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Engineering properties of fine grained soils of Kathmandu Valley, Nepal

[1] T.P. Katel, [2] B.N. Upreti and [3] G.S. Pokharel

[1]Department of Soil Conservation, Ministry of Forestry and Soil Conservation, HMG, Babarmahal, Kathmandu, Nepal

[2]Department of Geology, Tri-Chandra Campus, Tribhuvan University, Ghantaghar, Kathmandu, Nepal

[3]Soil, Rock and Concrete Laboratory, Nepal Electricity Authority, Bhagwanpau, Swayambhu, Kathmandu, Nepal

ABSTRACT

This paper primarily deals with the distribution, and engineering and geotechnical properties of fine grained soils in the Kathmandu Valley. Not much studies have been done on these soils in the past except at some engineering construction sites such as bridges and heavy buildings. Very little data are available on the engineering and geotechnical properties of soils of the valley (IOE, 1983a, 1983b, 1986a, 1986b, 1986c; Koirala et al., 1993; Sadaula, 1993; Shakya, 1987; Soil Test, 1990a, 1990b). The authors conducted detailed laboratory studies on the soils of the Thapathali and Ratnapark areas in the central part of the Kathmandu Valley and the results are presented and discussed. An attempt is also made to broadly evaluate the soil conditions of the valley based on the available data from previous studies conducted by various agencies.

The soils of the Kathmandu Valley are mainly produced by weathering of rocks within its watershed boundary. They are in most part lacustrine and fluvial in origin and composed of clayey, silty, sandy and gravely sediments. The maximum thickness of the sediment is found in the central part (550 m at Bhrikutimandap) and southern part (>457m at Harishidhi) of the valley.

The engineering properties, basically the index properties such as grain size, natural moisture content, specific gravity, Atterberg limits; and the mechanical properties such as penetration resistance, cohesion, unconfined compressive strength, compressibility as well as angle of shearing resistance of fine grained soils were determined and found to vary considerably both in horizontal and vertical directions. The bearing capacity and settlement values of the soils were also determined.

It is commonly found that most of the buildings in the Kathmandu Valley are founded on isolated or strip types of foundations and the foundation depth is between 1 and 1.5 m. The study of soil properties of the Kathmandu Valley indicates that the heavy loaded structures should be founded on either raft, mat or pile types of foundation.

INTRODUCTION

Most engineering structures in the Kathmandu Valley are founded on soil. Due to the lack of appropriate legislation as well as unawareness among common people, soil investigations are not carried out as a routine work for engineering constructions except for a very few important and large structures. Almost all private residential houses are constructed without soil investigation. Rapid urbanization of the Kathmandu Valley in recent years has led to the construction of thousands of private and public buildings without giving due considerations to the nature and the bearing capacity of the foundation soils and the seismic hazards. Even today no systematic and detailed study of the distribution and engineering and geotechnical properties of the soils of the Kathmandu Valley has been carried out by the concerned agencies of the government or the Kathmandu Municipality. Data are rare on the engineering and geotechnical properties of soils of the valley (IOE, 1983a, 1983b, 1986a, 1986b, 1986c; Koirala et al., 1993; Sadaula, 1993; Shakya, 1987; Soil Test, 1990a, 1990b). This paper deals primarily with the distribution, and engineering and geotechnical properties of fine grained soils in the Kathmandu Valley based on the works at two sites in the central part of the valley. An attempt is also made to evaluate the engineering properties of the soils of the valley in general based on the available data from previous studies.

DISTRIBUTION OF SOILS IN KATHMANDU VALLEY

The Kathmandu Valley is an intermontane basin and lies within the Lesser Himalaya of central Nepal (Fig. 1). The soils of the valley are mainly the product of weathering of rocks within its watershed boundary. They are mainly Quaternary sediments of lacustrine and fluvial origin. The soils are composed of clayey, silty, sandy and gravely sediments and are more or less unconsolidated. These sediments lie unconformably over the basement rocks (Yoshida

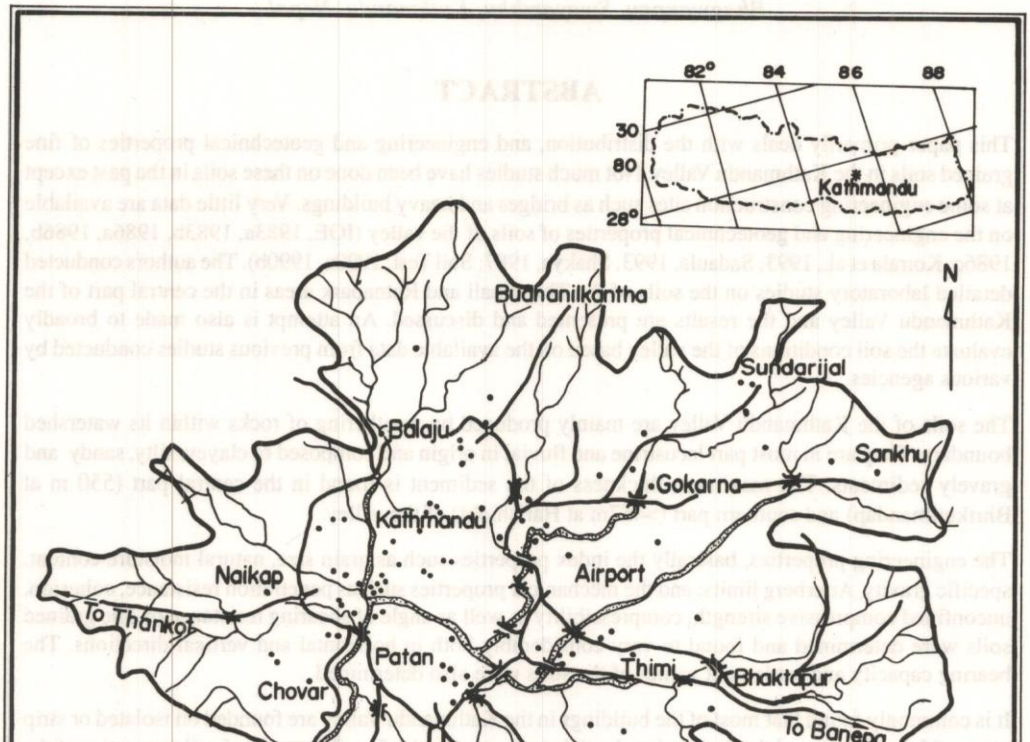

Fig. 1: Locations of soil investigation sites in Kathmandu Valley.

and Igarishi, 1984). Moribayashi and Maruo (1980) conducted gravity survey to understand the basement topography of the Kathmandu basin and concluded that the maximum depth of the basement below the sediments is a little more than 650 m. Based on the bore hole data of Japan International Cooperation Agency (JICA, 1990), Department of Mines and Geology (DMG), and other miscellaneous works, the pattern of subsurface sediment distribution in the Kathmandu Valley (up to 300 m depth) is prepared and shown in two fence diagrams (Fig. 2a, b) and cross-sections (Fig. 3a, b). However, it should be noted that the fence diagrams are based on a limited number of bore hole data. Since there is a significant lateral variations in lithology and thickness of sediments, the diagrams can be used as a general reference and not for site specific works.

The drilling data show that the maximum thickness of the sediments in the valley is more than 457 m at Harishidhi (JICA, 1990, and Fig. 4) where the bore hole did not reach the bedrock. At Bhrikutimandap (exhibition ground) the thickness is about 550 m up to the bed rock (Fig. 4). The thickness of sediment at Bansbari, Gausala and Katunje also touched the bed rock at depths of 79 m, 113 m and 160 m, respectively. But close to these locations bore holes at Gokarna, Koteshwor, Sanothimi and Bhadgaon (Bhaktapur) drilled to depths of 305 m, 305 m, 278 m and 278 m below the ground level respectively did not touch the bed rocks.

The fence diagrams and cross-sections show that the coarse granular sediments occupy the north and north-eastern part of the basin while the fine grained deposits lie towards south and south-western part. The number of granular beds also increases towards north and north-eastern part of the basin. The bore holes at Harishidhi, Sunakothi and Lubhu, all lying in the southern part of the valley, show no pure granular zones and consist mainly of thick columns of the sticky black clay.

