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Research paper

Cementitious Materials for Stabilizing Clayey Soils In Road Building

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Abstract

This paper studies on different cementitious materials for clayey soil stabilization. One-kilometer rural road was taken into consideration. The road was divided into four segments of 250 meters each, which serve for testing four cementitious soil stabilizer materials. The first one was local clayey soil with 5% cement and 5% fine crushed stone; this was considered as reference or conventional method of soil stabilization. The second and third ones were materials with 9% and 5% fly ash respectively apart from 5% cement. Besides, in the third one the chemical admixture was also used with the amount of 5% cement weight. Fly ash was not added into the fourth mix, which uses only 5% cement and admixture. Experiments showed that fly ash can replace cement partially to make the binder materials in stabilization process more economically and environmental-friendly. However, it needs to take into account an expansive issue in case of submergence. Chemical admixture can also be used in combination with cement, since the higher soil strength was observed. Particularly, the expansive issue of clayey soil stabilization would be taken under control while using the admixture. The combined use of cement, fly ash, and chemical admixture yielded the most effective results from technical point of view, however in this case the economic issue should be taken into consideration.

Keywords: *Soil Stabilization; Cement; Fly Ash; Admixture; Real Road Testing.*

1. Introduction

Soil stabilization has been a technique introduced for many years with the main purpose to render the soils capable meeting the requirements of the specific engineering projects, especially used for road building. As very well-known over the world, lime and ordinary Portland cement (OPC) have been the most common stabilizer since they are readily available at reasonable cost. In cement stabilized soils, the stabilization mechanisms are associated with hydration and pozzolanic reactions [1-5]. When OPC or lime is mixed with soils, the particles become closer and the soil is stabilized through flocculation and pozzolanic reactions [2-6]. A major issue with conventional soil stabilizers (i.e., OPC and lime) is that their production processes are energy intensive and emit a large quantity of CO2. For instance, approximately one ton of CO2 is emitted for the production of one ton of cement [7]. Furthermore, the raw materials readily available for cement production are being over-consumed. Therefore, civil engineering industry is always searching for new, viable sustainable alternatives to replace fully or partially OPC as soil stabilizers.

In order to improve the environmental acceptability and reduce the construction cost of the deep mixing method, the replacement of OPC by supplementary cementing materials such as fly ash has been recently involved into road building [8]. Fly ash is inherently a fine powder that is a byproduct of burning pulverized coal in electric generation power plants. It is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water [9]. When mixed with lime and water, fly ash forms a compound similar to OPC. When used with cement, fly ash improves the strength and durability, particularly where the locally available soil is poor [10].

When OPC, fly ash and water are added to clayey soils, at the mixing stage a proportion of the clay particles that were coating the coarse aggregates can be become detached and are dispersed in the aqueous phase. This has the effect of adjusting the exothermic hydration of cement paste and hence affecting both the setting time and the strength gain [11]. The remaining clay particles stay attached to the aggregate surfaces, which adjusts the interfacial transition zone at the cement paste-aggregate surface interface. The relative proportion of clay dispersed into the aqueous solution, and therefore becoming part of the hardened cement paste microstructure, depends upon the mineralogy and particle diameter of the clays. The detachment and dispersion of kaolinite clay, for examples, is increased from 50% to 79% when the pH is raised from its natural value of 2 up to 12, when an alkaline substance such as cement is added. Besides, expansive clay minerals suffer macroscopic swelling, which decreases the rate of hydration and reduces the rate of strength gain in cement-stabilized soils [10], [11].

As a result, this paper presents the experimental study on samples, which were extracted from a real road building test of different cementitious materials for clayey soil stabilization. Physical properties, especially the expansive issue of clayey soil, are studied. Moreover, mechanical properties based on unconfined compressive strength and splitting tensile strength of different cementitious materials are also paid an attention.

2. Cementitious materials and sample extraction

In order to study the properties of different cementitious materials used for in-situ soil stabilization, real road building test was performed. One-kilometer rural road in Ward Huu Lung, Lang Son

Province of Vietnam is taken into consideration. The road is divided into four segments of 250 meters each, which serve for testing four cementitious soil stabilizer materials, as shown in Table 1. The first mix is local clayey soil with 5% cement and 5% fine crushed stone; this mix is considered as reference or conventional method of soil stabilization. The second and third ones are mixes with 9% and 5% fly ash respectively apart from 5% cement. Besides, in the third mix the chemical admixture is also used with the amount of 5% cement weight. Fly ash is not added into the fourth mix, which uses only 5% cement and admixture. Cement PCB40 with commercial brand Vissai and fly ash in accordance with ASTM C 618 are used; according to the supplier, these materials have a specific weight of 3.1 g/cm^3 and 2.2 g/cm^3 respectively. Cement amount from all mixes was considered in accordance with practical experiences of VIETRACO Company.

