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Mineralogical Influence on the Geotechnical Properties of Shallow Landslide Hazard Site Soils of Rangamati Sadar Area, Bangladesh

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Abstract

This study has evaluated the mineralogical influence on geoengineering properties of some soil samples of the landslide site in the Rangamati Sadar area, Bangladesh. This research has assessed field data interpretation, i.e. borehole lithology, SPT data analysis, the mineralogical composition, and basic engineering properties such as grain size analysis, moisture content, specific gravity, Atterberg limit i.e., liquid limit, plastic limit, plasticity index, engineering soil classification of Rangamati Sadar, Bangladesh. The studied soil is broadly divided into cohesive and non-cohesive soils and the SPT values increase with increasing depth. The field SPT values suggest that the ground condition of the studied cohesive soil is mainly stiff to hard silty clay (CL-ML) and non-cohesive soils are medium-dense to densely compacted sandy (SM) soil. The uppermost part of cohesive soil up to 3m is mainly composed of silty clay with low SPT values which is highly vulnerable to landslides. The non-cohesive soil sand up to 7.5 m is also highly vulnerable to landslides. The mineralogical information on soilclay and non-clay minerals has been identified by using XRD (X-ray Diffractometer). The non-clay minerals include quartz, orthoclase, plagioclase, and Mica and the clay minerals are mainly illite, chlorite, and kaolinite occur in very small amounts. The natural moisture content values of the samples range from 15.65% to 32.19% and the average is 25.67%. The specific gravity value ranges from 2.20 to 2.93, the average is 2.48, and the values decrease with increasing depth. The obtained values are closer to the values recommended for Illite –Chlorite. For geotechnical investigations, three types of soils (sand, silt, and clay) have been categorized based on grain size distribution. The soil samples are mainly composed of sand with silt and a small amount of clay and might be defined as silty sand. The values of Cu and Cg suggest that the studied soil is well-graded. The liquid limit values range from 28.01% to 48.06%. The plastic limit is in the range of 14.72% to 23.69%. The plasticity index values lie between 7 % and 21.48%. According to the plasticity chart, the Clay soils of Rangamati can be characterized as low to medium plasticity inorganic clay and classified as CL to CM from their position in the plasticity chart which has low to medium swell potential.

Keywords: Geotechnical, Grain size, Landslide hazard, Mineralogical, SPT.

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Introduction

The study area is situated in the Rangamati Sadar area, Rangamati District which falls in tropical regions with warm to hot climates, and the soils of this area are fluvial in origin. Fluvial soils vary from region to region due to their heterogeneous nature and highly variable degree of weathering, controlled by regional climatic and topographic conditions and the nature of bedrock. Extremerainfall, seismic activity, water level changes, storm surges, or erosion from fast-flowing streams, geology, topography, slope geometry, groundwater saturation, vegetation cover, and human activities can cause landslides [1,2,3]. These factors can increase the shear stress or decrease the shear resistance of sloped terrain [3]. Consequently, the properties of the ground unit are fundamental to the landslide trend. Furthermore, the weathered zones of the consolidated soil mechanically behave like loose soil, which requires the determination of the geotechnical parameters of the soil unit [4], the angle of internal friction, the mineral composition, and the nature of the fine-grained lithological units must be specified. The behavior of landslides shall be determined by particle size distribution, water content, consistency limits, cohesion, internal friction angle, mineral composition, and fine-grained lithological units. The comprehensive study of the geotechnical properties of soil units is also a substantial aspect of predicting landslides [5,4].Geotechnical engineering properties of soils play an important role in understanding ground response and influencing the surrounding environment.

According to [6] asserts that certain fundamental minerals, including feldspar, mica, augite, hornblende, and quartz, may change into clay minerals depending on environmental factors. The basic engineering properties are the most important factor in the identification and determination of the behavior of clay. Though clay mineral composition is the main controlling factor, it is impossible to classify all soils and clays or predict their properties solely based on mineral composition. Other factors such as particle size distribution, non-clay mineral composition, organic material, and geological history also play an important role in many properties [7]. The significant research into the engineering properties should be multi-disciplinary and include geotechnical engineering and the mineralogy of the soils [8].

Unconsolidated collections of solid particles make up soil, and the spaces between them might hold either air, water, or both. The sort of processes used to break down rock and the amount of sediment transit affect the soil's structure, which in turn affects how it behaves under engineering conditions [9]. Numerous soils might present challenges in geotechnical engineering due to their propensity for expansion, collapse, dispersion, excessive settlement, noticeable lack of strength, or solubility. According to [10], these features may be attributed to the materials' chemistry, the makeup of their pore fluids, their mineralogy, or their fabric.

In the Rangamati district, deep brown soil predominates on low hills with steep slopes, whereas shallow to deep brown soil can be found on very steep high hills [11]. According to [12-15], unplanned settlement, inadequate forestation in hilly areas, illegal hill cutting, and rapid urbanization are the most frequent causes of landslides in Rangamati District. Other common causes include heavy rainfall, high elevation with weak soil texture, high elevation with weak soil texture, and geological settings (location, soil type, altitude, slope angle, structural discontinuity, etc.). In the Rangamati Hill Tract region, the landslide has recently become a recurrent calamity throughout the monsoon season. The pattern and frequency of landslides in this region both grew quickly. The tendency and frequency of landslides in this area quickly increased as a result of the intense rains [16-18]. The slope of the hill generally experienced a shallow landslide as a result of regional differences in soil type, slope angle, and initial moisture content [19]. In the research area very limited works on mineralogical and geotechnical influence on the stability of slope surface. The major goal of this study is to assess the Rangamati soils' precise mineralogical influence on the geotechnical properties of shallow landslide hazard sites. Not only these, but it also evaluates the ground response based on SPT data and grain size properties of the soil. Also, natural slopes, which have been stable for many years, may suddenly fail due to some hidden causes.Geographically, the area of Rangamati lies between 22°50' to 22°30' North latitude and 92°00' to 92°20' East longitude (Figure 1).

