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Stress-Strain and Strength Behavior of Undrained Organic Soil in Kupondol, Kathmandu

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Abstract: The Kathmandu valley is mostly composed of an organic layer locally known as Kalimati, meaning black soil in Nepali. In spite of the unsuitability of organic soil as foundation subsoil, due to its high compressibility and low strength, many civil engineering structures (i.e. residential buildings and high-rise commercial buildings) are being built at an alarming rate. Even more alarming is the fact that no systematic and comprehensive studies have ever been conducted on the geotechnical properties of this highly problematic soil deposit. Geotechnical investigations that have been performed for construction projects, including those structures whose foundation lies on Kalimati soil, typically contain data on general properties of the soil and only to some extend the consolidation and the shear parameter obtained from unconfined compression tests and direct shear tests. As the local name indicates, these soils are black in color, having a high water content and high liquid limit and they are hard when dry but soft when wet. The organic soil is found at different depths and different thicknesses. Sometimes it exists too deep to have a significant effect on the foundation. In many areas it exists at a shallow depth with significant thickness, thus having considerable effect on the foundation of the structure above it. While existing data provides useful information for the design of foundations, almost no data exists on the undrained behavior of the soil, which foundation design on this type of soil should be based on. There is a serious need for research work related to behavior of undrained organic soil deposits in the Kathmandu. Specifically pore pressure, shear strength and stress-strain characteristics, especially under triaxial compression.

Key Words: Organic deposit, foundation, engineering properties, Kalimati, geotechnical investigation

1. Introduction

Kathmandu Valley is located in the central part of Nepal which stretches 30 km. in east –west and 25 km in north –south directions covering an area of about 650 km^2. The soil in the Kathmandu Valley is originated mainly from rocks within the watershed boundary. They are in most part lacustrine and fluvial in origin and composed of clay, silt, sand and gravel sediments. The maximum thickness of sediment above the bed rock was found to be 550 m in Bhrikutimandap and greater than 475 m at Harishidhi [1].

2. Formation of Organic Soil

Organic deposits generally come into existence during the forming of lake deposits in the Kathmandu Valley. Most of the lacustrine deposits are fine grained material deposited on the lake bottom. Silt and clay size particle eroding from the nearby watersheds were deposited in the lake over a long time. As lake level rose and fell plant life around the edges increased. Rotting vegetable matter and decay of dead animals produced organic colloids that were deposited with silt and clay to form organic soil. If vegetable matter is not decayed completely and is present in the soil in the form of fibre or other forms, the soil is known as peat.

3. Definition of Organic Soil

Organic soils are soils whose physical properties are highly influenced by the presence of even a small amount of organic matter. Organic soils are generally weaker and more compressible than soils having the same mineral composition, but without organic matter. They generally posses lower density, higher water content and a higher liquid limit than inorganic soils. The presence of organic matter can usually be recognized by a dark to black colour, bad odor and some form of decaying material, especially when the organic content is higher. The grain size of organic soils are usually silt or clay size, therefore they are usually defined as organic silts or organic clays.

Different standards with different criteria are available to distinguish organic soils from inorganic soils [2] [3] [4]. According to the Unified Soil Classification system, a soil is classified as organic if it falls below the A line of Casagrande's plasticity chart [5]. Soils with a liquid limit higher than 50 % are known as high plasticity silt or clay and soils with a liquid limit less than 50 % are known as low plasticity silt or clay. The existing soil classifications are hampered by the lack of standardized methods for determining the organic matter content. The loss on ignition method, hydrogen peroxide oxidation method and the Tiurin method of potassium bichromate oxidation are most frequently employed [6]. The ignition method consists of numerous sources of error. Soil with high sulphide content may show a high loss on ignition and may be classified as organic soil even though the organic content is low.

Geotechnical Problems Associated with Organic Soil

A number of geotechnical problems have been associated with organic soils. These problems range the full spectrum of geotechnical work, starting from the first stage of investigating the soil (i.e. undisturbed sampling), to inherent engineering problems such as low bearing capacity and high compressibility.

Engineering Properties of Organic Soil in Kathmandu Valley

Until now, geotechnical investigations were generally limited to the determination of the Atterberg limit, water content, bulk density, specific gravity, unconfined compressive strength and direct shear. These tests have shown that the unconfined compression strength of organic clay is generally 4.4-9.5 t/m^2.

