Mechanical Behavior of Cement Stabilized Dredged Soil

Bashir Ahmed Mir

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Abstract

Dredged soil is a solid waste generated from the dredging of a river and possesses low bearing capacity and high compressibility. Concern over environmental effects of dredging, disposal and the increasing unavailability of suitable disposal sites, has put pressure for characterization of this material. This material can be a valuable resource for many practical purposes such as fill material, sub-grade construction, reclamation, landscaping, agriculture, landfill covers, constructing wetlands for water quality improvement, creation of islands, wildlife habitat wetlands, and amongst others. In this study, various in-situ and disturbed soil samples were collected from three different sites of flood channel of river Jhelum in Srinagar. Various soil tests like gradation, specific gravity, consistency indexes, light compaction, unconfined compressive strength, and direct shear tests were conducted. The results of three samples were compared and the weakest soil sample was selected for cement treatment. The cement was added to the dredged soil in varying percentages of 4

Index terms— cement; dredged soil; flood channel; mechanical properties; solid waste.

1 I. Introduction

oft soil deposits usually have a low bearing capacity and undergo excessive settlement over a long period of time. Such soil deposits pose a great challenge to geotechnical engineers as both safety and serviceability requirements may not be satisfied (Mir 2015). Dredged soil is one such soft soil deposit of solid waste generated by dredging of a river. The present study deals with dredged soil generated by the dredging of flood spill channel of river Jhelum in Srinagar. The river Jhelum rises from the Verinag Spring situated at the foot of the Pir Panjal in the southeastern part of the valley of Kashmir. It flows through Srinagar and the Wular lake before entering Pakistan through a deep narrow gorge. Jhelum is the lifeline of the city of Srinagar, flowing through the Kashmir valley giving it pristine glory, essentially forming the backbone of all its economic activities. However, the Jhelum river has also been a source of worry for the people of Kashmir, as frequent small and large scale floods have been reported throughout its history. One such floods of unprecedented magnitude in decades was witnessed in September 2014, killing nearly 277 people in India and 280 in Pakistan. Due to the deposition of sediment and silt carried by the river during its normal course and floods the carrying capacity of the river reduced drastically. In such a scenario, there is a dire need for dredging of the river bed to enhance its carrying capacity. But due to dredging of the river Jhelum and flood spill channel there is accumulation of the dredged material, which causes not only the serious health and environmental problems, but also disposal problems due to scarcity of proper disposal sites (Mir 2005). Dredged material is an under-utilized resource that can be used for beneficial purposes once physical, engineering, chemical or biological properties are determined (DOER 1999). Therefore, there is a dire need for stabilization of this dredged material that can be used in aquatic environments like habitat creation, erosion control (underwater berms made of geotextile tubes filled with dredged material), construction of dikes, augmenting decreasing wetland resources including freshwater and saltwater marshes, bio filters for landfill leachate, constructed wetlands for waste water treatment, or fill for sloughs in riverine areas or denuded reservoir banks. There are a vast number of beneficial uses in upland areas including construction of roads or airport runways, landscaping (manufactured soil products), parks and recreational area development, cemetery development, and others. In the present investigation an attempt has been made to improve the mechanical behavior of dredged soil using ordinary Portland cement. Test results reveal significant improvement in the engineering properties of dredged soil. All products made from dredged material will have to meet the performance specifications established for existing material and will have to be cost competitive, available in a timely manner, and tested for performance. Therefore, this study presents the effect of cement stabilization on geotechnical properties of dredged material for its bulk utilization. The main contributions of this study to practice are on quantifying improvement in mechanical behavior due to cement treatment and highlighting the fact that higher percentages of cement could turn stabilization from beneficial to an extremely dangerous practice.

