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IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Experimental Study on the Use of the Modifying Agent for Expansive Soil Stabilization: Mockup Test on a Case Study

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DOI: https://doi.org/10.30880/ijscet.2022.13.01.015
Received 30 November 2021; Accepted 13 March 2022; Available online 16 May 2022

Abstract: To improve the soft grounds, soil stabilization has been used widely in many tropical countries including Vietnam. This paper presents the experimental study on the use of the modifying agent for expansive soil stabilization. A real-scale one-kilometer rural road was used for the experimental test. It was divided into four parts, and each part was subjected to different stabilization tests. The specimens extracted from every quarter were denominated as Q1 (soil + cement), Q2 (soil + cement + fly ash), Q3 (soil + cement + fly ash + modifying agent) and Q4 (soil + cement + modifying agent). The assessment test showed that specimen Q1 yielded the highest water absorption percentage after 24 hours and 72 hours of soaking. The longer the soaking time, the more water diffusion occurred at specimens Q1 and Q2 rather than at specimens Q3 and Q4. When subjected to the unconfined compressive and indirect tensile tests, specimens Q1 and Q3 yielded the lowest and highest strength, respectively. The use of the modifying agent in the specimens Q3 and Q4 has improved noticeably unconfined compressive strength, indirect tensile strength, and water stability compared to the specimens Q1 and Q2. However, ettringite-based sulfate heaving might be exhibited with the use of fly ash, this may cause damage to the overlying pavement structure in the long term. Therefore, to improve the expansive soil stabilization using the modifying agent, it is recommended to use the constituent materials in specimen Q4 rather than in Q3.

Keywords: Soil stabilization, mock-up real-scale test, modifying agent, unconfined compressive strength, indirect tensile strength

1. Introduction

At present, to improve the ground's phys-chemical and geotechnical properties resulting in desired characteristics of soil for structural works, stabilization is a common technique (Pham et al., 2020). Doing this, it needs to use different methods for improving the expansive soils to make them suitable for construction (Nelson and Miller, 1997). In civil engineering, the problems of soil expansion are still remaining issues (Tran and Trinh, 2019). Besides, it is also essential to deal with procedures and techniques by which soft soils may be improved to serve constructional purposes (Nguyen and Nguyen, 2020). Indeed, various physical, phys-chemical, and chemical methods have to be involved to make a soil perform better and achieve its desired engineering purposes (Miura et al., 2001; Brooks, 2009).

Expansive clayey materials are unfavorable for road and dam construction, and engineers may remove the unsuitable material and substitute them with more suitable ones in terms of strength and durability (Fattah et al., 2013).

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These undesirable properties relate to soil volume variation when its moisture content is changed (Anwar Hossain, 2011). The expansive soils' volume change behavior is a cause of numerous problems in structures, resulting in the reduction of the strength and causing settlement of the pavement.

Two methods are often employed to improve the strength and stiffness of expansive soils, which are mechanical and chemical stabilizations (Estabragh et al., 2014; Radhakrishnan et al., 2017; Soltani et al., 2018). The first one includes compaction, reinforcement, and solid wastes (Ikeagwuani and Nwonu, 2019). While, the second one has become more common in practice. In the latter method, the commonly-used materials for stabilization include cement and fly ash (Estabragh et al., 2014; Horpibulsuk et al., 2012; Barbosa et al., 2000; Luong, 2010; Pham and Tran, 2020; Salim, 2021). In this case, the stabilization mechanisms are associated with hydration and pozzolanic reactions (Pham and Tran, 2020; Salim, 2021; Nicholson, 2005). When fly ash and/or cement is mixed with clayey soils, the clay particles become closer, and the soil is stabilized through flocculation and pozzolanic reactions (Estabragh et al., 2014; Adaska and Luhr, 2004).

Apart from cement and fly ash, one promising approach for soil stabilization is to use a modifying agent. Li et al. carried out the experiments at the laboratory and found that the addition of modifying agents improved strength and water stability of soil significantly. Besides, the agent could accelerate the cement system's hydration; needle-like AFt and fibrous C-S-H gel were observed in the mixtures, resulting in the cementation effect among the mixture particles and a more compact microstructure. However, this study is limited to the laboratory scale.