Table 1: Cementitious Soil Stabilizer Materials and Sample Extraction after 28 Days

	Mix 1	Mix 2	Mix 3	Mix 4
Local clayey soil	1	1	1	1
Cement PC40	0.05	0.05	0.05	0.05
Fine crushed stone	0.05	-	-	-
Fly ash	-	0.09	0.05	-
Admixture	-	-	0.0025	0.0025

All of tests were carried out by mean of various sorts of equipment from VIETRACO JSC such as SAKAI® stabilizer machine, rollers, rammers, etc. Firstly, the optimum moisture content of the local clayey soil is determined; depending upon the content water might be added to the soil. For the first road segment (Mix 1), after placement of fine crushed stone, on which cement is dispersed with a thin layer, as it can be seen in Figure 1. For the rest road segments (Mix 2 - Mix 4) cement and/or fly ash are placed above the local clayey soil. After placement of raw materials (fine crushed stone, cement, and/or fly ash), The SAKAI® stabilizer machine comes in and blends all of local soil and raw materials together, yet chemical admixture and water are added during mixing process. Finally, rammer and roller come in to press and vibrate the composite material; they carry on working several times to make a plane surface and a dense composite material.

Fig. 1: Cement Placement on the Road before Mixing with Local Clayey Soil Underneath.

At 28 days after a real testing, sample extraction was taken from all of four road segments by mean of hand-held coring machine in order to study the physical and mechanical properties. The samples from those segments are shown in Figure 2. After extraction from the field, all of samples were moved to the laboratory for further study. Regarding the physical properties, samples of four mixes are used for determining a series of unit weight in dry condition, after 24h and 36h submergence. Besides, water content after submergence is also defined. In order to study mechanical properties, the samples were prepared to obtain proper cylinders subject to compression and splitting tensile tests, as shown in Figure 3 and Figure 4 respectively, which are carried out at 30 days after real testing. The samples submerged 72h under water are considered to be in a saturated condition.

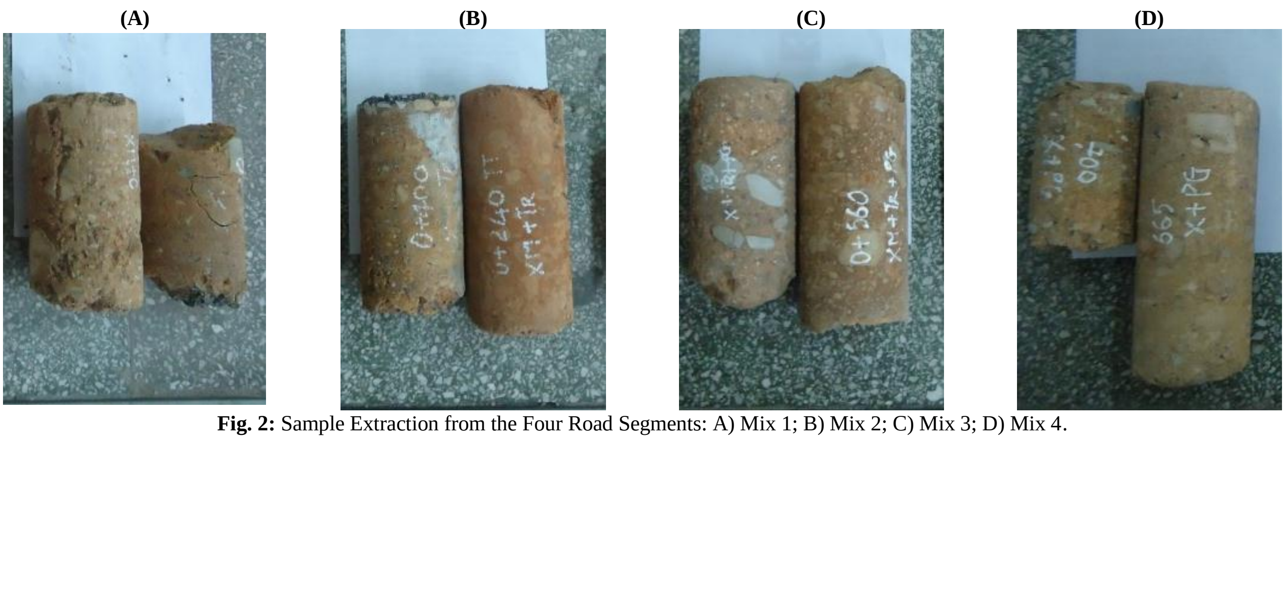

Fig. 2: Sample Extraction from the Four Road Segments: A) Mix 1; B) Mix 2; C) Mix 3; D) Mix 4.

