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Improvement of soil strength using cement and lime admixtures

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Abstract: Many geotechnical structures are constructed on weak and loose soil deposits. Thus for safe design this formation needs improvement before construction starts. A popular technique to improve such soil condition is to use cement and lime in the soil. This technique is now being used all over the world in various applications such as embankment, foundations, road pavement etc. The soil properties need to be improved by using cement and lime admixtures. For this reasons a detail investigation of the behaviors of the soil-cement and soil-lime therefore became imperative. In this research work, a comprehensive testing program has been carried out to study the stress change behavior of non stabilized soil. The soil used in this research is taken from Godagari Upazila, near the Rajshahi city. The research work amongst others investigated three aspects, such as the effect of admixtures, the effect of percentage of admixtures and the effect of curing time after mixing of admixtures. Compressive strength is conducted using universal testing machine. Series of tests are conducted for stabilized soil under twenty categories; ten on cement admixture and ten on lime admixture. In addition, a series of compressive strength test are also carried out for stabilized and without stabilization of soil to study the effect of admixture on shear strength. Compressive strength test results show the shear strength of soil varies from 25 psi to 210 psi with respect to the different percentage of cement after 3 days curing and the same value varies from 25 psi to 220 psi for 7 days curing. The compressive strength for mixing of lime admixture varies from 22 psi to 70 psi and 23 psi to 95 psi for 3 days and 7 days curing period respectively. It is also found that stabilized soil with higher percentage of admixture exhibit higher shear strength. The strength also increased with increasing curing period. Charts are also presented to predict the strength of stabilized soil.

Keywords: Loose Soil, Cement, Lime, Soil-Cement, Soil-Lime, Admixtures and Stabilization of Soil

1. Introduction

In a broad sense, stabilization incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance (Bowles, 1998). Stabilization of soil means improving of soil strength under applied load. The soil properties will be increased reasonably with or without the help of admixtures so that base/sub-base soil is capable of supporting the traffic load in all weather condition (Buddhu, 2000). In the recent year the stabilization of soil with suitable admixture such as lime, cement, calcium chloride, fly ash, bituminous material etc. has been successfully used on increasing scale for the construction of road foundation in Bangladesh, India, United Kingdom, and U.S.A etc. (Bardet, 1997). In this research work two admixtures such as lime and cement are considered. Some admixture improves poor soils and then capable of supporting greater loads but they are not economical (Leonards, 1962). If volume of earth involves under a pavement or under a foundation is huge, that result the quantity of stabilization prohibitive. The high pressure exerted on the pavement and base course generally preludes using the stabilized soil for bases (Cernica, 1995). Therefore, stabilization, except for secondary roads is centered on use in sub-grade and sub-bases. For secondary roads, a stabilized material (particularly a mechanically stabilized soil) can be used as the principal component of the pavement (Carraro, 2008). Secondary road construction includes gravel surfaces of types, soil cement and oiled earth surfaces. The choice of the proper admixtures, which should be used, depends upon the use for which it is independent (Craig, 1997). The quantity of stabilizer is generally determined by means of arbitrary tests, which simulate field condition of weathering and other durability processes.

2. Research Significance

In this research work soil stabilization is performed to achieve the following objectives:

[1] To increased the strength or stability of soil and to reduce the construction cost by making best use of the locally available materials.
[2] To modifying or increase the properties of soil by using locally available admixtures.
[3] To device the method of adding the lacking property through the economical method.
[4] To modify the chemical properties of soil this is to be stabilized.
[5] To evaluate the physical properties like density, expansion, shrinkage, stability etc of soil samples.

3. Methods of Soil Stabilization

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Methods of soil stabilization may be grouped under two main types:

(a) Modification or improvement of soil property of the existing soil without any admixture, and

(b) Modification of soil with the help of admixtures.