ENGINEERING PROPERTIES OF SOILS OF KATHMANDU VALLEY

The present investigation was aimed at the determination of the engineering properties mainly the index properties such as natural moisture content, grain size, specific gravity, Atterberg limits and mechanical properties such as penetration resistance, cohesion, unconfined compressive strength, compressibility as well as angle of shearing resistance of the fine grained soils of Ratnapark (at Jame Masjid site) and Thapathali (at New Bagmati Bridge site). Index properties of surface soils from various locations of the valley were also determined. As far as possible, previous data on soil investigations at different locations of the Kathmandu Valley were also collected to determine some soil parameters. The results are presented in the Annex.

Index properties

Particle size

The grain size analysis of the soils from the Thapathali site (Table 1) shows a clear dominance of fines (i.e. fraction smaller than 75 m). The percentage of sand and gravel is generally very low. The soils of Ratnapark site contain a higher percentage of coarse fraction compared to the Thapathali soils (Table 2).

Natural Moisture Content

The natural moisture content (NMC) of the soils of the Thapathali area (Table 1) is generally high (72.96-126.37 %) due to the high content of organic matter. The moisture content of the soils of the Ratnapark area (Table 2) varies between 9.1-33.0% (in coarse grained soils) and 9.6-66.3% (in fine grained soils). Various other studies have shown that the moisture content of cohesive soils of parts of the Kathmandu Valley varies between 19.96-94%.

Specific Gravity

The specific gravity of the subsurface soils of Thapathali (up to a depth of 15 m) ranges from 2.44 to 2.70 and soils of Ratnapark ranges from 2.66 to 2.73 (Table 1 and 2). The specific gravity of the surface soils of Lukundol on the other hand showed a minimum value (2.34) and that of Arubari the maximum (2.67) (Table 3). The lower specific gravity value of soil of the Lukundol area may be due to organic content and that of

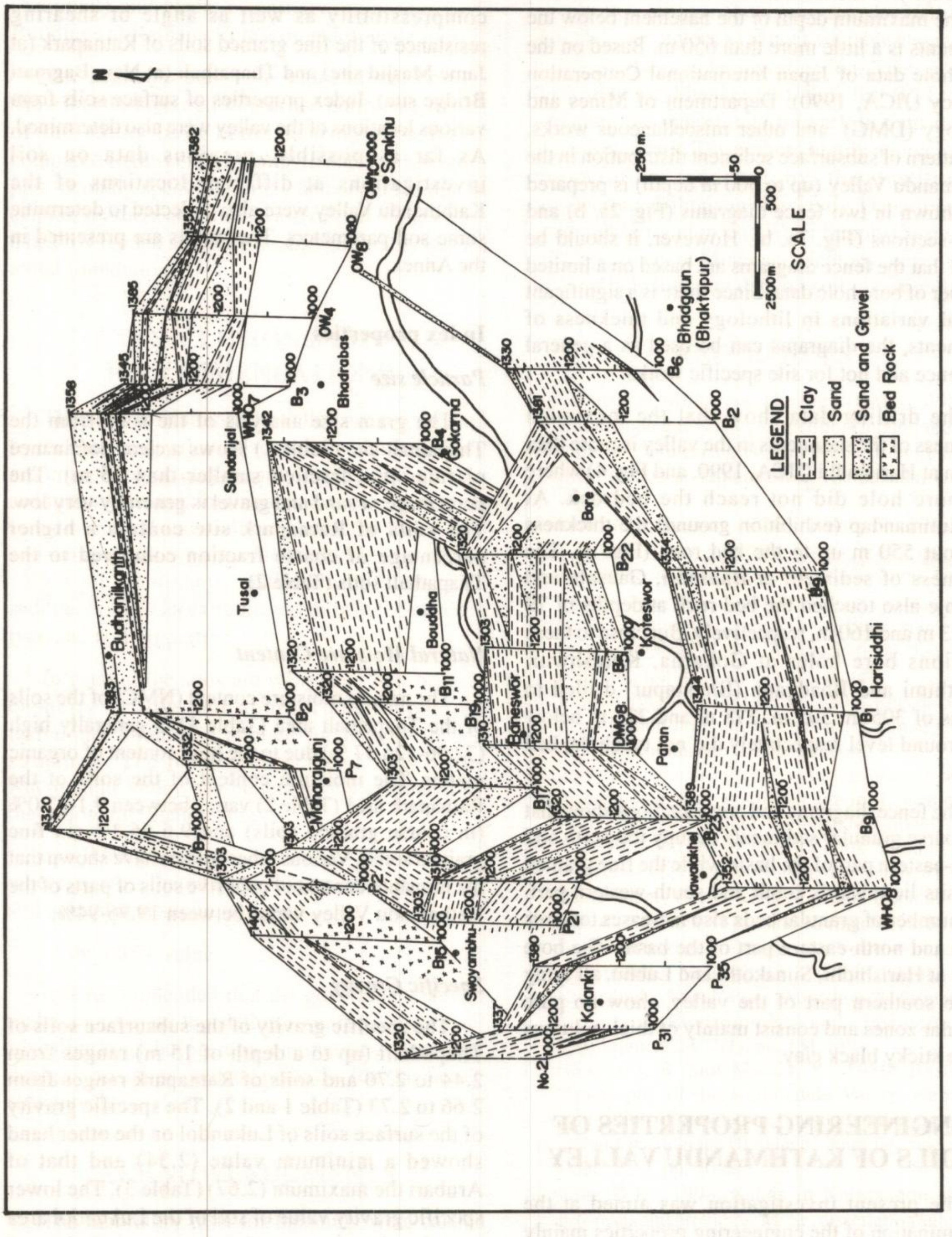

Fig. 2a: Fence diagram of sediment distribution in the Kathmandu Valley

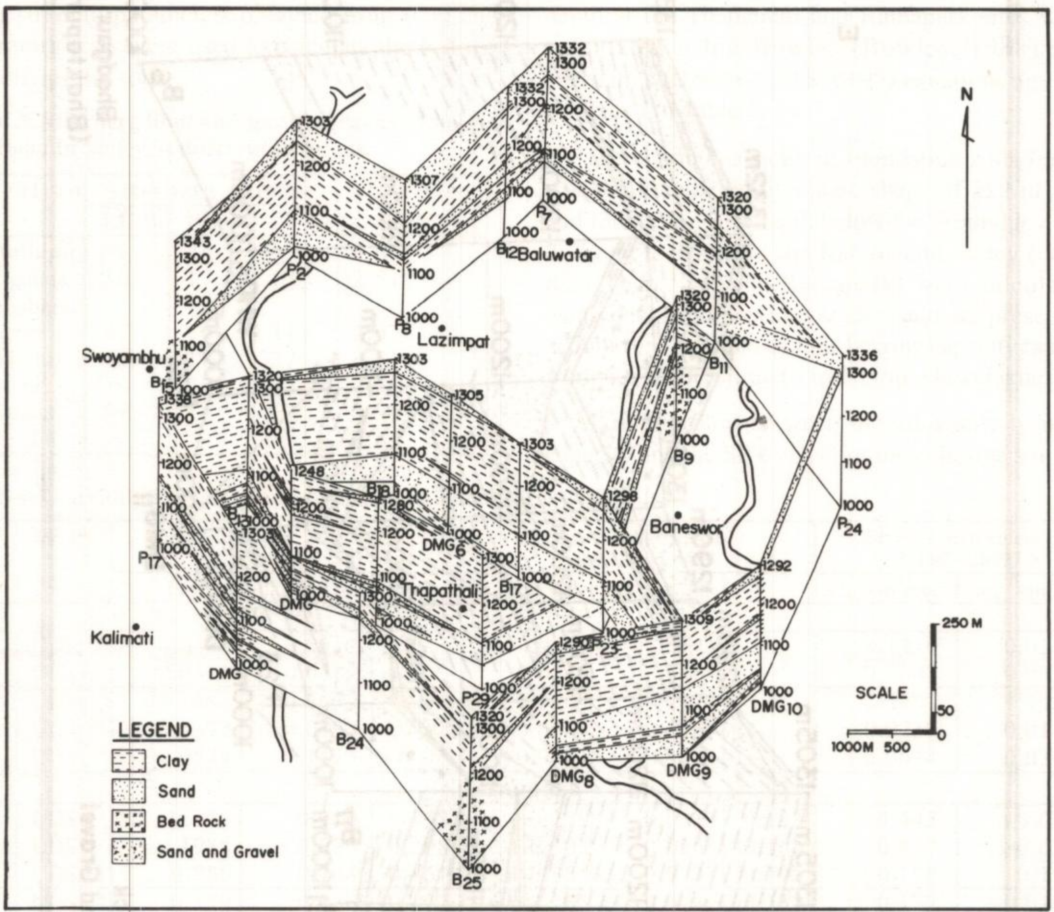

Fig. 2b: Fence diagram of sediment distribution within and adjacent areas of the ring road.

