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Suggestion on Foundation Soil Layer Selection at Prabasi Palli: Constrained From Geological and Geotechnical Engineering Survey

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Abstract:- Environmental and Geospatial Solutions (EGS, Bangladesh) carried out a comprehensive geological and geotechnical engineering survey at the Prabasi Palli area, and submitted a soil test report to Geological Survey of Bangladesh (GSB). The purpose of this survey was to assess the feasibility of the site for building construction that at the same time was needed to be approved by GSB after evaluating the soil test report. Regionally, predominant occurrence of clay at very shallow depths, complex tectonic condition, and varied geomorphology, rendered the site for especial consideration and investigation. The occurrence of clay there corroborates the necessity of investigating the geological conditions as well as engineering properties of the soil layers, which is the preliminary concern for predicting sustainability of desired civil structures. EGS performed in situ Standard Penetration Test (SPT) along with sampling at different locations within the project area. The investigation strictly followed the GSB guideline. Two predominant geomporphologic units were identified there along with demarcating four major geotechnical units or soil layers, considering the collected soil samples and SPT N-value. Differing soil strength characteristics were recognized in either of the two geomorphologic units. The authors recommended on selection of foundation soil layer there by characterization of soil strength. They kept foundation design out of scope of this work.

Keywords: - *Borehole, Standard Penetration Test, N value, Bearing capacity, Foundation soil layer*

I. INTRODUCTION

Determination of subsurface geological and geotechnical properties is essential for an economic and intelligent design of foundation of civil structures, such as building, road, railway, dam, embankment, bridge etc. A reasonably accurate conception on the geological set-up in relation to the sedimentary history is a prerequisite to correlate or review the consistency of the subsurface section.

The Probasi Palli project was undertaken to raise some buildings in a planned way within the privately possessed area at the locality. Such works need GSB approval based on geological and geotechnical engineering survey report on the area. Therefore, EGS, as a client of Habitat Planning Associates Ltd. carried out the survey. The subsurface geological and geotechnical investigation works include identification and delineation of subsurface geological and geotechnical units using SPT borehole data. 13 boreholes up to 20m depth and 2 up to 30m along with standard penetration test (SPT) have been completed at different selected positions as per guidelines of GSB. Moreover, samples were collected at 1.5m interval for geotechnical laboratory tests with a view to preparing a complete geological and geotechnical engineering report on the site.

Probasi Palli Project area is situated in the Eastern periphery of Gazipur Sadar Thana and broadly within Dhaka-Tongi or Gazipur-Tongi region of Bangladesh that covers parts of Khilgaon and Kamaira village of Pubail Union. The area is nearly 45 km by road from Dhaka. It is bounded approximately by latitudes from $23^{o}55'27.8472''$N to $23^{o}55'31.386''$N and longitudes from $90^{o}28'0.725''$E to $90^{o}28'3.961''$E from North to South, and by latitudes from 23°55′27.8472″N to 23°55′26.526″ N and longitudes from 90°28′0.725″E to from 90°28′17.645″E from West to East.

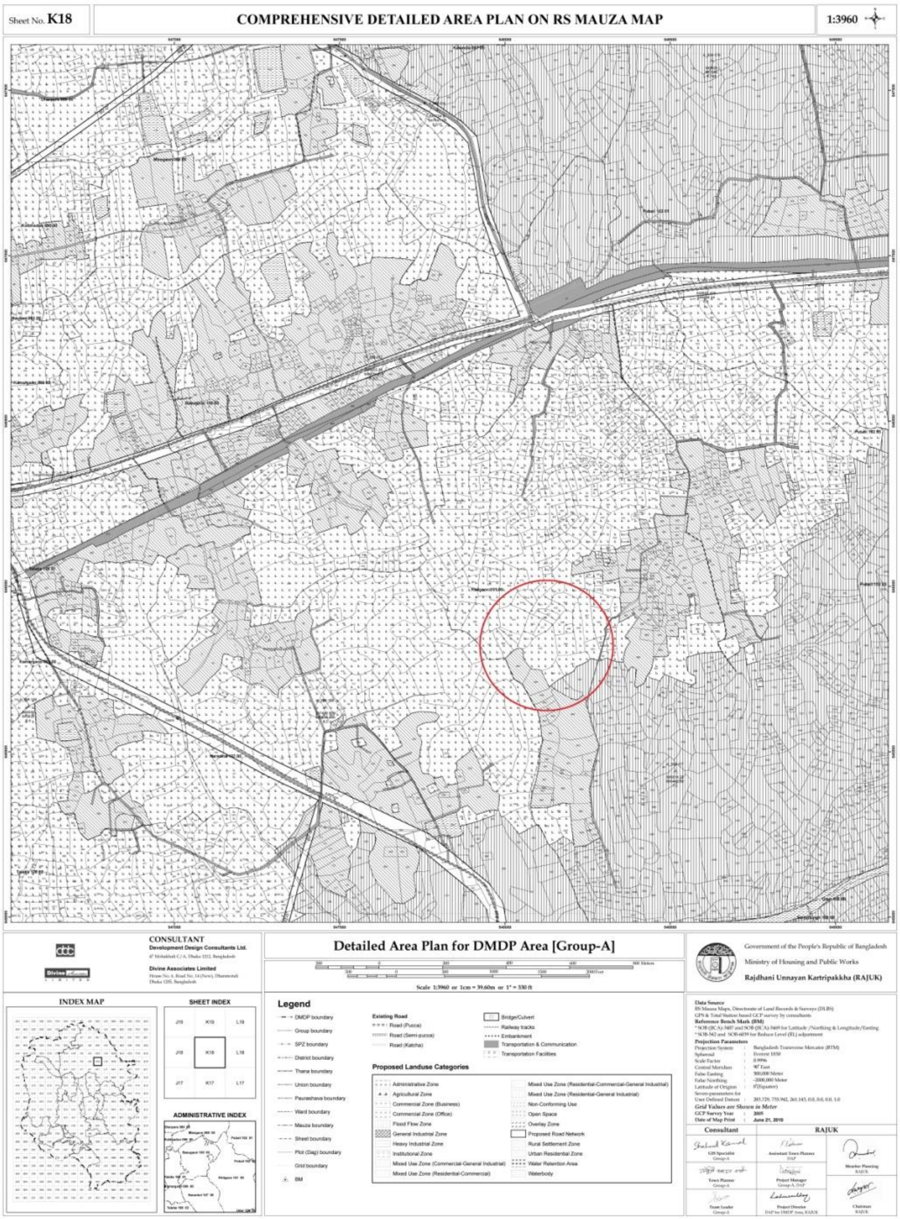


Figure 1. Location map of the project area (red circle highlights the project area) (source: Rajdhani Unyayan Kortripakkha (RAJUK))

The area is of rugged topography and relief, comprising of characteristics of the Pleistocene terraces. Small discreet terraces with adjacent low and flat flood plains are distinguishable. Highest topography recorded is 11.89 m and the lowest is 7.01 m.

Nagda river, a distributary of Balu river, is adjacent to the are in the South. Natural small channels (most appropriately Khal in local name) in a cross-cutting manner occupies around the terraces of the area. They are dry in the dry season and water flows through them during wet season. Overall drainage pattern of the area is dendritic to trellis.

It is within a village area and density of population is medium. Not much structure have been raised. Flat lands are mainly used for irrigation and habitation is seen on the terraces.

Figure 2. Represents topography, drainage and landuse pattern at the locality.

II. METHODOLOGY

Standard penetration Test (SPT) was conducted at the site by 15 boreholes. Among them, 2 were up to 30m depth and the others were up to 20m depth. Standard of testing was ASTM D1586. Samples were collected at 1.5 m interval and SPT N value was determined from blow counts. Borehole log has been prepared by documenting the borehole data. This data has been used for subsoil stratification and foundation soil layer selection. Borehole layout map, N value correction and log sheets have been presented in Appendix II.

