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Assessment of Soil Dispersibility Behaviour In-Relation to Soil Internal Erosion Resistance

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ABSTRACT

A study was conducted to assess soil dispersibility behaviour in-relation to soil internal erosion resistance. Dispersive soils can be a problem for many geotechnical projects and structures. Water flowing in a crack of earth dam or infiltration of rainwater through the crack of slope surface with enough erosion energy can detach the soil particles into suspension and transport it along the movement that will lead to internal erosion process. Soil samples from sloping area within UiTM Shah Alam Campus were collected and a laboratory study was carried out to assess the soil dispersibility behaviour. A laboratory pinhole test and crumb test were conducted to identify soils which are easily dispersed hence susceptible to internal erosion. Indication of the removal of soil particles during testing is a factor in assessing the possibility of internal erosion. Fine-grained soils are known to have low resistance to erosion however laboratory result shows that soils fraction with high coarse-grained percentage has high dispersibility grade that lead to lower internal soil erosion resistance whereas the high moisture content percentage would enhance the dispersibility characteristic of the soils performance.

Keywords: *Soil dispersibility, internal erosion, and rainwater infiltration.*

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Introduction

There are two factors which must be considered in assessing the possibility of internal erosion namely, the conditions which lead to the development of cracking and the removal of material (soils particles which easily eroded). Both are necessary for internal erosion study however it need to be of different issues and should be treated separately [1]. This research mainly focused on the dispersibility characteristic of soils since the study of internal erosion has been closely linked to the identification of dispersive soils.

Certain fine-grained soils are structurally unstable, easily dispersed and therefore highly erodible. Soils in which the clay particles will detach spontaneously from each other and go into suspension in quiet water are termed as dispersive clay [2]. These dispersive clays cannot be differentiated from ordinary erosion-resistant clays by routine civil engineering tests [3]. Dispersibility is a physico-chemical process which is mainly affected by the type of soil minerals and chemical properties of the soil pore fluid [3]. Based on the effect of pore fluid on the dispersibility behaviour of soils, it can be said that once a dispersive soil is exposed to water, clay particles may disperse and remain as suspended particles [4].

The dispersive clays characteristic is also depends on the influence of clay-sized particles and plasticity. Soils with the fraction finer than 0.005 mm ≤ 12 percent and with plasticity index ≤ 4 generally do not contain sufficient colloids to support dispersive erosion [3]. These fine-grained soils are known to have low resistance to erosion.

Internal Erosion

Site reconnaissance is required to confirm the information acquired from the desk study and also to obtain additional latest information from the site. It is also very important to locate and study the outcrops to identify previous landslides or collapse that can act as an indicator of the stability of the existing slopes.

The study of internal erosion has been closely linked to the identification of dispersive clays. It has recognized that natural clays in a dispersive state is an important and fundamental factor that contribute to geotechnical engineering problems. The formation of piping phenomena in earth dam, deterioration and demolition of roads sub-base, the erosion of the compacted soils of landfill clay liners and the instability of soil sloping area are some examples of geotechnical problems due to internal erosion effect. These have been recognized for many years. Sherard *et al.* [5] has developed an understanding of the erosion and piping process and introduced the pinhole erosion test to identify soils which are susceptible to erosion. There are two factors that must be considered in assessing the possibility of internal erosion; the conditions which lead to the development of cracking and the removal of material. Both are necessary for internal erosion studies however both conditions are of different issues and should be treated separately [1].

i. Mechanism of Internal Erosion - If a water-filled crack occurs, soil adjacent to the crack, will swell in the presence of free water and effective stresses will approach zero.
ii. Crack Development in Clay Soil - Crack tends to develop during cycles of long dry spell. During period of rainfall that follows the dry spells, water fills the cracks and fissures.

Problem Statement

Dispersive soils can be a problem for many geotechnical projects and structures. Problems involving dispersive soils include rainfall erosion on slopes, potential slope failure after prolonged heavy rainfall, piping failure of earth dams, erosion of shoreline on reservoirs due to wave action, deterioration and demolition of roads, the erosion of the compacted soils of landfill clay liners and erosion of channels (both unlined and lined) constructed in dispersive soils. In appearance, dispersive soils are like normal soils that are stable and somewhat resistant to erosion but in reality they can be highly erosive and subject to severe damage or failure [6]. For that reason it is important to understand the nature of dispersive soils and to be able to identify their dispersibility characteristic so that these types of soils can be treated or replaced them with non-dispersive soils. Figure 1 and Figure 2 show the examples of a failure due to internal erosion at embankment dam and a potential slope failure due to the development of crack at slope crest.

