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DISPERSIVE CLAY STABILISED BY ALUM AND LIME

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ABSTRACT: Dispersion phenomenon can cause erosion problems during hydraulic construction projects such as earth dams, channels, hydraulic installations and embankments. However, aluminum sulfate can be used to stabilize dispersive clay. Tests were done to consider the effects of alum and lime additions on shear strength parameters of clay as secondary effects. Clay for samples was taken from the Mirzakhanluo Dam, located in Tarom County, northwestern Zanjan Province of Iran. In this research, the clay sample was subjected to direct shear testing; the clay was tested with optimum moisture under varying percentages of alum (0, 0.3, 0.6, 1, 3, and 5 as percentage of dry soil weight) for 28 days. Also, unconfined tests were conducted on samples with equal amounts of moisture, alum and lime under the different treatment durations of 7, 14, and 21 and 28 days, separately. Results for the direct shear test indicated that the maximum cohesion was recorded in the sample with 1% alum. Results also showed that the internal friction angle decreased in samples with alum percentage up to the level of 0.6% and at levels higher than that it showed an increase. Generally, results showed that soil shear strength was higher in soil stabilized by alum than in unstabilized soil. Results of the uniaxial test, determined that alum and lime additions to dispersive soil and its treatment, compression strength was not limited and elastic modulus showed an increase. The highest evaluations were determined for amounts of elastic modulus and uniaxial strength in soil with 3% lime or 5% alum on the 28th day of treatment.

Keywords: *Dispersive Clay, Alum, Lime, Unconfined Compression Test, Direct Shear Test*

1. INTRODUCTION

Type of soil is an important consideration in selection for resources. A lack of understanding of soil type has caused many problems in hydraulic construction projects and in some cases destruction like shrink-swell can occur. Clay soil in many parts of the world can contain plate-like minerals that contribute to shrink-swell characteristics. Dispersion is another common phenomenon in some types of soil [1].

Soil in which its mineral content is dispersed when in contact with water is called dispersive clay. This type of clay soil is easily eroded and will flow under conditions of low-level stress and low hydraulic gradient [2]. Clay usually contains calcium, potassium and manganese; dispersive clay contains sodium [3].

Dispersion in clay occurs through complicated chemical and physical mechanisms and is related to the absorption quality of its particular mineral structure and ion exchange capacity [3]. Contact with water activates these mechanisms that cause the minerals in dispersive clay to become suspended [4]. This dispersion phenomenon can cause piping in earth dams, erosion and destruction of roads and water channels and destruction of foundations [3].

Aluminum sulfate, known as alum or white alum, is an important aluminum compound. Aluminum sulfate is used in water purification and as a mordant in dyeing and textile printing. In water purification, it causes impurities to coagulate into larger particles and then to settle at the bottom of a container (or be filtered out) more easily.

According to previous studies, white alum has higher solubility in water than lime and lower cost while being mixed with soil in order to reduce dispersion and is less harmful than lime on contact with human skin. However, using this material has certain disadvantages including high cost, high acidity and CO2 that causes problems associated with plant growth and corrosion [1].

Studies have reported use of aluminum sulfate in a dam project for stabilizing part of an embankment in a 152m channel near Sabradinho City in Brazil [5]. In Iran, the effect of aluminum sulfate was evaluated in terms of dispersive rate in the Gotvand Dam project [6]. According to these above-mentioned investigations, addition of 0.6 % aluminum sulfate changes soil to a non-dispersive state [7]. Also, Jafari reports that addition of 3%

alum to dispersive soil, which was tested in this research, made the soil completely non-dispersive [8]. Mohammadi et al. reports that by adding about 1% alum to dispersive clay, dispersion is decreased and consolidation and swelling is improved [8].

In this research, white natural alum (AL2 (SO4)3.18H2O) and lime (or calcium hydroxide (Ca (OH) 2)) were mixed with dispersive clay. Effectiveness of the mentioned materials was determined as follows: firstly, by replacing aluminum trivalent cation (AL3+) and calcium bivalent cation (Ca2+) with sodium monovalent cation (Na+), the soil structure changed from disperse to clod, the ejection force between the granules decreased and double layer thickness decreased; finally, with increased cohesive force, there was a decrease in dispersive potential in samples, the granules got closer together and the swelling showed a remarkable decrease [9].

2. MATERIALS USED AND THE TESTING PROGRAM

The dispersive clay used in this study was from clay deposits of the 2nd Mirzakhanlou Dam, located 16 km distance from Darram area in Zanjan. According to test results and different standards of evaluating dispersive soil, this soil was ranked as highly dispersive and erosive (Tables 1 and 2) [8].

