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European Journal of Experimental Biology, 2012, 2 (4):1034-1038

ISSN: 2248 –9215
CODEN (USA): EJEBAU

An experimental study for identification and comparison of plastic index and shrinkage properties of clay soils with the addition of cement

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ABSTRACT

There has been an increasing application of various clay minerals with high plasticity in environmental and geotechnical projects. One of the weaknesses of clay minerals is their shrinkage potential while desiccating. It is imperative to modify the properties of these minerals by combining them with other materials. The present article tries to examine the effect of adding cement to clay on its shrinkage properties and to compare it with normal clay. A considerable number of expansion experiments were carried out on mixed samples with different weight percentages. The results suggested the significant effect of modification of clay soils in Golestan Province by adding cement on their shrinkage properties, such that increased percentage of additives increases the shrinkage limit of clay-additive mixture and the cracks caused by shrinkage decrease in terms of length and width. Finally, the clay-additive mixture pattern can be obtained that provides the basic, necessary properties which correspond to the aims of the project. In the present article, cement is used as a chemical for improving the shrinkage properties of expansive and problematic soils in Golestan Province. During the course of experiments, four samples of different soils are used with plasticity indices of 20, 30, 35, and 40. Here, the plasticity properties (including liquid limit, plastic limit, shrinkage limit, and plastic index) of clay soils in the region will be examined and compared before and after adding different percentages of cement.

Keywords: Plastic Index, Shrinkage Properties, Clay Soils, Addition of Cement

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INTRODUCTION

One of the topics that have recently received much attention from soil and foundation specialists is the study of problematic soils. Basically, a soil is problematic when it exhibits an unexpected behavior under specific conditions and this unpredicted behavior will, in many cases, cause problems. The problematic nature of these soils is due to different parameters that lead to certain behaviors in these soils and the study of each individual parameter has been the subject of many a research. Clay soils are among these problematic soils [8]. Iran is one of the countries where there are clay soils in most of its regions and if these soils and its different minerals are not identified, the structures built on these soils will undergo cracking and buckling in the event of pipe burst or rising up of underground water tables. It thus seems necessary to identify and classify these soils and take necessary measures to deal with their shrinkage properties. The natural soil in the operation site is not always suitable for supporting the structure of interest. Building a structure on unsuitable soil can lead to problems like swelling and buckling. To avoid such problems, specific methods must be employed to improve soil condition [12].

There are various methods for improving problematic soils the most important of which are [10]:

1. Compaction
2. Vibro compaction
3. Surcharging
4. Deep drainage
5. Soil stabilization by injection
6. Vibro stone columns
7. Geogrid encasement
8. Chemical stabilization
9. Pre-wetting

Applying any of the above methods leads to changes in soil properties including:
1. Reduced buckling of the structure
2. Imported soil shear strength
3. Increased bearing capacity
4. Increased reliability against sliding of slopes, landfills, and embankments
5. Reduced shrinkage and swelling

Choosing the right soil improvement method is difficult. The geotechnical engineer chooses the optimal method by taking into account all the technical and economic issues, human resources, machinery, experience, the results of experiments [5].

In situ improvement of soil properties using additives is known as soil stabilization. This method is mostly applied to fine-grained soils. In fact, soil stabilization is a process through which natural or artificial materials are added to the soil, leading to improved soil properties [14]. Different additive materials can be used for soil stabilization and the most common ones are [1, 14]:

1. Lime
2. Cement
3. Lime-fly ash mixture
4. Lime-silica fume mixture

The main reasons for soil stabilization are [5]:
1. Improving fine, low-resistant soils
2. Increasing the durability of soils
3. Increasing soils' bearing capacity
4. Reducing swelling
5. Reducing plasticity
6. Preventing erosion

Advent of Cement

The archeological studies on ancient monuments show that Romans were the first to become familiar with the value of cement as a binder and hardener. From 2600 years BC to the mid-eighteenth century, burnt lime was another binder along with clay and plaster which was also referred to as quicklime (CaO). By adding water to burnt lime it was converted into hydrated lime which subsequently turned into lime dust [7]. The lime mortar noted above was exclusively used in construction of brick walls of temples and such but had no application in construction of canals, for it lacked the hardening quality when exposed to water. Thus, it could not fulfill water-related requirements such as in construction of bridges, dams, quays, and the like [9]. Centuries passed until Romans made a great discovery by adding pozzolan to hydrated lime and created a mortar that could sustain under water. After this discovery, the advantages of burnt lime-clay mixture were understood and this was the first step for creating cement [6]. In those eras the product of blending pozzolan and burnt lime was called cement (caemente) that is derived from the Greek word caedere which means hewing or chopping and was used to refer to rubble. Up to mid-eighteenth century, the term "caemente" was used to refer to materials that hardened an object when added to it [10]. In 1824, Joseph Aspdin, the British architect from Leeds, created an artificial mixture of limestone and clay and pulverized it wet until it turned into slurry and homogeneous. Then, the mixture was dried in a kiln with low temperature (i.e. less than melting temperature) and the product was called Portland cement due to its striking similarity to the oolitic limestone of Portland, England. In 1843, Aspdin began manufacturing Portland cement in a newly built plant and at that time the British Parliament realized that this cement is much better cement than the Roman one. Further investigations revealed that the main reason for this high quality cement is because Portland cement is heated to the point of sintering [4].

