GEOTECHNICAL INTERPRETATION OF SOIL FOR THE PROPOSED UNDERGROUND UTILITY TUNNEL FROM KURIL TO MALIBAGH IN DHAKA CITY

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Abstract— For the proposition of establishment of upcoming 7.7 km common utility tunnel under Progoti Sarani in Dhaka between Kuril flyover and Malibagh Chowdhurypara, Dhaka North City Corporation (DNCC) has stepped forward to complete a feasibility study report accumulating all soil test data around Dhaka city found from different secondary organizations. Besides that, four boreholes to a depth of about 30m each were drilled at different locations and consequent laboratory tests are also done as per the requirement. In that perspective, a new aspect of geological and geotechnical site of Dhaka city soil profile is prepared based on those primary and secondary data focusing a single part of city from Kuril to Malibagh. The prepared soil profile is compared with the geomorphological map of Dhaka city published by Geological Survey of Bangladesh (GSB) and found that most of the soil in Dhaka city is of Madhupur terrace (clayey silt and silty clay) of Pleistocene era. The range of liquid limit of maximum data in the project is between 40 and 60, plasticity index is greater than 4 and limit values between 'A' line [0.73(LL-20)] and 'U' line [0.9(LL-8)] of plasticity chart, so the soil criteria will be CL (Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays) and CH (Inorganic clays of high plasticity, fat clays). The soil is found Over Consolidated Clay (OCC) because in most of the cases natural water content (W) is close to Plastic limit (PL). Most of the clay minerals are found Illite and Kaolinite which is classified between Inactive and Normal clays (Activity ratio, A = 0.38 to 0.90) which means that there may be no significant swelling and shrinkage characteristics in the project area along with changing of water contents as well as the possibility of structural damage is also negligible. But a matter of concern is that in some points soils are collapsible according to plasticity index. Results of chemical analysis indicate that the sub-soils are not aggressive to concrete and not corrosive to reinforcement steel.

Index Terms— Dhaka City, Geotechnical Interpretation, Subsurface Soil Profile, Soil Properties.

I. INTRODUCTION

Dhaka, the capital of Bangladesh, has a history of 400 years of trade and commerce as the main center point of British, India and East Pakistan. In present, different service providers are working to meet the basic requirements of water, sewerage, storm water, electricity, telephone, gas etc of almost 16 million citizens in this over populated mega city. Despite of having big organizations, public are always facing rapid cutting and digging in major transportation riding roads almost in every area throughout the year for the maintenance and rehabilitation works of service lines. As these agencies do not have sufficient plans of existing service lines and also these lines are laid in unplanned way, public sufferings and misuse of public funds are increasing day by day. In order to mitigate this disorder and for effective management, Dhaka North City Corporation (DNCC) had taken the initiation to accumulate all utility lines and organize them into one common secured utility tunnel/ duct under the road/ footpath. DNCC has already selected Development Design Consultants Ltd. (DDC) as the responsible consulting firm to conduct a comprehensive feasibility study report for the selected road segment of Progoti Sarani (From Kuril Flyover to Malibagh Chowdhurypara, approximate length 7.70km) as a pilot basis. In this regard, preliminary geotechnical investigation has done to interpret that if the soil is viable to construct the tunnel or not. This investigation was done based on four bore holes tests, collection of secondary soil tests data, collection of data from Geological Survey Bangladesh (GSB) and calculations depending on prospective references. The outcome of this study will focus on longitudinal soil profile of the selected area drawn in respect with the collected soil data and the characteristics of soil along the project area in terms of engineering properties.

II. METHODOLOGY

- Drilling of four boreholes to a depth of about 30m each along the proposed tunnel alignment and performing subsequent laboratory tests
- Collection of relevant data from secondary sources in the form of borehole logs and test results
- Building up a reliable subsurface profile along the proposed alignment based on soil tests data
- Collection of relevant data from GSB and compare these with the findings of investigation
- Identification of soil characteristics based on the engineering properties

III. INTERPRETATION AND ANALYSIS

- *Primary Data Collection from test borings*

Four boreholes specified by DNCC were drilled to a depth of about 30m (30.45m in exact) each were carried out along the proposed tunnel alignment covered the total length from Kuril intersection to Malibagh Chowdhurypara.

