Erosion and Dispersion of Sandy Soil with Addition of Fine Materials

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ABSTRACT

For a better understanding of the performance of earth structures, it is essential to define and evaluate the variables that determine the erosion and dispersion of soils. A laboratory study has been carried out to characterize the soil internal erosion due to the water flow and the effect of fine materials percents on the erosion and dispersion of sandy soil.

A double hydrometer test, crumb test, slacking test and pinhole erosion test were conducted to investigate the soil dispersibility characteristics. Sandy soil samples were collected from a region in Mosul city – North of Iraq, and treated with different percents of fine materials of clayey soil, these percents were ranged from (0 – 80 %) of the dry weight of sandy soil.

The results showed that, the addition of fine materials enhanced both the compaction and dispersibility characteristics of sandy soil. As the fine materials increases, the soil resistance to internal erosion increased. So, the pinhole erosion test was the more reliability test to classify the soil according to the dispersibility.

Keywords: Sandy soil, Fine materials, Erosion, Dispersion, Pinhole test, Slacking test.

التعرية والتشتت للتربة الرملية المضاف إليها المواد الناعمة

الخلاصة

يهدف البحث إلى دراسة كل من التعرية والتشتت لتربة رملية مضاف إليها نسب مختلفة من المواد الطينية الناعمة المارة من منخل رقم (٤٠). وتم إجراء العديد من التجارب المختبرية لمعرفة التآكل الداخلي للتربة نتيجة التعرض لجريان الماء ونتيجة إضافة المواد الطينية الناعمة.

تم إجراء كل من فحص المكثاف المزدوج، فحص الفتات، فحص التآكل وفحص التسرب التآكلي (فحص الثقب الصغير لقياس الانتشار) وذلك لمعرفة خصائص التشتت للتربة الرملية والتربة المعاملة بالمواد الناعمة. تم اختيار تربة رملية من أحدى مناطق مدينة الموصل - شمال العراق وتم إضافة نسب مختلفة من المواد الناعمة تراوحت بين (٠ – ٨٠%) من وزن التربة الرملية الجافة.

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أظهرت التجارب المختبرية بأن إضافة المواد الناعمة أدت إلى تحسين كل من خصائص الرص وخصائص التشتت للتربة الرملية. كذلك وجد أن إضافة المواد الناعمة أدت إلى زيادة المقاومة الداخلية للتربة الرملية ضد التعرية. أخيراً يعتبر فحص التسرب التآكلي من أكثر الفحوصات التي يعول عليها في تصنيف الترب حسب التشتت.

INTRODUCTION

In the case of engineering earth structures, especially earth dams, it is of interest to know the various fundamental variables involved that determine the safety of these structures against failure. One of the major concerns regarding the safety of earth dams or earth embankment is the problem of internal soil stability, when soil particles are subjected to drag forces resulting from reservoir seepage [1 and 2]. Earth structures failure by piping or erosion is often due to the effects of the force of flowing or permeating water on a cohesive soil in which interparticle forces were reduced by decreases or exchanges of pore fluid cations [3 and 4].

Many hydraulic earth structures such as earth dams, irrigation canal linings, etc. were constructed on different types of soils. Such soils which are classified as difficult soils are responsible for destruction of hydraulic structures in many countries. This group of soils is categorized as soluble, liquefiable, collapsible and dispersive. There are some examples that show hydraulic structures founded on these soils, have been damaged or destroyed in many projects in the world [5,6,7,8,9 and 10].

Piping and erosion of soils are a common problems down stream of earth dams and earth embankments under the influence of upward seepage [4,11,12 and 13]. When the seepage velocity exceeds the critical velocity, piping occurs and the soil in the constructed areas flows out and the structures are weakened [14].

Studies concerning piping and erosion phenomena of soils have been reported in the last years by many investigator. These studies have also been concentrated on the effect of moisture content and density, shear stress, water temperature and velocity, lime and fiber percents, among others, on the piping and erosion of soils [3,14,15,16,17,18, 19,20,21 and 22].

To minimize the construction cost for the earth dams projects the use of locally available materials will always be a necessary task for geotechnique engineers. And nevertheless, the influence of fine materials additions on the erosion and piping of soils require further study. This is of paramount importance when looking for improvements of the piping and erosion behavior.

