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Geotechnical properties of soil at Sundhara and Jamal area in Kathmandu, Nepal

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ABSTRACT

The Kathmandu Valley lies in a synclinal basin filled up by fluvio-lacustrine sediments of Pleistocene age. Sundhara and Jamal lie at the core of Kathmandu City. The area is mostly occupied by public buildings. This paper primarily deals with distribution and engineering and geotechnical properties such as allowable bearing capacity of soil at Sundhara and Jamal area. For the purpose of identification of geotechnical properties of subsurface strata for multi-storeyed buildings, data of borehole logging from fifteen drill holes and laboratory test of disturbed and undisturbed soil samples were used for the investigation. In the laboratory, index and mechanical properties such as grain size, natural moisture content, specific gravity, Atterberg limits, penetration resistance, cohesion, uniaxial compressive strength, angle of shearing, rate of consolidation, and settlement were evaluated.

According to the National Building Code of India, the Kathmandu Valley is located in Seismic Zone V, and the recommended coefficient of horizontal acceleration for this zone is 0.08 g. Based on the present study of geotechnical properties of subsurface strata, it is recommended to increase the coefficient by up to 50 per cent for important structures. For multi-storeyed building, the tentative allowable bearing capacity for different types of foundation (strip, isolated, and raft) at different depths are determined as per the average parameters valid for the whole area.

INTRODUCTION

The Kathmandu Valley, the capital of Nepal, lies in a synclinal basin filled up by fluvio-lacustrine sediments of Pleistocene age (Koirala et al. 1993). Sundhara and Jamal lie in the core of Kathmandu City (Fig. 1). In the study area, the area is incorporated by already constructed, under construction or planned heavy buildings. The study area is mostly occupied by public buildings. Bir Hospital, Military Hospital, Royal Nepal Airlines Corporation Buildings, Karmachari Sanchaya Kosh Building and Post Office are the major structures of the area. Similary, numbers of small private and public buildings, few departmental stores are found in Mahabauda and New Road area. Due to lack of appropriate legalization as well as unawareness among common people, soil investigations are not carried out except for the major buildings. This paper primarily deals with engineering and geotechnical properties of soil such as allowable bearing capacity at Sundhara and Jamal area.

Available the data are rare on the engineering and geotechnical properties of soil for the area. Borehole logging and laboratory test of disturbed and undisturbed soil samples were carried out from 15 drill holes. Data from the present study could not cover the whole area so data of IOE (1985) and HEET Consult Pvt. Ltd. (1999) are also used for this study.

SEISMICITY IN THE AREA

Himalaya is a juvenile mountain range of the World. They are in the mobile state and therefore, earthquakes are frequent in the whole region including Nepal. The seismic record of the Kathmandu region suggest a return period of about 25 years, indicating that a devastating earthquake is inevitable in the long run and likely in the near future (Dixit et al. 1993 and Basnet et al. 1998). Similarly, minor earthquakes are quite frequent. Because of such activity, due consideration is to be given to the earthquake resistant design of structures. The seismic velocity information obtained from the microtremor survey (Pandey et al. 1992) shows that the granular fluvial section of the valley is attributed to a P-wave velocity of 1850-1900 m/s and clayey sediments of lake is characterised by 1600-1650 m/s. Similarly the S-wave velocity of the fluvial-granular section shows 1100 m/s and clayey sediments belonging to lake shows 300 m/s. The S-wave velocity in bed rock is assumed to be 3000 m/s.

According to the National Building Code of India (IS: 4326-1993), the Kathmandu Valley is located in Zone "V" and the recommended co-efficient of horizontal acceleration for this zone is 0.08 g. The co-efficient of horizontal acceleration should be increased by up to 50 percent for important public buildings. Since the Sundhara-Jamal area is prone to heaving areas of Kathmandu, the co-efficient of horizontal acceleration should be adequately increased. According to the liquefaction hazard map of Kathmandu valley (HMG/ UNDP/ HABITAT, 1993; Jnawali and Busch 2000), the Sundhara-Jamal area lies in moderate liquefaction potential area indicating that the area may liquefy under heavy seismic shaking.

