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Study of Stabilization of Black Cotton Soil using Lime

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ABSTRACT

With the increasing of population and the reduction of available land, more and more construction of buildings and other civil engineering structures have to be carried out on weak or soft soil. Owing to such soil of poor shear strength and high swelling & shrinkage, a great diversity of ground improvement techniques such as soil stabilization and reinforcement are employed to improve mechanical behaviour of soil, thereby enhancing the reliability of construction. There are several techniques have been researched up till now whether it may be using lime, fly ash, or certain add-mixtures. As a good stabilizing agent, lime is extensively applied in soil stabilization of foundation or roadbed. The study proceeds in such a way that a soil sample will be collected from the areas near Bhusawal, Maharashtra that will be the Black Cotton soil. Soil sample is tested barely without any mixture of lime and then it will be tested after addition of lime at certain amounts of lime like at 5%, 10%, 15% and the results study will be done after these tests. A series of basic tests will be practised and these tests will be helpful to make study that using lime will be a best and cheap method of ground improvement.

1. INTRODUCTION

Soil is the indispensable element of this nature. It is attached to everyone in one or another way. All the basic amenities of life, whether it is concerned with food, clothes and house, have been fulfilled by the soil. Without the soil it is just next to impossible to think about life on this earth. The word ‘soil’ is derived from the Latin word solium which according to Webster’s dictionary means the upper layer of the earth that may be dug or plowed; specifically, the loose surface material of earth in which plant grows. The top soil contains a large organic quantity matter and is not suitable as a construction material or as a foundation for structures The term soil in soil engineering is defined as an unconsolidated material, composed of solid particles produced by disintegration of rocks. The voids space between particles may contain air, water or both. The solid particles may contain organic matter.

The soil particles maybe separated by such mechanical means as agitation and water. Soil deposits in nature exist in an extremely erratic manner producing thereby an infinite variety of possible combination which will affect the strength of the soil and the procedures to make it purposeful. So is the particular case of black cotton soil with a wide range of challenges associated with the construction at sites with black cotton soil. The engineering behaviour of a soil mass is expected to be greatly influenced by the mineral composition of the soil grains forming the soil mass. This, however, is only partly true. In case of coarse grained soil, the mineralogical composition of the grain hardly affects the engineering properties of the soils perhaps the grain to grain friction is influenced to a degree. Is such soils, inter particle forces other than those due to gravity are of no consequence, but the finer particles, the more significant becomes the forces associated with the surface area of the grains.

The chemical character of the individual grain assumes importance especially when the surface area is large related to the size of the grain - a condition which is associated with the fine grained soil. Thus, inter-particle attraction holding the grain together becomes increasingly important as the size decreases. The soil structure means the mode of arrangement of soil particles related to each other and the forces that are acting between soil particles to hold them together in their positions. The concept is further extended to include the mineralogical composition of the grains, the electrical properties of the particle surface, the physical characteristics, ionic composition of pore water, the interactions among the soil particles, pore water and the adsorption complex. The formation of soil structures is governed by several factors in coarse grained soils, the force of gravity is the main factor, while in fine grained soils, and the surface bonding becomes predominant. The specific surface (the ratio of the surface area of a mineral to its mass or volume) is a parameter which is often used to decide the importance of surface bonding forces relative to forces of gravity. Smaller particles have much larger surface area than the larger particles. for the same void ratio water content are more for fine grained soil than for the coarse grained. 'Clay' is understood to mean a clay soil whose grains are predominantly composed of clay minerals and which has plasticity and cohesion. Though the clay soils are fine grained but, not all fine grained soil possess plasticity and cohesion. The presence of water, its content plays a decisive role in the engineering behaviour of a clay soil. On the other hand, grain –size distribution and grain shape influence the engineering properties of granular soils and hardly affect the behaviour of clays. Expansive soils occurring above water table undergo volumetric changes with change in moisture content. Increase in water content causes the swelling of the soils and loss of strength and decrease in moisture content brings about soil shrinkage. Swelling and shrinkage of expansive soil cause differential settlements resulting in severe damage to the foundations, buildings, roads, retaining structures, canal linings, etc. The construction of foundation for structure on black cotton soils poses a challenge to the civil engineers. Chemical stabilization is one of the oldest methods of stabilization of problematic soil. In general, all lime treated fine-grained soils exhibit decreased plasticity, improved workability and reduced volume change characteristics. However, not all soils exhibit improved strength characteristics. It should be emphasized that the properties of soil-lime mixtures are dependent on many variables. Soil type, lime type, lime percentage and curing conditions (time, temperature, and moisture) are the most important.

