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URBAN GEOLOGY: A CASE STUDY OF KHULNA CITY CORPORATION, BANGLADESH

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Abstract

The Khulna City Corporation (KCC) in southwestern Bangladesh lies on the Late Holocene- Recent alluvium of the Ganges deltaic plain in the north and Ganges estuarine plain in the south. Lithologically the area is composed of coarse to very fine sand, silt, silty clay and clay in various porportion upto a depth of 300m. Stratigraphically shows seven cycles of sedimentation having age connotation from Upper Miocene to Recent age. The SPT (Standard Penetration Test) value of the investigated area range between 1 and 9 from surface to 5m deep and 1 to 27 from 5m to 15m below which was used to prepare a SPT zonation map that clearly delineates the KCC area into 4 zones. Here, the liquid limit, plasticity index and the natural moisture content (NMC) range from 38 to 59%, 9 to 30% and 16.5% to 42% respectively. The shear strength of the upper subsoil horizons in the investigated area is low. Low shearing strength in the upper soil horizon with compressive index from 0.123 to 0.335 is indicative of soil vulnerability to excessive settlement under high load. The cohesive nature of soil in the KCC area with high colloidal content, high liquid and plastic limit indicate medium to high sensitivity of the soil to moisture that could not support heavily loaded buildings and structures. The problems can be avoided by considering special type of foundation, increasing the width of basements of structures and granular backfilling. Based on geomorphology, stratigraphic litho-succession, soil types, percentage of sand, silt and clay in the soil, liquid limit, plasticity index, NMC, liquefaction, settlement and SPT zonation, the study area have been classified into four geotechnical units, where unit-I is best and unit-IV is rank lowest for urbanization. Considering the factors of geotechnical parameters and environmental degradation by natural and anthropogenic hazards a future land suitability map has been prepared for future urban planning of the Khulna City area.

Key Wards: Urban Geology, Khulna City Corporation, Bangladesh.

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Introduction

Engineering Geology is the application of the knowledge of Geology to understand various natural conditions that affect the safety, soundness, capability and economy of engineering structures that are governed by lithological and structural conditions, particularly the geometry and dimension of structure discontinuities and the nature, thickness and arrangement of infillings. Structural safety and longevity depend on geodynamical conditions such as seismicity, subsidence, movement of ground water and surface water, bearing and shear strength of the soil etc. The study area of Khulna City is situated in the southwest region of the Bangladesh. The city is bounded by the longitude of 89?28? to 89?37? East and latitude of 22?48? to 22?58? North which administratively lies in Khulna district. The Bhairab in northern side, Rupsa River in the middle part and Pasur in the southern side flows along eastern margin of the city and Mayur in the northern side and Hatia River in the southern side flow along the western side of the city (Fig.1)

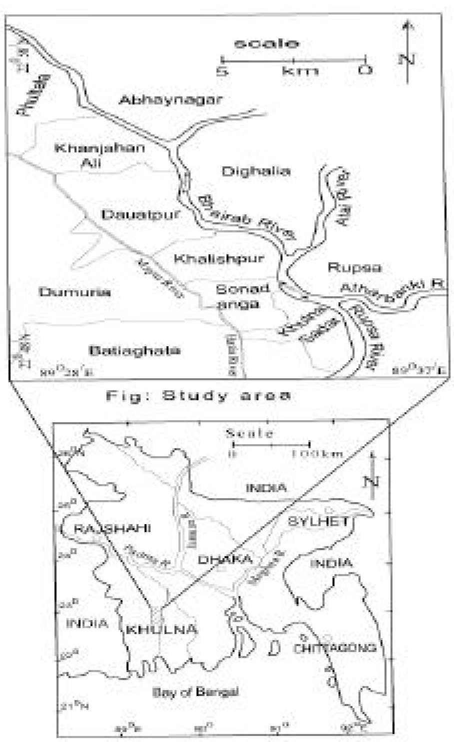

Fig.1. Location map of the study area (Source: Roy et al., 2005).

The main objectives of the research work on urban geology of Khulna City Corporation (KCC) are: (a) Identification of general conditions and especially main potential geotechnical problems; (b) Problems concerning geotechnical design and construction; (c) Collection of data for estimating the strength, stability and susceptibility to deformation of foundation soil; (d) Selection of sites for the proposed engineering works; and (e) Assurance of development without destruction, without jeopardizing the stability and integrity of the ecological balance and without despoiling the nature's beauty.

The depth up to 15m is taken maximum / standard for the foundation of any medium to heavy construction up to 8 to 10 storied building in the Khulna City area where SPT (Standard Penetration Test) values ranges to 9 to more than 27 (Anonymous, 2006). In KCC area generally 4 to 6 storied are high buildings for which SPT 'N' in the range of 6 to 9 are sufficient. One ten storied commercial building is only the high raise structure now in KCC area where the maximum depth was considered the standard 15m. In this case SPT 'N' value was in the range of 18 to 27 and special type of foundation was provided such as granular backfilling and piling.

Materials and Methods

The materials and methods used in this study include

Collection of topographic map, KCC and Khulna Development Authority (KDA) map, Spot imagery, available deep tube well and engineering bore hole logs as well as geological data.

A detailed investigation over the whole study area was carried out during 03-11-2002 to 30-12-2002 and 7-4-2003 to 15-4-2003 on the basis of which geomorphologic units were delineated and a geological map was prepared.

Bore holes data were collected, bore-hole logs were studied, some shallow bore-hole logs were done by hand auger. Lithologies were noted down in the field notebook. All the collected data were later analyzed in the laboratory to prepare subsurface geological map, stratigraphic cross section and panel diagram. Stratigraphic succession of the study area is prepared on the basis of data collected from field and other published/unpublished scientific papers.