The present study was aimed at the determination of the engineering properties of soil of the area for construction of

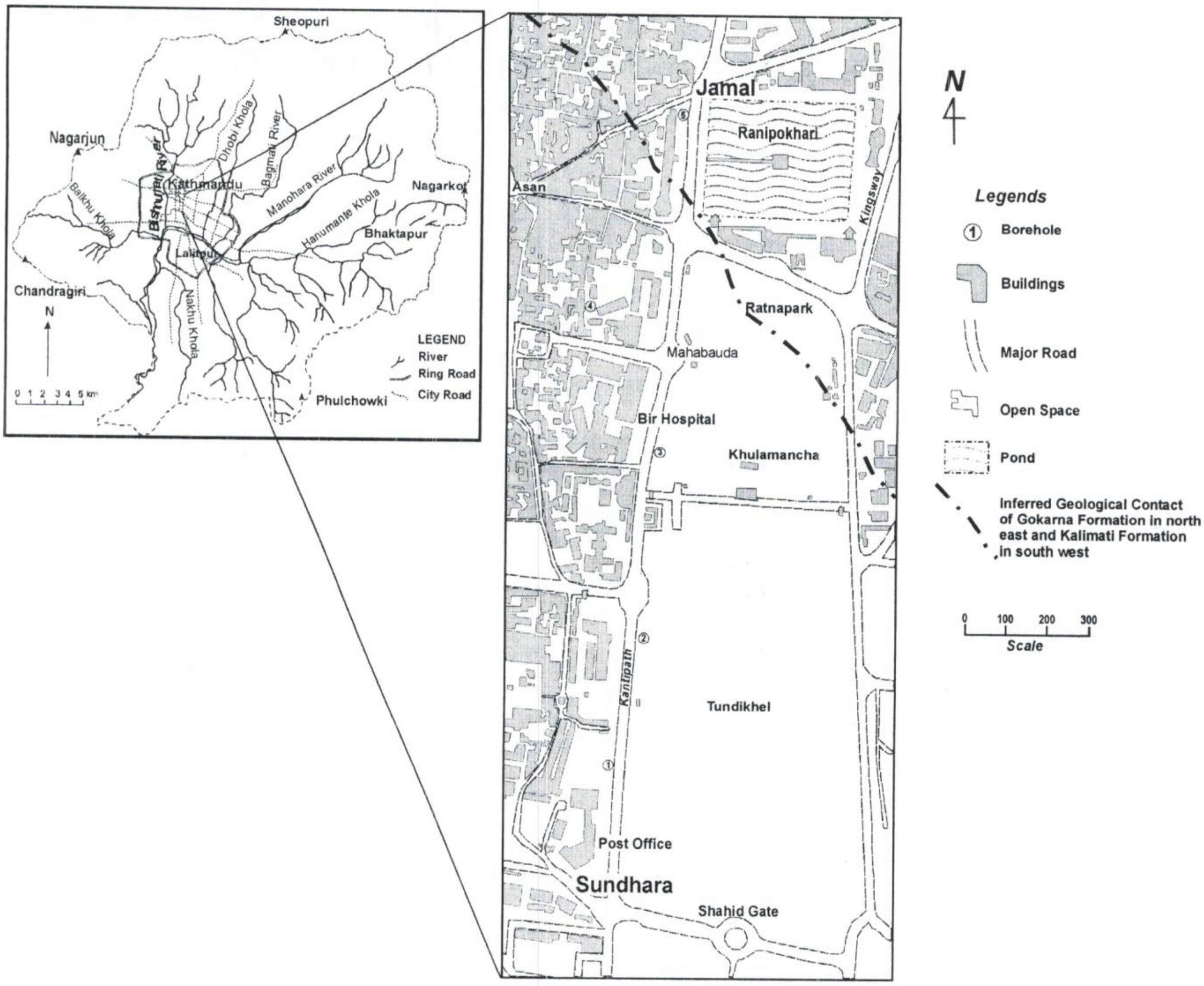


Fig. 1: Location map of the study area (modified after KVMP 2002).

multi- storeyed complexes. For this purpose, although fifteen borehole data were considered for the study, five most representative drill holes were taken for detail engineering and geotechnical analysis. Sanchyakosh building of Sundhara, in front of Royal Nepal Airlines building, Khulamanch, Mahabaudda and Jamal are the locations (Fig. 1) of representative five drill holes. Similarly, laboratory and drill holes data from remaining drill holes were also incorporated during the study.