2 II. Materials and Methods

In this study, various soil samples from three different sites of the flood channel were collected. The disturbed samples were subjected to various soil tests like gradation, specific gravity, light compaction tests. Consistency limits were performed on both oven dried and air dried samples to check for the organic content. Unconfined compressive strength and direct shear tests were conducted on in-situ samples to determine shear strength parameters as per the Standard Codal procedures. After geotechnical evaluation of the physical and mechanical properties, the weakest soil sample was selected for cement stabilization using commonly available ordinary Portland cement (OPC) conforming to a compressive strength of 43 MPa. The fineness test conducted on the cement revealed a fineness value of 2 %. The standard consistency of the cement was determined using Vicat's plunger apparatus and a value of 31 % was observed. The physical properties of the selected soil sample are given in Table 1. Test specimens were prepared with dredged soil using a range of cement from 4% to 16 % (with 4 % increment by dry weight of the soil) at ? dmax and optimum moisture content. The specimens were subjected to tests on consistency limits, direct shear parameters and unconfined compressive strength tests at immediate, 7 days and 28 days of curing period.

3 Cement stabilization of soils

The chemical stabilization of clays using cement is a common method that can be used to improve properties of soil to provide a workable platform for construction projects (Brandon et al., 2009). Cement is often used as an additive to improve the strength and stiffness of soft clayey soils (Lee 1991, **??**itchell, 1981). Soil-cement is widely used to improve foundations of structures, in basement improvement, in rigid and flexible highway, airfield pavements, in embankment slope protection, stream bank protection, waterproofing, grade control structures, and reservoir and channel linings **??**Ingles et al 1972, Williams 1986, Teng et al 1973). The role of hydraulic cement such as portland or slag cement is to bind soil particles together, improve compaction, and decrease void spacing, improve the engineering properties of available soil such as, unconfined compressive strength, modulus of elasticity, compressibility, permeability, the drying rate, workability, swelling potential, frost susceptibility and sensitivity to changes in moisture content (Leonards 1962, Woods 1960, Robert et al 1971). Cement can be used to stabilize any type of soil, without those having organic content greater than 2% or having pH lower than 5.3 (ACI 230.1R-90 1990).

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4 . Mechanism of cement stabilization

The fundamental mechanism of soil cement stabilization has been outlined by Schaefer et al (1997), amongst others. The components of Portland cement are tricalcium silicate (C 3 S), dicalcium silicate (C 2 S), tricalcium aluminate (C 3 A) and tetracalcium aluminoferrite (C 4 A) (Lea, 1956). These four main constituents are major strength producing components. The major reactions that result in increase in strength of soft soil are: 1. Calcium hydroxide will be formed when quick lime reacts with water as a result pH increases.

5 Isomorphous substitution of calcium in the clay

particles decrease the interlayer spacing and cause coagulation of the clay particles, thus reducing the plasticity of the soil.

6 Calcium silica hydrate(C-S-H) compounds are

formed by the dissolution of silica in the clay particles followed by its reaction with calcium oxide. These compounds form bonds between binder particles or between binder particles and soil particles to form stiff matrix. The composition and structure of the C-S-H gel and the type and amount of other hydration products can alter due to presence of organic matter in soil.

The reactions that take place in soil cement stabilization can be represented in the following equations, the reactions given here are for tricalcium silicate (C 3 S) only, because it is the most important constituent of Portland cement. In order to have additional bonding forces produced in the cement-clay matrix, the silicates and aluminates in the compound matrix must be soluble. In the above equations, the strength of the primary cementitious products is much stronger than the secondary ones. The cement hydration and the pozzolanic reactions can last for months or even years after the mixing and thus the strength of cement treated clay are expected to increase with time (Bergado et al., 1996). Thus, in the soil cement reactions, primary and secondary cementing substances are formed. The primary products harden into high-strength additives. The secondary processes increase the strength and durability of the soil cement by producing an additional cementing substance to further enhance the bond strength between the particles.

7 III. Results and Discussions

8 Effect of cement on consistency limits

The addition of first increment of 4% cement on dredged soil increases the liquid limit, plastic limit, and plasticity index as shown in Fig. ??. This improvement of liquid limit attributed that more water is required for the cement treated soil to make it fluid and the increase of plastic limit implies that cement treated soil required more water to change it plastic state to semisolid state (Sarkar et al 2012). When final increment of 16 % cement is mixed to the dredged soil all the consistency limits decrease with plasticity index reporting a value of 11.1 which is higher than the untreated value of 10.4 (Table 2). This suggests that the addition of cement to the dredged soil made the soil more plastic making it difficult to work with.