For delineation of geotechnical conditions, soil types were classified on the basis of field survey and laboratory analysis, which includes liquid limit and plasticity index. Liquid limits and plastic limits are determined in the laboratory with the help of the apparatus (model no. DREW L-201: Casagrande/ ASTM/AASHTO; Type- JS 5RK/CL) designed by Casagrande in the laboratory of the Dept. of Geology and Mining, University of Rajshahi. Physical and geotechnical properties of various soil and sub-soil unit have been determined by the natural moisture content (NMC), specific gravity, grain size diameter and proportion of sand, silt and clay up to a depth of 15m. The grain size like median grain size (D50) has been measured by sieving using American Standard Testing Mesh (ASTM) in the range of 60 to 325 in the laboratory of the Dept. of Geology and Mining, University of Rajshahi. Compression ratio has been taken from the engineering report of the KCC. The specific gravity was determined by balance in the laboratory following the standard method. The compression indices (Cc) were also calculated using the Skempton (1944) formula, Cc= 0.009 (L_L=10%) and are found to be greater than those determined from other test measurements including that given by Terzaghi (1943). NMC was determined in the laboratory of the KDA and data were used in the research.

SPT values were determined for 3 depth horizons, surface to 5m, 5 to 10m and 10m to 15m depth using the standard method (American Standard) suggested by Terzaghi and Peck (1967) and Gibbs and Holtz (1957) and the apparatus model no. Soil Test Chicago, U-160A. The data from various depths were collected and on the basis of these data SPT zonation maps were prepared.

Geotechnical problems for foundation of civil, commercial and industrial constructions in the investigated area include low bearing capacity of soil, settlement/low scale subsidence, shrinkage, swelling, low rank construction aggregate and liquefactions.

a) Low bearing capacity of soil and sub soils were determined by shear strength, friction and cohesive force.

b) Settlement or low scale subsidence was determined by pressure versus void ratio curve. Shrinkage and swelling were determined on the basis of liquid limit, plasticity index and clay minerals. On the basis of available data and also data by sieve analysis, a quick estimation of the construction materials is made. The locally available construction materials are not good for stable high-rise building, unless these are mixed with imported materials of high SPT values. Liquefaction was determined by the liquefaction characteristics of soil.

Results and Discussion

Geological Settings: The Khulna City Corporation in southwest Bangladesh lies on the Ganges deltaic plain in north and Ganges tidal plain in south of Holocene-Recent age. Tectonically the area lies within the Faridpur Trough of the foredeep part of the Bengal Basin and no subsurface fault has been demarcated in the KCC area. Lithologically the area is composed of coarse to very fine sand, silt and silty clay up to a depth of 300m with peaty soil and calcareous as well as non-calcareous soil at the top. Stratigraphically the litho-succession is divided into seven units. The Unit 1 represents back swamps and floodplains with small channels. The Unit 2 consists of coarse to fine sand deposited by large channels, which may be equivalent to either lower part of the Dupi Tila or upper part of the Tipam Formation of Late Miocene to Pliocene age. The Unit 3 being composing of silty clay is a depositional unit of tidal channels, tidal creeks and estuarine plain. The Unit 4 is of Late Pleistocene to Holocene age and a sand dominated unit that was deposited under deltaic condition. The Unit 5 consisting of silt and silty clay was deposited under marine transgression within Bengal Basin during 7000-5000 years BP. The Unit 6 composing of sand, silt and clay with peaty soil was deposited under regressive condition with intermittent small transgressions when the Ganges delta prograded south to its present boundary during the period of 3000yr BP to 1100±90yr BP. The Unit 7 is a complex of natural levee, flood basin, marsh and active as well as abandoned channel in southern inactive area of the Ganges delta locating in the northern part of the study area and tide dominated coastal- estuarine plain of Recent age lying in the southern part of the study area (Roy et al., 2005) and it represents topsoil. The area has studied in detail to prepare a geological map with the help of land sat imagery, toposhet, LGED (Local Government Engineering Department) map, geological boring and field investigation. Channel, present and abandoned, natural levee, flood plain, flood basin, back swamp, eatuarine plain etc have been delineated and location of the geological bore holes are shown in (Fig. 2). The stratigraphic cross–section (Fig. 3) and one panel diagram (Roy et al., 2005) are made to have a better insight of the underground condition for civil engineering purpose**.** Topsoils are calcareous and non-calcareous but there are sandy soils (coarse, medium and fine) and clay soils (clay, silty clay and clay with silt). There are seven cycles of sedimentation up to 300m depth in the area of KCC covering channels, bars, swamps etc. The area is located within the least earthquake prone zone of Bangladesh having intensity in the range of 6- 6.5 in Richter scale. Hence geologically the KCC area is fit for urbanization provided the geotechnical condition are favourable.

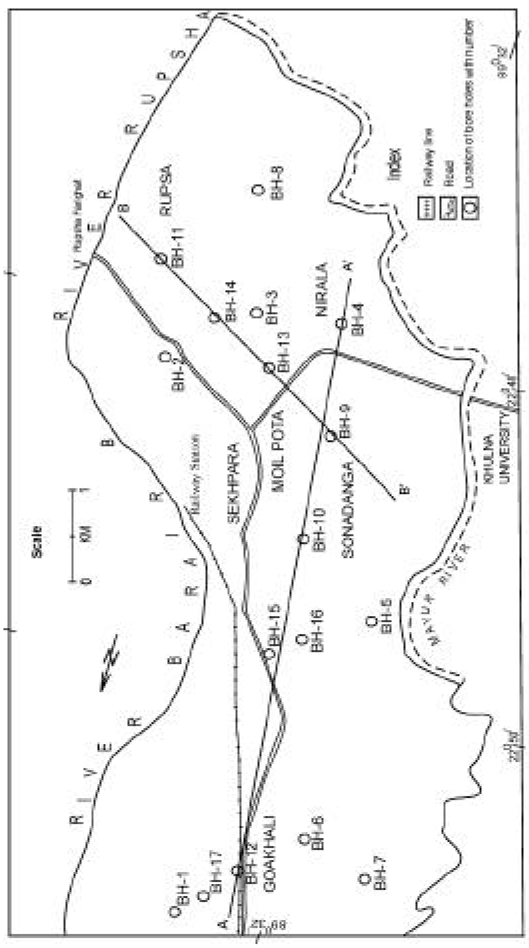

Fig. 2: Borehole location map in Khulna City Area. (Source: Roy et al., 2005)

