Journal of Engineering and Development, Vol. 18, No.6, November 2014, ISSN 1813- 7822

Modification of Pinhole Apparatus for Identification and Classification of Dispersive Clay Soils

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Abstract

In this research, modification of pinhole apparatus is made as required by specification of the American Society for Testing and Materials (ASTM D4647 – 93)[3], which works on the basis that distilled water is passed horizontally under the influence of flow of hydraulic amount (50 mm) through a small hole diameter (1 mm) in the soil sample. The nature of the solution, which passes through the sample under the primary head (50 mm) gives index through which a principle to distinguish between dispersive and non-dispersive clays, where the flow of clay diffuses dark and increasingly hole diameter that operate in the sample quickly resulting in an increase in the flow rate.

The apparatus has been modified to take into consideration any angle with the horizon (from zero up to 90^o) and thus can represent cases of flow closer to reality, as the standard apparatus is applicable to prove horizontally, i.e., it is assumed inevitably flow horizontal (horizontal flow) and direction perpendicular to the layers of the soil. Since the primary application to pinhole is in the earth dams, the flow of water through the earth dam rarely is horizontal. So the current development represents more accurately practice.

In addition, the modification included a method to prepare the sample in the compaction model in a manner similar to standard compaction test when the moisture content and dry density are required. This required the use of a pipe pushed in the compaction mold to extract the pinhole test sample. The model is cut to the desired length and then admitted into the cylinder of the pinhole accurately, and this way assures getting a sample with the required properties of density and water content accurately and easily while ensuring homogeneity of the soil instead of the previous method.

As well as water tank has been developed through mobile sitting on a metal platform to achieve different mobile hydraulic heads provided by the test specification.

Keywords: Pinhole test, dispersion, clay, angle of alignment.

تطوير جهاز الثقب الصغير لتمييز و تصنيف الترب الطينية الانتشارية

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الخلاصة:

تم في هذا البحث تطوير جهاز الثقب الصغير (Pinhole) حسب ما تنص عليه مواصفة الجمعية الأمريكية للفحص و المواد (ASTM – D4647 - 93)[3] و الذي يعمل على أساس أن يتم امرار ماء مقطر يجري أفقيا تحت تأثير شحنة هيدروليكية مقدارها (50 ملم) من خلال فتحة صغيرة قطرها (1 ملم) في نموذج التربة. وتكون طبيعة المحلول الذي يمر خلال النموذج تحت الشحنة الأولية (50 ملم) المؤشر الذي من خلاله يستمد المبدأ للتمييز بين الترب الطينية الانتشارية (Dispersive) و غير الانتشارية (Nondispersive)، حيث يكون الجريان من الأطيان الانتشارية غامقا و يتزايد قطر الفتحة التي تعمل في النموذج بسرعة مما ينجم عنه زيادة في معدل الجريان.

و قد تم تحوير جهاز الفحص ليأخذ أي زاوية مع الأفق (من صفر لغاية 90^{o}) وبذلك يمكن تمثيل حالات الجريان بشكل أقرب للواقع، حيث ان جهاز الفحص القياسي المعمول به يفترض أن يثبت بشكل أفقي أي أنه يفترض حتما أن الجريان أفقي (Horizontal Flow) و اتجاهه عمودي على طبقات التربة. ولما كان التطبيق الأساسي لفحص جهاز الثقب الصغير (Pinhole) هو في السدود الترابية (Earth Dams) فان جريان الماء خلال السد الترابي يندر أن يكون أفقيا. و لذلك فالتطوير الحالي يمثل الواقع العملي بشكل أدق.

و تم في هذا العمل أيضا تحوير طريقة اعداد النموذج عن طريق رص النموذج بطريقة فحص الرص القياسي (Standard Compaction Test) عند محتوى الرطوبة و الكثافة الجافة المطلوبة و يتم استعمال أنبوب حديدي بضغطه في قالب فحص الرص لاستخراج نموذج ثم يدفع النموذج من الأنبوب باليد لاستخراجه مع المحافظة عليه من التخلخل و يتم قطع النموذج الى الطول المطلوب ثم يتم ادخاله داخل اسطوانة فحص الثقب الصغير (Pinhole) بدقة، و بهذه الطريقة يمكن الحصول على نموذج يحمل خواص الكثافة المطلوبة بدقة و بسهولة مع ضمان تجانس التربة بدلا من الطريقة السابقة.

و كذلك تم تطوير خزان ماء متحرك من خلال جلوسه على منصة حديدية متحركة لتحقيق مختلف الشحنات الهيدروليكية التي تنص عليها مواصفة الفحص.

Introduction:

Dispersive soils have been the cause of excessive erosion in some soil practices or structures such as dams or channels. Laboratory tests such as the pinhole test have been developed to identify dispersive soils so that they can be avoided or treated to prevent the erosion caused by dispersive characteristics. It is important to identify any dispersive soils as they may be used in construction or be in contact with water when associated with conservation practices or engineering structures. This is usually done by obtaining field samples of the soils involved and sending them to a laboratory for testing.

Dispersive soils are prevalent in many areas around the world and the presence of these soils has always posed a serious problem on potential construction sites. The use of dispersive soils in hydraulic and other engineering structures such as roadway embankments can also lead to serious failures if the problem is not properly identified and addressed appropriately. Although the causes and consequences of dispersion are well understood, one of the main problems is the inability to positively identify such soils and thereby to reduce the potential for failure of many engineering structures.

Soils that are dislodged easily and rapidly in flowing water of low salt concentration are called dispersive soils. Structures such as embankments, channels and other areas are susceptible to severe erosion, when such soils are used for construction. The erodabilty of clayey soil due to flow of rain water is a critical factor in long term performance of earth structures.

Hence, for these applications, it becomes essential to test the erodablity especially during conditions of high surface flow. This kind of erosion manifests itself as the internal erosion which creates a progressive removal of soil particles along the internal pore channels termed as “piping”. The dispersive nature of the soil minerals and its erodability can be assessed by a “pinhole test”. This comprises of measuring the rate of flow through a 1mm diameter hole in the test soil of standard dimension under specified condition. The erodabilty is decided based on increase in rate of flow and turbidity of the outflow. The dispersive soil can also have a high swell shrink potential and low resistance to erosion and have low permeability in an intact state; hence an attempt was made by Bhuvaneshwari and Soundara (2006)[6] to alter this basic characteristic by stabilizing with suitable additives. The effect of these stabilization agents were studied through the pinhole tests, double hydrometer, crumb test and chemical tests. The strength development takes place through the alteration in the microstructure and mineralogy.