The specific objectives of this study are to examine the possibility of using fine materials for controlling seepage velocity and improving piping resistance of sandy soil using laboratory experiments. Also, to provide more information on the piping and erosion behavior of sandy soil mixed with different percentages of fine materials, a theoretical model by GEOSLOPE program (Seep / W version 5) was carried out to define its response under studied experiments.

EXPERIMENTAL PROGRAM AND TESTS PROCEDURES.

Materials

Soil

Locally available sandy soil was used in the current study. The soil samples were collected from a depth of (1.5 m) below the ground surface from the region of

Al-Gabat district within Mosul city. The soil was classified as a silty sand (SM) according to Unified Soil Classification System (USCS). The grain size distribution shows that the soil consists of (59%) sand, (37%) silt and (4%) clay. Specific gravity of the soil particles (Gs) is 2.67, and it did not exhibit any plasticity. The soil samples were mixed with (5,10,20,40 and 80%) fine materials (F.M.) of clayey soil (passing sieve # 40) which was selected from Al-Sedeeq district, and it was composed of (2%) sand, (48%) silt and (50%) clay.

Water

Distilled water was used in the preparation of samples as well as in all the tests.

2.2 Compaction Procedures.

Soil used for compaction was oven dried for 2 days at 60 ^{0}C. The soil samples were treated with different percentages of fine materials ranged from (0 to 80%) by weight of dry soil. For natural soil (i.e. sandy soil), the soil samples were wetted with tap water and stirred with a trowel during hydration to ensure an even distribution of water. Afterward the soil samples were sealed in plastic bags and allowed to hydrate for at least (24 hours) prior to compaction (Annual 1993).

Soil samples treated with fine materials were prepared by first thoroughly mixing dry predetermined quantities of soil and fine materials to obtain a uniform color. Then a required amount of water was added and remixed thoroughly. The mixing continued until the final mixture gets a uniform moisture distribution. Then the mixture was placed in plastic bags for elapse time of (24 hours) as mellowing time (Annual 1993). Thereafter, the mixtures were compacted in a specific mould of each type of the required testing. A modified compactive effort was considered and the moisture content and density were kept the same for each soil sample.

Test Procedures.

Dispersive Soil Identification Tests.

In this study, four laboratory tests commonly used to identify dispersive soils. These tests are: the double hydrometer test, crumb test, slacking test and the pinhole erosion test. The testing procedures are as follows.

A – Double Hydrometer Test.

This test was carried out according to the procedure that suggested by (Sherard et al., 1976a)[2], which consist on performance twice of the hydrometer test for the sandy soil samples and that samples treated with (5,10,20,40 and 80%) of fine materials. For the first one, a standard hydrometer test was performed according to (ASTM D – 422), while the other was carried out as the previous test but with out using any chemical dispersant and mechanical or electrical agitation. After that, the dispersion percent can be expressed in the following equation:

$$Despersion(\%) = \frac{\mathrm{A}}{\mathrm{B}} \times 100 \qquad \ldots\textbf{(1)}$$

Where:

A = percent of particles finer than (0.005 mm) in untreated method.

B = percent of particles finer than (0.005 mm) in standard method.

B – Crumb Test

Crumb test is a quick method for identification of a dispersive soil. This test is run using two sets of soil samples having different sizes in order to study the effect of soil sample size on the crumb behavior. In the first one, small (10 – 15 gm) crumbs of soil samples at optimum moisture content were used, while the second set contained on samples having size (10) times the size of the first set. The crumbs were carefully placed on the bottom of (100 ml) clear glass beaker about one-third full of distilled water. The reaction of the soil crumbs was observed for (10 to 40) minutes.

Dispersion is detected by the formation of a colloidal clued, which appears as a fine misty halo around the soil crumb. The crumb test is rated for reaction or colloidal clued formation as follows:

1. No sign of cloudy water caused by colloidal suspension.
2. Bare hint of colloidal clued formation at surface of soil crumb.
3. Easily recognized colloidal clued covering one fourth to one half of the bottom of the glass container.
4. Strong reaction with colloidal clued covering most of the bottom of the glass container.

Since the crumb test involves a small quantity of soil, four tests have been done on each soil samples (i.e. each fine materials percent) before making an evaluation.

C – Slacking Test.