ENGINEERING PROPERTIES OF SOIL

Field Investigation

Boreholes advancement (Fig. 2) and logging were carried out at different sites. The logs are reconfirmed and suitably corrected as per the laboratory test results. The logs of the boreholes (Fig. 3) and the cross-borehole diagram (Fig. 4) are prepared, which show that almost similar kind of the soil strata are found in the area except in Khulamanch (Fig. 3). The soil strata at these sites mainly consist of five layers of

Fig. 2: Initiation of borehole advancement in the Bir Hospital compound.

Project:		Total Depth:	20 m	Borehole No:	4
Location:	Mahabaudda	Started Date:	7/12/1998	Hole Dia.:	100 mm
Drill Rig:	XU 300-2	Finished Date:	8/12/1998	Logged By :	Arjun

Depth (m)	Description of Soil Strata	N Value 15 cm	15 cm	15 cm	N-Value	Sample Depth (m)	Type of Sample	Water Table (m)
0.00–1.00	Back fill, Top Soil							1.00
1.00–3.30	Alternating bands of medium grained and fine grained silty sand	2	3	4	7	1.5-2.0		
		1	1	2	3	3.0-3.5		
3.30–4.90	Silty clay Black, plastic, silty clay layer with bands of fine sand and silt	3	3	10	13	4.3-4.8		
4.90–7.50	Sandy clay Medium dense gravelly coarse sand with little fines and thin layers of silty clay	7	4	3	7	6.0-6.5		
		6	8	8	16	7.1-7.6		
7.50–10.00	Sand Dense coarse sand with thin bands of clayey silt fine sand	6	10	11	21	9.0-9.5		

Sampler Internal Diameter:	85 mm	***SPT***	N-Value (In-situ)
Type of Sampler:	Split Spoon	***UD***	Undistrub Soil Sample
Drilling Method:	Rotary	***DS***	Distrub Soil Sample

Fig. 3: Borehole Log of Borehole No. 4 (contd. in next page).

Fig. 3: contd.

Location: Mahabaudda | Started Date: 7/12/1998 | Hole Dia.: 100 mm

Drill Rig: XU 300-2 | Finished Date: 8/12/1998 | Logged By : Arjun

Depth (m)	Symbol	Description of Soil Strata	N Value 15 cm	15 cm	15 cm	N-value	Sample Depth (m)	Type of Sample	Water Table
10.00									
10.20									
10.40									
10.60			13	13	16	31	10.5-11.0		
10.80		Sand Dense coarse sand with thin bands of clayey silt fine sand							
11.00									
11.20									
11.40									
11.60									
11.80									
12.00									
12.20			7	9	10	19	12.0-12.5		
12.40									
12.60									
12.80									
13.00									
13.20									
13.40									
13.60			1	2	3	5	13.5-14.0		
13.80									
14.00									
14.20									
14.40									
14.60		Silty clay Blackish, medium stiff, slightly organic silty clay with thin different colour bands							
14.80									
15.00			1	2	2	4	15.0-15.5		
15.20									
15.40									
15.60									
15.80									
16.00									
16.20									
16.40									
16.60									
16.80									
17.00			1	3	3	6	16.8-17.3		
17.20									
17.40									
17.60									
17.80									
18.00									
18.20			2	3	3	6	18.0-18.5		
18.40									
18.60									
18.80									
19.00									
19.20									
19.40									
19.60									
19.80			2	3	4	7	19.8-20.3		
20.00		End of Hole							

Sampler Internal Diameter: 85 mm

Type of Sampler: Split Spoon

Drilling Method: Rotary

SPT N-Value (In-situ)

UD Undistrub Soil Sample

DS Distrub Soil Sample

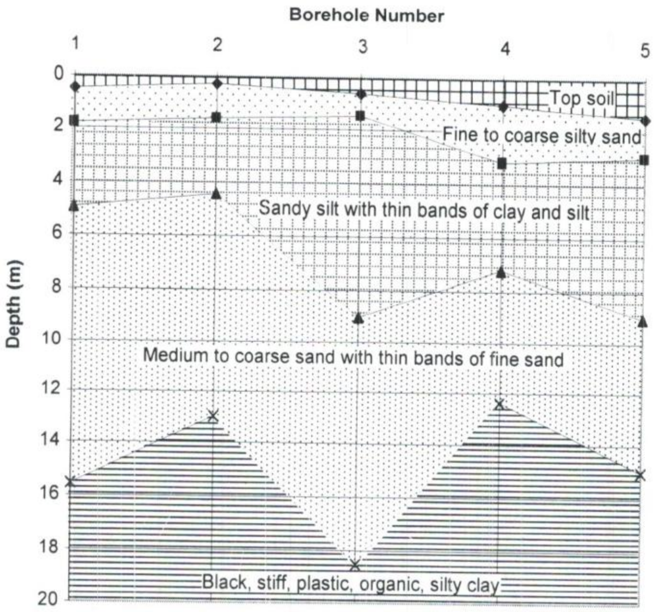


Fig. 4: Crosshole log diagram.