A study was conducted by Ismail et al. (2008)[7] to determine the mechanism of internal soil erosion resistance to soil slope instability. The common understanding is that higher probability of slopes failure normally occurred after prolonged heavy rainfall or antecedent rainfall. The infiltration of rainwater through the slope surface creates a path within the soil mass and/or flowing through crack surfaces which penetrate meters in depth. When the soil particles disperse into suspension and transported by water along the flowing movement, the removal particles will lead to internal erosion process. A laboratory study has been carried out to characterize the soil internal erosion resistance to slope instability due to rainwater infiltration and the effect of percentage of coarse to fine-grained soils composition. A pinhole test, crumb test and cylinder dispersion test were conducted to investigate the soil dispersibility characteristic. A randomly selected soil samples were extracted from soil slopes within UiTM, Shah Alam Campus. Samples were collected before and after rainfall. Initial result showed that the soil was prone to disperse near dry or at lower moisture content. Soil samples with higher composition of coarse-grained particles have higher dispersibility that lead to lower resistance to internal erosion.

The research carried out by Maes (2010)[10] aimed at evaluating the pinhole test device described by Sherard et al. (1976)[13] for the assessment of the susceptibility of different horizons in loess derived soils to piping in a quantitative way. Quantitative data on the susceptibility of soil horizons to piping and the contribution to piping to sediment yield are still scarce. By performing laboratory experiments using the pinhole test device, it was tried to (i) evaluate the effects of different hydraulic heads and (ii) evaluate the effect of different initial moisture contents on the hydrological and erosion response of different loessderived soil horizons (disturbed samples): i.e. a clay-enriched horizon, decalcified horizon (C1) and calcareous horizon (C2).

Many identification methods have been proposed but none has been completely successful. The primary test methods that are currently used for the identification of dispersive soils are the pinhole test; the crumb test and various chemical analyses of the soils with the crumb test being the most basic and unsophisticated test to perform. No single test and even the use of a combination of methods are reliable and it is possible that the reason lies in the actual testing procedures. A study by Maharaj (2011)[11] involving the collection of various samples and execution of a single standard dispersive laboratory test, namely the crumb test, has identified some shortcomings. Maharaj (2011)[11] discussed some of the various problems identified in the crumb test method and suggests some solutions to overcome them.

The objective of this study is to develop a pinhole apparatus to distinguish between dispersive and non-dispersive clay soils. The development of the device is to represent the cases flow of water to any angle with the horizon by the modification of testing apparatus to take any angle (from zero up to 90^o) and thus can represent cases of flow closer to reality.

Theoretical Analysis:

Testing through pinhole device aims to direct measurement of dispersibility or colloidal erodability for soft soils stacked. The research summary of the idea that the water that flows through models of clay soils carry plankton diffuse color of colloidal particles while flowing through soil with resistance to erosion of any plankton or crystals of this type. Sodium ion is the more colloidal particles, **Figure (1)** illustrates the relationship between the ratio of sodium ion and the proportion of dissolved salts with determining the boundaries between soils and other diffuse materials.

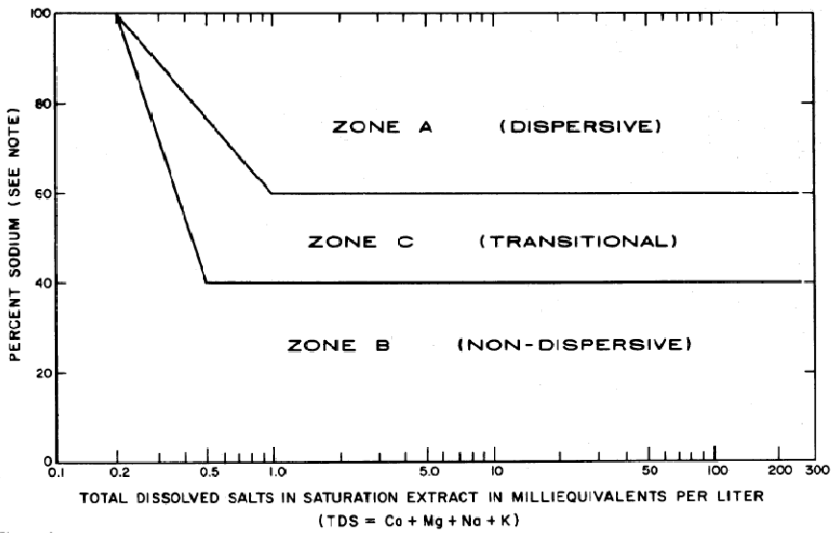


Fig .(1) Identification of soils in terms of the proportion of diffuse sodium ion (United States, Department of Agriculture, 1984)[14].

Pinhole test is a test for direct measurement of the dispersibility (colloidal erodibility) of compacted fine-grained soils. Water is caused to flow through a small hole punched in a specimen. The water running through samples of dispersive clay carries a cloudy colored suspension of colloidal particles, whereas the water running through erosion resistant clays is crystal clear.

The idea of pinhole test is using a small hole as required by the specification of the American Society for Testing and materials (ASTM - D4647 - 93)[3] through which distilled water is being horizontally passed under the influence of the hydraulic pressure head amount (50 mm) through a small hole diameter (1 mm) in the soil model. The nature of the solution that passes through the sample under a primary hydraulic head (50 mm) derives a principle to distinguish between soil clay diffused; dispersive and non-dispersive, where flow from clays diffuse dark and increased hole diameter that operate in the sample quickly resulting in an increase in the flow rate. The flow through the non-dispersive clay soils lead the solution with a little dark with a fixed size of the hole in the static model, as well as the flow rate through the non-dispersive clay soils is pure, clear with no change in the slot of the sample.

Limitations of the Test:

1. This test is applicable in soils that contain very fine materials (finer than 0.005 mm) less than (12%) or plasticity index less than or equal to (4). These types of soils in general have low resistance to spread regardless of the propagation characteristics of the clay.
2. Results can be obtained with acceptance of reality is good if it has to maintain the natural moisture content of the model through the stages of modeling, transport, storage and laboratory testing operations.
3. This test was developed to examine the chaotic models of undisturbed soil samples, which are stacked in the cylinder test. The examination can be performed on undisturbed samples if a well-trimmed tube is inserted inside the standard compaction test mold. It has been found that the present method of testing is not applicable in assessing the propagation characteristics of the models in highly sensitive clays which can be classified as dispersive in the pinhole test, but in their behavior act as non-dispersive in nature.

