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A DETAILED SUBSOIL INVESTIGATION AND CALCULATION OF BEARING CAPA CITY OF FOUNDATION

Sahil Nur Rahman*[1], Suhrit Kashyap[2], Uday Bhaskar Buragohain[3], Bhargov Hazarika[4], Abhash Moran[5], Mustakur Rahman[6], Rituparna Goswami[7]

[1,2,3,4,5,6](B.Tech Student, Department of Civil Engineering, Jorhat Engineering College, Garmur, Jorhat.

[7](Assistant Professor, Department of Civil Engineering, Jorhat Engineering College, Garmur, Jorhat.

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***Corresponding Author: Sahil Nur Rahman**
B.Tech Student, Department of Civil Engineering, Jorhat Engineering College, Garmur, Jorhat.

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ABSTRACT

This study presents an evaluation of subsoil conditions and bearing capacity to support safe and economical foundation design. Field investigations, including borehole drilling, soil sampling, and in-situ testing, were conducted to characterize the subsurface strata and assess their engineering behavior. Laboratory analyses, comprising soil classification, moisture content determination, and shear strength testing, were performed to obtain the geotechnical properties required for foundation assessment. The results indicated a heterogeneous subsoil profile consisting of clay, silt, and sand layers with varying moisture conditions at different depths. Based on standard geotechnical design procedures, the bearing capacities for both shallow and deep foundations were estimated under different loading conditions. The findings emphasize the importance of detailed subsoil investigations in selecting appropriate foundation systems and ensuring the stability, safety, and long-term performance of civil engineering structures.

KEYWORDS: Subsoil Investigation, Bearing Capacity, Foundation Design, Soil Classification, Shear Strength, Geotechnical Engineering, Borehole Drilling, In-situ Testing, Shallow Foundation, Deep Foundation.

1. INTRODUCTION

Substructures form the foundation system of a structure and transfer loads from the superstructure to the underlying soil. Based on the depth-to-width ratio, foundations are classified as shallow foundations (D ≤ B), intermediate foundations (B ≤ D < 20B), and deep foundations (D > 20B). A suitable foundation must safely support structural loads, resist excessive settlement, and remain durable throughout its service life. Soil bearing capacity, whichgovernstheload-carrying ability of the ground, is expressed intermsofultimate bearing capacity (q_u), allowable bearing capacity (q_a), and net safe bearing pressure (q_{ns}). Reliableevaluationoftheseparametersrequiresdetailedsubsoilinvestigationsusingfieldtests such as SPT, CPT, and ERT, along with laboratory tests on soil samples. The present study aims to determine the safe bearing capacity and suitable foundation system for the proposed site.

2. LABORATORY TESTS AND RESULTS

Laboratorytestsinvolvedetermining Water Content (W.C.), LiquidLimit (W_L), PlasticLimit (W_P), Plasticity Index (I_P) and Shear Parameters as follows:

A. WaterContent Determination

Table-1: Depth wise water content.

Depth	Wet(gm)	Dry(gm)	W.C%
1m	19	15.5	18.42
2m	38	31	18.42
3m	51	41	19.61
4m	22	17.5	20.45
5m	30	23.2	22.67
6m	20	15	25
7m	25	17.5	30
8m	20	13.6	32
9m	17	10.8	36.47
10m	19	11.7	38.42

B. Liquid Limit, Plastic Limit and Plasticity Index

For each soilsample at 1m intervalupto 10 mdepth, using No. of blows vs Moisture content curve; depth wise Liquid Limit, Plastic Limit and Plasticity Index. Knowing the liquid limit and plasticity index, soil can be classified with the help of plasticity chart (IS 1498-1970).

Table-2: Depth wise soil classification.

Depth	LL	PL	PI	Soiltype
1m	25.24	5.55	19.69	CL
2m	25.26	9.09	16.17	CL
3m	25.39	8.33	17.06	CL
4m	25.44	9.09	16.35	CL
5m	25.46	11.11	14.35	CL
6m	25.52	11.36	14.16	CL

7m	25.65	9.09	16.56	CL
8m	25.89	10.52	15.37	CL
9m	26.34	13.63	12.71	CL
10m	26.44	13.63	12.81	CL

C. Shear Parameteres

UnconfinedCompressionTestisperformed(Provingringconstantis0.0030211KN)and Stress-Strain Curves are obtained for each 1 m depth interval.

