Using Natural Pozzolan, Cement and Lime for Stabilizing Soil in Earth Dams

Huu Nam Nguyen, Van Quan Tran, Anh Quan Ngo, Quang Hung Nguyen

Abstract: The paper has focused on studying the ability of using natural pozzolan to combine lime and cement in process of stabilized soil, implementing experimental contents for on-site soil including: grain composition, plastic limit, plasticity index, mineral parts and other common mechanical properties, standard compaction. Followed by experiments for soil, cement and pozzolan stabilized soil mixtures, including standard compaction, compressive strength. A suitable model of physical experiments to simulate and prove lime, cement and pozzolan stabilized soil meets the criteria for making waterproofing materials for earth dams in the Central Highlands

Keywords* : *Stabilized soil, natural pozzolan, lime, cement.

I. INTRODUCTION

Most of the dams that have been built in Vietnam are earth dams that account for 90%, dams are filled with local materials, so they are vulnerable. Permeability occurs very commonly in earth dams, resulting in reservoir dehydration. When large seepage treatment is difficult and causes great economic losses. The seepage incident is shown in a variety of ways. Unstable due to permeability accounts for nearly 45%, often expressed in the following aspects: smuggling downstream dam roof; seepage flow at the contiguous surfaces between dam body and concrete structures such as overflow and sewer intake; animal cave, termite nest in the dam body; or cracks in earth dams due to deflection, etc.

Materials for basaltic material originating from young basalt belong to the unfavorable group when used as embankment material, due to their special properties such as low dry weight, high moisture content, natural moisture in the dry season. It is low in construction so it is necessary to irrigate with more water, high dust content is difficult to compact, these properties lead to difficult to control during construction, so the soil is disintegrated and wet so the reservoir operates. potential risks of many problems. In fact, basaltic embankments occupy a very large proportion of about 56%, these dams have been constructed long ago, technology and techniques of construction have not yet developed so most of these dams are being absorbed and lost. country.

Currently, there are a lot of waterproofing and permeability control solutions for small and medium earth dams such as drilling, soil piles, geomembranes, bentonite - cement trench walls, downstream pressure embankment, collection ditches. dam body, etc. In order to ensure economy, take advantage of local materials, research on stabilizing on-site soil with adhesives to improve materials of embankment soil as well as waterproofing materials Earth dams are essential.

Although natural pozzolan has been used a lot in mass concrete, roller compacted concrete, pavement concrete and adobe brick production. But there is no published scientific study on the use of natural pozzolan to strengthen weak soil, or mix with local soil to make waterproofing material for earth dam body. Based on scientific stabilized of soil with inorganic binders, natural pozzolan can replace a part of cement to build concrete works and mix with soil in place in combination with some adhesives such as lime to increase the strength and waterproofing ability of the soil. Therefore, the solution to use natural pozzolan materials to serve the repair of small and medium earth dams in the Central Highlands is a positive solution to overcome the above situation. This solution is judged to be superior because the Central Highlands has a very large amount of natural pozzolan minerals in all provinces. If the successful application of pozzolan solution to replace cement in making adhesives in stabilizing soil will bring great economic value in construction in general and in upgrading and repairing medium earth dams and small in particular.

The paper has focused on studying the ability of using natural pozzolan to combine lime, cement in stabilizing soil, implementing experimental contents for on-site soil including: grain composition, plastic limit, plasticity index, mineral parts and other common mechanical properties, standard compaction. Followed by experiments for soil, cement and pozzolan stabilized soil mixtures, including standard compaction, compressive strength. A suitable model of physical experiments to simulate and prove lime, cement and pozzolan stabilized soil meets the criteria for making waterproofing materials for earth dams in the Central Highlands

II. EXPERIMENTAL STUDY IN ROOM TO DETERMINE THE STRENGTH OF POZZOLAN STABILIZED SOIL

A. Experimental design

1) Cement content selection

The ratio of cement used to reinforce soil depends mainly on soil group (soil classification). According to US military documents [1] classifying soil according to M 145 AASHTO standards and Porlan Cement Asscociation [2], the minimum amount of cement required for stabilizing soil is shown in

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Table 3 1 (Table I, PCA, 1992). In this table, the amount of cement is calculated as a percentage of the amount of stabilized soil. From the results of the study in the room, the soil in the study area belongs to group A-7 (AASHTO) or MH group (USCS), the cement content requires 10-16%.