Table i: Location of boreholes

Borehole No.	**Location**
BH-01	Near Notun Bazar, Gulshan
BH-02	Near Rampura Bridge
BH-03	Near Rampura Bazar
BH-04	Malibagh Chowdhurypara

Tests adopted for these boreholes are mentioned below:

1. Standard Penetration Test (SPT)
2. Sampling of disturbed and undisturbed soils
3. Ground Water measurement
4. Laboratory Work
   a. Physical tests on disturbed and undisturbed soil samples- grain size analysis by sieve and hydormeter, Atterberg limit test, Specific gravity test, Natural water content determination
   b. Mechanical tests on disturbed and undisturbed soil samples- Unconfined compression test, Consolidation test, Dry and wet unit weight soil.

- *Secondary Data Collection*

Apart from the four boreholes drilled for the purpose of this study, the data from other boreholes of some other projects located along Progoti Sarani were collected from secondary sources and a sub-surface soil profile was built up with the help of these data.
The other projects from which the data were collected are as follows:

1. Kuril flyover project
2. JW Marriot Hotel, Baridhara
3. Jamuna Future Park, Baridhara
4. De Mazenod Church, Nayanagar
5. Rupayan Millennium Square, UttaraBadda
6. Commercial Building of ME Consortium at 95/C, ProgotiSarani, MaddhaBadda
7. South U-Loop at Progoti Sarani near BTV centre
8. Rupayan Kamaruddin tower, Chowdhurypara, Malibagh

- *Longitudinal soil Profile Establishment*

Based on these primary and secondary data, a longitudinal profile was drawn and from that profile an approximate view of the geology of the project area was expressed.

From previous investigations for the soil of Dhaka Metropolitan City it can be declared that, Bangladesh can be divided into three physiographic units namely, (i) the tertiary hill formations, (ii) the Pleistocene terrace, and (iii) the recent flood plains.

Nearly 85 percent of Bangladesh is underlain by quaternary sediments consisting of deltaic and alluvial deposits of the Ganges, Brahmaputra and Meghna rivers and their numerous tributaries. According to the study of Morgan and McIntire (1959), there are two major areas of Pleistocene sediments, commonly known as the Madhupur tract and Barind tract. Dhaka is situated on the southern tip of a Pleistocene Terrace, called the Madhupur tract. Two characteristics units cover the city and surroundings, viz. Madhupur clay of Pleistocene age and alluvial deposits of recent age.
Now from the proposed soil profile of the project area and in comparison with the Geomorphologic Map of Dhaka City published by GSB, up to Rampura Bridge Madhupur Terrace (high) are found. Some major findings from the soil profile are that the soils are mostly clayey silt/ silty clay and consolidated. Moreover, from Kuril flyover to Notunbazar, it has been observed from produced soil profile that up to approximately 20m there is the first layer of clayey soil and at places thin layers of fluvial silt are focused.