Table 1 Properties of the used dispersive clay [7]

Classification based on pinhole test	Classification based on double hydrometric test	Percentage of dispersiveniss by double hydrometric test
D_1: Totally dispersive	Totally dispersive	59.20

Table 2 Chemical specifications of the used dispersive clay [7]

PH	Na^+ $\frac{meq}{lit}$	K^+ $\frac{meq}{lit}$	Ca^{2+} $\frac{meq}{lit}$	Mg^{2+} $\frac{meq}{lit}$	EC	TDS %	CL+	SO42-
7.2	174.3	9	34.8	13.9	96	0.6	10.22	38.9

The results of hydrometric and aggregation tests (single and double) were obtained. In Figure 1 circles with voids represent a double hydrometric and filled circles represent a single hydrometric. The double hydrometer test is a good example of misinterpretation due to ambiguity. Despite the test being an ASTM standard, many laboratories simply duplicate the standard hydrometer analysis procedure (ASTM), which invariably produces incorrect results. Variability of the results obtained from the double hydrometer test appears to be the cause of much ambiguity and discrepancy in the classification systems used during this research. Problems relating to the double hydrometer tests have the potential to mislead results since the test is associated with a number of different parameters in the rating systems. Inaccurate results from the double hydrometer test can significantly affect the correlation of the final rating, particularly when this test method is used as the reference method for preliminary classification of soil dispersion. In order to resolve these problems, a mixture of single and double hydrometric results were used.

Table 3 shows percentages of granule passing and ASTM standard soil ranking. Figure 2 indicates that clay in the unified ranking system was the plastic type (CH) [10].

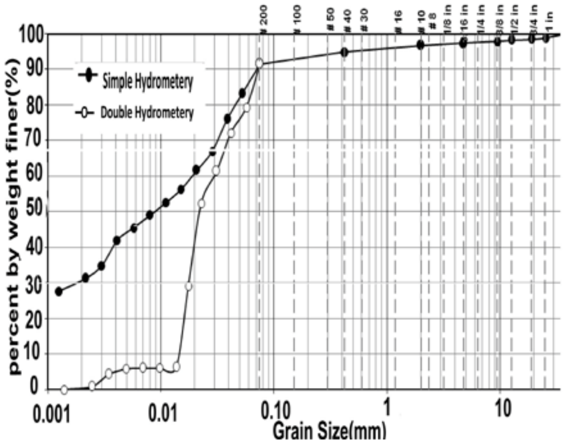

Fig. 1 Particle size distribution by simple and double hydrometric methods [6, 11]

Table 3The results of used soils granular [7, 12]

AASHTO Class	Gs	Pas 0.005 double hydrometric	Pas 0.005 simple hydrometric	D60 mm	D30 mm	D10 mm
A-7-5	2.76	5.92	43.96	0.019	0.20	-

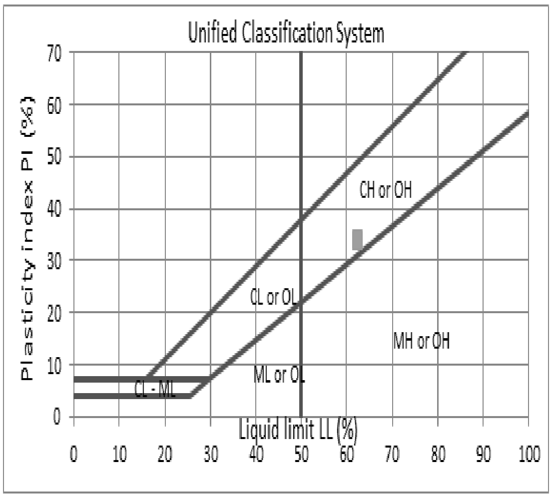

Fig. *2* Soil classification [7, 10]

The step to produce and treat samples was to apply the density test through application of the proctor compaction test on natural soil (Table 4). Tests were done of percentages of alum mixed with soil and duration of the treatment period (28 days). Dispersive tests showed that after 21 days, the dispersive soil mixed with aluminum sulfate was completely stabilized and that an increased treatment duration had no further effect on stabilization.

