Soil geotechnics in urban planning- A case study from Kolkata megacity

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Abstract

Detailed soil investigation in Chandannagar area of Kolkata Megacity project area was carried out for urban planning. Soil is characterized predominantly by fine grained texture. The SPT (N values) values obtained from the soil down to 10m have been found to vary from 4 to 12. This wide variation may be attributed to variation in composition and proportion of silt, sand and organic matter. Various geotechnical properties including Cohesion (C) and Angle of shearing (Φ) have been determined. Based on the united classification system on consistency limit the soil of the area can be classified into MI, MH, CH, ML, CI and CL group. Bearing capacity as well as settlement for different types of loaded structure has been computed from the geotechnical parameters.

1. Introduction:

Rapid urbanization is one of the most spectacular features since the second half of the 20^{th} century. This is directly proportional to the significant population expansion throughout the world. The strongest growth in urbanization is to be seen in developing countries especially in Africa and South Asia.

The necessity of advance urban planning is now generally accepted throughout the world as a vital public service in place of unorganized and uncontrolled use of land in earlier days. This planning involves optimum use of land so that the physical development of cities may best meet the needs of people. Since the science of geology is concerned with all aspects of the crust of the earth, the use of geological information becomes an essential part of the physical planning of all cities. The application of geoscience in urban development and planning requires integration of whole spectrum of earth related disciplines. Apart from the more traditional field like stratigraphy, petrography, sedimentology, tectonics and geomorphology, some interdisciplinary fields such as engineering geology, hydrogeology and environmental geology play a significant role in urban geology. All of these disciplines, sub-disciplines and interdisciplinary fields have to be integrated with a thorough knowledge of regional and local geological condition together with relevant Quaternary geological process. Thus, urban geology entails the application of geological knowledge and principles to the planning and management of cities and their surroundings and involves geological studies including soil geotechnics for physical planning, waste disposal, land use, water resources management and extraction of useable raw material.

Based on the above premises a comprehensive study on urban geology including the soil geotechnics has been conducted at the behest of Kolkata Metropolitan Development Authority (KMDA) during 1998-2000 for their expansion of city. The report generated has become immensely helpful in evolving a viable management plan for their urban development activity in the area.

2. Study Area:

2.1 Location:

The study area forms a part of Kolkata megacity project area under KMDA, west of Hugli River near Chadannagar, Hugli district, West Bengal (figure 1). The area is bounded by latitude 22^o 49'20''-22^o 52'36", longitude 88^o 18' 15"-88^o 21' 18" and falls in Survey of India toposheet no.79B/5. The total area under study is about 30 sqkm. The area belongs to Gangetic West Bengal and globally monsoon Asia. It is characterized by humid sub-tropical with mean annual temperature is about 26^o. The mean annual rainfall is 1500mm.

2.2 Geomorphology:

The study of aerial photos, satellite imageries, toposheets and field survey reveal that the area is more or less flat with regional master slope from north to south and comprises a set of well-preserved landforms viz. distributary levee, inter-distributary marsh, point bar etc. The river Hugli and its distributaries form the principal drainage of the area. The land slopes away from the Hugli Channel till it meets oppositely sloping land segments which slope away from another present or palaeo channel. The highlands (levee) are generally associated with present or palaeo course and low-lying areas occur in between the highlands. The study area comprises number of both natural and anthropogenic landform elements which are delineated in geological- geomorphological map (figure 2).

2.3 Regional Geological Setup:

The area constitutes the lower part of the Bengal Delta that lies in the southern portion of the Garo-Rajmahal gap. The Garo-Rajmahal gap has an east-west axis through Rajmahal at about 25°00' Latitude. This axis forms a hinge that has the Gangetic fore deep to its north and the lower part of the basin forming the Bengal delta lying to the south. Geophysical survey as well as deep drilling of the basin revealed a thick pile of Cretaceous-Tertiary-Quaternary sediments and indicated the existence of Precambrian basement at 5566m to 6666m depths below ground level. From ground water resource point of view the Quaternary sequence comprising unconsolidated sediments is of much significance. The enormous thickness of sediment implies subsidence of the basin synchronous with the sedimentation. The structure and lithology indicate number of pulses of

sedimentation, marine transgression and regression and tectonic uplifts took place during past.