This test is similar to crumb test which has been developed by (Rahimi et al., 2003) [17]. In this test, cylindrical samples of (50 mm x 100 mm) size of sandy soil and soil treated with (5,10,20,40 and 80%) fine materials were compacted with optimum moisture content (OMC) and (90%) of the maximum dry unit weight. After that, the soil samples were covered with a (No. 4) wire mesh and supported by a metal spring, then placed into one liter of distilled water up to a half depth. The time period for complete collapse of the soil samples was determined and used as a measure for quantitative evaluation of dispersivity potential.

D – Pinhole Erosion Test.

The pinhole erosion test is the most reliable test for identifying dispersive soils. It was developed by many investigators [16 and 20], for the purpose of identifying dispersive soils. This test was conducted on compacted samples of natural sandy and treated soils with fine materials. These samples were compacted as in the slacking test (i.e. moisture content and density were kept the same for each soil).

The pinhole erosion apparatus manufactured by (Abdullah, 2005)[15], which was designed to accommodate a soil samples having (106 mm in diameter and 116.9 mm in height) were used, these apparatuses are shown schematically in Fig. (1). At the beginning, the soil sample was compacted in the pinhole cell having (106 x 240 mm) size, and a central hole was made along the length with a diameter equal of (2 mm), by using an electrical drill. Then, the (No. 4) wire meshes were placed at the bases area of the sample (i.e. top and bottom), these meshes were positioned so that the pinhole is centered in an opening in the meshes. After that, adhesive impervious material such as silicon was placed around the perimeter of the meshes to hold them in place. Pea gravel having (K=1.0 cm/sec.) and (¼″ to ⅜″) in size which acts as filter was placed next to the meshes, then all auxiliary apparatus were assembled, so the test has been started following the procedures that suggested by (Abdullah, 2005)[15].

To interpret the results of the pinhole erosion test and to develop a classification system containing intermediate grades between dispersive and non dispersive soils, it is necessary to determine the relationship between quantity of flow and initial hydraulic head as a function of the size of the pinhole, as shown if Fig. (2). This relationship is determined by substituting aluminum cylinders with varying pinhole diameters (2,4 and 6 mm) for the soil sample and measuring the quantity of flow for various hydraulic heads. To calibrate the pinhole erosion apparatus (i.e. aluminum cylinders), a previous aforementioned procedures were adopted with different hydraulic heads.

