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Study of the Index Properties and the Predominance of Shear and Cohesion of Soil in the Lower Flood Plain of River Daya of Odisha

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Abstract

River Daya flowing along the S-E of the state of Odisha has become a vital zone as far as the constructions and infrastructural developments are concerned. The entire subsurface is dominated by thick blend of clayey particles. Technocrats and Architects are not in a state of mind to provide suitable and stabilized foundations for those upcoming massive structures. The present study reflects the complex behavior of the soil parameters whose index and engineering properties have been determined strictly based on Indian Standard codes. The lithological variation of the land shows the entire region is spread by a thick blanket of clayey soil comprising of red and black soil, having high porosity with less permeability believed to be the end product of laterites and argillaceous materials, generating a swampy land throughout the year. But fortunately at a shallow to deep the stratum is defined by a compact, hard and impervious lateritic bed that gives ample support for a safe and stable foundation. Due to this, selection of foundation for construction purpose has become a challenging job. Two nos. of bore hole logs were drilled and collected from the field area to determine the index properties of the given samples as well as finding the safe bearing capacity of the soil.

Keywords: SPT, UDS, Borehole Logs, Shear Strength, Safe Bearing Capacity.

Introduction

The coastal alluvium forms unconsolidated material of which the study area is a part of that. These formations composed of sand, gravel, silt, clay and laterite. It has extensive unconfined and confined zone down to 150m - 300m. This zone is underlain by the Mahanadi graben extending in a NW-SE direction. The physical and index parameters of soil under the study area with an aerial extension of around 120km2 are completely dependent on the percolation and penetration of surface and groundwater. As the water of Daya is comparatively sweeter it may be assessed that impact of saline environment is too negligible on the soil characters. The spectacular hydrogeological set up of the study area owes to the varied geomorphic and geological set up which controls the physical and chemical behavior of the soil strata. Geotechnical parameters at various depths of soil strata along the river Daya is alarming. The primary reason behind the variation is the impact of coastal environment, rapid growth of population, abandonment of agricultural lands and conversion of cultivable lands to infrastructural projects. Stratigraphic, lithologic and geomorphic set ups partially control the performance of soil. The annual rainfall in the area also varies considerably from year to year which affects the physico-chemical characteristic of soil and its strength parameters.

Large number of central and state level organizations has been setup to investigate the soil strength in district and block level to meet the requirement for infrastructural development but still remarkable work is lacking.

The study area which extends from Sundarpada under Bhubaneswar Municipal Corporation to Harirajpur block of Khurda district a stretch of 12.3km locates between the latitude of 2008′ to 20029′ and longitude 85044′ to 85073′ constituting the part of Khurda district has its own importance due to massive infrastructural growth, mushrooming educational institutes and high rise apartments. The scope of work comprises of conducting detail soil investigation, laboratory testing, conducting and estimation of safe bearing capacity for the proposed work on drilling two nos. of boreholes.

Methodology

The methods of investigation consist of visual reconnaissance, drilling of boreholes, laboratory experiments and determination of soil parameters and analysis of the results. The field borehole drillings are extended up to 10m below Natural Ground Level (NGL) or refusal. This is followed by collection of UDS samples as per IS specification and finally the soil samples are

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transported to the Civil engineering laboratory of Orissa Engineering college. The bulk density, moisture content, grain size analysis, shear strength, liquid limit, plastic limit, specific gravity, DFS, water absorption, porosity and density of the samples are determined in the laboratory (2010). For detailed laboratory investigation SPT is conducted at 1.5m intervals or at change of soil strata in different boreholes. Disturbed soil samples from both the boreholes were collected at 1.5m. SPT tests were conducted as per IS: 9640-1980 and IS: 2131-1981 respectively in different levels at the boreholes in a continuous manner using spilt-spoon samplers. The SPT sampler was lowered inside the borehole after drilling the required level and is driven by a 63.50kg hammer with a free fall of 750mm driving 450mm in three stages 150mm each and the number of blows for each 150mm penetration for 2nd and 3rd 150mm drive recorded as "N". Refusal is considered for N>100. In the course of drilling groundwater was encountered at a depth of 1.20m to 1.50m NGL.