2.4 Near-surface Geology:

The entire area is covered by Holocene unconsolidated sediments, which is considered as lower deltaic deposit brought down by the river Hugli and its distributaries. The sediment is constituted by different proportion of sand, silt and clay. Since there is a close linkage between landform, sediment content and depositional process, the sediment composition varies systematically. The distributary levees are characterized by very fine sand to silt, point bar by very fine sand and inter-distributary marsh by silt, clay and organic matter. For detailed study of the near surface lithological sequence a number of shallow boreholes have been drilled down to l0m depth. A critical analysis of the shallow borehole logs reveals the presence of a yellowish to brownish grey silt to sandy silt followed downwards by a very fine micaceous sand upto 5.7m depth. This is underlain by a thick sequence of grey, silty clay to clayey silt with presence of decomposed vegetative matter (Peat) at different between 6 and 9m. This, in turn, is followed by light bluish grey, silty clay with profuse calcareous nodules (kankar). The peat layer is met almost all the boreholes with thickness varying from 0.6m to 1.8m. Sub-surface distribution of depth of occurrence of this organic clay reveals that at northern and southern part the clay is intercepted at deeper level. The bluish grey clay 'kankar bearing' is usually intercepted between 8.4m and 10.2m b.g.l.

2.5 Sub-surface Geology:

Sub-surface geology of the area can be reconstructed on the basis of lithological data provided by drilling for groundwater. Analysis of available litho logs from a few boreholes located adjacent to core area reveals the presence of a thick Clay/silt sequence with occasional fine to medium sand down to a depth of 59. 13m bgl. This is underlain by a fairly thick medium to fine to coarse sand with occasional gravel down to a depth of 120m. This sand sequence forms the principal repository of groundwater of the area understudy. A summarized lithological sequence is given below:

Depth range (m)	Lithology
0-59.13	Topsoil/silt/clay with occasional medium sand.
59.13 – 92.35	Fine to medium sand
92.35 – 120.0	Coarse sand with occasional gravel of pea size.

3. Methodology:

In order to evaluate the subsoil character of the area a detailed soil investigation has been carried out. The field tests like Standard Penetration Test (SPT), collection of undisturbed soil samples (UDS-7nos) from different

depths was undertaken. For sample collection 10cm dia steel tubes were inserted into the required soil layer by hammering and then lifting the same at the top. SPT was also performed using split spoon sampler with cutting shoe as per dimensions provided in I.S. 9640-1987. The study was conducted at two locations down to 10m depth. However, number of disturbed samples was also collected for granulometric and consistency limit study from shallow boreholes (14 nos.) drilled in the area. Laboratory tests to determine the engineering properties of the soil were carried out in ER, GSI. Lab. Undisturbed samples were subjected to various test for determination of bulk density (wet and dry), natural moisture content, consistency limit, mechanical composition (sand, silt, clay percentage), shear parameter (cohesion & angle of shear), Void ratio, porosity, degree of saturation, consolidation parameter etc.

4. Results and Discussion:

4.1 Textural Character of Soil:

To determine the soil texture a number of soil samples were drawn from different depth levels down to 10m. Data reveal that majority of the soil belongs to silt, silty loam and silty clay loam with occasional sand, sandy loam and silty clay group. Range of sand silt and clay percentage along with their average content (within bracket) at different depth is given below (table1).

Table1

Depth (m)	Sand%	Silt%	Clay%
0.3	1-30(5)	70-96 (86)	0-20 (8)
1.0	1-53(13)	39-95 (80	0-26 (7)
3.0	2-59 (13)	35-85 (71)	0-32 (15)
5.0	1-87 (16)	13-94 (71)	0-48 (12)
7.0	1-92 (13)	8-90 (68)	0-45 (18)
10.0	1-16 (5)	66-95 (83)	0-33 (11)

4.2 Mineralogy of Soil:

Mineralogically, the soil is more or less uniform in nature. Analytic data obtained by X-Ray reveals that quartz is the most dominant mineral. Among the clay mineral illite is dominant. Other minerals like chlorite and plagioclase feldspars occur in considerable amount. Minerals like amphibole, kaolinite and siderite are also occasionally found.

4.3 Chemical Character of Soil:

For determining chemical character of soil, samples (17 nos.) were drawn from various depths down to 10m. Analytical data reveal that pH of the soil varies

from 6.85 to 8.45 indicating neutral to moderately alkaline character. Organic carbon content ranges from 0.50% to as high as 8.24% (in peat layer) indicating medium to high value. Chloride content varies between 100-250 ppm indicating normal to high range. Na content of soil rangesfrom25ppm to 150 ppm, K content varies from 30- 125 ppm indicating low to high. P_20_5 content is always below 0.1%. Trace elements like Cu, Pb, Cd, Cr, Fe, Mn and As are generally low.