Reasons for Modification and Features of the New Apparatus:

In addition to the reasons mentioned in the preceding paragraph, some reasons are listed below that have been deduced by studying the practical applications of this test:

1. The standard instrument is supposed to prove any horizontal inevitably, it is assumed that the flow is horizontal and its direction is perpendicular to the layers of the soil, and this is not always actual case since the primary application to examine a pinhole is in earth dams. It is noted through **Figure (2)** that the flow of water through the dam rarely be

horizontal. It is well known that the permeability of the soil in the direction[1] of the composition classes up to about ten times the permeability in the vertical direction, and this leads to a change in the flow rate values.

2. The specification indicates that the use of sample preparation method to get almost 95% of the maximum dry density that can be obtained from the standard compaction test.

The sample preparation process in this case is difficult to implement because of the small size of the sample in addition to the failure to ensure access to dry density representing the density at the work site.

American Standard (ASTM D422)[2] states to determine the sizes of soil constituents; gravel, sand, silt and clay by the size gravel starts from No. 4 sieve size with openening (4.75) mm and so there is a contradiction in determining the sizes of gravel. The gravel must be greater than (4.75 mm) and not (2 mm), and therefore, the suitable size for gravel can be dealt with (6 - 10) mm, note that the template testing pinhole device is small and that the sand measured (2 mm) does not provide the appropriate layer.

Studies have shown that the shape of the clay core in earth dams and the direction affect in determining the amount of flow that passes through the core of the dam and its stability through normal flow and also rapid draw down as referred by (Lauffer and Schoer, 1961[9], Sherard et al., 1963[12]).

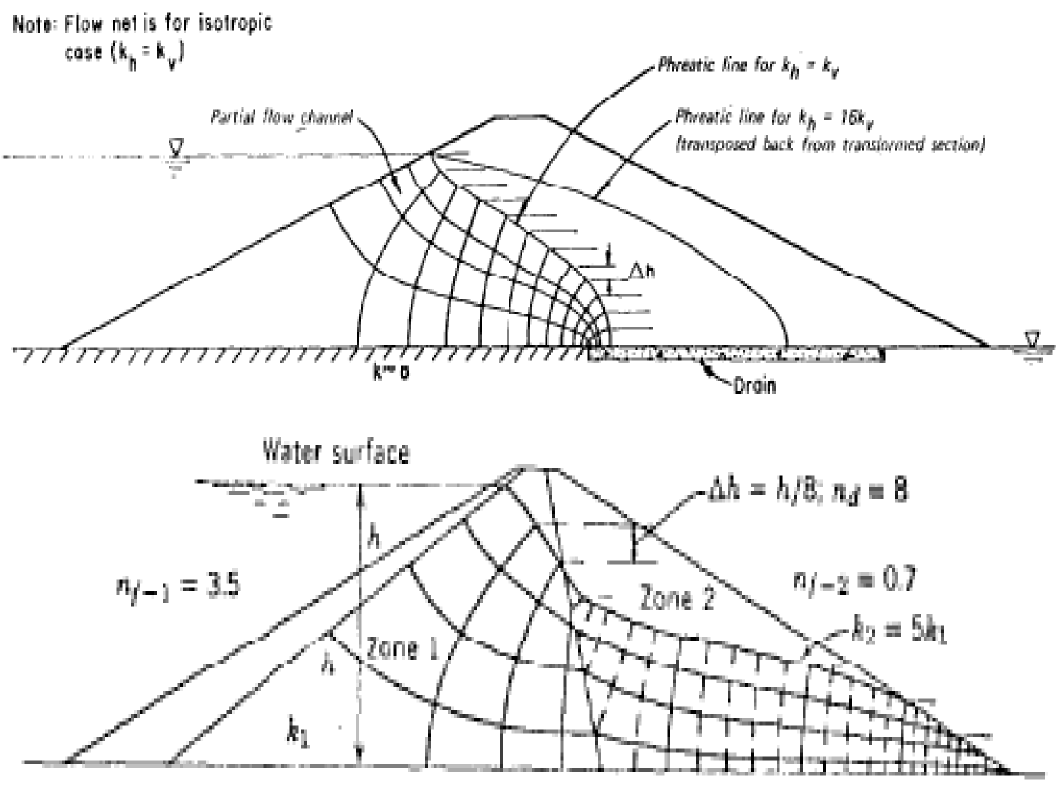
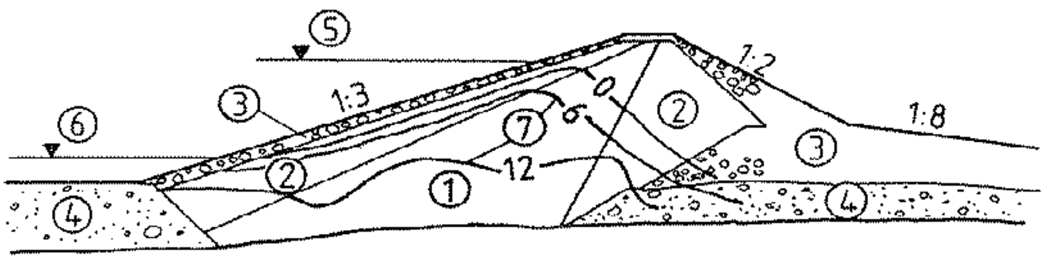


Fig .(2) The cases of flow in earth dams (US Bureau of Reclamation, 1987)[14].

Figures (3) and (4) present the flow shape and direction of flow lines which pass through the core of the dam, which tends different angles. The different lines of flow affects the amount of flow through the core of dam and thus differs determine the degree of dispersion as was proven in the results.



1 Impervious zone
2 Semi-permeable zones
3 Free-draining zones
4 Alluvial river deposits
5 Full supply level at 1655 m a.s.l.
6 Water level after rapid drawdown at 1619 m a.s.l.
7 Lines of equal pore pressure after rapid drawdown (pressures in m of water head)

Fig .(3) Earth dam with inclined core (US Bureau of Reclamation, 1987)[15].