Table- I: Cement content required for stabilizing soil

N°	Soil group Classification by AASHTO	Ratio of cement (%) according to the volume of soil	Ratio of cement (%) according to the volume of compacted soil	Weight of cement (kg) for 1 unit of compacted soil volume
1	A-1-a	3-5	5-7	80-110
2	A-1-b	5-8	7-8	110-130
3	A-2-4 A-2-5 A-2-6 A-2-7	5-9	7-9	110-140
4	A-3	7-11	8-11	130-180
5	A-4	7-12	8-11	130-180
6	A-5	8-13	8-11	130-180
7	A-6	9-15	9-13	140-210
8	A-7	10-16	9-13	140-210

US Army (1987) [1] recommends the selection of cement content based on soil type classified according to USCS standards, as shown in Table II.

Table- II: Cement content required for stabilizing soil

N°	Soil classification	Estimated cement content (%) by weight of dry soil
1	GW-SW	5
2	SP, SW-SM, SW-SC, SW-GM, SW-GC	6
3	GM, SM, GC, SP-SM, SP-SC, GP-GM,GP-GC,SM-SC, FM-GC	7
4	SP, CL, ML, ML-CL	10
5	MH, OH	11
6	CH	10

Research results of the independent State-level project "Researching appropriate technology for rural road construction" code DTĐL-2012-T / 15, Assoc.Prof.Dr. Nguyen Huu Tri is the chairman, pointed out that the 28-day compressive strength of saturated state of 6% to 8% cement basalt reaches from 0.54 Mpa to 0.80 Mpa; The compressive strength of 28 days of saturated state of basalt soils is 6% to 8% of cement and 20% of macadam is from 0.7 Mpa to 0.82 Mpa. The surface of the pavement consists of basalt soil layer reinforced with 20% macadam and 6% to 8% cement, then staked with macadam to meet the requirements of rural roads with low traffic volume as level A in 22TCN 210-92 , or categories B and C in TCVN 31080-2014. Reasonable cement content in stabilized is: 6-8% [3].

Thus, the soil in the study area of Group A-7-5 according to the results inside and outside the country, the amount of cement needed to use is 6-16%.

2) Lime content selection

Summarizing the method of designing lime stabilized soil by National Lime Association [2], the amount of lime selected depends on the grain composition and the plastic number is shown in Figure 1. Recommended lime content (Coach) to reinforce coarse-grained soil based on the total dust and clay content (BS) as follows: Coaches 2, 3, to 5% if BS is less than 50%; Coach from 5, 7, to 10% if BS is greater than 50%.

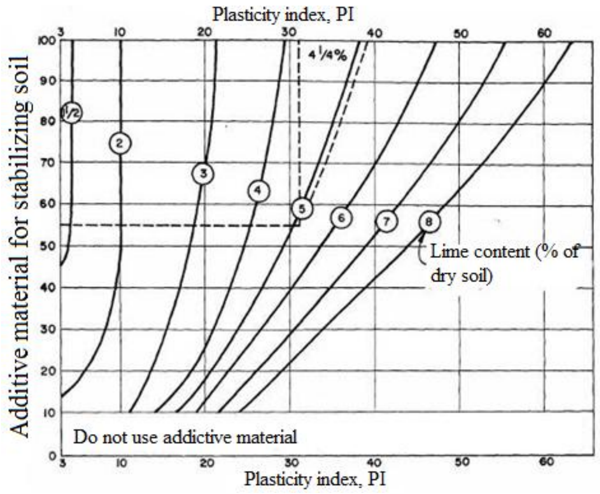

Fig. 1.Selection of lime for stabilizing soil

Based on the content of clay dust particles and the plastic index of the soil in the study area, the lime content needed to reinforce soil in the test area is 4-8%.

