The effect of modern and conventional additives on compaction behavior of dispersive soils

Alireza Hosseini[1], Haniye Oftadeh Rahmati[1], Soheil Karimi[1], Farzad Saber Tanha[1]
[1] *Geotechnical Engineer, Sadjad University of Technology, Mashhad, Iran*

Farzad Daliri, PhD. P.Eng., M.ASCE [2]
[2] *Senior Geotechnical Engineer and Tailings Lead, GHD Pty Ltd., Vancouver, BC, Canada*

ABSTRACT
Dispersive soils in surface and construction materials of embankment dams can causes technical problems associated with internal erosion, piping and erosion of natural slopes. Erosion can cause damage and destruction in many hydraulic structures such as earth dams, embankments, and other infrastructures. The main factor governing the sensitivity of dispersive clays is the amount of Sodium cation dissolved in pore water relative to the number of divalent cations (Magnesium and Calcium). These soils normally have relatively high strength in the dry state; however, in wet conditions by absorbing water, they deflocculate and cause erosion with the dispersive phenomenon. The presence of dispersive clay soils at the diversion channel of a dam led to erosion and resulted in cavities and water leakage from the channel walls. The purpose of this study was to explore solutions that can reduce the sensitivity of dispersive clays to remediate erosion potential at the diversion channel and investigate the effect of additives on compaction behavior of dispersive soil. The following conventional and modern additives were used in this study: Lime, Polypropylene fibers, Magnesium chloride, Calcium chloride solutions and PVA polymer. Soil dispersion detection tests in this study included double hydrometer and pinhole tests. To eliminate erosion potential at the diversion channel and verify compactibility of the material for earthdam construction, this study investigated the effectiveness of the additives to i) reduce the dispersivity of the soil and ii) increase/decrease compactibility of the material. Standard proctor and modified proctor tests were conducted on improved soils with different additives types and quantities. The results showed that if the purpose of the treatment and stabilization is to only reduce the dispersivity of the soil, addition of 2.5% polypropylene fibers or 4% PVA or 3% - 4% Magnesium/Calcium Chloride are recommended. If the purpose is to reduce the dispersivity along with improving compactibility of the soil to be used as borrow material for earthdam construction, addition of 3% PVA is recommended.

RÉSUMÉ
Les sols dispersifs sont problématiques lorsqu'ils sont exposés à l'eau et peuvent causer des problèmes techniques et d'ingénierie dans les projets de construction. Le principal facteur régissant la sensibilité des argiles dispersives est la quantité de cation sodium dissous dans l'eau interstitielle par rapport au nombre de cations divalents (magnésium et calcium). Ces sols ont normalement une résistance relativement élevée à l'état sec ; cependant, en conditions humides en absorbant l'eau, ils défloculent et provoquent une érosion avec le phénomène dispersif. La présence de sols argileux dispersifs au niveau du canal de dérivation d'un barrage a conduit à l'érosion et a entraîné des cavités et des fuites d'eau des parois du canal. L'érosion peut endommager et détruire de nombreuses structures hydrauliques telles que les barrages en terre, les remblais et autres infrastructures. Le but de cette étude était d'explorer des solutions qui peuvent réduire la sensibilité des argiles dispersives pour remédier au potentiel d'érosion au niveau du canal de dérivation et d'étudier l'effet des additifs sur le comportement de compactage du sol dispersif. Les additifs conventionnels et modernes suivants ont été utilisés dans cette étude : chaux, fibres de polypropylène, chlorure de magnésium, solutions de chlorure de calcium et polymère PVA. Les tests de détection de la dispersion du sol dans cette étude comprenaient des tests à double hydromètre et à trou d'épingle. Pour éliminer le potentiel d'érosion au niveau du canal de dérivation et vérifier la compactibilité du matériau pour la construction du barrage en terre, cette étude a examiné l'efficacité des additifs pour i) réduire la dispersivité du sol et ii) augmenter/diminuer la compactibilité du matériau. Des tests proctor standard et proctor modifié ont été menés sur des sols améliorés avec différents types et quantités d'additifs. Les résultats ont montré que si le but du traitement et de la stabilisation est de réduire uniquement la dispersivité du sol, l'ajout de 2,5 % de fibres de polypropylène ou de 4 % de PVA ou de 3 % - 4 % de magnésium/chlorure de calcium est recommandé. Si le but est de réduire la dispersivité tout en améliorant la compactibilité du sol à utiliser comme matériau d'emprunt pour la construction de barrages en terre, l'ajout de 3% de PVA est recommandé.