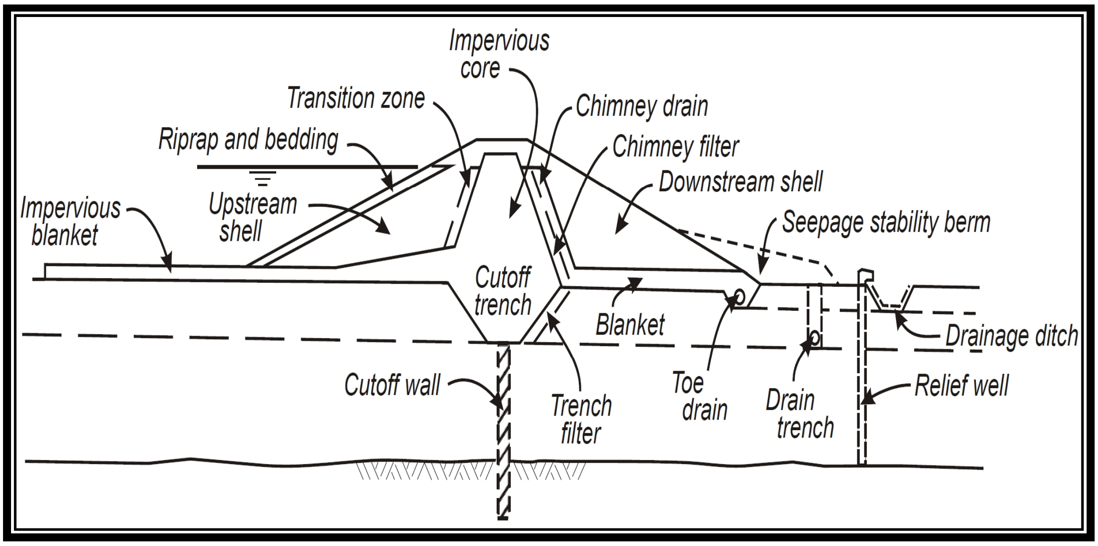


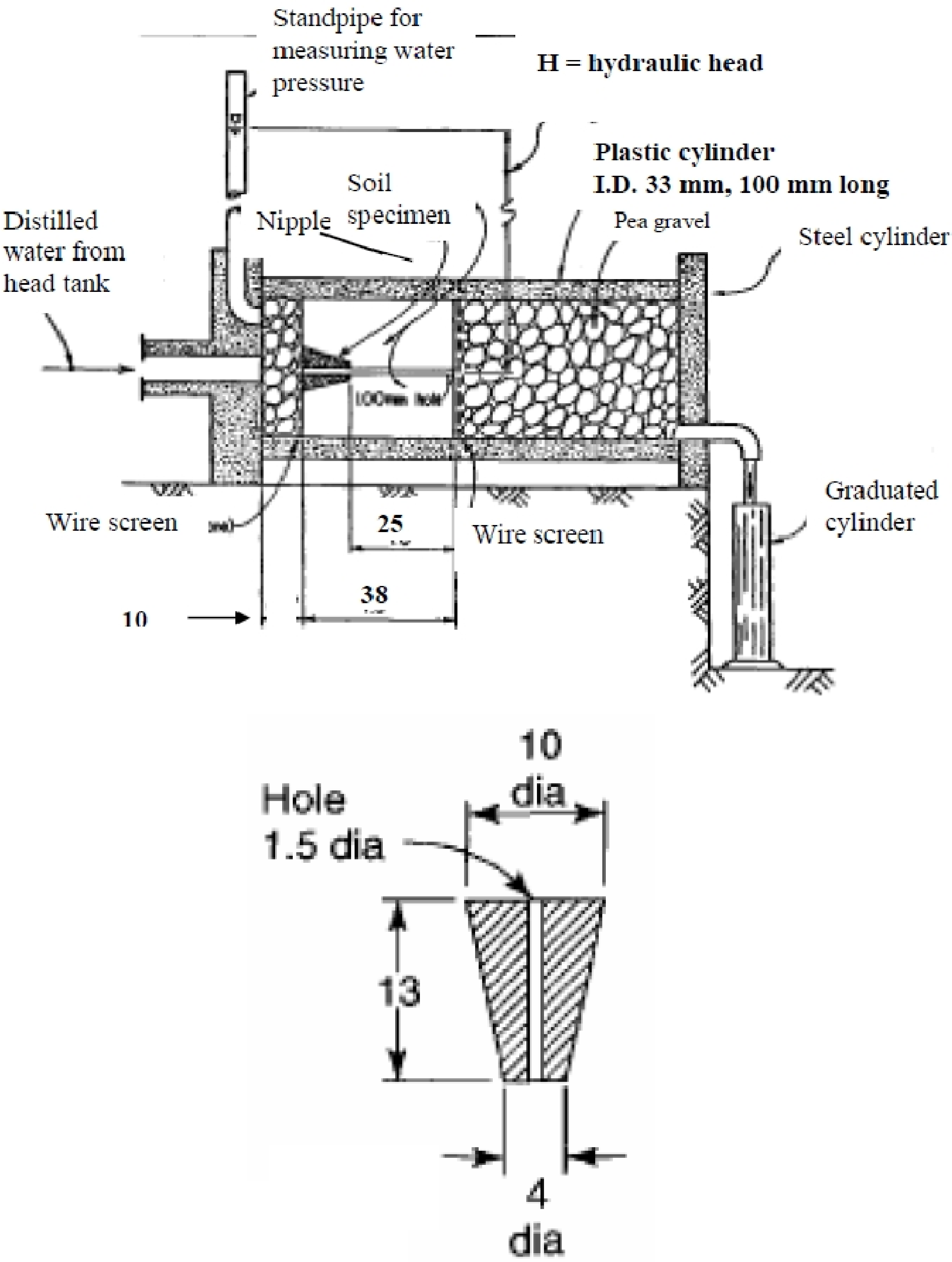
Fig .(4) Earth dam with vertical core (Kutzner, 1997)[8].