III. GENERAL GEOLOGY

SURFACE GEOLOGY

The project area lies within Dhaka-Gazipur terrace, a part of Madhupur Tract, located in the central part of Bangladesh. The tract is a structural high that extends from the folded hills in the eastern fringe of Bengal basin. This elevated area is only a few meters above the surrounding rivers such as the Buriganga and Turag on the west and the Balu on the east (Alam and Aurangzeb, 1975). Locally, the Tract is subdivided into the Dhaka and Bhawal Garh terraces [1]. The terraces are parts of an inlier, a technical term for an elevated area surrounded by lowlands. The elevation of the Tract varies from 2 to 14 m above mean sea level. The terraces are surrounded by the Ganges-Meghna floodplain in the south, the old Brahmaputra floodplain in the east and the Jamuna floodplain in the west. It is formed of Madhupur Clay Residuum and is exposed as a monoclinal limb. Due to higher elevation than the surrounding plains, the terrace has become a seat of urban and industrial development [2]. A series of dendritic to trellis drainage system has developed on the terrace following the fractures or shear zones [1].

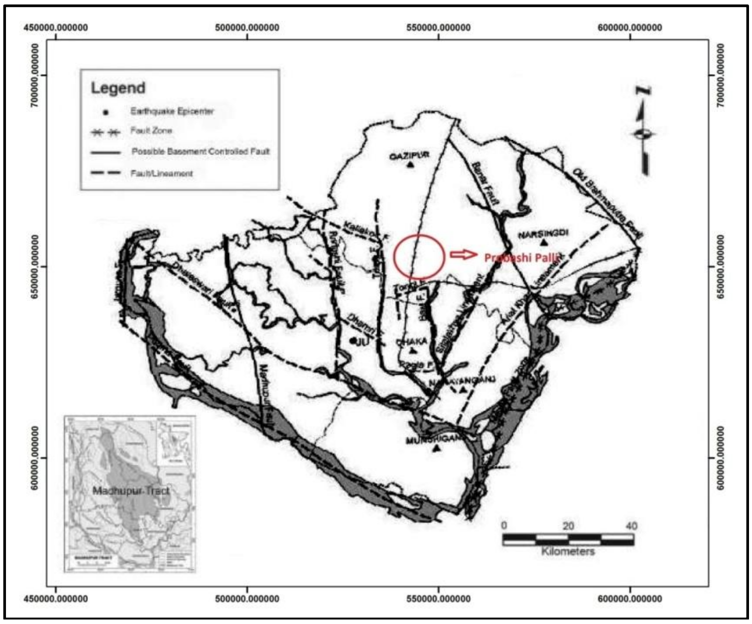


Figure 3. Geological map of map of Dhaka-Tongi region—after EPC/ MMP 1991 and Khandoker 1987 (inset) (red circle in the figure shows the project area)

TECTONIC SET-UP

Stable shelf (SS) in the Northwestern region, Bengal Foredeep (BF) and hinge zone between SS and BF broadly describes the tectonic subdivision of Bangladesh. The Bengal basin is asymmetric; the thickness of the sediments increases toward the south and east to more than 16 km (Curray and Moore, 1971; Murphy, 1988). Interpretations of the tectonic setting of the basin are varied and rather convolute. Desikachar (1974) considered the Bengal basin as a pericratonic basin of the Indian plate. His proposition suggests that the deeply subsided central portion of the Bengal basin forms part of the Indian plate, whereas the eastern basin margin is actually part of the Burmese plate. In his view, the Burmese plate has moved toward the Indian plate beginning in the Miocene, and just east of the Ninety-East ridge (or its northern extension), where he inferred maximum subsidence, the Burmese plate overrode the Indian plate to form a subduction zone between the two plates [4]. Today most authors agree that convergence between India and Burma has resulted in subduction of oceanic crust beneath Burma, with the trailing margin of India currently passing obliquely into the foreland of the Indo–Burman ranges (Murphy, 1988; Mukhopadhyay and Dasgupta, 1988; Alam et al., 2003). This convergent margin has been complicated by right-lateral strike-slip motion (e.g., Kaladan fault, Sagaing fault), possibly throughout the history of the collision (e.g., Ni et al., 1989).

The project area lies within the Bengal foredeep or the deeper part of the Bengal basin. The deeper part of the Bengal basin, a zone of very thick sedimentary strata lying over deeply subsided basement, was subdivided based on gravity studies. The division is a northwestern platform flank just east of the Hinge zone, and an eastern folded flank that includes the Chittagong Hills and the Sylhet trough in the northeastern part of the Bengal basin (Khandoker, 1989; Khan, 1991). The platform flank shows small-amplitude, isometric or geographically equant anomalies, whereas the folded flank exhibits large-amplitude, linear or elongated anomalies (Bakhtine, 1966). The Sylhet trough is a conspicuous trough of thick sedimentary fill along the northeastern part of the Bengal basin (Holtrop and Keizer, 1970; Woodside, 1983). The Sylhet trough is a depositional low, located just south of the crystalline Shillong Plateau with a structural relief of about 20 km between the trough and the neighboring plateau (Murphy, 1988; Johnson and Nur Alam, 1991) [4]. The folded flank of the deeper basin is composed of elongated folds of north–northwest to south–southeast trend. Structural complexity of the folded flank increases from west to east and merges into the Indo– Burman ranges farther east (Khan, 1991).