Table 4 Variations of the optimum moisture content and maximum dry density [7, 13]

Percentage of added alum as percentage of soil dry weight	0	0.3	0.6	1	3	5
Percentage of the Optimum Moisture	30.4	28.1	27.7	27.3	28.4	27.9
Maximum Dry Density Of the Soil Gr/cm^3	1.45	1.54	1.533	1.55	1.53	1.52

3. RESULTS OF DIRECT SHEAR TEST

Direct shear testing was done according to ASTM D3080 standard with 1mm/min velocity by the CU method (Consolidated Undrained) [9]. Direct shear testing was first performed on dispersive clay without additives and on samples with different percentages of aluminum sulfate (0.3, 0.6, 1, 3, and 5). All samples had maximum density and optimum moisture and were treated for 28 days. After treatment, direct shear tests were done with different loads (0.5, 1, 1.5 kg/cm^2).

Results shown in Figure 3 indicate that adding aluminum sulfate increased shear strength of the soil. Variations of apparent cohesion and internal friction angle with alum content are presented in Figures 4 and 5, respectively. Figure 4 shows that cohesion increased from 0.3 to 0.5 kg/cm^2; i.e. about 67% by adding 1% alum. Further addition of alum to the dispersive clay led to a reduction in apparent cohesion. However, apparent cohesion at alum content above 1% still showed improvement compared to results for unstabilized dispersive clay. Figure 5 demonstrates that addition of alum reduced the internal friction angle from 32.5 to 27.5 degrees; however, at alum content of 5% the internal friction angle increased to 37.5 degrees. In other words, addition of alum beyond 6% increased the internal friction in clay.

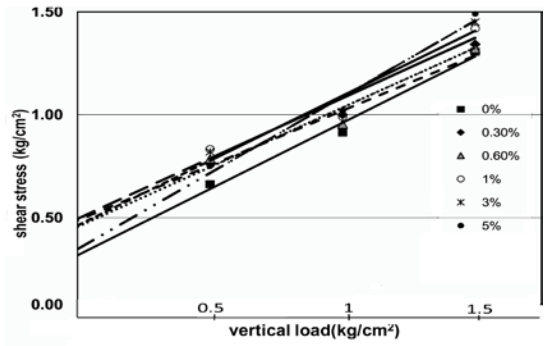

Fig. 3 Mohr – Coulomb shear failure envelope for different amounts of alum

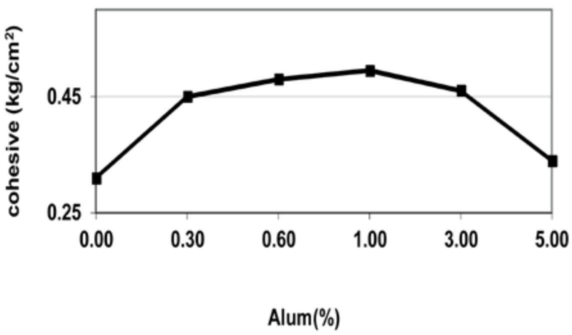

Fig. 4 Apparent cohesion for different percentages of additive

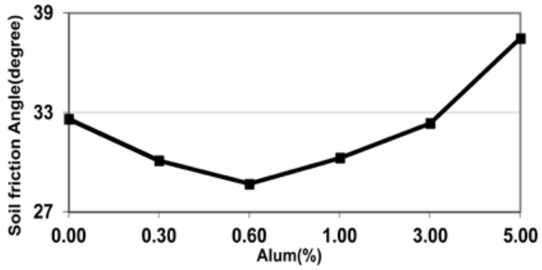

Fig. 5 International friction angle versus amount of alum

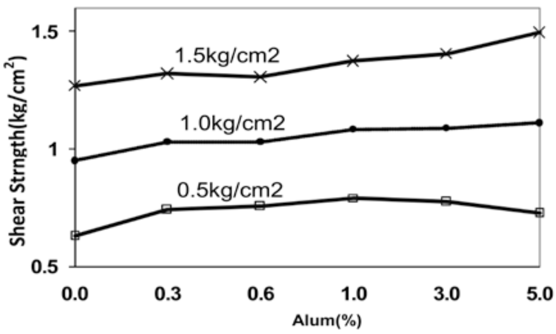

Fig. 6 Shear strength variations versus amount of alum

4. UNCONFINED COMPRESSION TEST

The uniaxial compression test is a special kind of triaxial shear test. This test can be described as an unconsolidated and undrained triaxial test without comprehensive stress it is used to define Cu cohesion in clay according to Eq. (1) below [11, 12]:

$$C_u = \frac{q_u}{2} \quad (1)$$

Where $q_u$the uniaxial compression strength and Cu is is the undrained cohesion of soil.

