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The Effect of Additives on Clay Soil Properties Using Cement and Lime

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Abstract

Iran is a country with large clay resources in most of its provinces. The problems associated with these soils arise out of a variety of parameters that result in variable behaviors in these soils. Different lines of research are required to deal with each type of behavior. A lack of understanding of clay soils and their minerals may result in adverse consequences. When a structure is built upon clay soils, such events as pipe bursts, water penetration and groundwater uplift may cause cracks and subsidence in the foundation of the structure following the soil shriveling so that this type of soil is categorized as problematic. Basically, a soil is considered problematic when it behaves unexpectedly under specific circumstances so that this unexpected behavior often brings about problems. That is why these soils are deemed problematic. It seems, therefore, necessary to identify and classify these soils and take measures to modify their swelling and shrinkage properties. In the present study, cement and lime were used as two chemical additives to improve swelling and shrinkage properties in expansive soils in Golestan province. To this end, we selected four soil types with plasticity indices 25, 30, 35 and 40. Then the plasticity properties of the soils including liquid, plasticity and shrinkage limits as well as plasticity index were investigated and compared among the specimens in different mixture proportions.

Keywords: Clay soil, Swelling, Shrinkage, Soil stabilization, Lime, cement, Atterberg limits.

Introduction

When exposed to moisture, clay soils often tend to swell and lose their strength. Thus, swelling clay soils are one the common problems in geotechnical engineering. Before a structure is built on these soils, adequate measures should be taken to control subsequent problems. The costs of soil structures may prompt the engineers to avoid transporting construction materials in high volumes as an alternative and to stick to local materials as much as possible. Making changes in soil performance with the purpose of improvement and utilization is typically referred to as soil stabilization. In other words, soil stabilization refers to in-situ improvements in soil properties using additives. It presses home various advantages the most significant of which is improved soil shear strength, hence the increased bearing strength and improved subsidence performance. Indeed, soil stabilization is a process whereby either natural or synthetic materials are added to the soil to improve its properties. There are various methods to stabilize soils used in different situations. However, they may be divided into two general categories: Chemical and physical-mechanical. Chemical stabilization refers to improvements in soil properties, particularly fine-grain soils, using additives. The stabilization then occurs as a result of chemical reactions induced by these additives in combination with soil. Several materials have yet been employed to stabilize soil or poor aggregates, including lime, Portland cement and fly ash. Physical soil stabilization refers to modifying soil properties without any changes in its chemical profile. Lime and cement have long been used to stabilize soils with lime being used since ancient times. These two materials are quite affluent throughout the world. As with other people, Iranians used to know lime for centuries and used it to stabilize soils. Over 3000 years ago, Iranians learned to produce lime concrete and used it to build buildings, bridges and pool foundations and to avoid water leakage and stabilize rocky terrain so as to increase soil bearing strength. Since ancient times, Iranians learned to mix water, lime and clay to produce new materials that did not dissolve in water and were almost impenetrable. This increased the soil strength, for which they could not find a reason. The first controlled soil-cement project was carried out in Johnsville, SouthCarolina, in 1935 (Al-Rawas, 2002). Several studies were conducted on the factors influencing condensed, improved soils in road substructures during 1940-1950 (Basma, 1991). Though lime was long used to modify soil in construction, it was not until 1945 that it became common to improve soils using slaked lime and stabilize clay sands using cement in the United States. In humid areas of Europe, soil improvement was carried out using quicklime rather than slaked lime. This improvement method was often employed in Northern Europe and Germany, Austria, Switzerland, France and Belgium during 1950s and 1970s. Miller and Nelson (1992), Terzaghi (1996), Feng (2002) and Al-raws (2002) found in laboratory experiments that adding cement to clay soils increased not only liquid limit, plasticity index and swelling potential but also shear strength in the mixture. In these experiments, a variety of mixture proportions were examined and the effects of variable ranges of soil-clay mixtures with different swelling potential and shear strength were simultaneously compared between the same specimens of soils.

Soil stabilization with lime

Soil stabilization with lime entails mixing oxide or hydroxide with soil and contracting the mixture at optimal moisture. Lime is usually added to soil based on dry weight percent of the soil. Slaked lime is lighter than quicklime and its average mass weighs 0.55 g/cm^3 while the average mass of quicklime weighs 0.99 g/cm^3. A variety of lime materials has long been used in different proportions to stabilize soil and sand materials. Soil stabilization with lime improves the quality and technical properties of soil, hence acceleration of road construction operations. A soil stabilized with lime shows better strength properties against atmospheric conditions (frost and moisture) and has higher bearing capacities comparing with unstabilized soil. Soil and lime may be mixed using common construction machinery (Basma, 1991). Lime may be used as quicklime, slaked or grout to stabilize soil. Materials stabilized with lime can be either produced in situ in the construction site or produced and transmitted to the site. In-situ soil stabilization includes making furrows, preparation, spreading lime and spraying water, pounding materials, leveling and processing. Quicklime is not commonly used with dry soils because lime hydration requires relatively much water, which decreases the speed of operations. However, quicklime does not mix with soil adequately; that is, the mixture is not homogeneous and bears a lower quality comparing with soil-slaked lime mixture. Besides, in wet soils, grains become saturated and quicklime granules condense and enlarge so that they are not appropriate to mix with hunks of clay (Rao, 2003). Adding lime to soil reduces liquid limit and plasticity index in the soil so that soil-lime mixtures may at times turn to be completely non-plastic. Decreased plasticity properties facilitate soil handling and displacement in the workshop. Cation exchanges and granule enlargement account for decreases in soil plasticity after mixing with lime. Besides, soil improvement with lime significantly reduces swelling in clay soils. Althougha soil stabilized with lime has less shrinkage than an unstabilized soil, the shrinkage of stabilized soils, resulted from decreased material moisture, may still lead to shrinkage cracks.

Effect of added cement on soil properties

Cement is widely used to stabilize soil particularly in highway and earth dam construction. Cement may be used to stabilize sandy and clay soils especially in the areas with high groundwater level. Most of the fine-grain soils may be stabilized with cement except for mineral soils. The proportion of cement needed to stabilize soils depends on their plasticity properties. The more fine-grain or plastic (higher range of plasticity) a soil is, the more cement proportion is needed to stabilize it (Serruto, 2001). Clay soil stabilization with cement is best effective when the soil liquid limit ranges from 45 to 50 and its plasticity index is less than 25. The decreases in soil liquid limit following cement addition depend on the type of the soil so that a general claim may not be made about the decreases in liquid limit in all fine-grain soils (Feng, 2002).

Methodology

The experiments were carried out consistent with ASTM standard. The experiments were conducted to investigate the effect of added cement and lime on soil specimens. Laboratory experiments are one of the main strategies to ensure the physical and mechanical properties of soils and to predict their behavior under different conditions. The experiments in the present study were set up to investigate atterberg limits (ASTM: D4318) in the specimens. In this regard, tests of liquid, plasticity and shrinkage limits were performed on mixture specimens to investigate the effect of cement and lime on soil plasticity properties using soils with primary plasticity indices 25, 30, 35 and 40. Lime and cement were added to soil specimens in different proportions (1,3,5,9,13,17 and 19 weight percent) and the results were compared.

Results

Effect of cement and lime additives on soil plasticity and shrinkage properties

The following figures illustrate the results of liquid, plasticity and shrinkage limit tests on soil specimens with different primary plasticity indices stabilized with different proportions of lime and cement additives.

