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CHARACTERIZATION OF HIGH PLASTIC CLAY UNDER VARYING PROPORTION OF ORDINARY PORTLAND CEMENT FOR SOIL-CEMENT STABILIZATION

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Abstract: The study investigates the influence of varying proportion of Ordinary Portland Cement (OPC) in high plastic clay soil while soil-cement stabilization of road embankment. Since, high plastic clay is unsuitable as subbase material of road embankment, our study provided as a guideline for the mixing ratios of OPC in soil-cement stabilization in this regard. Unconfined compressive strength (UCS) of soil samples were increased significantly with the addition of OPC to the soil. Optimum moisture content increased with higher percentage of cement added to soil. Besides, UCS of soil-cement mixture were improved with the increase of curing period. On contrary, increasing %OPC in soil-cement stabilization is costly. The test results recommended that the addition of 10% cement was sufficient enough to gain adequate UCS within 1-day curing.

Keywords: *Ordinary Portland Cement, soil-cement stabilization, road embankment, unconfined compressive strength, curing period.*

1. INTRODUCTION

High plastic clay soils are less preferable as subbase materials for road embankment construction, because of high compressibility and low strength. Clay soil exhibits liquid limit (LL) more than 50 are classified as high plastic clay according to AASHTO plasticity chart [1]. Since, clay soils are formed by the sedimentation under different geological processes, they show significant variation in engineering and physical properties, such as, strength, compressibility, void ratio, water content and grain size distribution. As a result, these soils are subject to low permeability, compactness and excessive expansion [1].

Soil-cement stabilization is the mixture of adequate proportion of cement with clay soil, which adopts widely to improve strength and deformation characteristics of subbase of road embankment. Proper mixing of clay, cement and water can provide adequate stability and strength to support structures [2]. Compressive strength test are usually conducted to observe the improvement of engineering properties of clay soil due to addition of cement. Laboratory tests carried out by Yilmaz et al. [3] showed that the inclusion of 10% cement can increase compressive strength of soil by more than three times.

Soil particles form a chemical bonding with cement, thus the physical and mechanical stability and strength of soils are improved. Water in soil-cement mixture react with cement and form calcium silicate and aluminate hydrate. They act as cementing materials to bind the soil particles together. In addition, hydration reaction in cement releases calcium hydroxide, which react with the clay minerals. When cement particles come in contact with water, hydration reaction starts immediately. However the secondary reactions may continue over long period of time [4].

High plastic clay samples were collected from Gazipur, Bangladesh in this study. Several laboratory tests were performed under varying Ordinary Portland Cement (OPC) contents to observe the influence of %OPC addition in soil samples. To our best knowledge, no such prior studies have been carried out to investigate the influence of soil-cement stabilization for the high plastic clayey soil of Gazipur.

2. LITERATURE REVIEW

Major challenges in road embankment construction come, when it is required to construct subbase on high plastic clay soils. If such soils are not properly treated, they are subjected to shear failure and excessive settlement after construction. Among many others soil treatment techniques, clayey soil stabilization with cement is widely adopted and low cost method. Several researches were carried out on soil-cement stabilization and its performance evaluation. Arifin and Rahman [5] revealed that cement can improve California Bearing Ratio (CBR) and shear strength in soft clay. Cement can improve mechanical strength and lower expansion in clayey soil [6]. Jan and Raj [7] found that cement content reduced plasticity, enhanced stability and CBR value in soil.

Our study determines the correlation between %OPC content and the compressive strength of soil-cement specimens. Compressive strength of soil is closely related to the stability of a road embankment construction. Lemos et al. [8] suggested that soil-cement stabilization increased compressive strength by five times in organic soft clay. Furthermore, Mamun et al. [9] performed compressive strength tests on several sand-cement specimens and found that 8%-10% cement were adequate for sand-cement stabilized subbase of heavy traffic road. Cement can improve engineering properties of clay soil, such as, stability, durability and strength over the lifespan of a pavement [10]. Bell [11] found that addition of small percentage of cement enhanced engineering properties of clay soil. Besides, Ho and Chan [12] suggested that increasing cement content, improved yield stress and reduced compression index of clayey soil.