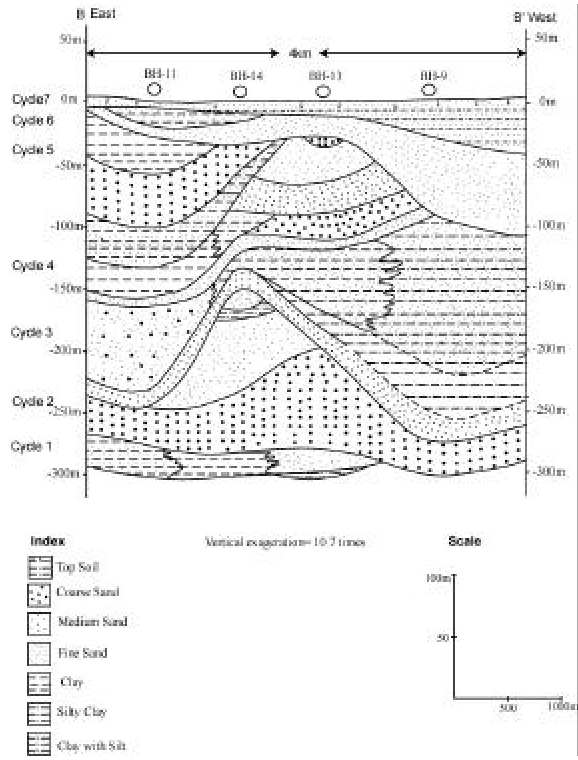

Fig. 3. Lithostratigraphic cross-section along east-west direction in the study area. (Source: Roy et al., 2005).

Soil Type: The soil sequences consist of medium to high plastic clay at top and poorly graded sand below which are described under the following heads. Table 1 shows the plasticity values of the soils in the KCC area.

Medium to high plastic clay (CI-CH): The soil is predominantly composed of inorganic clays of medium to high plasticity index varying from surface level to 8m below AMSL (Average Mean Sea Level). This clay can be classified into two types: Fat clay and Lean clay (Bowles, 1984)

Fat clay consists of inorganic clay with high plasticity (L_L> 50%) without silt, fine sand and organic clay. This clay has high crushing characteristic and toughness (consistency near plastic limit). Lean clay consists of inorganic clay with medium plasticity (L_L=35% to 50%) with inorganic silt and fine sand. Plasticity Index ranges in between 15% to 25%. The peat is also present in the western part of the study area in this depth zone. This soil sequence consists of fine grain soils characterized by low standard penetration test (SPT) resistance indicating a loose condition. Engineering boreholes were performed up to 15m. The Atterberg Limit has been shown in Table 3 and Fig. 4. It is shown in Fig. 4 that soils with plasticity index in the range 20% - 30% and liquid limit 50% - 60% are problematic for reconstruction, but in Table 3 by comparing Atterberg Limit with SPT value and grain size four engineering geological unit have been demarcated. Generally four to five storied structures can be constructed in these problematic soils when the width of basements of the constructing walls are widen and piling might not be needed as it might cost more money (Monim, 2006, personal communication).

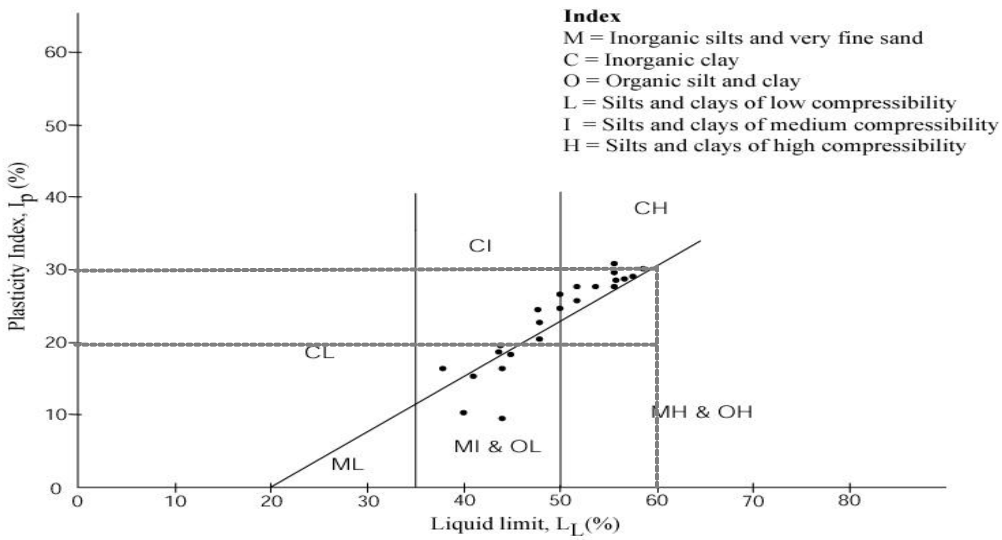

Fig. 4. Position of the cohesive subsoil unit on the Casagrande Plasticity chart

Poorly graded sand (SP-SC): This zone is predominantly mixing horizon of poorly graded sands, gravelly sands, with little or no fines (SP), silty sands and poorly graded sand-silt mixtures (SC). The depth of this zone depth varies from 8 m to 300 m below AMSL. From stratigraphic cross sections (Fig.3) it is evident that SP occurs at the beginning of every cycle of sedimentation. The SPT 'N' value of this sand values range from 9 to more than 27 exhibiting a general increasing trend with depth.