The primary objective of this investigation was to identify the dispersibiliy characteristic of soil samples collected at sloping area within UiTM Shah Alam Campus. The secondary objectives included are to study the influence of soils fraction/composition and moisture contents percentage with respect to the soil internal erosion resistance.

(a) (b)

Figure 1: A failure due to internal erosion which leaves a huge void space along the conduit and embankment failure due to discontinuity represented by the conduit. [Photo extracted from Federal Emergency Management Agency (FEMA), National Dam Safety Program, USA – conduit through embankment dam]

Figure 2: The development of tension crack at the crest of slope surface in which the present of rainwater will expedite the potential slope failure. Picture was taken at Wangsa Maju, Kuala Lumpur

Methodology

The research work is mainly an experimental based. Soil sampling was collected at about 0.5 to 1.0 m depth from original ground surface at the top, middle and bottom section of every slope. Laboratory tests were conducted to determine the soil physical properties and soil dispersibility characteristic. A flowchart in Figure 3 shows the focus or the research activities involved.

All soil samples were tested to determine the physical properties and classifications. For soil classification test, wet sieving, dry sieving and hydrometer test were conducted following the guidelines and

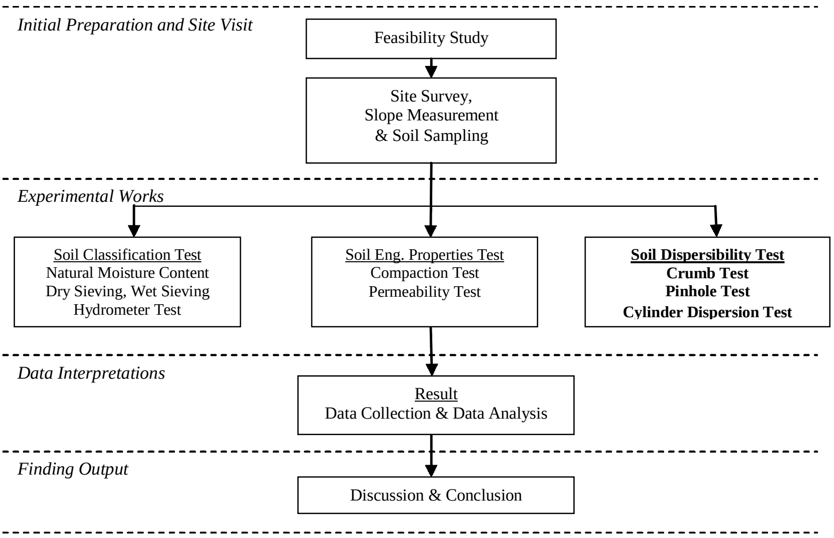


Figure 3: Research Methodology Flowchart

recommendations standard as suggested in BS1377: Part 2-5 [5]: Method of testing soils for civil engineering purposes. Soil specimens were prepared to cover a wide range of molding moisture contents (optimum moisture content). All the hydraulic conductivity tests were conducted in the compaction mold permeameters using the falling-head method in accordance with Head [7].

Soil Dispersibility Tests

Several methods can used to determine the dispersibility characteristic of soil as suggested in BS1377:Part5:1990. In this research, a laboratory pinhole test and crumb test were used to identify the dispersibility characteristic of soil samples.

Crumb test was developed in 1967 to identify dispersive soil behaviour in the field, but is now often used in the laboratory as well. In crumb test, identical procedures are used. The test consists of either preparing a cubical specimen of about 6 mm to 10 mm on a side at natural water content or selecting a soil crumb at natural water content of about equal volume. The specimen is carefully placed into a 100 ml glass beaker about one-third full of the sodium hydroxide solution, the reaction will be observed after allowing the crumb to stand for 5 to 10 minutes. As the