Hatigaudda due to coarse grained nature than that of other parts of the Kathmandu Valley. The values of specific gravity of cohesive subsurface soils of other parts of Kathmandu Valley ranges from 2.51 to 2.77 (Annex).

Density

The bulk density of cohesive soils of the Kathmandu Valley ranges between 1.09 and 2.77 gm/cm^3 (Annex).

Atterberg limits (consistency limits)

The plastic soils of Thapathali have a high liquid limit (LL) value which ranges between 81.10-108.0% and the plasticity index (PI) ranges between 13.01 to 40.0% (Table 1). The liquid limit of the plastic soils of Ratnapark site on the other hand ranges between 36.0-73.0% and the plasticity index ranges between non-plastic (NP) to 33.0% (Table 2). Soils with higher liquid limit and plasticity index are generally characterized

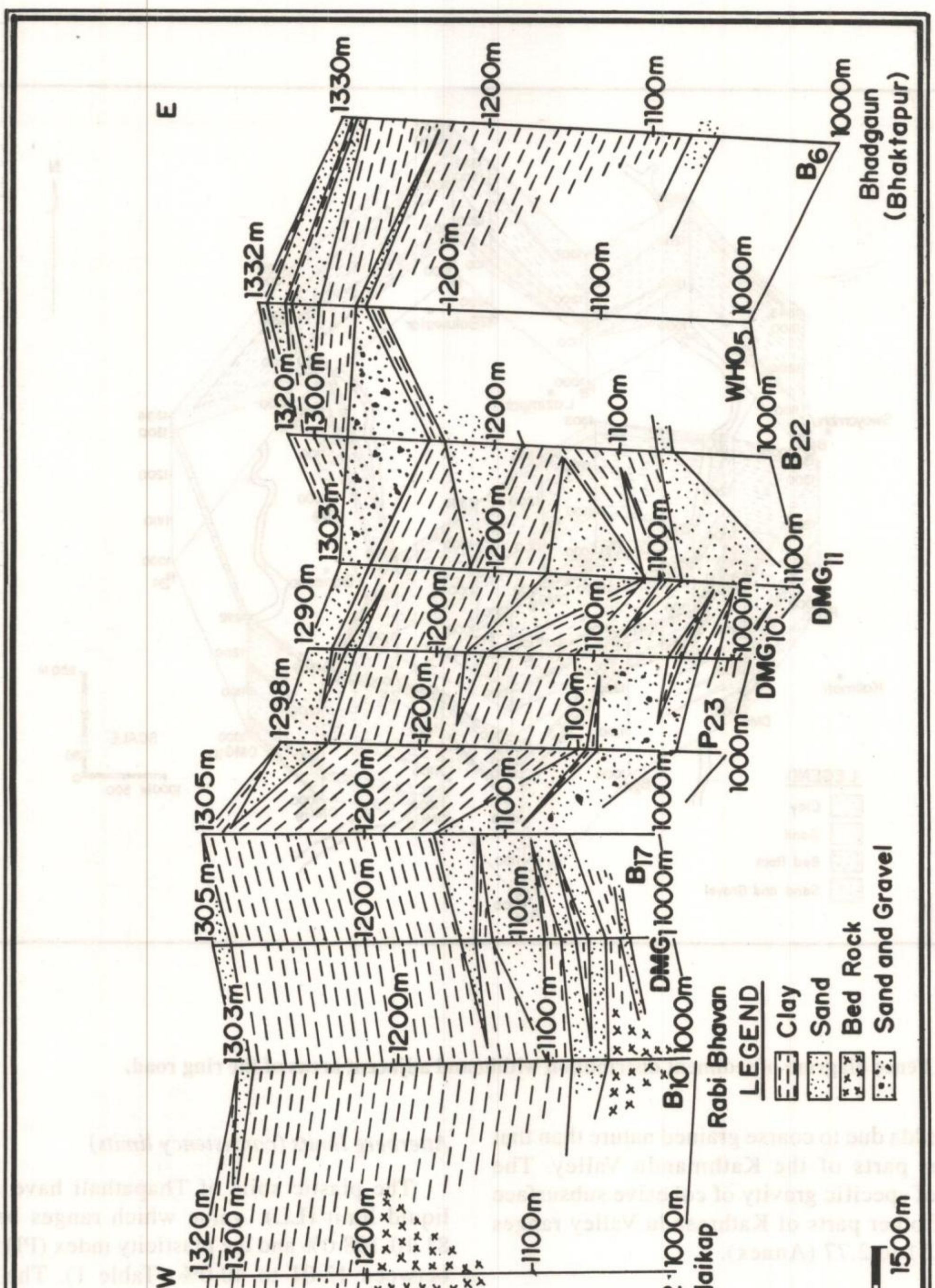

Fig. 3a: Lithological crosssection of Kathmandu Valley sediments along E-W directions.

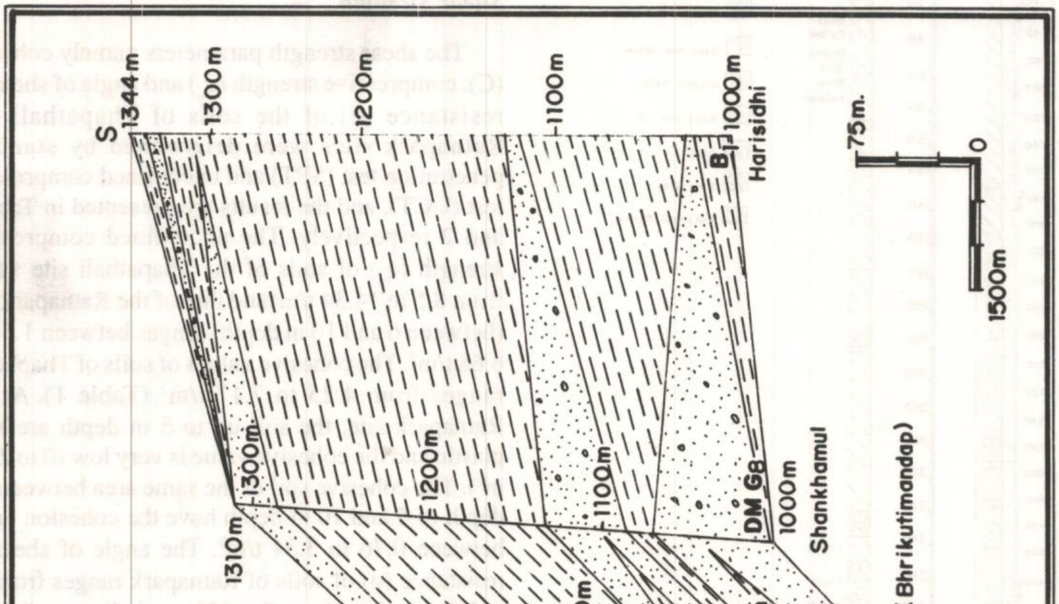

Fig. 3b: Lithological crosssection of Kathmandu Valley sediments along N-S directions.

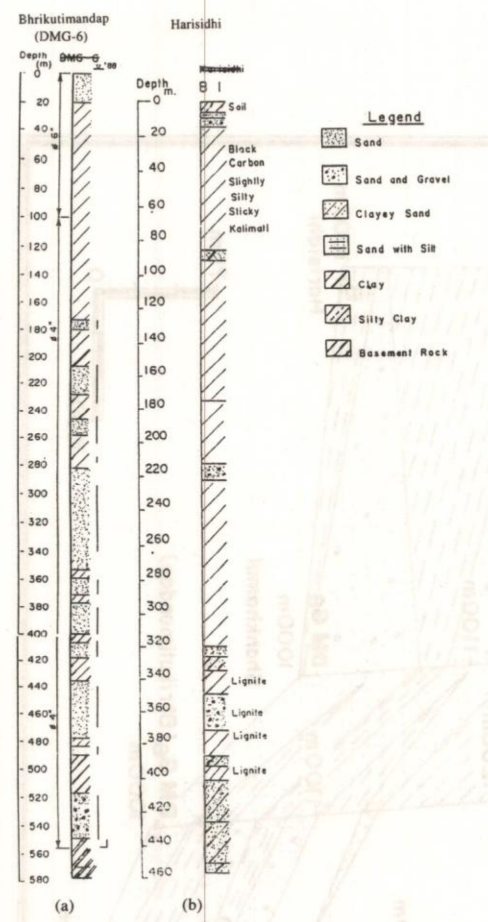

Fig. 4: Lithological logs at Bhrikutimandap, DMG-6 (a) and Harisiddhi (b).

by high cohesion, high compressibility and less shear strength (Annex).

