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Revised test protocols for the identification of dispersive soils

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Dispersive soils are prevalent in many areas of South Africa, and the presence of these soils has always posed a problem on road construction sites. The use of dispersive soils in roadway embankments and structures can lead to serious engineering problems if the soils are not accurately identified before use and appropriate mitigation measures taken. The current identification methods include the pinhole, double hydrometer, crumb and chemical tests, which are commonly used in combination to obtain the most reliable outcome. These laboratory tests, however, have not always been entirely consistent, whether used in combination or individually, and it is possible that the reason lies in the actual testing procedures. This paper discusses the observations made during a detailed investigation into the current methods used for testing and identification of dispersive soils. The test methods were thoroughly analysed and shortcomings identified. The differences resulting from different test techniques are examined and solutions to overcome the problems proposed. The paper concentrates mainly on the modification of the physical tests. The recommended solutions and process of identification are also proposed.

INTRODUCTION

Dispersive soils are prevalent in many areas of South Africa and the presence of these soils has always posed a problem on road construction sites. The use of dispersive soils in roadway embankments and structures can lead to serious engineering problems, manifested as piping, gullying and loss of material, if the soils are not accurately identified before use and appropriate mitigation measures taken.

Although the causes and consequences of soil dispersion are well understood, the positive identification of dispersive soils still remains a problem. Many identification methods have been proposed but none have been completely successful. It is therefore necessary to gain a better understanding of dispersive soils, thereby leading to positive identification and improved utilisation.

Since the state-of-the-art paper on dispersive soils in 1985 (Elges 1985) there has been some research into the complexities of dispersive soils and the difficulties they create, with the researchers coming to the same conclusions regarding the identification processes. Various rating systems have been proposed, the latest by Walker (1997). However, there still appears to be a number of problems regarding the positive identification of the soils. Dispersive soils therefore still pose a problem since no unique and precise method of classifying the soils exists.

Various tests are currently used in the identification of these soils and these are usually applied in combination to obtain the most reliable outcome. These laboratory tests, however, have not always been entirely consistent, whether used in combination or individually, and it is possible that the reason lies in the actual testing procedures.

The main objective of this project was to carry out a detailed investigation into the current methods used for testing and identification of dispersive soils, as suggested by Paige-Green (2008). The test methods were thoroughly analysed and shortcomings identified. The differences resulting from different test techniques are examined and solutions to overcome the problems proposed. This paper focuses on the test methods and not specifically any test results obtained during the study. These are described in detail in Maharaj (2013).

BACKGROUND

One of the fundamental properties controlling the susceptibility of a soil to dispersive piping is the percentage of the exchangeable sodium cations bound to the clay particles relative to the quantity of the other polyvalent cations (calcium, magnesium and potassium). Dispersive clay will erode in the presence of flowing water when individual clay platelets deflocculate and are carried away. As the water flows and erosion occurs, conduits/cracks widen into large tunnels which eventually collapse. According to Bell and Maud (1994), most earth dams that have

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failed in South Africa did so on the first wetting-up cycle after construction.

Currently there are four laboratory methods commonly used to identify the dispersive soils. These tests include the pinhole test, the double hydrometer test, the crumb test and various chemical analyses of the soil, and usually a combination of the results obtained from these methods is used to determine the potential of a soil to disperse.

The **pinhole test** measures the erodibility/dispersivity of a compacted soil sample in which water is allowed to flow through a small hole punched through the centre of the specimen. The test is considered to be one of the most reliable physical tests to determine the dispersivity of soils, since it simulates the action of water draining through a pipe/crack in the soil (Sherard *et al* 1976b). The flow rate, effluent turbidity and size of the pinhole at the end of each test are the parameters recorded. If the effluent is highly turbid (murky) and the pinhole is enlarged, then the soil is classified as being dispersive. If the opposite is observed, i.e. the effluent is clear and the pinhole size remains unaltered, then the soil is considered non-dispersive.

The **double hydrometer test** is another test that has been recorded in the literature as a highly suitable test for identifying dispersive soils. The test evaluates the dispersivity of a soil by measuring the natural tendency of the clay fraction to go into suspension. The procedure involves the determination of the percentage of particles in the soil which are less than 0.005 mm in size by use of the standard hydrometer test. A parallel test is also carried out, in which no chemical dispersant is added and the solution is not mechanically agitated. The quantity of 0.005 mm sized particles in the parallel test is expressed as a percentage of the 0.005 mm sized particles in the standard test, which is defined as the dispersion ratio or dispersivity of the soil. The soil is then classified as being dispersive, moderately dispersive or non-dispersive based on the ratio obtained from the test (Elges 1985).