3. MATERIALS AND METHODS

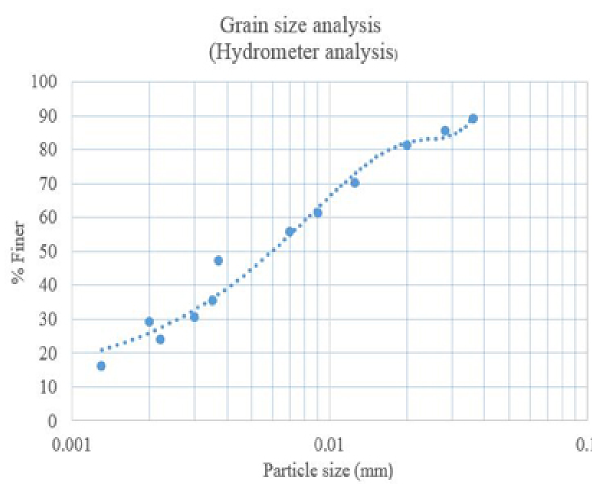
A. Sample collection and soil properties

The soil samples were collected from a site near Chandra bus stand (24°2’51.82” N, 90°14’14.98” E), Gazipur. The soil samples were collected on July, 2019. The season is monsoon period in the country. From visual inspection, the soil samples were brown colored clay. Several laboratory tests were carried out to determine physical properties of the soil specimens (shown in Table 1). Firstly, amount of fines (particle passing #200 sieve) was determined as per ASTM D1140-92 [13]. % of fines was found more than 90% with trace amount of sand and silt. Therefore, grain size analysis (hydrometer analysis) test was carried out according to ASTM D7928-17 [14]. The results of hydrometer analysis are presented in the Figure 1a. After that, specific gravity of soil sample, %moisture content and %organic content were determined according to ASTM D854 [15], ASTM D2216-10 [16] and ASTM D2974-07 [17] respectively. Finally, Atterberg limit test was performed to determine liquid limit, plastic limit and plasticity index of soil in accordance with ASTM D4318 [18].

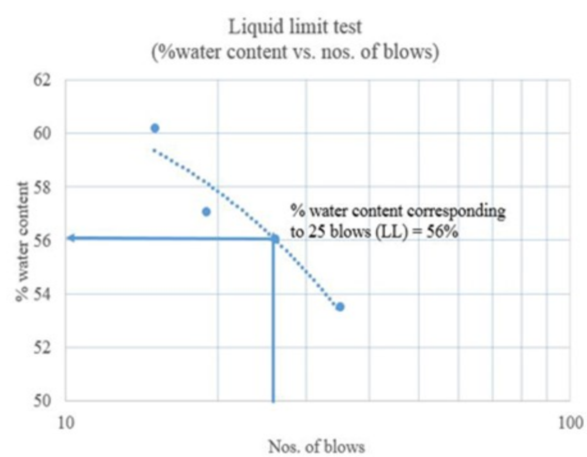
TABLE 1: PHYSICAL PROPERTIES OF SOIL SPECIMEN

Initial water content (%)	40	Plastic Limit (PL) (%)	26
Organic matter content (%)	3.5	Plasticity Index (PI)	30
Liquid Limit (LL) (%)	56	Specific gravity	2.7
Soil description	Inorganic high plastic CLAY		

The shape of hydrometer analysis graph was flatten S-curve with slightly skewed at top (shown in Figure 1a). Liquid limit (LL) is the % water content corresponding to 25 blows as shown in Figure 1b, i.e. LL = 56%. Plastic limit (PL) was found 26%. Therefore, Plasticity index (PI) = LL-PL = 30%. According to AASHTO plasticity chart [19] the soil specimen has LL>50, therefore, the soil specimens were found to be high plastic clay. The soil sample had very trace amount of organic matter (only 3%) and hence the soil specimens were inorganic soil.