Mechanical Properties

Compressibility

The consolidation tests were conducted on the cohesive soils and the test results of Thapathali and Ratnapark sites are presented in Table 4. The compressibility values of both sites are found to be low to very low. These results are also supported by SPT values and unconfined compression test (Table 1 and 2). The result of consolidation tests (m_v, c_v and c_c) of different soil groups obtained by previous studies at various locations and depth in the Kathmandu Valley also shows that the soils are characterized by low to very low compressibility values (Annex).

Shear Strength

The shear strength parameters namely cohesion (C), compressive strength (q_u) and angle of shearing resistance (ø) of the soils of Thapathali and Ratnapark sites were determined by standard penetration test (SPT) and unconfined compression test (UCT), and the results are presented in Table 1 and 2 respectively. The unconfined compressive strength (q_u) of soils of the Thapathali site varies from 8.5 to 14.34 t/m^2 and that of the Ratnapark site (between 6 and 10 m depth) ranges between 1.5 and 6.68 t/m^2. The cohesive values of soils of Thapathali ranges from 4.25 to 7.17 t/m^2 (Table 1). At the Ratnapark site, the soil up to 5 m depth are non-plastic and the cohesive value is very low (0 to 2.5 t/m^2). The cohesive soil of the same area between the depth of 5 and 10 m depth have the cohesion value between 0.76 to 3.34 t/m^2. The angle of shearing resistance (ø) of soils of Ratnapark ranges from 28 to 36^0, whereas the soils of Thapathali are cohesive. The previous studies conducted by various agencies have shown that the cohesive value of soils in other parts of the Kathmandu Valley ranges between 0.3 and 11.15 t/m^2 and the angle of shearing resistance varies from 2-42^0 (Annex).

Geotechnical Properties

The soil characteristics of the Kathmandu Valley generally vary laterally as well as vertically. Therefore to find out the nature of this change, an adequate and elaborate soil investigation programme is required. The selection of the type and depth of the foundation, the allowable bearing capacity and the settlement analysis depend upon the soil properties. The following geotechnical properties were determined for the soils of the area under investigation:

Bearing Capacity

A design of a foundation must satisfy the requirements that no shear failure occurs and the settlement remains within the allowable limits. The bearing capacity of a foundation design depends

Table 1: Summary of field and laboratory test results of Thapathali soils.

Bore hole No.	Sample No.*	Depth m	SPT value		Grain size analysis				NMC %	Atterberg Limit			Specific gravity	UC test	
			N_f	N_c	Gravel %	Sand %	Fines %	USCS		LL %	PL %	PI %		q_u t/m^2	C t/m^2
1	DS_2	3.0-3.45	7	8.75	-	5.00	95.00	MH	72.96	-	-	-	2.44	-	
	UDS_1	6.0-6.35	-	-	3.45	13.64	82.91	MH	100.69	81.10	74.34	14.76	2.43	14.34	7.17
	DS_6	8.0-8.45	15	13.8	-	6.00	94.00	MH	89.92	-	-	-	2.54		
	UDS_2	10.0-10.35	-	-	6.40	14.60	79.00	MH	126.37	89.50	76.49	13.01	2.52	13.39	6.69
	DS_9	12.0-12.45	11	8.58	-	5.00	95.00	MH	81.52	-	-	-	2.50		
	DS_{11}	15.0-15.45	25	17.5	3.60	15.20	81.20	MH	88.98	-	-	-	2.50		
2	DS_2	2.0-2.45	9	12.45	-	0.50	99.50	MH	79.38	-	-	-	2.60		
	DS_3	3.0-3.45	5	6.25	-	0.30	99.70	MH	73.82	-	-	-	2.69		
	UDS_1	4.0-4.45	-	-	-	0.26	99.74	MH	101.95	101.0	75.00	26.00	2.46	8.5	4.25
	DS_4	6.0-6.45	7	7.07	-	7.00	93.00	MH	90.00	-	-	-	2.47		
	UDS_2	8.0-8.45	-	-	-	6.00	94.00	MH	90.96	88.9	54.38	34.52	2.28	10.03	5.00
	DS_7	9.0-9.45	15	13.2	-	7.00	93.00	MH	87.50	-	-	-	2.48		
	UDS_3	12.0-12.45	-	-	-	0.28	99.72	MH	125.13	108.0	68.0	40.0	2.60	13.50	6.75
	DS_{12}	14.0-14.45	17	12.41	-	0.12	99.88	MH	100.74		-	-	2.56		

Nf Field SPT value Nc Corrected SPT value LL Liquid limit PL Plastic limit PI Plasticity index
qu Unconfined compressive strength C Cohesion value NMC Natural moisture content