Compaction and drainage are the examples of the first type, which improve the inherent shear strength of soil. Example of second types is mechanical stabilization: stabilization with cement, lime, sand, bitumen and chemicals etc. Some of the more commonly used methods will be discussed in this section.

3.1. Mechanical Stabilization

Mechanical stabilization is termed as granular stabilization. It involves two operations (i) changing the composition of soil by adding or removal of certain constituents and (ii) densification or compaction. In this process, gradation of soil aggregate mixture is the only factor which controls the stability of the engineering behaviors of a soil. For mechanical stabilization, where the primary purposes is to have a soil resistance to deformation and displacement under loads, soil materials can be divided into two fraction: the granular fraction retain on a 75micron ASTM sieve and the soil fraction passing a 75micron sieve. The granular fractions impart strength and hardness. The fine fraction provide cohesion or binding property, water retention capacity and also act as filter for the voids of the coarse fraction (Das, 1983). Mechanical stabilization has been largely used in the construction of less important roads. Instead of strictly observing the specifications emphasis should be laid on making the maximum use of locally available materials are found to be quite satisfactory under load condition.

3.2. Stabilization Using Soft Aggregates

In hard variety of aggregate are not available locally soft ones which are available locally can be adopted in the construction of mechanically stabilized roads. Soft aggregates have very poor crushing strength but still it can be used in the construction of mechanically stabilized sub base, base and even in surface course (Das, 2005). Kankar, Moorum, broken brick aggregates are most commonly used.

3.2.1. Stabilization Using Broken Bricks Aggregates

The brick aggregate and soil mixed in ratio of 1:2 is laid on a course of sandy soil are very good stabilizer for roads construction (Mehra, 1963). Indian Road Congress (IRC, 1988) has also accepted this method of stabilization as a standard method. In this method a base course of sandy soil 7.5cm compacted thickness with 8 ton roller is laid on the prepared sub grade. Base course material consists of 50% sand and the plasticity index must be 5 to 7. After laying the base, surface or wearing course of thickness 7.5 cm is provided. The soil used in the mix should all pass through 0.425mm sieve and retained fully on 0.75micron sieve (Das, 1998). Sand content in the soil should not be less than 33% and plasticity index in between 9.5 and 12.5. Rolling of base and wearing course is done using 8 ton roller. After rolling the surface is left to stabilize for the night. Next morning surface is again rolled and finished. Finished road is allowed to stabilize for 4-5 days during which water is daily sprinkled on it.

3.3. Bituminous Stabilization

Bitumen when mixed with soil, imparts binding property and makes it water proof. Waterproofing property imparter to the soil helps retain its strength even in the presence of water (Gupta, 1990). In case of fine grained soils bituminous materials seal the voids between fine soils and keep soil away from coming in direct contact of water and thus inherent properties of the soil are retained. In the case of soil like sand and gravel individual particles get coated with a very thin film of bituminous material and thus binding property to the soil (Kirkpatrick, 1965). The maximum dry density of the compacted layer in decreased whereas water absorption increases in the first stage at very low bitumen content but then starts decreasing.

3.4. Lime Stabilization

When stabilization of soil is done by mixing lime in proper proportion, the process is known as soil lime stabilization. Lime is an excellent choice for short term modification of soil properties. Lime can modify almost all fine grained soils but the most dramatic improvement occurs in clay soils of moderate to high plasticity (Koerner, 1970). Modification occurs as calcium captions supplied by the hydrated lime replace the captions normally present on the surface of the clay mineral, promoted by the high p^H environment of the lime water system (Hejazi, 2012). Thus the clay surface mineralogy is altered producing the following benefits:

a) Plasticity reduction.
b) Reduction in moisture-holding capacity.
c) Swell reduction.
d) Improved stability.
e) The ability to construct a solid working platform.

Soil stabilization occurs when lime is added to a reactive soil to generate long term strength by pozzolanic reaction. The key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol and reliable construction practices.