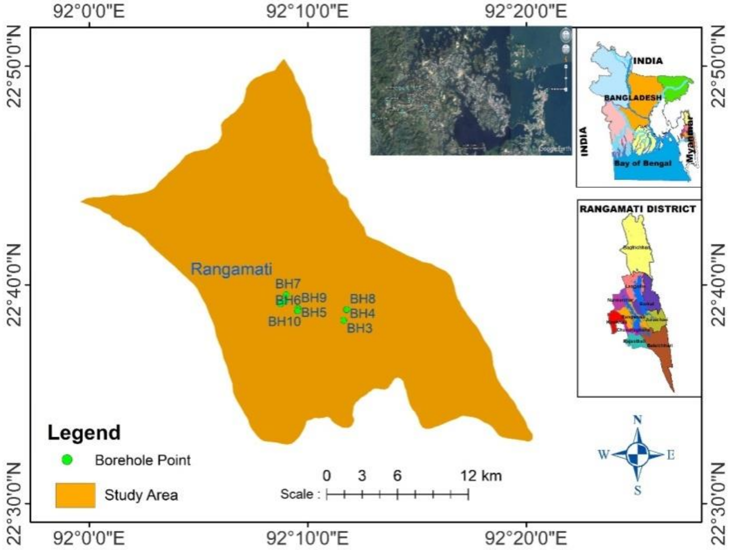

Figure 1. Geographic location Map of the Study area

Materials and Methods

The XRD method determines the mineralogical composition of the soil/rock material of the study area. The bulk samples are analyzed in air-dried conditions for mineral identification in all the locations. Ten samples have been analyzed from five locations identification of clay and non-clay minerals. XRD (X-ray Diffraction) tests have been executed at the “Wazed Miah Science Research Center”, Jahangirnagar University, Savar, Dhaka. A detailed site investigation of the study area in accordance with [20]has been carried out to know the geology, geomorphology, topography, soil surface, and physical properties of the soils. Ten (10) boreholes have been drilled in the studied area with the technical assistance of “Creative Soil" in different locations at Rangamati Sadar. The disturbed soil samples have been collected simultaneously by using a split spoon sampler with the performance of the standard penetration test (SPT) method. The required undisturbed samples have been collected with open Shelby tubes (U100).Samples both in the disturbed and undisturbed state were collected continuously. The basic geotechnical properties i.e., natural moisture content, specific gravity using pycnometer, Atterberg limit by Cone Penetration Test method, and shrinkage limit have been determined according to[21] and [22] at the Engineering Lab of Geological Sciences department of Jahangirnagar University. The particle size distribution has been carried out by both the wet and dry sieving methods according to [22]. The graphical presentation of the SPT-N value has been plotted with various functions of Python software (version 3.7.4). Soil classification of the area has been classified according to [20].

Results Interpretation

Field Data Interpretation

According to [20], field site investigations were conducted, and ten (10) boreholes were drilled in the investigated area. Each borehole underwent SPT (Standard Penetration Test) testing with split spoon samplers at 1.5 m intervals, and the SPT (Standard Penetration Number) "N" value for each soil layer was noted. Based on the variation of SPT value with depth three zones have been identified.

Borehole Lithology

Knowledge about the geotechnical properties of soil has a vital role in every project involving earth structures that require a soil or rock foundation or are constructed below the ground surface [23]. These properties are related to the type and amount of clay minerals, the water contents, and the consolidation pressure to which the soil had been subjected in the past. The subsurface investigation work includes the execution of ten nos. of 50’-0” deep borings. Performance of the required field and several geotechnical properties of the have been measured by laboratory tests. The area of research is associated with the evaluation of the subsurface ground condition from a geo-engineering point of view.

The lithology of the study area has been revealed from the soils/rocks encountered in the wells bored (Table 1). The variety of soils has been developed because of the difference in the degree of weathering in different boreholes of the study area. Three units namely 1, 2, and 3 have been identified. Individual soil/rock unit has different lithology in the study area.

Unit 3 is mainly a compact Silty clay unit. This unit is dark grey to grey in color, stiff to hard in nature. Some or little silt and organic content are also present in this unit. The thickness is around 3 m and the depth ranges from 0 to 3 m in BH-3, 4, 7,9,10 boreholes. Unit 2 is mainly a non-cohesive silty sand unit. Unit 2 underlies unit 3 in this area. This unit is brown to light yellowish brown in color and medium dense in nature. The thickness is around 4.5 m and the depth ranges from 3 to 7.5 m in BH-1, 2, 5,6,7,8, and 10 boreholes. Unit 1 represents the sand in nature, characterized by light yellowish brown in color, dense to very dense sand. The thickness is around 7.5m and the depth ranges from 7.5 to 15 m.

Table 1. The lithologic description of the study area from bore log data

Unit	Soil/Rock Type	Lithologic Description	Depth (m)	Thickness (m)	SPT/ N-value
C	Silty Clay	Dark grey to grey medium stiff to compact silt with Clay and very little sand	0-3	3.0	6 to 11
B	Silty Sand	Brown to light yellowish brown medium dense sand with silt and clay	3-7.5	4.5	20-28
A	Sand	Light yellowish brown dense coarse sand	7.5- 15	7.5	30 to >50

Standard Penetration Test (SPT)

The standard penetration test (SPT) is carried out during the advancement of the boring to obtain an approximate measure of the dynamic soil resistance. The procedures for the SPT are detailed in [21]. In the study area, the observed SPT values to depth in different boreholes are given in Figure 5. The SPT value of the study area ranges from 6 to 50 in the area up to 15m depth and shows that the values are higher at greater depth and comparatively lower at the near-surface which is very much consistent with the lithology of the individual units. The variation SPT value is shown in Table 4. The consistency of the cohesive soil is described according to [24] and the density of sandy soil is described according to [25]. The field SPT data has been corrected using the standard procedure. Both the field and corrected SPT are presented corresponding to the depth of the Boreholes in Figure 2. The field SPT varies from 5 to 70 and the corrected SPT varies from 10 to 42.5.

As SPT-N values vary with depth, for a specific alignment; if N-values are presented in a table to take input from Python, a strong numerical visualization and interpretation tool, contour plot can be obtained. The various built-in function of Python software was used to develop this model. The input data are presented in Table 2.