Soil Properties: The major physical and geotechnical properties of various soil units are given in Table 3. The data include the natural moisture content (NMC), specific gravity and mean grain diameter (D_{50}). Examination of the Table 3 reveals a broad similarity of the soil parameters at different sites and depth in the KCC area.

At the depth up to 5m, the percentage of sand varies from 4 to 38 (average 10.2%), silt from 20% to 70% (average 57.9%) and clay from 6% to 75% (average 31.9%)

The locations of the engineering boreholes are shown in Fig.5. At the depth from 5m to 15m at the same site the sand, silt and clay proportion varies greatly. Sand varies from 15% to 92% (average 69.8%), silt from 8% to 69% (average 26.3%) and clay from 12% to 36% (average 3.9%).

The SPT values of the study area range between 1 and more than 9 from surface to 5m (Fig.6). In general, these values increase with depth. Below this depth (up to 15 m), the SPT values range between 1 and more than 27 with more area covering by SPT value ranging from 9 to 27 (Figs 7 and 8). The D_{50} (particle size of 50% of sediment) of the soil samples range between 0.0015 mm in Muzguni R/A and 0.12 mm in BNS Titumir area to a depth of 5m. The D_{50} values in between 5 m to 15m depth range in between 0.085 mm in Tootpara and 0.5 mm in Ser-E-Bangla Road suggesting an increase in grain size with depth.

The index properties determined for cohesive soils indicate that the liquid limit (L_L) and plasticity

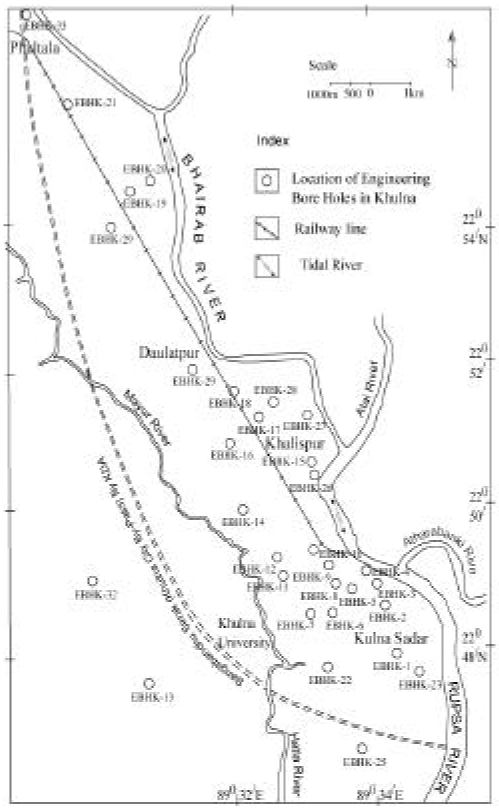

Fig.5. Location map of engineering bore holes in Khulna City area for SPT zonation.