The **crumb test** is the simplest and easiest of the physical tests and indicates the tendency of the particles to deflocculate in solution. The test, which can also be carried out in the field, involves placing a crumb of soil in a beaker of solution and observing the reaction as the crumb begins to hydrate (Walker 1997). The test is primarily a visual assessment of the behaviour of the soil in solution. After a certain time, the soil and solution in the beaker are observed and the soil is classified according to the quantity of colloids in suspension. Four grades can be noted, ranging from no reaction to strong reaction.

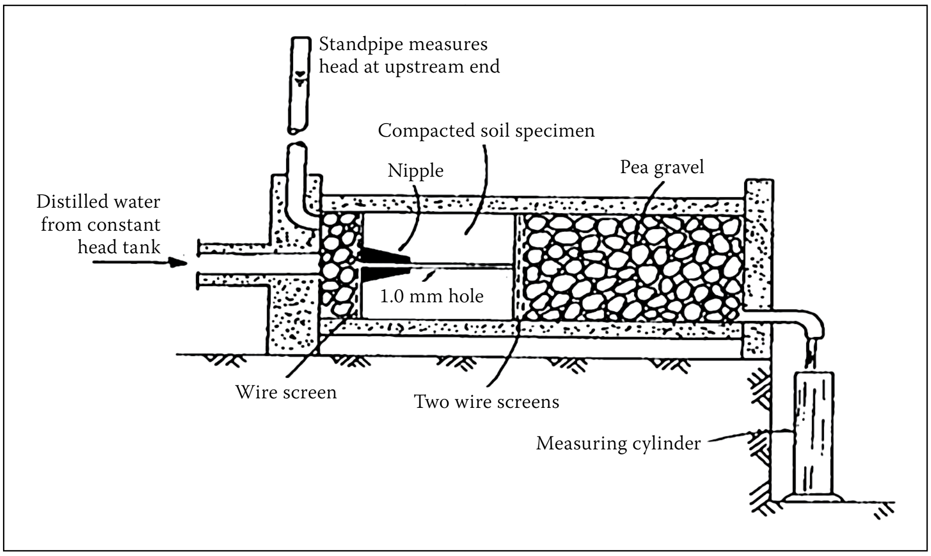

Figure 1 Pinhole test apparatus (adapted from Sherard *et al* 1976a)

Chemical analyses are also carried out to determine the amount of sodium relative to the other cations (calcium, magnesium, potassium) present in the soil sample. Tests are run to determine the exchangeable cations on the clays, as well the cations in the saturation extract. Since this paper aims to discuss shortcomings identified in the physical tests, the details of the chemicals tests will not be covered in detail.

INVESTIGATION OF CURRENT TEST METHODS AND SHORTCOMINGS IDENTIFIED

While the physical tests aim to accurately identify dispersive soils, they have not always been entirely successful. The literature shows that the tests often contradict one another, resulting in more than one classification for a particular soil sample (Maharaj 2013). Although no discussion regarding these anomalies has been found in the literature, interpretation of results from recent testing suggests that many of these shortcomings, as highlighted below, result from differences in the testing procedures, which may have been overlooked during routine investigations.

Each of the individual test methods is briefly discussed in this section, and the associated problems identified during this project are highlighted.

Pinhole test

In the pinhole test, water is allowed to flow through a small hole punched through the centre of the specimen. The test is generally considered in the literature to be one of the most reliable physical tests to determine the dispersivity of soils, since it simulates the action of water draining through a pipe/crack in the soil. The pinhole, which is punched through the centre of the compacted sample, is 1 mm in diameter and water flows through the sample at heads of 50 mm, 180 mm, 380 mm and 1 020 mm during the experiment (Sherard *et al* 1976a). The flow rate, effluent turbidity and size of pinhole at the end of each test are the parameters recorded. If the effluent is highly turbid (murky) and the pinhole is enlarged, then the soil is classified as being dispersive. If the opposite is observed, i.e. the effluent is clear and the pinhole size remains unaltered, then the soil is considered non-dispersive. In some cases, the water may be clear but the pinhole could be severely enlarged, in which case erodibility, but not dispersivity, is indicated.