The SPT values increase with increasing depth in all the boreholes (Figure2). The layer of the cohesive clay soil (Unit C), extending to a depth of 0-6 m, usually has a consistency that varies from medium to stiff. The topmost part of this layer shows medium consistency (depth ranges from 0-3 m) whereas the lower part shows stiff consistency (depth ranges from 3-7.5m). Further below, the non-cohesive silty and sandy layers (Unit B & A respectively), extending to the depth of about 7.5-15 m, usually have been found in a medium dense to very dense state.

From Fig. 2 it can be inferred that the N- value is increasing with increasing depth. For this particular data set, up to 4.5-6m of depth, the SPT-N value is within 5 to 20. However, the SPT-N has increased significantly afterward. Some soft pockets can be visualized at 17000 m chainage up to 7.5m depth, at 19000 m chainage within 3-4.5m depth, etc. The quality of soil can be judged easily with this plot. On the other hand, the highest SPT value ranging from 50 to 70 is found around the chainage 15100m to 18500m, within depth 9-15 m. The chainage is 17500m except for another chainage because of the high SPT from the beginning.

Table 2. Chainageand GPS Coordinates of Boreholes

Borehole Name	Chainage (m)	Latitude degree	longitude degree
RLBH1	15100	22.654096	92.149297
RLBH2	16000	22.652165	92.145839
RLBH3	17000	22.619883	92.103611
RLBH4	17500	22.625277	92.111944
RLBH5	18000	22.6525	92.143611
RLBH6	18500	22.659166	92.150277
RLBH7	19000	22.639655	92.194147
RLBH8	19500	22.647707	92.196259
RLBH9	20000	22.648633	92.159109
RlBH10	20500	22.646788	92.158908

Table 3. SPT values of different boreholes to a depth

	RLBH1	RLBH2	RLBH3	RLBH4	RLBH5	RLBH6	RLBH7	RLBH8	RLBH9	RLBH10
Chainage Depth	15100	16000	17000	17500	18000	18500	19000	19500	20000	20500
1.5	10	24	11	50	19	29	6	8	9	6
3	11	37	6	50	51	41	20	22	16	16
4.5	20	50	14	50	50	43	29	28	22	23
6	23	50	5	50	50	50	37	40	23	25
7.5	30	50	26		51	50	50	50	28	29
9	47	50	55			50	50	50	32	42
10.5	58		70			50	50	50	40	50
12	62						50		51	50
13.5	53								50	
15	60								50	