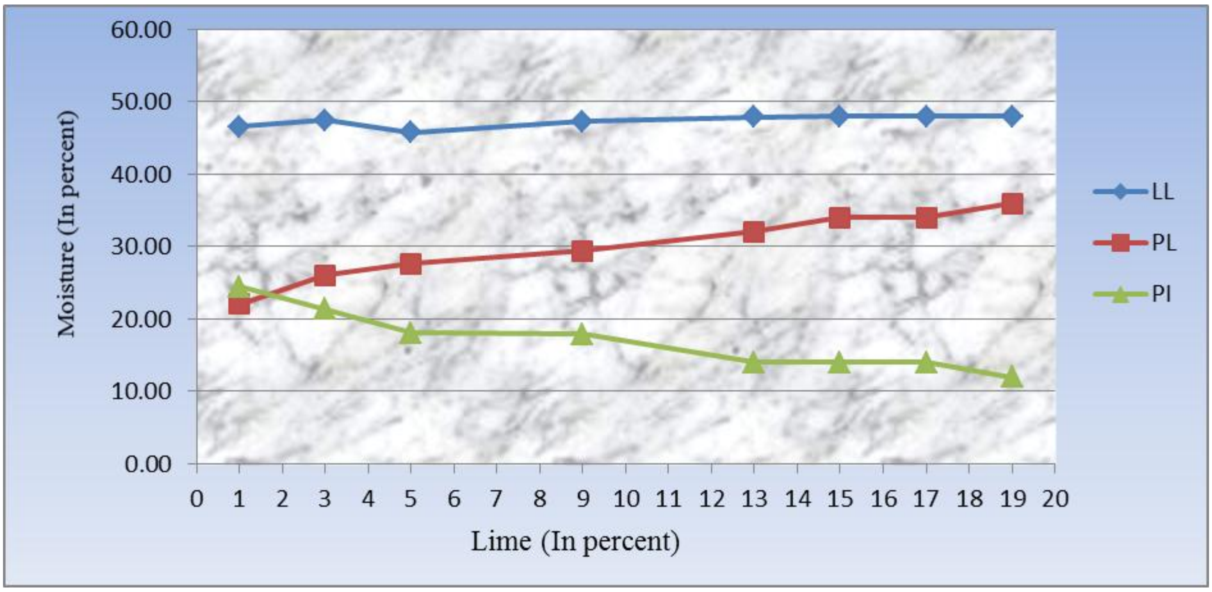


Figure1. Effect of lime addition in different proportions on the plasticity index of the soil specimen with PI=25.

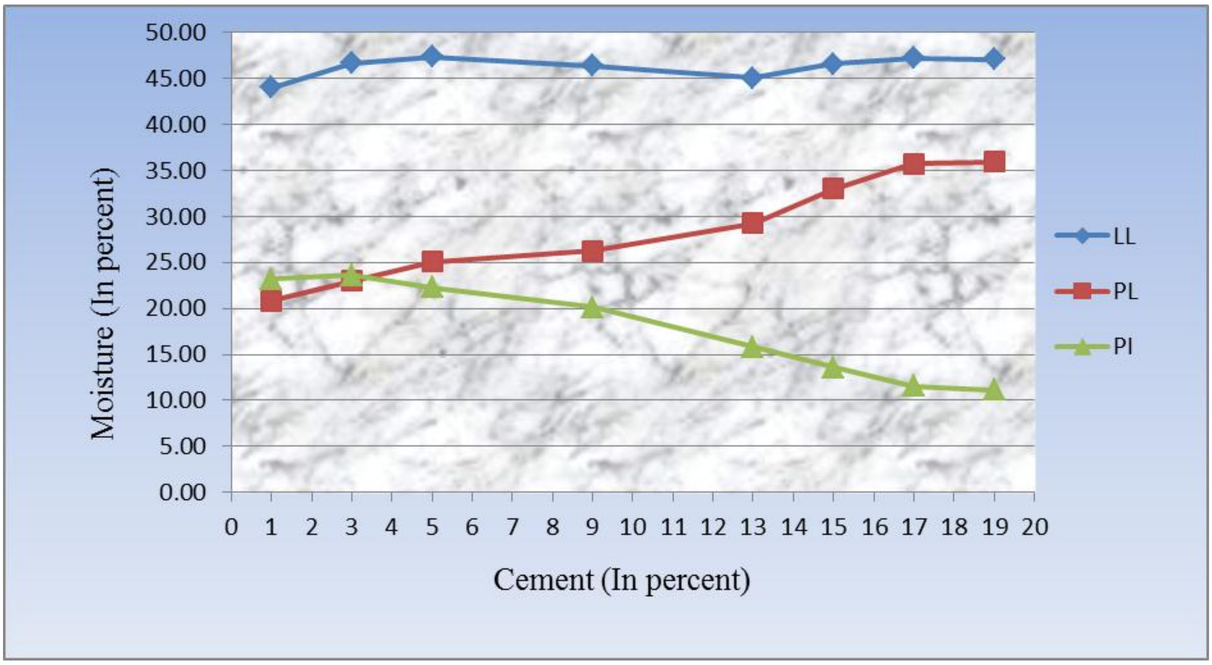


Figure 2. Effect of cement addition in different proportions on the plasticity index of the soil specimen with PI=25.

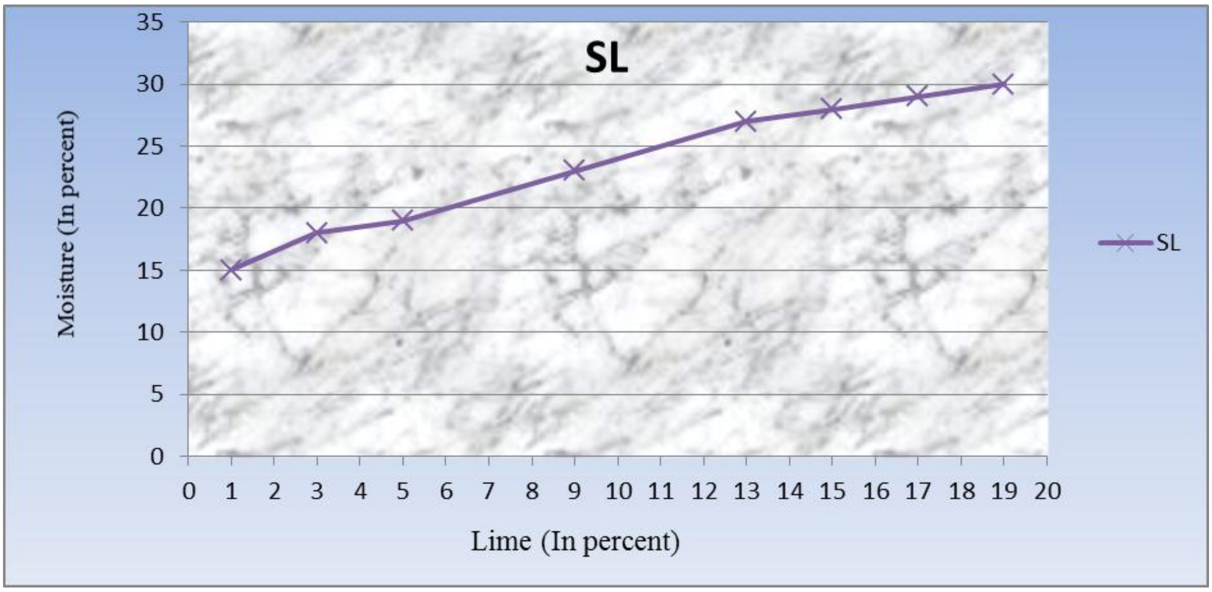


Figure 3. Effect of lime addition in different proportions on the shrinkage properties of the soil specimen with PI=25.