The pinhole test method is based on the guidelines described in a paper by Sherard *et al* (1976a). As stated by Sherard *et al* (1976a), "… the test was developed for the direct measurement of the erodibility of fine grained soils, using the flow of water passing through a small hole in the specimen." The main objective was also stated as being a reliable way of identifying dispersive soils. It should, however, be noted that all dispersive soils (high sodium content) can be erodible, but not all erodible soils (low cohesion) are necessarily dispersive (Paige-Green 2008).

The test procedure involves separating the material finer than 2 mm and compacting it into a cylinder 100 mm in length and 34 mm in diameter. According to the guidelines and test methods, the material should be compacted at moisture contents at or close to the plastic limit of the soil. The material is compacted in the cylinder on top of pea gravel and a wire screen. After compaction, a 1 mm hole is punched through the centre of the specimen and the remainder of the cylinder is filled with pea gravel (Figure 1). After the specimen is prepared and the apparatus assembled, water is percolated through the pinhole under heads of 50, 180 and 380 mm for periods of 5–10 minutes at each head. The quantity of flow and time at different flow volumes are measured continuously and recorded on data sheets. The turbidity of the effluent (colour of the water) during the test is also recorded.

Since the test aims to identify dispersive soils, it should be first noted that erodible soils are very different from dispersive soils. The pinhole test is likely to identify highly erodible soils, which can be mistaken for dispersive soils.

According to Bell and Walker (2000), the diameter of the pinhole at the end of the test proves to be the most reliable indicator for recognising dispersivity. This, however, should not be the only determining factor for the identification of dispersivity, as the pinhole diameter of erodible soils will increase more so than for dispersive soils. The nature of the effluent plays a vital role in the test procedure, not only for the colour, but also the type of sediment/material present in the water. The effluent from a soil can be highly turbid as it exits the test, but it is not necessarily dispersive. If the soil is dispersive, the effluent should stay turbid for a prolonged period, since clay particles will stay in suspension, whereas the suspension in purely erodible materials will settle out rapidly and the solution will become clear (or possibly stained if the soil contains certain elements such as iron or organic matter).

One of the major problems associated with the pinhole test is that of preparation of the specimen in the cylinder. According to the procedure, the sample (with moisture content at or near the plastic limit) is compacted on top of the pea gravel with the use of a Harvard Compaction apparatus. Observations during preliminary testing found that, firstly, some soils appear to be excessively moist at their plastic limits, which makes the compaction process difficult, as the material shears under the applied load instead of compacting. Secondly, during the compaction process the soil particles at the bottom of the cylinder tend to migrate (squeeze) through the mesh and into the voids in the pea gravel. This leads to blockages in the pea gravel and once the test starts, the water flows through the pinhole, mixes with the soil in the pea gravel and flows out as a highly turbid effluent. This then leads to misleading results.

The test method states the type of compaction (Proctor density) and an estimated target density of 95%. However, it should be noted that this is just an approximation. There is no control available in the test methods to ensure that the actual target density is achieved, making the test procedure very ambiguous. This could lead to significant differences in the behaviour of the material, as many geotechnical properties are affected by low degrees of compaction of the material. The lower densities obtained using the Proctor compaction effort (compared with the much higher energy in the MOD AASHTO effort), are most commonly utilised for dams and not for roads, which poses the question of the suitability of the test for purposes other than dam construction. Further investigations have found that no study has been carried out to determine the influence of density on the pinhole test results.

All of the above problems noted during the experimental study highlighted the various inconsistencies associated with the test procedure itself. These are suggested as the main reasons for inconclusive results obtained in past investigations when the pinhole test was used as an identification tool (Heinzen & Arulanandan 1977).

Double hydrometer test

The Soil Conservation Service (SCS) double hydrometer test is one of the first methods developed to assess the dispersivity of soils (Knodel 1991). The test assesses the dispersivity of a soil based on the fine fraction (0.005 mm) using an adaptation of the hydrometer test. Dispersion ratios greater than 50% are considered highly dispersive, between 30 and 50% are moderately dispersive, between 15 and 30% are slightly dispersive, and less than 15% are non-dispersive (Elges 1985). Other authors (Gerber & Harmse 1987; Walker 1997) base the categorisation on different dispersion ratio limits. There is currently no standard criterion set for the dispersion ratio limits.