9 Effect of cement on compaction characteristics of dredged soil

One of the basic and least expensive construction procedures used for soil stabilization is compaction. Compaction improves the engineering properties of foundation material so that the required shear strength is obtained. Generally, a high level of compaction of soil enhances the geotechnical parameters of the soil, so that achieving the desired degree of relative compaction necessary to meet specified or desired properties of soil is very important (Nicholson 1994). The OMC of cement stabilized soil varies in a very narrow range (Fig. ??). From Fig. 3 it is seen that OMC decreases and MDD increases continuously up to 16 % cement content without giving any optimum value.

10 Effect of cement on strength characteristics of dredged soil

Strength characteristics are fundamental for any engineering application of the soil. In this study unconfined compression tests and direct shear tests were conducted on the cement stabilized dredged soil. The test results are discussed below:

11 i. Unconfined compression test

Unconfined compression test is the simplest and quickest method to determine the shear strength of cohesive soils. Test specimens were prepared, compacted under standard compaction at ? dmax and optimum moisture content. The samples were tested immediately, 7 days and after 28 days of curing period (Fig. ??a, 4b, 4c). The test results revealed that addition of cement has significant effect on the strength gain of the dredged soil. The optimum cement content has been found out to be 12 % (Fig. 5). With increase in curing period the strength of the dredged soil increased from 115 kPa to 1412 kPa (Fig. 5). Thus the cement treatment improves the soil consistency from soft in in-situ state to hard in treated state. ii. Direct shear test Direct shear tests were conducted on untreated and treated test specimens. The specimens were prepared, compacted under standard compaction at ? dmax and optimum moisture content. The test results reveal that in-situ dredged soil exhibits soft consistency. The angle of internal friction of 16 degrees indicates loose denseness of the soil. However, cement treatment drastically improves both cohesion (c) and frictional shearing angle (?) as shown in Fig. ?? changing the soil state from loose to dense state. The shear parameters showed decreasing trend beyond 12 % cement content. The variation of c and ? with increase in cement content is shown in Fig. ??.

12 IV. Conclusions

The addition of cement to the dredged material proved an effective means of improving the engineering properties of soils. The unconfined compressive strength increased by about 15 % than the untreated soil. The liquid limit, plastic limit, however showed varying trend, increasing the plasticity index, suggesting that the soil becomes less workable on mixing with cement. The Mohr Coloumb parameters showed significant gain, improving the soil consistency from soft to hard state and soil state from very loose to dense. Thus, using dredged soil as a resource has a twofold advantage. First, to avoid the serious health and environmental problems caused by large scale dumping of this material and second to use the treated dredged material as an engineering construction material for various applications. [1]

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Properties	Results
In-situ water content w n (%)	36.8
Permeability Coefficient, k (m/sec)	1.2x10 -8
Field dry density ? d (kN/m 3)	13.8
Specific gravity (G)	2.69
Clay (%)	15.9
Silt (%)	79.6
Sand (%)	3.7
Gravel (%)	0.80
Coefficient of uniformity, C u	–
Coefficient of curvature, C c	–
Suitability number, S n	–
Liquid limit L L (%)	38.5
Plastic limit P L (%)	28.1
Shrinkage limit (%)	17.3
Plasticity index PI (%) (L L -P L)	10.4
PI A -line (%)	13.5
PI U -line (%)	27.4
Classification	MI
Clay mineral	Kaolonite
Flow index, I f	10.2
Toughness index, I T	1.0
Activity	0.7
Consistency index, I c	0.2
In-situ UCS, q u (kN/m 2)	34.7
In-situ Cohesion, c u (kN/m 2)	23.7
Angle of Friction, ??	16.1
Optimum moisture content, (%)	26
Max m dry unit weight, (kN/m 3)	15.4
Un soaked CBR (%)	2.6
Soaked CBR (%)	2.4

Figure 1: Table 1 :

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Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
0	38.5	28.1	10.4
4	51.3	34.1	17.2
8	48.2	33.8	14.4
12	49.6	35.9	13.7
16	45.4	34.3	11.1

Figure 2: Table 2 :

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