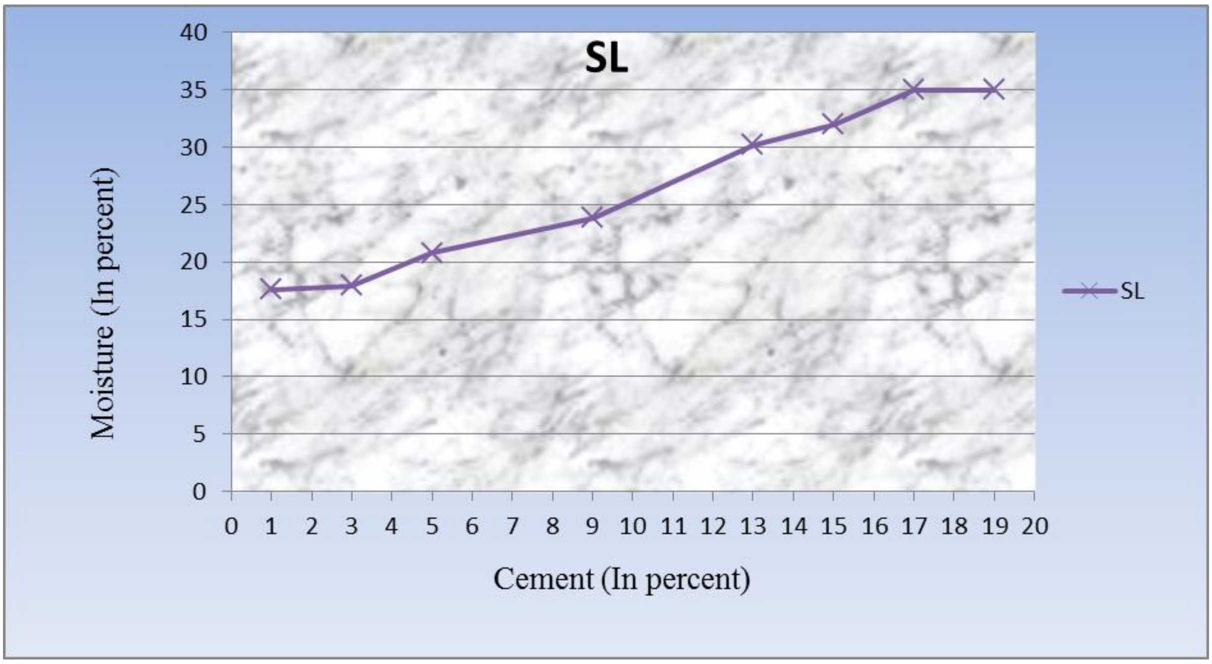


Figure 4. Effect of cement addition in different proportions on the shrinkage properties of the soil specimen with PI=25.

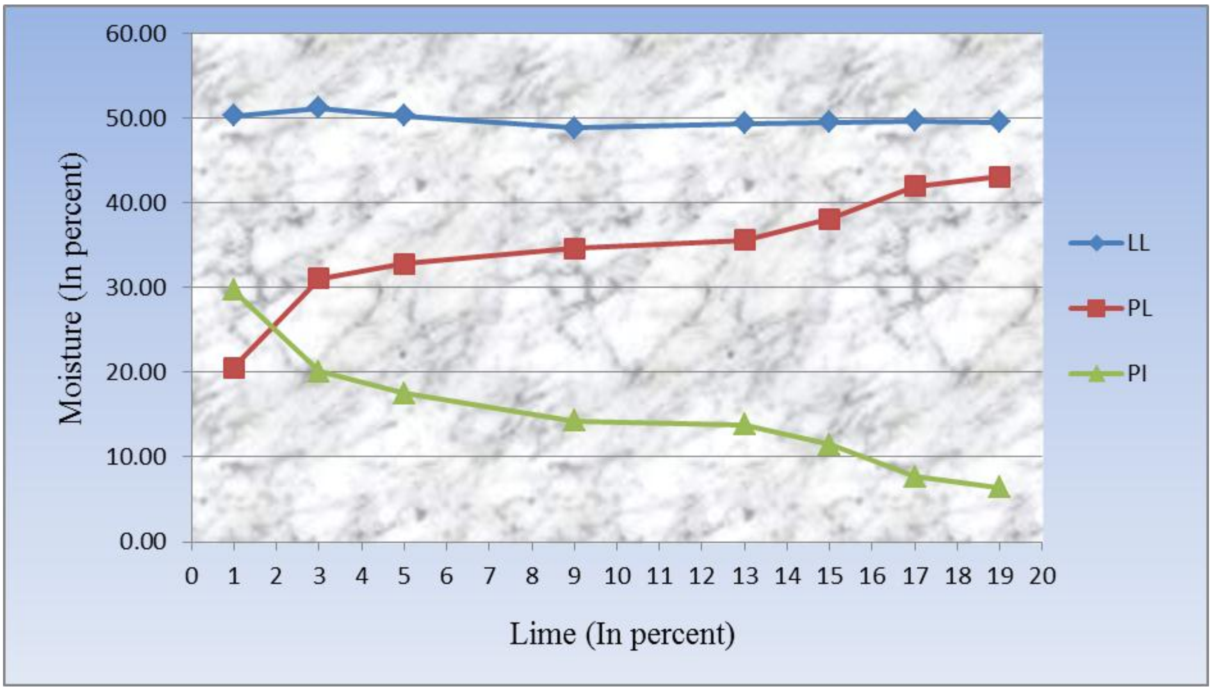


Figure 5. Effect of lime addition in different proportions on the plasticity index of the soil specimen with PI=30.