SOIL STABILIZATION

Soil stabilization with lime can be done by mixing dosage of un soaked lime into damp soil creates both immediate and medium – term effects. Some of immediate effects are:

Drying: On mixing, there is immediate exothermic hydration reaction. It reduces water content with further reduced by aeration of soil. Water – fall percentage varies by 2 to 3 % of added lime.

Flocculation: Mixing affects the ultrasonic field between clay particles which changes to granular structure.

Reduction in Plasticity Index (PI): It switches from being plastic to stiff and grainy.

Improvement in compaction properties of soil: Maximum dry density drops, while the OMC rises, so that the soil moves into a humidity range that can be easily compacted.

Improvement in bearing capacity: After two hours of mixing, CBR of a treated soil is between 4 and 10 times higher than that of an untreated soil. The reaction greatly relieves on –site transportation difficulties.

Soil Lime Stabilization
Basic Properties of Soil Lime Mix

Soil – lime has been widely used as a modifier or as a binder.
Soil – lime is used as modifier in high plasticity soils.
Soil – lime also imparts some binding action even in granular soils.
It is effectively used in expansive soils with high plasticity index.

Factors Affecting the Properties of Soil with Lime

Lime Content: Generally, increase in lime content causes slight change in liquid limit and considerable increase in plasticity index. The rate of increase is first rapid and then decreases beyond a certain limit up to lime fixation point.

Types of Lime: After long curing periods all types of limes produce some effects. However, the quick lime has been found more effective than hydrated lime. Calcium carbonate must be treated at higher temperature to form quick lime calcium oxide. Calcium oxide must be slaked to form hydrated lime.

Curing: The strength of soil – lime increases with curing period up to several years. The rate of increase is rapid during initial period. The humidity of the surroundings also affects the strength.

Additives: Sodium met silicate, sodium hydroxide and sodium sulphate are found to be very much useful.

Lime Meets the Construction Challenge: Using lime can substantially increase the stability, impermeability and load p bearing capacity of the subsurface.

Facts: One million metric tons of lime used annually in the US for soil modification and stabilization.

Effects of addition of lime on Black Cotton Soil

Martin Jacob and K. Pandeu: conducted a series of lab tests and evaluated the effects of hydrated lime on the engineering behaviour of highly plastic clay soil. Tests were performed with different percentages of hydrated lime. On the basis of all tests and their results they concluded:

Effects of lime (6 % addition of lime) on Atterberg Limits: The plasticity index values of the clay soil are substantially and immediately decreased with increasing lime content; no significant effect of curing time is noted; the large increase in the plastic limit thus increasing the granular nature of the clay with lime.

Effect of lime surface areas obtained by the methylene lime method (8 % addition of lime): Increasing the lime content and curing time decreases the surface areas of the treated soil; 20 % added lime decreases 40 % in surface area.

Effect of lime on swelling potential and swelling pressure: A significant decrease in the swelling potential and pressure values was obtained with an increase of lime up to 4 %. Further addition of 10 % to 20 % lime swelling potential quickly dropped to zero. The addition of lime below 6 % has practically a non-significant effect on the swelling potential of this highly clay soil.

Effect of lime on the mineralogical structure: The reaction of lime and clay minerals leads to the formation of a new crystalline phase identified as CAH; identified by the X – ray diffraction tests. This new phase appears when lime is added above 6 %.

Peter Evans based on current research and experiences in Border District, the following interim recommendations would appear to be appropriate given the current state of knowledge which as following:

- Thorough laboratory testing should be undertaken before lime stabilization of sub-grades is embarked on. This recommendation applies particularly for coastal soils where acid sulphates are suspected. Where acid sulphates soils are suspected, testing should be for the potential development of these sulphates, and not just those present when the sub-grade is exposed.
- Adequate quantities of lime should be used. At this stage, it would appear that a conservative approach would be to base the design lime content on Thompson's method, and adopt a lime content which yields the maximum 28 day UCS. Less conservative approaches have an element of risk, which is probably not warranted given the moderate marginal cost of adding the additional lime.
- Until firm data is available from controlled trials using appropriate lime contents for particular soil types, it may be prudent to continue to assume that lime stabilized sub grades do not contribute greatly to pavement strengths. It is acknowledged that this recommendation could appear to be ultra-conservative. However, once adequate data becomes available from trials, design methods should change to allow exploitation of this technology.
- Long term data based on lime stabilization using high doses of lime should be developed in controlled trials throughout the state, and these trials should be based on soil classifications and well-coordinated so as to gain maximum value from the trials.