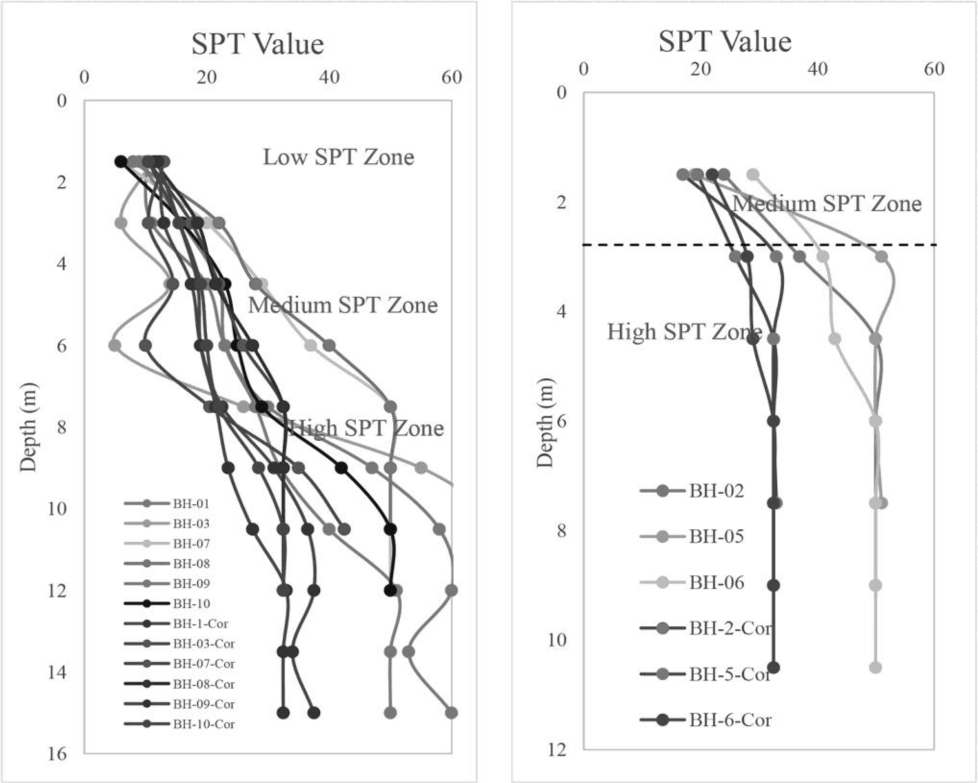

Figure 2. Variations of SPT values for BH-01 to BH-10 to depth

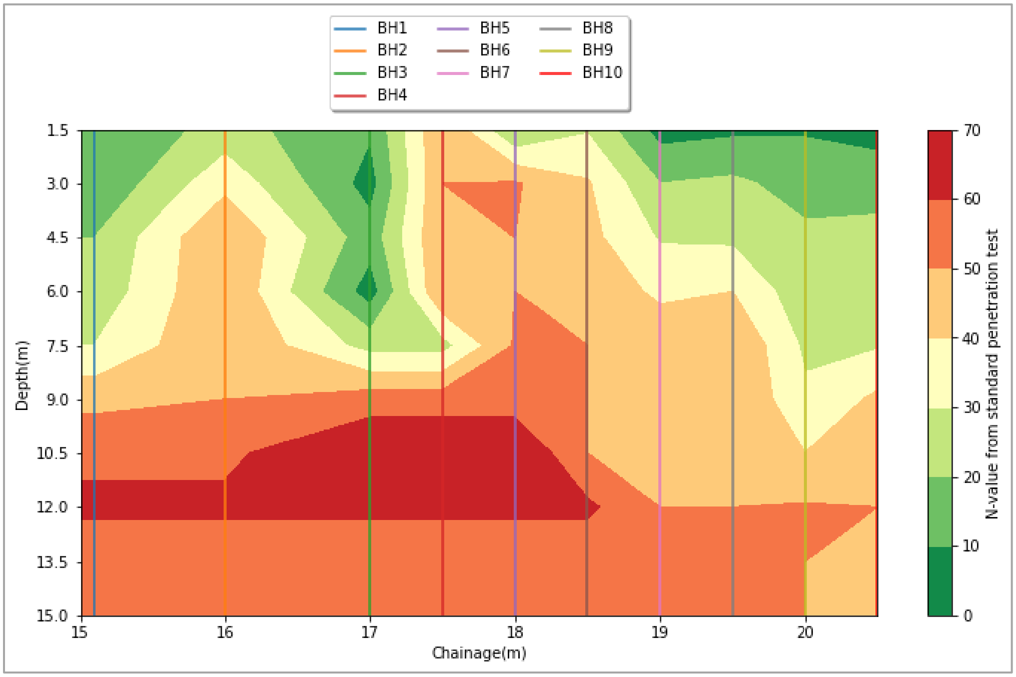

Figure 3. Variation of SPT-N value with depth

Mineralogy/ X-ray Diffraction Analysis

Identification and estimation of different clay and non-clay minerals have been done by XRD (X-ray diffraction) analysis. The bulk powdered samples were analyzed after air-dried conditions for mineral identification in all the locations. The different minerals in bulk samples of the Rangamati Clay Formation of the studied area are listed in Table 4.

The mineralogical composition of the samples was identified after [26-29].The semi-quantitative estimation of clay and non-clay minerals was made after [30-32]. The clay and non-clay minerals were quantified by considering the peak area by taking the sum of all peak height measurements across the peak. The peak height has been multiplied by the correction factor (i.e. 1 for illite, 0.54 for chlorite, and 0.1 for microcline and orthoclase) by [32]. Then from the whole samples of clay and non-clay percentages, each of the mineral percentages is calculated. The identified clay and non-clay minerals are shown in Table 4. In the study sample, non-clay minerals like quartz, microcline, orthoclase, and mica are present. Illite and chlorite clay minerals were identified in all the samples and a small amount of kaolinite minerals were identified at BH-04 and BH-7 samples. The X-ray diffraction analysis of the bulk sample indicates that the Rangamati Clay mainly consists of illite-chlorite and kaolinite with a small amount of montmorillonite mixed layer. In bulk samples, huge amounts of quartzpresent with a small amount of feldspar as non-clay minerals.

Table 4. Different identified minerals in bulk samples of Rangamati Clay by using an X-ray diffractogram.

Location	Sample no.	Depth (m)	Identified minerals (Bulk sample)							
			Qtz	K-f	B	Pl	I	Cl	K	M
BH-1 (Vedvedi/BB)	RS-1	1.5	+++	+	+	+	+	++	+	-
	RS-2	3.0	+++	+	+	+	+	++	+	-
BH-3 (Ghagra Cantonment)	RS-1	1.4	+++	+	+	+	+	++	+	+
	RS-2	2.6	+++	+	+	+	+	++	+	+
	RS-3	4.0	+++	+	+	+	+	++	+	+
BH-4 (Gayyechara)	RS-1	1.8	+++	+	+	+	+	++	+	-
	RS-2	3.0	+++	+	+	+	+	++	+	-
BH-7 D.C. Bhabon	RS-1	1.5	+++	+	+	+	+	++	+	-
BH-9 (Monoghor Master Bari)	RS-1	1.4	+++	+	+	+	+	++	+	+
	RS-2	2.6	+++	+	+	+	+	++	+	+
	RS-3	4.0	+++	+	+	+	+	++	+	+

The XRD of a few selected samples at different locations are shown in figure-4 to figure-8.

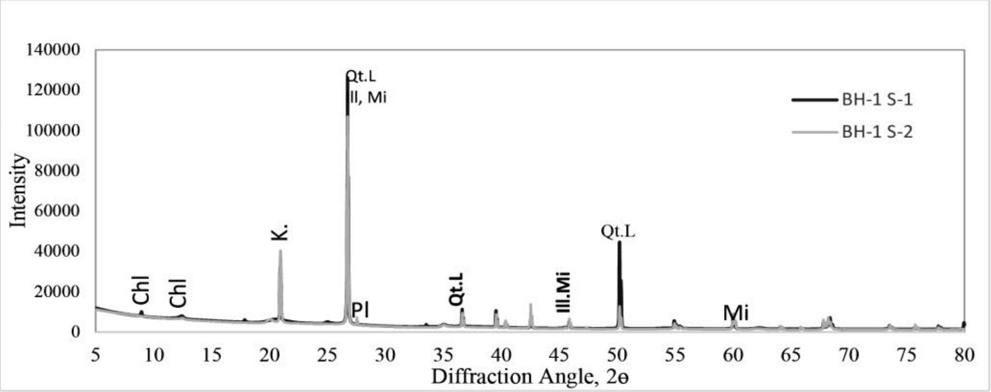

Figure 4. X-ray diffractogram showing the bulk mineral of sample BH-01 at Bangladesh Betar/Vedvedi

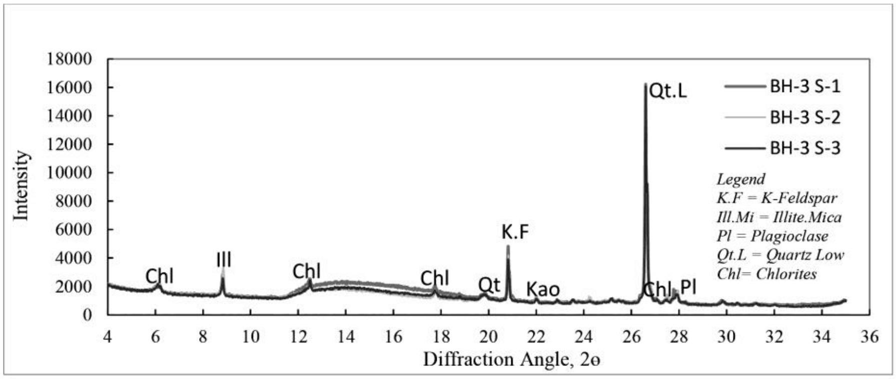

Figure 5. X-ray diffractogram showing the bulk mineral of sample BH-03 at Ghagra Cantonment