1 INTRODUCTION

The presence of dispersive soils in construction projects can cause practical and engineering problems. Fine grained soils are normally used in homogeneous dams or in impervious core sections of zoned embankment dams. Existing fine-grained soils in the embankment dams or using them as construction embankment material are attributed to low strength, compressibility, and dispersive clays (Yong, 1996; ICOLD, 1990). Existence of dispersive

soils in surface and construction materials of embankment dams. Dispersive clayey soils are relatively strong in the dry state; however, when they are exposed to water, they can deflocculate and become dispersed, which can causes serious problems associated with internal erosion, piping, erosion of natural slopes and erosion of channel slopes of the earth dam embankments. The dispersivity can be considered a progressive phenomenon starting from one point with the focus of the water pressure concentration and increasing the water pressure over time and it can be attributed to physical or chemical causes (USSD, 2011; ICOLD, 1990b, 1994; Tosun, 2006). One of the major factors that contribute to clayey soils' dispersivity is the magnitude of sodium cations. Clayey soils normally contain chemical dispersivity due to the adsorption of cations on the soil particle surface. Dispersive soils normally contain a higher level of dissolved sodium ions in the pore water compared to ordinary soils, which increases the thickness of the diffused double layer of water around each clay particle. Thus, the repulsive forces make the clay particles suspended in the pore fluid. Physical dispersion normally occurs in fine-grained sands or coarse silt due to the fineness of the particles and the lack of adhesion between the particles (Umes et al. 2011). Several construction issues including asymmetrical and unusual subsidence in foundations, cracks in walls, water leaking from earthen dams and canals, and subsidence and cracks in road surfaces were reported in appearance of dispersive soils in civil projects. The most common problem caused by this phenomenon is erosion, which can cause damage to hydraulic infrastructures like earth dams, embankments, and other structures.

Several researchers have examined the impact of additives to treat the dispersive soil behavior. Naval et al. (2017) investigated the improvement of dispersive soils using two nanomaterials (MgO and Al_2O_3). These two materials were added to the soil at various dosages, and this study showed that nanomaterials decreased the dispersion potential. Gidday et al. (2020) examined the effect of lime as a stabilizer to enhance the sub-grade of a road constructed by dispersive soils and concluded that the optimal dosage of this additive is between 7% and 9% of the soil's dry weight (Gidday et al. 2020). Changizi and Haddad (2015) investigated the effects of recycled polyester fibers and nano-silica on dispersive clays. Increasing the nano-SiO2 content resulted in failure strain reduction, whereas increasing the content of recycled polyester fiber resulted in an increase in failure strain. When recycled polyester fiber and nano-SiO2 are included in the soil mixture, both shear strength and UCS are improved. Saber et al. (2021) used magnesium chloride solution and polypropylene fibers as modern additives in addition to lime as a traditional stabilizer. Polypropylene fibers and magnesium chloride were found to be very effective in reducing dispersion and compressibility of dispersive soil. This study showed that either 8% lime or 4% PVA polymer are the most cost-effective additive for reducing soil dispersity.

The presence of water leakage, erosion and cavities in the wall of the diversion channel of the Abivard dam located in North East of Iran was attributed to the presence of dispersive clayey soils. To provide solutions to treat the erosion and improve the dispersive soil of the diversion channel, traditional and modern stabilizers and additives are studied in this research program. To evaluate suitability and effectiveness of the dispersive soil treated with additives for earth dam construction, compactibility of the material for earth dam construction was examined by geotechnical compaction tests. Several modern stabilizers are examined in this research program, including polypropylene fibers, PVA polymers, magnesium and calcium chloride solutions, and lime as a traditional stabilizer. Pinhole and double hydrometer tests were conducted on samples collected from the diversion channel. To study the effects of various types and quantities of additives on the compaction behavior of improved soils, standard proctor and modified proctor tests were conducted. The results obtained from this research program will be used to provide guidelines for the dam operators to find the most practical additives to reduce dispersivity of the material and also to verify the compacitibility of the material to evaluate suitability for earthdam construction.