Fig. 3: Compression Test on Extracted Sample.

Fig. 4: Splitting Tensile Test on Extracted Sample.

3. Results and discussion

The results of physical properties are included in Table 2. Among four mixes, the first one (Mix 1) has the highest unit weight in dry condition, while the second and third ones (Mix 2 and Mix 3) have the smallest. It indicates that the use of fly ash for soil stabilization in this study causes a moderate reduction in soil unit weight. After 24h submergence, the unit weight of four mixes increases, this means the water has penetrated into the sample, and increment of weight is higher than that of volume. However, after 36h submergence, the unit weight of Mix 1 and Mix 2 reduces slightly, on the contrary, those of Mix 3 and Mix 4 even keep unchanged in comparison with that after 24h submergence. In the meantime, after 24h and 36h submergence water contents of all four mixes are quite similar, as it can be observed in Table 2. It points out that for the case of Mix 1 and Mix 2 the increment of volume is higher than that of weight, while this is not observed in Mix 3 and Mix 4. The main difference between the latters and the formers is the use of chemical admixture. It is noteworthy that the admixture has played an important role in preventing the clayey soil expansion while submerging under water for a long time.

Table 2: Physical Properties of Cementitious Soil Stabilizer Materials

Parameters	Units	Mix 1	Mix 2	Mix 3	Mix 4
Unit weight in dry condition	T/m^3	1.98	1.74	1.7	1.89
Unit weight after 24h submergence	T/m^3	2.05	1.87	1.85	2.00
Water content after 24h submergence	%	7.6	7.13	6.60	5.21
Unit weight after 36h submergence	T/m^3	2.02	1.85	1.85	2.00
Water content after 36h submergence	%	7.65	7.18	6.66	5.28

Similarly, the results of mechanical properties are provided in Table 3. It is seen that unconfined compressive strength of sample reference Mix 1 in both dry and saturated conditions is the smallest one among that of four mixes. Regarding Mix 2 and Mix 3, in which fly ash is used in combination with cement, the later using 5% fly ash yields higher strength than the former using only 9% fly ash. However, it needs to take into account that the Mix 3 implements chemical admixture. Indeed, although fly ash was not used in Mix 4, unconfined compressive strength of this mix is higher than that of Mix 2. Regarding the splitting tensile strength, it is observed that the strength of Mix 3 and Mix 4 is significantly higher than that of Mix 1 and Mix 2 in both dry and saturated conditions. While, the strength of Mix 1 and Mix 2 is quite similar, even though fly ash was involved into the latter.
As a result of that, mechanical properties of cementitous soil stabilizer materials in this study shows that apart from fly ash, the admixture used in this study might be able to increase the unconfined compressive strength of clayey soil, especially for case of saturated condition or submergence under water for a long time.

Table 3: Mechanical Properties of Cementitious Soil Stabilizer Materials

Parameters	Units	Mix 1	Mix 2	Mix 3	Mix 4
Unconfined compressive strength in dry condition	MPa	1.8	3.5	4.9	4.1
Unconfined compressive strength in saturated condition	MPa	0.4	1.4	2.7	2.4
Splitting tensile strength in dry condition	kPa	141	149	233	221
Splitting tensile strength in saturated condition	kPa	104	109	200	194

4. Conclusion

Cementitious materials for clayey soil stabilization was studied in this paper. Based on the experimental examination on samples extracted from four real testing road segments, it can be withdrawn as follows:

- Fly ash can be used properly in combination with cement for soil stabilization, since it plays an important role in improving the soil strength. It can also replace cement partially to make the binder materials in stabilization process more economically and environmental-friendly. However, it needs to take into account an expansive issue in case of clayey soil stabilization with a long time submergence.
- Chemical admixture can also be used in combination with cement, since the higher soil strength was observed. Particularly, the expansive issue of clayey soil stabilization would be taken under control while using the admixture.
- The combined use of cement, fly ash, and chemical admixture yielded the most effective results from technical point of view, however in this case the economic issue should be taken into consideration, because it might be over budget due to material cost.

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