soil strata. The upper layer (depth varying between 0.0 m to 1.5 m from ground level) is inconsistent and consists of top soil, back filled material and thin layers of clayey silt, medium sand and coarse sand in not-regular sequence and thickness. The second layer varying generally from 0.5 m to 3.0 m consists of fine to coarse silty sand layer. The third layer generally ranges between 2.0 m and 8.0 m mainly consist of sandy silt with thin bands of clayey and fine silt. The fourth layer generally ranges between 6.0 and 16.0 m mainly consists of medium to coarse sand with thin bands of fine sand. This sand layer is dense and is mainly coarse clean sand with occasional occurrence of very thin bands of clayey silt and micaceous fine sand. The lower layer is consistent in all the holes and constitutes of black to gray plastic, soft, slightly organic clayey silt. The thickness of the fourth layer and the lowermost layer at Khulamanch differ from others. Moreover, scattered thin band of yellowish sticky silty clay and very thin bands (few millimeters) of lignite are occasionally found in the lowermost layer. This lower layer of slightly organic clayey silt is typical of the Kalimati Formation (Yoshida and Igarashi 1984).

Measured N-value from Standard Penetration Test (SPT) of the upper two layers varied from 2 to 20 depending upon whether the test was conducted in soft clayey soil or dense clean coarse sand. The corrected N-value is presented in Table 1. Water table was observed in the bore holes were close to ground surface and found to lie at 1 to 2 m from ground surface. Pressurised aquifer was not found in the investigated area.

Laboratory Investigation

Index Properties

The results of physical and index properties of soil samples collected from various depths at five boreholes are presented in Table 1. The grain size distribution of selected samples at selected depths is provided in Fig. 5a, 5b, 5c, and 5d with Unified Soil Classification System (USCS) symbols. Atterberg limit test indicates that the soil stratum at lower depth is plastic. The value of Specific Gravity and Natural Moisture Contents (NMC) indicate that the lower layer is rich with organic matter.

Strength Parameters

Unconfined Compression Tests and Direct Shear Tests were carried out on some selected undisturbed samples. The test results are provided in Table 1. Failure envelope lines of Direct Shear Tests are given in Fig. 6. Direct Shear Tests were performed on saturated sample under consolidated drained conditions. From the test it is found that soil strata in north portion (Mahabaudda) of the investigated area comprise lower value of cohesion (less than 10 kN/m^2) where as in southern area (Sundhara), the value is high (28 kN/m^2).

Consolidation Parameters

Consolidation Tests were carried on undisturbed samples with particular emphasize on samples from soft formations. Test results of compression index (C_c) are tabulated in Table 1 and the e-log p plots are presented in Fig. 7. The value of compression index of soft strata is high (0.35) in Mahabaudda area, but low (0.13) in Sundhara area.

ALLOWABLE BEARING CAPACITY

Based on the analysis of laboratory and borehole data, the tentative allowable bearing capacities for different types of foundation (strip, isolated and raft) at different depths are calculated. The calculations are based on the average parameters valid for the whole area. Once the type, location and loading intensities are available, refinement in the calculation can be made.

Allowable Bearing Capacity by SPT method

Measured values of SPT N-value are corrected for dilatancy correction and also normalised for overburden pressure using the following methods. Such correction are deemed unnecessary in clay layer and hence avoided. Corrected N-value is presented in Table 1.

For dilatancy correction Terzaghi and Peck in 1967 recommend the following correction in the case of silty fine sand when the observed value of Standard Penetration Test (SPT) exceed 15 (Arora, 1997).