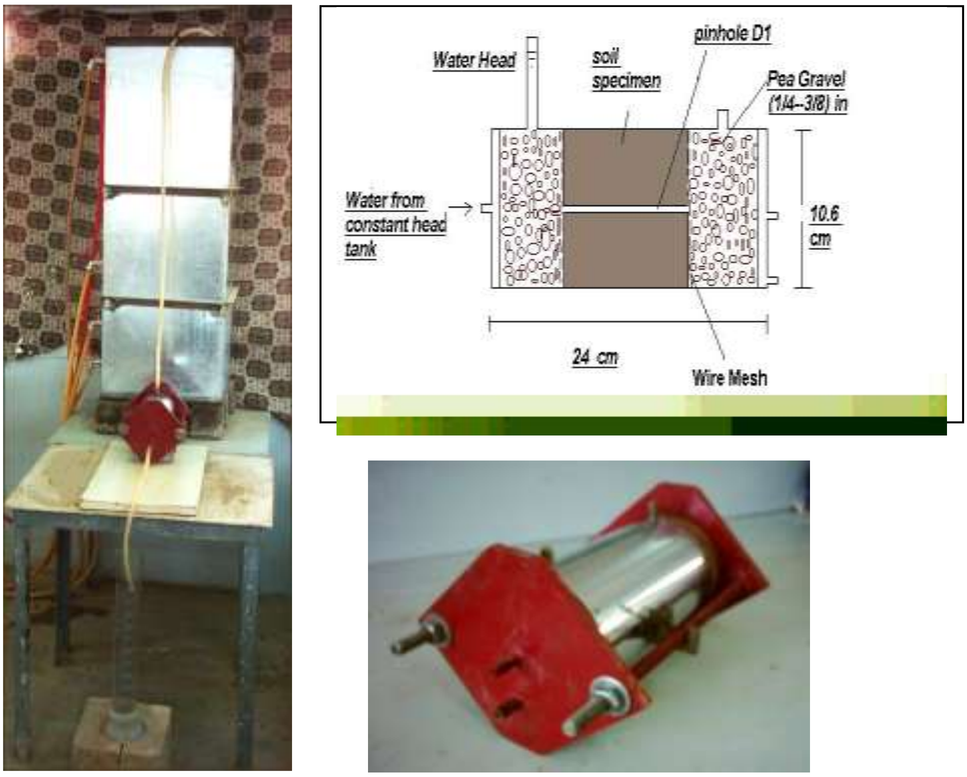


Figure (1) Testing device with all apparatuses.

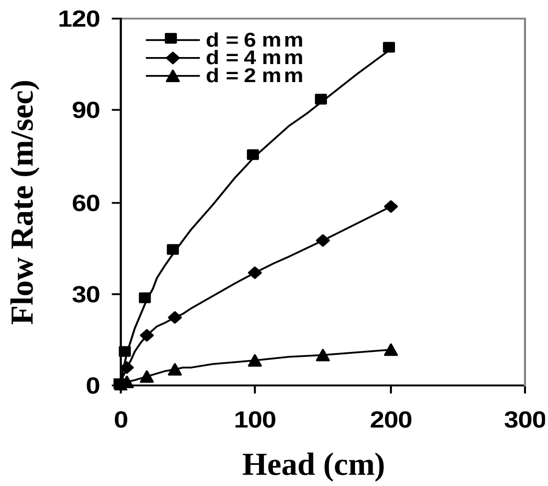


Figure (2) Calibration curves for the pinhole test using aluminum cylinder sample

RESULTS AND DISCUSSIONS

Characterization of Sandy Soil with the Fine materials.

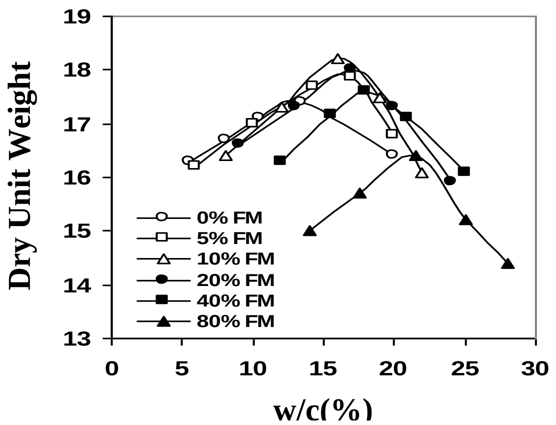
Table (1) shows some of the index properties of treated soil with fine materials. The date indicate that, the soil becomes more plastic upon the addition of fine materials and the treated soil transforms to (CH) type soil. Such changes occurred due to more clay particles were added. Also, the specific gravity (Gs) increased with fine materials, where by the increasing in (Gs) was primary attributed to higher specific gravity of added materials.

Table (1) Index properties of natural soil with addition of fine materials.

Fine Materials (%)	Atterberg Limits				Specific Gravity (Gs)	Soil Classification According to (USCS)
	L.L (%)	P.L (%)	P.I (%)	L.S (%)		
0	27	23	4	1.6	2.67	**SM**
5	29	23	6	5.8	2.67	**SM – SC**
10	33	25	8	6.4	2.69	**SC**
20	39	28	11	7.8	2.71	**ML**
40	51	31	20	12	2.73	**MH**
80	69	34	35	18.6	2.75	**CH**

Compaction Characteristics.

The compaction curves of natural and treated soil with different percentages of fine materials are shown in Fig. (3). It is observed that, the maximum dry unit weight (γ_{max}) increases up to (10%) fine materials then decreases. This belongs to fine materials that were added which filled the voids between the coarse particles of sandy soil and lead to increase the weight of solids in the unit volume. Similar behavior has been reported by (Jaro, 2000) [23]. The reduction in (γ_{max}) when the soil treated with (20, 40 and 80%) fine materials is due to extra fine particles that were added which have a small unit weight. So, the optimum moisture content (OMC) increase with fine materials, this behavior may be due to more fine particles were added which tend to react with water.



Figure(3) Compaction curves of natural and treated soil with different percents of fine materials.

Identification of Dispersive Soil.