2 MATERIALS AND METHODS

2.1 Soil Properties

The soil samples used in this study were collected from the left side of Espian diversion channel of Abivard Dam located in the southeast of Dargaz city of Khorasan Razavi province (Figure 1). These samples are transferred to the laboratory according to ASTM D4220 guidelines.

Figure 1. Dispersive soil of the wall of the Espian diversion channel

A variety of identification tests including Particle Size Distribution (PSD), Atterberg limits, classification of USCS soils, and standard specific gravity tests were conducted on the field samples following ASTM standards. According to ASTM-D422, soil classification was performed by sieving and hydrometer. In the Atterberg Limit test, LL and PL limits were determined based on ASTM-D4318 and specific gravity was determined using ASTM C127. Table 1 presents the physical properties of the soil used.

Table 1. Physical properties of the tested soil

Characteristics	Content
Soil classification	CL-ML
Specific gravity(G_s)	2.66
Plasticity index(PI)	5.2%
Plastic limit(PL)	16.8%
Liquid limit(LL)	22%
Optimum moisture content(OMC)	14.2%
Initial moisture	3.2%
Fines content	97.7%

The degree of soil dispersivity was determined using both pinhole and double hydrometer tests. The pinhole test equipment was built and operated at the geotechnical laboratory of Sadjad University of Technology (SUT) as shown in Figure 2. In order to investigate the effect of additives on the compaction behavior of improved soils, standard proctor and modified proctor tests (ASTM D1557) were conducted on natural and stabilized dispersive soils.

Figure 2. Pinhole test equipment built at Sadjad University of Technology Soil Mechanics Laboratory

2.2 Additives and stabilizers

The additives used in this study were polypropylene fibers, PVA polymers, magnesium and calcium chloride solutions as modern stabilizers, and lime as a traditional stabilizer.

Stiff polypropylene fibers are made through spinning synthetic fibers and are usually colorless and transparent and have a crystalline shape with a crystallization rate of about 70%. Their density is 0.9 gr/cm^3. Non-magnetic properties, lower prices, and wider availability distinguish polypropylene fibers from other types of fibers. The dispersive clay has been improved by the use of polypropylene fibers with cuts of 12 mm in the research.

PVA or polyvinyl alcohol is a type of liquid polymer. Magnesium chloride is the primary precursor of magnesium metal, which is made through electrolysis. Dust control, erosion control, soil stabilization, and defrosting of highways are common usage for magnesium chloride. The 6-aqueous magnesium chloride with a density of 1.59 (gr/cm^3) was used in this study. Calcium chloride is an inorganic compound salt with a white crystalline solid at room temperature and soluble in water. This compound is mainly used for de-icing and dust control. Since the anhydrous salt is hydroscopic and deliquescent, it is used as a desiccant. In addition to modern additives, lime has been used as a traditional additive. Calcium oxide (CaO) reacts when mixed with water and normally generates 280 calories heat. Lime swells due to water absorption and turns into a white, dry powder, also called calcium hydroxide (Ca(OH)2). The lime used in this study is hydrated or slaked lime, which is calcium hydroxide All additives were mixed homogeneously to make a homogeneous soil with the original dispersive soil.

2.3 Test Matrix

Table 2 illustrates the test matrix for the research program including the types of tests performed on samples and additives, as well as the percentage of additives in the samples (percentage by weight).

Table 2. The types of additives and conducted tests on improved dispersive soil

Type of additive	Percentage of additive %	Pin hole	Double hydrometer	Standard proctor	Modified proctor
Polypropylene fibers	1,1.5,2	✓	-	✓	✓
PVA	2,3,4,6	✓	-	✓	✓
Magnesium chloride	1,2,3,4	✓	✓	✓	✓
Calcium chloride	1,2,3,4	✓	✓	✓	✓
Lime	4,6,8,10	✓	✓	✓	✓

3 RESULTS

In this section, the results of the pinhole and double hydrometer experiments are discussed to provide the effectiveness of the additives in improving soil dispersivity. In addition, the results of standard and modified proctor tests on dispersive soils improved with a variety of physical and chemical additives are also investigated.

3.1 Pinhole test

A pinhole test of untreated natural dispersive soil with a water pressure of 50 mm showed a dark-colored drained water sample, which suggested the existence of dispersive soil. The dispersion level was determined by the diameter of the hole created in the soil. Figure 3 shows the hole created after pinhole test for the Calcium chloride-stabilized soil sample.