The results and procedure of the uniaxial test were determined according to ASTM 2166.

The first step was to test dispersive clay without additives, then further tests were applied with additions of, 0.3, 0.6, 1, 3 and 5% of alum and lime was added to the soil to the soil dry weight, separately. Then, samples were produced in optimized moisture and maximum density (Table 4) and loaded on days 7, 14, 21 and 28.

4.1 Results of Unconfined Compression Tests

According to Figure 7, on the 7th day of treatment, adding alum increased the uniaxial strength, which was at its highest level at 5% alum. In soil samples with lime, the uniaxial strength increased until 1% and, after that showed a decrease until 5%. Figure 8 shows that soil with lime had 183% increase in strength and soil with alum had an increase of 87%. On the 14th day of treatment, the increasing rate of uniaxial strength still showed growth and increasing alum; 5% caused an 80% increase in strength. In soil samples with lime, the uniaxial strength increased until 1% and then it started to decrease until 5%. The maximum strength reached 190%. According to Figure 9, on the 21st day of treatment, the uniaxial strength still increased and addition of alum resulted in an increase; at 5%, the strength increase was about 103%. In soil with lime there was also an increase in strength that reached 231%[13].

According to Figure 10, the increasing amount of uniaxial strength after 28 days of treatment was twice that of the 5% alum sample. In soil with lime, the increasing rate continued until 3% and reached about 5 times as much and after that it showed a decrease until 5%.

In Figures 11 and 12, variations of the uniaxial strength versus treatment time are shown with different alum and lime percentages; results indicate increased uniaxial strength in soil stabilized with alum and lime. Aluminum has good ability for transmitting ions on the first day, so the strength of growth of alum-stabilized soil was faster at the beginning of the treatment and the growth rate decreased after the 28th day.

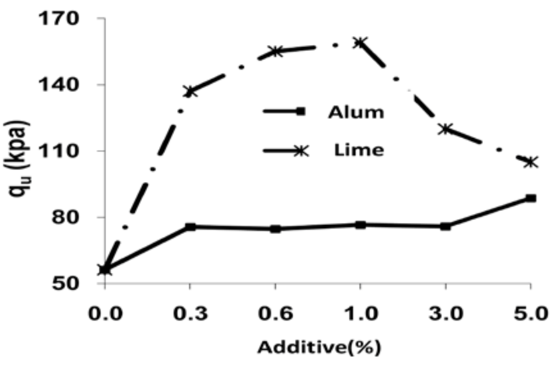

Fig. 7 Unconfined compression strength versus amount of additives (7 days' curing time)

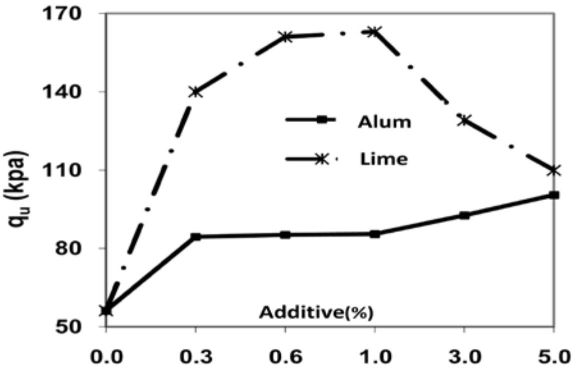

Fig. 8 Unconfined compression strength versus amount of additives (14 days' curing time)

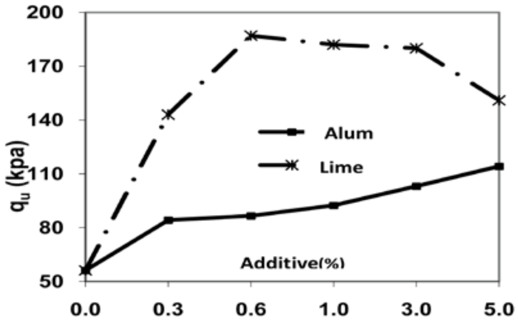

Fig. 9 Unconfined compression strength versus amount of additives (21 days' curing time)

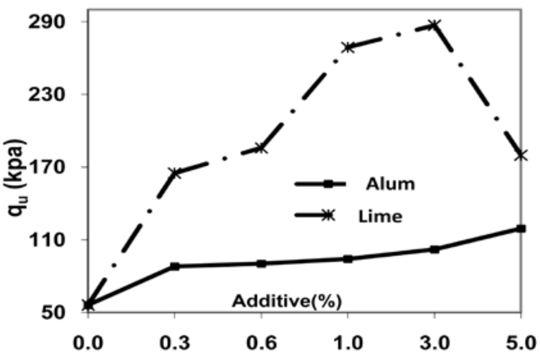

Fig. 10 Unconfined compression strength versus amount of additives (28 days' curing time)

