International Journal of Technical Research and Applications e-ISSN: 2320-8163
www.ijtra.com Special Issue 12 (Jan-Feb 2015), PP. 04-09

SOME STUDIES ON GEOTECHNICAL CHARACTERIZATION OF DREDGED SOIL FOR SUSTAINABLE DEVELOPMENT OF DAL LAKE AND ENVIRONMENTAL RESTORATION

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Abstract- Dredged soil is a solid waste generated due to dredging of Dal Lake. The Dal Lake has been the centre of Kashmir civilization and is among the most beautiful National heritages. This lake with its multi-faceted eco-system and grandeur has been inviting the attention of national and international tourists. The urban lake, which is the second largest in the state, is integral to tourism and recreation in Kashmir. But during the past few years grave concern is being voiced by people from different walks of life over the deteriorating conditions of Dal Lake. It has been estimated that on an average 90,000 ton's of silt flows annually into the lake resulting in large quantities of silt deposits in the lake. The problems of Lake have been well recognized and efforts are on to save it. The scheme for shoreline dredging of Dal Lake has been formulated with the primary objective to help in Eco-regeneration and sustainable development of the lake. Dredging of the Dal Lake generated the dredged soil in large quantity posing serious disposal and environmental problems all-around the Dal Lake. Concern over environmental effects of dredging, disposal of dredged soil, and the increasing unavailability of suitable disposal sites, has put pressure for characterization of this soil as a resource for various beneficial uses/engineering applications. For all above applications, a brief study about some physical and mechanical properties of dredged soil forms an important consideration, which will help in proper use of this unwanted soil as well as sustainable development of the Dal Lake. Hence, using dredged soil has a two-fold advantage. First, to avoid the tremendous environmental problems caused by large scale dumping of dredged soil and second, to help in sustainable development of the world famous lake in the capital City Srinagar.

Keywords-Solid waste soil, Waste management, Dredged soil, Sustainable soils management approach, Environmental problems, Soil stabilization

I. Introduction

Due to rapid urbanization and huge population increase particularly in developing countries around the world, there is scarcity of good construction sites as well as construction soils. Hence, there is lot of pressure on Structural and Geotechnical Engineers to use marginal/weak soils for construction of various infrastructures. On the other hand, due to set-up of various industrial units, lot of solid waste soils is produced every day, which need to be disposed-off or used in various construction activities in a scientific way to avoid any environmental or health problems.

Knowledge of the sources and types of solid wastes, along with data on the composition and rates of generation is basic to the design and operation of the functional elements associated with the management of solid wastes. The goal of a waste characterization study is to identify the sources, characteristics, and quantities of the waste generated, and the goal of a waste diversion study is to identify the types and quantities of waste soils that are now separated for recycling or otherwise diverted from disposal in Lakes. Sources of solid wastes in a community are, in general, related to land use and zoning such as residential, commercial, institutional, construction and demolition, municipal services, treatment plant sites, industrial, and dredging of water bodies. But this study deals with the solid waste generated by dredging the world famous Dal Lake, one of the most beautiful lakes of India and the second largest in the J&K State with the primary objective to increase the clear water expanse of the lake, improve water circulation and consequently help in Eco-regeneration of the lake. Dredging is simply the removal of sediments from a body of water that have accumulated due to upland erosion in order to maintain a desired depth, as in a reservoir, dam, shipping berth, marina or navigation channel. But the Dredged soil has posed serious problems of disposal and environmental hazards all around Dal Lake (Fig. 1). The condition of Dal Lake before and after dredging is shown in Fig. 2.

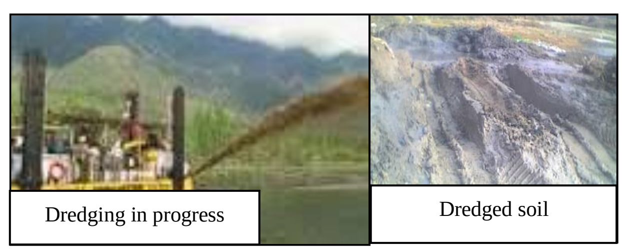

Fig. 1. Dredging of Dal Lake in progress and accumulation of dredged Soil along Lake Shores