Figure 3. The photo of a hole created after pinhole test for the Calcium chloride-stabilized soil sample

Table 3 to Table 7 present the results of the pinhole experiment on dispersive soil stabilized with polypropylene fibers, PVA, calcium chloride, magnesium chloride and lime. As can be seen from Table 3, adding polypropylene fibers up to 2.5% of the soil weight slightly reduced soil dispersivity, although this did not lead to a significant reduction in soil dispersivity. Table 4 shows that mixing 3% - 4% PVA polymer with dispersive soil resulted in significant reduction of soil dispersivity, and the addition of 4% polymer made it non-dispersive. Combining of either calcium chloride or magnesium chloride with dispersive soils resulted in cation exchange decreasing the thickness of the diffused double layer of water surrounding each clay particle and improving resistance to water erosion. According to this study, increasing calcium chloride proportion from 3% to 4% eliminated soil dispersion. Magnesium chloride was less effective in reducing dispersion potential compared to calcium chloride and the rate of soil dispersivity became moderate after adding 4% magnesium chloride to the mixture. Furthermore, Table 7 presents that the use of lime in the soil samples significantly reduces the soil dispersivity. By adding more than 8% by weight of lime, the soil became completely non-dispersive.

Table 3. Results of pinhole tests on samples treated by polypropylene fibers

Polypropylene (%)	Color of water	Outflow rate (ml/s)	Test time (min)	Hydraulic head (mm)	Hole diameter after test	Dispersivity classification	Dispersive level
1	Dark	0	5	50	>2	D1	Dispersive
1.5	Medium dark	0	5	50	>1.5	D2	Dispersive
2	Medium dark	0	5	180	>1.5	D2	Dispersive
2.5	Almost transparent	0	5	180	>1.5	ND4	Moderate

Table 4. Results of pinhole tests on samples treated by PVA polymer

PVA polymer (%)	Color of water	Outflow rate (ml/s)	Test time (min)	Hydraulic head (mm)	Hole diameter after test	Dispersivity classification	Dispersive level
2	Dark	0	5	50	>1.5	D2	Dispersive
3	almost dark	0	5	180	>1.5	ND3	Moderate
4	almost transparent	0	10	380	<1.5	ND2	Non
6	transparent	0	5	1020	<1.3	ND1	Non

Table 5. Results of pinhole tests on samples treated by magnesium chloride

magnesium chloride (%)	Color of water	Outflow rate (ml/s)	Test time (min)	Hydraulic head (mm)	Hole diameter after test	Dispersivity classification	Dispersive level
1	Very dark	0	5	50	>2	D1	Dispersive
2	dark	0	10	50	>2	D1	Dispersive
3	dark	0	5	180	>1.5	ND4	Moderate
4	Almost dark	0	5	180	>1.5	ND3	Moderate

Table 6. Results of pinhole tests on samples treated by Calcium chloride

Calcium chloride (%)	Color of water	Outflow rate (ml/s)	Test time (min)	Hydraulic head (mm)	Hole diameter after test	Dispersivity classification	Dispersive level
1	Very dark	0	5	50	>2	D1	Dispersive
2	dark	0	10	50	>1.5	D2	Dispersive
3	Almost dark	0	5	180	>1.5	ND3	Moderate
4	Almost transparent	0	5	380	<1.5	ND2	Non

3.2 Double hydrometer

The results obtained from double hydrometer experiments on dispersive soil samples stabilized with lime, magnesium chloride, and calcium chloride solutions are presented in Figures 4 through 6. It is shown that adding either 8% lime or 3% to 4% magnesium chloride and calcium chloride, changes soil properties from dispersive to non-dispersive.