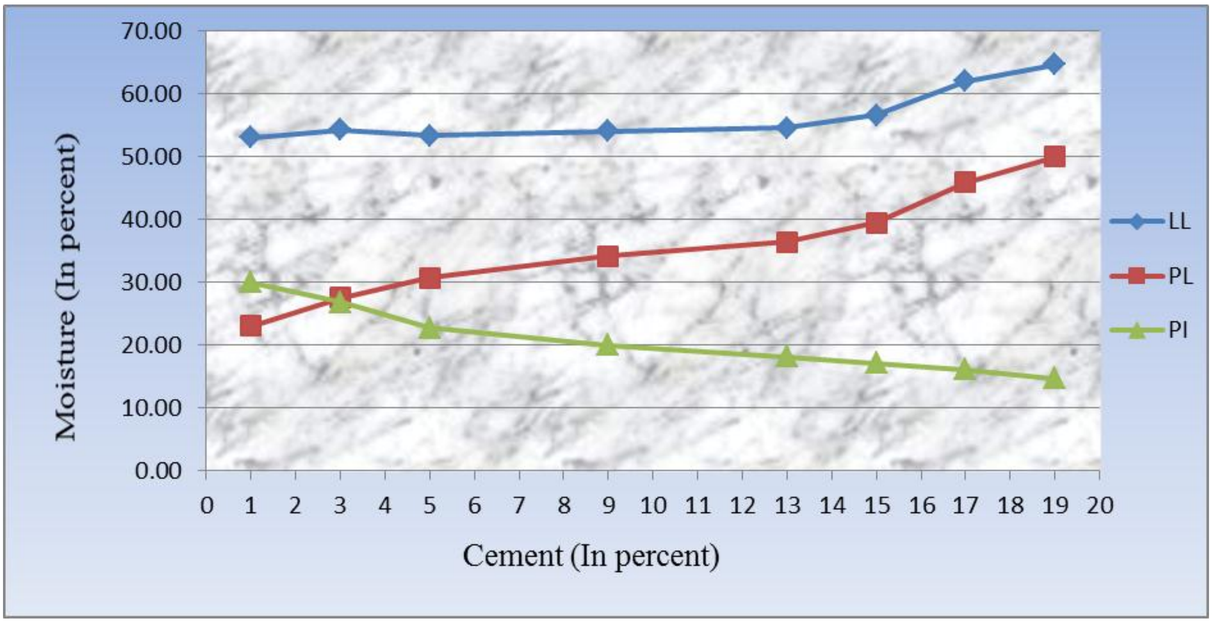
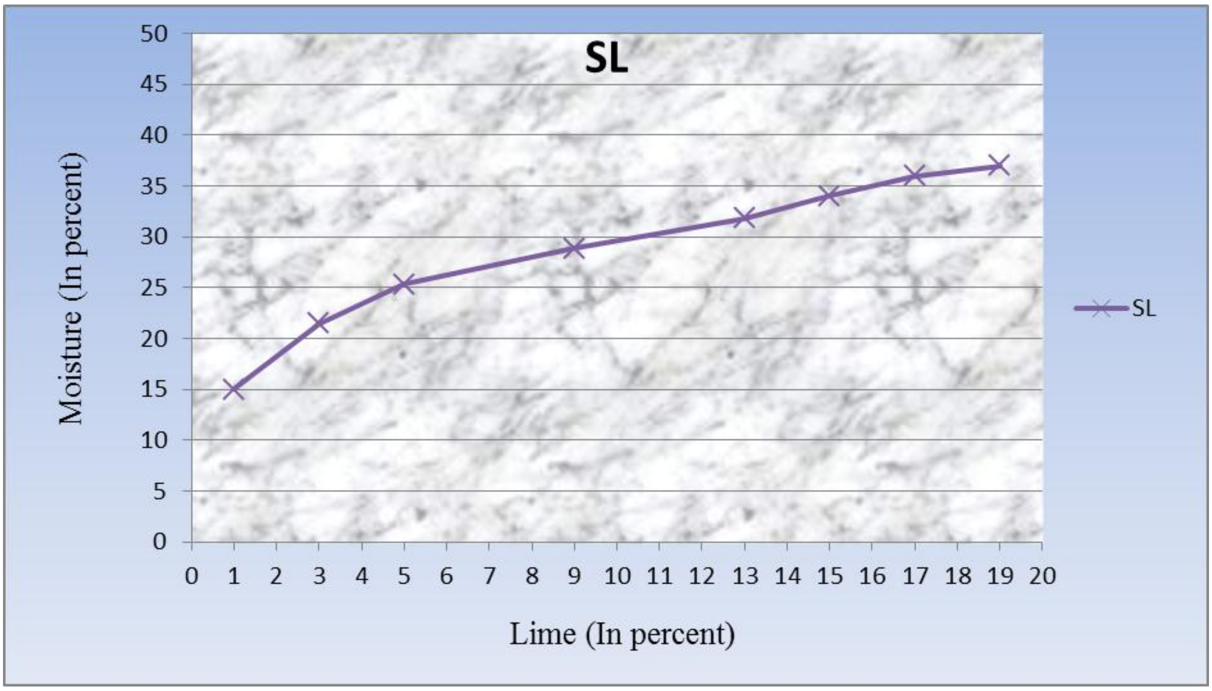
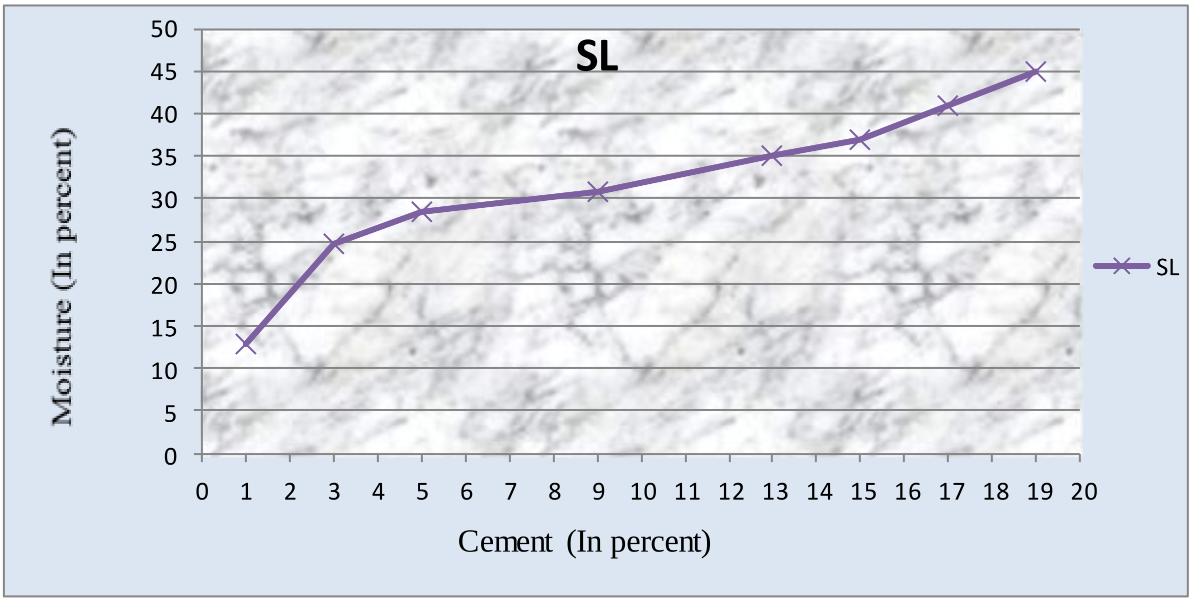