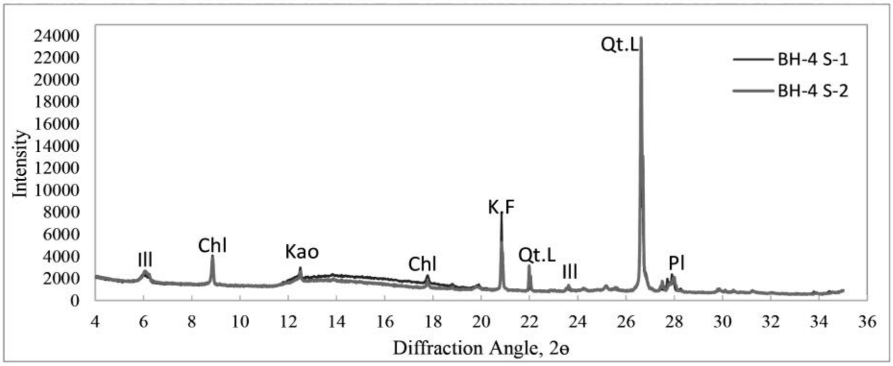

Figure 6. X-ray diffractogram showing the bulk mineral of sample BH-04 at Gayyechara

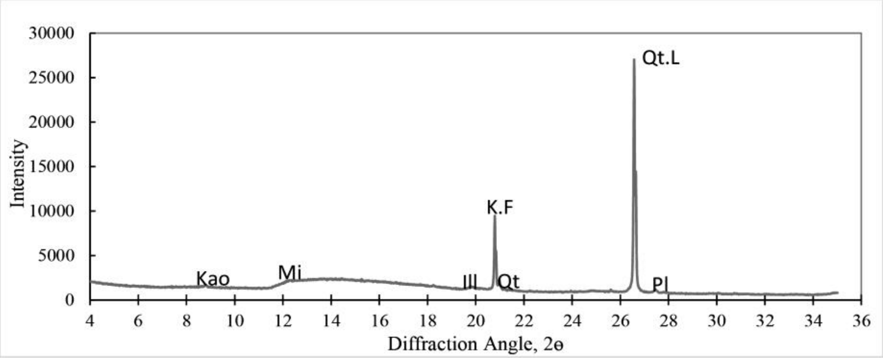

Figure 7. X-ray diffractogram showing the bulk mineral of sample BH-07 at D.C Bhabon

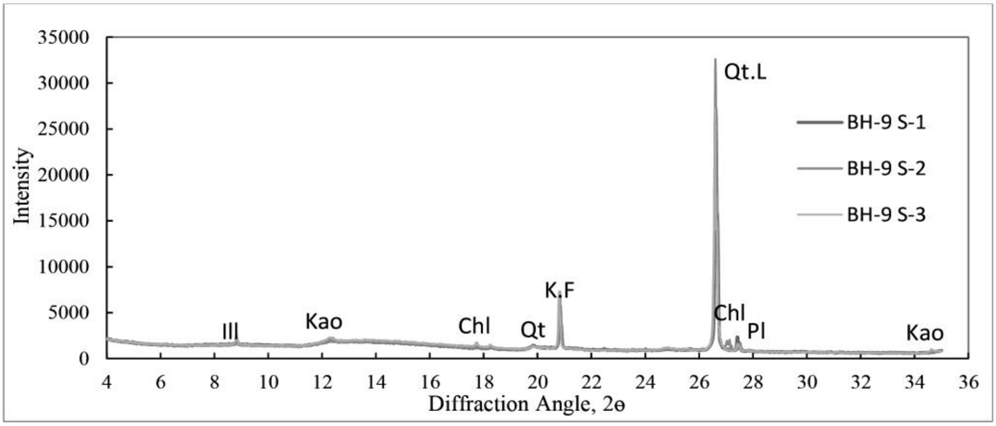

Figure 8. X-ray diffractogram showing the bulk mineral of sample BH-09 at Monoghor Master Bari

Basic Engineering Properties of Soil

Grain Size Analysis

The grain size analysis of a soil sample involves determining the percentage by weight of grains within the different size ranges [33]. [7] noted that the grain size or the fineness of particles largely affects the limit values and permeability values of soil. According to [34], particle size distribution influences the strength and compressibility of soils both of which are important in the consideration of bearing and stability for engineering purposes. The particle size distribution of all the samples of the study area is listed in Table 5. It is observed that there is a range of variations in the size of particles. The analyzed sample shows very little clay fraction.

Table 5. Grain size distribution of the analyzed samples.

Location	**Sample no.**	**Depth(m)**	**Grain (%)**		**Grading Properties**	
			Sand	**Silt & Clay**	**$Cu=\frac{D_{60}}{D_{10}}$**	**$Cg=\frac{{D_{30}}^2}{D_{10}*D_{60}}$**
BH-1	RLS-1	1.5	94.67	5.3	4.49	0.0089
	RLS-2	3.0	95.75	4.25	4	0.0067
	RLS-11	16.5	94.91	5.09	4.18	0.0091
BH-2	RLS-1	1.5	83.96	16.04	0	0
	RLS-3	4.5	93.75	6.25	2.25	0.0044
	RLS-6	9.0	96.24	3.76	3.46	0.0055

Location	**Sample no.**	**Depth(m)**	**Grain (%)**		**Grading Properties**	
			Sand	**Silt & Clay**	**Cu=$\frac{D_{60}}{D_{10}}$**	**Cg=$\frac{{D_{30}}^2}{D_{10}*D_{60}}$**
BH-5	RLS-1	1.5	92.96	7.04	3.86	0.0062
	RLS-2	3.0	89.12	10.88	0	0
	RLS-5	7.5	92.24	7.76	4.1	0.0080
BH-6	RLS-1	1.5	95.79	4.21	0.44	0.1435
	RLS-3	4.5	99.82	0.18	3.36	0.0143
	RLS-4	6.0	96.09	3.91	3.76	0.0086
	RLS-7	10.5	95.25	4.75	3.95	0.0073
BH-7	RLS-1	1.5	94.24	5.76	3.62	0.0172
	RLS-3	4.5	96.73	3.27	3.27	0.0166
	RLS-5	7.5	92	8	4.66	0.0090
	RLS-8	12.0	93.77	6.23	3.71	0.0087
BH-8	RLS-2	3.0	87.29	12.71	-	-
	RLS-3	4.5	98.31	1.69	2.62	0.0185
	RLS-7	10.5	95.02	4.98	3.53	0.0191
BH-9	RLS-5	7.5	92.7	7.3	4.79	0.0079
	RLS-6	9.0	95.53	4.47	3.88	0.0092
	RLS-8	12.0	93.87	6.13	2.55	0.0113
	RLS-10	15	97.41	2.59	3.94	0.0134
BH-10	RLS-1	1.5	96.24	3.76	4.35	0.0155
	RLS-3	4.5	93.87	6.13	4	0.0082
	RLS-4	6.0	93.52	6.48	4.74	0.0084
	RLS-8	12.0	96.21	3.79	4.47	0.0108