Table 1: Summary of Different Properties of Organic Soil in Kathmandu Valley

Location	Bore hole	Depth(m)	Soil Type	LL	PL	Unconfined compression strength t/m^2)	Direct Shear		Remarks
							C	Ø	
		6.00		62	43.96	-	-	-	Central Material Testing Laboratory Report
	1	9.00	OH	75	66.74	9.5	2.7	26.5	
		12.00		92	63.33				
Balkhu	2	6.00	OH	54.5	32.98	-	-	-	
		10.50		94.3	64.14	-	-	-	

Location	Bore hole	Depth(m)	Soil Type	LL	PL	Unconfined compression strength t/m^2)	Direct Shear		Remarks
		13.50		112.1	55.84	-	-	-	
	3	6.00	OH	77.5	53.97	-	-	-	
		9.00		76	52.70	-	-	---	
		12.00		68	42.07	-	-	-	
	4	9.00	OH	103	68.97	-	-	-	
		12.00		88.5	51.94	-	-	-	
	5	6.00	OH	-	-	5.45	1.9	18.0	
		7.50		66.25	40.83	-	-	-	
		9.00		63.50	26.23	-	-	-	
		10.50		58.46	39.46	-	-	-	
		15.00		80.00	46.49	-	-	-	
	6	3.00	OH	86.00	55.88	6.57	2.20	27.7	
		4.50		70.00	47.36	-	-	-	
		6.66		72.75	54.21	-	-	-	
		9.00		68.40	46.67	-	-	-	
		12.00		81.00	55.40	-	-	-	
Bhakatapur	1	3	MH	69	53.28	5.5	1.8	10	
	2	3	MH	132.5	116.01	4.42	0.8	18.75	
Koteswor	-	5-40	OH	58	36	-	-	-	T.P Katel
Gothatar	-	10-20	OH	66.2	32.5	-	-	-	
Kalimati	-	0-5	CH/OH	62	33	8.40	-	-	
Kuleshowr	-	10-20	OH	59	20	6.12	-	-	

4. Results and Discussion

During their thesis work, Ramesh Neupane and Sujit Dhital, students of the M.Sc. Geotechnical Engineering program at IOE Pulchowk Campus, have studied the properties of organic soils, taking the samples from Kopundole, near the Bagmati Bridge. General properties of the samples are based on Neupane's study. The samples, except at depth ~2m, were found to be homogenous with no inter bedded band. All samples can be categorised as OH or MH according to USCS. The sample at ~2m depth had an inter-bedded layer of coarser particle in center compared to the periphery.

The soil tested is fine grained, with nearly 75% silt and 25% clay sized particles. Organic content was determined by loss on ignition method per ASTM D 2974. Organic content, 8.3-13.07%, increased with depth. Soil with organic content in this range can be categorised as organic soil, and specifically it is medium organic clay [7]. Specific gravity, 2.14-2.33, is a maximum at ~2m depth and decreases onward. From the data it can be concluded that soil with high organic content has a low specific gravity. The water content, 94-145%, increased with depth up to ~8m and then decreased with additional depth. The increase in water content does not follow a trend but the decrease follows a linear trend. Neupane also determined the liquid limit, plastic limit and plasticity index after different methods of drying: oven dried, air dried and natural condition. In all cases, the maximum value of the Atterberg limit was found at ~6m depth and minimum the value at ~2m depth. The Atterberg limit at any depth is higher in case of the natural sample and lower in the case of the oven dried sample. Neupane also performed a series of one dimensional consolidation tests on samples from different depths. It was found that the soil was normally consolidated up to 2.5m depth and overconsolidated onward. The wet density is 1.28-1.55 gm/cm^3 and the dry density, is 0.57-0.96 gm/cm^3.

Unconsolidated Undrained Test Result

Dhital performed a series of unconsolidated undrained tests in order to determine the variation of the undrained shear strength with depth. Two samples from each depth were sheared under the confining pressure of 206 and 414 kN/m^2.