Double Hydrometer.

Figure (4) and Table (2) show the results of the double hydrometer test of the natural sandy soil and soil treated with fine materials addition. It is observed that, in case of untreated hydrometer test the percent of particles finer than (0.005 mm) was less than that percent in standard hydrometer test, and this percent increased with increasing fine materials. According to the classification that was suggested by (Sherard et al. 1976a) [2] the natural soil and soil treated with fine materials were classified as non dispersive soil.

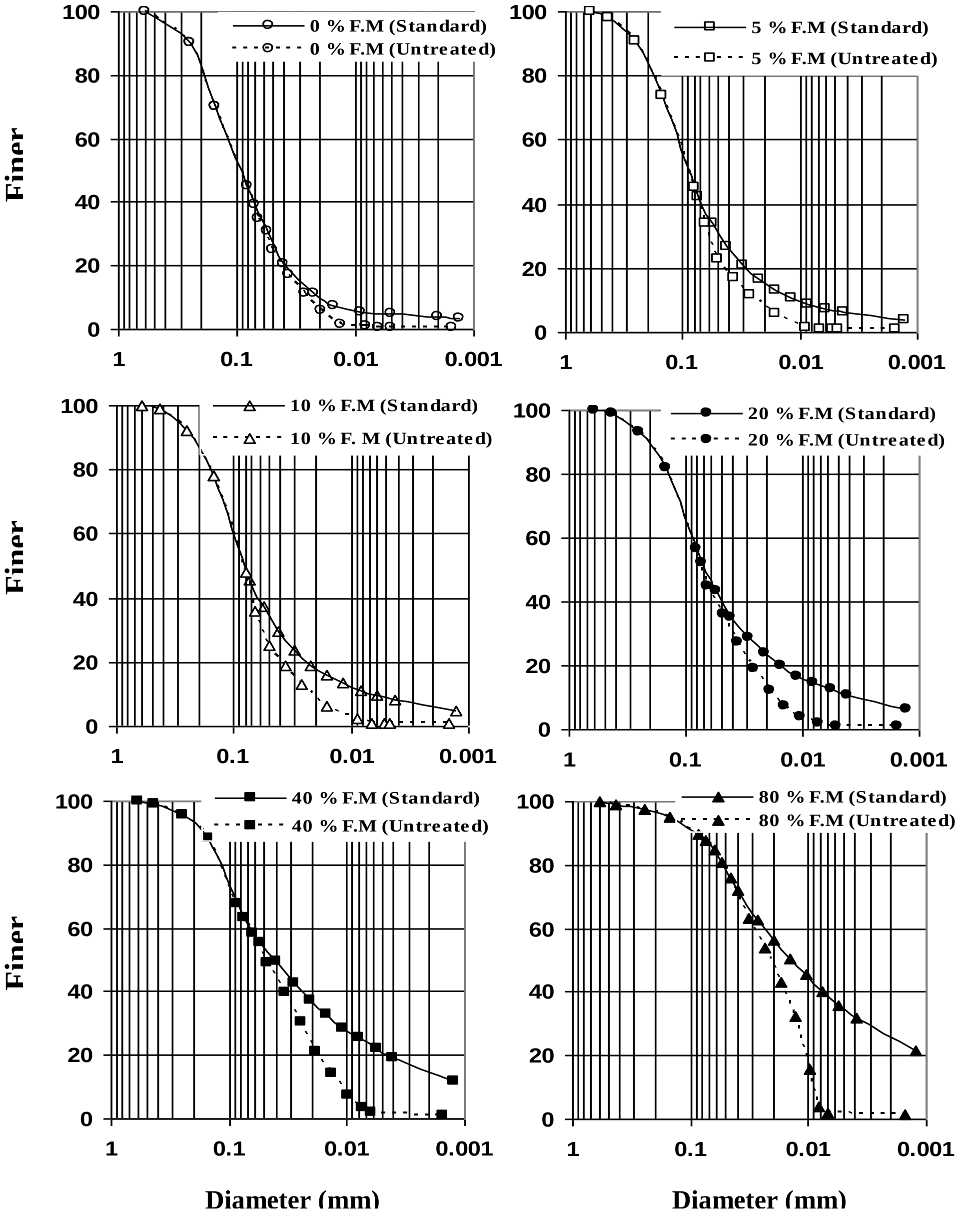


Figure (4) Grain size distribution curves for double hydrometer test with different percents of fine materials.