The corrected penetration number $N = 15 + \frac{1}{2(N'-15)}$

Where, N=corrected N-value and N'=measured N-value

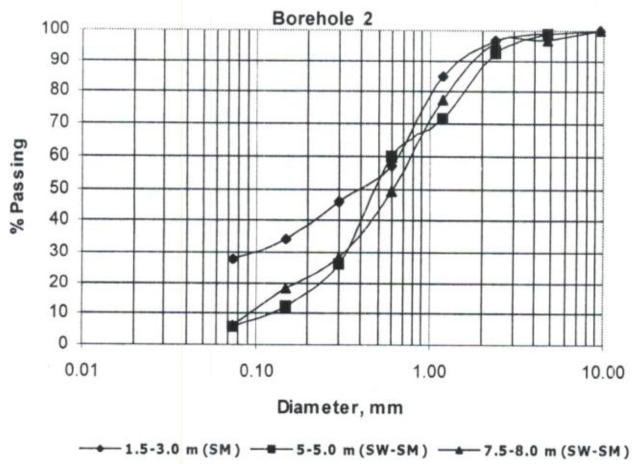
For overburden pressure correction, a constant C_N is used as defined by Peck, Hasen and Thornburn with a chart (Peck et al. 1974; Arora 1997), according to them,

$$C_N = 0.77 \log_{10}(1905 / p_o) \text{ for } p_o \, ^3 \, 24 \text{ kN/m}^2$$

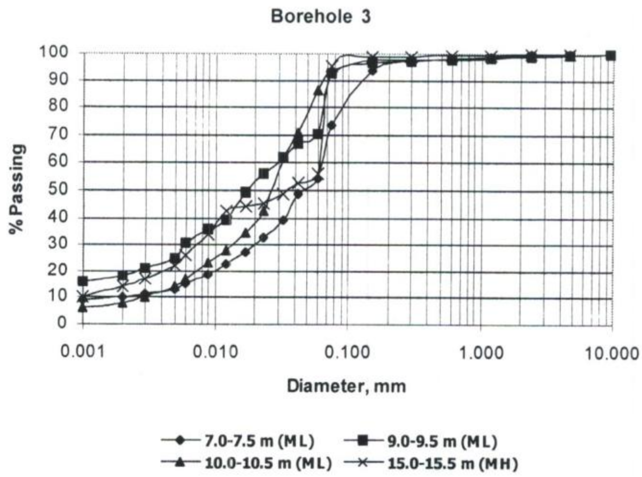
and $N = C_N \times N'$

Table 1: Index properties of soil from different depth.

BH No.	Location	Depth m	SPT Corrected	USCS	NMC %	Sp. Gr.	A. Limit LL	A. Limit P L	A. Limit P I	Direct Shear C kN/m²	Direct Shear ϕ°	U C q_u kN/m²	C_c
1	Sundhara Sanchaykosh	1.5-1.5	9	SM	28.7		30	-	NP				
		2.5-3.0	6	ML	49.3		32	24	8	15.9	7	31.3	0.21
		9.0-9.5	8	ML	43.7		35	27	8				
		16.5-17.5	7	MH	27		68	47	21	28.91	9	57.8	0.13
2	In front of RNAC	1.6-3.0		SM				NP					
		4.5-5.0	11	SM									
		5.0-5.5	7	SW-SM	19	2.76		NP		-	28		0.17
		6.0-6.5	12	ML				NP					
		7.5-8.0	15	SW-SM									
		8.5-9.0	20	SP		2.66	40	32	8				
3	Khulamanch	7.0-7.5	9	SM	50.7	2.67	27	NP	-	14	19		0.26
		9.0-9.5	8	SM			40	24	16				
		10.0-10.5	12	SM	50.6	2.67	42	25	17	10	20		0.22
4	Mahabaudda	1.5-2.0	7	SM	22.0		-	NP	-				
		4.3-4.8	7	SM	33.0		-	NP	-				
		7.1-7.6	16	ML	24.9	2.56				4	19		0.35
		9.0-9.5	21	SP			-	NP	-				
		12.0-12.5	19	SM	25.0		37	27	10				
		15.0-15.5	4	ML	49.3	2.72	40	30	10			74.1	0.35
		18.0-18.5	6	ML	33.0	2.70	37	31	6	6	8		
5	Jamal	1.6-3.0	12	SM			32	22	10				
		3.0-3.5	5	SM									
		4.0-4.5	8	SM									
		5.0-5.5	7	SM	36	2.65		NP			28		0.21
		6.0-6.5	10	ML									
		7.5-8.0	26	SM		2.63		NP					
		8.5-9.0	26	SP									