BLACK COTTON SOIL

Black cotton soil (BC soil) is a highly clayey soil. The black colour in Black cotton soil (BC soil) is due to the presence of titanium oxide in small concentration. The Black cotton soil (BC soil) has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in colour. Expansive soils are the soils which expand when the moisture content of the soils is increased. The clay mineral montmorillonite is mainly responsible for expansive characteristics of the soil. The expansive soils are also called swelling soils or black cotton soils.

The structures on Black cotton soil (BC soil) bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. The physical properties of Black cotton soil (BC soil) vary from place to place 40 % to 60% of the Black cotton soil (BC soil) has a size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 % to 300% and results in swelling pressure as high as 8 kg/cm^2/ to 10 kg/cm^2. As such Black cotton soil (BC soil) has very low bearing capacity and high swelling and shrinkage characteristics. Due to its peculiar characteristics, it forms a very poor foundation material for road construction. Soaked laboratory CBR values of Black Cotton soils are generally found in the range of 2 to 4%. Due to very low CBR values of Black cotton soil (BC soil) excessive pavement thickness is required for designing for flexible pavement. Research & Development (R&D) efforts have been made to improve the strength characteristics of Black cotton soil (BC soil) with new technologies. The construction of foundation for structure on black cotton soils poses challenge to civil engineers.

Problems of Construction in Black Cotton Soil Areas
Problems Arising out of Water Saturation

It is a well-known fact that water is the worst enemy of all structures, particularly in expansive soil areas. Water penetrates into the foundation from three sides viz. top surface, and from bottom layers due to capillary action. Therefore, specifications in expansive soil areas must take these factors into consideration. The surfacing must be impervious, sides paved and soil beneath well treated to check capillary rise of water. It has been found during handling of various investigation project assignments for assessing causes of structural failures that water has got easy access into the foundations. It saturates the soil and thus lowers its bearing capacity, ultimately resulting in heavy depressions and settlement. Water lubricates the soil particles and makes the mechanical interlock unstable. In the top surface, ravelling, stripping and cracking develop due to water stagnation and its seepage into the bottom layers.

Generally, construction agencies do not pay sufficient attention to the aspects of construction and maintenance of sides. In expansive soil areas, unpaved offsets pose the maximum problem as they become slushy during rains, as they are most neglected lot.

Design Problems in Black Cotton Soils

In India, CBR method developed in USA is generally used for the design of crust thickness. This method stipulates that while determining the CBR values in the laboratory and in the field, a surcharge weight of 15 kg and 5 kg per 62 mm and 25 mm thickness respectively should be used to counteract the swelling pressure of Black cotton soils (BC soils). BC soils produce swelling pressure in the range of 20-80 tons/m^2 and swelling in the range of 10-20%. Therefore, CBR values obtained are not rational and scientific modification is required for determining CBR values of expansive soil. For the study of the soil we have used the CBR test as a prime indicator to the strength of the soil.

Lime

In general, all lime treated fine-grained soils exhibit decreased plasticity, improved workability and reduced volume change characteristics. However, not all soils exhibit improved strength characteristics. It should be emphasized that the properties of soil-lime mixtures are dependent on many variables. Soil type, lime type, lime percentage and curing conditions (time, temperature, and moisture) are the most important.

Types of Lime

Various forms of lime have been successfully used as soil stabilizing agents for many years. However, the most commonly used products are hydrated high-calcium lime, monohydrated dolomite lime, calcite quicklime, and dolomite quicklime. Hydrated lime is used most often because it is much less caustic than quicklime; however, the use of quicklime for soil stabilization has increased in recent years mainly with slurry-type applications. The design lime contents determined from the criteria presented herein are for hydrated lime. If quicklime is used, the design lime contents determined herein for hydrated lime should be reduced by 25 percent. Specifications for quicklime and hydrated lime may be found in ASTM C 977.