Sand percentage ranges from 83.96 to 98.31% and silt & clay 0.18 to 16.04%. The sand percentage is very much higher in BH-9 and BH-10 whereas in BH-8 the sand percentage is very much lower in comparison with boreholes 9 and 10. The obtained result suggested that the research area is sand-dominated. It is observed that there is a range of variations in the size of particles with respect to depth.

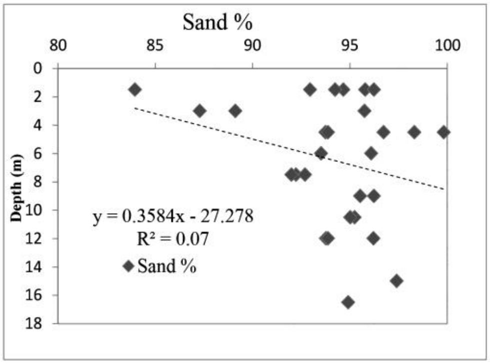

Figure 9. Variations of sand percentage (%) with respet to depth(m) at different location

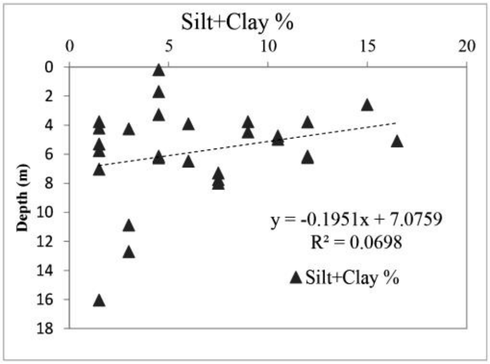

Figure 10. Variations of silt & clay percentage (%) with respet to depth(m) at different location

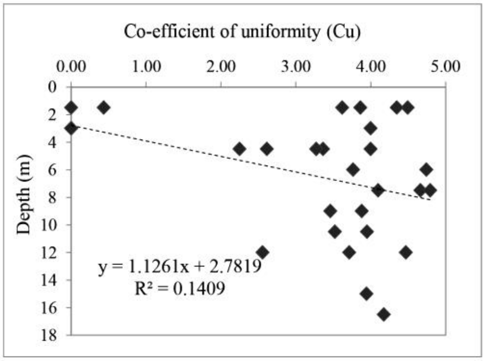

Figure 11. Variations of Co-efficient of uniformity (Cu) to depth (m) for the Sample of BH-01 to BH-10

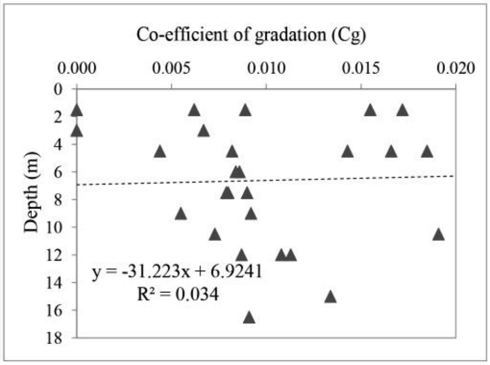

Figure 12. Variations of Co-efficient of gradation (Cg) to depth (m) for the Sample of BH-01 to BH-10

The coefficient of uniformity (Cu) and co-efficient of gradation (Cg) have been determined and the values are presented in Table 5. The value of Cu ranges between 0.44 to 4.79 and the values range from 0-0.1435. Variations of Cu and Cg are shown in Figures 9-12. [8] mentioned that if Cu<4.0, then the soil is uniformly graded ab=ndCu>4.0, representing wellgrading. [35] mentioned that Cu<30 represents uniform grading and Cu>5.0 represents well grading soil. The obtained ‘Cu’ and ‘Cg’ for the studied soil sample suggest that it is uniformly well graded according to [8] and [35].

Moisture Content

Moisture content plays an important role in understanding the behavior of fine-grained soils. Due to the propensity of clay particles to absorb water, natural moisture content increases with increasing clay concentration. The natural moisture content values of the selected disturbed samples of Rangamati soillie from 15.65% to 32.19% and the average is 25.67% (Table 6). According to [36], the variation may be due to the location of the soil sample, the position of the groundwater table, recent rainfall, etc. Author [16] pointed out that the moisture content of the Rohingya Refugee Camp area is about 13.04-29.39%. [37] reported that the moisture content of the soils of the Kutupalong Rohingya Camp area is about 8.90-36.25%. [38] analyzed some soils in Malaysia and found that soil moisture content (w) of Clayey silt and Silty sand was recorded as 7.76-100% and 17.66- 61.07%, respectively.Obtained moisture content values show consistency with the moisture content values by [39-40, 37,41,42,17,43-44].The moisture content and specific gravity values of the samples are shown in Table 6. The natural moisture content (Wn) values are closer to the plastic limit values except for a few values which suggest that the analytical soil of the study area is normally consolidated in nature [45]. [46] pointed out that soils containing organic matter have a higher value of moisture content. So, the soil samples may be inorganic soil.