Benefits of soil-lime stabilization include:

1. Very substantial increases in resilient modulus values (by a factor of 10 or more in many cases).
2. Very substantial improvements in shear strength (by a factor of 20 or more in some cases).
3. Continued strength gain with time, even after periods of environmental or load damage (auto genius healing).
4. Long-term durability over decades of service even under severe environmental conditions. This performance benefits translate into short and long-term economic benefits.
5. In the short-term, considering the structural contribution of lime- stabilized layers in pavement design can create more cost effective design alternatives. Recent interstate project in Pennsylvania for example began with a \$29.3 million traditional design approach. An alternate design using lime stabilization, consistent with AASHTO mechanistic empirical designs, cost only \$21.6 million more than 25 percent savings (Yasin, 2003).
6. In the longer term, lime stabilization provides performance benefits that reduce maintenance costs. To illustrate, stabilizing 8-inch native clay sub grade with lime as part of an as asphalt pavement project can reduce 30 year life cycle costs for \$24.49 to\$22.47 per square yard.
7. Lime stabilization is not difficult to carry out. After proper mix design and testing is performed, in-place mixing is usually used to add the appropriate amount of lime to soil, mixed to an appropriate depth. Pulverization and mixing is used to thoroughly combine the lime and soil. For heavy clays preliminary mixing may be followed by 24 to 48 hours of moist curing, followed by final mixing. For maximum development of strength and durability, proper compaction is necessary. Proper curing is also important if sulfates are present at levels greater than 0.3 percent, special procedures are required (Natlime, 2001).

3.5. Cement Stabilization

When stabilization of soil is done by mixing cement with soil it is known as soil cement stabilization. Soil-cement is a mixture of pulverized soil and measured amount of cement and water, compacted to the desired density and cured (Liu, 1998). The role of cement is to improve the engineering properties of available soil such as strength compressibility, permeability, swelling potential, frost susceptibility and sensitivity to changes in moisture content. Soil cement materials range from semi flexible to semi rigid depending on the type of soil and amount of cement used. When granular soils are used and the concentration of cement is increased the mixture approaches a rigid behavior. In rigid pavements contraction expansion construction and longitudinal joints are used. For smooth riding and low-maintenance cost, reduction or elimination of the joints is desirable. The thermal properties of soils such as specific heat, thermal resistivity and thermal diffusivity are lower than that of concrete. The thermal properties of soil cement particularly for fine grain soils are expected to be lower than that of concrete. This will result in lower warping and lesser interior stresses in pavements of soil-cement as compared to concrete in rigid pavement. Reinforced may be used to improve the load carrying capacity of seal in fill construction. Armstrong reported the use of steel reinforcement in soil cement mixture for trench capping follow level nuclear waste disposal trenches of 6m x 3m x 3m (Leonard and Nagih, 1995).

The amount of cement required expressed as a percentage by weight of dry soil, generally varies between 5 to 10%, finer soil require more cement.

3.6. Thermal Stabilization

Thermal stabilization may be adopted in the case of stabilization of highly clayey soils. This is quite old method of stabilization. In this method heat treatment is given to the soil in situ with the help of traveling furnace, which can develop a temperature of more than 500^0C. Heat treatment of soil is found to be very costly and hence, this method did not achieve universal acceptance. This method of stabilization can be adopted with advantage in the treatment of black cotton soil. This method reduces plasticity of black cotton soil. Studies conducted reveal that temperature between 500^0C to 600^0C is the optimum temperature which renders highly plastic soil non plastic.

3.7. Chemical Stabilization

There are many chemicals which are used for soil stabilization. Such as-

a) Calcium chloride: It acts as soil flocculent. It facilitates compaction and usually causes a slight increase into the compacted density. The salt may be spread not the surface, or incorporated into the soil by miss-in-place and plant mix methods (Punmia, 1994).

b) Sodium chloride: Its stabilizing action is somewhat similar to that of calcium chloride but sir neither has nor vein so widely used.

c) Sodium silicate: Its solution in water known as water glass, in combination with other chemicals, such as calcium chloride is used as an injection for stabilizing deep deposits of soil.