Table 7. Results of pinhole tests on samples treated by lime

Lime(%)	Color of water	Outflow rate	Test time (min)	Hydraulic head (mm)	Hole diameter after test	Dispersivity classification	Dispersive level
4	moderate dark	0	5	50	>1.5	D2	Dispersive
6	almost transparent	0	10	180	>1.5	ND3	Moderate
8	transparent	0	10	380	<1.3	ND1	Non
10	Very transparent	0	5	1020	<1.3	ND1	Non

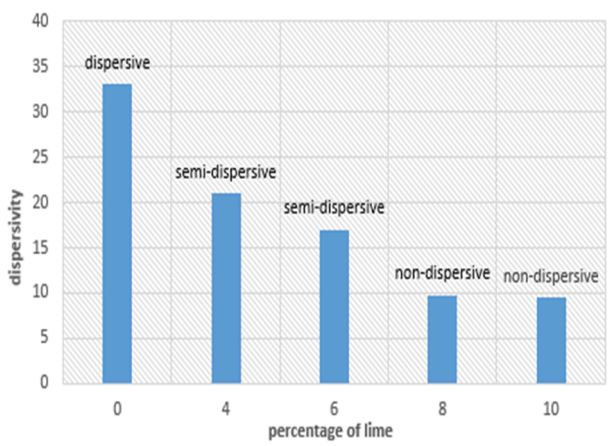

Figure 4. The results of double hydrometer experiments on dispersive soil samples stabilized with lime

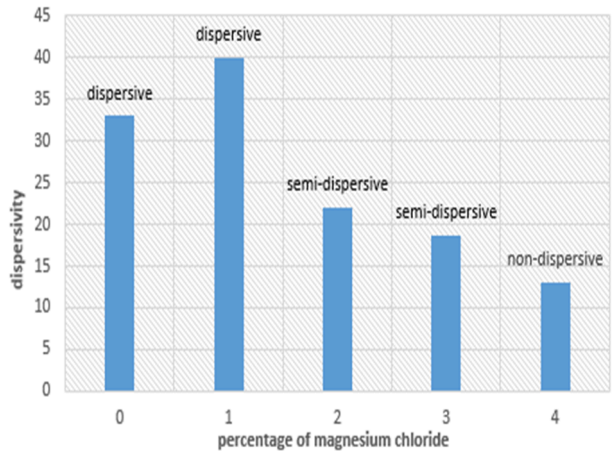

Figure 5. The results of double hydrometer experiments on dispersive soil stabilized with magnesium chloride

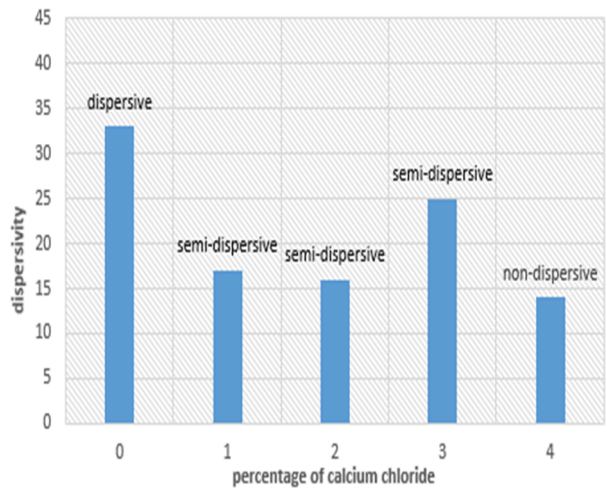

Figure 6. The results of double hydrometer experiments on dispersive soil stabilized with calcium chloride

3.3 Standard Proctor Test Results

Figure 7 presents the results of the standard proctor test conducted on dispersive soils treated with PVA. The result shows that with increasing the percentage of the PVA to 3%, the maximum dry density (MDD) and optimum moisture content significantly increases. By increasing the PVA percentage to 4% and 6% the MDD slightly reduces; however, the value is significantly higher than the original dispersive soil.

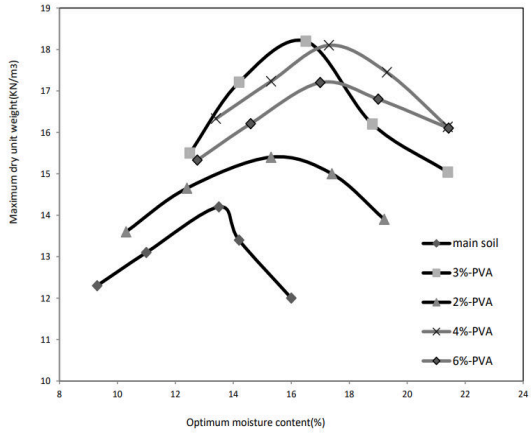

Figure 7. Results of Standard Proctor test on soils treated with PVA

Figure 8 compares the maximum dry density obtained from standard proctor tests for natural dispersive soil samples and soils treated with polypropylene fibers, PVA polymer, magnesium chloride, calcium chloride solutions, and lime. The results of standard proctor tests indicated that adding Magnesium, Calcium Chloride solutions and PVA polymer to the dispersive soil had a considerable effect on increasing the maximum dry density. However, polypropylene fibers and lime do not show a satisfactory response in improving compaction behavior.