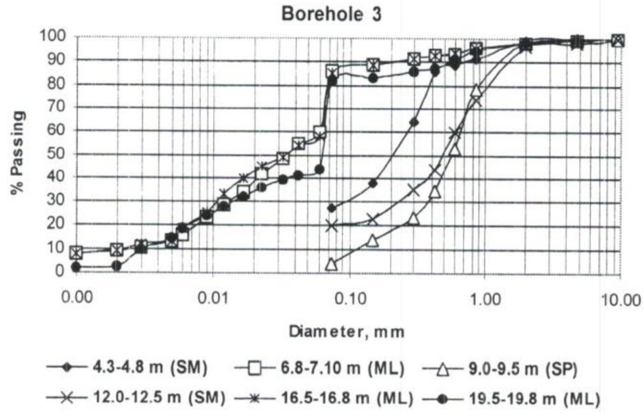
(5a)



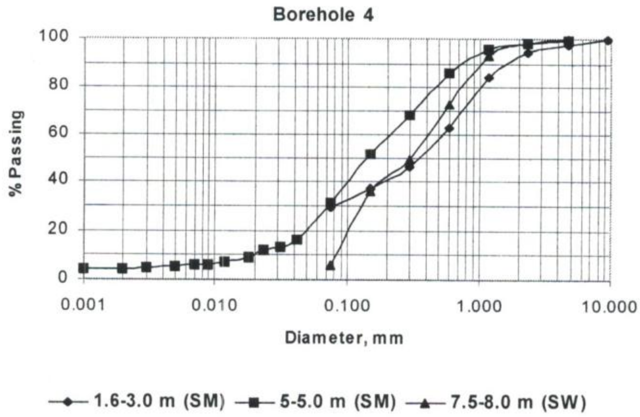
(5b)

Fig. 5: Grain size distribution curves for different soil from different depth (contd. in next page).

Fig. 5 (contd.)



(5c)



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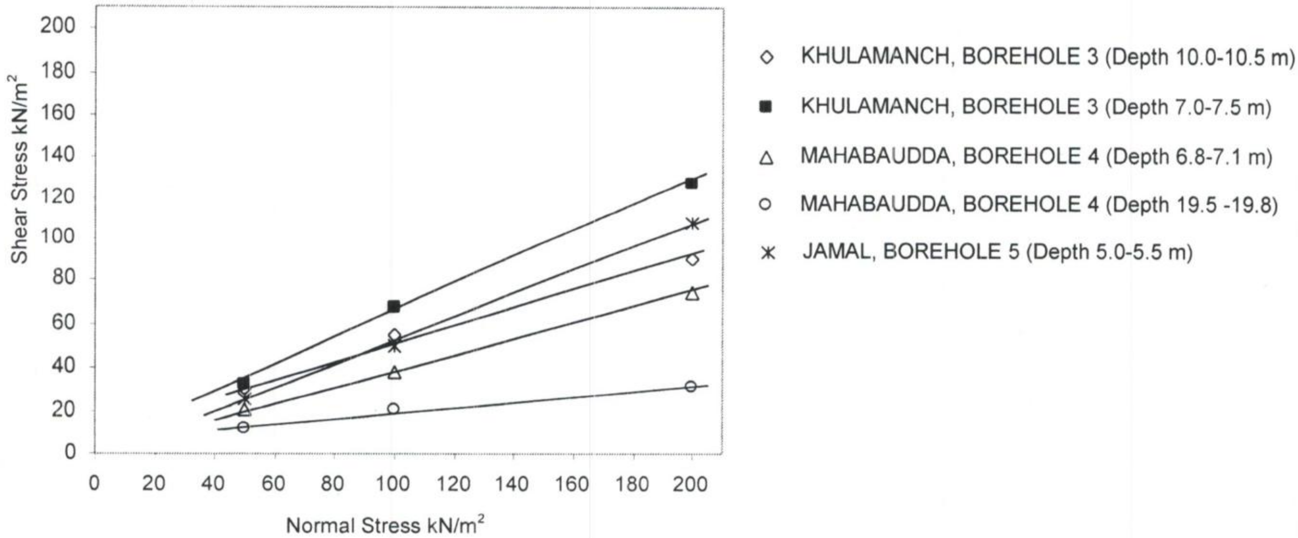

Fig. 6: Failure envelope from direct shear tests.

Where N is corrected N-value, N' is recorded N-value, p_o is effective overburden pressure.

After correcting the value of SPT, the allowable bearing capacity for the factor of safety 3.0 can be calculate according to following formula derived by Bowles in 1988 (Arora 1997).