The test methods for hydrometer analysis currently in use locally are mainly the American Standard (ASTM 2007a), the British Standard (BSI 1990) and the South African Technical Methods for Highways – TMH1 (NITRR 1986). However, not all local laboratories adhere to these standards, rather using their own in-house modifications of the methods. As this is a critical component of the identification process, using such modifications is not acceptable, as discussed below and in detail by Maharaj (2013).

Analysis of these test procedures illustrates little variation in the method of determination of the particle size of the fine fraction, except with regard to the types of dispersing agents used. The ASTM (ASTM 2007b) and BSI standards specify that sodium hexametaphosphate be used as a dispersing agent. However, the solution is prepared differently and at different proportions in each standard. The volume required to disperse the sample is also significantly different. TMH1 specifies that a mixture of sodium silicate and sodium oxalate be used as the dispersing agent.

An experimental study was carried out to evaluate the effects of the different dispersing agents on the test results. Results showed a wide variation (up to 36%) in the apparent clay fraction between the two different dispersants (Maharaj 2013). This leads to varying dispersion ratios and misleading classification of the soils. Another inconsistency noted is that different test methods, as well as authors, indicate different particle sizes for the clay fraction. TMH1 and ASTM use the 0.005 mm fraction as the boundary for the clay fraction, whereas BSI uses the 0.002 mm. Many authors quote the 0.005 mm fraction as the clay fraction when determining dispersivity of a soil. *A dictionary of geology* (Whitten & Brooks 1972) defines the clay fraction as a mineral particle having a diameter less than 0.004 mm (1/256 mm). According to Reeves *et al* (2006), the ASTM standards define the clay fraction as being less than 0.005 mm, and Japan defines the fraction as less than 0.006 mm. However, a majority of the countries listed define the clay fraction as particle sizes less than 0.002 mm. Once again there is no standard definition with regard to the unit size for clay particles, although a scan of the literature shows that 0.002 mm is used more widely. As the 0.002 mm fraction is also the basis for classification of South African soils, according to Brink and Bruin (2002), this size fraction is taken as the upper limit of clay-sized particles for this study.

It should be noted that dispersivity is a function of the clay mineralogy and not the clay size fraction. It is possible to have a high percentage of material passing the 0.005 or 0.002 mm fraction that is entirely quartz. This would not have dispersive properties. On the other hand, if all the material passing these fractions consists of clay minerals, the dispersive behaviour would differ considerably.

The literature indicates that during studies of dispersive soils the initial indicator of dispersivity of the material is generally classified on the basis of the double hydrometer test by means of various indicator graphs/plots. Many workers (Gerber & Harmse 1987; Bell & Maud 1994; Walker 1997) then proceeded to indicate that no single test (including the double hydrometer test) can be used to identify dispersive soils, and then proposed classification rating systems using a number of tests. It is postulated that many of the ambiguities (i.e. the variations of results among different researchers) are the result of the incorrect initial classification of the dispersivity of materials as a result of variations introduced in the double hydrometer test.

Most of the rating systems used currently in South Africa seem to have been based on the initial classification of dispersivity by the double hydrometer test. Gerber and Harmse (1987) used the test as a primary parameter when developing the ESP-CEC chart. Walker (1997) included the ESP-CEC chart as a parameter in the rating system, and studies carried out by Bell and Walker (2000) also make use of the double hydrometer test when initially classifying the dispersive soils.

This has resulted in the overlap of results within single classification bands. Although it is assumed that in these investigations the materials have been tested following uniform and standard procedures, preliminary testing has indicated spurious results when sodium silicate/oxalate (the South African road standard) is used as the dispersant (NITRR 1986). It is also noted that the dispersant standard in South Africa has changed over time, possibly affecting the results, if they were obtained from different laboratories over a prolonged period of time.

The problems discussed above pose the potential for misleading results, since the double hydrometer test is associated with a number of different parameters in the rating systems. Inaccurate results from the double hydrometer test can significantly affect the correlation of the final rating, particularly when this test method is used as the reference methods for the preliminary classification of the dispersivity of soils (Gerber & Harmse 1987; Bell & Maud 1994; Walker 1997; Maharaj 2013).

