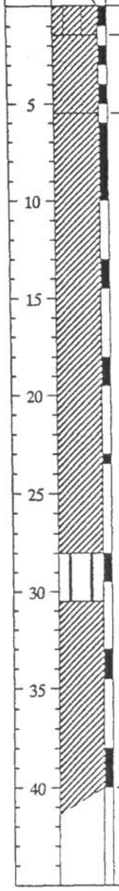
FUGRO McClelland

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	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	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
				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

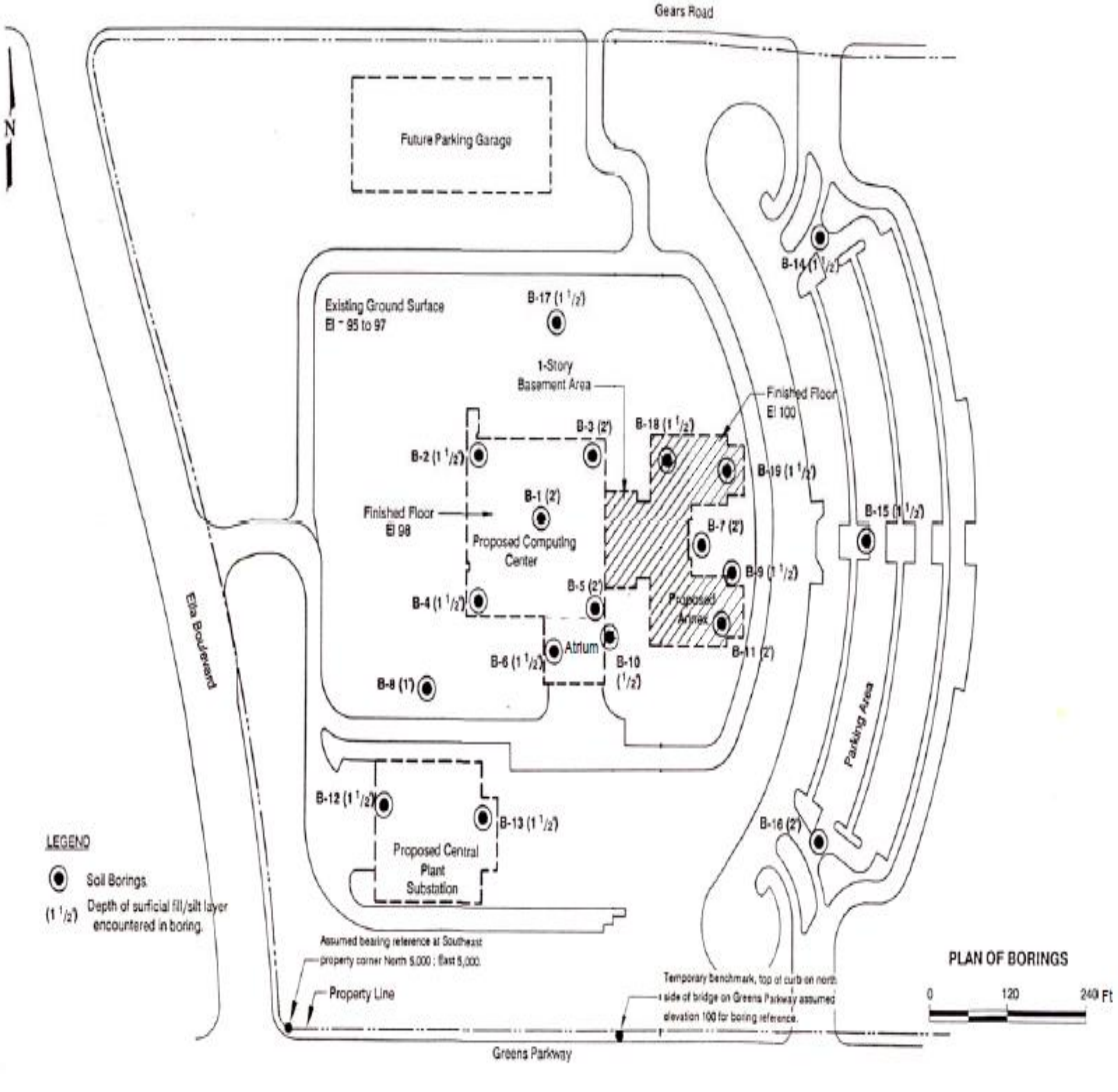
Water First Noticed: --
Completion Depth: 50.0' Date: November 3, 1991
Type: Dry Auger to 10'; Wet Rotary below 10'
Logger: T. Mireles