Table (2) Classification of soils by double hydrometer test.

Fine Material (%)	(%) of Particles Finer than (0.005 mm)		Dispersion (%)	Classification	Classification After (Sherard et al. 1976)	
	Standard	Untreated			Dispersion (%)	Categories
0	5	0.9	18	Non Dispersive	**0 – 35**	**Non Dispersive**
5	6.5	1	15.4			
10	9	1.05	11.7		**35 – 50**	**Intermediate Dispersive**
20	12	1.18	9.8			
40	22	1.9	8.6		**> 50**	**Dispersive**
80	35	2.1	6			

Crumb Behavior.

The results of the crumb test are presented in Table (3). These results indicate that, the soil has been transformed from dispersive to non dispersive soil as the fine materials increased. Also, it was observed that the size of soil samples did not affect soil dispersion as shown in Table (3).

Table (3) Classification of soils by crumb test.

Fine Material (%)	Collapse Time			Grade	Classification After (Sherard et al. 1976)		
	Small Crumb		Large Crumb min.		Reaction	Grade	Categories
	sec	min.					
0	85	1.41	6	Grade 4	**No Reaction**	**G1**	**Non Dispersive**
5	95	1.58	9				
10	110	1.83	13		**Slight Reaction**	**G2**	**Non Dispersive**
20	116	1.93	15	Grade 3			
40	120	2	31	Grade 2	**Moderate Reaction**	**G3**	**Dispersive**
80	150	2.5	36	Grade 1	**Strong Reaction**	**G4**	**Dispersive**

Slacking Behavior.

Based on the results obtained from the slacking test, it was found that the effective factors on the rate of physical dispersivity potential were fine materials and particles diameter (i.e. D_{50}). Table (4) shows the results obtained from slacking test. It was observed that the time of slacking increases with increasing fine materials percent as well as the mean particle diameter (D_{50}) decreases.

In order to develop a relationship between slacking time and physical dispersivity, the time of slacking was plotted against mean particle diameter (D_{50})

for the natural soil and soil treated with different percentages of fine materials, as shown in Figure (5). This figure is suggested to be used for evaluation of the physical dispersivity potential of soil. In this figure, physically dispersive samples will be located under the curve and non – dispersive ones will locate above it. So as the fine materials increases the soil transform from dispersive soil to non dispersive one.

Table (4) Variation of slackening time versus fine materials percents.

Fine Material (%)	Collapse Time (min.)	D_{50} (mm)
0	3	0.092
5	5	0.088
10	9	0.081
20	16	0.07
40	32	0.041
80	> 2880	0.015

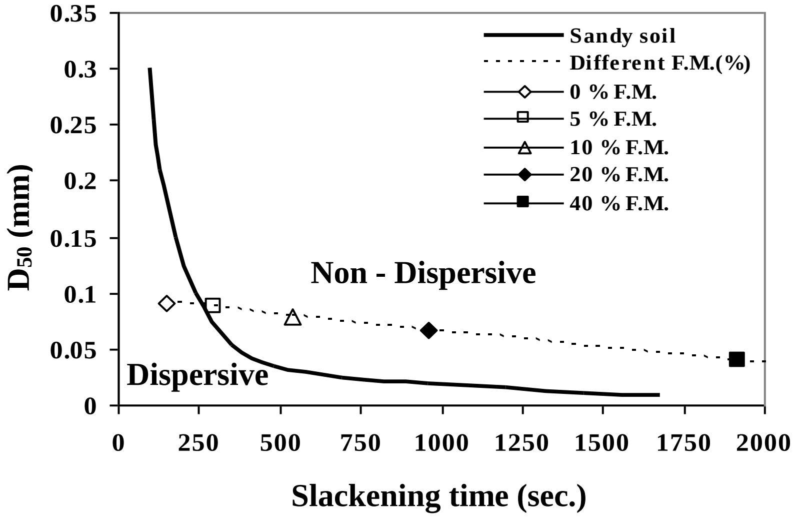


Figure (5) Diagram developed for evaluation of physical dispersivity based on slackening time.

Pinhole Erosion Behavior.