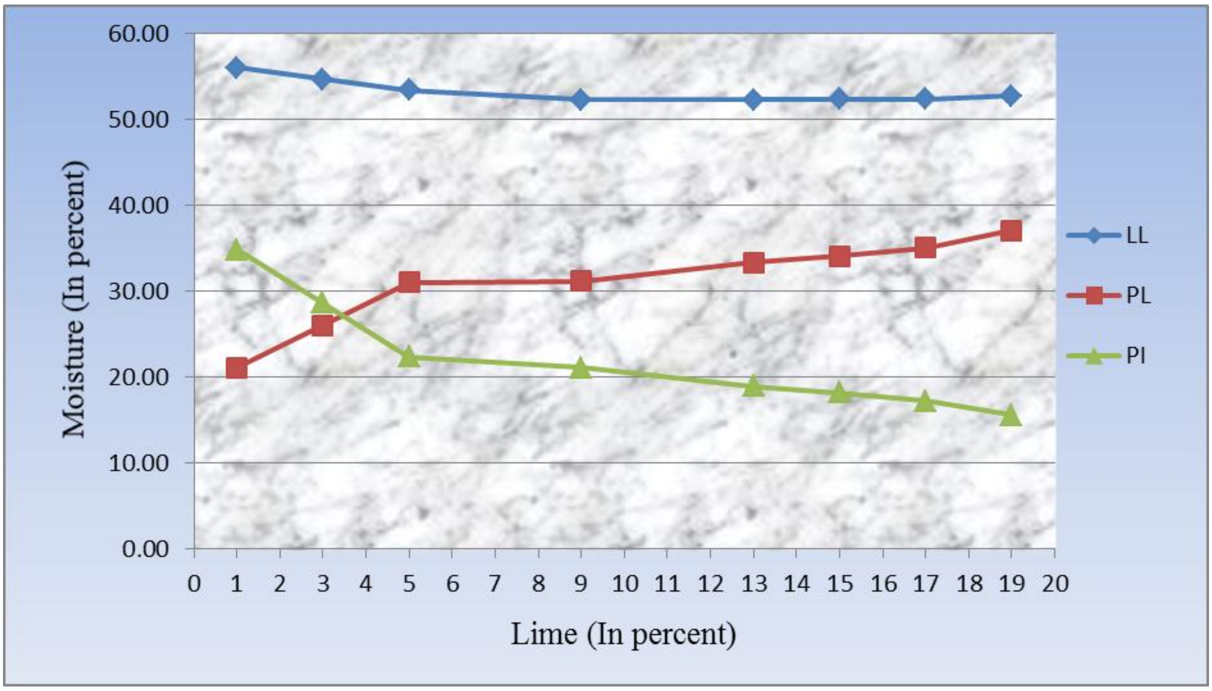
Figure 6. Effect of cement addition in different proportions on the plasticity index of the soil specimen with PI=30.



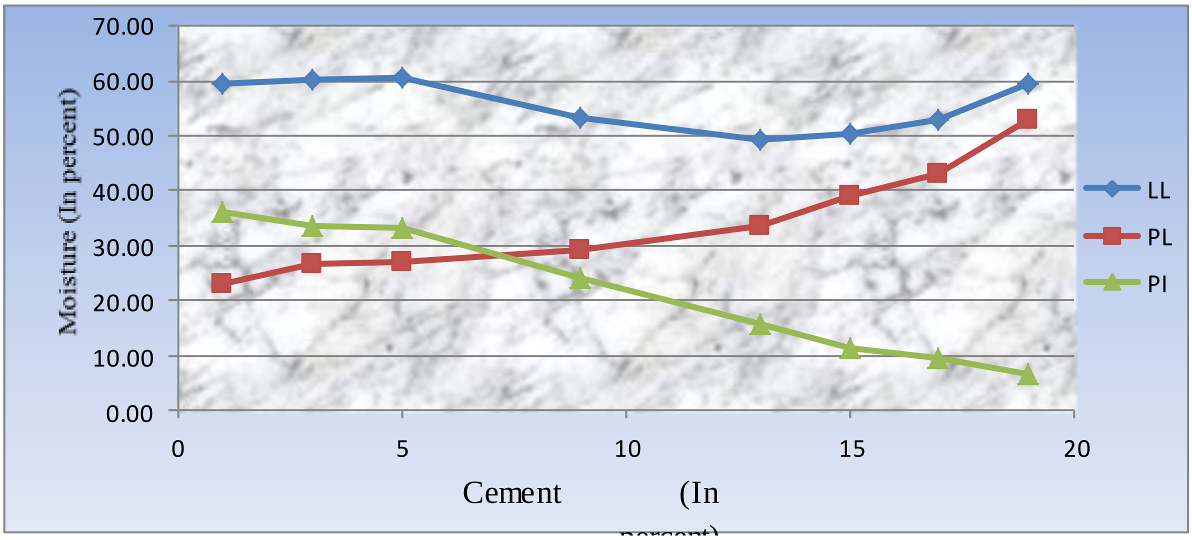
Figures 7. Effect of lime addition in different proportions on the shrinkage properties of the soil specimen with PI=30.



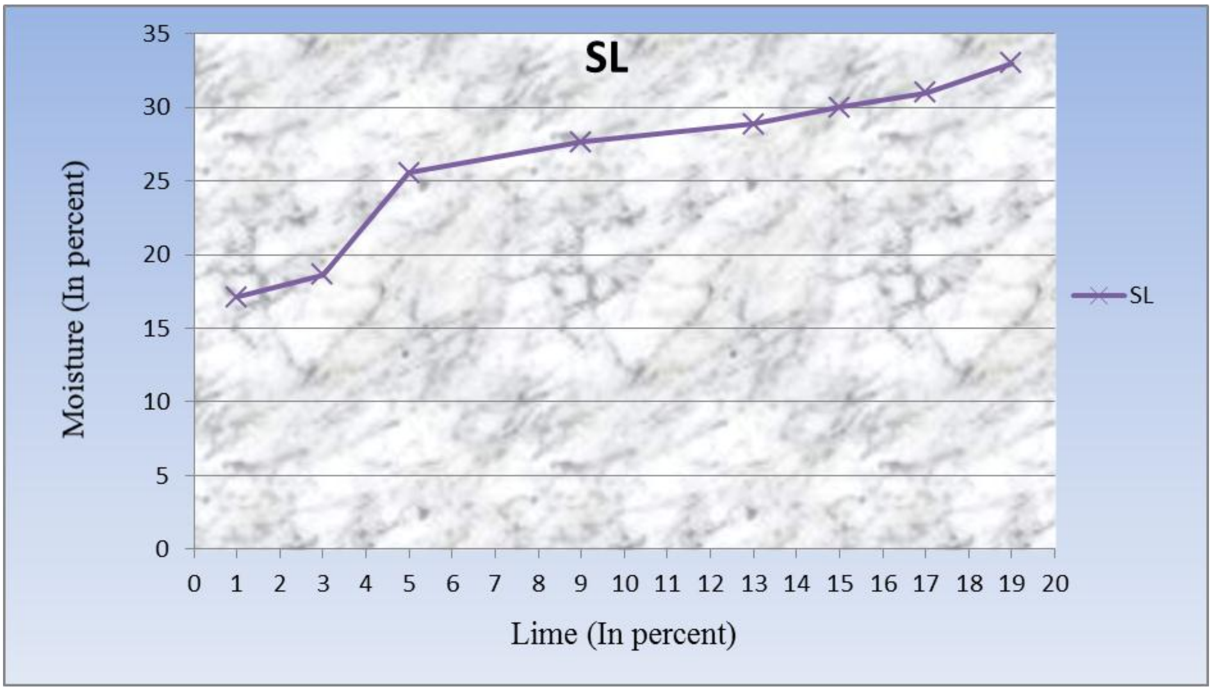
Figures 8. Effect of cement addition in different proportions on the shrinkage properties of the soil specimen with PI=30.