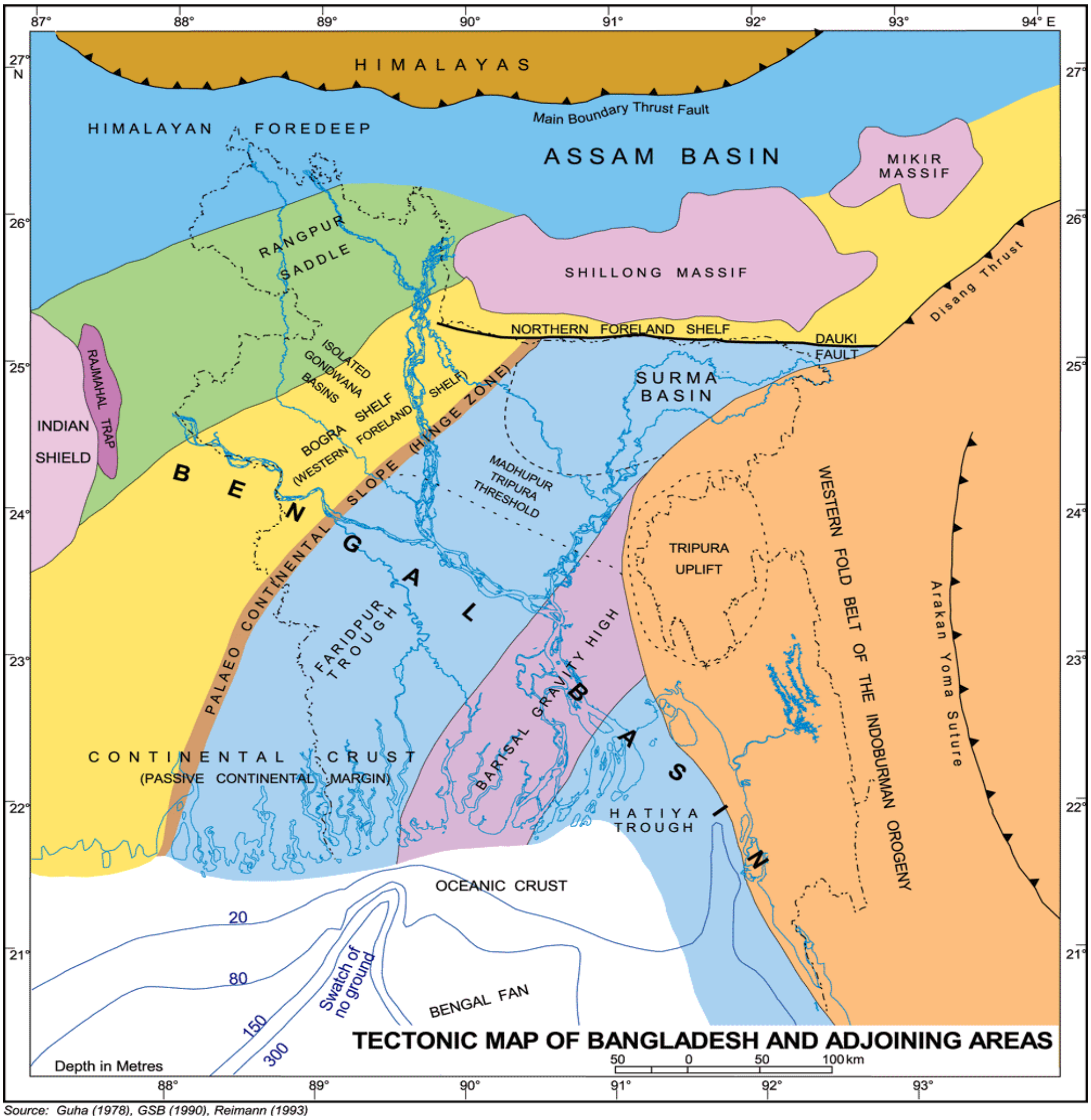


Figure 4. Regional tectonic map of Bangladesh (Source: Guha (1978); GSB (1990); Reimann, 1993).

The Madhupur tracts are broken into several fault blocks, the surfaces of which are a few meters higher than the nearby floodplain land. Most of the authors including Fergusson (1863), Hirst (1916), Morgan & McIntire (1959), Rizvi (1975), Khandoker (1987&1989), Huq et al. (1991), Coates et al. (1988, 1990 &1991), A1am (1988 & 1995) and Kamal (1998, 2005) believed that the Madhupur tracts represent tectonically uplifted surface. Some researchers including Monsur (1995) opined that the La1mai hills and the small portion of Madhupur (locality) represent tectonically uplifted blocks but the entire Barind and the major portion of the Madhupur tracts were originated by erosional processes, rather than structural. [3]

According to the second thought, during glacial and interglacial periods the combined effects of seaward subsidence and landward uplift have caused a warping of the alluvial terraces, which are called the ‘Pleistocene terraces’. Afterwards these dissected valleys were filled up with alluvial sediments, generating a recent floodplain surface at lower position than the initial Pleistocene Terraces. [3]

A further research, therefore, is needed to bring forward the history of the formation, deformation of these tracts by using modern equipments, which may help to resolve the problems associated with origin and evolution of the tracts.

Subsurface Geology

The terraces are surrounded by the Ganges-Meghna floodplain in the south, the old Brahmaputra floodplain in the east and the Jamuna floodplain in the west [1]. Alam (1988) identified the following geological units in and around the Dhaka-Tongi area.

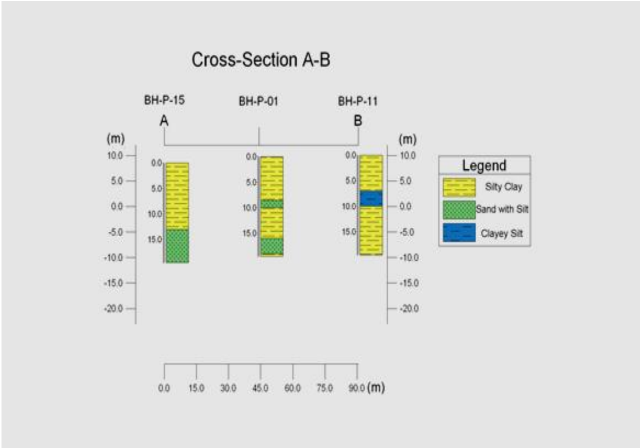
Table 1. Stratigraphic succession in and around Dhaka-Tongi area. [1]

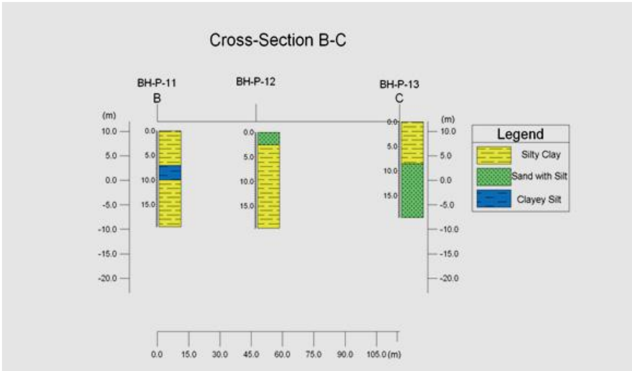
Age	Formation	Lithology	Thickness (meters)
Holocene	Alluvium	Lowland: River bed deposit: Grey sand and silty sand, medium to fine grained.	0-9
		Local unconformity	
		Natural levee and interstream deposit: Sandy silt, silt and loam, grey and friable. Backswamp and depression deposits: Clay and silty clay, grey, bluish grey to dark grey.	1.21-4.7 0.61-1.5
		Highland: Silt and clay above the present flood level.	0-3.5
Pleistocene	Madhupur Clay	Red clay: Light brown to brick red and massive, pisolitic with fossil wood, ferruginous and calcareous nodules and surficial deposits of slag. Mottled clay: Earthy grey with patches of orange, brown colour, massive and containing calcareous and ferruginous nodules Unconformity	31
Pliocene	Dupi Tila	Sandstone: Yellow to yellowish grey, massive, cross bedded, mostly fine to medium grained containing scattered gravel lenses, moderately consolidated.	90+

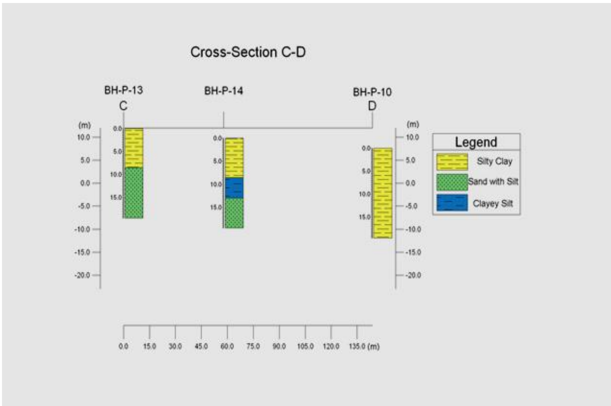
Subsurface geology of the project area was studied using 15 boreholes up to 20m depth, two of which is of 30m depth. Geological lithologs and cross-sections obtained from the boreholes has been presented in figure 5. Clay, silty clay, organic clay with iron concretions and organic materials occupies the Lithology of the area. Reddish brown, yellowish brown, grey colors with mottling are prominent in the clays. Some localized sand deposits have also been found. The stratigraphic succession of the area along with geotechnical units, established from the borehole data is given in the following table.

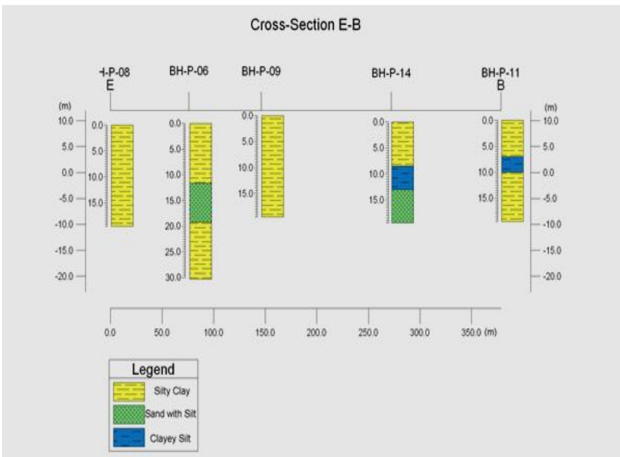
Table 2. Generalized stratigraphic succession of the Probashi Palli project area.