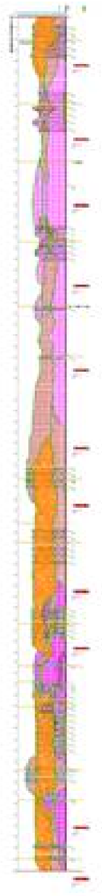

Fig. 1: Soil Profile

From Kuril flyover to Nadda, the second layer is of approximately up to 30m silty soil and from Kuril flyover to Jamuna Future Park area the last layer is recognized as sand. From Nadda to Notun Bazar a huge layer of clay is observed. But after Notun Bazar to South Badda, a layer of stiff silt is prominent from the depth of approximate 15m to 25m. From South Badda to link road, the main point of attention is after finding a silty soil layer upto 13.5m, only sand layer is observed below. There is a slight problem having a 3m layer of rubbish materials in Merul Badda, near Rampura Bridge and South U-Loop region. In Badda beneath the organic layer, up to 25m clay and silt are mostly governed again. Near Rampura Bridge, the clay is the governing one in the whole soil profile though there is also a layer thickness of 3m stiff silt from the depth of 22.5m. From South U Loop to Malibagh Chowdhurypara up to about 15m, clay and silty soils are found layer by layer. The last layer of sand with high SPT value is found from Rampura Bridge to Malibagh Chowdhurypara till end of testing location. Point to be noted is the soil profile along the alignment is found to be approximately similar to the morphological map of Bangladesh issued by GSB.

- *Identification of Soil Characteristics:*
- *Soil Type based on Atterberg Limit*

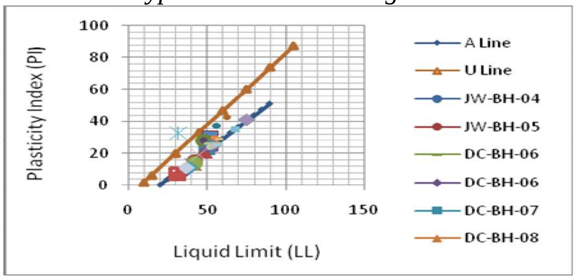

Fig. 2: Plasticity Index vs Liquid Limit

*JW-JW Marriot
DC-De Majenod Church

According to Unified soil classification by Casagrande in 1948, for soils plotting nearly on "A" line it should be used dual symbols, i.e., IP =29.5, LL=60 gives CH-OH or CH-MH and when LL is near 50 CL/CH, ML/MH should be used.

Here W = Natural water content, LL= Liquid limit, PL = Plastic limit, CH = High plastic clay, CL = Low to medium plastic clay, ML = silty or clayey fine sands, or clayey silts with slight plasticity, MH = fine sandy or silty soils or elastic silts, IP = Plasticity index.

From the available data of Atterberg limit test, Liquid limit vs Plasticity index are plotted in the graph. From the graph, we can conclude to the point that, range of liquid limit of maximum data is between 40 and 60, plasticity index is greater than 4 and limit values between 'A' line [0.73(LL-20)] and 'U' line [0.9(LL-8)] of plasticity chart. So the soil criteria will be CL and CH.

- *Soil Type based on Consolidation*

Consolidation is an important property of soil. From studying the consolidation property [6], over consolidation clay is found in maximum locations.

Table ii: Soil Type based on consolidation property for different moisture content

Condition	Soil Type
W Close to LL	Soil is Normally Consolidated
W Close to PL	Soil is Some to Heavily over consolidated
W is intermediate	Soil is somewhat over consolidated
W > LL	Soil is on verge of being a viscous liquid.

Table iii: Soil types of different locations based on moisture content

Sample	Approx. Chainage	Depth	LL	PL	W	Soil type
JW-BH-05	800-900	23	42	27	22	OCC
DC-BH-06	2200-2400	6	55	26	23.57	OCC
RM-BH-01	3350-3450	5.94	52	22	25.51	OCC
DDC-BH-01	2900-3000	2.6	53	28	21.3	OCC
DDC-BH-02	5700-5900	13.5	54	29	46.1	NCC
DDC-BH-03	6500-6700	21	45	26	18	OCC
DDC-BH-03	6500-6700	25.5	29	20	19.3	OCC
DDC-BH-04	7600-7800	2.6	58	29	22.3	OCC

*RM-Rupayan Millennium Tower
DDC-Development Design Consultant
BH- Bore Hole

From the geological map and from our test results, it was found that this soil formed during Pleistocene era and this soil has been in compressed situation for a long time which causes over consolidated or pressurized state.