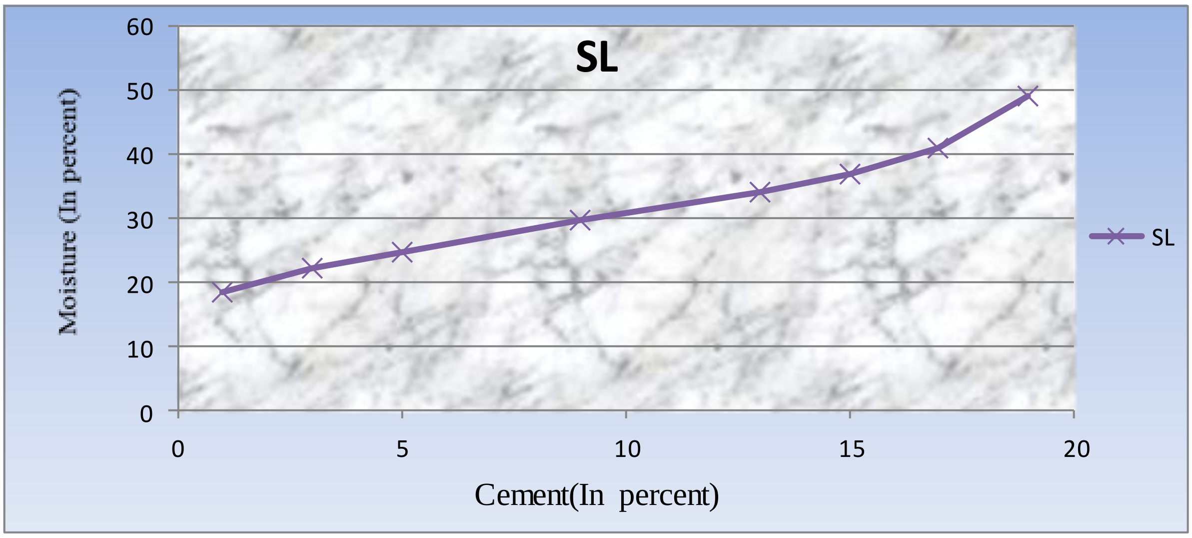
Figures 9. Effect of lime addition in different proportions on the plasticity index of the soil specimen with PI=35.



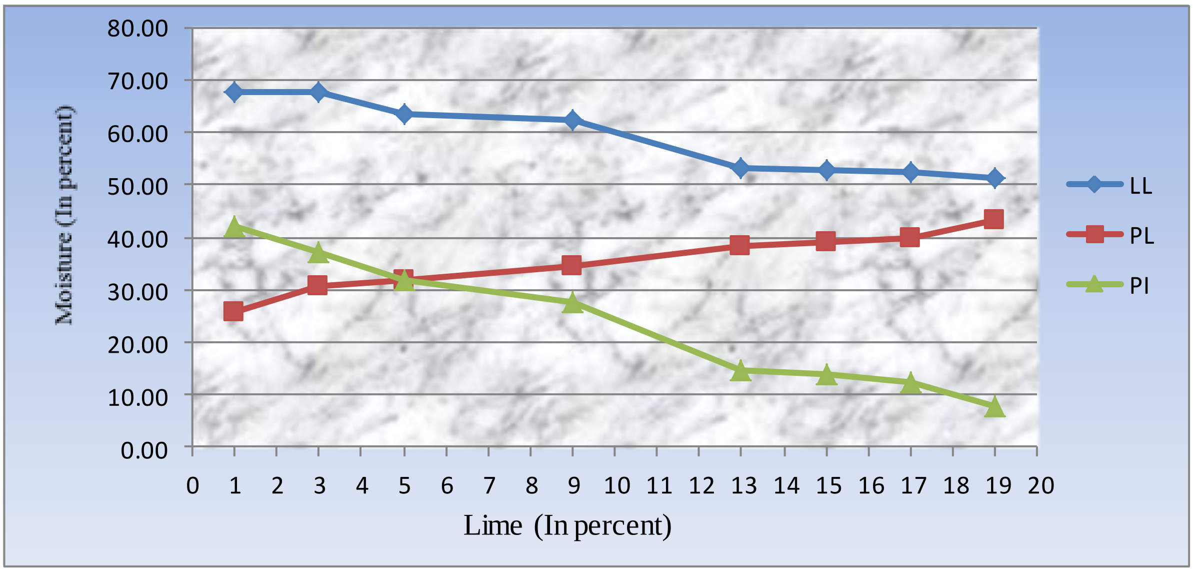
Figures 10. Effect of cement addition in different proportions on the plasticity index of the soil specimen with PI=35.



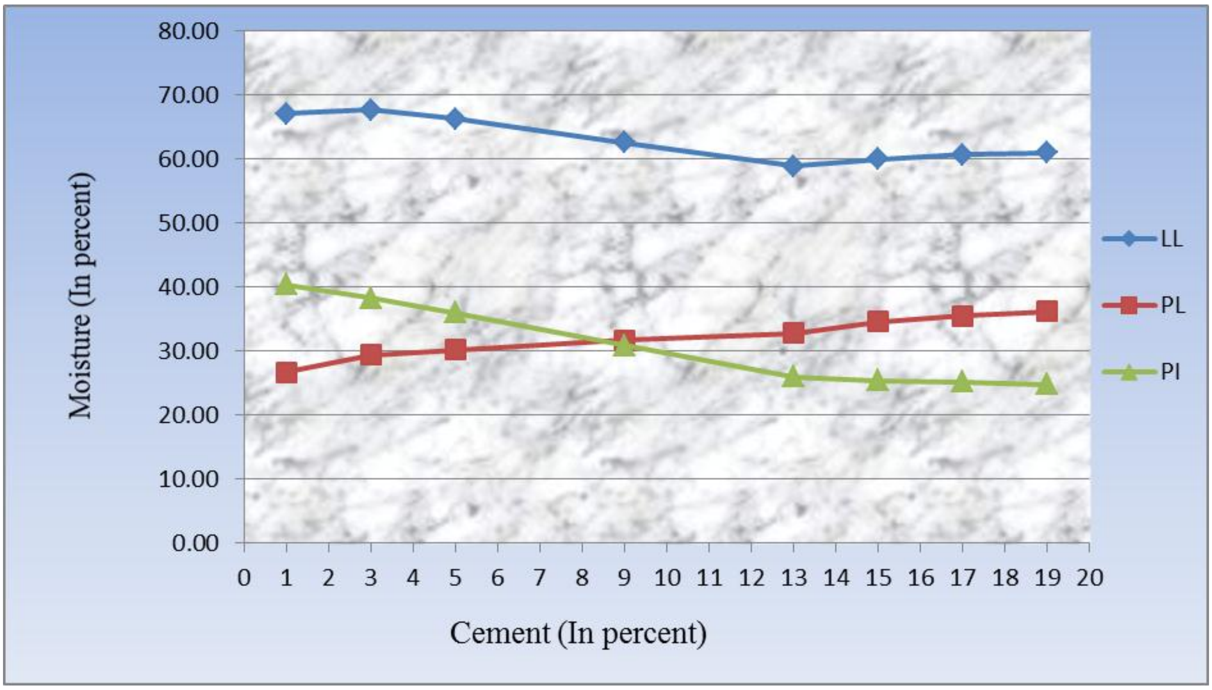
Figures 11. Effect of lime addition in different proportions on the shrinkage properties of the soil specimen with PI=35.