FromeachStress-StrainCurve;UnconfinedCompressivestrengthandthenCohesionis obtained.

Table-3:Valueof$q_u$andC_u.

Depth(m)	**UnconfinedCompressivestrength(KN/m^2)**	**CohesionCu (KN/m^2)**
1	97.45	48.72
2	129.51	64.75
3	75	37.59
4	81.55	40.77
5	84.02	42.01
6	88.33	44.16
7	64.83	32.41
8	93.64	46.82
9	98.44	49.22
10	104.88	52.44

3. CALCULATION OF SAFE LOAD ON FOUNDATION

A. Shallow Foundation

(i) BearingCapacityofPileFoundations

Itcanbecalculated by:

Q_{nu}=2/3xCxN_cxS_cxd_cxi_c+qx(N_q-1)xS_qx.d_qxi_q+O.5BxNγxSγxdγxiγxw' clause 5.1.2ofIS:6403)

Where, Qnu, C, Barenet ultimate bearing capacity of footing, Cohesion and width of foundation respectively.

S_c,S_q,S_γ= Shape factor d_c,$d_q$$d_\gamma$= depth factor i_c,i_q,i_γ=inclinationfactor

N_c,N_q,N_γ=Bearingcapacityfactor

Nowfor afoundation ofDf=2m, B =1.5m, L =2m, Using Formula ofthe Bearing Capacity ofpile foundations and for Φ= 0byassuming Nγ = 0,N_q= 1, N_c= 5.14. Significant depthof foundation is 3m below the base of foundation.

Therefore, Q_{nu}=2/3x40.12 x5.14 x1.15x1.27+0 +0=200.27KN/m^2 Then $Q_{ns}$and q_s can be calculated.

Differentfoundationsizescanbeexploredusingthesameprocedureandislistedin Table-4.

Table-4: Ultimate, Safe and Net Safe Bearing Capacities of Different Foundation.

Df	B	L	Qu(KN/m^2)	Qns(KN/m^2)	qs(KN/m^2)
2	1.5	2	200.27	80.11	112.31
2	2	2	219.91	87.96	120.96
2	2	2.5	196.23	78.49	110.69
2	2.5	2.5	225.41	90.16	122.36
2.5	1.5	2	249.99	100.00	144.60
2.5	2	2	229.02	91.61	136.21
2.5	2	2.5	227.86	91.14	135.74
2.5	2.5	2.5	233.17	93.27	137.87

(ii) Settlement Calculation

Totalsettlementcanbecalculatedbytheformula: $S_t=S_c+S_i$; Where S_c and S_i are Instantaneous and Consolidation Settlement respectively.

Instantaneoussettlementcanbeneglectedforclayeysoil,andtheconsolidationsettlementcan be calculated by the formula:

$S_c=C_c x H/(1+e_0)$ x log $((p_0'+\Delta p)/ p_0')$…….Cl9.2.2.2ofIS: 8009(Part I) –1976 For, D_f= 2m, B= 1.5m, L= 2m; p_0' = 50.9 KN/m^2,

Δp = [112.31x1.5x2]/[(1.5+3)x(2+3)= 14.97KN/m^2

S_c=[(0.13887x3)/1.7329]$\log_{10}$[(50.9+14.97)/50.9]=0.02691m= 26.91mm.

Different foundationsizescanbeexploredto find $S_c$usingthesameprocedureand is listed in Table-5.

Table-5: Settlement of different foundation.

Df	B	L	Sc (mm)
2	1.5	2	26.91
2	2	2	27.63
2	2	2.5	34.25
2	2.5	2.5	33.74
2.5	1.5	2	30.3
2.5	2	2	29.7
2.5	2	2.5	33.71
2.5	2.5	2.5	34.46

(iii) AllowableBearingCapacity

If$S_c$islessthanthepermissiblesettlement;thesafebearingcapacitycanbetakenasallowable bearing capacity, and if not then allowable bearing capacity is taken as: $q_{al}= q_{safe} x\ S_p/S_c$;

where, S_p,$S_c$arePermissibleandConsolidationsettlement.