The Modified Testing Apparatus Components:

Apparatus consists of a pinhole of the parts shown in **Figures (5) and (6**) are:

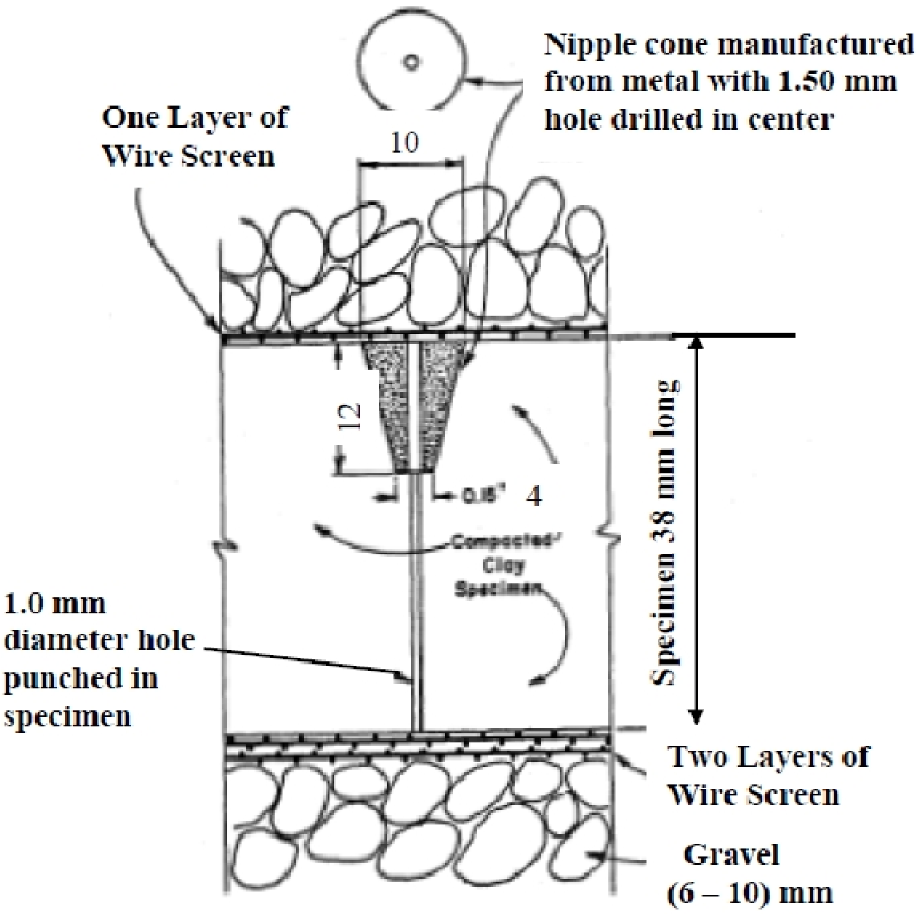
1) A metal tube or a template with an internal diameter (33 mm) and length (100 mm).
2) The plastic ring help ensure the hole form from his part with an average cone diameter (1.5 mm) or (0.06 in) and length (12 mm) or (0.5 in) and are working aperture diameter (1 mm) at the end of this episode.

3) There is a hole in the top of the tube through which iron hook a measure of the pressure of the water to control the shipment of water pressure in the sample.
4) A layer of fine gravel with a regular gradient (6-10 mm), where the granules were isolated on sieve size (3/8 in) and remaining on the sieve size (1/4 in).
5) There are two of the circular wire networks operated business candidate (filter) on both sides of the sample as shown in **Plate (1).**



Note: All dimensions in millimeters.

Fig .(5) A schematic diagram of the pinhole apparatus.



Note: All dimensions in millimeters.

Fig .(6) A diagram of the soil sample in the pinhole apparatus.

Plate .(1) Components of pinhole apparatus.

Testing Procedure:

1. A sample of silty clay was selected for test. Standard compaction test was carried out according to (ASTM D698-00)[4], **Plate (2).** The relationship between moisture content and dry density is shown in **Figure (7).**

   The optimum moisture content was found to be equal to (24%) and the dry unit weight (17.20 kN/m^3). The model has been compacted in the same standard mold for compaction device at the optimum moisture content. It is worth mentioning that the dry density and moisture content of the model must refer to the real models used in the construction of the earth dam and the method has been developed to simulate reality better.
2. Sampling tube is used to cut a sample from within the standard monitoring device as shown in **Plate (3).**
3. The sample was extracted from inside of the sampling tube carefully as shown in **Plate (4)**. Then it was cut to the desired length (38 mm) and has been verified diameter (33 mm) as it appears in **Plate (5).**
4. After placing the bottom cover of the cylinder, a layer of fine gravel with a thickness (50 mm) is put as shown in **Plate (6)** and above is placed a circular wire mesh (2) as shown in **Plate (7).**
5. The clay model is inserted into the mold carefully to ensure that it rests on the mesh, and then a conical ring is inserted that contains a slot of diameter (1.5 mm) to the center of the top of the form by clicking fingers to determine the center of the hole as shown in **Plate (8).**

Plate .(2) Preparation of sample by the standard compaction device.

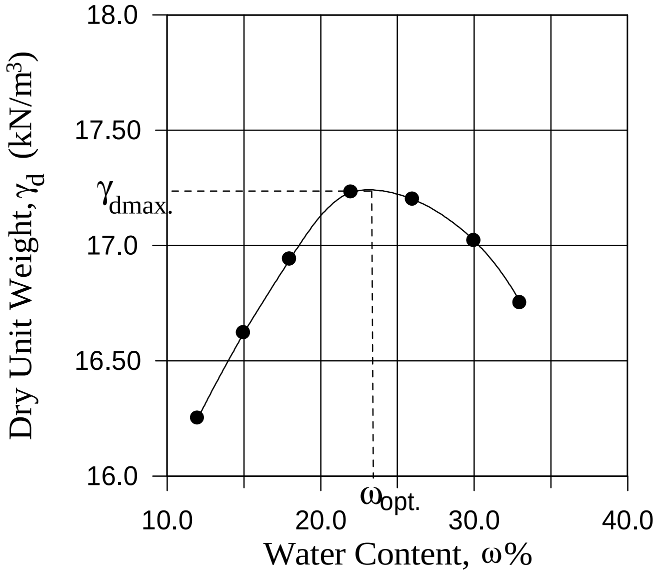


Fig .(7) Standard compaction test results on the soil model used.

Plate .(3) Extraction of he desired measurement model using tube-making for this purpose.

Plate .(4) Extracting the sample of sampling tube.

Plate .(5) Cutting the model to achieve the desired length.

Plate .(6) Putting a layer of fine gravel at bottom of the sample.

Plate .(7) Circular wire mesh No. (2) above the layer of fine gravel.