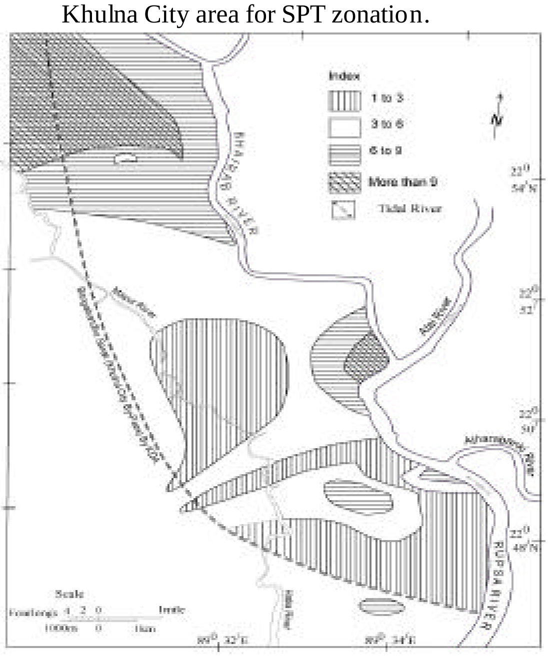

Fig. 6. SPT Zonation map from Surface to 5m

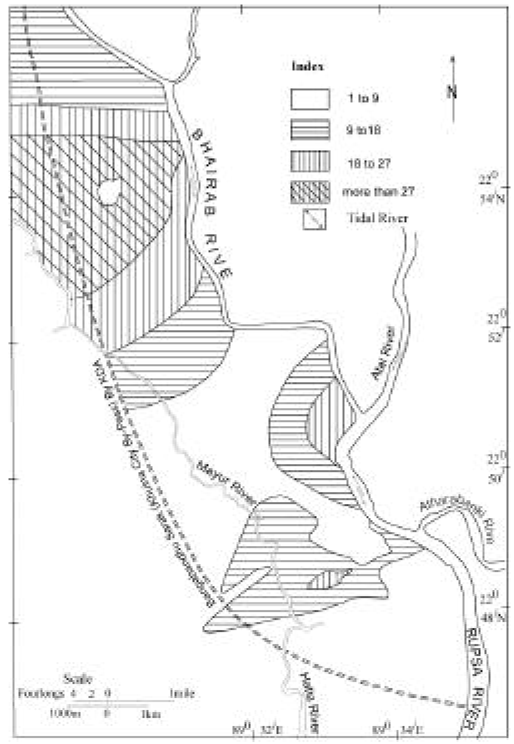

Fig. 7. SPT Zonation map from 5m to 10m**.**

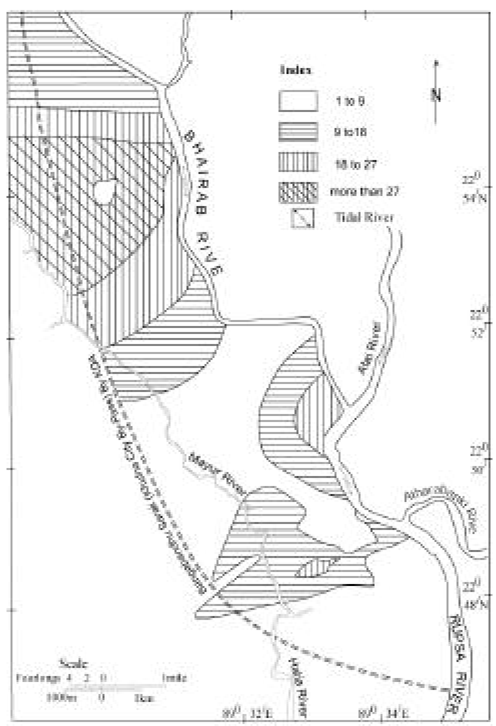

Fig. 8. SPT Zonation map from 10m to 15m.

index range from 38 to 59% and 9 to 30% respectively (Table 1). These data, together with data from more than 21 samples are plotted on Casagrande plasticity chart (Fig. 4). These all lie within a narrow range along the straight (A line) on the chart. Low plasticity (L_L<40%) is possibly attributed to the occurrence of abundant free silica. The high plasticity of some subsoil samples (L_L>50%) is indicative of potential foundation problems associated with these soils, which can be remidied by widening the besements of the structures withing piling as piling is much more expensive.

The natural moisture content (NMC) of the samples ranges between 16.5% and 42%. The NMC values vary significantly with season, depth, texture and composition. Specific Gravity of the soils ranges from 2.63 to 2.7.

Associated Problems: Alluvial deposits are generally granular and present favorable condition for urbanization. However, development activities on these deposits in Khulna City area are encountered with numerous geotechnical and environmental problems, which greatly affect the safe and economic land utilization of the plains in and around the city. The geotechnical problems are either related to soil and structure, or are defined as a complimentary type, not related to the structure itself. Most often the two problems are interrelated.

Geotechnical Problem: Geotechnical problems are related to the nature and distribution of soils and their properties. These problems encountered in excavation, sand filling, improvements of soils by mixing coarser sediments etc. are necessary for consideration of construction and maintenance of highway, building, bridge, foundations and hydraulic fills.

Low Bearing Capacity of soils: The ultimate bearing capacity of soil beneath a foundation load depends primarily on the shear strength. The data on Table 2 and 3 revel that the shear strength is low, particularly in the upper horizons, of the KCC area and depends on friction and cohesive forces. Soils with low shear strength are not strong enough to support the most common structures of single to 5 storied buildings with conventional shallow foundation systems and, therefore, pose a serious foundation problem for the entire region of the study area along with many other parts of Bangladesh.

The shallow foundations are of the various types such as pad, strip and compensating types. These foundations are used for light structures with pressures ranging from 25 to 40 kPa at depths between 1.5 m and 3.0 m. The low bearing capacity of the soils requires the adoption of a raft foundation created for major civil and engineering structures, which are often transferred through RCC piles on the sand stratum which has a high bearing value. For smaller loads, timber piles with a diameter of 120-150 mm and a length of 8-10m are economical and, therefore, often used. However, the durability of these poles is only guranted when the piles remain constantly in the groundwater. The process of drying

Table 1. Plasticity values for soil of the Khulna City (complied from engineering reports of KCC area).

Area	Depth (m)	Liquid limit (%)	Plasticity Index (%)
Chanmari Approach Road, Tootpara	3.1	44	16
39, Khan-A-Sabur Road	3.1	52	25
	6.2	48	22
Helatala	4.6	44	19
Forajipara Road	4.6	44	9
214, Sar-E-Bangla Road	1.5	58	28
	6.2	48	20
Basupara Lane	1.5	56	29
	4.6	50	26
KDA Commercial area (New Market)	4.6	44	18
Sonadaga	1.5	54	27
	3.1	56	29
	4.6	50	24
Bashbariya, Botiyaghata	3.1	56	28
	7.7	45	18
18, Basupara	3.1	59	29
	6.2	56	28
Upasham, BNS Titumir, Khalishpur	4.6	41	15
	7.7	48	24
Muzguni R/A	7.7	40	10
171, Khalispur	3.1	57	28
	4.6	50	24
Housing Estate, Khalispur	6.2	38	16
Badamtala, Shiromony	1.5	56	27
KDA I/A, Shiromony	1.5	57	28
	4.6	50	24
Gilatola	3.1	56	30
	6.2	52	27

and wetting increases the possibility of attack by insects and enhance weathering action thus rapidly shortening the life of timber piles. However, for economic consideration piling weather RCC or timber is avoided and widening of basement of the foundation, particularly shallow to medium type structures is increased often along with sand back filling (Azad, personal communication, 2006).

Settlement (compaction and Low scale subsidence): Settlement is another major foundation problem in the study area related to the loose and compressible nature of the soil. The compression index (Cc), extracted from the previous record, ranges between 0.123 and 0.335 (Table 2). The Cc values were also calculated using the Skempton (1944) formula, Cc= 0.009 (L_L=10%) and are found to be greater than those determined from other test measurements including that given by Terzaghi (1943). The Cc values of more than 0.22 in Table 2, associated with some soils, are attributed to high in-situ void ratios and moisture content. These values are indicative of their vulnerability to excessive settlements under applied loads.

The magnitude of the ground movement cannot be attributed to compressibility of soils under such light loading conditions; these movements represent typical subsidence problems that arise from poor compaction of soil, and erosion and piping caused by storm water or tide or flood etc and to some extent of earthquake.