Age	Formation	Geotechnical Units	Lithology	Thickness (m)
Holocene	Alluvium	Unit 1	Lowland: Floodplain deposit: Grey to light grey sand, fine grained.Local unconformity	1.5
		Unit 2	Backswamp and depression deposits: Grey, light grey, dark grey, black clay and silty clay with organic materials	3-7
Pleistocene	Madhupur Clay	Unit 3	Light brown to brick red mottled clay with some silt, organic materials and iron concretions. Light grey with patches of orange, brown, black color containing silt, organic materials and iron concretions.	20+
Plio-Pleistocene	Dupi Tila	Unit 4	Unconformity Massive sand: Yellowish brown very fine grained micaceous sand with silt and clay	3-7.5+


Cross-Section A-B
BH-P-15
A
BH-P-01
BH-P-11
B
(m)
(m)
Legend
Silty Clay
Sand with Silt
Clayey Silt
(m)


Cross-Section B-C
BH-P-11
B
BH-P-12
BH-P-13
C
Legend
Silty Clay
Sand with Silt
Clayey Silt


Cross-Section C-D
BH-P-13
C
BH-P-14
BH-P-10
D
Legend
Silty Clay
Sand with Silt
Clayey Silt


Cross-Section E-B
-I-P-08
E
BH-P-06
BH-P-09
BH-P-14
BH-P-11
B
Legend
Silty Clay
Sand with Silt
Clayey Silt

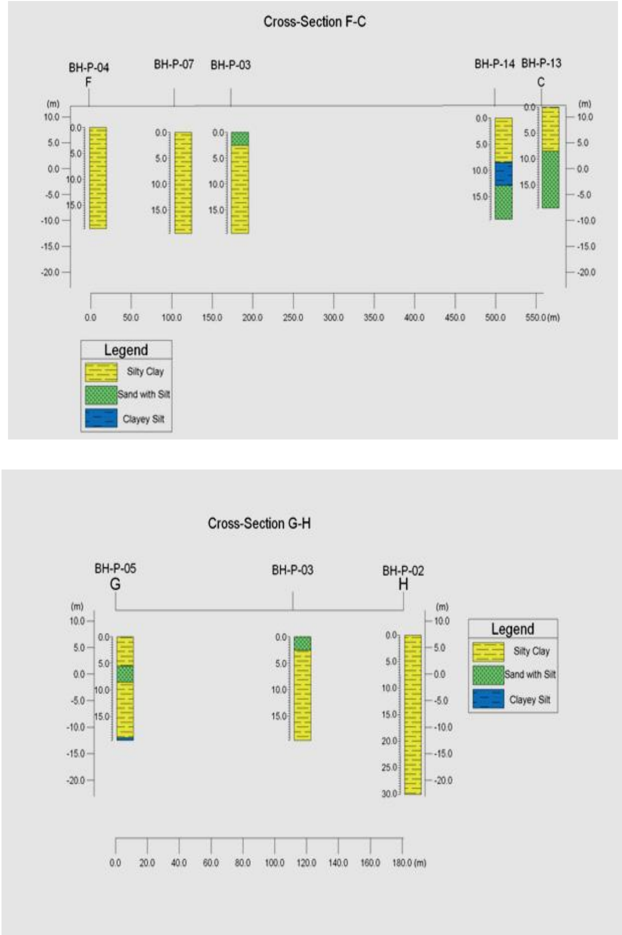


Figure 5. Presents litho logs and geological and cross-sections obtained from the boreholes.

Geomorphology And Geologic History Of The Site

Geomorphologically, the area shows two clear units. One is the inlier type Pleistocene terraces and the other is the surrounding shallow valley type flat lands. These low lands remain under water during the monsoon season of Bangladesh and wet during the winter. The villages recognize the mound type terraces, and the adjacent low lands are recognized by farm lands.

The lower Dupitila Sandstone Formation was deposited in fluvial environment of Plio-Pleistocene time. The Madhupur Clay deposit of the project area is of early Pleistocene time and originated in fluvial environment (Md. Hussain Monsur, Banglapedia), which later suffered Neotectonic upliftment and Late Pleistocene dissecting events that remained in inlier form also popularly known as Pleistocene terraces or tracts. Unconformity between Dupi Tila and overlying Madhupur Clay Formation indicates a depositional break in the area. The adjacent low land of the area contains recent flood plain deposits.

IV. SUBSOIL STRATIFICATION

Soil layer belonging to the subsurface of the project site was investigated by boring and sampling; up to 30m depth in boreholes BH-P-02 and BH-P-06, and others were limited to 20m. From N value range and visual sample classification, we divided the soil layer there into 4 subsoil units and named as:

1. Unit 1 (sandy)
2. Unit 2 (organic clay)
3. Unit 3 and (clay)
4. Unit 4 (sandy)

These units also correlate well with our stratigraphic subdivision presented in the Table 2 and hence, the same names have also been adopted here.

Unit 1, consisting of grey to light grey very loose to loose fine-grained sand, having high water content. This unit has been encountered in only two boreholes (BH-P-03 and BH-P-12) up to 1.5m depth. SPT “N” value range (3-4) has been reckoned for this unit. The deposits may be of recent flood plain origin.

Unit 2, mainly grey and dark grey clay and silty clay with organic content, has soft to very soft engineering property, and high water content. This unit is found in BH-P-02 and BH-P-06, BH-P-07, BH-P-08,. "N" value range (1-4) has been found for this unit. The unit displays very recent alluvial nature.

The geotechnical unit 3 is red and mottled in color, medium stiff to hard. Clays with higher SPT values are associated with iron concretions. From borehole observation, we got the occurrence of this unit throughout the project area at various depths with an average thickness of about 16m. The unit in most cases was found at the surface of the highlands of the area while found underlain by Unit 1 and Unit 2 at low lands, mostly at 7.5m depth from the surface. Maximum N value (44) was found in this unit 19.5m depth. From table 1 and table 2, it is discernible that Unit 3 represents the Madhupur Clay Formation, which has 31m of regional thickness (Alam, 1998). N-value range (3-44) has been reckoned at various depths.

Unit 4 is composed of yellowish brown medium dense to dense fine grained massive micaceous sand with silt and clay. The sand body is possibly equivalent to the Plio-Pliestocene (upper) Dupitila Formation; is medium dense to dense in its engineering property. The formation has regional thickness of more than 90m (Alam, 1998).. BH-P-01, BH-P-06, BH-P-13, BH-P-14, BH-P-15 are the boreholes where this unit has been encountered. SPT value range (10-41) was counted at various depths. This unit was found only within the inliers, underlain by the Unit 3; occurring from 9 to 16.5m below the surface.

There has been seen a general trend of increasing N value with depth. Subsoil stratification and there visual characteristics along with N value range has been summarized in the following table. The geotechnical units yielded from sub-soil stratification have been presented by geotechnical cross-sections in figure 6.

Table 3. A summary of subsoil units with their N value range and boreholes of occurrence at Prabashi Palli project site.