Crumb test

The crumb test is the simplest and easiest of the physical tests, and is often used as a preliminary test to indicate the tendency of the particles to deflocculate in solution. The test, which can also be carried out in the field, involves placing a crumb of soil in water in a beaker and observing the reaction as the crumb begins to hydrate. The test is primarily a visual assessment of the behaviour of the soil in solution. After 10 minutes, the soil crumb and the solution in the beaker are observed and the soil is classified according to the quantity of colloids in suspension (Walker 1997). Different researchers use different techniques involving the use of either undisturbed or remoulded crumbs, with some using distilled water and others a very dilute solution of sodium hydroxide (NaOH) (Sherard *et al* 1976b; Walker 1997).

An assessment of the literature has found that most researchers appear to misquote Emerson's (Emerson 1964; Emerson 1967) work and use his findings incorrectly. There have been many cases in which the method has been misinterpreted with regard to variables such as moisture content and dispersing medium (Heinzen & Arulanandan 1977; Bell & Maud 1994; Walker 1997; Bell & Walker 2000). Walker (1997) states that a densely compacted, remoulded sample is less likely to slake/breakdown. However, as the crumb test aims to determine the dispersivity of the sample and not the behaviour when densely compacted, it should have no significance on the test method. An ASTM standard is also available for the crumb test (ASTM 2000). The standard, however, takes other variables into account. Neither temperature nor the remoulding of the sample into a specific size, has been shown to have any effect on the dispersivity of the soil, but only makes the preparation and testing more laborious (Maharaj 2013).

The method mostly followed currently, which can be carried out in the field or a laboratory, involves placing a crumb of soil in a beaker of solution and observing the reaction as the crumb begins to hydrate. The test is primarily used as a subjective visual assessment of the behaviour of the soil, as it indicates the tendency of the particles to deflocculate and remain in suspension in the solution. After a certain time, usually 5–10 minutes, the soil crumb and the solution in the beaker are observed and the soil is classified according to the quantity of colloids in suspension (Walker 1997; Bell & Walker 2000).

A literature search highlighted some variations in the test methods given by various authors. It was found that there is no standard protocol available regarding which solution or crumb condition to use when carrying out the test. Tests are carried out using diluted NaOH (0.001N) or distilled water, and samples can either be in their natural density and moisture state (in situ conditions) or in various combinations of natural or remoulded and air-dried, oven-dried or moist (Sherard *et al* 1976b; Knodel 1991; Walker 1997). All of these variables can have significant effects on the outcome of the test and thus the classification of the soil. Figure 2 illustrates the variance in appearance and results when the crumb test was carried out on the same material, but under different conditions. The first test was carried out on a remoulded crumb in NaOH solution (a), the second was carried out on an air-dried crumb in distilled water (b), and the third on a remoulded crumb in distilled water (c).

One of the consistent observations that has come up many times, however, is the time taken to 'run' the test. It is most commonly stated that observations on the dispersivity (or suspension cloud) should

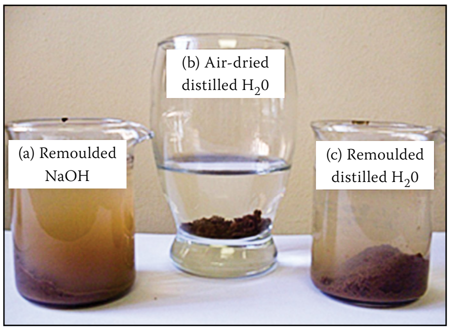

Figure 2 Variation in results based on different testing variables

Figure 3 Colloidal suspension of a highly dispersive soil – Grade 4 – strong reaction (courtesy of Paige-Green 2010)

be taken 5 to 10 minutes after the crumb is immersed in water (Elges 1985; Walker 1997). It should, however, be noted that if a soil is dispersive, the colloidal suspension will not settle and will still be present after a few hours. Figure 3 gives an example of what the colloidal suspension of a dispersive soil should look like after more than an hour.

Another observation found through discussions with various laboratories and researchers is that of the actual classification process. It should be noted that there is a significant difference between dispersive soils and erodible/slaking soils. If, during the crumb test, the soil breaks down completely (slakes) without any colloidal suspension, then the soil will be classified as non-dispersive. The presence of colloidal suspension is the fundamental aspect of the classification process, as this is the defining feature of dispersive soils (Paige-Green 2008).