Table 1: Guide for the Interpretation of Observation for Crumb Test

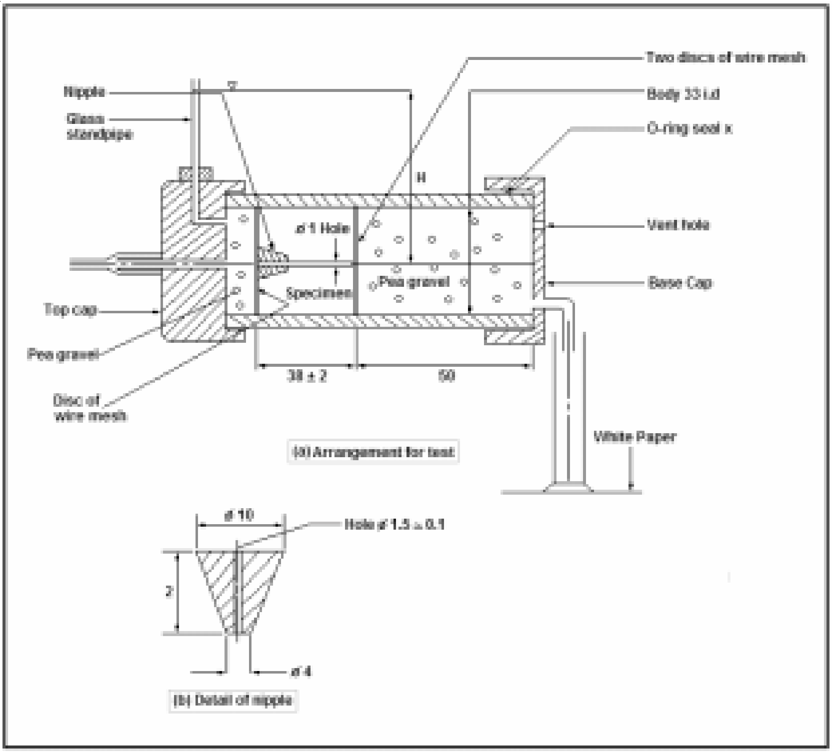
Reaction	Grade	Categories
NO REACTION Crumbs may slake or run out to form a shallow heap on the bottom of the beaker, but there is no sign of cloudiness caused by colloidal in suspension.	G1	Non-Dispersive
SLIGHT REACTION A very slight cloudiness can be seen in the water at the surface of the crumb.	G2	
MODERATE REACTION There is an easily recognizable cloud of colloidal in suspension usually spreading out in thin streaks at the bottom of the beaker.	G3	Dispersive
STRONG REACTION A colloidal cloud covers most of the bottom of the beaker, usually as a thin skin. In extreme cases all the water becomes cloudy.	G4	

soil crumb begins to hydrate, the tendency for colloidal-sized particles to deflocculates and goes into suspension is observed in accordance with the guideline in the BS1377: Part 5 [12]. Table 1 shows the characteristic grading guidelines for crumb test.

The pinhole erosion test is the most reliable test for identifying dispersive soils. The pinhole erosion test was developed for the purpose of identifying dispersive soils. This test method presents a direct, qualitative measurement of the dispersibility and consequent colloidal erodibility of clay soils by causing water to flow through a 1.0 mm diameter hole punched in specimen of re-compacted soils under a controlled hydraulic head. Detail guidelines and standard procedure is as suggested by BS1377: Part 5 [12]. The resistance to erosion of the soil sample is judged visually by the presence or absence of turbidity in the water, which emerges, and from measurements of rates of flow and the final holes diameter. Distilled water was used as a basis of comparison, but it has been found that the effect of using natural ground or river water was generally somewhat less server. Figure 4 shows the pinhole apparatus and its schematic diagram.

Detail criteria for evaluating results were given in the Table 2, which forms the basis for the method of reporting results. The dispersibility

a. Laboratory Set-up



b. Schematic Diagram

Figure 4: Pinhole Test Apparatus

categories of the soils were classified under six different grading ranging from ‘dispersive soils’ (categories D1 and D2) to ‘non-dispersive soils’ (categories ND 1 to ND 4).

Table 2: Classification of Soils by Pinhole Test Data

Dispersive classification	Head (mm)	Test time for given Head (min)	Final flow 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	5	1.4 to 2.7	barely visible	slightly dark	≥ 1.5
	380	5	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

BS1377: Part 5 [8]-Extracted, with permission, from the annual book of ASTM standards.Copyright American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

Results and Discussion

There were eight locations of sloping area where the soils sampling were taken. Slope gradient ranging from 17 ° to 32 ° with varying vertical slope height ranging from 7 m to 20 m. The soil classification tests showed that most of the soil samples collected was governed by fine grained soils except for L7 which consisted of 67 % of coarse-grained soils. The natural moisture content percentage is between the range of 15 % and 34 %. Table 3 shows the soil classification test results conducted using wet sieving, dry sieving and hydrometer method. The permeability, natural and optimum moisture content of samples is stated for every site location including the slope physical measurements.

Table 3: Soil Physical Properties

Site location	Slope Height/ Slope Gradient (m/ ^{0})	Soils		Natural Moisture content (%)		Omc (%)	Max Dry Density ρ_d (Mg/m^3)	Permeability (m/s)
		Coarse-grained (%)	Fine-Grained (%)	Clear Day	After Rain			
L1	15m /17^0	47 sandy clayey SILT	53	15	27	11	1.90	7.34×10^{-7}
L2	20m /21^0	49 sandy clayey SILT	51	20	30	12	1.82	3.29×10^{-7}
L3	8m / 28^0	55 sandy clayey SILT	45	16	30	10	2.33	8.64×10^{-7}
L4	18m / 17^0	43 sandy clayey SILT	57	26	31	8	1.65	1.05×10^{-8}
L5	20m / 29^0	63 gravely clayey SILT	37	25	20	11	1.91	4.02×10^{-8}
L6	18m / 30^0	54 gravely clayey SILT	46	25	34	8	2.35	3.37×10^{-8}
L7	15m / 30^0	67 very silty gravely SILT	33	16	-	16	2.05	1.14×10^{-7}
L8	7m / 32^0	16 slightly sandy clayey SILT	84	29	-	7	2.03	5.41×10^{-8}