As a result, this paper aims to present the experimental study on the use of the modifying agent for expansive soil stabilization at a real-scale on site. Although the primary stabilizer in this study is cement, the modifying agent with a small amount act as an activator to improve the essential physical and mechanical performance of the stabilized soil. Besides, the study involved the stabilization mock-up test at a real scale. A one-kilometer rural road with a four-meter breadth was used for the experimental test. This road was divided into four parts when four different types of stabilizers were implemented. The outcome was the assessment of extracted specimens from stabilized soil in terms of water stability, unconfined compressive strength, and indirect tensile strength.

2. Materials and Method

2.1 Material Uses

The experimental test was carried out in the Viet Yen Ward of Bac Giang Province, North of Vietnam. The non-stabilized local soil of the rural road was collected for analysis. The soil grading was determined by sieving analysis. According to ASTM D6913-1, the sieved material showed a very fine texture, with 94.15% of the material passed through sieve number 200. The Atterberg limits were determined according to ASTM D4318-17. The soil presented a liquid limit of 57% and a plastic limit of 28%. While, the plasticity index was 29%. The chemical composition of the local soil in this study can be found in Table 1. It can be observed that the local soil possesses a high content of SiO_2 and Al_2O_3 that can be classified as clayey category or inorganic clays of high plasticity (CH) following the USCS (ERDC, 2015). Under the soaking condition, this type of clayey soil represents the high potential for expansiveness (ASTM, 2015).

Table 1 - Chemical composition of cement, fly ash and local soil (in weight percentage)

Compound	Cement	Fly ash	Local soil
SiO_2	22.32	34.54	41.54
Al_2O_3	4.95	21.19	20.95
Fe_2O_3	4.84	13.09	21.55
CaO	64.22	12.04	1.49
MgO	1.62	2.82	1.86
SO_3	-	6.71	-
K_2O	0.11	2.34	0.14
Na_2O	0.26	0.57	0.48
TiO_2	0.05	0.40	1.81
LOI	1.24	5.71	9.85

Table 2 - Physical and mechanical characteristic of cement and fly ash

Parameters	Units	Cement	Fly ash
Specific density	g/cm^3	3.11	2.22
Bulk density	g/cm^3	1.32	-
Blaine fineness	cm^2/g	3430	3818
Consistency	%	28.5	-
Initial setting time	min.	145	-

Final setting time	min.	225	-
Soundness of cement	Mm	1.0	-
3 days compressive strength	N/mm^2	25.5	-
28 days compressive strength	N/mm^2	45.6	-

For the soil stabilization, the ordinary Portland cement 42.5R Type II with commercial band Vissai, which conforms to the European cement standard EN 197-1, was used. Besides, fly ash from the dumping pond of the nearby coal-fired power plant was also used. The chemical composition of cement and fly ash are also included in Table 1. It is seen that fly ash possesses a high content of SO_3, or this is high-sulfur fly ash (Luong, 2010). The physical and mechanical characteristics of cement and fly ash are presented in detail in Table 2. Another two crucial constituent materials used for the experimental study were water and modifying agent, which is a liquid with a dark-brown color; their characteristics are provided in Table 3.

Table 3 - Characteristic of modifying agent and water

Parameter	Units	Modifying agent	Water
Density	g/cm^3	1.38	1.0
pH value	-	9.5	7.0

2.2 Mockup test on the rural road

The mockup test was conducted on a one-kilometer rural road of the Viet Yen Ward in Bac Giang Province. This road has a breadth of 4 meters, and the capacity only allows for the movement of vehicles, including bicycles, motorbikes, small tractors, etc. The one-kilometer rural road was divided into four parts. Each quarter was served for different stabilization tests. The first quarter involved the conventional method of stabilization that uses cement as the primary stabilizer. Apart from cement, the second implemented fly ash. For the third quarter, cement, fly ash, and modifying agent were used. And finally, the fourth quarter differentiates from the conventional method being the inclusion of the modifying agent. The material content for the stabilization in each quarter can be found in detail in Table 4.