3.8. Electrical Stabilization

The stability or shear strength of fine-grained soils can be increased by draining them with the passage of direct current through them (Mehmet, 2008). This process is also known as electro osmosis. Electrical drainage is accompanied by electro-chemical composition of the electrodes and the deposition of the metal salts in the soil pores. They may also be some change in the structure of soil. The resulting cementing of the soil due to all those reaction is known as electro-chemical hardening and for this purpose the use of anodes is recommended.

4. Materials and Methods

The soils are collected from Godagari Upazila in Rajshahi district. The soils are collected from this area because the soils are of very low bearing capacity. The basic engineering properties of soils are determined without mixing admixtures. The basic engineering properties of soil determined from various test is shown in Table 1.

5. Result and Discussion

To carry out the research work 60 **cubes ($2^{//}$x $2^{//}$ x$2^{//}$)** are prepared in 20 groups having same proportion of the mix. 3 Nos. of cubes are made in different percentage by weight of cement and lime (1%, 3%, 5%, 7%, and 9%). Thus two groups specimen are prepared for curing periods of 3 and 7 days. The cubes are tested for compressive strength by using universal testing machine. Compressive strength is calculated by the following formula: $f_C^{/} = P / A$,

Table 1. *Basic engineering properties of soil*

Basic properties	Tested value
Diameter corresponding to 30 % finner, D_{30}	0.15
Diameter corresponding to 60 % finner, D_{60}	0.21
Uniformity co-efficient, C_u	2.66
Co-efficient of curvature, C_c	1.125
Fineness Modulus, FM	1.23
Water content (%)	12.35
Liquid limit (%)	30.00
Plastic limit (%)	18.86
Shrinkage limit (%)	14.98
Optimum moisture content (%)	16.20
Maximum dry density (gm/cm^3)	1.78

Where $f^{/}c$ = Compressive stress, P = applied load and A = Cross- sectional area. The compressive strength of soil-cement stabilized soils and soil without admixture with different percentage is shown in table 2. The compressive strength of soil-lime stabilized soils and soil without admixture with different percentage is shown in table 3. In 3days curing period, the compressive strength of cement stabilized soil increases from 50.41 psi to 202.91 psi with the percentage of cement admixture. The same value of cement stabilized soil varies from 60.41 psi to 259.58 psi

Table 2. *Compressive strength of soil with different percentage of cement admixture*

Admixture	% of admixture	Curing period (days)	Size of specimen	Compressive strength (psi)
Cement	1	3	2//x 2// x2//	50.41
	3	3	2//x 2// x2//	76.25
	5	3	2//x 2// x2//	130.41
	7	3	2//x 2// x2//	171.25
	9	3	2//x 2// x2//	202.91
	1	7	2//x 2// x2//	60.41
	3	7	2//x 2// x2//	89.58
	5	7	2//x 2// x2//	147.91
	7	7	2//x 2// x2//	209.16
	9	7	2//x 2// x2//	259.58
Without	---	---	2//x 2// x2//	23.33

Table 3. *Compressive strength of soil with different percentage of lime admixture*

Admixture	% of admixture	Curing period (days)	Size of specimen	Compressive strength (psi)
Lime	1	3	$2^{//}$x $2^{//}$ x$2^{//}$	24.98
	3	3	$2^{//}$x $2^{//}$ x$2^{//}$	37.25
	5	3	$2^{//}$x $2^{//}$ x$2^{//}$	50.67
	7	3	$2^{//}$x $2^{//}$ x$2^{//}$	67.24
	9	3	$2^{//}$x $2^{//}$ x$2^{//}$	70.87
	1	7	$2^{//}$x $2^{//}$ x$2^{//}$	27.91
	3	7	$2^{//}$x $2^{//}$ x$2^{//}$	42.08
	5	7	$2^{//}$x $2^{//}$ x$2^{//}$	62.08
	7	7	$2^{//}$x $2^{//}$ x$2^{//}$	82.91
	9	7	$2^{//}$x $2^{//}$ x$2^{//}$	95.83
Without	---	---	$2^{//}$x $2^{//}$ x$2^{//}$	23.33