3) Natural pozzolan content selection

According to research by Nader Abbasi (2018) [1], when studying for silt sand soil in Jandagh region - Garmar, Iran, the author studied mixing 4 levels of Pozzolan (0, 5, 10 and 15%) with 4 lime ratios (0, 1, 3, 5 and 7%). Results of compressive resistance intensity at 14 days naturally showed that the sample achieved the highest compressive resistance intensity when the ratio of pozzolan / lime was 3-5 times. Khelifa Harichane and Mohamed Ghrici (2011) [4] when studying on highly flexible soil in the town of Chlef north Algeria, with 3 ratio of pozzolan (0, 10, 20%) combined with 3 lime content (0, 4, 8%), results of compressive resistance intensity at 28 days showed that when puzoln ratio on lime reached 2.5 for maximum compressive strength. Fanghai Yang (2002) [6], Research results using fly ash (FA) showed that FA content of 10-20%, the amount of lime needed is 3-5-7%. Thus, the FA / lime ratio is 3 times. Recommendation of the American Army Association (US Army Corps of Engineers manual EM1110-03-137 and TM 5-822-14) [1], when using fly ash combined with lime, the intensity is not satisfactory 1% of cement, if the strength does not meet the requirements, increase the cement content gradually until it reaches the desired intensity. The total added material should not exceed 15% in the dry content of the soil.

The quality of natural pozzolan in the study area has quite good minerals, the lime absorption of pozzolan reaches the average activity. Therefore, when using natural pozzolan to reinforce the outer soil directly combined with lime, additional cement is needed. To assess the effect of pozzolan binders in combination with the maximum use of pozzolan content in soil reinforcement, the natural content of pozzolan was 0, 5, 10, 15 and 20%.

4) Mix design

The goal is to reasonably use natural sources of pozzolan to reinforce the soil, reducing the content of cement and lime. The content of selected binders is as follows: Natural Pozzolan: 0, 5, 10, 15, 20%; Lime: 0, 4, 8%; Cement: 0, 3, 5, 10, 12%. Summary of experimental mixtures is shown in Table III.

Table- III: Summary table of experimental mixtures

N°	Mix designs		
1	P0C0L0	P0C0L4	P0C0L8
2	P0C3L0	P0C3L4	P0C3L8
3	P0C5L0	P0C5L4	P0C5L8
4	P0C10L0	P0C10L4	P0C10L8
5	P0C12L0	P0C12L4	P0C12L8
6	P5C0L0	P5C0L4	P5C0L8
7	P5C3L0	P5C3L4	P5C3L8
8	P5C5L0	P5C5L4	P5C5L8
9	P5C10L0	P5C10L4	P5C10L8
10	P5C12L0	P5C12L4	P5C12L8
11	P10C0L0	P10C0L4	P10C0L8
12	P10C3L0	P10C3L4	P10C3L8
13	P10C5L0	P10C5L4	P10C5L8
14	P10C10L0	P10C10L4	P10C10L8
15	P10C12L0	P10C12L4	P10C12L8
16	P15C0L0	P15C0L4	P15C0L8
17	P15C3L0	P15C3L4	P15C3L8
18	P15C5L0	P15C5L4	P15C5L8
19	P15C10L0	P15C10L4	P15C10L8
20	P15C12L0	P15C12L4	P15C12L8
21	P20C0L0	P20C0L4	P20C0L8
22	P20C3L0	P20C3L4	P20C3L8
23	P20C5L0	P20C5L4	P20C5L8
24	P20C10L0	P20C10L4	P20C10L8
25	P20C12L0	P20C12L4	P20C12L8

P: pozzolan, C: cement, L : lime ; PxCyLz : x, y, z % content of additive material

To minimize the volume of experiments, the research content focus on test the compressive strength Rn at 14 days (saturated state) to find out the proper aggregation from the combination according to TCVN 8858: 2011 [5]: Soil × 05 pozzolan × 05 content cement content × 03 lime content. In it, there is a lime content = 0% and a cement content = 0%. It is expected to find a reasonable combination of soil, pozzolan, cement and lime.

B. Result and discussions

1) Standards compaction

Standard compaction tests determine the largest dry volume and best moisture content of the soil mix with 18 different mix designs (PCL), according to standard 22TCN333-06: Soil and rock compacting process Laboratory.

Table- IV: Results of compaction of P-L-C reinforced mixture with different contents

N°	Mix designs	OMC (%)	MDD (Mpa)	N°	Mix designs	OMC (%)	MDD (Mpa)
1	P10C0L0	24,5	1,60	10	P0C10L0	25,0	1,59
2	P10C0L4	27,0	1,55	11	P15C0L0	24,0	1,63
3	P10C0L8	29,0	1,51	12	P15C0L4	26,0	1,57
4	P10C3L0	25,5	1,63	13	P15C0L8	28,0	1,55
5	P10C3L4	28,0	1,54	14	P15C3L0	24,5	1,64
6	P10C3L8	28,5	1,53	15	P15C3L4	26,5	1,58
7	P10C10L0	23,5	1,65	16	P15C3L8	27,5	1,56
8	P0C3L4	28,5	1,50	17	P20C0L0	22,5	1,66
9	P0C0L8	30,5	1,48	18	P20C3L4	25,0	1,59