Fig. 2. View of Dal Lake before and after dredging operation

But Dredged soil is no longer being regarded as a "spoil" or "waste" but as a resource. Its mineralogy and Geotechnical properties qualify it for use in the manufacture of high value, beneficial use products [1-2]. The suitability of dredged soil for different uses varies, however, a wide variety of beneficial use options are- Engineered uses, environmental enhancement of wetlands, fisheries, and other habitats for wildlife utilization, and beneficial use end products including topsoil, construction-grade cement, lightweight aggregate, bricks, architectural tile and can be recommended as fill soil for low-lying areas, land improvement [3]. The range of engineering applications for dredged soil is diverse, being limited only by the ingenuity of the designer. Therefore, for bulk and an effective utilization of dredged soil, some study about some physical and mechanical properties of dredged soil was attempted in this paper. Laboratory tests involved determination of some physical and mechanical properties and the test results indicated that in-situ state of soil is not suitable for using it as a foundation or construction soil alone. Therefore, effects of lime on some physical and mechanical properties of dredged soil were evaluated. Test results indicate that lime can effectively improve some engineering properties of soil under consideration. Lime stabilization of sols has been successfully applied in Highway Works [4], [5], [6], [7]. Thus, the aim of this study is to improve the soil characteristics for sustainable development of Dal Lake and its surroundings in the capital City. Based on favorable results, it has been concluded that using dredged soil as a resource has a two-fold advantage, first, to avoid the tremendous environmental problems caused by large scale dumping of dredged soil and second, to help in sustainable development of the world famous lake in the capital City Srinagar.

II. ENVIRONMENTAL ISSUES AND PROBLEMS

Environment is explored through topics covering air, water, land, sea, climate, wild life, pollution, people and our life style, impact of business and industry, how we use resources and how we deal with waste. Man's mad race for acquiring power has posed greatest danger to environment and Eco-system. Increase in population and quest for higher living standards caused greater demand for earth's natural resources. The human activities have thus been altering the atmospheric composition, which in turn affects the regional or even global climate. Thus, environmental problems are multidimensional, multidisciplinary, and dynamic and require an integrated approach to examine the state of environment and to achieve sustainable industrialization.

III. MATERIALS AND METHODOLOGY

In the present investigation, dredged soil was collected from Tailbal Basin of Dal Lake. Disturbed and undisturbed soil samples were collected from the project site for conduct of various field and lab. tests. All the tests necessary for determination of physical and mechanical properties were carried out as per the relevant ASTM Standards [8], [9], [10], [11], [12]. The physical properties of the dredged soil used in this investigation are listed in Table 1. The particle size distributions curves and flow curves of these soils of Tailbal Basin are shown in Figs. 3 and 4 respectively. Naturally available commercial high calcium lime CaO_2 was used as an additive to stabilize the dredged soil. Lime was mixed in the dry state and the percentage of lime varies from 0 to 9% with 3% increments. The important properties that are necessary for using dredged soil in many geotechnical applications are index properties, compaction characteristics, CBR and strength characteristics. Lime stabilization is generally cost effective for clayey soils [13], [14], [15].

TABLE 1. PROPERTIES OF DREDGED SOIL USED

Property	Tailbal Basin of Dal Lake		
	I	II	III
Clay Size (%)	77	69	33
Silt Size (%)	19	26	55
Sand Size (%)	04	05	12
Specific Gravity	2.60	2.57	2.56
Liquid Limit (%)	49	46	39
Plastic Limit (%)	23	21	24
Plasticity Index (%)	26	25	15
Plasticity Index-A_{line} (%)	21	19	17
Plasticity Index-U_{line} (%)	37	34	28
Shrinkage limit (%)	15	12	11
Activity	0.3	0.3	0.5
Soil type and classification (unified soil classification system-USCS)	Clayey soil of low to medium compressibility (illite-mineral)		Clayey silts of low to medium compressibility
	CL	CL	ML
Soil type and classification (Indian standard soil classification system-ISSCS)	Clayey soil of medium compressibility (illite-mineral)		Clayey silts of medium compressibility
	CI	CI	MI
Free Swell Index (%)	03	01	---
Compression index, C_c	0.27	0.25	0.23
Natural Moisture Content (%)	41	39	37
Field Dry Density (kN/m^3)	13.5	12.8	13.9
Max^m. Dry Density (kN/m^3)	15.7	15.5	15.9
Optimum Moisture Content (%)	23.1	21	19
CBR (%)	03	03	05