for 7 days curing period where it is 23.33 psi of non stabilized soil. In lime stabilized soil, the compressive strength varies from 24.98 psi to 70.87 psi and 27.91 psi to 95.83 psi for 3 days and 7 days curing period respectively. The same result of non stabilized soil is 23.33 psi. The variation of strength with respect to percentage of cement and lime for 3 days and 7 days curing period are shown in figure 1 and figure 2 respectively. The comparison of cement and lime stabilized soil strength is shown in figure 3. The strength of cement stabilized soil is always greater that of lime stabilized soil for both 3 days and 7 days curing period. The binding properties of cement are much more than lime, so the strength of cement stabilized soil is greater.

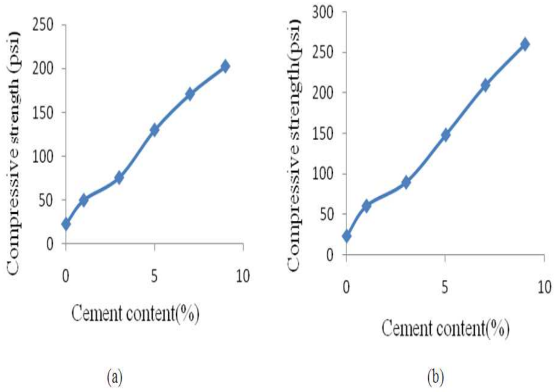

Figure 1. *The relationship between strength and % cement for cement stabilization for (a) 3 days curing and (b) 7 days curing period*

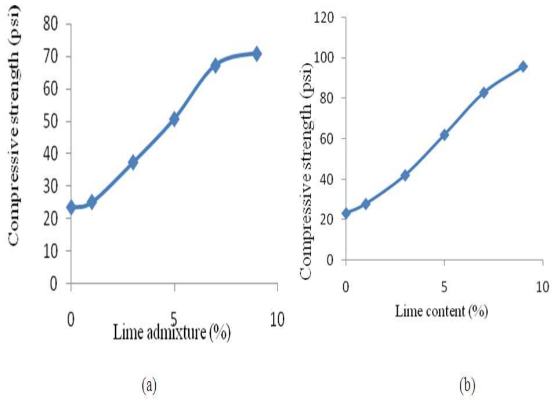

Figure 2. *The relationship between strength and % cement for lime stabilization for (a) 3 days curing and (b) 7 days curing period*

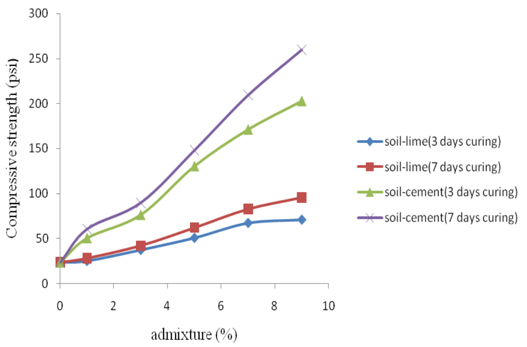

Figure 3. *Comparison of strength vs % of admixture of stabilized soil*

6. Conclusion

In the present study, the experimental investigations are carried out in five different mix proportions of soil-cement and soil-lime. Form the extension experimental study, the following conclusion may be drawn.

Strength of soil increases by adding admixtures.

1. Strength and stability increases with the increase of amount of admixtures.
2. Strength and stability increases with the increase of curing period.
3. Stability improved by cement is much higher than lime.

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