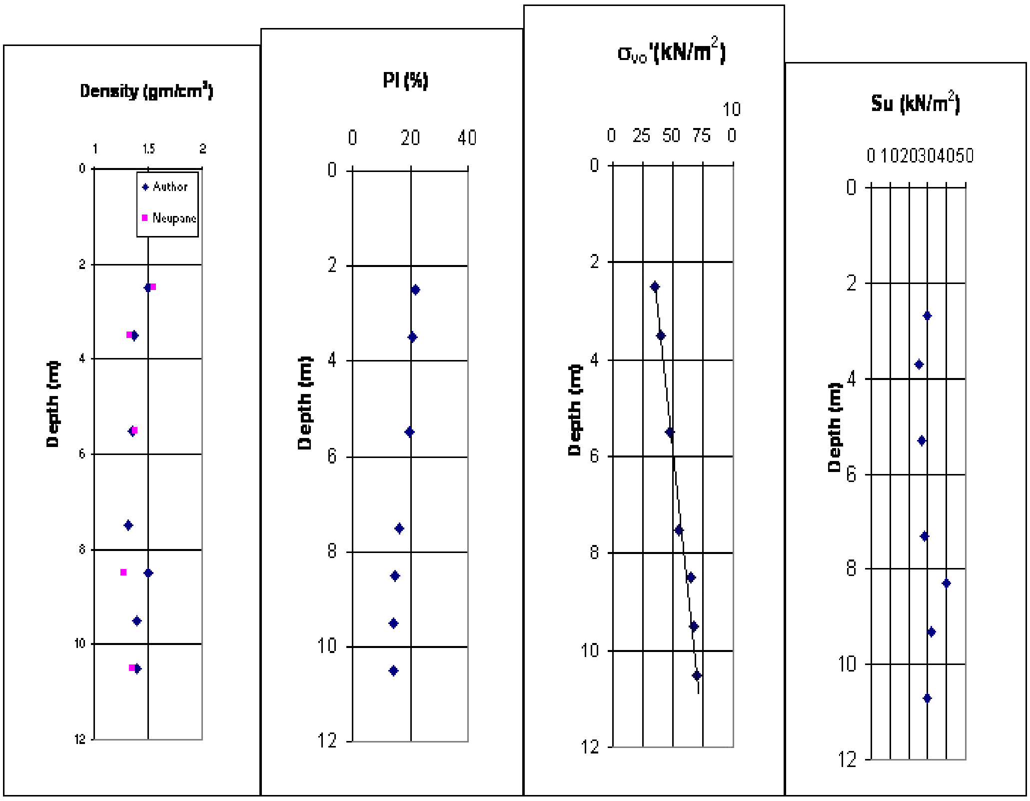

Figure 1: Variation of undrained shear strength of soil with depth.

The undrained shear strength shows a linear variation with the depth, except in the data points at ~2m and ~8m. The ~2m depth deviation is probably due to the fact that it was obtained at the boundary between the upper fine grain soil layer and the lower organic soil layer. This sample was observed to be more silty compared to samples from a greater depth. The ground water fluctuation at the site, found at ~2m depth, may also cause the apparent consolidation on the soil. The higher strength of the soil at ~8m depth may be due to the nature of deposition and the higher density of the sample.

Stress – Strain and Pore Pressure Relationship

The maximum deviator stress was found at a strain of 5-7% in the case of the normally consolidated samples, in the over consolidated samples it is 10-12%. Overall strain at the maximum deviator stress decreases with an increase in confining pressure. The normally consolidated sample shows a faster decrease in the deviator stress after reaching the maximum peak value, while the over consolidated sample shows smaller strain softening. This trend is opposite to the normally observed trend in other fine grained soils. The pore pressure increases with strain even after the maximum deviator stress has been reached. This trend is similar to that of sensitive clay.