The effect of adding cement on soil properties
Cement s widely used for soil stabilization, especially in the construction of roads and embankments. Cement can be used for stabilizing sandy and clay soils, particularly in regions with high levels of groundwater. Most fine-grained soils can be stabilized by cement except organic soils. The amount of cement required for soil stabilization depends on soil plasticity. Soils with higher fine-grained percentage or more plastic soils (higher plastic range) require a greater amount of cement for stabilization [11]. For field compaction, the correct amount of cement can be mixed with soil. The mixing can be in situ or in a mixing plant and then be transferred to the site. Then, a proper amount of water is added to the mixture and it is compacted until it is of the weight of interest. Cement slurry (water-cement ratio of 0.5 to 50) can be injected in weak soils that form the infrastructure of buildings or other structures. Cement injection leads to reduced permeability and increased resistance and bearing capacity of soils. Also in designing infrastructures, the soil is hardened by injection so that the resonance frequency of the subsoil increases. One of the problems of working with stabilized soils is that delay in soil compaction after mixing soil with cement and water has very undesirable effects on the properties of the stabilized soil; for instance, reduction of bearing capacity of soil by 60 percent and reduction of specific gravity by 20 percent due to a 4 to 6-hour delay in soil compaction. To solve the cement-soil mixing problems and to obtain a consistent, high quality mixture, sometimes big projects make use of a central facility. First, soil and cement are mixed in fixed machines and the mixture is transferred to the site for distribution and compaction in a relatively short time after mixing. Using this method, the interval between mixing and compaction can be reduced to 2 hours or less and consequently the quality of the stabilized soil increases. Of course using this method is not economically suitable for small projects. Another problem related to cement mixtures, which is mostly encountered in fine-grained soils, is the incidence of shrinkage cracks on the compacted layers that often will lead to undesirable consequences after implementation. In this case, shrinkage cracks can be considerably reduced by adjusting moisture to lower than 80 percent of saturation [13].

The effects of cement on Atterberg limits
For clay soils, cement stabilization is effective when liquid limit is less than 40-50 percent and when plastic index is around 25 percent. Reduction in liquid limit due to adding cement depends on the type of soil and it cannot be generalized to all fine-grained soils.

The effect of cement on soil's specific gravity
Adding cement to different soils has different effects. In collapsible soils, this leads to reduced dry specific gravity and increased optimum moisture. In clay or sandy soils, one the other hand, adding cement increases dry specific gravity but does not significantly change optimum moisture.

Soil stabilization using cement
The purpose of a project for soil stabilization using cement is to determine the desirable percentage of cement for a soil with specific properties. The percentage of cement not only should fulfill the soil stabilization aims, but it also should be economically reasonable. The initial cement percentage for soil stabilization depends on the purpose of stabilization as well as the aggregation and the fine-grained percentage of the soil. In general, the percentage of cement increases with the percentage of clay and silt in soils. Usually the amount of cement necessary for stabilizing well-aggregated clay and sandy soils is less than poorly aggregated soils. After estimating the percentage of cement for stabilizing a specific soil, samples of the stabilized soil with different percentages of cement must be examined in a laboratory and the suitable cement percentage must be chosen with respect to aims of stabilization [2].

Experimentation Procedure
The purpose of the present research was to examine the stabilizing effect of cement on the shrinkage properties of expansive soils. First, the effect of cement on the plastic properties of the soil was examined by using soil samples with plasticity of 20, 30, 35, and 40 and by adding different percentages of cement (1, 3, 5, 9, and 13 weight percentage). The effects were then compared.

The effect of cement on the plastic and shrinkage properties of the soil
The figures below show the results of liquid limit, plastic limit, and shrinkage limit experiments on soil samples with different plasticity, stabilized with different percentages of cement.