Results and Discussion

Sl. No.	Bore Hole Ref.	Sample Depth in m.	Natural Moisture Content	Bulk Denisty	Specific Gravity	Attenberg 's Limit in %			Void Ratio	Field SPT Value	Cohesion in Kg/cm2	Angle of Shearing Resistance (φ) in degrees	DFS in %	Soil Classificat ion
						LL	PL	PI						
1	BH-1 SPT-1	1.50	20.31	1.097	2.28	51.00	26.00	25.00	**1.5**	7.00	xxxxx	xxxxxx	50.00	MH
2	BH-1 SPT-2	3.00	49.55	1.589	2.37	42.00	25.00	17.00	1.23	12.00	xxxxx	xxxxxx	40.00	OI
3	BH-1 UDS-1	4.50	44.74	1.492	2.33	43.00	25.00	18.00	1.26	15.00	0.46	4.50	40.00	Cl
4	BH-1 SPT-3	6.00	44.32	1.332	2.28	50.00	26.00	24.00	1.47	18.00	xxxxx	xxxxxx	50.00	MH
5	BH-1 SPT-4	7.50	45.25	1.543	2.37	42.00	25.00	17.00	1.23	21.00	xxxxx	xxxxxx	40.00	Cl
6	BH-1 SPT-5	9.00	45.26	1.543	2.37	42.00	25.00	17.00	1.23	24.00	xxxxx	xxxxxx	40.00	Cl
7	BH-1 SPT-6	10.00	25.76	1.410	2.40	39.00	24.00	15.00	1.14	28.00	xxxxx	xxxxxx	30.00	Ml
8	BH-2 SPT-1	1.50	47.65	1.362	2.28	50.00	26.00	24.00	1.47	6.00	xxxxx	xxxxxx	50.00	MH
9	BH-2 UDS-1	3.00	42.46	1.315	2.28	50.00	26.00	24.00	1.47	7.00	0.48	4.50	50.00	MH
10	BH-2 SPT-2	4.50	37.75	1.544	2.40	39.00	24.00	15.00	1.14	14.00	xxxxx	xxxxxx	30.00	Ml
11	BH-2 SPT-3	6.00	29.90	1.380	2.37	42.00	25.00	17.00	1.23	17.00	xxxxx	xxxxxx	40.00	Ol
12	BH-2 SPT-4	7.50	35.46	1.235	2.28	51.00	27.00	24.00	1.50	24.00	xxxxx	xxxxxx	50.00	MH
13	BH-2 SPT-5	9.00	35.92	1.239	2.28	51.00	27.00	24.00	1.50	26.00	xxxxx	xxxxxx	50.00	MH
14	BH-2 SPT-6	10.00	34.58	1.387	2.33	43.00	25.00	18.00	1.26	31.00	xxxxx	xxxxxx	40.00	Cl

Table 1: Result of different properties from different boreholes

The result of different properties of soil samples in the study area in shown in Table 1.

Sl.No.	Borehole Ref.	Sample Depth in m.	% Passing through IS sieve in mm					
			10.000	4.750	2.000	0.425	0.075	0.001
1	BH-1 SPT-1	1.5	100.00	99.39	99.16	95.89	86.65	0.00
2	BH-1 SPT-2	3.0	100.00	96.90	94.87	88.61	79.50	0.00
3	BH-1 UDS-1	4.5	100.00	99.40	97.88	91.66	83.40	0.00
4	BH-1 SPT-3	6.0	100.00	99.88	99.61	94.86	86.80	0.00
5	BH-1 SPT-4	7.5	100.00	98.29	96.25	89.97	80.73	0.00
6	BH-1 SPT-5	9.0	100.00	98.36	96.56	90.41	80.98	0.00
7	BH-1 SPT-6	10.0	100.00	97.61	92.42	82.25	74.37	0.00
8	BH-2 SPT-1	1.5	100.00	99.88	99.32	93.85	85.88	0.00
9	BH-2 UDS-1	3.0	100.00	95.64	93.33	89.13	85.54	0.00
10	BH-2 SPT-2	4.5	100.00	85.22	82.44	77.78	73.52	0.00
11	BH-2 SPT-3	6.0	100.00	93.77	89.84	89.84	77.21	0.00
12	BH-2 SPT-4	7.5	100.00	99.43	98.32	94.41	89.85	0.00
13	BH-2 SPT-5	9.0	100.00	99.04	97.00	94.13	88.06	0.00
14	BH-2 SPT-6	10.0	100.00	96.77	94.40	89.25	83.90	0.00