The most extreme settlement can be seen in the major roads of the city corporation area, such as Ser-E-Bangla, Khan-A-Sabur, Khan-Jahan-Ali and Jessore road etc (Table 1). It is possible that these settlements are the result of consolidation of both fill materials and near surface compressible soil. Numerous settlements on a large number of road segments have made the bituminous running surface uneven, causing severe cracking and localized subsidence.

The present situation could be improved by excavation to hard bottom first and then re-establish grade with controlled compacted fill. The use of an admixture of cement to improve the bearing capacities of a sub grade or sub base can be investigated. However, equal slight or negligible, not differential, settlements in the scale of several mm does affect the structure very much (Monim, 2006, personal communication).

Shrinkage and Swelling: Shrinkage and swelling are well known phenomena causing damage to building foundations, roads, aircraft runways etc. It is caused by a deficiency or excess of water (Youssef *et al*., 1957; Popesco, 1980). Shrinkage and swelling of soils are often characterized by high liquid limit and plasticity index with a variable content of more active swelling clay minerals which are occasionally common in the KCC area. The clay minerals like smectite, vermiculite and holloysite etc are swelling in nature and these clays compose a dominant part in the clay and silty clay horizons of the topsoil and subsoil.

Most soils in Khulna City area up to a depth of 5m are of cohesive nature with a high colloidal content. Plasticity index values of these soils are given in Table.1. The values are indicative of medium to high sensitivity of the soils to moisture. Because the moisture condition in the country is seasonally dependent, the soil is subjected to cyclic wetting and drying with significant volume changes in different seasons. A swell potential is, therefore, often present in soils with plastic fines materials. For light structures, this can cause excessive uplift pressure inflicting damage. In Fig. 4 it has been shown that about 40% of the sediments occur in moderate to high compressibility zone and the depth varies for the sediments mostly under 5m. Though the research does not done with season variations, special foundation like footings, piers, piling etc should be placed at sufficient depth below the depth altered by seasonal change, specially high raise building. Sand filling can help at a large scale this problem for structures for shallow depth.

The problem of swelling can be handled, among others by designing structures sufficiently rigid or flexible to accommodate the anticipated movement. In practice, however, it is usually more economic to eliminate the possibility of swelling pressure than to make a design that takes swelling into account. Therefore, footings, piers, foundation etc should be placed at sufficient depths, below the depth affected by seasonal changes. Alternatively, sub grade soils may be replaced by a compacted granular backfill. If such material is locally not available, provisions should be made to prevent surface water from being ponded adjacent to the structure and to have sufficient drainage to control the seepage of water flow.

Construction Aggregates: Good construction materials are scarce in Bangladesh. Most quarries are located in the districts of Sylhet, Sunamganj, Lalmonirhat, Nilphamari, and Panchagarh of Bangladesh. The typical fineness modules (FM) of the aggregates are 2.5 mm to 2.8 mm in diameter. The original rocks are igneous, metamorphic and pre-existing sedimentary rocks. The coarse aggregate varies from 4 to 17mm in diameter as shingle, and from 17 to 230 mm diameter as rock fragments. Annual production averages about 34000 m^3 (Mollah, 1993). The main components of these aggregates include quarzites, schist, gneiss, amphibolites, gabbro, slate, granite and grano-diorite etc.

Generally the sand, available locally, does not fulfill the requirements of construction materials concerning grading and composition (ASTM, 1986; BS, 1983). Two major problems concerning the sand are the excessive fine content and variable but high amounts of micas (muscovite and biotite). The fine content and the mica contribute to loss of strength of concrete. The mica flakes (mainly muscovite) are upto 5-7 mm long. It is speculated that the low SPT 'N' values of the soil are caused by the effect of reduced confinement due to the presence of mica. Local sand is very similar to near subsurface soil zone (upto 5 m). The median diameter (Md) values of the local sand range between 0.5 mm and 1.5 mm.

Liquefaction: Liquefaction is the phenomenon by which saturated soils, essentially fine or medium-fine and loose sand are temporarily transformed into a liquefied state. In the process, the soil undergoes transient loss of shear strength, which commonly allows ground displacement or ground failure.

Studies of Seed and Idriss (1967); Casagrande (1976) and Seed (1979) demonstrate that liquefaction characteristics of a soil depend on several factors. These factors are:

a) Position of ground water table;
b) Grain size distribution;
c) Soil density;
d) Ground accelerations;
e) Sedimentation history;
f) Age of sediments;
g) Thickness of the deposit;
h) Location of drainage and
i) Magnitude and nature of superimposed loads

Table 2 Compression Index values (C_c) of surface soils of the Khulna City (Modified after KCC engineering reports).

Area	Depth (m)	Void (e_o)	Compression Index	Compression Ratio
Chanmari Approch Road (Tootpara)	3	1.05	0.155	0.076
South Central Road	2.5	1.08	0.157	0.075
39, Khan-A-Sabur Road	2.5	0.684	0.132	0.078
Helatala	2.5	1.06	0.155	0.075
22/ Forajipara Road	2.5	1.10	0.157	0.075
214, Sar-E-Bangla Road	4	0.924	0.156	0.081
Basupara Lane	4	0.755	0.142	0.081
Shake Para Mosque Road	2	0.852	0.123	0.066
KDA Avenue	2	0.921	0.140	0.073
KDA Commercial area (New Market)	2.5	0.98	0.148	0.075
Sonadaga R/A	2	0.851	0.125	0.068
Sonadaga	4	1.01	0.225	0.112
Bashbariya, Botiyaghata	4	1.05	0.22	0.107
18, Basupara	5.5	1.07	0.335	0.162
Upasham, BNS Titumir, Khalishpur	2.5	0.878	0.251	0.134
254/ Muzguni R/A	5.5	0.98	0.142	0.072
171/ Khalispur	4	0.749	0.141	0.081
Housing Estate, Khalispur	4	0.927	0.166	0.086
Badamtala, Shiromony	4	0.752	0.142	0.081
KDA I/A, Shiromony	4	0.819	0.139	0.076
Gilatola	2	0.902	0.165	0.087
Nirala R/A	2.5	1.10	0.157	0.075

Table 3. Physical and geotechnical properties of soil in the study area.