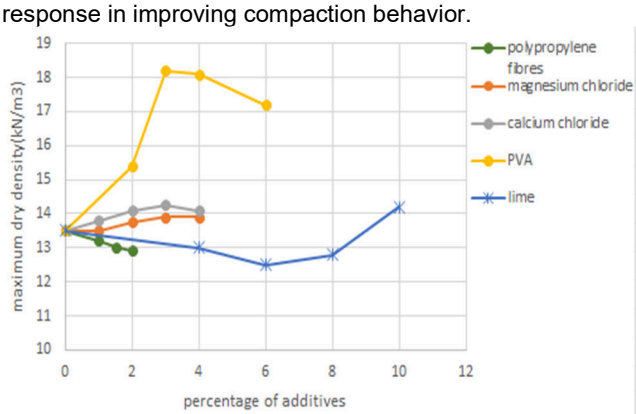

Figure 8. Comparison of Maximum Dry Density (MDD) values obtained from standard proctor tests for natural and improved dispersive soil samples

Figure 9 compares the optimum moisture content values obtained from standard proctor tests for natural dispersive soil samples and soils treated with the additives. The results of standard proctor tests indicated that adding Magnesium and Calcium Chloride solutions and PVA polymer with the dispersive soil had a considerable effect in increasing the maximum dry density. It is also shown that using polypropylene fibers, PVA polymer, and lime at 2%, 4% and 6% respectively resulted in increasing the amount of optimum moisture content, while the soils improved by magnesium chloride and Calcium Chloride solutions at 3% have had the lowest optimum moisture content. Figure 8 and Figure 9 show that the best compaction behavior of dispersive soil was achieved by using 4% PVA polymer.

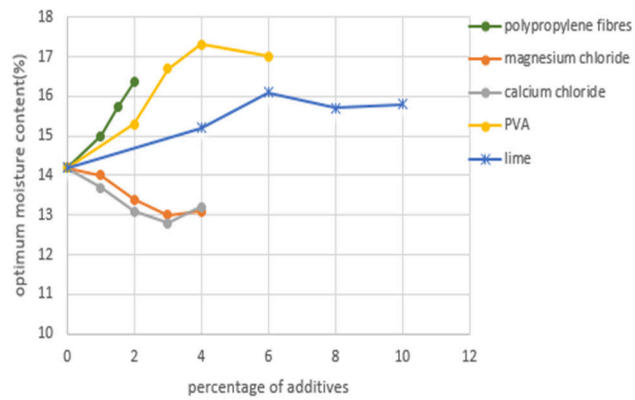

Figure 9. Comparison of Optimum Moisture Content values obtained from standard proctor tests for natural and treated dispersive soil samples

3.4 Modified Proctor Test Results

Figure 10 presents the modified proctor results of the proctor test conducted on dispersive soils treated with different percentages of lime. The result shows that the MDD values of the main soil do not improve with adding lime and even reduction of the MDD value was reported by adding 6% lime.