Unit	Soil description	Boreholes	Depth range (m)	SPT N value range
Unit 1	Grey to light grey very loose to loose fine grained sand	BH-P-03; BH-P-12	up to 1.5	3 to 4
Unit 2	Mainly grey and dark soft to very soft grey clay and silty clay with organic content	BH-P-02	0 to 7.5	1 to 4
		BH-P-06	0 to 7.5	
		BH-P-07	0 to 4.5	
		BH-P-08	0 to 7.5	
Unit 3	Red, mottled medium stiff to hard clay (Madhupur Clay) with rapid occurrence of iron concentration.	BH-P-01	0 to 7.5	3 to 44
			9 to 16.5	
			19 to 19.5	
		BH-P-02	7.5 to 30	
		BH-P-03	1.5 to 19.5	
		BH-P-04	0 to 19.5	
		BH-P-05	0 to 4.5	
			7.5 to 19.5	
		BH-P-06	6 to 12	
			18 to 30	
		BH-P-07	4.5 to 19.5	
		BH-P-08	7.5 to 19.5	
		BH-P-09	0 to 19.5	
		BH-P-10	0 to 19.5	
		BH-P-11	0 to 19.5	
		BH-P-12	1.5 to 19.5	
		BH-P-13	0 to 9	
		BH-P-14	0 to 9	
		BH-P-15	0 to 13.5	
Unit 4	Yellowish brown medium dense to dense fine grained massive micaceous sand with silt and clay	BH-P-01	16.5 to 18	10 to 41
		BH-P-06	12 to 19.5	
		BH-P-13	9 to 19.5	
		BH-P-14	9 to 19.5	
		BH-P-15	12 to 19.5	

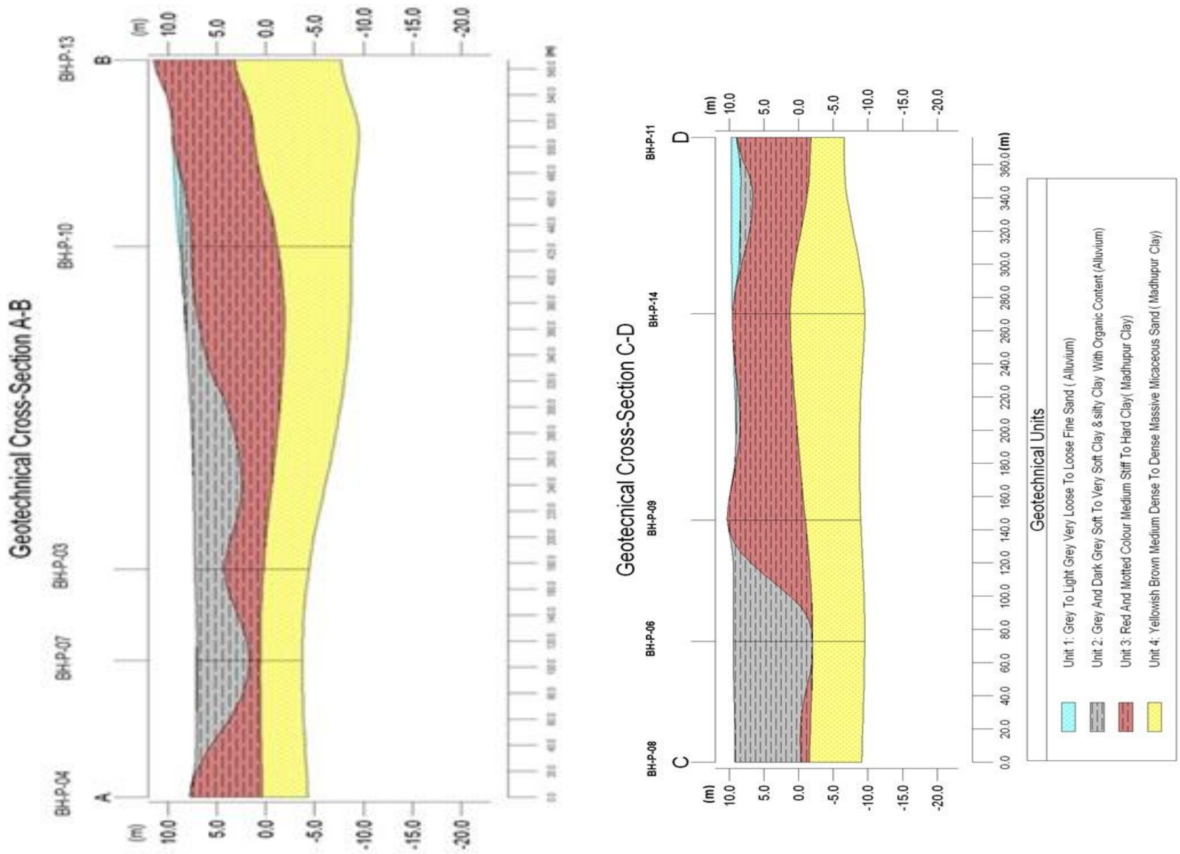


Figure 6. Cross sections along line A-B & C-D showing four geotechnical units as identified at the project site

Soil Strength Characterization and Discussion

Consistency of cohesive soil deposits and relative density of cohesionless soil deposits have been described in accordance with internationally accepted terms, which give approximate indication of strength of soil strata encountered at different depths. For cohesive soil, consistency terms indicate the following approximate bearing capacity of the different soil strata estimated on the basis of SPT N-values.

Table 5. Strength characteristics of cohesive soils

Consistency	SPT N-value	Allowable bearing capacity (KPa)
Very soft	0-2	<25
Soft	2-4	25-50
Medium	4-8	50-100
Stiff	4-15	100-200
Very stiff	15-30	200-400
Hard	>30	>400

For cohesionless deposits, relative density terms give the following approximate strength characteristicsbased on SPT N-values.

Table 6. Strength characteristics of cohensionless soils.

Relative density	SPT N-value	Estimated shearing angles	Strength characteristics
Very loose	>4	28^{o}	Very poor
Loose	4-10	30^{o}	Poor to fair
Medium dense	10-30	32^{o}	Fair to good
Dense and very dense	>30	34^{o}	Good to excellent

Both geological and geotechnical cross-section has been prepared using lithological and SPT data of the fifteen boreholes at the project site. It is remarkable that soils of high land and low land show different strength characteristics. Unit 1 and Unit 2 were encountered only in the low lands overlying Unit 3. The upper two units are completely absent in the Pleistocene tracts. Again, soil units of the low lands show low consistency (the N value was less than 30 in all of the boreholes at the low lands); on the other hand, soil units in the terraces show higher consistency (N value 44 and 41 was found at Unit 3 and Unit 4 respectively). Overall trend of SPT values showing increasing trend with depth, except in the Unit 3 of the higher ground. Unit 4 was not found in the low lands.

From geological and geotechnical point of view, it is clear that the soil subdivision Unit 1 has low SPT value, very loose to loose nature, and has very poor strength. Again, clayey Unit 2 is rich in organic matter, very soft to soft in nature, and has very limited allowable bearing capacity. Moreover, organic matter in soil highly attributes rapid settlement after getting exposure to any load. Hence, shallow foundation should be discarded there unless top soil improvement. Unit 3 of the low lands consists of very stiff clay, allowable bearing capacity of which varies from 200-400KPa. Therefore, we suggest that Unit 3 can be chosen as foundation soil layer there.

Only Unit 3 and Unit 4 were encountered in the tracts. Unit 3 there consists of hard clay mostly, 16.5 m below the surface, which has bearing capacity of over 400KPa. Again, Dense to very dense sand was found in the Unit 4 that has good to excellent strength. So both of these units can be chosen as foundation soil layer, depending on where maximum N-value occurred.

V. CONCLUSIONS

Probasi Palli Project area presents two distinct geomorphological subdivisions, Pleistocene terrace, and adjacent low lying shallow valley type lands, each showing difference in strength of the soil units. A comprehensive geological and geotechnical engineering survey was conducted there; primarily by 15 boreholes. Depth of two SPT boreholes was 30m whereas others were 20m. Based on borehole samples and SPT blow counts, 4 soil layers were identified each of which having distinguished lithology, depositional environment, engineering properties, and soil strength. Considering the strength characteristics of soils, we suggested to discard shallow foundations at the low lying lands unless top soil improvement, while to select the Madhupur Clay equivalent Unit 3 as the foundation layer. On the other hand, we recommended both Unit 3 and Unit 4 (Dupitila Sandstone Formation equivalent) as foundation soil layer, where maximum strength occurs. Further detailed study could be conducted by the geotechnical engineering laboratory test data. Also seismicity of the area and soil response should be taken care of.