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

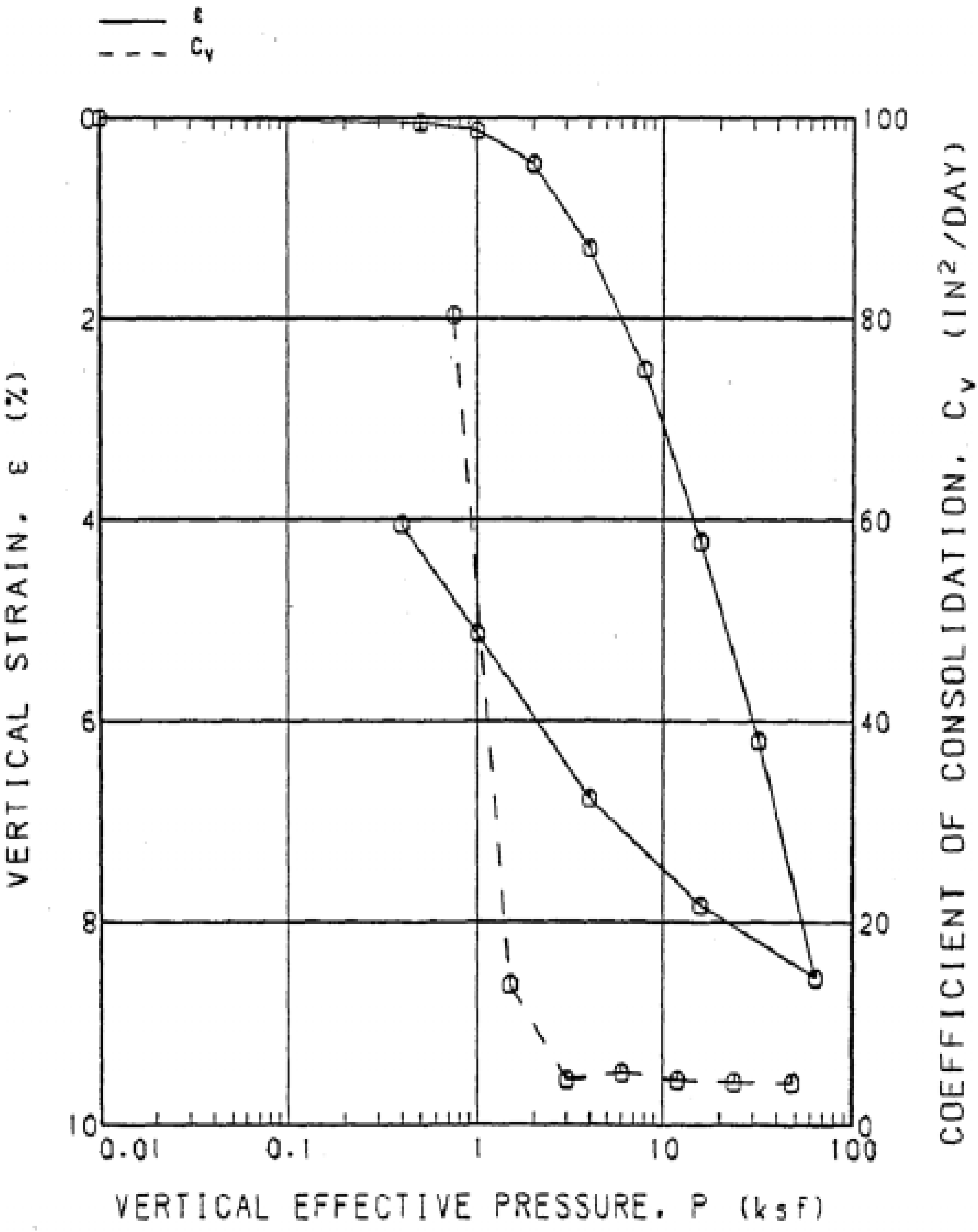
DEPTH, FT	SYMBOL	SAMPLES	BLOWS PER FOOT	Location: N 5634 ; E 5712 Surf El. 100.4' Note: Location and Elevation Relative to Temporary Benchmarks Shown on Plate 1 STRATUM DESCRIPTION	LAYER ELEV./DEPTH	WATER CONTENT, %	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX (PI)	PASSING NO. 200 SIEVE,%	UNIT DRY WEIGHT, 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