Results from testing showed that after 10 minutes most of the samples observed would be classified as being dispersive to some degree. Settlement of non-dispersive particles generally begins after approximately

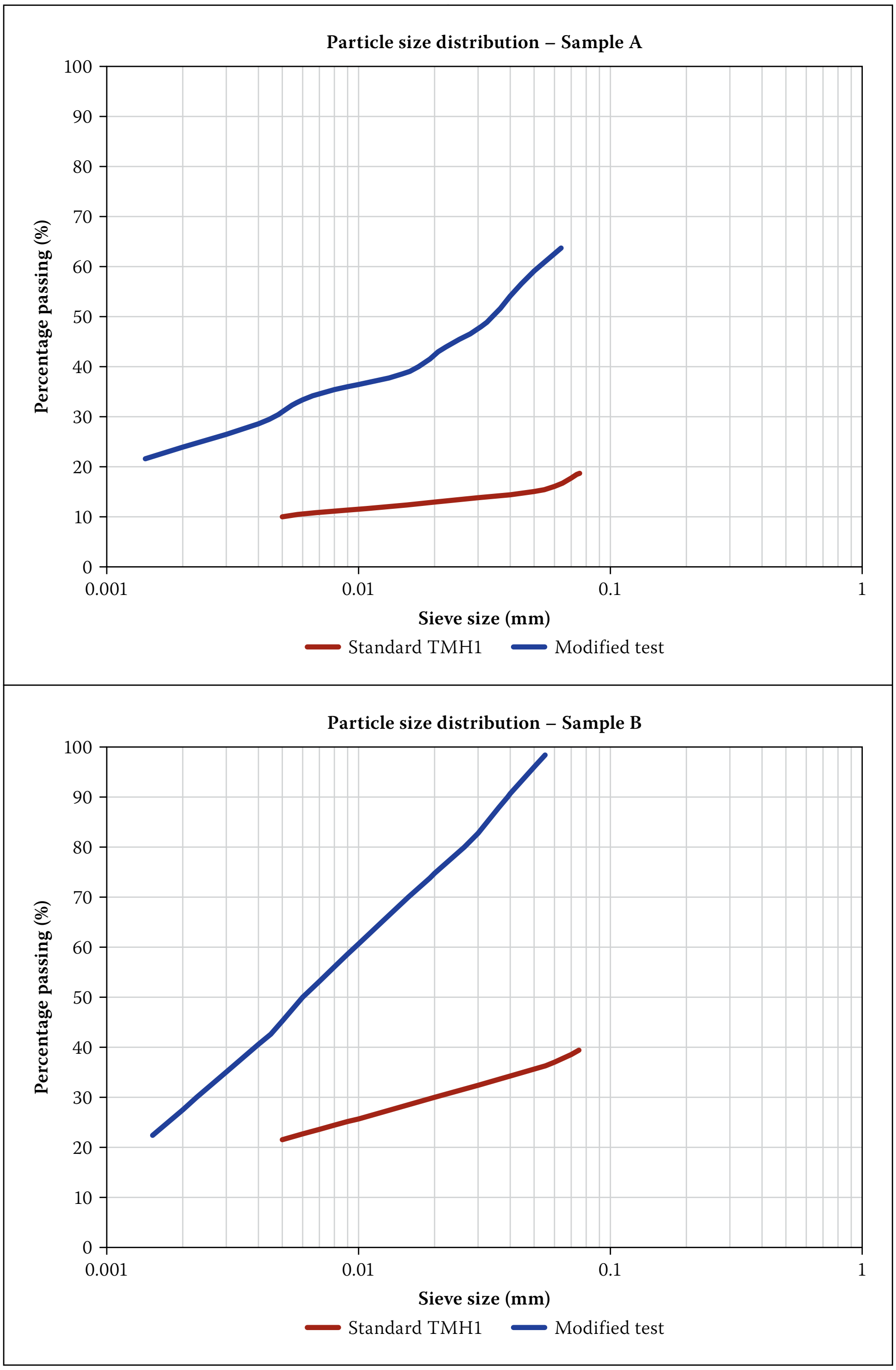

Figure 4 Comparison between the modified and TMH1 particle size distribution curves for two samples

30 minutes, and the maximum settlement is usually attained after two hours. Variations that could occur due to the lack of a standard protocol for testing and classifying the dispersivity of soils using the crumb test can lead to differences in classifications.