Using the Permissible Settlement Table-1 of IS: 1904-1986**);** Allowable Bearing Capacity of different foundation sizes can be calculated.

Table-6:Allow able Bearing Capacity.

Df	**B**	**L**	**Q_a(KN/m^2)**
2	1.5	2	112.31
2	2	2	120.96
2	2	2.5	110.69
2	2.5	2.5	122.36
2.5	1.5	2	144.60
2.5	2	2	136.21
2.5	2	2.5	135.74
2.5	2.5	2.5	137.87

B. PileFoundation

(i) Bearingcapacityofpilefoundations forcohesivesoil

Bearingcapacityofpile foundationsforcohesivesoilcanbecalculated by: $Q_u= A_p. N_c. C_p+ \alpha. C. A_s$;

Where, A_p, N_c, C_p, α, C, $A_s$are cross sectional area ofpile toe in m^2, Bearing Capacity factor usually taken as 9, Cohesion at pile tip, Adhesion factor, Average cohesion throughout the length of pile, Surface area of pile in m^2.

For apileofdimension,D=0.3m,L=8m,L_e=7m;

A_p= 0.07m^2,A_s=6.59m^2,C_p= 46.82KN/m^2,C=44.07,N_c= 9,α= 0.7

ThereforeBearingcapacityofpile foundation,Q_u=232.8KN Q_s= 232.8/2.5 = 93.12 KN

Different foundation sizes can be explored using the same procedure to find Safe bearing capacity and is listed in Table-7.

Table-7: Safe bearing capacity of variouspile.

Diameter	**TotalLength**	**Eff.Length**	**qu**	**qs**
0.3	8	7	232.8	93.12
	9	8	267	106.80
	10	9	303.53	121.40
0.4	8	7	321.72	128.69

	9	8	360.59	144.23
	10	9	417.33	166.93
0.5	8	7	419	167.63
	9	8	486.64	194.65
	10	9	540.3	216.12

(ii) Analysisoflaterallyloadedpiles

Forpiles inclay:Stiffness factorR=4√EI/KB(m)

Where,E,IareYoung'smodulusofpile material, in $MN/m^2$and momentofinertiaofthepile cross-section, in $m^{4.}$

K= K1/1.5 x0.3/B

Where;K1,BareTerzaghi'smodulusofsubgradereactionAnd widthofpileshaft(m).

Allowablelateralloadforfixedheadpile, $Y = H (Le + Lf)^2 \times 10^3/12EI$

Where, H, y, I, E, Lf,Leare lateralload (KN), deflectionofpile head (mm), Young's modulus of pile material (KN/m^2), moment of inertia of the pile cross-section (m^4), depth to point of fixity (m) and

cantileverlengthabovegroundrespectively.

Lfcanbe find out fromtheDepthoffixitycurve(IS-2911(part 1/Sec1):2010). Deflection is assumed as 5mm.

Table-8:Lateralloadforvariouspile.

Diamete r	TotalLength	Eff.Length	LateralLoad
0.3	8	7	0.281
	9	8	0.294
	10	9	0.3
0.4	8	7	0.476
	9	8	0.502
	10	9	0.541
0.5	8	7	0.618
	9	8	0.665
	10	9	0.696

(iii) Late ral Load calculation

Forthefoundation,D=0.3m, L=8m, Le=7m

Y=5mmLe=1m, Lfcanbe find fromtheDepthoffixitycurveas-K = K1/1.5 x 0.3/B = (16.86x1000)/1.5 x 0.3/B = 11240

$R=4 (EI/KB)^{1/2}=0.234$

NowcomparingL$_f$/RandL$_e$/Rfromthe Depthoffixitycurve wecanfindthe L$_f$= 0.35m

Now, Fixed end moment for fixed head pile, M$_f$= H (L$_e$+ L$_f$)/2……. Cl-4.3((IS:2911 (part 1/Sec 1)-2010)

The fixed end moment, MF of the equivalent cantilever is higher than the actual maximum moment Minthepile. Theactualmaximummoment canbeobtained bymultiplyingthefixed end moment of the equivalent cantilever by a reduction factor (m), from IS:2911 (part 1/Sec 1)-2010. Therefore, fixed end moment for the pile (D = 0.3m, L = 8m, Le = 7m) is; M$_f$= 0.189KN

ActualMoment,m=0.96x0.189=0.182KNm

Differentfoundationsizescanbeexploredusingthesameprocedureandis listedinTable-9.