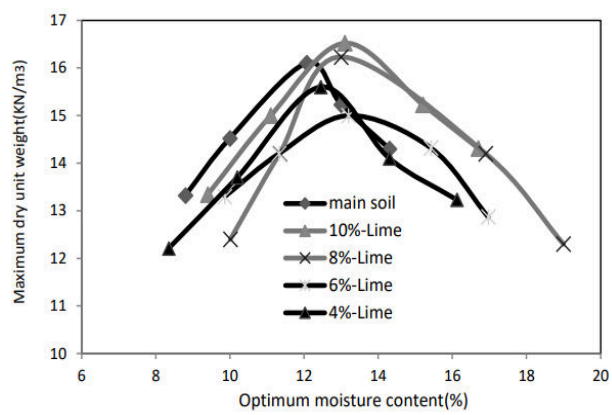

Figure 10. Results of Modified Proctor Test on soils treated with Lime

Figure 11 compares the maximum dry density values obtained from modified proctor tests for natural dispersive soil samples and soils treated with polypropylene fibers, PVA polymer, magnesium chloride, calcium chloride solutions, and lime. It is shown that the PVA polymer additive with a weight percentage of 3% was found to demonstrate the highest dry density value (21.8 kN/m^3), followed by calcium chloride and magnesium chloride solutions in amounts of 3% by weight percent. The results shows that the maximum dry density of soil decreased by adding up to lime or polypropylene fibers, which shows ineffectiveness of these two additives to improve the compaction behavior of the soil.

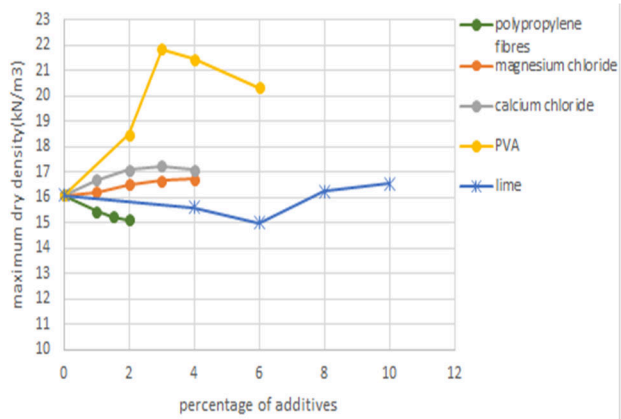

Figure 11. Comparison of Maximum Dry Density (MDD) values obtained from modified proctor tests for natural and improved dispersive soil samples

Figure 12 compares the optimum moisture content values obtained from modified proctor tests for natural dispersive soil samples and soils treated with the additives. Similar to results of standard proctor experiments, with increasing the percentage of polypropylene fibers, PVA polymer and lime, optimum moisture content of soil increased, while it decreased by addition of magnesium chloride and Calcium Chloride solutions.

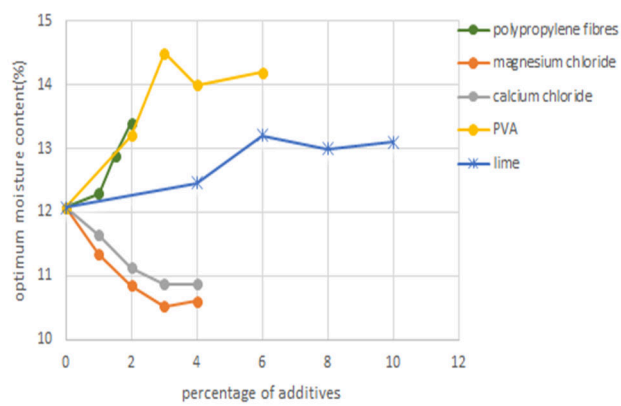

Figure 12. Comparison of optimum moisture content values obtained from modified proctor tests for natural and improved dispersive soil samples

4 CONCLUSIONS

The purpose of this research study was to find a solution to improve and stabilize the dispersive behavior of soil sampled from the diversion channel of the Abivard dam in Iran with traditional and modern additives and to study the effectiveness of the additives to improve compaction behavior of dispersive soils. Traditional and modern additives including lime, polypropylene fibers, PVA polymer, Magnesium Chloride, and Calcium Chloride solutions were used to improve the dispersivity of dispersive soil samples collected from the Diversion Channel of Abivard Dam in Iran. Double hydrometers and pinhole tests were carried out to identify soil dispersion characteristics and determine the optimal amounts of additives. The compaction behavior of the treated soils was examined by Standard and Modified Proctor tests. The following conclusions can be obtained from the results of this study:

- The results of double hydrometer and pinhole tests identified the original soils as highly dispersive soil. The soil structure is somehow closer to physical dispersivity than chemical dispersivity.

- Addition of 2.5% polypropylene fibers to dispersive soil was moderately effective in reducing the physical dispersivity of the soil. Addition of 4% PVA polymer to the tested soil changed the dispersive soil to completely non-dispersive. Addition of 3% - 4% Magnesium Chloride and Calcium Chloride solutions by weight percentage, resulted in reducing soil dispersivity.