4.4 Geotechnical Character of Soil:

SPT result (N value): The SPT values obtained from the soil have been found to vary from 4 to 12. SPT values of top most strata consisting mainly of silt varies from 4 to 6.The strata down to about 8m consisting mainly of grey silty clay with decomposed vegetative matter (peaty) have SPT value ranging between 4 to 12. This wide variation may attribute to variation in composition and proportion of silt, sand and organic matter. However, SPT values of the organic rich layer (peat) vary from 4 to 6 signifying its soil consistency. SPT values (10) obtained from the 'kankar' bearing clay layer indicate the material to be in stiff state. N values along with C and Φ alone with their corresponding lithology are graphically represented in figure 3

Other Geotechnical Characters are:

Bulk density (yd and yw*):* Wet density of soil vanes between 1.79 and 2.04gm/cc. whereas corresponding dry density ranges from 1.18 to 1.69 gm/cc indicating moderately dense soil.

Moisture content (Mc): Natural moisture content vanes between 20.85% and 51.52% indicating the material to be in moderately soft state.

Cohesion (c): It ranges between 0.10 and 0.30 kg/cm^2 indicating low to medium cohesive soil.

Angle of shearing (Φ): The angle of internal friction varies from 15° to 24° depending on sand content of samples.

Void ratio (e) and porosity (n): Void ratio ranges between 0.59 and 1.28 indicating normal to high settlement problem. Porosity value ranges between 0.37 and 0.56.

Degree of saturation (S): The degree of saturation varies between 80.39% & 97.61 %.

Consistency limit: Soil of the area is characterized predominantly by fine grained texture with average sand, silt, clay content which varies between 2-16%, 75-87% and 4-16% respectively. Liquid limit (LL) varies from 33% to as high as 49% indicating medium to high compressible nature. Plastic limit (PL) ranges from 22-34% with corresponding plasticity (PI) index which varies from 10 to17 indicating low to

moderate swell potential. Average value of consistency limit of different depth is furnished below (table 2). Data reveal that PI value is increased with depth.

Table 2

Depth (m)	LL %	PL %	PI %
0.30	43 (28-61)	29 (23-35)	14 (5-30)
1.0	39 (22-61)	26 (19-30)	12 (1-32)
3.0	46 (25-64)	29 (20-34)	17 (0-34)
5.0	52 (39-69)	33 (25-40)	18 (14-31)
7.0	48 (28-66)	33 (26-43)	16 (2-26)
10.0	51 (39-65)	31 (24-40)	20 (10-31)

Bearing capacity and settlement characteristics: In order to estimate the bearing capacity of the soil layer, strip footing of 1.5m width down to a depth 1.5m has been considered. As the standing water level in all the holes varies from O.8m to 2.56m, the influence of groundwater level was given due cognizance and the ultimate bearing capacity was calculated. A strip footing 1.5m wide and down to a depth of 1.5m has been considered in calculating the bearing capacity. The settlement that may occur due to imposition of 1 kg/cm^2 pressure has to be calculated. The result thus arrived at two different locations is given below.

Location	Ultimate bearing capacity, (kg/cm)	Allowable bearing capacity, (kg/cm)	Settlement at a depth of 1.5m below the foundation (cm)
Altara (SPT/l)	8.06	1.00	1. 91
Garji (SPT /2)	3.75	2.19	2.11

Soil Group: Based on the united classification system on consistency limit the soil of the area can be classified into MI, MH, CH, ML, CI and CL group. Foundation characteristics of soil at different depths have been evaluated following the specification prescribed by IS: 1498-1970.A perusal of the data reveals that the soil in general possesses wide range of variation of foundation characters (good to poor bearing value). However, this evaluation gives a merely general guidance for treating the soil for a particular engineering purpose.

5. Conclusion:

In general, a fining upward sequence has been encountered in all the boreholes indicating deltaic environment of deposition with a waning energy condition through time. The near surface grey to dark grey clay with decomposed vegetative matter (Peat) which have wide occurrence in the present area suggests the existence of mangrove swamp forest in the north approximately 120 km inland from the present day coast during Holocene time (approx 6000 YBP). Mineralogical composition of the soil indicates its deltaic nature deposited under estuarine environment.

The detailed geotechnical study of soil indicates more or less moderately dense type of deposit within the limit of 10m depth. In sector where the soil profile is highly heterogeneous, if pile foundation is preferred, even good samples may not be representative of the whole of the various layers affected by pile. It is, therefore, very difficult to assign correct value of internal friction and as such the bearing capacity of piles has to be decided from the results of in-situ tests.

However, based on the analytical result as discussed above it may be concluded that low-rise structures may be conveniently raised in the area following the conventional building practice. High-rise structure may also be constructed for which suitable soil investigation would be necessary at the specific individual site. The result of such investigation will guide the functional design of the structure. For keeping foundation the 'peat' layers generally occurring between the depth 6-9 m bgl should be avoided.