Table 4 - Material content for the stabilization in each quarter

Materials	Units	Conventional method	Proposed method		
		1st quarter (Q1)	2nd quarter (Q2)	3rd quarter (Q3)	4th quarter (Q4)
Soil	m^3	1	1	1	1
Cement	kg	100	100	100	100
Water	L	250	250	250	250
Fly ash	kg	-	200	100	-
Modifying agent	L	-	-	5	5

There are various kinds of equipment and machine to perform the stabilizing process, including water tank truck, lamb-roller machine, scraper machine, iron-wheel vibrator machine, and the most important being the soil stabilizer machine, as shown in Figure 1. This type of machine allows for loosening the actual road's soil and stirring it with the stabilizers. During the test, the soil stabilizer machine moved with a velocity of 5 meters per minute, and the road depth in operation was 25 cm, as the machine parameters are provided in Table 5. This means that a topsoil layer of 25 cm thickness is broken and stirred with stabilizers above it. The machine's actual breadth in operation is 2 meters (Table 5), i.e., to work on a four-meter-breadth road of 250 m length, it needed to move 500 meters. Thus, in general, it took one hour and 40 minutes to stabilize each quarter.

Table 5 - Parameter of the soil stabilizer machine PM550-S in operation

Description	Units	Magnitude
Velocity	m/min	5.0
Road breadth	mm	2000
Road depth	cm	25

Before all of the above-mentioned machine initiated, cement and/or fly ash was placed on top of the actual road's soil. As shown in Table 4, 100 kg cement is used for every cubic meter of soil for stabilization. Since the road breadth is 4 meters and the depth in operation is 25 centimeters, every meter of the road presents one cubic meter of soil. Hence, for convenience, two cement packages, 50kg each, were placed at every meter of the road. The package was then opened, and cement was spread evenly on top of the soil, as shown in Figure 2. For the case of Q2 and Q3, fly ash was sprinkled over the cement.

During the stirring process, water and/or modifying agent from the water tank truck, which moves ahead of the soil stabilizer machine, was sprayed into the mix of soil, cement and/or fly ash, as shown in Figure 1 (top). Essentially, the lamb-roller-, scraper-, iron-wheel vibrator machines, in turn, moved behind the soil stabilizer machine to compact the stabilized soil properly.

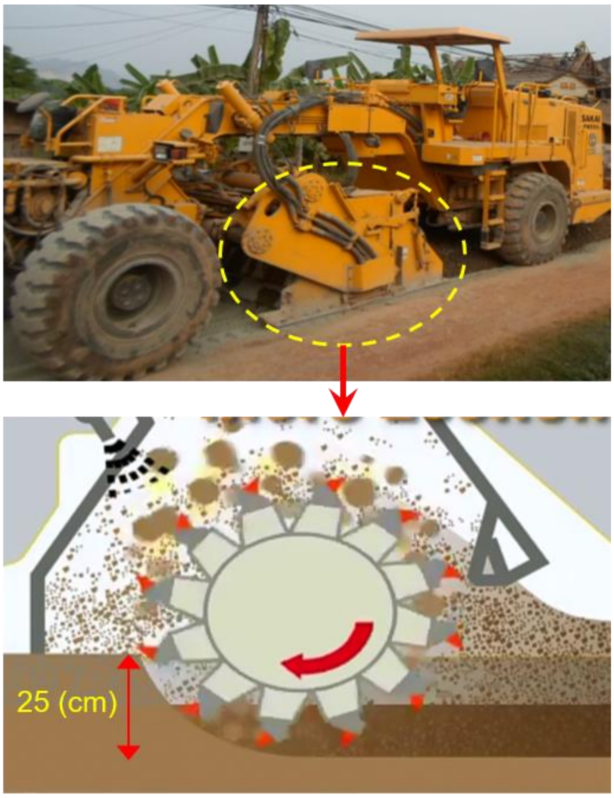

Fig. 1 - Soil stabilizer machine PM550-S

Fig. 2 - Placement of cement before the stabilizing process

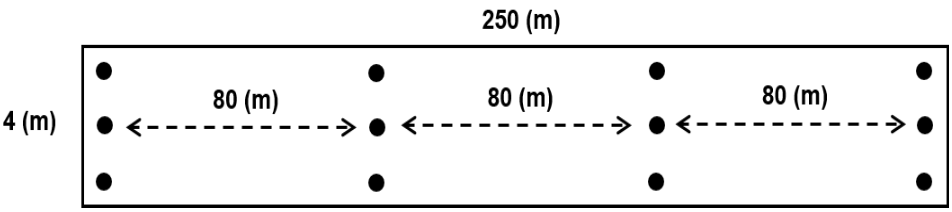

Fig. 3 - Location of borehole for specimen extraction for the assessment in every quarter