(a)



(b)

Figure 1: Graphical representation of (a) Hydrometer

analysis of soil specimen (b) Liquid limit test

B. Properties of OPC

We used Ordinary Portland Cement (OPC) as an admixture material to improve unconfined compressive strength of soil-cement stabilized specimens in our study. The brand of the cement was CEMEX cement Bangladesh Ltd. We performed several laboratory tests to determine normal consistency, setting time, fineness and compressive strength of OPC, which are presented in Table 2 in details.

TABLE 2: PHYSICAL PROPERTIES OF OPC

Properties	Test Method	Values
Normal consistency	ASTM C187-98 [20] Standard Test Method for normal consistency of hydraulic cement	25%
Initial setting time	ASTM C403/C403M-99 [21] Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance	53 minutes
Final setting time		330 minutes
Fineness	ASTM C204 – 11 [22] Standard Test Methods for Fineness of hydraulic Cement by Air-Permeability apparatus.	3.79%
Compressive strength: ASTM C349 – 08 [23] Standard Test Method for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure).		
3 days	1800 psi	
7 Days	3000 psi	

C. Preparation of specimens and curing

After removal of dirt and unwanted materials from soil, fresh OPC was mixed with it. Height and diameter of the cylindrical molds used in this experiment were 5.6” and 2.8” respectively. Specimens were prepared with varying percentage of cement content of 5%, 10%, 15%, 20% and 25%. For each %OPC content 5 specimens were prepared, therefore there were in-total 25 specimens. Additional five specimens of each %OPC content were prepared to test physical properties of the soil-cement mixture. After that, specimens were wrapped with air tight polythene and kept under water for submerged curing. Each 5-specimens of same %OPC content were cured for 1, 3, 7, 14 and 28 days respectively.

D. Physical properties of soil-cement mixture

Similar to soil properties identification, %water content, Atterberg limit values (such as, LL, PL, PI) and specific gravity of soil-cement mixture were determined as per ASTM D2216-10 [16], ASTM D4318 [18] and ASTM D854 [15] respectively.

TABLE 3: PHYSICAL PROPERTIES OF OPC-SOIL MIXTURE

Sample	% of cement	Water content used (%)	Liquid Limit (LL)	Plastic Limit(PL)	Plasticity Index (PI) =(LL-PL)	Specific gravity
1	5	34.00	46.40	28.71	17.69	2.685
2	10	34.19	45.50	28.89	16.61	2.695
3	15	35.20	44.94	29.20	15.74	2.711
4	20	36.90	43.15	29.62	13.53	2.724
5	25	38.50	42.45	30.10	12.35	2.731

E. Unconfined Compressive Strength test

Unconfined compressive strength (UCS) test was performed to determine the compressive strength of the specimens according to ASTM D2166/D2166M [24]. The UCS test apparatus consisted with loading device to record applied load, two steel plates—where axial stress was transferred from loading device to the specimen and compressor meter to measure axial and lateral deformation. Axial load was applied on the specimens at a rate of 0.5 MPa/sec to 1.0 MPa/sec until failure occurred within 10 minutes. Stress and deformation data were recorded through loading device and compressor meter respectively. The maximum load was recorded in kPa within a 1% accuracy. The results of UCS are presented in Table 4.

4. RESULTS AND DISCUSSION

UCS results showed that 25% OPC in soil-cement specimens had highest unconfined compressive strength (UCS) than others (as shown in Figure 2). 25% OPC in soil-cement specimens showed 18% to 38% higher UCS than that of 20% OPC in soil-cement specimens over different curing periods.

Similarly, 25% OPC in soil-cement specimens had 77% to 84% increased UCS compared to 5% OPC in soil-cement specimens for different curing periods. Observing Figure 2, 5% OPC in soil-cement specimens had insignificant effect on UCS by curing, their unconfined compressive strength of 5% OPC in soil-cement specimens varied from 180 kpa to 232 kpa for 1-day and 28-days curing respectively, raised only 22%. However, UCS in 20% and 25% OPC in soil-cement specimens were increased by 40% and 43% respectively. 25% OPC-soil specimens showed increase (34%) significantly in unconfined compressive strength comparing 1-day to 3-days curing period.