OMC: Optimum moisture content

Limestone soils have reduced dry volume and optimum moisture content compared to natural soil. This is because lime has a lighter density (20.7 kN/m^3) than soil (27.8 kN/m^3) and lime water absorption is higher than soil;

Cement stabilized soil has the largest volume of dry volume increased and the optimum moisture content decreased compared to un-reinforced natural soil. Because cement has a specific density (31.8 kN/m^3), heavier than soil and the ability to absorb cement water is no bigger than soil;

The resulting cement mixture with lime showed that the cement-lime stabilized soil mixture with the largest dry volume volume reduced and the optimum moisture content increased compared to the non-reinforced case. This shows the apparent effect of lime on the best dry and moisture volume of the mixture;

Pozzolan stabilized soil with the largest dry mass volume increased, the best moisture content decreased, because of the density of pozzolan (28.5 kN/m^3) greater than the soil and water absorption capacity of pozzolan. not tall;

Soil added with mixed pozzolan and cement increases the dry volume and reduces the best moisture content of the mixture compared to non-stabilized soil;

The pozzolan - lime mixture when stabilized soilfor maximum dry volume increases and the best moisture content is smaller than in the case of non-stabilized soil. The more lime content, the lower the volume of dry volume, whereas the more pozzolan content, the higher the volume of dry volume. This is because the density of pozzolan is much larger than that of lime;

When stabilizing the soil with pozzolanic mixture + cement + lime, the maximum dry volume of the mixture is smaller than that of the unopened soil while the optimum moisture content increases. The lime content increases, resulting in a reduced volume of dry matter, the best moisture content increases and vice versa when the pozzolan content increases, the volume of dry volume increases and the best moisture decreases.

2) Compressive strength at 14 days of age

Testing the 14-day-old compressive strength according to ASTM D1633 - Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders. Experimental results are shown in Table V to Table VII.

Table-V: Results of compressive resistance strength of P-C-L reinforcement mixture, lime content 0%

N°	Mix design	R_n, Mpa	N°	Mix design	R_n, Mpa
1	P0C0L0	0,00	14	P10C10L0	0,86
2	P0C3L0	0,70	15	P10C12L0	0,97
3	P0C5L0	0,78	16	P15C0L0	0,00
4	P0C10L0	1,21	17	P15C3L0	0,59
5	P0C12L0	1,35	18	P15C5L0	0,64
6	P5C0L0	0,00	19	P15C10L0	0,74
7	P5C3L0	0,68	20	P15C12L0	0,81
8	P5C5L0	0,73	21	P20C0L0	0,00
9	P5C10L0	1,05	22	P20C3L0	0,57
10	P5C12L0	1,18	23	P20C5L0	0,61
11	P10C0L0	0,00	24	P20C10L0	0,69
12	P10C3L0	0,65	25	P20C12L0	0,79
13	P10C5L0	0,69			

Table-VI: Results of compressive resistance strength of P-C-L reinforcement mixture, lime content 4%

N°	Mix design	R_n, Mpa	N°	Mix design	R_n, Mpa
1	P0C0L4	0,56	14	P10C10L4	2,01
2	P0C3L4	0,77	15	P10C12L4	2,28
3	P0C5L4	0,91	16	P15C0L4	0,77
4	P0C10L4	1,31	17	P15C3L4	1,13
5	P0C12L4	1,47	18	P15C5L4	1,55
6	P5C0L4	0,63	19	P15C10L4	1,84
7	P5C3L4	0,94	20	P15C12L4	1,99
8	P5C5L4	1,38	21	P20C0L4	0,72
9	P5C10L4	1,62	22	P20C3L4	1,02
10	P5C12L4	1,89	23	P20C5L4	1,38
11	P10C0L4	0,81	24	P20C10L4	1,54
12	P10C3L4	1,21	25	P20C12L4	1,79
13	P10C5L4	1,73			

Table-VII: Results of compressive resistance strength of P-C-L reinforcement mixture, lime content 8%