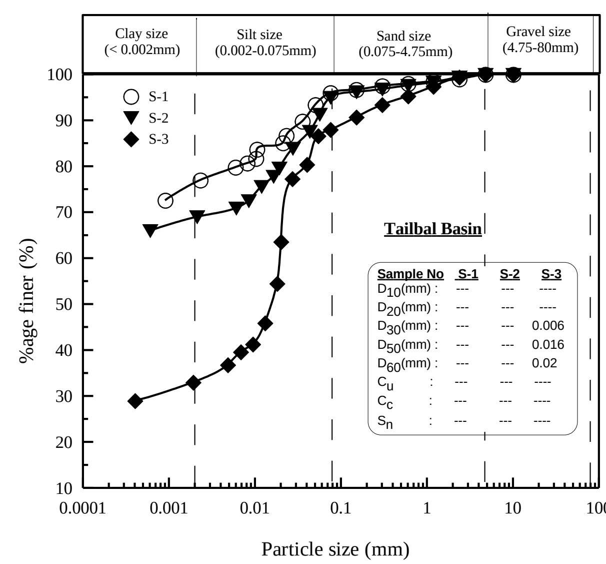

Fig. 3. Particle Size Distribution Curves for Tailbal Basin

From Fig. 3, particle size distribution analysis revealed that the dredged soil contained about 77% and 69% clay for samples I & II, which are far away from the point of disposal and 55% silt (< 0.075mm) and 12% fine sand size particles for sample III which is near by the point of disposal of dredged soil (Table 1 above). From test results, it is concluded that the dredged soil is classified as poorly graded clayey/silty soil with appreciable fines. The particle size distribution curves gives, at a glance, the nature of size gradation, range of particle sizes, and a comparison of different soils. The particle size curve is used to know the susceptibility of a soil to frost action, required for the design of drainage filters, an index to the coefficient of permeability and the shear strength of the soil. The suitability of a backfill material also depends on the gradation.

The consistency limits of untreated dredged soil are given in Table 1 and shown in Fig. 4. It is observed that liquid limit is very high and natural moisture content is more than plastic limit indicating that the soil is in a wet and sticky condition, impossible to compact and impossible to traffic. The dredged soil is classified as clayey soil of medium compressibility (illite-mineral) with very high rate of loss of shear strength. From test results, it is seen that dredged soil in its in-situ state is not suitable as a "stand-alone" construction material, and needs to be stabilized for use as engineered construction material in various construction activities in bulk for sustainable development of Dal Lake and environmental restoration.