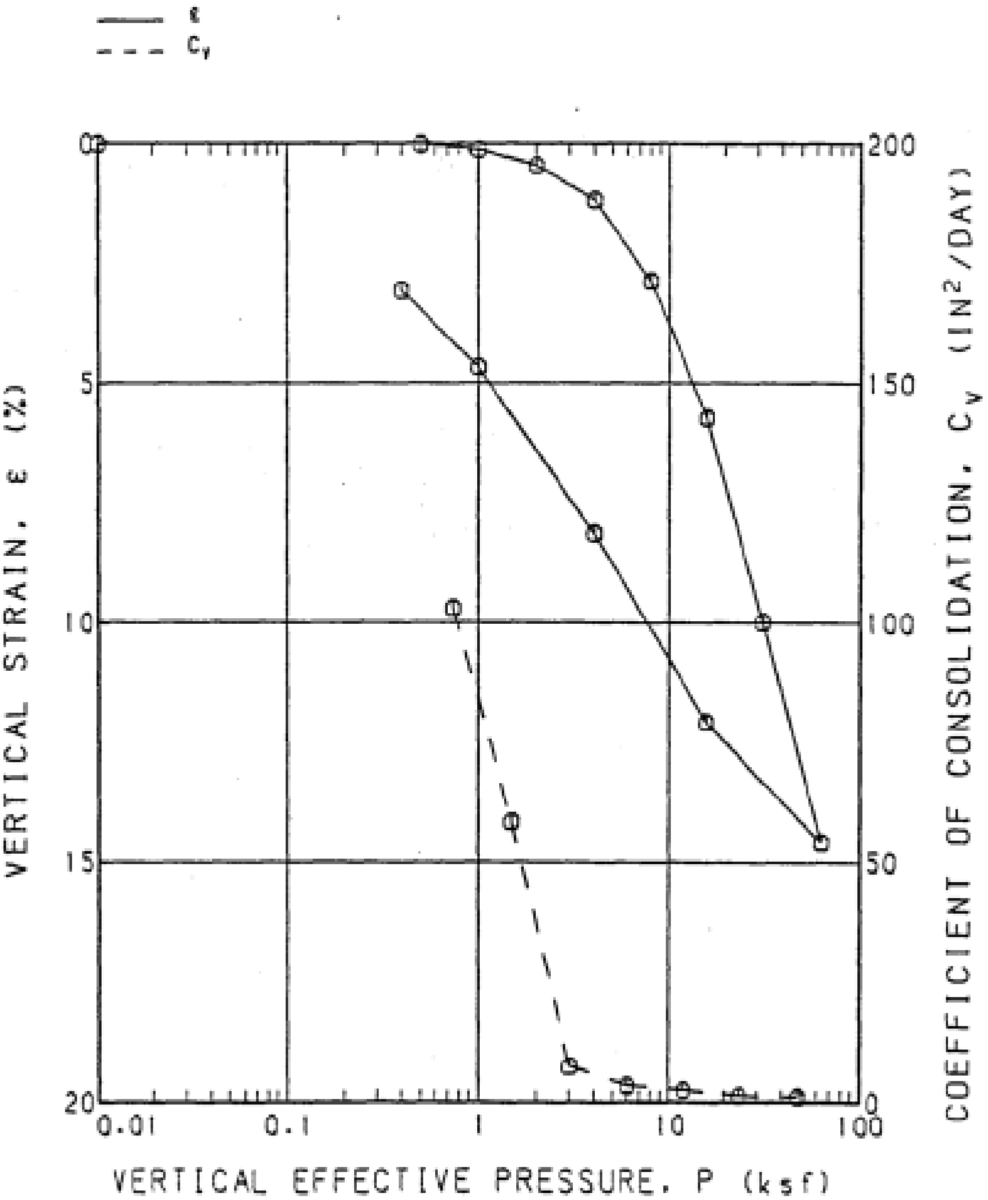
PLATE A-19b


Gears Road
N
Future Parking Garage
Existing Ground Surface
El ~ 95 to 97
B-17 (1 1/2')
1-Story
Basement Area
Finished Floor
El 100
B-3 (2')
B-18 (1 1/2')
B-2 (1 1/2')
B-19 (1 1/2')
B-1 (2')
Finished Floor
El 98
Proposed Computing
Center
B-7 (2')
B-9 (1 1/2')
B-4 (1 1/2')
B-5 (2')
Proposed
Annex
B-11 (2')
Atrium
B-6 (1 1/2')
B-10
(1/2')
B-8 (1')
B-14 (1 1/2')
B-15 (1 1/2')
Parking Area
B-16 (2')
Ella Boulevard
B-12 (1 1/2')
B-13 (1 1/2')
Proposed Central
Plant
Substation
LEGEND
Soil Borings.
(1 1/2') Depth of surficial fill/silt layer encountered in boring.
Assumed bearing reference at Southeast property corner North 5,000 ; East 5,000.
Property Line
Temporary benchmark, top of curb on north side of bridge on Greens Parkway assumed elevation 100 for boring reference.
Greens Parkway
PLAN OF BORINGS
0
120
240 Ft

BORING: 1
PENETRATION: 8.0 Ft
MATERIAL: SANDY CLAY, stiff, gray
DRY UNIT WEIGHT: 113.3 pcf
WATER CONTENT: 17 %
LIQUID LIMIT: 40
PLASTIC LIMIT: 11
SPECIFIC GRAVITY: 2.70 (assumed)
INITIAL VOID RATIO: 0.487



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



CONSOLIDATION TEST RESULTS

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