Table 2: Summary of field and laboratory test results of Ratnapark soils

Bore hole No	Sample No.	Depth m	SPT value N_f	SPT value N_c	Grain size analysis Gravel %	Sand %	Fines %	USCS	NMC %	Atterberg Limit LL %	PL %	PI %	Specific gravity	Direct shear test C, t/m^2	Shear angle, (ø)	UC test q_u, t/m^2	C, t/m^2
	DS	2.0-2.45	8.0	8.56	13.7	82.3	4.0	SW	9.1	-	-	NP	2.72	0	35		
	DS	3.0-3.45	3.0	3.15	0.0	74.9	25.1	SM	28.9	-	-	NP	-				
	DS	4.0-4.45	7.0	7.28	0.6	81.6	17.8	SM	25.9	-	-	NP	2.67	1	28		
	DS	5.0-5.45	35	-	3.9	94.8	1.3	SP	13.1	-	-	NP	2.66	2.5	29		
	UDS	6.02-6.45			0.0	-	-	ML	52.1	42.0	27.0	15.0	2.71			6.68	3.34
	UDS	6.45-6.90			0.0	0.5	99.5	CH	51.9	53.0	28.0	25.0	2.67				
	DS	7.0-7.50	2.0	-	-	0.6	98.6	CL	44.1	45.0	28.0	19.0	-				
	DS	7.50-7.95	7.0	6.23	-	1.4	88.7	ML	55.3	-	-	NP	-				
	UDS	8.0-8.45			-	-	-	ML	40.5	36.0	28.0	8.0	-			1.52	0.76
1	DS	9.0-9.45	6.0	4.68	-	8.1	87.9	ML	39.2	-	-	NP	-				
	UDS	10.0-10.45			-	-	-	ML	35.8	-	-	NP	2.07			5.99	2.995
	DS	11.0-11.45	2.0	1.48	-	9.7	89.9	ML	36.9	53.0	32.0	21.0	-				
	DS	12.0-12.45	2.0	1.38	-	1.1	99.5	MH	48.8	57.0	35.0	22.0	-				
	UDS	13.0-13.45			-	-	-	MH	62.2	61.0	42.0	19.0	-				
	DS	14.0-14.45	4.0	2.60	-	0.7	99.5	MH	30.7	67.0	43.0	24.0	-				
	DS	15.0-15.45	4.0	2.52	-	0.4	99.3	MH	55.4	64.0	42.0	22.0	-				
	DS	2.0-2.45	8.0	5.56													
	DS	3.0-3.45	10	10.50	13.6	74.3	12.1	SW	22.7	-	-	NP	2.67	0	33		
	DS	4.0-4.45	6.0	6.24	0.3	83.7	16.0	ML	33.0	-	-	NP	2.67	0	32		
	DS	5.0-5.45	7.0	6.72	0.8	-	-	SW	-	-	-	NP	-				
	DS	6.0-6.45	47		-	-	-	-	-	-	-	NP	2.69	0	33		
	UDS	6.45-7.0			-	-	-	SP-SW	22.1	-	-	NP	-	0	32		
	DS	7.0-7.45	50	-	1.3	93.9	4.8	SW	13.3	-	-	NP	-				
	DS	8.0-8.45	52	-	4.2	91.6	4.2	SP	12.2	-	-	NP	2.70				
	DS	9.0-9.45	61	-	10.9	85.2	3.9	SW	38.0	-	-	NP	2.69				
	DS	10.0-10.45	7.0	5.46	-	6.6	93.4	CL	41.1	-	-	NP	2.72				
	DS	11.0-11.45	6.0	4.44	-	6.9	93.1	CL	66.3	39.0	17.0	22.0	-				
	UDS	12.0-12.45			-	-	-	MH	53.6	73.0	50.0	23.0	-				
	DS	13.0-13.45	5.0	3.35	-	1.5	98.5	MH	62.2	67.0	34.0	33.0	2.69				
2	UDS				-	-	-	MH	56.6	73.0	50.0	23.0	2.69				
	DS	15.0-15.45	6.0	3.78	-	2.8	97.2	MH	68.3	61.0	46.0	15.0	-				
	DS	1.0-1.45															
	DS	2.0-2.45	2.0	2.14	1.9	85.5	12.6	SW	22.7	-	-	NP	2.75	0	31		
	DS	3.0-3.45	4.0	4.2	1.5	79.4	19.1	SW	23.5	-	-	NP	2.67	0	35		
	DS	4.0-4.45	9.0	9.36	0.0	95.9	4.1	SP	33.0	-	-	NP	-	1	30		
	DS	5.0-5.45	10	9.6	2.4	84.1	13.5	SW	22.1	-	-	NP	-				
	DS	6.0-6.45	10	9.4	1.8	97.4	0.8	SP	15.0	-	-	NP	2.73	1	36		
	DS	7.0-7.45	25	-	0.0	20.2	79.8	ML	9.6	-	-						
	DS	8.0-8.45	8.0	6.56	13.4	78.1	8.5	SW-SM	13.3	-	-	NP	-				
	DS	9.0-9.45	6.0	4.68	-	12.3	87.7	ML	12.2	-	-	NP	-				
	DS	10.0-10.45	3.0	2.34	-	0.7	99.3	ML	56.4	40.0	33.0	13.0	-				
3	DS	11.0-11.45	4.0	2.96	-	1.3	98.7	ML	65.4	46.0	41.0	5.0	-				
	DS	UDS			-	-		MH	66.3	43.0	38.0	5.0	2.77				
	DS	13.0-13.45	3.0	2.01	-	1.0	99.0	MH	63.6	56.0	43.0	13.0	2.67				
	DS	14.0-14.45	3.0	1.95	-	0.7	99.3	ML	62.2	54.0	43.0	11.0	-				
	DS	15.0-15.45	3.0	1.89	-	0.8	97.2	MH	56.6	47.0	32.0	15.0	-				

Nf Field SPT value   Nc Corrected SPT value   LL Liquid limit   PL Plastic limit   PI Plasticity index
qu Unconfined compressive strength   C Cohesion value   NMC Natural moisture content

upon various factors such as type of soil, size and depth of foundation, amount of settlement that the structure can stand, groundwater condition, etc. The shear strength parameters obtained from field and laboratory tests were used to calculate the bearing capacity of the soils.

Table 3: Atterberg limit and specific gravity of soils of Kathmandu Valley at different locations.

Location	Atterberg Limit			Specific
	LL %	PL %	PI %	Gravity
Sanothimi	32	24	8	2.66
Hatigauda (Bansbari)	30	17	13	2.51
Arubari	47	16	31	2.67
Chabahil	45	18	27	2.51
Chovar	70	37	33	2.58
Lukundol	59	16	43	2.34
Gangabu				2.66

The allowable bearing capacity calculation for a strip type foundation of 1 m width and an isolated foundation of 2x2 m size founded at 1 m and 2 m depth at the Thapathali and Ratnapark sites were calculated using Bowles (Bowles, 1988) and Terzaghi's (Bowles, 1988, p195) equations and are presented in Table 5.

The bearing capacity of foundation soils for an isolated foundation of square shape of 2x2 m size and founded at 2 m depth below the ground level at different locations of the Kathmandu Valley (other than Thapathali and Ratnapark) were calculated using data from previous studies and are presented in Table 6. It is found that the bearing capacity ranges from 6.6 t/m^2 (Kalimati) to 20 t/m^2 (Jawalakhel).

A relationship between the allowable bearing capacity and the SPT value for the cohesive soils of

Table 4: Consolidation test results of Thapathali and Ratnapark soils.

Bore hole	Sample	Stress range kg/cm^2 0.0181-0.7244			Stress range kg/cm^2 0.0.7244-1.4489			Stress range kg/cm^2 1.4489-2.8977	
No.	No.	C_v, cm^2/sec	m_v, cm^2/kg	Cc	C_v, cm^2/sec	m_v, cm^2/kg	Cc	C_v, cm^2/sec	m_v, cm^2/kg
Thapathali									
A_1	UDS_1	0.0483	0.0912	-	0.0877	0.0374	-	0.1216	0.0289
	UDS_2	0.0576	0.0787	-	0.0546	0.0346	-	0.0607	0.0333
A_2	UDS_1	0.1488	0.7037	-	0.1504	0.7217	-	0.1206	1.4439
	UDS_2	0.0373	0.0197	-	0.0600	0.0190	-	0.0739	0.0142
	UDS_3	0.0544	0.1123	-	0.0661	0.0443	-	0.0614	0.0289
Ratnapark									
1	UDS_1	0.355	0.910	0.398	0.279	0.032	0.133	4.445	0.020
	UDS_3	0.1988	0.083	0.398	0.303	0.026	0.166	0.417	0.022
	UDS_4	0.280	0.764	0.461	0.325	0.033	0.195	0.198	0.198
2	UDS_1	0.179	0.086	0.422	0.165	0.028	0.133	0.127	0.0105
	UDS_2	0.199	0.0076	0.033	0.249	0.076	0.033	0.349	0.004
3	UDS_1	0.164	0.0155	0.066	0.239	0.023	0.099	0.295	0.0118

m_v = Modulus of volume change, C_v = Coefficient of volume change, C_c = Coefficient of compressibility

Table 5: Allowable bearing capacity of different types of foundations at Thapathali and Ratnapark sites.

Foundation Type	Size, m	Depth, m	Min. SPT value	Unit wt., t/m^2	Cohesive value, t/m^2	Shearing angle, degree	Allowable settlement, mm	Allowable bearing capacity, t/m^2 Field Method	Lab Method	Design value
Thapathali										
Strip	1x1	1	7	*0.8	4.25	-	25	11.65	4.20	4.20
	1x1	2	8	*0.8	4.25	-	25	13.30	4.30	4.30
Isolated	2x2	1	9	*0.8	4.25	-	25	8.67	5.30	5.30
	2x2	2	9	*0.8	4.25	-	25	9.89	5.52	5.52
Ratnapark										
Strip	1x1	1	6	1.6		31	25	9.98	9.15	9.15
	1x1	2	6	1.6		30	25	9.98	11.83	9.98
Isolated	2x2	1	6	1.6		30	25	5.78	9.128	5.78
	2x2	2	5	1.6		30	25	6.60	13.03	6.60

* submerged unit weight

Table 6: Bearing capacity for foundation soils of different locations of the Kathmandu Valley for an isolated foundation of 2 m x 2 m sides founded at 2 m below the ground level.