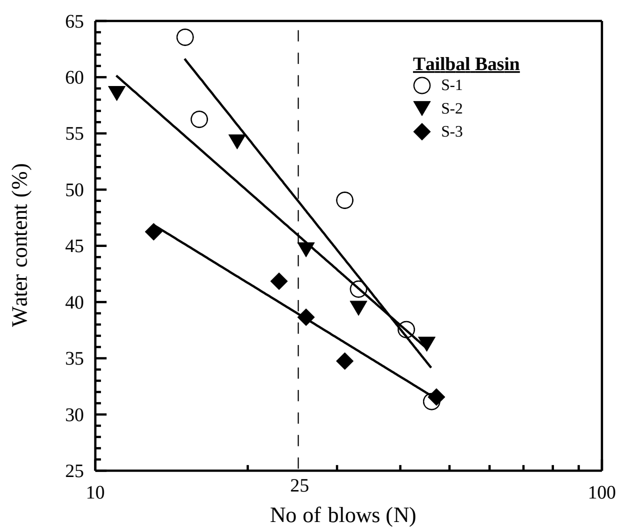

Fig. 4. Flow Curves for Tailbal Basin

IV. RESULTS AND DISCUSSION

Effect of lime stabilization on index properties

Consistency limits are extensively used in geotechnical engineering and these include; liquid limit, plastic limit and shrinkage limit. They provide an overall idea for the engineering properties of the soils. The consistency limits of untreated dredged soil are given in Table 1. It is observed that natural moisture content is more than plastic limit indicating that the soil is in a wet and sticky condition, impossible to compact and impossible to traffic. It is also seen that the rate of loss of shear strength is more prominent in case of sample-1 (Fig. 4 above), hence this has been selected for stabilization using lime as an additive. The index properties of dredged soil are significantly altered by the addition of lime. The variation of consistency limits with addition of lime is shown in Fig. 5. From Fig. 5, it is seen that addition of 6% of lime ash has changed the classification of dredged soil from CI to ML, CL-ML. The trends of variation exhibited by plastic limit and plasticity index are also on the same expected lines. The plastic limit of dredged soil–lime composite samples first increases (23% to 30.7%) and then decreases marginally from 30.7% to 28.3%) as a function of lime percentage increase (beyond 6%), which shows that the behaviour changes from expansiveness to non- expansiveness in nature. The increase in plastic limit on addition of lime is due to lime content imparted to the dredged soil, which causes reduction in the diffuse double layer thickness and flocculation of the clay particles. The marginal decrease in the plastic limit with an increase in percentage of lime content is due to the reduction of soil available for the lime to react to form a calcium silicate gel which coats and binds lumps of clay together and occupies the pores in the soil. Plasticity index is a good indicator of swelling potential. The addition of lime to clayey soils also reduces their potential for swelling which means that there is increase in moisture absorption in lime treated soils. The swell potential of the treated soil is often of great importance for modified sub-grades.

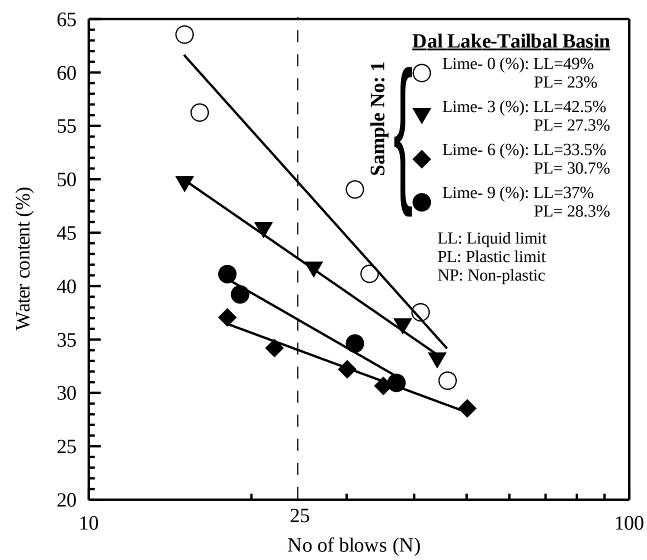

Fig. 5. Effect of lime on index properties of dredged soil

Effect of fly ash stabilization on compaction characteristics of dredged soil

The density of soils is an important parameter since it controls its strength, compressibility and permeability. Compaction of lime stabilized soils is more tolerant than those stabilized with cement. The compaction curves for untreated soil and soil-lime mixes are shown in Fig. 6. From Fig. 6, it is observed that lime treatment flattens the compaction curve, thereby ensuring that a given percentage of the prescribed density can be achieved over a much wider range of moisture contents, so that relaxed moisture control specifications are possible. Also the optimum moisture content is moved towards higher values, enabling soils in wetter than original condition to be compacted satisfactorily. Low unit weight of soil-lime mixes will result in lower earth pressure leading to savings. The "OMC" and "MDD" is 23% and 15.7kN/m^3 for untreated dredged soil for sample-1 and 22% and 15.8 kN/m^3 with addition of lime for (soil+6%lime) mix. The variation of OMC & MDD with lime content is shown in Fig. 7.