N°	Mix design	R_n, Mpa	N°	Mix design	R_n, Mpa
1	P0C0L8	0,63	14	P10C5L8	1,87
2	P0C3L8	0,71	15	P10C10L8	2,12
3	P0C5L8	0,86	16	P10C12L8	0,96
4	P0C10L8	1,26	17	P15C0L8	1,26
5	P0C12L8	1,44	18	P15C3L8	1,83
6	P5C0L8	0,69	19	P15C5L8	2,06
7	P5C3L8	0,89	20	P15C10L8	2,38
8	P5C5L8	1,30	21	P15C12L8	1,18
9	P5C10L8	1,57	22	P20C0L8	1,58
10	P5C12L8	1,85	23	P20C3L8	2,21
11	P10C0L8	0,88	24	P20C5L8	2,48
12	P10C3L8	1,13	25	P20C10L8	2,82
13	P10C5L8	1,66			

Effect of additive materials (pozzolan, cement and lime) on compressive strength of stabilized soil, at 14 days of age, saturation state shown in Figure 2 to Figure 4

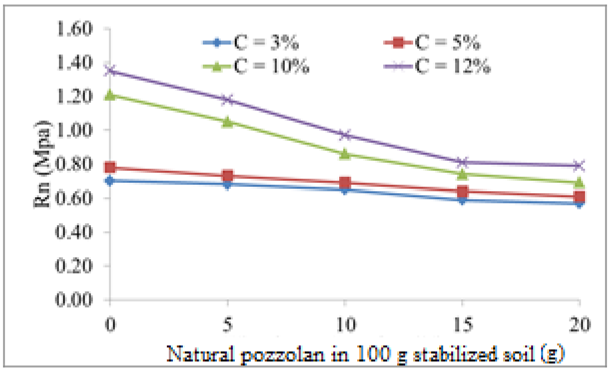

Fig. 2.Compressive strenth of stabilized soil with 0% lime content

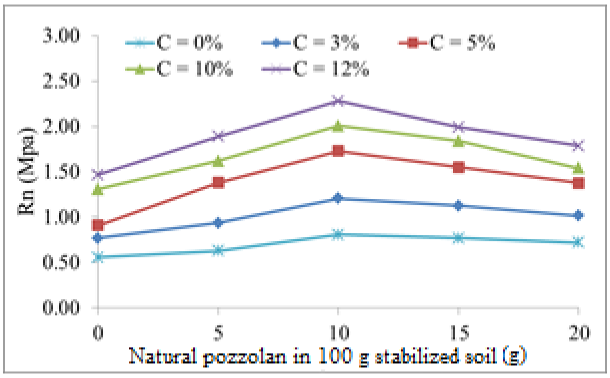

Fig. 3.Compressive strenth of stabilized soil with 4% lime content

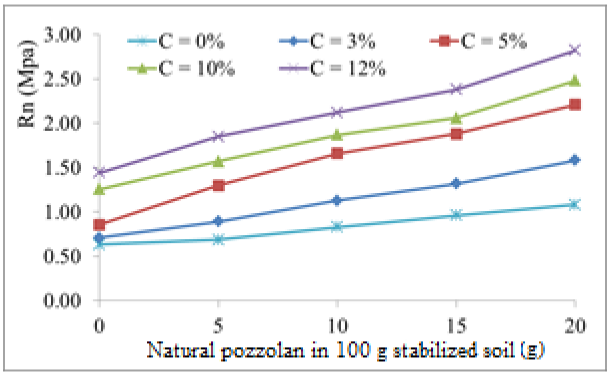

Fig. 4.Compressive strenth of stabilized soil with 8% lime content

(1) Effect of lime on compressive resistance strength of stabilized soil. The lime stabilized soil has a compressive resistance intensity that increases proportionately with the lime content. The post-stabilized soil is no longer disintegrated; The compressive resistance intensity of stabilized soil 8% lime (Rn = 0.63 Mpa) increased by 12.5% compared to the case of stabilizing 4% lime (Rn = 0.56 Mpa). However, the compressive resistance intensity is less than the required intensity [Rn] = 1.5 Mpa [5], so only lime reinforcement is ineffective.

(2) Effect of cement on the mechanical properties of stabilized soil

Soil in the study area when supplemented from 3-12% of cement, the compressive resistance strength of stabilized soil samples increases linearly with cement content. Soil after stabilizing cement, limiting soil disintegration. The compressive resistance strength of soil reinforced 12% cement Rn = 1.35 Mpa <[Rn] = 1.5 Mpa, so only reinforced with lime is not effective.