Table 2 Grain size analysis of the soil samples in study area

A. Calculation of Safe Bearing Capacity from Strength Parameters (SPT Values)

(At 1.50m) Borehole No-1

Square Footing
Field SPT Value N = 7
Overburden Pressure 0.164kg/cm^2 (IS: 2131-1981, Clause 3.6.1)
Dilaitancy Factor, the corrected SPT Value N$'$ 7 (IS: 2131-1981, Clause 3.6.1)
Taken corresponding C= 0.00 kg/cm^2
Angle of shearing resistance value Φ for zone = 29 degrees
Size of Footing = 2m. X 2m.
Cohesion C = 0.00 kg/cm^2 (IS: 2720-1973, Part X)
Angle of Shearing resistance Φ = 29 degree (IS: 2720-1978, Part XI)
Φ$'$ = 20 degree (IS: 2720-1978, Part XII)
Specific Gravity Gs = 2.28 (IS: 2720-1980, Part III)
Void ratio e = 1.50 (IS: 2720-1973, Part X)
Bulk density γ = 1.097 g/cc (IS: 2720-1973, Part II)
Depth of foundation Df = 1.50 m
Assuming width of footing B = 2.00 m
Q = [Df X (γ)]/10 0.164 kg/cm^2
Bγ = (Bxγ)/10 0.2194 kg/cm^2

Bearing Capacity Factors (From IS: 6403-1981, Table-1)

Φ & Φ′	Nc & Nc′	Nq & Nc′	Nγ & Nγ′
29	28.256	16.85	20.09
20	14.83	6.4	5.39

Shape Factors (From IS: 6403-1981, Table-2)
Sc = 1.3 Sq = 1.2 Sγ = 0.8

Depth Factors & Inclination Factors (IS: 6403-1981, Table-2)
$d_c = 1 + 0.2 \times (Df/B) \times \tan(45 + \Phi/2) = 1.254$
$d_p = d_\gamma = 1.127$ $i_c = i_q = i_\gamma = 1$

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Effect of Water Tables (IS: 6403-1981, Clause-5.1, 2.4)
w′ = 0.5

In Case of Local Shear Failure for Circular Footing (IS: 6403-1981, Clause-5.1.2)
$Qd' = q (Nq' - 1)S_q d_q i_q + 0.5\ B_\gamma N_{\gamma S\gamma d\gamma i\gamma} W$
= 1.197 + 0.266
= 1.463 kg/cm^2

Ultimate Bearing Capacity Obtained from Interpolation = Qd (IS: 6403-1981, Table-3)
= 1.463 kg/cm^2

Net Safe Bearing Capacity Considering Factor of Safety as 3 = 0.487 kg/cm^2
=> NSBC=4.87 t/m^2

B. Calculation of Safe Bearing Capacity from Strength Parameters (SPT Values)

(At 3.00m) **Borehole No. 1**

Square Footing	Depth of foundation = 3.00m	
Field SPT Value N =	12	
Overburden Pressure	0.408 kg/cm^2	(IS: 2131-1981, Clause 3.6.1)
Dilaitancy Factor, the corrected SPT Value N'	12	((IS: 2131-1981, Clause 3.6.1)

Taken corresponding C = 0.00 kg/cm^2
Angle of shearing resistance value Φ for zone = 32 degrees
Size of Footing = 2m X 2m

Cohesion C =		0.00 kg/cm^2
Angle of Shearing resistance	Φ =	32 degree
	Φ′ =	22 degree
Specific Gravity	Gs=	2.28
Void ratio e =		1.47
Bulk density γ =		1.362 g/cc
Depth of foundation D_f =		3.00 m
Assuming width of footing B =		2.00 m
Q = [D_f X (γ)]/10		0.408 kg/cm^2
Bγ = (Bxγ)/10		0.272 kg/cm^2

Bearing Capacity Factors (IS: 6403-1981, Table-1)

Φ & Φ′	Nc & Nc′	Nq & Nc′	Nγ & Nγ′
32	36.53	24.36	32.65
22	17.18	8.104	7.586

Shape Factors (From IS: 6403-1981, Table-2)
$S_c = 1.3$ $S_q = 1.2$ $S_\gamma = 0.8$

Depth Factors & Inclination Factors (From IS: 6403-1981, Table-2)
$d_c = 1 + 0.2 \times (Df/B) \times \tan(45 + \Phi/2) = 1.541$
$d_p = d_\gamma = 1.27$ $i_c = i_q = i_\gamma = 1$

Effect of Water Tables (From IS: 6403-1981, Clause-5.1, 2.4)
w′ = 0.5

In case of Local Shear Failure for Circular Footing (Clause-5.1.2)
$Qd' = q (Nq' - 1)S_q d_q i_q + 0.5\ B_\gamma N_{\gamma S\gamma d\gamma i\gamma} W$
= 4.417 + 0.524
= 4.941 kg/cm^2

Ultimate Bearing Capacity Obtained from Interpolation = Qd (From IS: 6403-1981, Table-3)
Qd = 4.941 kg/cm^2