Engineering Geological unit (Geological unit)	Atterberg limit		SPT range	Grain size (percentage)						Remarks
	Liquid limit (L_L)	Plasticity Index (P_I)		Up to 5m			5m to 15m			
				Sand	Silt	Clay	Sand	Silt	Clay	
Unit-I (Natural levee and Floodplain)	41-48	Low to Medium	6 - 27	4-20	32-67	13-64	70-87	13-30	-	Best for urbanization
Unit-II (Natural levee and Floodplain)	> 50	High	6 - 27	9-38	56-69	6-22	21-83	17-67	0-12	Good for urbanization
Unit-III (Natural levee, Floodplain, Flood basin and Abundant channel)	>50	Low to High	1 - 18	4-12	30-70	18-60	41-86	14-35	0-36	Good to fair urbanization
Unit-IV (Flood basin, Abundant channel and wet land)	--	--	1 - 9	5-11	20-70	20-75	15-88	12-69	15-16	Urbanization with specially care

This phenomenon has been observed to occur in several fairly recent earthquakes. It also sometimes occurs during pile driving. In Khulna City Area, soils are typically young of Recent to Holocene age, comprising clay and sandy material, and occurring in a saturated condition as ground water table here lies less than 1m below the surface. Therefore, these soils up to 5 m are sensitive to liquefaction at different degree. Again foundation problem can be solved to certain degree by sand filling and widening of the structural besements. Main township of KCC extends from Goakhali (north)–Sonadanga-Moilapara-Sheikpara-Rupsha ferry ghat (south), which actually lies over the areas of less water saturation of bars as evident of stratigraphic cross section (Fig.3) and over the zone having high SPT value (Fig.9).

Description of Engineering Geological Map: An engineering geological map of the area have been prepared considering sediment characteristics, geological and engineering properties, such as grain size parameters, liquid limit, plasticity index, natural moisture content (NMC), compression index, soil type, settlement (compaction), shrinkage and swelling, construction aggregates and liquefaction etc. The study area has been classified into four engineering geological units (Fig.9) considering their suitability of construction and urbanization. This engineering division has close similarity with the geomorphological division of the geological map of the KCC area prepared by Roy *et al.*, 2005.

UNIT-1: This unit consists of natural levee of the Bhairab-Rupsa-Pasur Rivers on their western bank. At the depth up to 5m, the percentage of sand varies from 4 to 20, silt from 32 to 67 and clay from 13 to 64 (Table 3). At the depth from 5 m to 15m, sediments are mainly sand dominated that ranges from 70% to 87% with minor amount of silt (13% to 30%, Table.3). The liquid limit of this unit ranges from 41 to 48%. So plasticity index of this unit is low to medium and SPT varies from 6 to 27 with an average of 18 (Figs. 6, 7 and 8). Considering foundation characteristics and geological condition of the area, this unit has fair bearing value. So this unit is best for urbanization in the Khulna City Corporation area and shallow to medium deep foundation of high-rise residential, commercial and industrial buildings is possible in it.

UNIT-2: This unit consists of moderately raised natural levee with flood plain. It is observed that the percentage of sand, silt and clay in this unit ranges between 9 and 38%, 56 and 69% as well as 6 and 22% respectively up to a depth of 5m. At the depth in between 5 m and 15 m, sand varies from 21 to 83%, silt from 17 to 67% and clay from 0 to 12% (Table 3). As the liquid limit of this unit is more than 50% (Table 3), plasticity index of this unit is also high. The value of SPT varies from 6 to 27 that increase with depth with an average value of 18. This unit is generally situated above flood level. So this unit is good for urbanization.

UNIT-3: This unit consists of area occupied by less raised natural levee, flood plains and abandoned channels. The percentage of sand, silt and clay ranges between 4 and 12%, 30 and 70% as well as 18 and 60% up to 5m respectively with fine consistency. At the depth below 5 m up to 15m, sand varies from 41 to 86%, silt from 14 to 35% and clay from 0 to 36%. Low to high plasticity (10% to 28%) is present in this zone. The value of SPT varies from 1 to 18 (up to 15m), which increases with depth with an average of 9. This unit has poor values for foundation characteristics. This unit is considered relatively weak for foundation than Unit -1 and Unit - 2.

UNIT-4: Mostly marshy lands, back swamps and flood basins with some abandoned channels occupy this unit. Sediments are mainly peaty soils. At the depth up to 5m, sand, silt and clay range from 5 to 11%, 20 to 70%, and 20 to 75% respectively with stiff consistency. At depth below 5 m to 15m, sand, silt and clay range from 15 to 88%, 12 to 69% and 15 to 16% respectively. At the depth between 5 and 15 m, the percentage of sand decreases from east to west of the study area in exchange of clay. The SPT values vary from 1 to 9. Most part of this unit remains under water for a considerable span of the year. Swelling may occur in clay layers. This unit is very weak for foundation. It is not possible for civil engineering and industrial construction with normal foundation in this unit. Very careful attention and special foundation treatment and design are necessary for any construction in this unit.