ACKNOWLEDGEMENT

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APPENDICIES

APPENDIX I

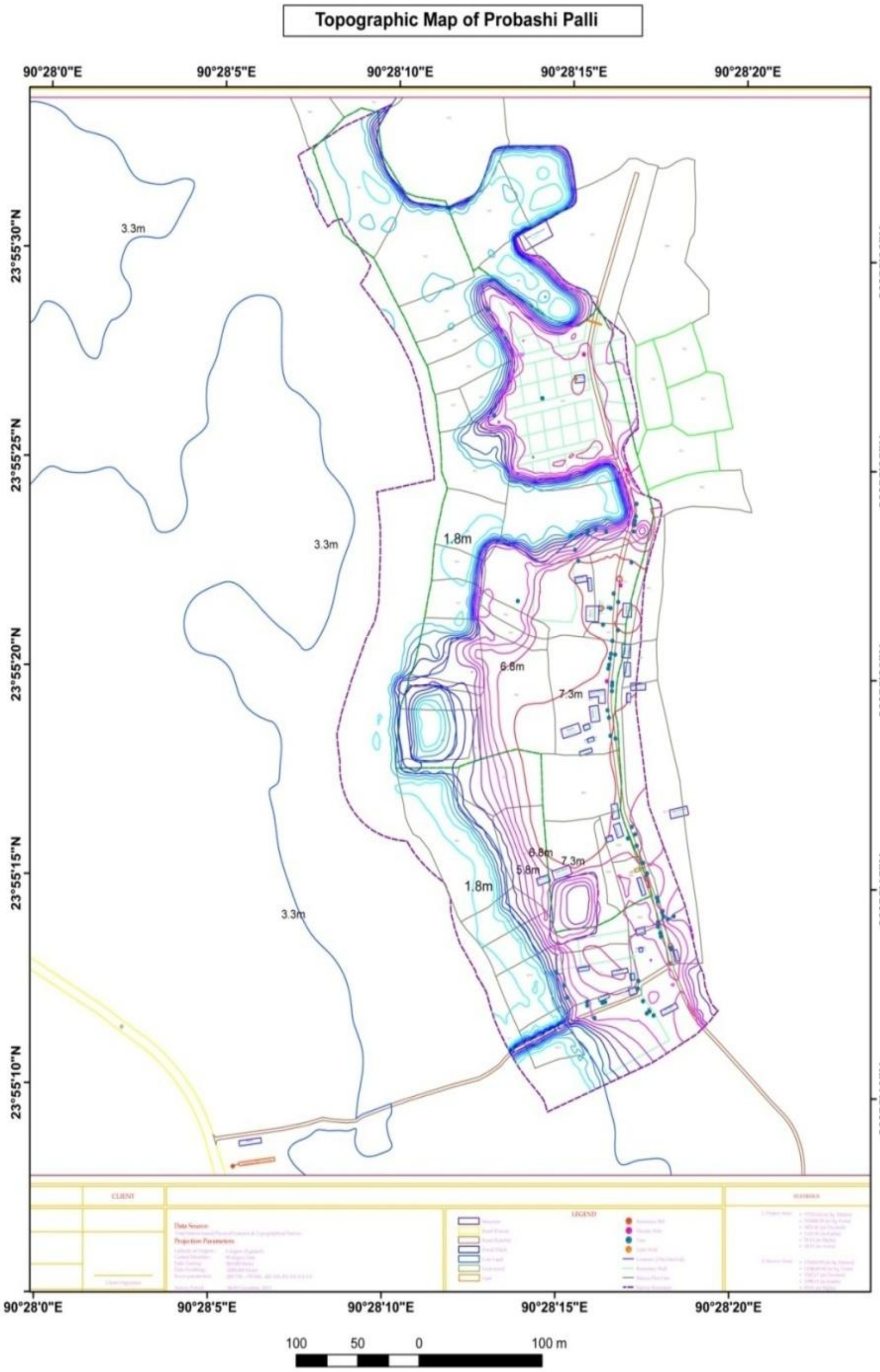


Figure 7. Topographic map of the project area (source: Habitat Planning Associates Ltd.)

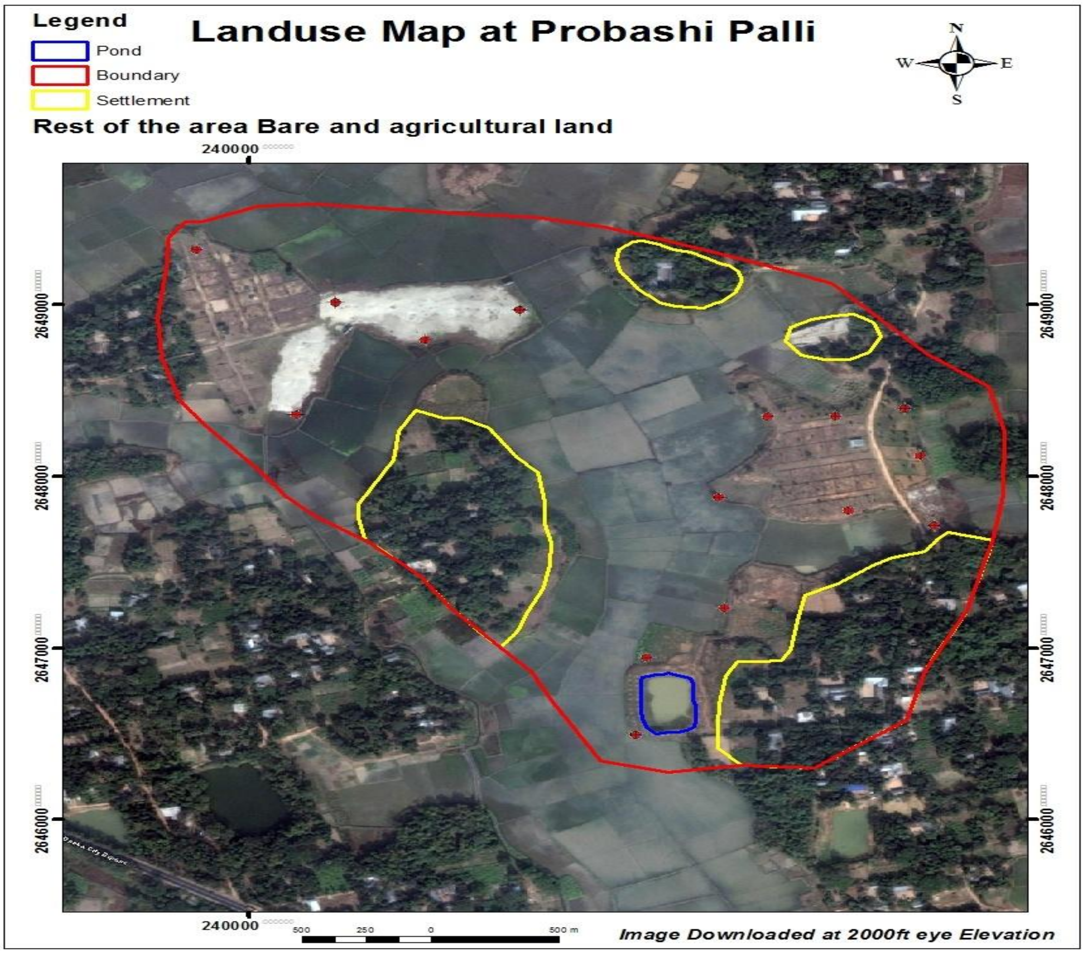


Figure 8. Existing landuse map of the site.