Plate .(8) Insertion of conical ring inside the clayey sample.

6. A needle of diameter (1 mm) is inserted inside the conical ring that works as a guide that maintains the needle in the middle of the entry form, then the needle is pressed into the soil slowly to penetrate the needle all the clay model and up to the fine gravel layer. Then the needle is withdrawn cautiously while maintaining the slot.
7. Keep circular wire mesh (1) on the form accurately with clay stay conical ring in its place, and fill the remaining space at the top of the model layer of gravel, sand, which is supposed to be 10 mm thick as shown in **Plate (9).** Steel tube will close the upper lid and plastic tube is linked to a water source and proves water pressure gauge, as well as the clear plastic tube, which marks the shipment as it appears in pressure **(Plate 10).** To ensure that the device is horizontal or inclined, a device is used to measure the angle of inclination and one can also use manual balance to achieve the horizontal position of the device as shown in **Plate (11).**

Plate .(9) introduction of circular wire mesh No. (1) above the clayey sample.

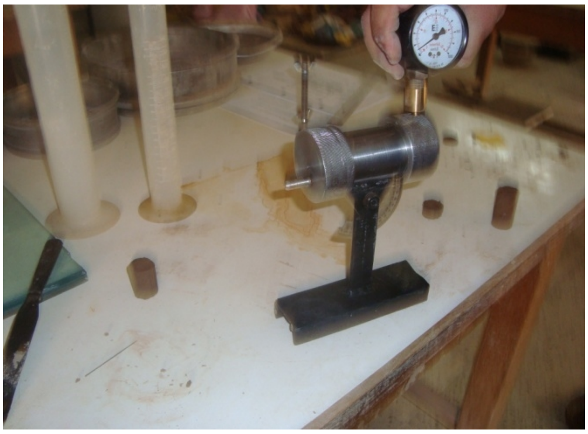


Plate .(10) Connecting the top cover and the pressure gauge.

8. The introduction of screening begins distilled water inside the device so that the shipment at the level of hydraulic pit (pinhole) equal to (50 mm) and this is done through the use of a mobile water tank through sitting on a metal platform and plugged into a mobile device through a plastic tube as shown in **Plate (12).**
9. A graduated cylinder is used to collect water outside of the device and measuring the amount of water that comes out of the current model as in **Plate (13).** If there is no flow of water, the test is stopped and one have to make sure that the hole is not closed.
10. The time required to collect water volume (10 ml) in the cylinder is recorded, and other measurements are made at periods of time to assemble (25 ml) or (50 ml) or (100 ml) of water flowing (effluent).

Plate .(11) Use of manual water bubble for ensuring the device horizontally.

Plate .(12) The use of a mobile water tank for achieving hydraulic head.

Plate .(13) Assembling the water leaving the model in a graduated cylinder and recording time.

Criteria for Evaluating Results:

1. Note brownish (turbidity) abroad each water discharge is measured by looking at aspects of the cylinder listed, as well as consider a vertical column of liquid in the cylinder. The degree of discharge of the model is described using one of the following terms (ASTM D 4647-93)[5]:
   (a) Very Dark
   (b) Dark
   (c) Moderately Dark
   (d) Slightly Dark
   (e) Barely Visible
   (f) Completely Clear
2. Continue examination under the influence of hydraulic shipment of (50 mm) for five minutes, if it was outside of the sample at the end of five minutes of a very dark and the flow was gradually increasing at a rate up to (1.0 to 1.4 ml/sec), the test is considered terminated.
3. The cylinder is opened and the clay is extracted, the mold is split longitudinally and the size of the hole is measured and compared with the diameter of the needle used for the work of this hole. If the final diameter of the aperture was larger than twice the diameter of the needle, the soil is classified as a high prevalence D1, as observed in **Plate (14).**
4. If the water flowing from the dark form and the flow rate does not exceed (1.0 ml / sec) at the end of five minutes, the examination continues for another five minutes. At the end of ten minutes, if the water outside is still dark stop examination and aperture size is measured, and the soil is classified as a pervasive D2, observed (**Plate 15).**
5. If the water flowing from the model a bit dark at the end of ten minutes and the flow rate was between (0.4 - 0.8 ml / sec), increase the hydraulic head to (180 mm) by raising the level of the water tank, which equips the system with water. If the shipment abroad under water pressure of (180 mm) dark and the flow rate was between (1.4 - 2.7 ml / sec), stop testing and the hole diameter is measured, if the orifice diameter equal to or greater than (1.5 - 2) the needle diameter, the soil is classified as low or medium-proliferation ND3.
6. If the water was flowing from under the consignment model of (50 mm) or pure dark quite a bit at the end of ten minutes and the flow rate was between (0.4 - 0.8 ml / sec), then increase hydraulic head to (180 mm). If the water abroad under the influence of this shipment is dark and the rate of flow is increasing rapidly up to (4.1 to 7.2 ml / sec), then stop the test and measure the hole diameter. If the hole diameter is equal to or greater than (1.5 - 2) the needle diameter, the soil is classified as low or medium-proliferation ND3.

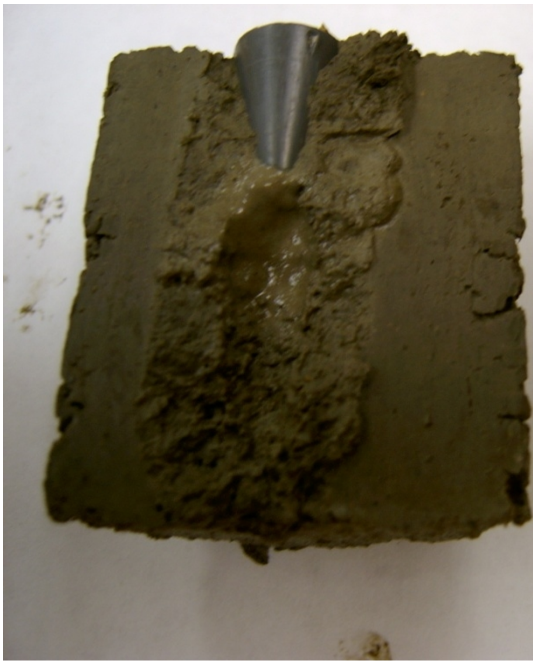
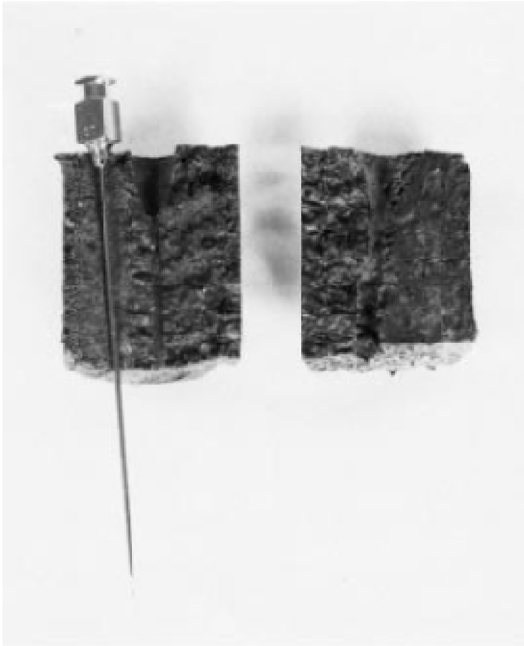
 