The laboratory crumb test and pinhole test data are used to evaluate the soil dispersibility grade to link with internal erosion resistance. Additional three types of laboratory soil samples were prepared for crumb test with the percentage of soils fraction for coarse-grained to fine-grained of 50:50, 30:70, and 10:90 percent respectively. These samples were marked as sample S1, S2, and S3. Sand with particles size between 0.3 mm – 0.425 mm and kaolin clay were properly mixed together and tested at different moisture contents. Table 4 shows the results of the crumb test.

Result shows that soil samples experienced dispersive characteristic (G4) at low moisture content of about 10 % and indicated similar behaviour when the percentage of moisture content is increased to higher values (more than 30 %). The soils dispersibility grade decrease to nondispersive categories (G1 and G2) when the moisture content percentage lies between 17 % - 25 %. Except for L7 where fine-grained soils percentage is less compare to other sites, in-which generally do not contain sufficient

Table 4: Crumb Test Results

Sites Samples/ Lab Samples	Soil		Dispersibility Grade at Initial Moisture Content (%)			
	Coarse Particles (%)	Fine Particles (%)	G1	G2	G3	G4
			Non-Dispersive		Dispersive	
L1	47	53	20%	22%	-	10%, 35%
L2	49	51	20%	18%	20%	10%, 35%
L3	55	45	-	16%	-	8%
L4	43	57	17%	22%	10%	35%
L5	63	37	20%	22%	21%	10%, 35%
L6	54	46	20%	22%	-	10%, 35%
L7	67	33	-	-	-	13%, 27%
L8	16	84	-	25%	23%	-
L9	73	27	20%, 30%	-	10%	-
L10	79	21	20%, 30%	10%	-	-
L11	72	28	30%	10%, 20%	-	-

colloids to support dispersive erosion. Result also shows that sample from L7 fall into dispersive categories (G4).

However for all the laboratory samples, results fall into non-dispersive characteristic (G1 and G2). With the moisture content at 10 %, the samples exhibit slight reaction to the dispersibility characteristic which resulted in a very slight cloudiness can be seen in the water at the surface of the crumb. A different result is obtained for sample S1, where high coarse-grained percentage of 50 % is expected to increase the dispersibility grade to G3 at low moisture contents (10 %).

Table 5 shows the tabulation of the results for pinhole tests. Three additional soil samples were taken from location L9, L10 and L11 for pinhole test. For samples with coarse-grained percentage of more than 65 %, result shows dispersive categories of D1, indicating that these types of soil were easily dispersed. The reverse results are observed for the rest of the samples.

Conclusion

Fine-grained soils are known to have low resistance to erosion however laboratory result shows that soils fraction with high coarse-grained

Table 5: Summary of Pinhole Test

Sites	Soil Composition (%)		Average Pinhole Grade	Categories
	Coarse Particles (%)	Fine Particles (%)		
L1	47	53	ND1	Non-Dispersive
L2	49	51	ND1	Non-Dispersive
L3	55	45	ND1	Non-Dispersive
L4	43	57	ND3	Non-Dispersive
L5	63	37	ND1	Non-Dispersive
L6	54	46	ND2	Non-Dispersive
L7	67	33	D1	Dispersive
L8	16	84	ND1	Non-Dispersive
L9	73	27	D1	Dispersive
L10	79	21	D1	Dispersive
L11	72	28	D2	Dispersive

percentage has high dispersibility grade that lead to lower internal soil erosion resistance whereas the high moisture content percentage would enhance the dispersibility characteristic of the soils performance. Ample void spaces between coarse-grained and fine-grained of such soils were expected to cause the flow of removal particles of fine-grained soils to be easier compare to the soil samples containing higher fine-grained soils fraction finer than 0.002 mm. Thus, soils consisting of coarse-grained percentage of more than 65 % content are vulnerable to disperse easily. While soils with fine-grained contents of more than 35 % is considered to have a resistance to the soil particles removal subjected to the moisture content percentage. However both factors are unite to each other in contributing to the dispersibility grade. Earth fills/structures constructed of dispersive soils have failed because of internal erosion through cracks or other openings in the fill. Water flowing through the crack rapidly enlarges the crack of dispersive soils and accompanying failure is sudden and dramatic.

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