Figures (6) and (7) present the results of the pinhole erosion test. It is observed that, the quantity of water that was collected during the test at each hydraulic head decreased with increasing fine materials. At the end of the test, the size of hole that was made in the center of the soil samples increased for the natural soil samples and samples treated with (5,10 and 20%) fine materials as shown in Figure(6). While the soil samples that were treated with (40 and 80%) fine materials, showed some contraction in the size of hole, this behavior may be due to the soil swelling that occurred during the test. Figure (7) and Table (5) show the five gradings of soil dispersibility ranging from dispersive soils to non – dispersive soils. From the results shown in Figure (7) and Table (5), the natural soil samples are classified as dispersive soil having category (D_1), while the soil samples that were treated with (5, 10 and 20%) fine materials are classified as intermediate dispersive soil, categorized as (ND_4, ND_3 and ND_2 – ND_3). Finally, the soil treated with (40 and 80%) fine materials are classified as non – dispersive soil categorized as (ND_1).

Table (5) Classification of soils by pinhole test.

Fine Material (%)	Dispersive Classification	Final flow at (200 cm) water head (ml/sec)	Hole size after test (mm)	Cloudiness of flow at end of test
0	D_2	66	> 4.4	**Dark**
5	ND_4	51	> 3.5	**Moderately Dark**
10	ND_3	40	> 3.0	**Slightly Dark**
20	ND_2 – ND_3	20	> 2.3	**Barely Visible**
40	ND_1	10	~ 1.7	**Clear**
80		~ 0	~ 0.4 – 0.5	**Perfectly Clear**

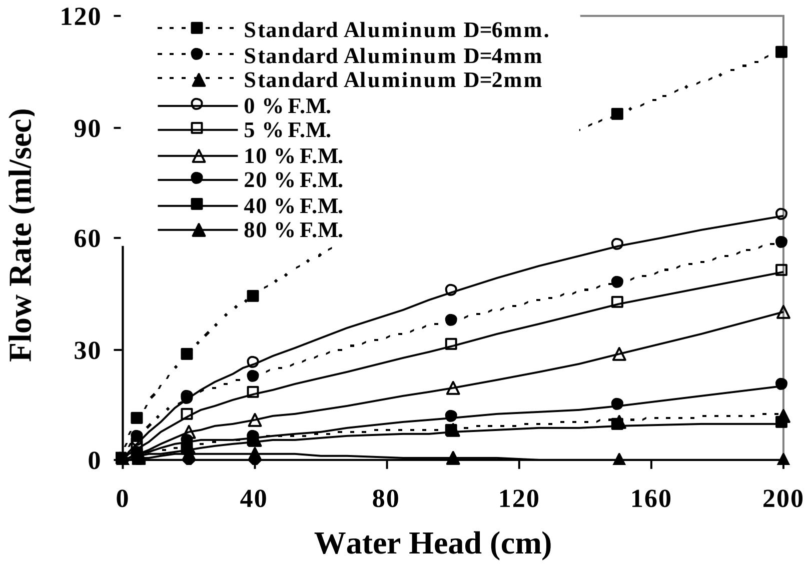


Figure (6) Variation of flow rate and hole size with water head and fine materials additions .

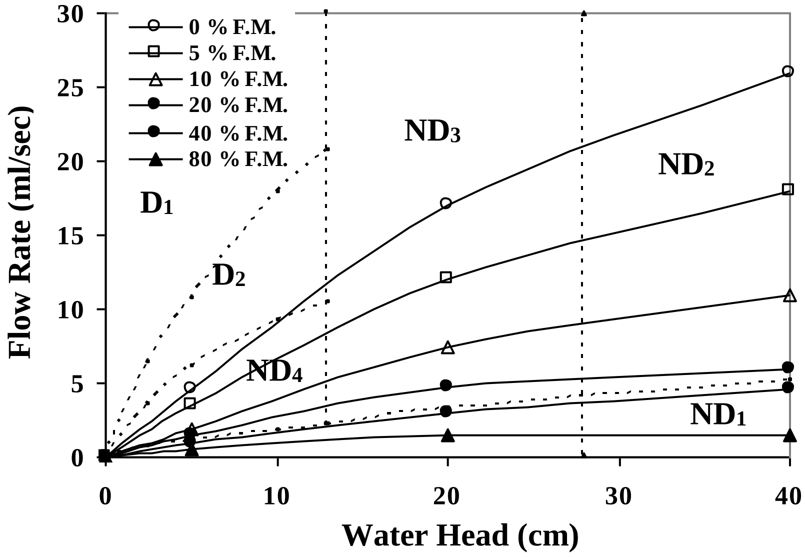


Figure (7) Classification curves of soil by pinhole test.