Lime Content for Lime-Modified Soils

The amount of lime required to improve the quality of a soil is determined through the same trial-and error process used for cement-modified soils given as below:

Lime content for lime-stabilized soils

The following procedures are recommended for determining the lime content of lime stabilized soils:

Step 1. The preferred method for determining initial design lime content is the pH test. In this method several lime-soil slurries are prepared at different lime treatment levels such as 2, 4, 6, and 8 percent lime and the pH of each slurry is determined. The lowest lime content at which a pH of about 12.4 (the pH of free lime) is obtained is the initial design lime content. An alternate method of determining initial design lime content is by the use of Figure 3.5. Specific values required to use Figure 3.5 are the PI and the percent of material passing the No. 40 sieve.

Step 2. Using the initial design lime content conduct moisture-density tests to determine the maximum dry density and optimum water content of the soil lime mixture. The procedures contained in ASTM D 3551 will be used to prepare the soil-lime mixture. The moisture density test will be conducted following procedures in ASTM D 1557.

Step 3. Prepare triplicate samples of the soil lime mixture for unconfined compression and durability tests at the initial design lime content and at lime contents 2 and 4 percent above design if based on the preferred method, or 2 percent above and 2 percent below design if based on the alternate method. The mixture should be prepared as indicated in ASTM D 3551. If less than 35 percent of the soil is retained on the No. 4 sieve, the sample should be approximately 2 inches in diameter and 4 inches high. If more than 35 percent is retained on the No. 4 sieve, samples should be 4 inches in diameter and 8 inches high. The samples should be prepared at the density and water content expected in field construction. For example, if the design density is 95 percent of the laboratory maximum density, the sample should be prepared at 95 percent density. Specimens should be cured in a sealed container to prevent moisture loss and lime carbonation. Sealed metal cans, plastic bags, and so forth are satisfactory. The preferred method of curing is 73 degrees F for 28 days. Accelerated curing at 120 degrees F for 48 hours has also been found to give satisfactory results; however, check tests at 73 degrees for 28 days should also be conducted. Research has indicated that if accelerated curing temperatures are too high, the pozzolanic compounds formed during laboratory curing could differ substantially from those that would develop in the field.

Step 4. Test three specimens using the unconfined compression test. If frost design is a consideration, test three specimens to 12 cycles of freeze-thaw durability tests (ASTM D 560) except wire brushing is omitted. The frost susceptibility of the treated material should be determined as indicated in appropriate design manuals.

Step 5. Compare the results of the unconfined compressive strength and durability tests with the requirements given in ASTM D code. The lowest lime content which meets the unconfined compressive strength requirement and demonstrates the required durability is the design lime content. The treated material also must meet frost susceptibility requirements as indicated in the appropriate pavement design manuals. If the mixture should meet the durability requirements but not the strength requirements, it is considered to be a modified soil. If results of the specimens tested do not meet both the strength and durability requirements, higher lime content may be selected and steps 1 through 5 repeated.

RESULTS & DISCUSSION

Particle Size Analysis

Dry Sieve Analysis with 0 % lime content

Size of Sieve(in mm)	% Finer
4.750	92.39
2.360	72.46
1.180	43.11
0.600	23.75
0.425	10.90
0.300	9.17
0.150	5.90
0.075	5.02
0	0.00

Hydrometer Test

Size of particles (in mm)	0% Finer	5% Finer	10% Finer	15% Finer
0.043	80.3	96.36	93.148	93.148
0.0313	77.08	89.93	86.72	89.93
0.0227	73.876	89.91	83.512	86.72
0.0169	64.24	86.72	80.3	80.3
0.0119	54.604	83.72	77.08	80.3
0.0089	49.786	72.27	77.08	77.08
0.0063	44.968	61.028	67.45	77.08
0.0043	38.54	57.816	61.02	73.876
0.0033	32.12	51.816	57.81	70.66
0.0025	28.12	46.23	52.23	66.23
0.0012	25.03	40.21	46.23	60.21
0	0.00	0	0	0

DISCUSSION

Since the investigation is performed on soils from the central area of India, materials found in this area were selected in accordance with base and sub-base gradation types of the Indian Code for Highway Design (correlates with AASHTO standards). Natural materials, as a consequence of the geological and geographical history of this area and sediments for the rivers, consist of sandy soils, clays, and mostly a mix of the two. The major clay minerals in lime, especially where the program was performed, are very similar to kaolinite clay, in terms of their plastic properties and grain sizes. Almost pure kaolinite (that contains more than 90% clay fraction) produced in factories in this area was used in these tests. Some other clay minerals were tested and the results showed that the kaolinite clay provided for the test has the same properties as the general clay found in the north of India. The investigation program was started by using five different clayey sands with gradations similar to the ones in situ. These are commonly used as borrow materials for road work in this area. The clay content of the materials ranges from 5 to 36 percent. These five types of soils were then reconstituted in the laboratory using gradations obtained from a special borrow. The coarse materials, consisting of coarse to fine sands, were washed and then mixed with clay to obtain a mix similar to natural materials. Kaolinite clay was used as the fine content of all mixes. A gradation chart of all mixes is shown in chart presents the gradation chart for clay content of samples obtained by a hydrometer test.