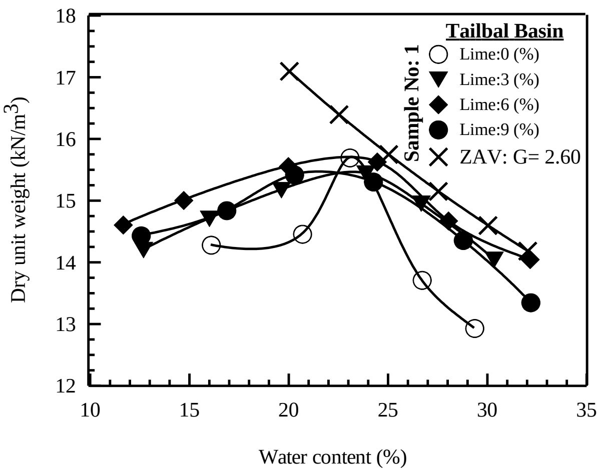

Fig.6. Effect of lime on compaction characteristics of dredged soil

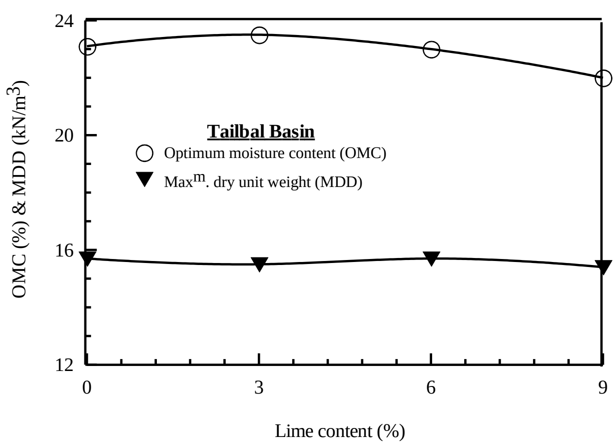

Fig. 7. Effect of lime on compaction parameters of dredged soil

Effect of lime stabilization on CBR characteristics of dredged soil

An extensive road network is one of the major indicators of a nation's economic prosperity, and soil is used as construction soils for roads and airfield pavements. The principles involved in design of flexible road pavements consist of testing the sub-grade soil and then, from correlation data or theory, determining the thickness of pavement required to protect the sub-grade. Ideally, the pavement is built to a depth where stresses on any given layer will not cause undue rutting, shoving, and other differential movements resulting in an uneven wearing surface. Most methods of design are either empirical or semi-empirical in nature and are based upon correlations with field performance. Of all the available methods of flexible pavement design, the CBR (California Bearing Ratio) method has been found the most reliable practical means of evaluating the strength of the sub-grade (bearing capacity of the soil) and construction soils, and estimating the required thickness of pavement to satisfy a given loading. CBR is a measure of the load carrying capacity (resistance to direct penetration) of any soil which is expressed as a percentage of the load carrying capacity of a standard crushed rock specimen (which is taken as of 100% value) determined by a penetration test. Resistance to penetration of a rigid plunger is measured and the loads at penetrations of 2.5mm and 5.0mm are expressed as percentage of two standard loads (1370kg and 2055kg). The higher percentage is taken as the CBR value (usually at 2.5mm penetration) under soaked conditions for a period of four days. The soaking period is intended to simulate sub-grade saturation due to high water table and precipitation, and thus the design test is made when the soil is in its weakest condition. In the present study, an attempt was made to conduct CBR tests [16] on dredged soil stabilized with lime. Figure 8 shows the variation of CBR for different lime contents. From Fig.8, the CBR values for dredged soil are found to be 3% and 2.6% for un-soaked and soaked conditions. The decrease in CBR upon soaking is due to the decreased effective stress and loss of surface tension forces. The CBR of the soil is contributed by its cohesion and friction components. The low CBR of dredged soil is attributed to its inherent low strength due to the dominance of clay fraction. Addition of 6% lime to the dredged soil increases the CBR due to the pozzolanic reaction between lime and dredged soil. The addition of dredged soil beyond 6% causes a little reduction in the CBR value, which is the optimum lime content to enhance the CBR characteristics of dredged soil.