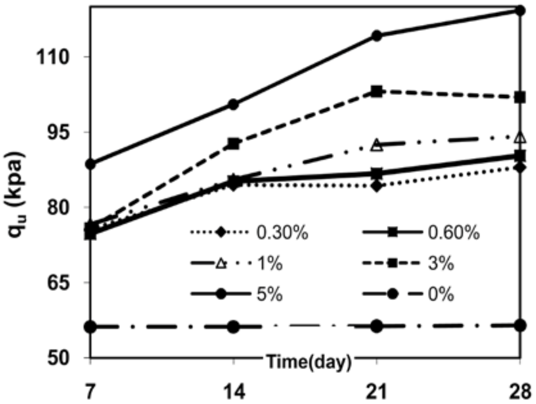

Fig. 11 Unconfined compression strength versus treatment time (day) for different amounts of alum

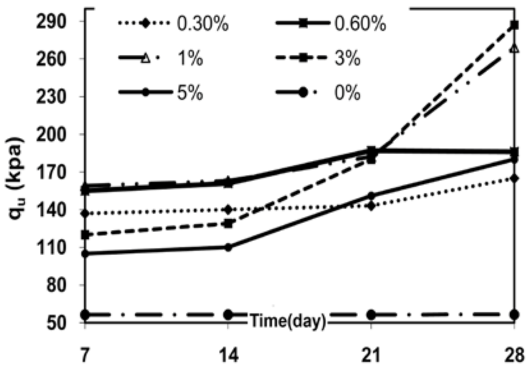

Fig. 12 Unconfined compression strength versus treatment time (day) for different amounts of lime

4.2 Comparison of the Elastic Modulus among Soil Samples

Figure 13 indicates that adding alum increased evaluations of elastic modulus, showing a %50$q_u$increase. In all diagrams, an increasing rate of elastic modulus was higher in the lime-stabilized soil than in the alum-stabilized soil [14, 15]. The highest value of elastic modulus for the alum-stablized specimens was 5% alum content with a 37% increase over the untreated clay, while the highest elastic modulus for the lime-stablized samples 409% increase over evaluations for untreated clay.

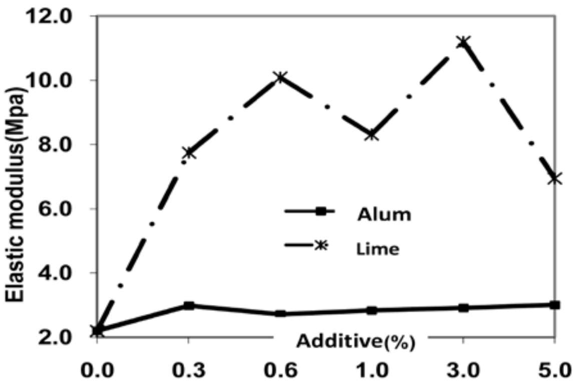

Fig. 13 Elastic modulus versus amount of additive (28 days' curing time).

5. CONCLUSION

According to studies on dispersive soil stabilized by alum and lime and using uniaxial and direct shear tests, the following conclusions were made:

1- Adding alum at different percentages both controlled soil dispersion and increased its shear strength. Adding alum caused increased shear strength of up to 50%.

2- Increasing alum content to 1% led to an increase of up to 61% in apparent cohesion of the dispersive clay. Any further increase in alum content led to a reduction in apparent cohesion.

3- Increasing alum content caused a reduction of the internal friction angle of the dispersive clay. The minimum friction angle of the dispersive clay was reduced. The minimum friction angle was observed at 0.6% alum content, after which any further increase of alum content resulted in an increased internal friction angle.

4- Under unconfined compression tests, both strength and stiffness evaluations of the dispersive clay were improved through addition of lime or alum.

5- Aluminum has high ion transmission ability on the first day so the increasing rate of the axial strength was faster in the lime modified soil and this growth rate decreased after the 28th day. For soil modified by lime, the highest amount of uniaxial compression strength was with 5% lime, which was about twice that recorded for unmodified soil.

6- The largest increase in elastic modules (of up to 5 times that of the untreated clay) was observed for the specimen with 3% lime content.

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