Fig. 1 **LOCATION MAP OF CHANDANNAGAR, DIST. HOOGHLY, WEST BENGAL**

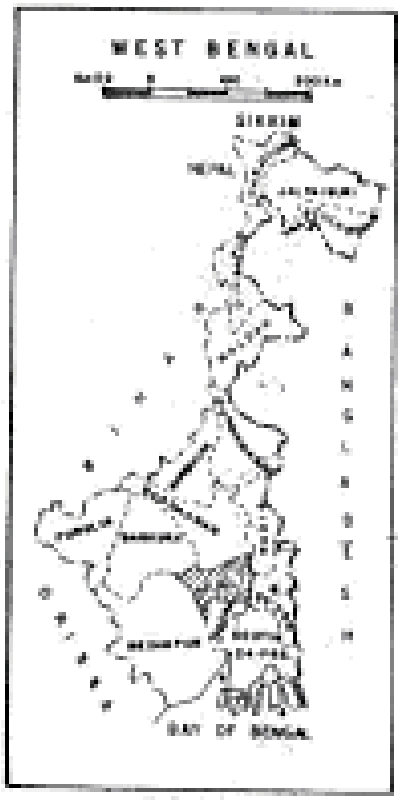

Figure 1

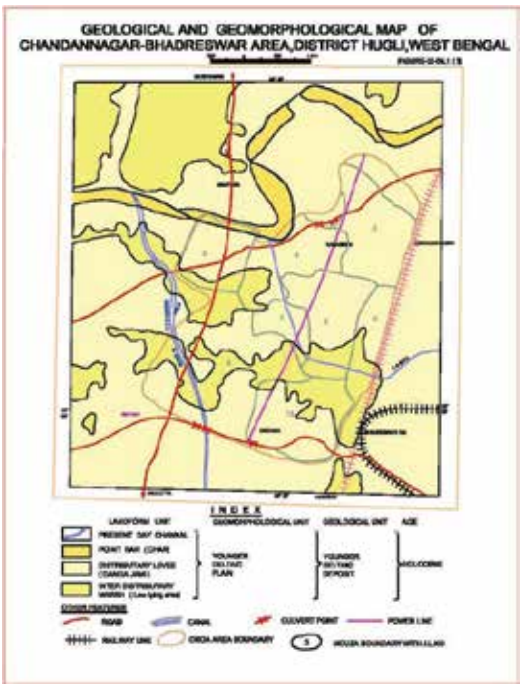

Figure 2

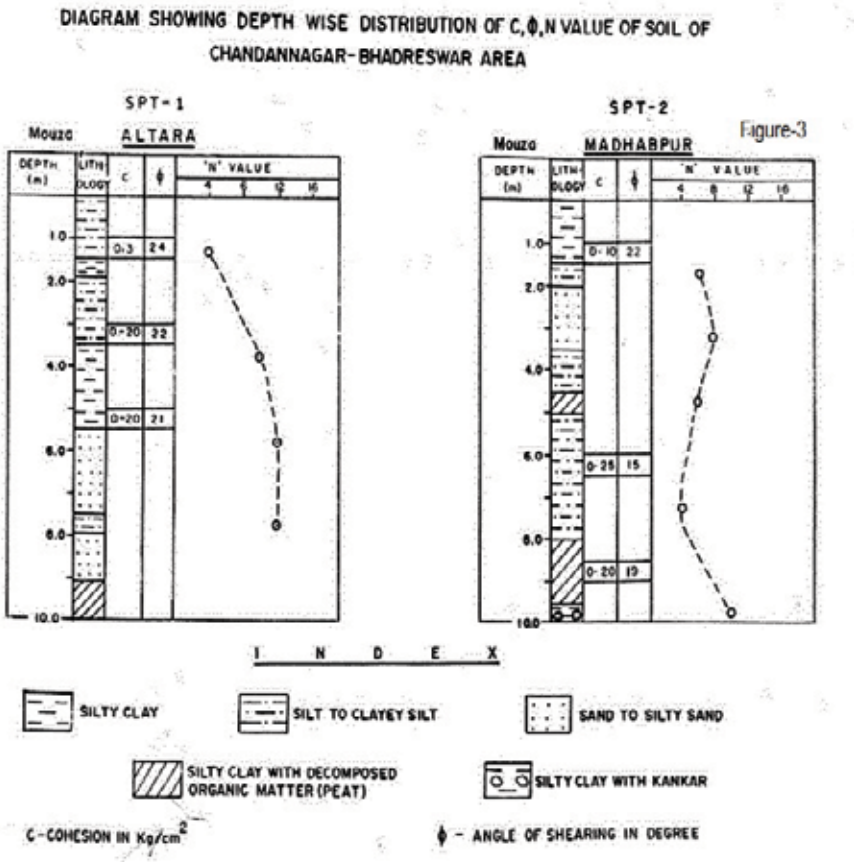

Figure 3