To assess the soil stabilization, 28 days after the stabilizing process of the mockup test on the rural road, a series of specimens was prepared from every quarter using a core-cutting machine. Figure 3 shows the location of the borehole in every quarter where the specimens were extracted. Indeed, there were 12 specimens extracted from every quarter. All of the specimens present a cylindrical shape with a diameter of 100 mm and a length varying in the range of 120÷150 mm, depending on the borehole's location and the condition of the core-cutting machine. Some specimens, which were cut and polished at both ends, can be seen in Figure 4.

Fig. 4 - Series of extracted specimens used for the experimental assessment

3. Results and Discussion

3.1 Water Stability

One of the criteria to assess soil stabilization quality is to examine the stability of the extracted specimens under soaking condition. Four specimens from every quarter were soaked in water in order to determine water absorption after 24 hours and 72 hours. Figure 5 shows the experimental assessment result. After 24 hours of soaking, the percentage of water absorption at specimen Q1 shows that the highest and the magnitude decreases in the case of Q2, Q3, and Q4.

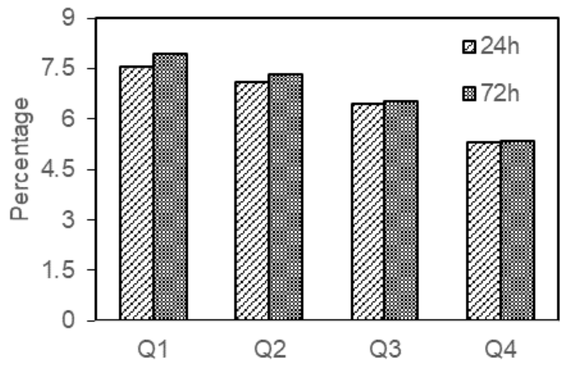

Fig. 5 - Water absorption in the specimens after 24 hours and 72 hours of soaking

A similar situation can be detected after 72 hours of soaking. However, looking into the discrepancy of the percentage between 24 hours and 72 hours of soaking, it points out that the longer soaking time, the more water diffusion occurs at specimens Q1 and Q2 rather than at specimens Q3 and Q4. Take a look at Table 4; the main difference between these specimens is the use of the modifying agent in the latter. This depicts that the agent improved water stability of stabilized soil, which is similar to the outcome obtained by Li et al., who carried out the stabilizing process in the laboratory.

3.2 Unconfined Compressive Strength and Indirect Tensile Strength

Apart from water stability assessment, the rest of extracted specimens from every quarter were used to determine mechanical performance at different conditions. Figure 6 and Figure 7 represent the results of unconfined compressive strength and indirect tensile strength respectively of the specimens at dry and saturated conditions. It can be seen that specimens Q1 present the lowest strength at both dry and saturated conditions.

Regarding indirect tensile strength, the use of fly ash in specimen Q2 (Table 4) has improved slightly by about 7% compared to specimen Q1. However, the unconfined compressive strength of the former excels that of the latter markedly about 80%. Fly ash has a particle size smaller than that of cement (Table 2). Thus it acts mainly as a role of filler among cement particles to make the matrix denser. As a result, unconfined compressive strength improved significantly. Apart from the fact that the specimens Q3 and Q4 present the highest magnitude in terms of unconfined compressive strength and indirect tensile strength, fly ash's primary role was also observed in the former's strength enhancement compared to the latter (Table 4).