Location	Minimum SPT value	Unit weight t/m^2	Cohesive value t/m^2	Allowable settlement mm	Allowable bearing capacity, t/m^2		
					Field Method	Lab method	Design value
Sundhara	9	1.60	5.00	25	19.8	17.2	17.2
Tripureswor	6	1.57	4.00	25	13.2	14.7	13.2
Kirtipur	8	1.28	4.50	25	17.6	16.2	16.2
Chovar	4	1.31	3.00	25	8.8	11.1	8.8
Kupondol	7	1.60	4.00	25	15.4	14.7	14.7
Pulchok	9	1.47	3.80	25	19.8	13.9	13.9
Jawalakhel	11	1.97	5.60	25	24.2	20.0	20.0
Hatiban	5	1.60	3.49	25	10.9	13.0	10.9
Thamel	6	1.60	4.40	25	13.2	16.1	13.2
Bansbari	9	1.60	4.60	25	19.8	16.8	16.8
Sundarijal	5	1.41	2.80	25	10.9	10.5	10.5
Kamaladi	7	1.60	4.00	25	15.4	14.7	14.7
Hatisar	8	1.60	4.00	25	17.5	14.7	14.7
Kamalpokhari	5	1.60	3.00	25	10.9	11.1	10.9
Gyaneshwor	9	1.60	5.00	25	19.8	18.2	18.2
Singhadurbar	12	1.25	5.30	25	26.4	19.8	19.8
Baneshwor	8	1.60	4.00	25	17.5	14.7	14.7
Sanothimi	9	1.60	4.50	25	19.8	16.2	14.2
Suryabinayak	4	1.60	4.00	25	8.8	10.9	10.9
Kalimati	3	1.60	3.00	25	6.6	4.0	4.0
Tahachal	6	1.60	3.80	25	13.2	13.9	13.2

Kathmandu Valley has been prepared (Fig. 5). It is found that the bearing capacity of cohesive soils of Kathmandu Valley generally increases with increase in the N value.

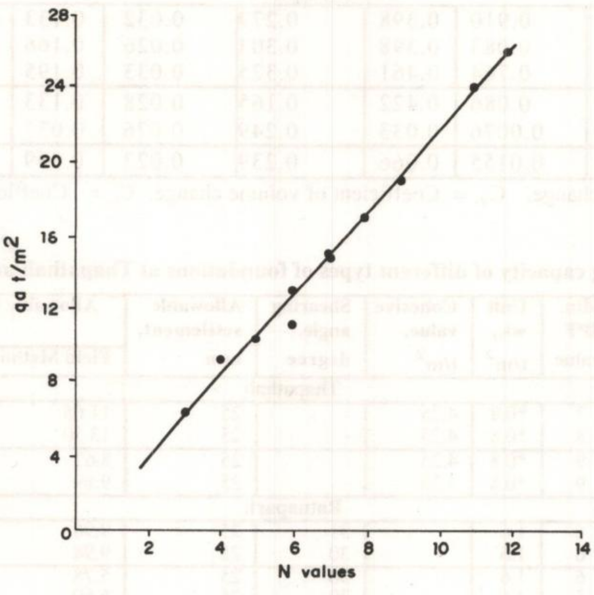

Fig. 5: Relationship between SPT value (N) Vs. bearing capacity (qa) of cohesive soils of Kathmandu Valley.

Settlement

The settlement of foundation soil of Thapathali up to a depth of 4 m below the foundation level (according to the standard practice, the settlement of the foundation soil is calculated up to a depth twice the foundation width below the foundation level) calculated for an isolated foundation of sides 2 m taking the calculated minimum allowable bearing capacity of 5.3 t/m² and also assuming the foundation soil being homogeneous. The settlement was calculated using Bowels equation (Bowels, 1988). The expected settlement was 33.00 mm (but according general practice the maximum allowable vertical settlement is limited to 25 mm for normally loaded structure assuming the foundation soil is homogeneous). Thus the recalculation of an expected settlement were carried out for a net load of 3 t/m² (selected arbitrarily on trial basis). The expected settlement obtained was 19.09 mm for a long term settlement (Table 7).

Allowable loading intensity for Thapathali soils

The calculation of the net loading intensity corresponding to the allowable settlement of 25 mm for the Thapathali soil was calculated as under:

q_a = q x (design settlement)/(actual settlement)

$$q_a = 25/19.04 \times 3.0 = 3.94 \text{ t/m}^2$$

Hence, with the addition of unloading intensity caused due to foundation excavation, the allowable loading intensity of the foundation soil is calculated as:

$$q_n = q_a + rh$$
$$= 3.94 + 0.8$$
$$= 4.74 \text{ t/m}^2$$

Table 7: Settlement analysis for Thapathali soils.

Depth below ground surface (z), m	Depth below founda-tion, m	m = b/z	n = a/z	Iz		sz t/m²			Stress due to self wt, t/m²	Settlement analysis		
				corner	centre	corner	centre	mean		mv, cm²/kg	dh, mm	settlement, s (mm) s = mv. Δp.H
0.0	0.0	0.0	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0000	0.00	0.00
0.5	0.0	0.0	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.4	0.0000	0.00	0.00
1.0	0.0	0.0	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.8	0.0000	0.00	0.00
1.5	0.5	1.4	1.4	0.2102	0.8408	0.6306	2.5224	2.6562	1.2	0.0298	500	3.96
2.0	1.0	1.0	1.0	0.1752	0.7008	0.5256	2.1024	2.3124	1.6	0.0298	500	3.45
2.5	1.5	0.8	0.8	0.1461	0.5844	0.4383	1.7532	1.9278	2.0	0.0298	500	2.88
3.0	2.0	0.7	0.7	0.1277	0.5108	0.3831	1.5324	1.6428	2.4	0.0298	500	2.45
3.5	2.5	0.6	0.6	0.1069	0.4276	0.4827	1.2828	1.4076	2.8	0.0298	500	2.10
4.0	3.0	0.5	0.5	0.0840	0.3360	0.2520	1.0080	1.1454	3.2	0.0298	500	1.71
4.5	3.5	0.4	0.4	0.0602	0.2408	0.1806	0.7224	0.8652	3.6	0.0298	500	1.39
5.0	4.0	0.4	0.4	0.0602	0.2408	0.1806	0.7224	0.7224	4.0	0.0298	500	1.10
Total settlement = 19.09 mm												

The foundation soil of Thapathali site, therefore, may be considered weak. The foundation should rest on compact material placed over the soil to achieve high density or the foundation soil should be compacted to avoid local shear failure in the foundation soil.

The soil profile at Ratnapark has sandy zone up to a depth of 5 m. As this depth lies within the foundation depth (range for normally loaded structures), the settlement analyses were not carried out.

FOUNDATION TYPES USED IN KATHMANDU VALLEY

The available bore hole data shows that the main geological units for the foundations in the Kathmandu Valley are the inhomogeneously distributed fluvio-lacustrine sediments. There are only a few areas where foundations can rest on basement rocks.

Except a few heavily loaded buildings owned by the government, semi-government and private parties, all other structures of the Kathmandu Valley have the foundation depth range of 1.0 to 1.5 m and are designed and constructed without considering the soil behavior and loading intensity. It is also observed that most of the normally loaded structures of the Kathmandu Valley are constructed over the isolated and strip type of foundations. Such types of foundations are normally adequate only for lightly loaded structures and on good soil condition. However a few buildings like Karmachari Sanchaya

Kosh (Tridevi Marg), Hotel Sakura International (Lal Durbar), Bagmati Watershed Project (Babarmahal), St. Xavier College (Maitighar), Casino Nepal (Kalimati) and Nepal Electricity Authority (New Buildings at Ratnapark) rest on mat foundations.

The available bore hole data and soil profiles show that the soils of northern and north-eastern part of the valley have better bearing capacity as compared to the central, southern and southwestern part. Broadly speaking it may be concluded that in central, southern and south western part of the valley a heavily loaded structure should preferably rest on a mat foundation.

CONCLUSIONS AND RECOMMENDATIONS

The soils of Kathmandu Valley are represented by the Quaternary fluvio-lacustrine sediments. They are composed of clayey, silty, sandy and gravely sediments. The maximum thickness of sediments is found in central and southern part of the valley. The southern, south-western and central parts of the valley are dominantly underlain by clays. The sediments show an extreme variation in the material type and soil properties.

In general the soils are weak, i.e. their bearing capacity is low and appropriate foundation techniques should be applied for heavily loaded structures. The bearing capacity of soils of the Kathmandu Valley can be tentatively estimated by the following relationship:

$q_a = 0.6 \times N$

where, q_a = estimated allowable bearing capacity of soil at explored site in t/m^2, and

N = SPT value

It is recommended that the government should make appropriate legislation to enforce detail site investigations before any engineering structural designs are approved (especially for the heavy structures).

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Annex: Representative engineering properties of the Kathmandu Valley soils.