For strip foundation of B = 1.2 m at 1.2 m depth (25 mm settlement)

$$q_a = \frac{N}{0.05} \times K_d$$

For isolated foundation of 2 m × 2 m at 2 m depth (25 mm settlement)

$$q_a = \left(\frac{N}{0.08}\right) \times \left[\left(\frac{B+0.3}{B}\right)\right]^2 \times K_d$$

For raft foundation of 5 m × 5 m at 2 m and 5 m depth (50 mm settlement)

$$q_a = \left(\frac{2N}{0.08}\right) \times K_d$$

where, $K_d = 1 + 0.33\frac{D}{B}$ and D and B are depth and width of footing respectively and $K_d \leq 1.33$

Allowable Bearing Capacity by Laboratory Method

Shear parameters in plain strain measured in the laboratory by Direct Shear Test are used for calculations. For sandy layers, the parameters are deduced from corrected SPT N-value as undisturbed sampling in such strata were not possible. The following equation for general shear failure as suggested by IS 6403 – 1981 is used for computation (Arora 1998). A factor of safety of 3 is applied to calculate the safe bearing capacity (SBC). Lower factor of safety such as 2.5 as suggested by National Building Code of India, 1983, Part II, Section 2 could be adopted (Arora 1998) at later stage of design when more details about the type of foundation, loading intensity and the location of the structures are available. Following equation is used to calculate bearing capacity.

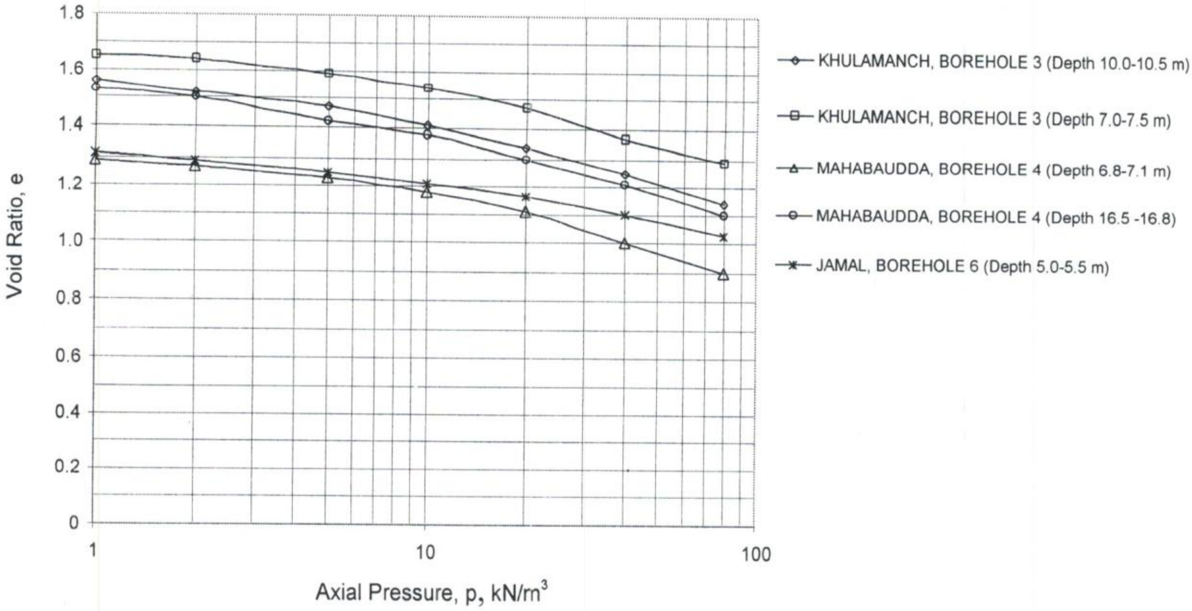

Fig. 7: Plot of e and log p of soils from different strata of the study area.

$$q_d = c \times N_c \times s_c \times d_c + q \times (N_q - 1) \times s_q \times d_q + \frac{1}{2} B \times \gamma \times N_\gamma \times s_\gamma \times d_\gamma \times W'$$

Where,

q_d is net ultimate bearing capacity.

c is cohesion.

N_c, N_q, and N_g are Vesic's Bearing Capacity Factors.

s_c, s_q, and s_g are Vesic's Shape Factors.

d_c, d_q, and d_g are depth factors proposed by IS: 6403-1981.

q is the effective pressure at the base.