"A pozzolan is defined as a finely divided siliceous or aluminous material which in the presence of water and calcium hydroxide will form a cemented product. The cemented products are calcium-silicate hydrates and calcium-aluminate-hydrates. **These are essentially the same hydrates that form during the hydration of Portland cement"**

Plastic Limit
With 0% lime content

Container No.	N	9	3
Wt. of container ,W1 (gm)	31.1	13.2	12.6
Wt. of container+ wet soil sample,W2(gm)	34.0	13.80	13.4
Wt. of container+ dry soil sample, W3 (gm)	33.4	13.65	13.22
Water content(%)={(W2-W3)/(W3-W1)}*100	26.0	33.30	30
PLASTIC LIMIT (MEAN VALUE, %) = 29.78			

With 5% lime content

Container No.	9	8	2
Wt. of container ,W1 (gm)	13.2	31.1	12.5
Wt. of container+ wet soil sample,W2(gm)	13.80	31.5	13.1
Wt. of container+ dry soil sample, W3 (gm)	13.65	31.39	13
Water content(%)={(W2-W3)/(W3-W1)}*100	33.33	33.3	20
PLASTIC LIMIT (MEAN VALUE, %) = 28.86			

With 10% lime content

Container No.	3	4	8
Wt. of container ,W1 (gm)	12.6	12.2	11
Wt. of container+ wet soil sample,W2(gm)	13.4	13.1	13.12
Wt. of container+ dry soil sample, W3 (gm)	13.2	12.9	12.6
Water content(%)={(W2-W3)/(W3-W1)}*100	17	28.5	32.5
PLASTIC LIMIT (MEAN VALUE, %) = 26			

With 15% lime content

Container No.	2	9	8
Wt. of container ,W1 (gm)	12.5	13.1	31.1
Wt. of container+ wet soil sample,W2(gm)	15.5	16.9	34.0
Wt. of container+ dry soil sample, W3 (gm)	14.90	16.1	33.4

Water content(%)={(W2-W3)/(W3-W1)}*100	25.0	25.8	26.0
PLASTIC LIMIT (MEAN VALUE, %) = 25.6			

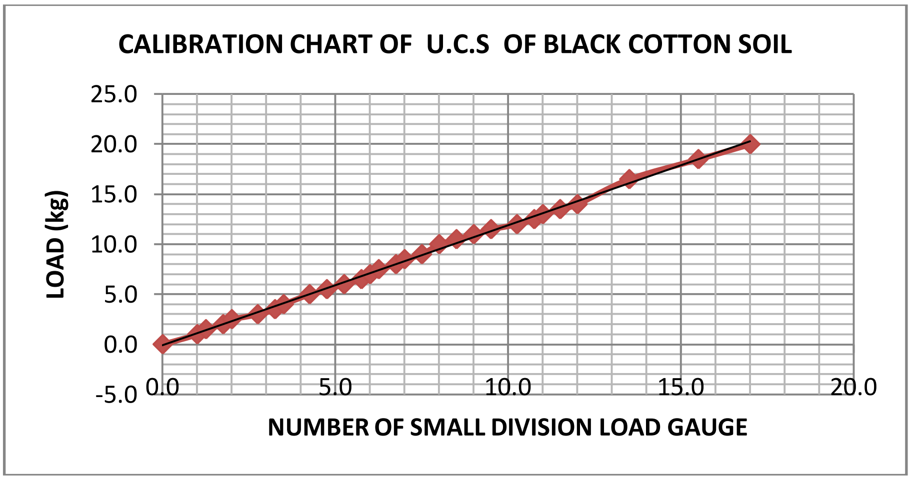
Based on test results, it appears that the variation in bearing strength, for samples with clay content in the range of 5 to 15%, is minimal. But for higher values of clay content, especially for 20 to 30% clay content, there is a great variation of bearing strength; a 5% increase of clay content results in 30% increase in bearing strength. As shows the variation of strength of different specimens versus various fine contents. Any further increase in clay content will decrease the compressive strength of the specimen. Almost similar results are observed for compressive strength. The maximum variation in compressive strength of the specimen is when the clay content ranges from 15 to 30%. Increase in clay content beyond 30% has relatively no effect on strength of samples. The variation of tensile strength of the specimens for different lime contents, i.e. 0%, 5%, 10%, and 15%, is presented in chart.