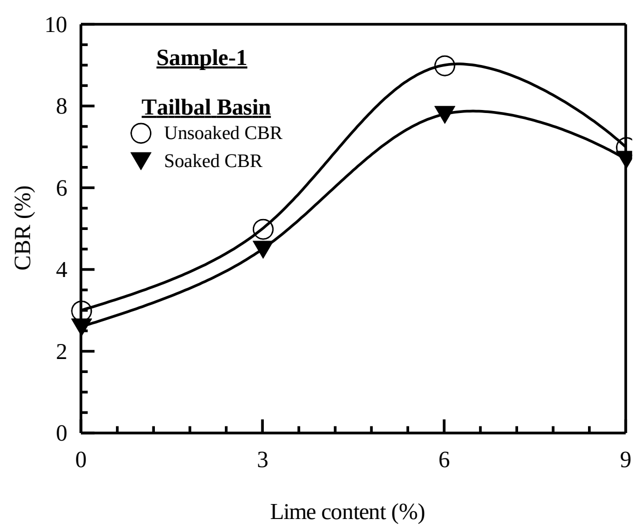

Fig. 8. Effect of lime on CBR characteristics of dredged soil

Effect of Lime on Strength Behavior of Dredged Soil

For any engineering application of soil, its strength characteristics are essential. In some special cases, as for checking the short-term stability of foundations and slopes where the rate of loading is fast but drainage is very slow, one of the most common shear tests is the unconfined compression test. The behavior of dredged soil under a load is a measure of its shear strength. Before a dredged soil can be used for construction purposes, its shear strength must be determined. In some special cases, as for checking the short-term stability of foundations and slopes where the rate of loading is fast but drainage is very slow, one of the most common shear tests is the unconfined compression test (UCT). In the present study, UCT test [17] and Direct shear test [18] with varying lime content were conducted to evaluate shear strength parameters as per relevant procedures. The tests results for UCS tests are shown in Fig. 9. From UCT results, undrained cohesion "c_u" varies from 19 kN/m^2 for untreated soil to 53 kN/m^2 for an optimum lime content of 6% respectively. The variation of unconfined compressive strength with addition of lime content is shown in Fig. 10.

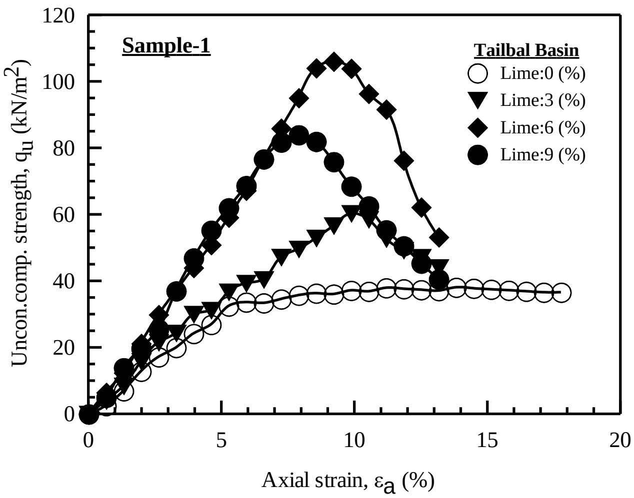

Fig. 9. Uncon. compression strength tests for lime treated dredged soil

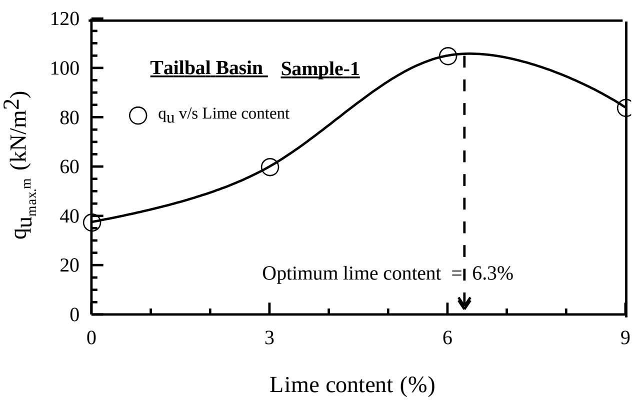

Fig. 10. Effect of lime on unconfined compression strength dredged soil

It has also been observed that the strain corresponding to the peak stress varies with addition of lime content. Hence, care has to be taken for strains where ucs of composite soil matrix changes drastically. The DST results (Fig. 11) revealed that "c & ϕ" parameters vary in the range of 12 kN/m^2-50 kN/m^2 and 12–46 degrees indicating that the untreated dredged soil is of very soft/loose state of compactness in its in-situ conditions. The strength of lime-soil mixtures is influenced by several factors such as soil type and method, unit weight, moisture, mixing and compaction. The increase in shear strength parameters on addition of lime is attributed due to pozzolanic effect between lime and dredged soil. Hence, lime stabilization enhances the strength characteristics of dredged soil for its bulk utilization in various construction activities. Therefore, the use of pozzolznic additives in ground improvement is an effective means of waste management.