Numerical Analysis of Pinhole Erosion Test.

Over last few years finite element method have been used successfully for modeling most geotechnical engineering problems. In this work, a finite element GEO-SLOPE software was used. An axisymmetric modeling for pinhole test representation is used. The cell and specimen diameter=10.6 cm, length of the cell=24 cm, and sample height=11.69 cm, while the hole diameter =0.2 cm. 4-noded rectangle axisymmetric element used to simulated the model.

Figure (8) shows the finite element mesh for the analysis used. The boundary conditions were represented by zero flow at the side of the specimen, while the boundary at each constant head was applied at the top of the specimen as a function with the test time.

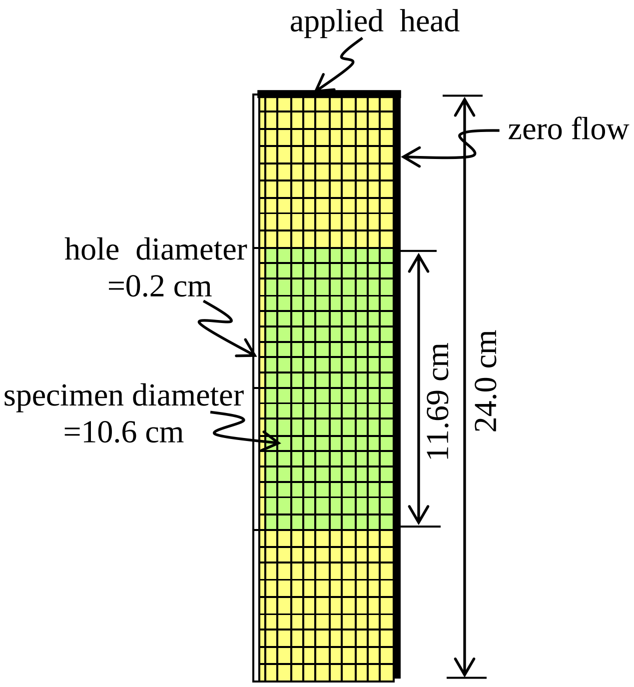
The comparison between the predictions and the observation have been made for the case of 0% fine material. Table (6) shows the pinhole test results.

It could be noted from the table that the finite element method gives a little more predicted value than the observation value, this is may be due to the erosion of the specimen was not be to represented well in the finite element model.

0% fine material with ($K=7.1x10^{-5}$ cm/sec.) was the represented only, while the other percentage of the fine materials representation does not show a clear difference in the calculation it may be due to the program depends largely on the permeability function which is close values, and also may be due to the erosion of the specimen was not be to represented well in the finite element model.

Table (6) Comparison between the predictions and the observation values.

Water head (cm)	Observed flow rate (ml/sec)	Predicted F.E.M flow rate (ml/sec)
5	4.6	4.8
20	17	19.2
40	26	27.8
100	45.6	48.2
150	58	60.2
200	66	69.8



Figure(8) Finite element mesh for the analysis.

CONCLUSIONS.

Based on the results of this study, it could be concluded that:

1. The addition of fine materials enhanced the compaction characteristics of sandy soil up to (10%) fine materials.
2. The sandy soil in nature is prone to disperse unless is treated by fine materials or any other techniques such as stabilization.
3. Sandy soil with higher composition of fine grained particles (fine materials) has lower dispersibility that lead to higher resistance to internal erosion.
4. The soil particles size (i.e. particles diameter D_{50}) and soil composition were the main factors that contributed to the grade and vulnerability of soil dispersibility.
5. The pinhole erosion test was the more reliability test to classify the soil according to the dispersibility.
6. Numerical analysis using finite element method represents a good tool to simulate the pinhole behavior of soil.
7. The soil dispersibility values may be used as one of the engineering index to predict the resistance to internal soil erosion.

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