TABLE 4: UNCONFINED COMPRESSIVE STRENGTH OF OPC-SOIL SPECIMEN

% of cement	Casting period days (Age of mix from OPC-soil specimen mixture date)				
	1	3	7	14	28
	Compressive strength (kpa)				
5	180*	210	215	220	232
10	210	300	450	510	580
15	630	660	750	700	790
20	650	740	850	1020	1091
25	794	1200	1300	1350	1394

*showing unconfined compressive strength (UCS) <192 kpa, UCS ranges from 192 kpa to 383 kpa represent very stiff consistent mixture according to Das [19]

Prior such studies were performed on different types of soils considering different aspects, such as, Mamun et al. [9] confirmed maximum increase of compressive strength at 10% cement for the sand-cement specimens and Yilmaz et al. [3] found three times increase in compressive strength by adding 10% cement with soil samples. Our study found that 25% OPC provided maximum unconfined compressive strength in OPC-soil specimens. Our sample soils were high plastic clay, which were unique and yet to be performed by other similar researches. Increasing %OPC content will enhance the cost of soil stabilization, as well as, construction cost. According to Das (2002), soil specimen having unconfined compressive strength 192 kpa to 383 kpa produce soil with very stiff consistency which can resist soil from considerable deformation and rupture consequently. 10% OPC in soil-cement specimen during 1-day curing had adequate unconfined compressive strength (>192 kpa) to become very stiff consistent mixture. Therefore, we recommended to use minimum 10% OPC for soil-cement stabilization.

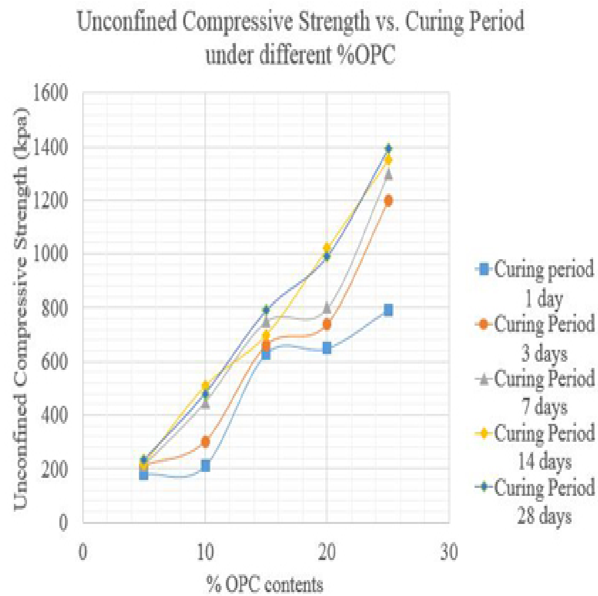


Figure 2: Unconfined Compressive Strength of soil-cement specimens under different %OPC in soil-cement specimens

5. CONCLUSIONS

Load on soil samples is applied very quickly under controlled strain in unconfined compression strength (UCS) test. Pore water do not get sufficient amount of time to dissipate, as a result, pore water pressure changes. UCS result of soils represent the road embankment construction site, where rate of construction is very high. Our study showed that UCS increases with the increasing %OPC in soil. Maximum UCS have been found for 25% OPC in soil-cement mixture. However, 10% OPC in soil-cement mixtures have adequate strength for road embankment construction. In this regard, our study provides as a guideline for mixing OPC in soil-cement stabilization.

It is very difficult to construct road embankment on high plastic clayey soil. There are various techniques have been developed to strengthen the road embankment, such as, crushed rock [25], geotextile [26], concrete block [27] and so on. However, stabilization of soil-cement is a low-cost effective measure which is very suitable for the construction of road embankment in developing countries like Bangladesh.

The research can be extended for other types of soils, such as, loom soil, black cotton soil and high expansive soils and so on. Long term performance of OPC in soil-cement specimen can be performed to investigate their suitability in road embankment construction. Variation of water content on OPC in soil-cement curing may provide valuable information. Moreover, relationship between soils with various liquid limit and OPC in soil-cement stabilization can be performed. Perhaps, our study was limited to laboratory tests only, an extensive research is necessary to implement the OPC in soil-cement stabilization in the field.

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