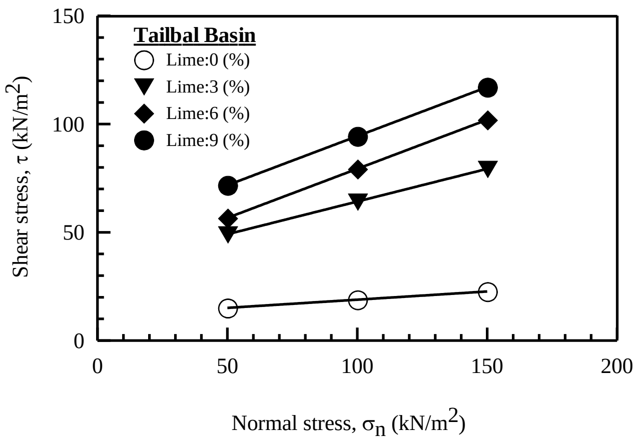

Fig. 11. Effect of lime on shear strength parameters of dredged soil

The undrained shear strength of clays or clayey soil (c_u) is taken equal to $q_u / 2$, which provides a conservative value and is also very widely used. For non-cohesive soils, shear tests give unreliable data because of sample disturbance, whereas in case of cohesive soils, loss of strength occurs if they are sensitive. However, thixotropy in such soils recovers part of the lost strength with passage of time. Hence, strength correlations are commonly used. In case of cohesive soils, c_u/p'_o correlation is used for preliminary design. It is well known that the undrained shear strength (c_u) of normally consolidated (NC) clays normalized with respect to the current effective vertical stress is unique, and for over consolidated (OC) clays, the following relationship adequately represents the normalized undrained shear strength (e. g. the effect of stress history induced over consolidation on undrained strength ratio c_u / p'_o) may be expressed in the following form [19], [20], [21], [22]:

$$(c_u / p'_o)_{OC} = a(OCR)^m \qquad (1)$$

Where: OCR is the overconsolidation ratio defined as the ratio between the maximum past effective vertical stress and the current effective vertical stress,
m is an empirical exponent equal to (1-κ/λ) and
κ, λ are soil model parameters obtained from laboratory testing; and a is the normalized undrained shear strength of NC clay (= $c_u/p_o)_{NC}$ for OCR=1.

SUMMARY AND CONCLUSIONS

Following are some of the broad conclusions deduced from the present study:

1. The stabilization of the solid waste soil such as dredged soil with lime is an effective means of chemical stabilization of soils.
2. It is seen that the index and engineering properties of dredged soil are significantly altered by the addition of lime.
3. It has been observed that 6 % of lime ash is the optimum amount required to minimize the compressibility characteristics of dredged soil.
4. The compacted density of soil-lime mixes is low compared to untreated soil that will be beneficial since a lower density will result in lower earth pressure leading to savings. However, the influence of marginal reduction of dry density may not lead by itself to significant reduction in lateral earth pressures.
5. With increase in lime content, CBR values are increased and hence stability of pavement increases.
6. The unconfined compressive strength of soils can be increased by addition of lime. Lime alters the shear strength parameters (c_u and ϕ) of dredged soil significantly by pozzolanic reactions that increase the strength.
7. The use of lime in ground improvement is an effective means of solid waste management, and it is particularly useful for reducing the porosity of blended soils.

ACKNOWLEDGMENT

The investigation reported in this paper forms a part of the research at the National Institute of Technology Srinagar. Thanks are due to supporting staff of the Soil Mechanics laboratory and the office staff of Civil Engineering Department for their timely help during the course of investigation.

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The main emphasis of this paper is to improve solid waste material by means of chemical stabilization using lime as an additive, as one of the most cost effective ground improvement techniques for sustainable development of Dal Lake and restoration of its environment.
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