- *Activity of Clay Minerals*

Clay minerals are produced mainly from the chemical weathering and decomposition of feldspars, such as orthoclase and plagioclase, and some micas. They are small in size and very flaky in shape. Clay minerals are very common in soils, in fine-grained sedimentary rocks such as shale, mudstone, and siltstone and in fine-grained metamorphic slate and phyllite. Clay minerals are usually (but not necessarily) ultrafine-grained (normally considered to be less than 2 micrometres in size on standard particle size classifications) and so may require special analytical techniques for their identification and study.

The key to some of the properties of clay soils, e.g. plasticity, compressibility, swelling/shrinkage potential, lies in the structure of clay minerals.

Clay minerals mainly include the following groups:

- Kaolinites
- Illites
- Montmorillonites

According to Soil Expansion Potential (ASTM D-4829) Atterberg Limits and clay content can be combined into a single parameter called Activity. Skempton (1953) defined the term as follows:

$$A = \frac{PI}{F} \qquad (1)$$

Where A=activity of soil, Ip=plasticity index of soil, F= clay fraction expressed in percentage that are finer than two micrometer.

The amount of retained water or state of water in soil mass depends upon available clay mineral in soil. Activity of a soil assesses capacity of soil to hold water. Obviously this term is applicable for clayey soil. 'Clay' soils are not 100% clay. The proportion of clay minerals flakes (<2mm size) in a fine soil affects its current state, particularly its tendency to swell and shrink with changes in water content. So, the change of volume that results swelling and shrinkage depend on activity of clay soil.

Skempton suggested three classes of clays according to activity:

•Inactive for activities less than 0.75

•Normal for activities between 0.75 and 1.25

•Active for activities greater than 1.25

Active clays provide the most potential for expansion. Typical values of activities for the three principal clay mineral groups are as follows:

Table iv: Activity values for different mineral groups

Mineral	Activity
Kaolinite	0.40
Illite	0.90
Montmorillinite	>1.25

For a particular soil, clay fraction and plasticity index are measured to prepare a plot, plasticity index vs. clay fraction where clay fractions are in abscissa and plasticity index in ordinates. As stated above a straight line will be found for particular soil, points corresponds to samples lies in straight line. Activity is derived conveniently from slope of straight line. A steeper slope represents greater activity.

Table v: Plasticity Index along with % clay fraction in soil sample

PI	Clay fraction(<2µm)	Remarks
7	23	DDC-BH-1
7	18	DDC-BH-1
9	88	KU-BH-17
11	18	DDC-BH-4
24	34	DDC-BH-2
25	31	DDC-BH-1
26	40	DC -BH-1
26	62	DC -BH-2
27	75	KU-BH-17
29	36	DDC-BH-4
29	48	DC -BH-6
39	69	KU-BH-16

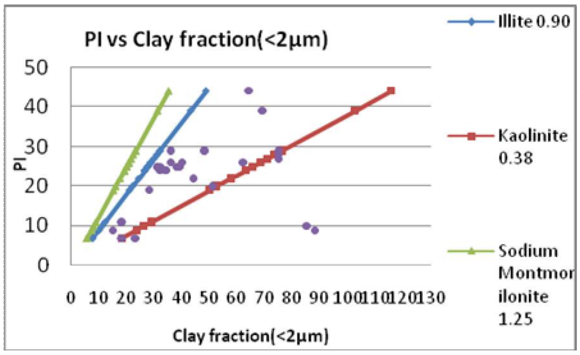

Fig. 3: Plasticity Index (PI) along with % clay fraction in soil sample

From the Activity Chart, the Plasticity Index (PI) along with % clay fraction in soil sample is analyzed and found the clay soils in project area are less susceptible to expand or swell because Illite is a non-expanding clay crystalline mineral and Kaolinite has also a low shrink-swell capacity. So, no significant swell and shrinkage characteristics will be exhibited by these geo-materials due to changing water contents. Upon review of Activity Chart, it is clearly evident from the graph that the clays encountered in project area were classified between Inactive and Normal clays (Activity ratio, A = 0.38 to0.90). Finally it can be said that the possibility of structural damage is negligible.