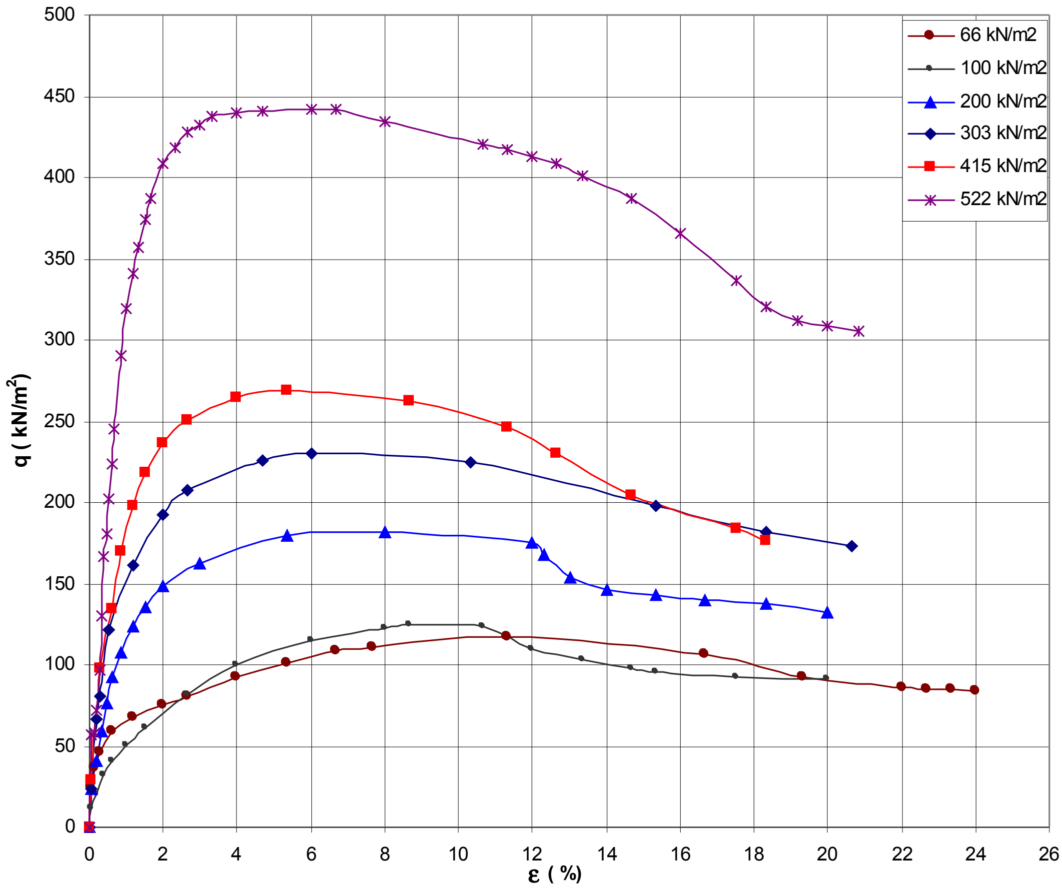

Figure 2: Stress-Strain Curve by Confining Pressure

Stress Ratio – Strain Relationship

For samples with confinging pressure greater than or equal to 200 kN/m^2, the stress ratio and strain plots show normalised behaviour (i.e. they merge to a single curve). Samples under confining pressures of 66 and 100 kN/m^2 do not show a similar trend to the normally consolidated samples, as the curve deviates significantly from the normalised curve. For the normally consolidated samples, the normalised stress ratio–strain behavior means that the shear strain is only a function of stress ratio and is irrespective of the consolidation pressure.

The strength of the unconsolidated undrained sample was found to increase with depth except for value at ~2.5m depth. A linear relationship between su/σ_{vo} and plasticity index is proposed based on the plot of su/σ_{vo} and PI , shown in Figure X.X - X.X.

Normally Consolidated Samples

In the normally consolidated range, the soil was found to behave in a normalised manner. The samples exhibit a curvilinear stress path that moves to the left of the (q,p) plot. The deviator stress increases with an increase in consolidation pressure. The strain at failure is within the range of 5-7 %, which decreases with an increase in consolidation pressure. The deviator stress after failure decreases with the increase of strain. The pore pressure however is found to increase with the continued increase in strain. The slope of the line joining the maximum deviator stress (M*) is 1.2. The friction angle is 17^{o} and 32^{o} for total and effective stress failure envelope, respectively. The cohesion is 40.9 and 53.8 for the total and effective stress condition, respectively. A linear relation between the normalised pore pressure and the stress ratio was obtained and the slope of the line, defined as pore pressure coefficient, is 0.5.

Overconsolidated Samples

The samples in the overconsolidated range have a concave stress path after reaching the peak deviator stress, and they form loops with the stress path. The strain at the maximum deviator stress is higher than that of the normally consolidated samples, and the overconsolidated samples do not show a normalised behavior. The overconsolidated samples with the same void ratio exhibit a maximum deviator stress which decreases with increasing overconsolidation ratio. The strains at the maximum deviator stress increase with the increase of OCR. The u/p_o vs η plot is bilinear, though the transition between the two straight lines is not as well defined as other soils, like Bangkok clay. The slope of the second line is approximately parallel to that of the normally consolidated sample sheared under the same void ratio. In shifting the (u/p_o, η) graph, the normally consolidated path provides a boundary for the overconsolidated path.

Isotropic Consolidation

The maximum past pressure determined for the isotropically consolidated sample is 200 kN/m^2 with λ=0.302 and κ=0.019, determined in (e,lnP) plot .

5. Conclusion

It is obvious that the research has a limited scope. Therefore, there is not sufficient data to extrapolate the findings to all organic soils in the Kathmandu valley. Nevertheless, important parameters regarding the strength characteristics of the soil have been established and they can be recommended for use as reference data in the preliminary design of foundations on such soils. Additionally, regular research mujst be conducted for detailed investigation of the subsoil in Kathmandu valley.