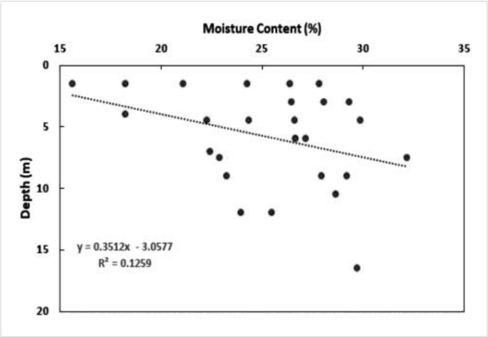

Figure 13. Variation of moisture content (%) concerning depth

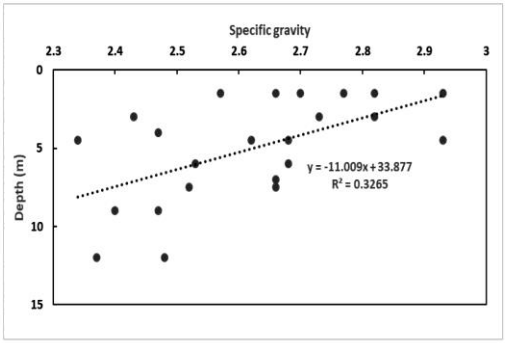

Figure 14. Variation of average specific gravity values to depth

Specific Gravity

The observed specific gravity values of Rangamati soil range from 2.34 to 2.93 and the average is 2.62 are shown in Table 6. [36] pointed out that the specific gravity of soils generally ranges from 2.65 to 2.72. The obtained specific gravity values (Table 6) of all samples are closer to the recommended values of [7]and[36]. [47] reported that the specific gravity of illite is 2.64 to 3.00, chlorite is 2.60 to 3.00, Kaolinite is

2.60 to 2.68, and *montmorillonite* is 2.22 to 2.75. The obtained values are closer to the values recommended by [47] for illite-chlorite with a small amount of kaolinite.

Table 6. Natural Moisture content and Specific gravity values of Rangamati soil samples.

Location	Sample no.	Depth (m)	Moisture content (%)	Specific gravity
BH-1	SRL-1	1.5	26.37	2.93
	SRL -2	3.0	26.45	2.82
	SRL -4	6.0	26.68	2.30
	SRL -7	10.5	28.67	-
	SRL-11	16.5	29.70	-
BH-2	SRL -1	1.5	24.27	2.66
	SRL -3	4.5	26.63	2.62
	SRL -4	6	27.17	-
	SRL -6	9	27.94	2.47
BH-5	SRL-1	1.5	27.85	2.77
	SRL-2	3	28.07	2.43
	SRL-5	9	29.22	2.40
BH-6	SRL-1	1.5	21.09	2.70
	SRL-3	4.5	24.36	2.93
	SRL-4	6	26.68	2.68
BH-7	SRL-1	1.5	18.25	2.82
	SRL-3	4.5	22.30	2.34
	SRL-5	7.5	22.90	2.52
	SRL-8	12	23.97	2.37
BH-8	SRL-1	1.5	24.95	2.70
	SRL-3	4.5	29.87	2.93
	SRL-4	6.0	31.75	2.68
BH-10	SRL-1	1.5	15.65	2.57
	SRL-3	4	18.25	2.47
	SRL-4	7	22.44	2.66
	SRL-6	9	23.26	-
	SRL-8	12	25.47	2.48

Atterberg Limits

Atterberg consistency limit i.e. liquid limit values along with plastic limit and plasticity index values are shown in Table 7. The experiment was determined using the cone penetrometer method.

Table 7. Atterberg consistency limits values of Rangamati soils.

BH No.	Atterberg consistency limits of the landslide sites' clay soils						
	Depth Zone (ft)	**Sample No.**	**Liquid limit %**	**Plastic limit %**	**Plasticity Index %**	**Liquidity Index %**	**Linear Shrinkage (%)**
BH-03 (Ghagra Cantonment)	Zone-A (4.6-10)	SRL-1	28.01	20.69	7.32	0.398	7.09
	Zone-B (13.6-20)	SRL-3	40.01	22.97	17.04	-0.029	7.14
	Zone-C (23.6-35)	SRL-5	48.06	13.18	34.88	0	9.93
BH-04 (Gayyechara)	Zone-A (3.6-10)	SRL-1	26.2	19.2	7	0	7.14
BH-07 (DC Banglo, Keranipahar)	Zone-A (3.6-10)	SRL-1	32.5	19	13.5	-0.018	9.93
BH-09 (Monoghar Headmaster House)	Zone-A (3.6-10)	SRL-1	37.2	16.12	21.08	0	-
	Zone-B (10-15)	SRL-3	36.2	14.72	21.48	0	-
BH-01 (Bangladesh Betar,Vedvedi)	Zone-A (1.5)	SRL-1	30.75	13.06	17.69	-0.752	7.09
	Zone-B (3 m)	SRL-2	28.5	12.00	16.5	-0.875	7.14

Liquid limit

The liquid limit values range from 28.01% to 48.06%. The highest liquid limit was found in sample BH-03 and the lowest was found in sample BH-04 (Figure 15). Obtained liquid limit values show consistency with liquid limit values quoted by[48],[39],[49], and [42].[7] mentioned that montmorillonite and illite have higher liquid limit values whereas kaolinite has generally lower values. The clay soils of the investigated area are mainly consisting of illite and kaolinite as quoted by [7]. The obtained test results suggest that the studied soil is low to intermediate plasticity soil to the recommended values of [22] and [50]. According to [51] classification of potential soil expansion, top-layer soils have low potential soil expansion in nature.

Plastic Limit

The plastic limit values of selected samples of the clay soils of the studied area were obtained by using the rolling thread method. The obtained values of the plastic limit are in the range of 14.72% to 23.69% and vary slightly in different areas. The highest plastic limit was found in sample BH-3 01 and the lowest was found in sample BH-9 (Figure 15). The clay soils of the investigated area are mainly consisting of illite. The obtained plastic limit is slightly lower than the values quoted by [7] and [52].