The reason for these variations is that the main factors in bearing strength of geo-materials are both cohesive strength and friction intercept of tested specimens; however, for compressive strength, cohesion has a greater role than internal friction angle of materials. Because the friction strength is mobilized in the presence of normal compressive stress bringing particles closer together, this results in the mobilization of frictional strength. But in extension, since no or negligible normal stresses act on particle surfaces, the frictional strength cannot be mobilized and the strength of materials is only a function of the cohesive component. So, the higher the clay content, the higher the cementation materials and the higher the tensile strength of materials; however, this is not true for very high values of clay content. The increase in clay content results in an increase of tensile strength until all internal porous cavities of soil are filled with fine clay particles and, then, the complete cohesive strength is mobilized in the specimen. But in compression, any increase in clay content more than sufficient for filling the internal cavities of a soil, results in a decrease of friction angle of the soil; more clay content than is required to fill the internal cavities, acts as a lubricant for frictional coarse particles of sand. The above noted explanation is the reason for an increase and/or decrease of compressive and strengths of specimens with clay content variation. As a result, here we can define special clay content as optimum clay content (OCC), that is, sufficient for the maximum dry strength as well as the maximum Bearing strength. For the tested materials, the optimum fine content has ranged from 5% to 30%.

UCS Test

It is the most important property that is considered in pavement design. This property can be defined for frictional materials when they are subjected to all-round or confining stresses. However, for cohesive materials the compressive strength is a resultant of the cohesion intercept of materials and can be obtained by a simple compressive test. Many different authors have presented the correlations between compressive strength and other mechanical characterizations of geo-materials including: tensile strength, bending capacity, and elastic modulus

UCS Chart



CONCLUSION

Some clayey sand mixes with determined gradations, abundant in northern India, was stabilized with different lime contents and then subjected to Bearing strength, Shrinkage property, and CBR tests. Materials were reconstituted in the laboratory and the fine content of mixes was provided from Kaolinite clay to reach a constant plastic characterization for all specimens. Results of this investigation are as below:

1. With proper lime treatment it is possible to make the clay almost non plastic with plasticity index reducing to practically zero. Increase in lime content also considerable reduction in swelling and increase in shrinkage limit. All these changes are desirable for stabilization of clay.

2. Lime-stabilization of geo-materials by producing cohesive materials in the soil increases the strength and decreases materials plastic properties. This is why these materials can be used for projects where high strength and high performance materials are desirable. The increase in strength of lime-stabilized materials in compression as well as in tension is attributed to the reactions between clay particles and lime. The clay content of lime-stabilized materials can affect the strength of the materials. The clay–lime compound provides the cemented material in soil.

3. Some mechanical properties of clayey sands were investigated and the behaviour of these materials was expressed in simple mathematical equations based on test results on soil samples provided from the Northern areas of India. These functions are applicable for materials that have the same or close gradations to those, which were used in this investigation. According to the results, it is noticeable that lime-stabilized materials with high clay contents are more brittle that others.

4. A 24-hour delay should be built in between the initial application and mixing of lime and a subsequent application, with no more than 50% of the total quantity of lime spread during the first application. This is to allow the lime to modify the plastic properties of the clay through "flocculation".

5. By adding lime in increasing percentages result in decrease in maximum dry density up to a certain value i.e. 5 % lime content and then it increases and optimum moisture content decreases. With this it can be inferred that there is an improvement of compaction behavior of soil only after adding certain lime content. Before this the voids in the soil are being replaced by the lime strands which are of lighter weight thereby decrease in the dry density; same reason can be applied for the decrease in optimum moisture content. It can also be concluded that due to increase in the lime content dry density increases, which is shown in the graph. Due to this, the curve obtained in standard proctor test shifts to the top left side. Hence use of lime is beneficial only after we add certain percentage of it. Though addition of lime gives good result and can be used for large projects.

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