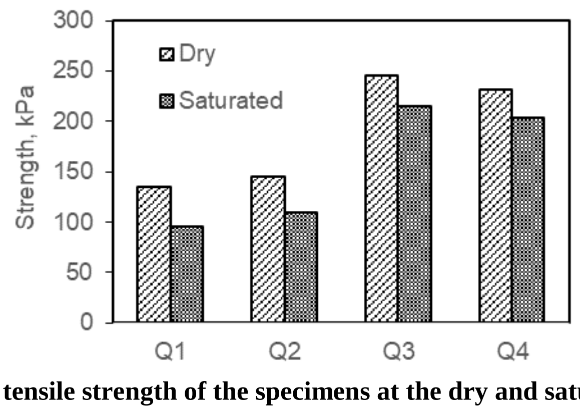

Fig. 6 - Indirect tensile strength of the specimens at the dry and saturated condition

The use of the modifying agent in the specimens Q3 and Q4 has improved unconfined compressive strength and indirect tensile strength noticeably compared with the specimens Q1 and Q2, as shown in Figure 6 and Figure 7, as well as water stability as mentioned before (Figure 5). The reason is that the agent changes the physical properties of the expansive soil. The soil then turns into solid particles of higher stiffness than normal particles and can bind tightly to inorganic binder like cement to form a solid, block structure and stable in water (Onyejekwe and Ghataora, 2015; TS Polymer).

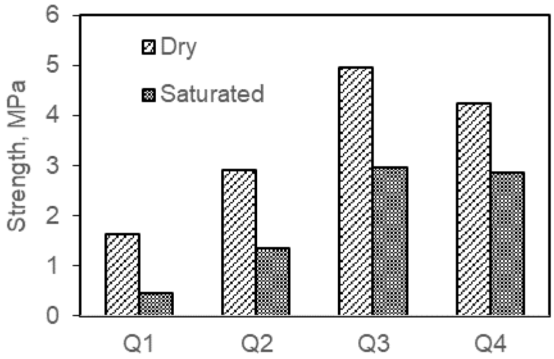

Fig. 7 - Unconfined compressive strength of the specimens at the dry and saturated condition

Although the use of fly ash in specimens Q2 and Q3 outperformed the corresponding cases without this stabilizer (Figure 6 and Figure 7), it needs to bear in mind the high amount of sulfur in fly ash (Table 1), which in turn ettringite-based sulfate heaving might be exhibited (Mitchell, 1993). This is a crystalline mineral that can be highly expansive when it comes in contact with water which in turn may cause damage to the overlying pavement structure (Rivera et al., 2020). Therefore, the use of this type of fly ash for expansive soil stabilization should be taken under control or limited.

4. Conclusion

The experimental study on the expansive soil stabilization was carried out in this study by conducting the mockup test on the rural road. A one-kilometer road was divided into four parts, and each one was subjected to different stabilization tests. The specimens from every quarter were denominated as Q1 (soil + cement), Q2 (soil + cement + fly ash), Q3 (soil + cement + fly ash + modifying agent) and Q4 (soil + cement + modifying agent). Several conclusions can be withdrawn as follows:

- The experimental assessment test showed that specimen Q1 from the first quarter stabilized by cement yielded the highest water absorption percentage after 24 hours and 72 hours of soaking. The longer the soaking time, the more water diffusion occurred at specimens Q1 and Q2 rather than at specimens Q3 and Q4. Thus, the use of modifying agent significantly improved the water stability of stabilized soil.
- Regarding the experimental results of unconfined compressive strength and indirect tensile strength of the specimens at dry and saturated conditions, the specimens Q1 and Q3 yielded the lowest and highest strength, respectively. The use of the modifying agent in the specimens Q3 and Q4 has improved noticeably unconfined compressive strength and indirect tensile strength compared to the specimens Q1 and Q2. The use of fly ash in specimens Q2 and Q3 outperformed the corresponding cases without this stabilizer. However, it needs to consider that ettringite-based sulfate heaving might be exhibited, subsequently resulting in damage to the overlying pavement structure in the long term. Therefore, to improve the expansive soil stabilization by using a modifying agent, it is recommended to use the constituent materials in the specimen Q4 rather than the Q3.

Future work should consider the long-term study of the use of the modifying agent for expansive soil stabilization to perceive the durability of stabilized soil for road construction. Besides, the adjustment of the modifying agent content could be taken into account to achieve the suitable soil properties in a economical manner.

Acknowledgment

Special thank is given to colleagues at Industrial University of Ho Chi Minh City, Vietnam for the interest and invaluable contributions to the paper.

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