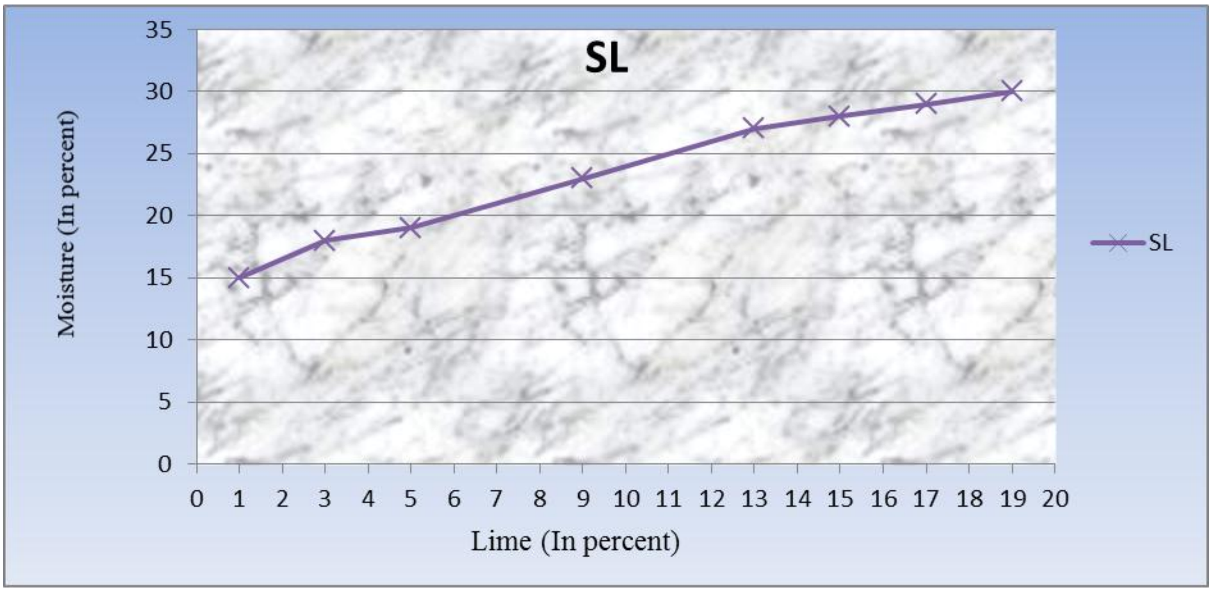
Figures 12. Effect of cement and lime addition in different proportions on the shrinkage properties of the soil specimen with PI=35.



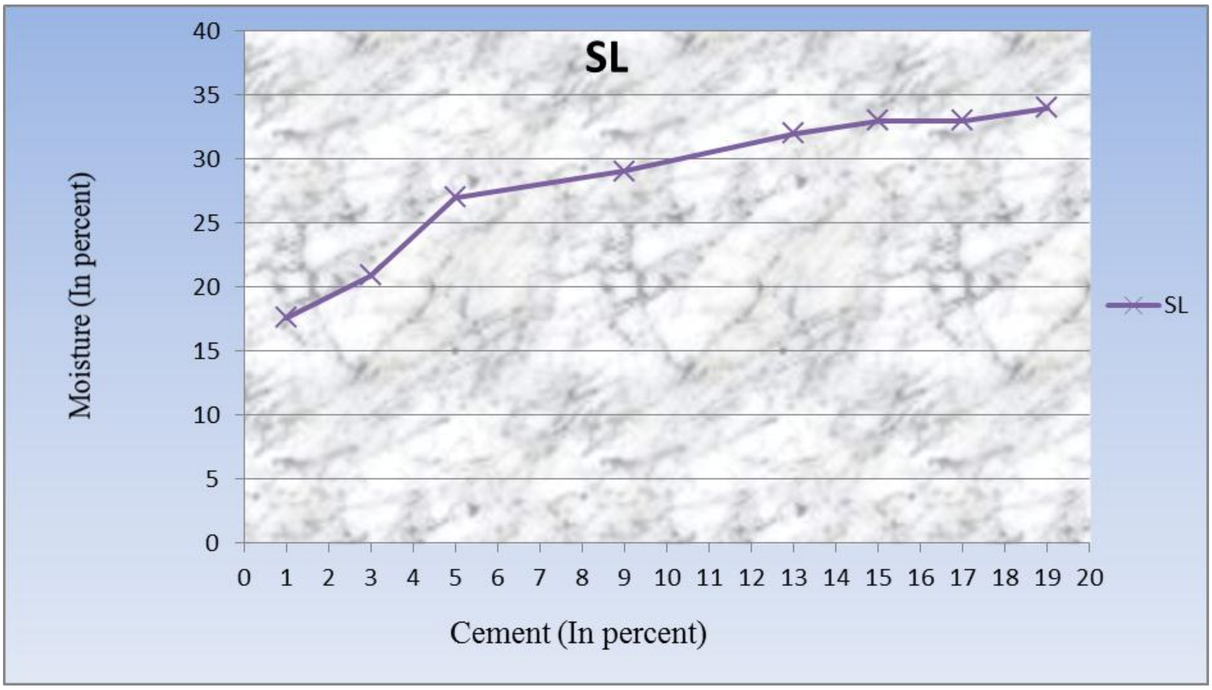
Figures 13. Effect of lime addition in different proportions on the plasticity index of the soil specimen with PI=40



Figures 14. Effect of cement addition in different proportions on the plasticity index of the soil specimen with PI=40.



Figures 15. Effect of lime addition in different proportions on the shrinkage properties of the soil specimen with PI=40.



Figures 16. Effect of cement addition in different proportions on the shrinkage properties of the soil specimen with PI=40.

Discussion and Conclusion

We conducted experiments to stablize specimens of problematic soils with different plasticity indices using cement and lime in different proportions. In this regrad, the following conclusions may be drwan from experimenations on different soil specimens with different primary plasticity indices.

Soil with PI=25 stablized with cement

1. Increased proportion of cement in clay-cement mixture did not produce uniform changes in the liquid limit of the mixture so that no generalization could be made about its behavior. In some proportions, the liquid limit of the mixture increased while in some it decreased comparing with the liquid limit of unmixed soil specimen.
2. Increased proportion of cement in clay-cement mixture resulted in increased plasticity index in the mixture so that in the mixtures with 9-13 percent cement proportions, the plasticity index increased with a steep slope. The greatest change was onserved in the mixture with 19 percent cement addition whereby the plasticity index increased as much as 70 percent in the mixture comparing with unmixed soil specimen.
3. Increased proportion of cement in clay-cement mixture brought about increases in shrinkage limit so that in the mixures with 9-13 percent cement, the shrinkage limit increased with a very steep slope. From small proportions of cement in the mixture up to 5 percent, the shrinkage limit was decreasing in the mixture; however, from 5 percent and over, this index increased cumulatively in the mixture until it reached its maximum value in the mixture with 19 percent cement.
4. The most appropriate proportion of cement in the clay-cement mixture was found to be 13 percent, in which volume change in the mixture was the lowest (almost equal to zero).

Soil with PI=25 stablized with lime

1. Variations in the liquid limit did not follow a discernable pattern in the clay-lime mixture so that in low proportions of lime, considerable fluctuations were observed in the liquid limit. As the proportion of lime increased in the mixture, the liquid limit either increased or decreased randomly. However, in the mixture with 9 percent lime, the liquid limit began to follow an increasing trend and maintained this trend up to 19 percent lime addition.
2. Adding lime to clay soil increased the plasticity limit in the mixture so that the increase in this index had a uniform slope. The increase continued with a reasonable distanceat relatively identical intervals.
3. Increased proportions of lime in the clay-lime mixture increased the shrinkage limit in the mixture specimens. However, with small proportions of lime up to 5 percent, a decrease was observed in the shrinkage limit. Yet, the decrease in this limit was stopped with higher proportions of lime in the mixture and an increasing trend was observed in the limit as the lime proportion increased in the mixture.
4. The most appropriate proportion of lime in the clay-lime mixture was found to be 13 percent, in which volume change in the mixture was the lowest.