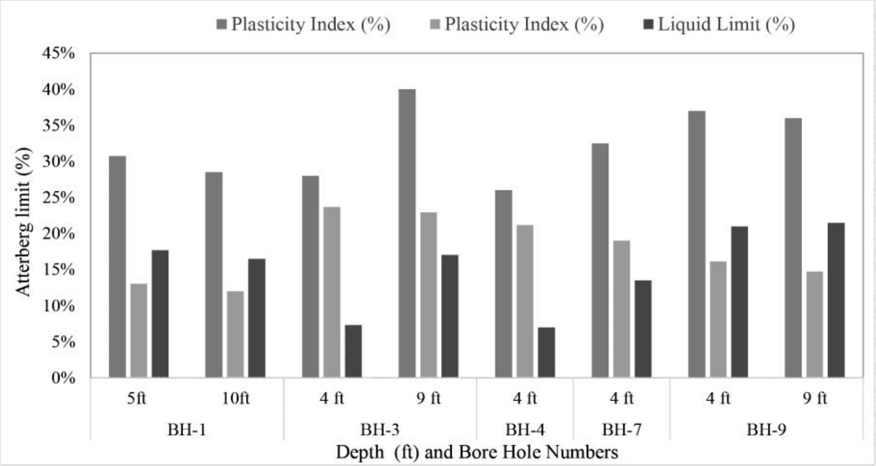

Figure 15. Variation of Atterberg limits (%) with respect to depth.

Plasticity Index

The plasticity indices are an important parameter to classify soil, these are calculated as the difference between liquid limit and plastic limit values. The obtained plasticity values lie between 7% to 21.48% (Table 7) and are nearer to the values recommended by [49] & [42]. The obtained values of analyzed samples show an intermediate plasticity index as observed from the plasticity chart (Figure 15).Broadly the observed plasticity index values in the investigated area are consistent with kaolinitic and illitic contents according to [53] and [7].

Liquidity Index & Linear Shrinkage

The liquidity index value ranges between 0 to -0.017778 (Table 7). Stiff clays have a LI which approximates zero and maybe even negative. The obtained linear shrinkage values lie between 7.09% to 12.86% with an average of 9.01% (Table 7). The obtained results are close to the typical values of illite and kaolinite minerals as quoted by [54]. According to [55], clays with linear shrinkage <5% are “non-critical”, 5% to 8% are marginal and values>8% are critical in terms of volume change. According to [55], the Rangamati clay soils are considered critical.

Engineering soil classification of Clay soils of the Rangamati landslide area

From the British soil classification system [56]; the Rangamati clay soils can be characterized as low to intermediate plasticity silty clay. According to the plasticity chart (Figure 16), the clay soils of Rangamati can be classified as CL to CI plasticity inorganic clay.

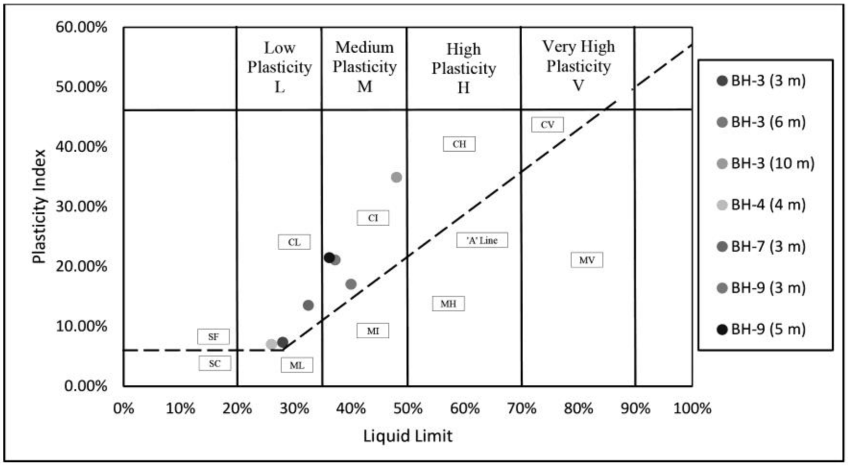

Figure 16. Engineering classification chart of Rangamati Clay soils (After [56]).

Conclusion and Discussion

The main purpose of this research is to evaluate the Rangamati soils' particular mineralogical influence on the geotechnical properties of shallow landslide hazard sites. At the same time, evaluates the ground response based on SPT data and grain size properties of the soil. The associated difficulties related to the geo-hazard problem structures of these.

The field SPT values suggest that the ground condition of the studied soil is mainly stiff to hard. The SPT values of Non-cohesive soils suggest that the studied soil is medium-dense to densely compacted. The SPT values along with other geotechnical parameters suggest that the analyzed soils have an impact on landslide occurred.

The studied soil samples are mainly composed of silt with some amount of clay and sand. Sand percentage ranges from 83.96 to 98.31% values are increased with increasing depth. Silt and clay 0.18 to 16.04%. and values are decreased with increasing depth. The obtained result suggested that the research area is sand-dominated.

The mineralogical information on soils in Bangladesh is limited. Samples were collected from 5(five) boreholes for the analysis of mineralogical properties. The clay and non-clay minerals have been identified by using XRD (X-ray Diffractometer). The non-clay minerals include quartz, orthoclase, plagioclase, and Mica and the clay minerals are mainly illite, chlorite, and kaolinite occur in very small amounts. The presence of illite influences the atterberg consistency of soil. The higher the amount of illite in the soil, the higher the activity in the soil. The presence of clay minerals has marked influences on the shrinkage limit of the soil.

The natural moisture content values of the samples range from 15.65% to 32.19% and the average is 25.67%. The natural moisture content is closer to slightly higher on the plastic limit of the analyzed soil indicating that the soil is normally slightly overconsolidated in nature.

The specific gravity value is in the range of 2.20 to 2.93 and the average is 2.48 and the values decreased with increasing depth. The obtained values are closer to the values recommended for Illite –Chlorite. The liquid limit values range from 28.01% to 48.06%. The plastic limit is in the range of 14.72% to 23.69%. The plasticity index values lie between 7 % and 21.48%. The obtained value suggests that the Rangamati area is vulnerable to highly vulnerable landslides.

According to the plasticity chart, the Clay soils of Rangamati can be characterized as low to medium plasticity inorganic clay and classified as CL to CM from their position in the plasticity chart. The behavior of landslides was mostly influenced by fluctuating water content and stresses in the unsaturated zone resulting from soil characteristics such as clay content. Clay becomes the potential slip zone in an outcrop causing landslides.These outputs from this research will certainly help the geo-engineers, and policymakers reduce rainfall-induced landslide risks in the Rangamati Sadar area of, Bangladesh.

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