(3) Effect of cement - lime on mechanical properties of stabilized soil

At the same lime content, the compressive resistance strength of the soil sample increases with the ratio of cement. In the area of stabilizing soil from 3-12% cement: The compressive strength of the mixture when stabilizing 4% lime is higher than the reinforcement with 8% lime. When soil is added with lime, lime has the effect of improving the pH of the soil environment to facilitate the hydration process of cement. However, when the lime content exceeds a permissible value, excess lime will reduce cement hydration. The compressive resistance strength of soil reinforced 12% cement, lime 4% Rn = 1.47 Mpa <[Rn] = 1.5 Mpa, so reinforced with cement and lime ineffective.

(4) Effect of pozzolan on mechanical properties of stabilized soil. Samples of soil preparation with Pozzolan when immersed in water were almost completely disintegrated, the compressive resistance strength was not determined, proving that, in the soil does not contain mineral and chemical components to create pozzolanic reaction with natural pozzolan. Want to reinforce soil with natural pozzolan effectively, lime or cement is required.

(5) Effects of pozzolan - cement on the mechanical properties of stabilized soil. The compressive resistance strength of pozzolan stabilized soil and cement increased in proportion to the cement content. With the same cement content, the compressive resistance strength of the sample decreases as the pozzolan ratio increases. During the hydration process of cement, the amount of Ca (OH) 2 produced partly reacts with natural pozzolan, causing the hydration process of cement to be hindered, or not to continue hydration. The compressive resistance intensity of the mixture is greatest when the content of cement is 12%, Rn = 1.18 Mpa <[Rn] = 1.5 Mpa, so reinforced with cement, pozzolan is not effective.

(6) Effect of pozzolan - lime on the mechanical properties of stabilized soil. In case of lime 4%: The compressive resistance intensity of the reinforcement mixture reaches the maximum value when pozzolan is 10%. When the pozzolan content is increased, the reduction intensity is inversely proportional to the amount of pozzolan given. In case of 8% lime: The compressive strength increases in proportion to the content of pozzolan, reaching the maximum value at 20% pozzolan.

(7) Effects of pozzolan - cement - lime on the physical properties of stabilized soil. In case of 4% lime: For each pozzolan content, the sample intensity increases linearly with cement content; Within the range of 0-10% pozzolan, the strength of the stabilized soil increases linearly with the inclusion rate of Pozzolan and reaches the peak value at 10% pozzolan; Within a range of 10-20%, the compressive resistance intensity of the reducing mixture is inversely proportional to the pozzolan content; Some 5-15% pozzolan reinforcement content, 5-12% cement content gives Rn compressive resistance strength value> 1.5 Mpa, reinforced with this ratio is effective. Case of 8% lime: The strength of stabilized soil samples is proportional to the content of pozzolan and cement and reaches the maximum value when the content of pozzolan is 20%; Intensity increases strongly when the ratio of cement 5-12%; Compressive strength of stabilized soil 5-12% of cement with pozzolan 5-20%> [Rn] = 1.5 MPa (TCVN 8858: 2011), reinforced with this ratio is effective.

From the results of compaction experiment and the strength of soil compression resistance inorganic adhesives (pozzolan, cement, lime) can give some conclusions for basalt soil in the study area as follows:

-Want to use natural pozzolan as a binder for stabilized soil must incorporate lime.

- Soil consolidation with adhesives such as lime, cement, pozzolan - lime, pozzolan - cement, lime - cement are resistant to breakdown properties when meeting water;

-When stabilizing 8% lime, or 12% cement is not effective.

-The stabilized soil has the highest intensity when mixing ratio of pozzolan and lime is 2.5

III. CONCLUSION

From the results of analyzing compaction experiments and the compressive strength of stabilized soil using additive materials: pozzolan, cement, lime), it is possible to draw some conclusions for basalt soil in the study area as follows:

- Using natural pozzolan as a binder for stabilizing soil must incorporate lime.
- Mixtures of stabilized soil with adhesives such as lime, cement, pozzolan - lime, pozzolan - cement, lime - cement resist disintegration properties in water.
- Using 8% lime, or 12% cement to stabilize soil is not effective.
- The reinforced soil mixture has the highest compressive strength when mixing ratio between pozzolan and lime is 2.5

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