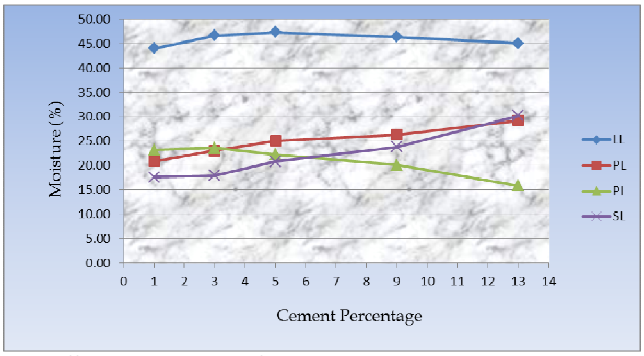

Figure 1. The effect of adding different percentages of cement on the plastic and shrinkage properties of the soil (PI = 20)

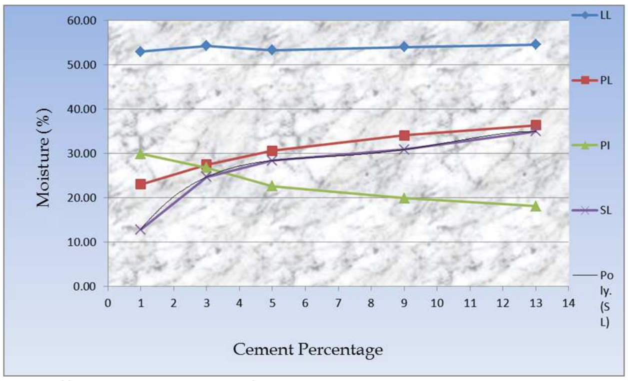

Figure 2. The effect of adding different percentages of cement on the plastic and shrinkage properties of the soil (PI = 30)

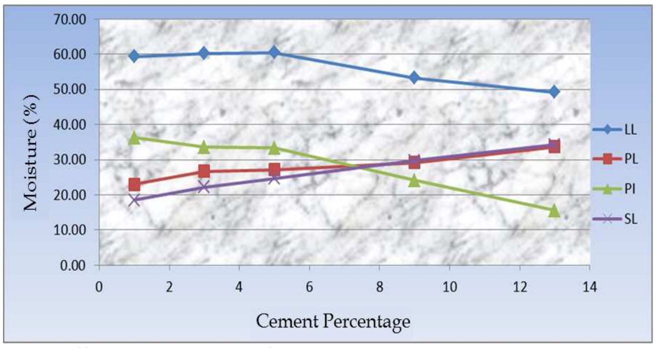

Figure 3. The effect of adding different percentages of cement on the plastic and shrinkage properties of the soil (PI = 35)

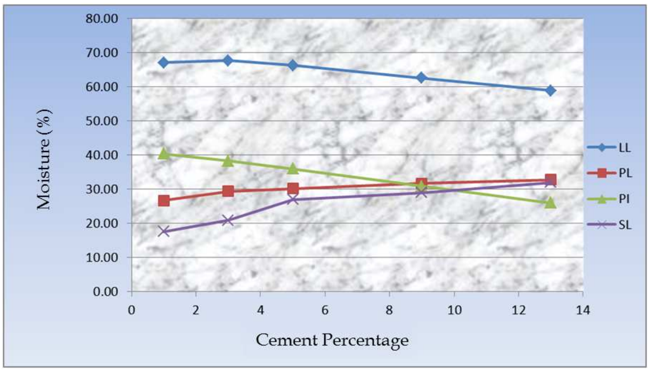

Figure 4. The effect of adding different percentages of cement on the plastic and shrinkage properties of the soil (PI = 40)

DISCUSSION AND CONCLUSION

In the present research, experiments were conducted to stabilize problematic soils of Golestan Province with different plastic indices and different percentages of cement. The following conclusions were made:

A. Adding cement up to 5 percent of the weight of sample soils increases their liquid limit (LL), and increased cement percentage will reduce the LL of the samples.
B. Adding cement to the sample soils is followed by increased plastic limit (PL) and the percentage of optimum moisture.
C. Adding cement to the studied samples will increase shrinkage limit (SL) and this increase is almost linear for samples with 20, 35, and 40 PI but ascending in samples with 30 PI and 3% cement addition.
D. Adding cement to the studied soil samples reduces the PI of the clay soils in the region. This reduction has a milder slope in soils with 20 PI.
E.Finally, the optimum percentage of cement added to the studied problematic soils is 10% of total weight for soils with up to 35 PI and 13% of total weight for soils with 40 PI. It can thus be concluded that adding cement to the problematic soils of Golestan Province improves the shrinkage limit and reduces the longitudinal and transverse cracks in these soils due to shrinkage.

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