Location	Soil Group	Depth m	Sp. gr.	NMC %	Direct shear test		Consolidation test			UC test	Density (gm/cc)			Atterberg limits		
					C, kg/cm^2	, kg/cm^2	m_v, cm^2/kg	C_v, cm^2/sec	C_c, cm^2/sec	q_u, kg/cm^2	T_w	T_d	N_c	LL%	PL%	PI%
Sundhara	OH/CH	0.0-5.00	2.54	81.40	0.5	2.80	0.0263	0.00106	0.33	0.29			1.2	62	31	31
	CL	0.0-5.00	2.45	50.77	0.03	-	0.0315	-	-	0.06			8.0	31.68	16.79	16
		5.0-10.0	2.52	50.00	0.03	6	0.0315	0.00125	0.20	0.06			14.0	38.70	19.3	19.4
		10.0-20.0	2.50	48.50	0.115	19	0.081	0.119	0.232	0.23			8.0	39.2	18.62	20.58
		>20.00	2.65	60.50	0.265	4	-	-	-	0.53			8.0	46.10	23.2	23.8
	CL-ML	10.0-20.0	2.60	42.66	0.060	6.5	0.0395	0.00413	0.120	40.12			4.0	30.8	20.7	6.10
	ML	0.00-5.00	2.65	48.55	0.18	17	-	0.00019	0.414	0.36			9.0	30.33	-	NP
		5.00-10.0	2.48	49.30	0.16	6.8	-	-	0.215	0.32			6.0	32.75	24.51	8.24
		10.0-20.0	2.60	43.92	0.1095	17.3	0.0919	0.00041	0.141	0.219			8.0	35.34	27.68	8.00
		>20.00	2.53	44.32	0.265	9.5	-	0.00517	0.13	0.53			6.0	27.65	23.27	4.38
	MH	0.00-5.00	2.65	79.91	0.31	-	-	-	-	0.62			8.0	58.0	41.0	17
		5.0-10.0	2.65	-	0.175	17	-	0.00019	0.414	0.35			12.0	60.0	39	21
		>20.00	2.45	48.59	0.295	-	0.0395	-	-	0.59			7.0	68	47.14	20.86
	CL	5.0-10.	2.54	32.61	0.41	27	0.0338	-	-	0.82	1.09	-	1.0	44.0	23.0	21.0
Tripureswor	ML	0.0-5.00	2.58	33.72	0.266	22	-	-	-	0.532	2.03	1.57	6.0	34.40	22.9	11.50
		10.0-20.0	2.66	29.87	0.1655	3.5	-	-	-	0.331	2.08	1.61	3.0	25.4	23.67	1.73
Teku	ML	10.0-20.0	-	-	0.785	-	-	-	-	1.57	-	-	6.0	40.0	29.0	11.0
Kuleswor	OH	10.0-20.0	2.52	-	0.306	-	-	-	-	0.612	-	-	3.0	59.0	20.0	29.0
Balkhu	MH	5.0-10.0	-	35.41	0.3975	-	-	-	-	0.795	-	-	4.0	56.2	31.0	24.2
Kirtipur	CL-ML	0.0-5.00	2.50	28.63	0.402	-	-	-	-	0.804	2.11	1.64	8.0	26.8	19.86	6.14
	CL	0.0-5.00	2.59	19.96	0.700	-	-	-	-	1.40	2.04	1.26	10.0	33.9	20.54	13.86
	ML	0.0-5.00	2.54	48.39	2.212	21.2	0.032	0.012	-	0.424	1.76	1.20	8.0	48.0	30.34	17.66
		5.0-10.0	2.46	68.78	0.2185	-	-	-	-	0.437	1.71	1.49	5.0	40.20	22.32	17.88
	MH	0.0-5.00	2.55	57.73	0.300	2.50	-	-	-	0.600	1.68	1.04	8.0	58.50	40.13	17.97
		5.0-10.0	2.55	66.51	0.61	-	-	-	-	1.22	1.73	1.03	7.0	51.7	30.29	29.47
Chovar	ML	0.02-5.00	2.63	36.70	0.292	23	0.0597	0.00046	-	0.584	1.71	1.31	4.0	50.1	30.84	19.26
		20.00	-	59.90	-	-	-	-	-	-	1.59	0.945	15	43.20	38.4	4.78
	MH	10.0-20.0	2.60	94.20	0.605	38	-	-	-	1.210	1.60	0.85	26	83.0	28.58	54.42
		20.0	-	71.30	-	-	-	-	-	-	1.59	0.92	14	63.0	45.96	17.04
Kupondole	CL	0.0-5.0	2.62	60.8	0.515	-	1.03	-	0.44	1.03	1.61	-	10.0	29.5	20.4	9.1
	ML	0.0-5.00	2.63	-	0.35	-	-	-	0.40	0.70	1.68	-	5.0	42.3	24.8	17.5
		10.0-20.0	2.65	74.25	0.47	-	0.84	-	0.66	0.94	-	-	4.0	39.8	24.4	15.4

Location	Soil Group	Depth m	Sp. gr.	NMC %	Direct shear test		Consolidation test			UC test	Density (gm/cc)			Atterberg limits		
					C, kg/cm^2	, kg/cm^2	m_v, cm^2/kg	C_v, cm^2/sec	C_c, cm^2/sec	q_u, kg/cm^2	T_w	T_d	N_c	LL%	PL%	PI%
Pulchok	CL-ML	0.0-5.00	2.60	28.9	0.26	-	-	-	-	0.52	1.98	1.43	10.0	30.7	24.0	6.7
		5.0-10.0	2.62	31.25	0.05	10	0.0031	0.0008	-	0.10	1.91	1.48	5.0	22.8	25.27	7.53
		10.0-20.0	2.63	38.0	-	-	-	-	-	-	-	-	5.0	23.81	16.33	7.48
		>20.0	2.63	-	-	-	-	-	-	-	1.92	1.46	-	28.4	21.91	6.49
	CL	0.0-5.00	2.66	34.18	0.31	-	0.0008	-	-	0.62	1.97	1.49	9.0	30.72	21.91	8.81
		10.0-20.0	2.63	35.73	-	-	-	-	-	-	1.82	1.34	6.0	25.35	15.74	9.26
		>20.0	2.62	92.68	0.25	5	0.074	0.0008	-	0.5	1.68	0.98	4.0	24.90	15.63	11.31
	ML	0.0-5.0	2.50	34.63	0.49	36	-	-	-	0.98	1.97	1.51	10.0	27.0	22.0	5.0
		5.0-10.0	2.52	35.22	0.265	10	0.074	'0.0024	-	0.53	1.92	1.57	7.0	30.0	23.0	7.0
		10.0-20.0	2.60	44.40	-	-	-	-	-	-	1.75	1.34	6.0	42.0	30.0	12.0
	MH	10.0-20.0	2.60	34.70	-	-	-	-	-	-	-	-	3.0	53.65	38.45	15.20
Jawalakhel	CL	5.0-10.0	2.60	14.80	-	-	-	-	-	-	-	-	15.0	40.0	24.0	16.0
	ML	0.0-5.0	2.63	16.60	0.56	-	-	-	-	0.12	2.77	1.97	11.0	29.0	27.0	2.0
Hatiban	CL	0.0-5.0	-	43.75	0.349	-	-	-	-	0.698	-	-	4.0	45.0	26.0	19.0
	ML	0.0-5.1	-	74.67	0.349	-	-	-	-	0.698	-	-	6.0	48.0	39.0	14.0
		10.0-20.0	-	74.72	0.351	-	-	-	-	0.698	-	-	6.0	48.0	29.0	19.0
Thamel	ML	0.0-5.0	-	19.07	0.44	-	-	-	-	0.880	-	-	6.0	40.0	27.0	13.0
Baluwatar	MH	10.0-20.0	2.57	53.30	0.3725	30.2	0.032	0.00013	-	0.745	1.68	1.09	4.0	45.0	36.5	8.4
		>20.0	-	75.40	0.405	18	0.10	0.0012	-	0.81	1.57	0.98	4.0	35.7	25.0	10.5
Bansbari	ML	0.0-5.0	2.59	32.87	0.46	24.25	0.468	0.0002	-	0.92	1.85	1.41	9.0	39.20	27.51	6.69
	MH	5.0-10.0	2.60	88.04	-	-	-	-	-	-	-	-	-	52.0	31.0	21.0
Sundarijal	CL	5.0-10.0	2.61	19.0	0.35	-	-	-	-	0.7	1.09	-	2.0	28.0	17.0	11.0
	ML	0.0-5.0	2.64	29.03	0.28	34	-	-	-	0.56	1.86	-	5.0	42.6	26.0	16.0
Kamaladi	MH	0.0-5.0	2.51	33.0	0.42	-	-	-	-	0.80	1.67	-	7.0	52.0	30.0	28.0
Hatishar	OL	0.0-5.0	-	-	0.395	-	0.175	-	-	0.79	-	-	7.0	38.2	19.5	18.7
	CH	0.0-5.0	-	54.3	0.395	27	0.17	-	-	0.79	-	-	10.0	58.3	31.2	26.1
	MH	0.0-5.0	-	-	-	-	-	-	-	-	-	-	6.0	51.0	32.0	19.0
Kamalpokhari	CL	0.0-5.0	-	-	0.23	-	-	-	-	0.46	-	-	5.0	42.0	16.0	26.0
	CH	0.0-5.0	-	-	0.36	-	-	-	-	0.72	-	-	5.0	62.0	35.0	27.0
	MH	0.0-5.0	-	-	0-25	0.36	-	-	-	0.51	-	-	7.0	56.0	41.0	15.0
		10.0-20.0	-	-	-	-	-	-	-	-	-	-	14.0	53.0	39.0	14.0
Gyaneswor	ML	0.0-5.0	2.65	21.10	0.46	-	-	-	-	0.32	'-	-	11.0	45.0	37.0	8.0
		5.0-10.0	2.65	-	0.30	-	-	-	-	0.92	-	-	6.0	46.0	34.2	11.8
	MH	0.0-5.0	2.65	50.85	0.606	-	-	-	0.13	1.212	1.79	1.25	7.0	63.0	38.0	25.0
		5.0-10.0	3.65	45.10	-	-	0.54	-	0.23	-	1.69	1.17	-	72.0	49.0	23.0