Plate .(14) Test hole size after the end of the examination.

If, however, the flow under the influence of a head of (180 mm) and the water continues abroad completely pure after (5) minutes and the flow rate was between (0.8 - 1.4 ml / seconds), the head is raised up to (380 mm), and after five minutes, if it shows an increase in runoff brownish or increased until the flow rate (1.8 - 3.2 ml / sec), stop the test and the soil is classified as a low prevalence ND3. **Table (1)** presents a summary of the classification of soils under the test steps above.

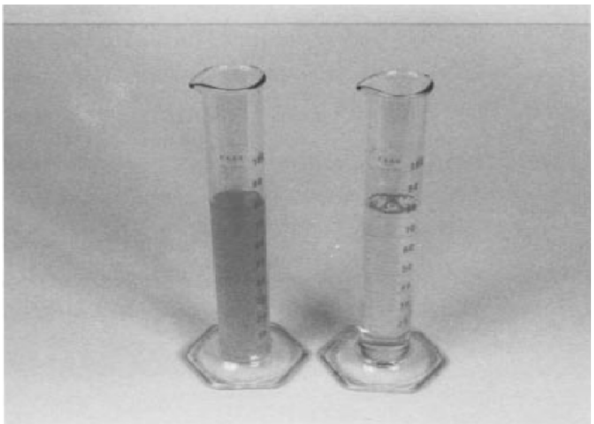


Plate .(15) Comparison of water brownish flowing from the model to determine the dispersion of the sample.

Table .(1) Classification of clay soils under the pinhole test results (ASTM D4647 - 93)[5].

Dispersive classification	Head (mm)	Test time for given head (min)	Final flow rate through specimen (ml/s)	Cloudiness of flow at end of test		Hole size after test (mm)
				from side	from top	
D1	50	5	1.0 to 1.4	Dark	Very dark	2.0
D2	50	10	1.0 to 1.4	Moderately dark	Dark	> 1.5
ND4	50	10	0.8 to 1.0	Slightly dark	Moderately dark	≤ 1.5
ND3	180 380	5 5	1.4 to 2.7 1.8 to 3.2	Barely visible	Slightly dark	≥ 1.5
ND2	1020	5	> 3.0	Clear	Barely visible	< 1.5
ND1	1020	5	≤ 3.0	Perfectly clear	Perfectly clear	1.0

Results and Discussion:

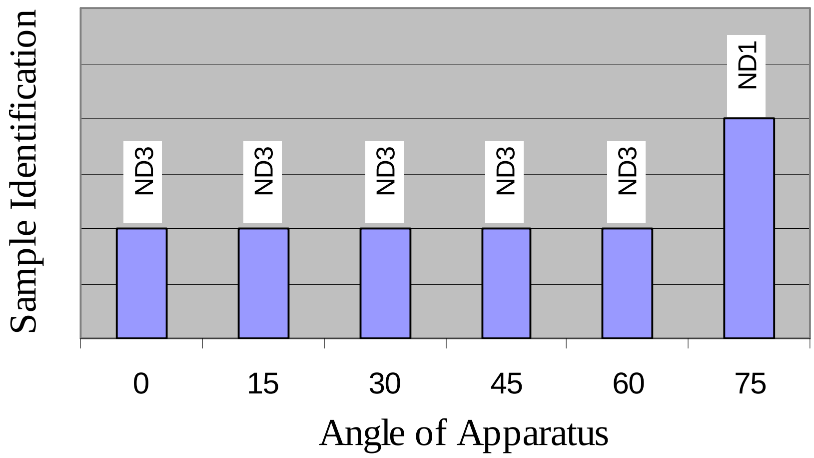
The device has been modified to work at different angles from zero to 90°. Thirty (30) tests have been conducted for the soil which has been prepared with varying angles; zero (landscape mode) and 15°, 30°, 45°, 60°and 75°. The results have been obtained; a set of results for one model is presented in data sheets to validate changing the inclination angles of the device. It can be observed that there is a difference in classification of the soil examined in terms of portability spread different inclination angles and this confirms and justifies the need to the represented soil sample angle in the modified apparatus. **Figure (8)** makes a comparison between the identifying symbols for different angles of the apparatus.

Conclusions:

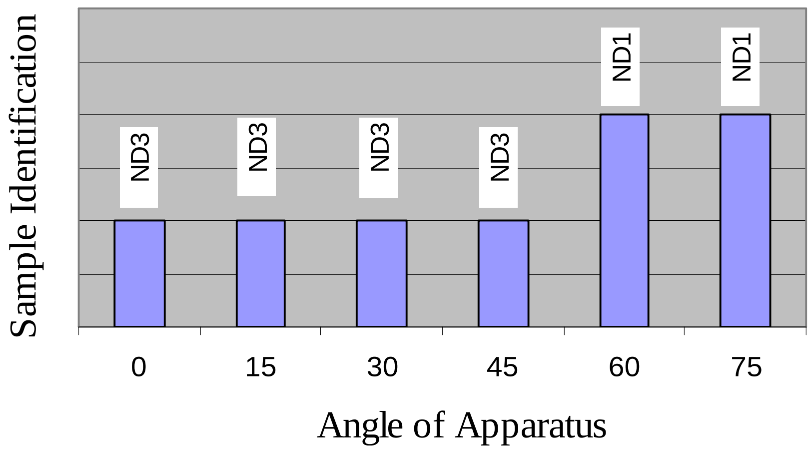
1. The modification of pinhole apparatus to distinguish between dispersive and non-dispersive clay soils, where runoff from land dark and increasingly diffuse hole diameter that operate in the sample quickly resulting in an increase in the flow rate.
2. The development of the apparatus is to represent the cases of flow of water to any angle with the horizon by the modification of testing apparatus to take any angle (from zero up to 90^{o}) and thus the apparatus can represent cases of flow closer to reality, and it is found

that this modification is successful and can be applied easily to express cases of anisotropy in the permeability of the soil properties.