Table-9:Fixed end moment for various pile.

Diameter	TotalLength	Eff.Length	ActualMoment
0.3	8	7	0.182
	9	8	0.188
	10	9	0.19
0.4	8	7	0.381
	9	8	0.395
	10	9	0.415
0.5	8	7	0.583
	9	8	0.625
	10	9	0.651

C. Under-ReamedPile

(i) BearingCapacity

For clayey soils the ultimate load carrying capacity of an under-reamed pile may be worked out from the following expressions:

$Q_u=A_p.N_c.C_p+A_s.N_c.C_a'+C_a'.A_s'+ \alpha.C_a.A_s$

Where, A_p=Cross-sectionalareaofpilestemattoe level N_c= Bearing Capacity factor (0.9)

C_p=Cohesionofthesoilaroundtoe

$A_a = \pi/4(D_u^2 - D^2)$ whereDuisdiameterofunder-reamedandd isthe diameter of the pile

C_a'=averagecohesionofsoilaroundtheunder-reamed bulbs A = reduction factor (0.5)

C_a=averagecohesionofthesoilalongthepilestem A_s= surface area of the stem

A_s'=surfaceareaofthecylinder circumscribingtheunder-reamedbulbs

Table-10: Bearing Capacity of under reamedpile foundation.

Diameter	Du	Length	Eff.Length	BearingCapacity(KN)
0.3	0.75	8	7	413.42
		9	8	429.26
0.4	1	8	7	671.48
		9	8	698.83

(ii) SafeloadforverticalBoredcastin-situunder-reamedpile

UsingSafe loadforverticalBoredcastin-situunder-reamedpileTable-1ofIS:2911(partIII) – 1980), Table-11 is prepared.

Table-11:Safeloadfor verticalBoredcastin-situunder-reamedpile.

Diameter	Du	Length	Eff. Length	Load due to		
				Compression	Uplift Pressure	Lateral Thrust
0.3	0.75	8	7	323.3	202.5	20
		9	8	370	237.5	20
0.4	1	8	7	451.7	309.2	34
		9	8	515	37.5	34

For;L = 8m, L_e= 7m, d = 0.3m, d_u=0.75m;N_c= 9,A_p= 0.071m^2, C_p= 46.82KN/m^2, A_a= 0.37m^2, C_a'= 46.82 KN/ m^2, A_s= 1.76 m^2, C_a= 44.07 KN/m^2, A_s= 6.59 m^2

Therefore;Q_u= 413.42KN

Andwecanfind thisbyusingthetableas:

For Compression; 16 + (350/30) x 1.4 = 32.33 t = 323.3 KN ForUplift resistance;8+(350/30)x1.05=20.25t=202.5KN Lateral thrust = 2t = 20KN

4. CONCLUSION

The present studyprovided a detailed evaluation of the subsurface conditions and foundation bearing capacity at the project site. Laboratory investigations showed that the natural water content increased from 18.42% at 1 m depth to 38.42% at 10 m depth**,** while the soil was classified as low-compressibility clay (CL) throughout the explored depth. The measured cohesionvaluesrangedfrom32.41KN/m²to64.75KN/m²**,**indicatingmoderateshearstrength characteristics. Based onthe geotechnicalpropertiesobtained, bearing capacityanalyses were carried out for shallow, pile, and under-reamed pile foundations. The maximum allowable bearing capacityofshallow foundations reached 144.60 KN/m², while pile and under-reamed pile foundations exhibited safe load capacities of 216.12 KN and 515 KN, respectively. The findings confirmthat detailed subsoilinvestigation is essential for selecting safe, economical, and durable foundation systems and for minimizing settlement and structural risks during service life.

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