Net Safe Bearing Capacity Considering Factor of Safety as 3 = 1.647 kg/cm^2
=>SBC=16.47 t/m^2

B. Calculation of Safe Bearing Capacity from Strength Parameters (SPT Values)

(At 1.50m) Borehole No-2

Square Footing		Depth of Foundation = 1.50m
Field SPT Value N =		6
Overburden Pressure		0.204 kg/cm^2 IS: 2131-1981, Clause 3.6.1
Dilaitancy Factor, the corrected SPT Value N'		6 IS: 2131-1981, Clause 3.6.1
Taken corresponding C =		0.00 kg/cm^2
Angle of shearing resistance value Φ for zone =		29 degrees
Size of Footing = 2m. X 2m.		
Cohesion C =		0.00 kg/cm^2
Angle of Shearing resistance	Φ =	29 degree
	Φ′ =	20 degree
Specific Gravity	Gs =	2.28
Void ratio e =		1.47
Bulk density γ =		1.362 g/cc
Depth of foundation Df =		1.50 m
Assuming width of footing B =		2.00 m
Q = [Df X (γ)]/10 =		0.204 kg/cm^2
Bγ = (Bxγ)/10 =		0.272 kg/cm^2

Bearing Capacity Factors (From IS: 6403-1981, Table-1)

Φ & Φ′	**Nc & Nc′**	**Nq & Nc′**	**Nγ & Nγ′**
29	28.256	16.85	20.09
20	14.83	6.40	5.39

Shape Factors (From IS: 6403-1981, Table-2)

Sc = 1.3 Sq = 1.2 Sγ = 0.8

Depth Factors & Inclination Factors (From IS: 6403-1981, Table-2)

$d_c = 1 + 0.2 X (Df/B) X \tan (45 + \Phi/2) = 1.254$

$d_p = d_\gamma = 1.127$ $i_c = i_q = i_\gamma = 1$

Effect of Water Tables (From IS: 6403-1981, Clause-5.1, 2.4)

w′ = 0.5

In Case of Local Shear Failure for Circular Footing (Clause-5.1.2)

$Qd' = q(Nq' - 1)S_q d_q i_q + 0.5\ B_\gamma N_{\gamma S\gamma d\gamma i\gamma} W$

$= 1.489 + 0.33$

$= 1.819\ kg/cm^2$

Ultimate Bearing Capacity Obtained from Interpolation = Qd (From IS: 6403-1981, Table-3)

= 1.819 kg/cm^2

Net Safe Bearing Capacity Considering Factor of Safety as 3 = 0.606 kg/cm^2

=> NSBC = 6.06 t/m^2

B. Calculation of Safe Bearing Capacity from Strength Parameters (UDS Values)

(At 3.00m) Borehole No-2

Cohesion	C	=	4.8 kg/cm^2
Angle of Shearing Resistance	Φ	=	4.5 Degree
	Φ′	=	3 Degree
Void Ratio	e	=	1.47 (Medium)
Specific Gravity	Gs	=	2.28
Submersible Density	γ_{Sub}	=	0.52 g/cc
Depth	D_f	=	3m
Let us assume width	B	=	2m

Overburden pressure

$Q = (D_f X \gamma_{Sub}) / 10 =$ 0.155 kg/cm^2

$B_\gamma = (B X \gamma_{Sub})/10 =$ 0.104 kg/cm^2

Bearing Capacity Factors (From IS: 6403-1981, Table-1)

Φ & Φ′	**Nc & Nc′**	**Nq & Nc′**	**Nγ & Nγ′**
4.5	6.49	1.57	0.45
3.0	5.95	1.342	0.27

Shape Factors (From IS: 6403-1981, Table-2)

Sc =1 Sq =1 Sγ = 1

$d_c = 1 + 0.2 X (Df/B) X \tan (45 + Φ/2) =$ 1.325

$d_p = d_γ = 1$ $i_c = i_q = i_γ = 1$

Effect of Water Tables (From IS: 6403-1981, Clause-5.1, 2.4)

w′ = 0.5

In case of local shear failure for continuous strip footing,

Qd′ = 2/3CNc′ + q(Nq′ - 1) + 0.5 $B_γ$Nγ

= 1.904 + 0.053 + 0.014

= 1.971 kg/cm^2

Safe Bearing Capacity Considering Factor of Safety as 3 = 0.657 kg/cm^2

= **6.57 t/m^2**

Load carrying capacity of single under reamed bored cast in-situ piles (IS-2911 part-III, Clause 5.2.3.1) (a)