For light to medium structures at shallow depth up to 5m the SPT 'N' in the range of 6 to 9 is sufficient provided other conditions are appropriate. The depth up to 15m is taken standard for the foundation of any heavy construction up to 10 to more storied building in the Khulna city area where SPT (Standard Penetration Test) values (N number) ranges to 9 to more than 27 (Khulna Development Authority, KDA , 2006: personal communication). In KCC area generally 4 to 6 storied are high buildings for which SPT 'N' in the range of 6 to 9 are sufficient. One ten storied commercial building is only the high raise structure now in KCC area where the maximum depth was considered the standard 15m. In this case SPT 'N' value was in the range of 18 to 27 and special type of foundation was provided such as granular backfilling and piling

In summary it can be stated that boundaries of the 7 cycles of sedimentation of the KCC area have been carefully studied and it has been seen that the migration of Bhairab River and position of mid channel bar has been somewhat shifted from east to west during the Miocene to Recent time (Roy *et al.*, 2005). Main township of KCC extends from Goakhali (north)– Sonadanga- Moilapara- Sheikpara- Rupsha ferry ghat (south), which actually lies over the areas of less water saturation of bars as evident of stratigraphic cross section and over the zone having high SPT value (Fig. 9). The city can be shifted safely toward north (Fig. 10).

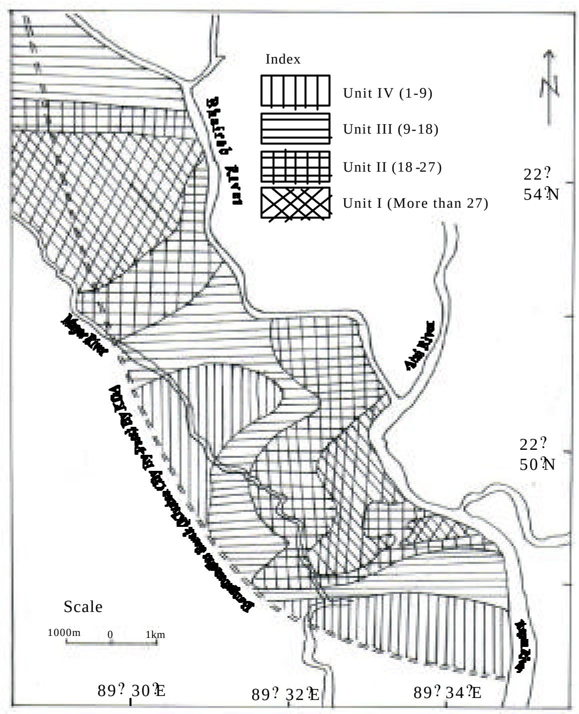

Fig. 9. Geotechnical Zonation map of the study area.

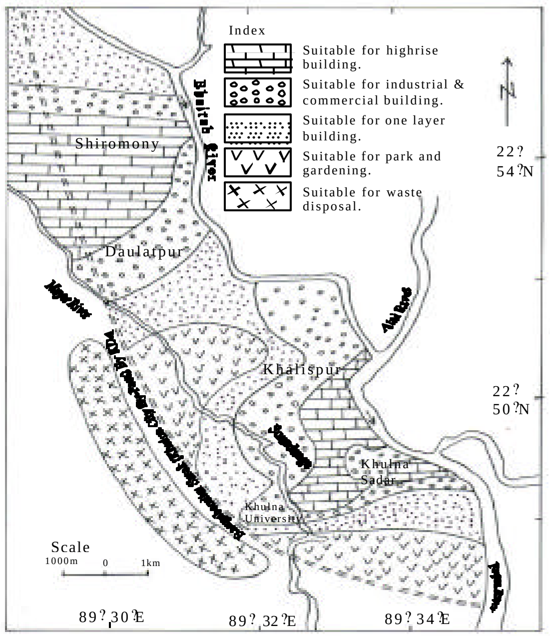

Fig. 10. Future urban planning map of the study area.

Conclusions

The late Miocene to Recent sedimentary succession of the KCC area consists of medium to high plastic clay upto 8m depth and moderate to poorly graded sand from 8m to 300m below.

Upto 5m depth percentage of sand, silt and clay are 10%, 58% and 32% respectively, which become about 70%, 26% and 4% respectively from depth of 5m to 15m.

The SPT value ranges from 1 to 9 in depth zone of surface to 5m and 1 to 27 from 5m to 15m.

The liquid limit and plasticity index range from 38% to 59% and 9% to 30% respectively.

The natural moisture content (NMC) ranges from 16.5% to 42%.

The shearing strength in the upper soil horizon is low with compressive index ranging from 0.123 to 0.335, which indicates soil vulnerability to excessive settlement under high load, which can be avoided by special type of foundation and sand filling

The cohesive nature of soil and subsoil of the area with high colloidal content, high liquid- and plastic limit indicate moderate to high sensivity to moisture that cannot support high-rise building and structures. The shallow occurrence (about 1m below surface) of ground water level in the KCC area also reduces bearing capacity of the soil and subsoil upto 50%.

It has been shown that about 40% of the sediments occur in moderate to high compressibility zone and the depth varies for the sediments mostly under 5m. Special foundation like footings, piers, piling etc should be placed at sufficient depth below the depth altered by seasonal change. Alternatively, sub grade soils may be replaced by a compacted granular backfill.

Locally available sand contains the excessive fine content (Md value 0.5 mm and 1.5 mm) and variable but high amounts of micas and thus does not fulfill the requirements of construction materials concerning grading and composition. It is speculated that the low SPT ‘N’ values of the soil are caused by the effect of reduced confinement due to the presence of mica. By mixing good quality sand upgrading can be made.

On the basis of the geomorphology, litho-succession and engineering properties the KCC area has been divided into four geotectnical units: I, II, III and IV, where Unit I is best and Unit IV is ranked lowest for engineering construction and urbanization.

Main township of KCC extends from Goakhali (north)–Sonadanga-Moilapara-Sheikpara-Rupsha ferry ghat (south), which actually lies over the areas of less water saturation of bars as evident of stratigraphic cross section and over the zone having high SPT value. The city can be shifted safely toward north from Daulatpur.

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