❖ *Collapsible/ non collapsible soil*

From plasticity index the collapse potentiality of soil is estimated.

Criteria for collapse potential from Prinklonski 1952

$$k_d = \frac{(W - PL)}{PI} \qquad (2)$$

k_d < 0 highly collapsible soils

k_d > 0 Non- collapsible soils

Table vi: Estimated collapse potentiality for different soil samples

Sample	Depth	Potential
RM-BH-01	5.94	non collapsible
RM-BH-02	33.54	non collapsible
JW-BH-04	15	collapsible
DDC-BH-01	24	non collapsible
DDC-BH-01	27	non collapsible
DDC-BH-02	13.5	non collapsible
DDC-BH-02	21	collapsible
DDC-BH-03	4	non collapsible
DDC-BH-03	16.5	non collapsible
DDC-BH-04	2.6	collapsible
DDC-BH-04	9	non collapsible

Collapsible soils are known as metastable soils. They are unsaturated and can undergo a large volume change. This potentiality to large volume change can cause considerable structural damage to the tunnel. This volume change may or may not occur due to an additional load. This collapsible potentiality should be assessed. Non collapsible soils are found in maximum places.

❖ *Chemical testing*

From BNBC 2015 (Vol2_3) the following charts provide guides in assessing the corrosivity of soils.

Table vii: Corrosivity rating based on corrosivity scores

Score/Mark	Corrosivity Rating
0 and above	Non-corrosive
0 to -4	Slightly Corrosive
-5 to -10	Corrosive
-10 or less	Highly Corrosive

Table viii: Soil corrosivity scores for various parameters

Item/Parameter	Measured Value	Score/Mark
PH	≥6 or	0
	< 6	-2
Chloride	≤100 mg/kg	0
	> 100 mg/kg	+1
Sulphate	≤200 mg/kg	0
	200-500 mg/kg	-1
	500-1000 mg/kg	-2
	> 1000 mg/kg	-3

Table ix: Assessing corrosivity based on values of chemical tests from different bore holes

Pit/Borehole No.	Chemical Test	Result	Corrosivity Rating
1	PH	6.8	Non-corrosive
	Chloride	78.6 ppm	Non-Corrosive
	Sulphate	97.7 ppm	Non-Corrosive
2	PH	7.2	Non-corrosive
	Chloride	165.5 ppm	Non-corrosive
	Sulphate	170.72 ppm	Non-Corrosive
3	PH	6.9	Non-corrosive
	Chloride	129.1 ppm	Non-corrosive
	Sulphate	165.5 ppm	Non- Corrosive
4	PH	7	Non-corrosive
	Chloride	130.2 ppm	Non-corrosive
	Sulphate	160.5 ppm	Non-Corrosive

According to the table vii and viii, table ix has been produced and from that it can be assessed that the soil properties are non-corrosive.

❖ *Ground water conditions*

For recording of ground water table the borehole for SPT and sampling was used. After completion of field test and sampling, the ground water table was measured as per standard procedure. Hence one important issue to mention is that there's a permanent impermeable layer (clay) in Dhaka City within several meter depth but the depth of actual ground water table is much more. So, the ground water tables are measured for this project is actually Trap Water Table sourced by rainwater, leakage in sewerage line, waste water etc.

CONCLUSIONS

The soil characteristics of Dhaka are not that much of an easy pattern as it seems so. It has many variations in different layers and in different depths unexpected soil types were also found. But what can be seen in most of the soil in selected project area was clay or silty clay with plasticity, over consolidated, non-collapsible, non-corrosive and safe for building and withstanding any structure. As the zone of concern for construction is within 30m depth and mostly are clay soil, the soil properties studied here are based on Atterberg limit test. For fluctuations in some points, investigations should be continued to dig out the reasons. In order to assessing additional information regarding tunneling more test i.e., hydraulic conductivity, modulus of elasticity, modulus of subgrade reaction should be conducted.

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