Bore Hole No.1

Type of Pile: Single under reamed bored pile

Length of Pile (L):	6.0m
Effective Length of Pile (L_e):	5.5m
Friction component not considered (l):	0.5m

a) **Bearing & Friction in clayey strata (0.5m – 6.0m i.e. 5.5m)**

Length of Pile in clayey strata (L_e) =	550cm
Diameter of Pile (D) =	30cm
Under reamed bulb dia =	75m
Cross Sectional area of pile stem (A_p) =	707.14cm^2
Cross Sectional area of under reamed bulb (A_a) = $\pi/4 (D^2_u – D^2)$ =	3712.43cm^2
Cohesion of Soil around the toe (C_p) =	0.46 kg/cm^2
Average cohesion of the soil along the pile stem =	0.43 kg/cm^2
Average cohesion of the soil around the under ream bulb (C'_a) =	0.43 kg/cm^2
Reduction Factor for clayey strata (α) =	0.5
Bearing Capacity Factor (N_c) =	9.0
Height of the under reamed portion (L_2) =	175.25 cm
Length of pile stem (L_1) =	375.00 cm
Lateral Surface Area of stem (A_s) =	35312.69 cm^2

Ultimate Bearing Capacity =

$Q_u = A_p N_c C_p + A_a N_c C'_a + \alpha C_a A_s$

= (707.13 X 9 X 0.46) + (3712.43 X 9 X 0.43) + (0.5 X 0.43 X 35312.69)

= 2927.518 + 14367.104 + 7592.228

= 24886.85 kg or 24.88 tonne

Considering the factor of safety as 2.5 the safe load bearing capacity of 300mm dia & 6m long single under reamed bored pile is 24.88/2.5 = 9.952 tons only.

Load carrying capacity of single under reamed bored cast in-situ piles (IS-2911 part-III, Clause 5.2.3.1) (a)

Bore Hole No.2

Type of Pile: Single under reamed bored pile

Length of Pile (L):	6.0m
Effective Length of Pile (L_e):	5.5m
Friction component not considered (l):	0.5m

b) **Bearing & Friction in clayey strata (0.5m – 6.0m i.e. 5.5m)**

Length of Pile in clayey strata (L_e) =	550cm
Diameter of Pile (D) =	30cm
Under reamed bulb dia =	75m
Cross Sectional area of pile stem (A_p) =	707.14cm^2
Cross Sectional area of under reamed bulb (A_a) = $\pi/4 (D^2_u – D^2)$ =	3712.43cm^2
Cohesion of Soil around the toe (C_p) =	0.48 kg/cm^2

Average cohesion of the soil along the pile stem =	0.45 kg/cm^2
Average cohesion of the soil around the under ream bulb (C'_a) =	0.45 kg/cm^2
Reduction Factor for clayey strata (α) =	0.5
Bearing Capacity Factor (N_c) =	9.0
Height of the under reamed portion (L_2) =	175.25 cm
Length of pile stem (L_1) =	375.00 cm
Lateral Surface Area of stem (A_s) =	35312.69 cm^2

Ultimate Bearing Capacity =

$Q_u = A_p N_c C_p + A_a N_c C'_a + \alpha C_a A_s$

= (707.13 X 9 X 0.48) + (3712.43 X 9 X 0.45) + (0.5 X 0.45 X 353120.69)

= 3054.8 + 15035.35 + 7945.35

= 26035.5 kg or 26.035 t/m^2

Considering the factor of safety as 2.5 the safe load bearing capacity of 300mm dia & 6m long single under reamed bored pile is 26.035/2.5 = 10.414 tonne only.

Conclusion

The study area is that zone where the importance of residential apartments and buildings are increasing day by day. Considering the importance of utility based on the present scenario the investigated results has been reviewed to ascertain the suitable type of foundation depending on stability and economy. The foundation may be shallow or deep but the most suitable type will be deep foundation for the following setbacks.

1. Soil bearing capacity is suitable to some extent for shallow foundation at a depth of 3m.
2. If shallow foundation of any suitable geometrical shape is suggested then the size of foundation will become too large as the SBC is very less and simultaneously gives un-economical foundation.
3. The soil characteristics below 3m depth show a drastic increase in differential free swell (DFS) and Plasticity Index Value (PIV).
4. This character indicates the soil is highly expansive in nature.
5. The pressure bulb lies in the soil which exhibits high compressibility, shrinkage and extremely high swelling characteristics under very little load. The permeability is extremely low.
6. Considering the above constraints in providing shallow foundation the alternative i.e. deep foundation/pile foundation is suggested.

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