B is width of the foundation.

g is unit weight of foundation soil.

W' is taken into account the effect of water pressure.

The safe bearing capacity (SBC) as per factor of safety is

SBC = $q_d / 3$.

Also for cohesive soils, based on the parameter obtained from unconfined compressive strength test and/or deduced frown N-value, net ultimate bearing capacity is calculated by using following equation;

$$q_d = c \times N_c \times s_c \times d_c$$

From the cross hole diagram, it is clear that the thickness of soil strata up to depth of 20 m are almost of same thickness and properties. So, calculated values of representative average safe bearing capacity of the soil strata of the study area for different type of foundation are tabulated in Table 2.

At 5 m depth mostly sandy layer is present in the study area, so the calculation can be made in $\phi = 0$.

Net increment soil pressure for settlement

Consolidation parameters for clayey/silty soils are measured in laboratory by consolidation test. One dimensional consolidation settlement for fine grained soils are calculated by the method suggested by USBR (1963) engineering monograph No. 13 which utilizes the following equation (Murthy 1991);

$$S = \frac{C_c}{(1+e_o)} H \log_{10} \frac{(p_o + \Delta p)}{p_o}$$

Where,

C_c is compression index determined in the laboratory

e_o is in situ void ratio

H is thickness of strata

p_o effective overburden pressure at the centre of clay strata

p is increase in pressure at the middle of clay strata due to external loading from elastic theory.

For cohesionless soils, elastic settlement (S_e) is calculated by following equation proposed by Terzaghi and Peck (Lee et al. 1983);

$$S_e = \frac{0.8}{N}\left(\frac{2B}{0.3+B}\right)^2 \times C_D \times C_W$$

where,

B is width of foundation

N is the corrected SPT value

Table 2: The average Safe Bearing Capacity by different methods in kN/m² around the study area.

Type of foundation and size	Depth of foundation (m)	Bearing Capacity by N-value	Bearing Capacity in General shear failure	Settlement Analysis	
			Lab Method	Settlement (mm)	Incremental Bearing Capacity
Strip 1.2 m wide	1.2	110	75	25	40
Isolated 2 m × 2 m	2.0	150	100	25	50
Raft	2.0	160	260	50	75
5 m × 5 m	5.0	175	145 (ϕ=0 analysis)	50	60

C_D is depth factor and $C_D = 1 - 0.25\frac{D}{B}$

Similarly, C_W is the water table correction band its value is 1 if depth of water table is greater than 2B and its value is 2 if the depth of water table is 0.

Allowable incremental soil pressures are obtained for 25 mm settlement in case of strip and isolated footings and for 50 mm settlement in case of raft foundation as given in Table 2. The limit of allowable settlement could be adopted as recommended by the National Building Code of India for the final design when more details of the structures are available.

CONCLUSIONS AND RECOMMENDATIONS

Following conclusions are derived from the investigation carried out with in the study area.

1) From geotechnical point of view, any building in the area should be constructed with proper design taking into consideration of the properties of foundation soils.

2) All over the investigated area, the following three distinct layers of soil strata of varying thickness are found.

- Uppermost layer: thin bands of clayey silt, fine sand, sandy silt
- Middle layer: sandy soil, mainly coarse in medium dense state
- Lowermost layer: black to gray plastic clayey silt.

3) Due to presence of compressible fine grained material within 5 to 15 m depth, due care should be taken regarding the type of foundation, size of foundation and depth of foundation.

4) Water table in the area lies at 1 to 2.5 m depth in the month of October to December. Water table is subject to rise during wet months. So, necessary precautionary measures should be taken regarding the design of foundation. Similarly provision of dewatering is necessary in basement.

5) Allowable bearing capacity depends on many variables such as adopted allowable settlement, type of foundation, size and depth of foundation, importance of structures, cost of the building construction etc. Hence based on parameters obtained from this investigation, calculations should be revised during design phase.

6) For the heavy buildings and other structures around the Sundhara – Jamal area, the exploratory safe bearing capacity of soil as per the factor of safety 3 can be estimated by the following experiential relationship.

$$SBC = 6.5 \times N\ kN/m^2$$

where, N is the corrected SPT value.

1) Due to presence of compressible soil layers at depth, egg shell type foundation might be only economical solution for the area if very wide foundations are necessary.

2) To prevent failure of buildings due to soil behavior during earthquake, the government should make proper codification to impose detail site investigations before any heavy structural design are made.

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