Location	Soil Group	Depth m	Sp. gr.	NMC %	Direct shear test		Consolidation test			UC test	Density (gm/cc)			Atterberg limits		
					C, kg/cm^2	, kg/cm^2	m_v, cm^2/kg	C_v, cm^2/sec	C_c, cm^2/sec	q_u, kg/cm^2	T_w	T_d	N_c	LL%	PL%	PI%
		0.0-5.0	2.62	38.35	0.556	-	-	-	-	1.112	-	-	10.0	31.68	16.79	15.0
	CL	5.0-10.0	2.67	54.23	0.061	-	-	-	-	0.123	-	-	-	34.25	9.91	24.34
		10.0-20.0	2.60	-	-	-	-	-	-	-	-	-	-	48.45	17.19	31.26
	CH	10.0-20.0	2.60	60.54	-	-	-	-	-	-	-	-	-	55.0	32.0	23.0
		0.0-5.0	2.59	51.73	0.48	-	-	-	-	0.96	-	-	14.0	42.0	26.0	16.0
Singhadurbar	ML	5.0-10.0	2.62	36.53	-	-	-	0.00086	0.30	-	-	-	14.0	44.0	32.0	12.0
		10.0-20.0	2.60	45.34	1.115	-	0.00028	0.00054	0.154	-	-	-	13.0	50.0	35.0	15.0
		5.0-10.0	2.48	77.51	-	-	-	-	-	-	-	-	-	60.0	39.0	21.0
	MH	10.0-20.0	2.55	60.82	-	-	-	-	-	-	-	-	-	60.5	39.5	21.0
		>20.0	2.55	55.70	-	-	-	-	-	-	-	-	-	68.0	47.14	20.86
	CL	0.0-5.0	2.63	73.53	0.36	-	-	-	-	0.73	1.55	-	9.0	'32.0	24.0	8.0
		5.0-10.0	2.63	66.11	0.406	-	-	-	-	0.812	1.74	-	9.0	33.0	24.0	9.0
Baneswor	ML	0.0-5.0	2.65	67.60	0.50	-	-	-	-	0.02	1.47	-	5.0	45.0	31.0	14.0
		5.0-10.0	2.72	84.37	0.91	-	-	-	-	1.82	-	-	-	40.0	27.0	13.0
	CL-ML	0.0-5.0	-	-	-	-	-	-	-	-	-	-	10.0	25..0	20.0	5.0
	MH	5.0-10.0	2.69	71.05	-	-	-	-	-	-	1.38	-	36.0	51.0	34.0	17.0
Koteswor	OH	5.0-40.0	2.47	-	-	-	-	-	-	-	-	-	4.0	58.0	36.0	22.0
	OH	10.0-20.0	-	50.80	-	-	0.36	-	-	-	1.38	0.49	17.0	60.2	32.5	27.8
Gothatar	MH	5.0-10.0	2.65	53.36	0.3875	-	-	-	-	0.775	1.58	1.03	'19.0	68.0	45.0	23.0
		10.0-20.0	2.63	55.55	0.4925	-	-	-	-	0.985	1.50	0.80	25.0	64.0	47.0	17.0
Sanothimi	CL	5.0-10.0	-	46.80	0.335	-	0.34	-	-	0.67	-	-	-	36.0	22.0	14.0
	CH	5.0-10.0	-	48.70	0.5	11	0.5	-	-	1.0	1.66	1.08	4.0	53.0	29.0	24.0
Hamumante	ML	10.0-20.0	-	37.40	0.42	10	0.67	-	-	0.84	1.73	1.19	2.0	40.0	30.0	10.0
	MH	0.0-5.0	-	68.0	0.32	-	0.31	-	-	0.64	-	-	9.0	52.0	'33.0	19.0
		10.0-20.0	-	41.90	0.45	10.5	0.34	-	-	0.9	1.72	1.13	4.0	64.0	30.0	28.0
	CL-ML	0.0-5.0	2.59	24.88	0.42	34	-	-	-	0.84	1.80	1.48	6.0	23.74	18.90	5.29
Suryabinayak	CL	0.0-5.0	2.61	32.43	0.425	42.3	-	-	-	0.85	1.92	1.45	2.0	28.3	15.2	13.1
	ML	0.0-5.0	2.62	36.0	0.42	35.5	0.259	0.021	-	0.84	1.37	1.25	4.0	23.5	19.79	3.71
		0.0-5.0	2.50	54.36	0.31	4	-	-	-	0.62	-	-	-	46.21	23.0	23.21
	CL/OL	5.0-10.0	-	50.0	-	-	0.009	0.006	0.37	-	-	-	4.0	39.5	19.8	19.7
		>20.0	-	53	-	2	-	-	-	-	-	-	-	'49.2	21.0	28.0
		0.0-5.0	2.56	84.01	0.42	2.5	-	-	-	0.84	-	-	2.0	62.0	33.0	27.0
	CH/OH	5.0-10.0	2.73	-	-	6.7	-	-	0.14	-	-	-	-	72.1	40.2	31.9
Kalimati		10.0-20.0				-			-	-	-	-	-	68.52	31.31	37.21
		>20.0	-	-	-	8	-	-	-	-	-	-	-	52.1	26.8	26.3
	ML	0.0-5.0	2.65	52.73	0.30	-	0.0073	-	0.60	0.95	1.61	-	3.0	48.0	30.0	18.0
		5.0-10.0	2.59	50.0	-	-	-	-	0.36	-	1.704	-	6.0	40.0	27.0	13.0
	MH	0.0-5.0	2.62	61.30	0.481	-	0.00054	-	0.32	0.962	-	1.69	4.0	57.0	34.0	23.0
		5.0-10.0	-	77.04	0.323	-	0.00015	-	0.079	0.646	1.61	1.56	-	60.0	32.0	28.0
	CL	0.0-5.0	-	39.0	0.36	-	-	-	-	0.72	1.63	-	6.0	38.0	16.0	22.0
Tahachal	ML	0.0-5.0	-	35.0	0.41	-	-	-	0.66	0.82	-	-	6.0	40.0	28.0	12.0
	MH	5.0-10.0	-	42.50	-	-	-	-	-	-	-	-	7.0	51.0	32.0	19.0

NMC = Natural moisture content, C = Shear strength, ø = Shear angle, Mv = Modulus of volume change, Cv = Coefficient of volume change, Cc = Coefficient of compressibility, q_u = Unconfined compressive strength, Tw = Wet density, Td = Dry density, Nc = In situ density, LL = Liquid limit, PL = Plastic limit, PI = Plasticity index.