APPENDIX II

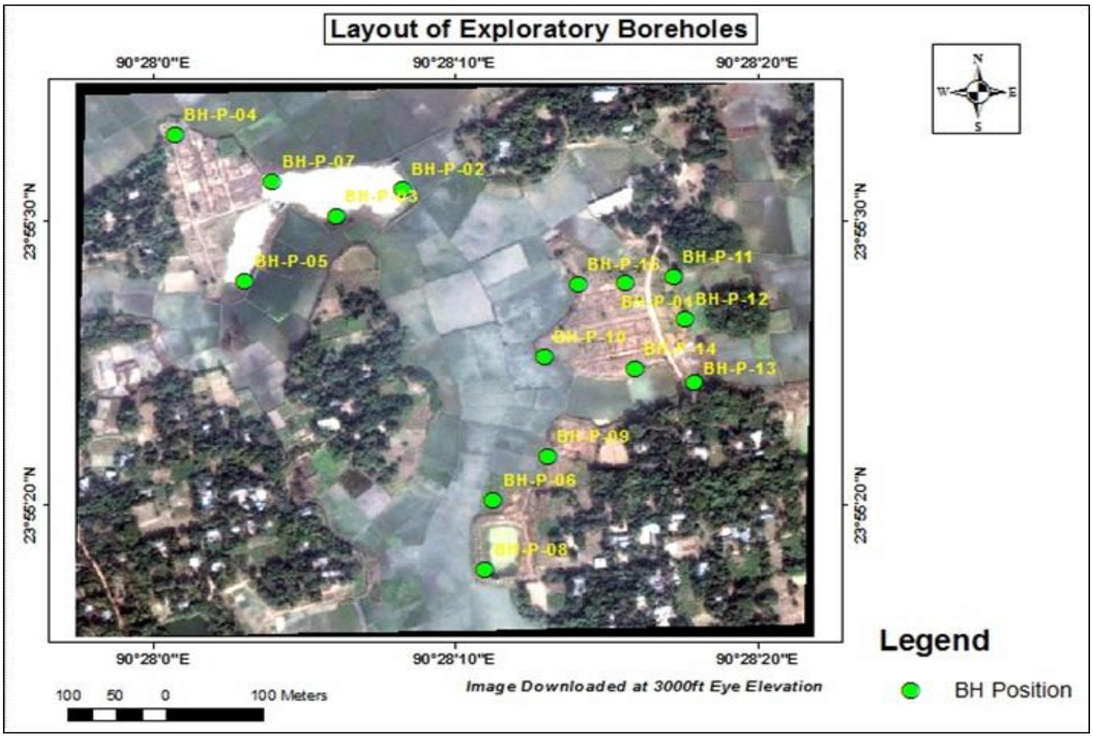


Figure 9. Exploratory boreholes layout map.

N Value Correction

Even after standardization, many variations still are significant, which means the test has a poor repeatability. The principal variants are:

- Method of drilling
- Cleanliness of the bottom of the hole (lack of loose dirt) before the test
- Presence or lack of drilling mud
- Diameter of the drill hole
- Height difference of falling hammer
- Number of turns of the rope around the cathead.
- Mass of the anvils that the hammer strikes
- Friction in rope guides and pulleys
- Wear in the sampler drive shoe
- Straightness of the drill rods
- Presence or absence of liners inside the samplers
- Rate at which the blows are applied.

So, the authors feel the necessity to correct the N-value for the selected17 boreholes. The variations in testing procedures may be at least partially compensated by converting the N recorded in the field to N_{60} as follows (Skempton, 1986):

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60} \qquad (1)$$

Where, N_{60} = SPT N- value corrected for field procedures

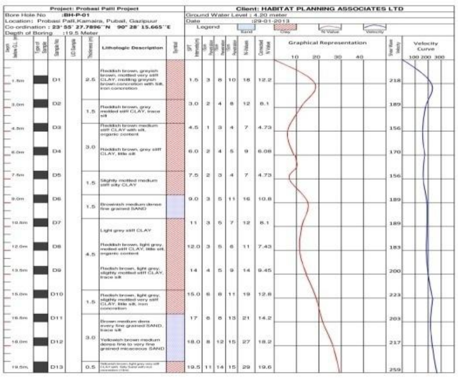
Em= hammer efficiency = 0.45 (for Dount hammer)

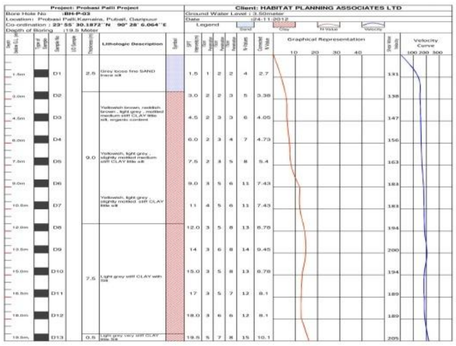
C_B= borehole diameter correction = 1.0

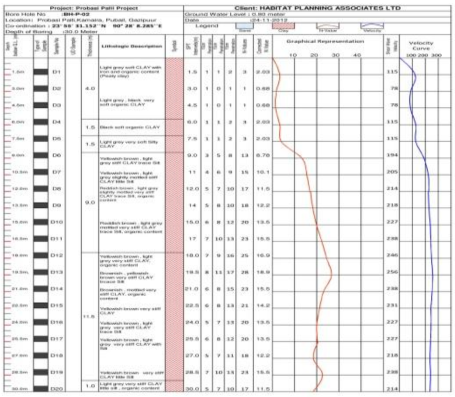
Cs= Sampler Correction = 1.20

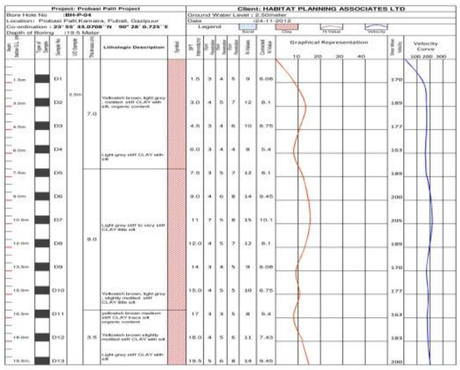
C_R= rod length correction 0.75

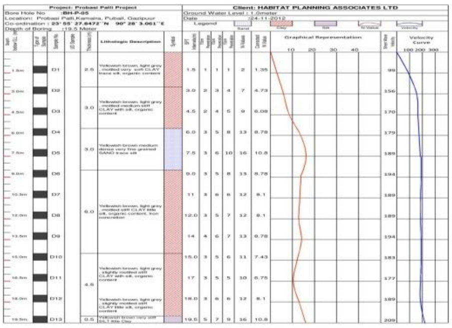
N= SPT blow counts recorded in the field