- Addition of 4% - 6% lime to dispersive soil improves soil dispersivity and make it non-dispersive. With increasing the lime percentage to 8%, the soil becomes completely non-dispersive.

- The results of Standard and Modified Proctor tests showed that polyvinyl alcohol (PVA) with a weight percentage of 3% has the best performance in compatibility of the soil by increasing the MDD of dispersive soil. By addition of 3% PVA, the optimum moisture content of the soil increased from 14% to 17%

- Magnesium Chloride and Calcium Chloride solutions with the weight percentage of 3% slightly increased the MDD and was moderately effective to improve compactibility of the soil.

- The results of Standard and Modified Proctor tests showed that polypropylene fibers and lime are ineffective in improving compactibility of the dispersive soil and even MDD reduction by 10% was reported by increasing the percentage of these additives.

- As a practical guideline for the dam operators, if the purpose of the treatment and stabilization is to only reduce the dispersivity of the soil addition of 2.5% polypropylene fibers or 4% PVA or 3% - 4% Magnesium/Calcium Chloride are recommended. If the purpose is to reduce the dispersivity along with improving compactibility of the soil to be used as borrow material for earthdam construction, addition of 3% PVA is recommended. This addition will result in increasing the optimum moisture content of the soil by about 10% and requires addition of more water to the soil before starting the compaction process.

5 REFRENCES

Acciardi RC. and Peck, R.B. 1982. *Quantification of Pinhole Test Equipment Hydraulic Characteristics*, Bureau of Reclamation, RECERC- 82-15.

ASTM D422-63(2007)e2, Standard Test Method for Particle-Size Analysis of Soils.

ASTM D4220 - Standard Practices for Preserving and Transporting Soil Samples.

ASTM D4221 - 18: Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer.

ASTM D4318 - 17e1: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

ASTM D4647 - BS 1377: Standard Test Method for Dispersive Characteristics of Clay Soil by Pinehole Dispersion test apparatus.

ASTM D698 - 07$^{\varepsilon}$: Standard Test Methods for standard proctor test of Soils.

ASTM D1557 - 09: Standard Test Methods for modified proctor test of Soils.

Changizi, F. and Haddad, A. 2015. Strength properties of soft clay treated with mixture of nano-SiO2 and recycled polyester fiber, *Journal of Rock Mechanics and Geotechnical Engineering*, S1674-7755(15)00059-1 ASCE, 109: 883-898.

Fooladi, A. and Ghosair, B. 2010. Recycle carpet waste strips as reinforcement in sand slops, *6th international conference on seismology and earthquake engineering '87*, IFAI, New Orleans, ON, Canada,1: 95-107.

Gidday, B.G. and Mittal, S. 2020. Improving the characteristics of dispersive subgrade soils using lime, *Elsevier*, Heliyon, volume 6, Issue2: e03384.

Naval, S. and Chandan, K. 2017. Stabilization of expansive soil using nanomaterials, *International interdisciplinary conference on science technology engineering management pharmacy and humanities '87*, IFAI, Singapore, ISBN: 9780998900001.

Onyelowe, K.C. 2018. Kaolin soil and its stabilization potentials as nanostructured cementitious admixture for geotechnics purposes, *International Journal of pavement research and technology*, ijprt: 717-724.

Saber, F., Yazdi, F., Daliri F., Shahasavai M. and Rashed A., 2021. Effect of magnesium chloride and polypropylene fibers stabilizers on hydro-mechanical behavior of dispersive soils, *GeoNiagara,* Canada,1: 95-107.

Tosun H., 2006. Internal erosion resulted from dispersive soils in earthfill dams and a case study.

Umesh, T.S. and Dinesh, S.V. 2011. Characterization of dispersive soils, *Materials sciences and applications*, 2: 629-633.

ICOLD (1990). Dispersive soils in embankment dams: review Bulletin 77. International Commission on Large Dams Paris.

ICOLD (1994). Embankment dams: granular filters and drain; Bulletin 95. International Commission on Large Dam; Paris.

Ingold, T.S. and Miller, K.S. 1983. Drained Axisymmetric Loading of Reinforced Clay, *Journal of Geotechnical Engineering*, ASCE, 109: 883-898. journal papers is: Last name, Initials. Year. Article title, Name of Journal, volume number in Arabic numerals, pages.