Soil with PI=30 stablized with cement

1. Increased proportion of cement in clay-cement mixture did not produce uniform changes in the liquid limit of the mixture so that with small proportions of cement, an alternate decreasing-increasing trend was observed in the liquid limit, which continued up to 9 percent cement addition. However, from over 9 to 19 percent cement proportion, an increasing trend was observed in the liquid limit of the mixture.
2. Increased proportion of cement in the clay-cement mixture resulted in increased plasticity index in the mixture so that in the mixtures with 15-19 percent cement, the plasticity limit had a very steep slope. The increase in the plasticity index was found to show a sudden leap so that with 13 percent cement in the mixture, it showed a 55 percent growth and with 19 percent cement, it doubled up and amounted to 113 percent growth.
3. Increased proportion of cement in the clay-cement mixture increased the shrinkage limit in the mixture. This limit, however, showed a decrease in the mixture with 1 percent cement proportion but then drammatically increased, reaching its peak in the mixture with 19 percent cement.
4. The most appropriate proportion of cement in the clay-cement mixture was found to be 13 percent, in which the volume change in the mixture was the lowest.

Soil with PI=30 stablized with lime

1. Liquid limit variaions did not show a discernible pattern in this mixture. The variations in liquid limit values were not tangible in different proportions of lime.
2. Increased proportion of lime in the clay-lime mixture increased the plasticity index in the mixture so that with 1-3 percent lime in the mixture, the increase in the index had a steep slope. However, with over 3 percent lime, the increase in the plasticity index followed a more uniform pattern with a more gentle slope.
3. Increased proportion of lime in the clay-lime mixture increased the shrinkage limit in the mixture so that with 1-3 percent lime in the mixture, the shrinkage limit had a very steep slope.

4. The most appropriate proportion of lime in the clay-lime mixture was found to be 13 percent, in which the volume change in the mixture was the lowest.

Soil with PI=35 stablized with cement

1. Liquid limit variaions did not show a discernible pattern in this mixture so that it fluctuated fuzzily in different mixture proportions.
2. Increased proportion of cement in clay-cement mixture resulted in increased plasticity index in the mixture with the increase having a steep slope. In low proportions of cement in the mixture, the plasticity index values showed a considerable leap in the slope. However, the slope changed more gently in the intermediate propotions of cement but it became steeper in high cement proportions again.
3. Increased proportion of cement in clay-cement mixture led to uniform increases in the shrinkage limit in the mixture. The shrinkage values increased at relatively equal intervals and had a normal slope.
4. The most appropriate proportion of cement in the clay-cement mixture was found to be 9 percent, in which the volume change in the mixture was the lowest.

Soil with PI=35 stablized with lime

1. The variations in the liquid limit was relatively reductive in the mixture so that in small proportions of lime in the mixture, the reduction was more tangible but in higher proportions, the values did not change significantly.
2. Increased proportion of lime in the clay-lime mixture resulted in increased plasticity index in the mixture so that in the mixture with 1-5 percent lime, the increase in plasticity value had a steeper slope. In higher lime proportions, increases in the plasticity index followed a reasonable trend and raised at relatively equal intervals.
3. Increased proportion of lime in the mixture led to increased shrinkage limit so that in the mixtures with 1-5 percent lime, the limit values had a very steep slope. In higher lime proportions, however, the variations in the shrinkage limit were not conspicuous so that the increasing trend followed slowly.
4. The most appropriate proportion of lime in the clay-lime mixture was found to be 9 percent, in which the volume change in the mixture was the lowest.

Soil with PI=40 stablized with cement

1. Liquid limit variaions did not show a discernible pattern in this mixture. However, experiments showed a difference between this type of soil and other soil specimens. In this regard, adding cement to soil specimens in any proportion increased the liquid limit in the mixture.Though the liquid limit increased fuzzily in the mixture, it followed an ascending pattern.
2. Increased proportion of cement in the clay-cement mixture resulted in increased plasticity limit so that in the mixtures with 1-3 and 13-15 percent cement, the values of this limit had a steep slope. In other proportions, the values of plasticity limit varied negligibly.
3. Increased proportion of cement in the clay-cement mixtureled to increased shrinkage limit so that in the mixtures with 1-9 percent cement, the limit values had a steep slope. In other proportions, the values followed a more moderate slope though the increasing pattern continued to 19 percent cement in the mixture.
4. The most appropriate proportion of cement in the clay-cement mixture was found to be 13 percent, in which the volume change in the mixture was the lowest.

Soil with PI=40 stablized with lime

1. Liquid limit variations were totally reductive in the clay-lime mixture. However, in the mixture with 1 percent lime, the liquid limit increased abruptly as much as 15 percent. Yet, increased proportions of lime in the mixture resulted in decreases in the liquid limit so that in the mixture with 19 prcent lime, the liquid limit reduced as much as 12 percent comparing with the unmixed soil specimen.
2. Increased proportion of lime in the clay-lime mixture led to increases in the plasticity limit so that in the mixtures with 1-9 percent lime, the limit values had a steep slope. In the intermediate lime proportions in the mixture, the slope became more moderate while in the final proportions, with 19 percent lime, a considerable ascending leap was found in the slope again.
3. Increased proportion of lime in the clay-lime mixture led to increased shrinakge limit so that in the mixtures with 1-5 percent lime, the shrinkage values had a very steep slope. However, in other proportions, the ascending pattern dropped significantly.
4. The most appropriate proportion of lime in the clay-lime mixture was found to be 5 percent, in which the volume change in the mixture was the lowest.

In the end, considering the present findings, the following conclusions may be drawn from experimentations on the effect of adding lime and cement to soil specimens with plasticity indices 25, 30, 35 and 40.

a) Adding cement and lime to soil specimens did not reveal tangible variations in the liquid limit of the mixtures so that the limit values either increased or decreased alternately but did not follow a certain ascending or descending pattern. However, in soil specimens with plasticity indices 25 and 30, the liquid limit values followed an irregular pattern up to 9 percent lime/cement addition but then followed an ascending pattern in the mixtures with over 9 percent lime/cement.
b) Adding cement/lime to soil specimens resulted in increased plasticity limit and optimum moisture so that in the mixtures with 1-3 percent lime/cement, the plasticity values followed a slowly ascending pattern. However, in the mixtures with over 5 percent lime/cement, a considerable ascending leap was observed in the plasticity limit values.
c) Adding cement/lime to soil specimens resulted in increased shrinkage limit in the mixtures. In this regard, in the soil specimens with plasticity indices 35 and 40, the increases in the shrinkage values were almost linear. However, in the soil specimens with plasticity indices 25 and 30, the shrinkage limit values tended to decrease in small lime/cement proportions in the mixtures. Yet, as the lime/cement proportion increased in the mixtures, the shrinkage values increased gradually so that the highest shrinkage values were observed in the mixtures with 19 percent lime/cement.
d) Adding cement/lime to soil specimens resulted in decreased plasticity index in the mixtures. The decrease was particularly significant in the soil specimen with PI=30 when 3 percent lime/cement was added and the soil specimen with PI=35 when 5 percent lime/cement was added.
e) The most appropriate proportion of lime/cement in the clay-lime/clay-cement mixtures was found to be 13 percent, in which the volume change in the mixture was the lowest. In the soil specimen with PI=35, the lowest volume change was observed in the mixture with 9 percent lime/cement while in thesoil specimen with PI=40, the lowest volume change was observed with 5 percent lime in the clay-lime mixture.

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