3. A method was developed to prepare model clay used by compaction of the soil sample in a manner similar to the standard compaction test. When the dry density is specified, a pipe is pushed in the compaction mold to extract the sample, and then the sample is cut to the desired length and entered carefully to the pinhole cylinder. This will ensure getting a sample with the required properties of density and water content accurately and easily and ensure soil homogeneity.



a. Sample 1.



b. Sample 2.

Fig .(8) Effect of angle of pinhole on results.

References

1. Al-Labban, S. N. Y., (2007), "Seepage Analysis of Earth Dams by Finite Elements", M.Sc. thesis, University of Kufa.
2. ASTM-D-422-00, "Standard Test Method for Particle – Size Analysis of Soils", Annual Book of ASTM Standards, Vol. 04.08, Soil and Rock, pp. 1 – 8.
3. ASTM D 4647 – 93 (Re-approved 1998), "Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test", American Society for Testing and Materials.
4. ASTM D 698 – 00," Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3(600 kN-m/m^3))", American Society for Testing and Materials.
5. ASTM D 4647 – 93 (Re-approved 1998), "Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test", American Society for Testing and Materials.
6. Bhuvaneshwari, S. and Soundara, B., (2006), "Stabilization and Microstructural Modification of Dispersive Clayey Soils", from internet.
7. Ismail, F., Mohamed, Z., Mukri, M., (2008), "A Study on the Mechanism of Internal Erosion Resistance to Soil Slope Instability", Electronic Journal of Geotechnical Engineering, EJGE, Vol. 13, Bund A.
8. Kutzner, E., (1997), "Earth and Rockfill Dams – Principles of Design and Construction", A. A. Balkema, Rotterdam.
9. Lauffer, H., and Schober, W., (1961), "Investigation for the Earth Core of the Gepatsch Rockfill Dam with a Height of 500 ft", Seventh Congress on Large Dams, Rome, Question 27, Report 92.
10. Maes, R., (2010), "Pinhole test device for identifying susceptibility of different soil horizons in loess-derived soils to piping erosion", Bachelor thesis, the Catholic University of Leuven (Belgium).
11. Maharaj, A., (2011), "The Use of the Crumb Test as a Preliminary Indicator of Dispersive Soils", Proceedings of the 15th African Regional Conference on Soil Mechanics and Geotechnical Engineering, pp. 299-306.
12. Sherard, J. L., Woodward, R.J., Gizienski, S.G., and Cleverger, W.A., (1963), "Earth and Earth Rock Dams", John Wiley and Sons.
13. Sherard, J. L., Dunnigan, L. P., Decker, R. S., (1976), "Identification and Nature of Dispersive Soils", Journal of Geotechnical Engineering Division, ASCE, Vol. 102, GT4, pp. 284-301.
14. United States, Department of Agriculture, (1984). "Soil Mechanics Testing Standards", Soil Mechanics Note No. 8, Soil Conservation Service, Washington.
15. U.S. Bureau of Reclamation, Department of the Interior, (1987), "Design of Small Dams", U.S. Govt. Print. Office, Washington, D.C., third edition.

Appendix

Test No. 1 **Sample symbol: C1**

Angle of sample: 0 (horizontal) **Date of test: 5 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side				Completely clear from top	Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear		None	Few	Heavy	
11:10	50	10	30				√	√	√			Sparkling clear
		10	45									
		10	60									
11:45	180	31	30				√	√	√			Sparkling clear
		48	45							√		
		66	60							√		Slightly dark Rate of flow (1.03 – 1.10) ml/sec.
												End Test ND3

Test No. 2 **Sample symbol: C1**

Angle of sample: 15° **Date of test: 5 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side				Completely clear from top	Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear		None	Few	Heavy	
11:35	50	10	30				√	√	√			Sparkling clear
		10	45									
		12	60									
12:55	180	34	30				√	√	√			Sparkling clear
		49	45							√		
		70	60							√		Slightly dark Rate of flow (1.08 – 1.16) ml/sec.
												End Test ND3

Test No. 3 **Sample symbol: C1**

Angle of sample: 30° **Date of test: 9 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side					Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear	Completely clear from top	None	Few	Heavy	
11:15	50	10	30				√	√	√			Sparkling clear
		10	45									
		12	60									
12:10	180	36	30				√	√	√			Sparkling clear
		51	45							√		
		73	60							√		Slightly dark Rate of flow (1.13 – 1.21) ml/sec.
												End Test ND3

Test No. 4 **Sample symbol: C1**

Angle of sample: 45° **Date of test: 9 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side					Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear	Completely clear from top	None	Few	Heavy	
11:35	50	10	30				√	√	√			Sparkling clear
		10	45									
		12	60									
1:20	180	37	30				√	√	√			Sparkling clear
		53	45							√		
		75	60							√		Slightly dark Rate of flow (1.17 – 1.25) ml/sec.
												End Test ND3

Test No. 5 **Sample symbol: C1**

Angle of sample: 60° **Date of test: 10 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side				Completely clear from top	Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear		None	Few	Heavy	
10:20	50	10	30				√	√	√			Sparkling clear
		10	45									
		12	60									
11:00	180	41	30				√	√	√			Sparkling clear
		61	45							√		
		83	60							√		Slightly dark Rate of flow (1.35– 1.38) ml/sec.
												End Test ND3

Test No. 6 **Sample symbol: C1**

Angle of sample: 75° **Date of test: 11 / 2 / 2010**

Clock time	Head (mm)	Flow rate		Color from side				Completely clear from top	Particles falling			Remarks
		ml	sec	Dark	Slight to medium	Barely visible	Completely clear		None	Few	Heavy	
10:25	50	31	30	√				√		√		Sparkling clear
		48	45									Slightly dark Rate of flow (1.03 – 1.07) ml/sec.
												End Test ND1