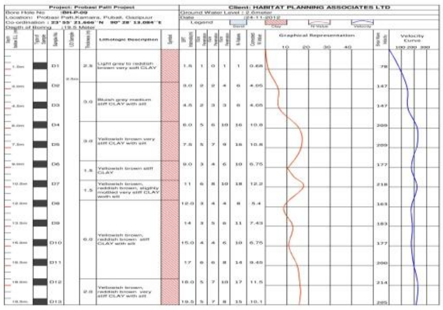


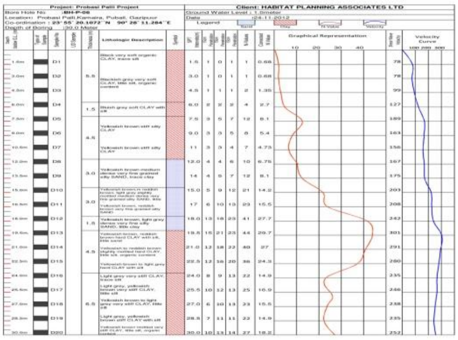


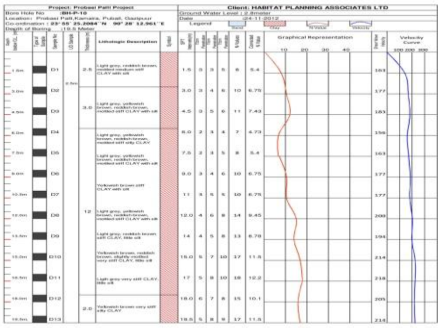


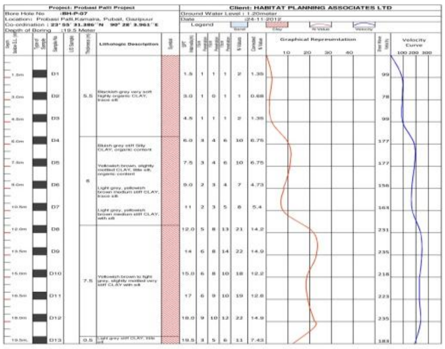


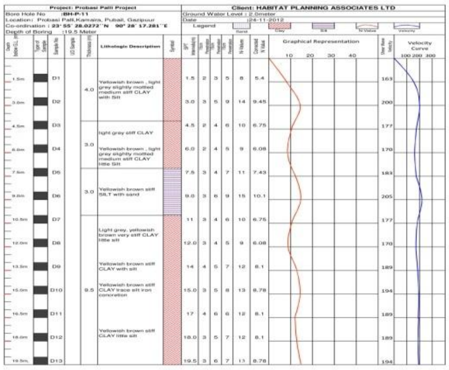


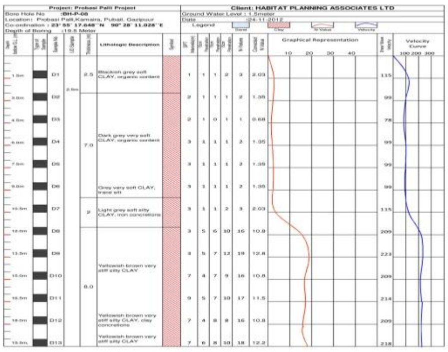


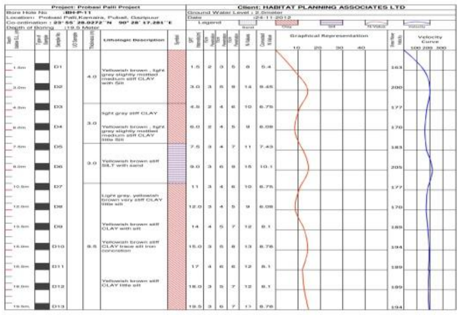


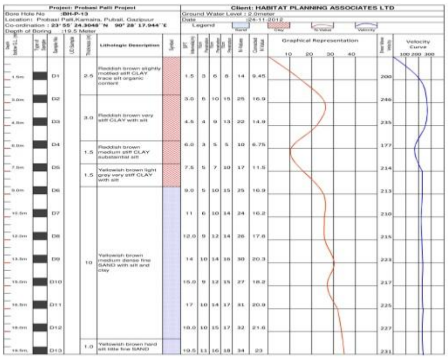


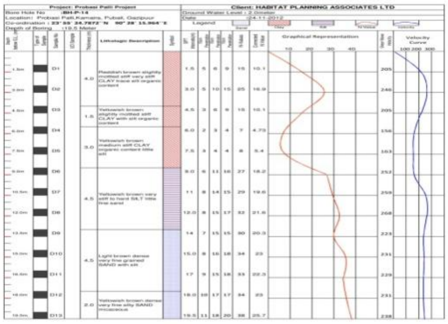












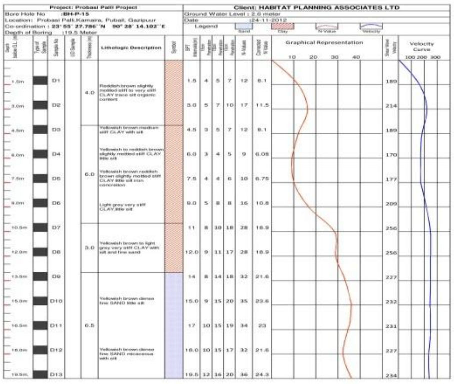


Figure 10. Log sheets of the 15 SPT boreholes completed at Prabasi Palli

APPENDIX III

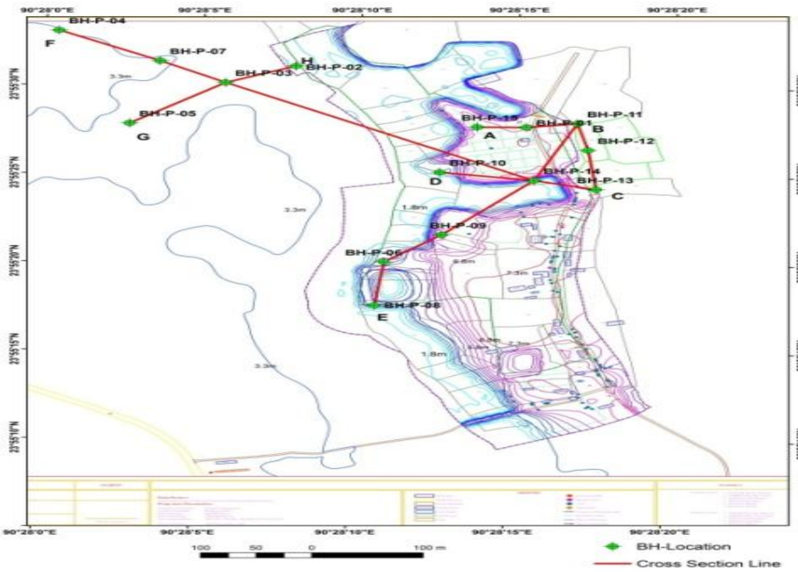


Figure 11. Map showing lines A-B, B-C, C-D, D-E, E-F and F-G taken for geological Cross-sections as in figure 5.

APPENDIX IV

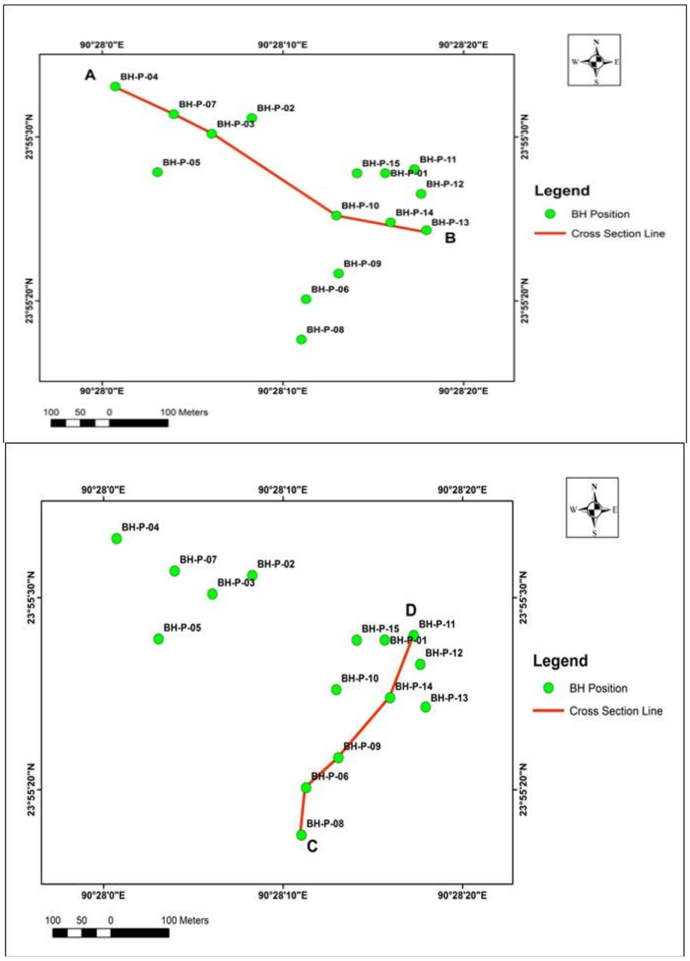


Figure 11. Maps showing line A-B and C-D taken for geotechnical cross-sections as in figure 6.