DISCUSSION AND RECOMMENDED MODIFICATIONS

Based on an extensive literature study, laboratory investigations and a testing programme carried out by Maharaj (2013), the following discussion related to each test method and a recommended classification procedure is presented.

Pinhole test

Investigations into the pinhole test prove the test to be unreliable when identifying dispersive soils. Although the test is based on a sound principle, it appears to be more adequate at identifying erodible soils through the inspection of the pinhole, and is only useful for dispersivity in terms of the effluent analysis, mostly being done incorrectly at present. Observations during the study found that the test itself can be unduly time-consuming.

Walker (1997) states that soils which test highly dispersive (D1) and moderately dispersive (D2) in the pinhole test will be problematic and will erode by dispersive piping. Those soils classified as intermediate (ND4) will erode slowly, and intermediate soils (ND3) will erode very slowly under high heads. The question one must ask now is, how does one differentiate between slowly and very slowly? Walker (1997) also states that soils classified as non-dispersive (ND2 and ND1) in the pinhole test will not erode through dispersive piping. It should be noted that an erodible soil, which has no dispersive properties, will still erode in the pinhole test and particles will fall into the cylinder. The particles will settle after some time, but as the experiment classifies the soil during the test, it is likely that the erodible soil will be incorrectly classified as dispersive to some extent. Observations made while carrying out the pinhole test found that the test is essentially an empirical test based on subjective evaluation.

Double hydrometer test

Since the introduction of the Technical Methods for Highways (TMH1), the majority of soil testing for roads and construction in South Africa has been carried out using this standard. Hydrometer tests have been carried out using the method A6 as stated in TMH1. Investigations into the use of the method (by means of interviews) has shown that some laboratories use the hydrometer test method A6 (TMH1) as the standard test and modify the same method for the parallel test for use in the double hydrometer test.

A thorough investigation into the test method (TMH1 Method A6) has found many inconsistencies, which can have a significant effect on the results for dispersive soil identification. The hydrometer reading taken at the one-hour time interval was taken to be the percentage of the clay fraction (0.005 mm) as specified in TMH1. This, however, was found to be incorrect. Using the equations based on Stoke's Law, the time for recording of the 0.005 mm fraction can be calculated to be within the two-hour range, and the time for the 0.002 mm fraction would be between the five-hour and 20-hour range, using the modified test method.

According to TMH1, the one-hour hydrometer reading gives the 0.005 mm fraction. The 18-second reading gives the percentage passing 0.075 mm and the 40-second reading is the silt-sized fraction (0.050 mm). These values were plotted along with the values obtained for the modified recommended test, in which the particle diameters were calculated using equations based on Stoke's Law and more hydrometer readings were taken at more frequent time intervals. Figure 4 illustrates the variation in particle size distribution (PSD) curves for two samples. There is a significant variation in the PSD curves with the 0.005 mm fraction ranging from approximately 10% to 32% for Sample A and 22% to 45% for Sample B. It is thus clear that the TMH1 method does not produce the correct results.

The second discrepancy noted is the variation in the definition of the clay fraction. TMH1 and ASTM use 0.005 mm as the boundary for the clay fraction, whereas BSI uses 0.002 mm. Many authors quote the 0.005 mm fraction as the clay fraction when determining dispersivity of a soil. By definition, clay mineral particles are colloids with a maximum diameter of 0.002 mm (Reeves *et al* 2006) and cation exchange activities will predominantly occur on this fraction. Therefore, the 0.002 mm fraction should be ideally used in dispersive soil identification analyses.

Based on the above-mentioned shortcomings identified with the TMH1 Method A6 test standard, it is concluded that, while the TMH1 standard is probably suitable for gravel or aggregate testing with low active clay content, it should not be used for dispersive soil identification as it is not sufficiently sensitive. With regard to the ASTM standards, it is recommended that the definition of the clay-sized fraction be re-analysed and a standard definition used, which should correspond to other available standards.

Crumb test

Crumb test results found that there are no significant differences in results with either distilled water or 0.001N NaOH when the soil is dispersive. However, if the soil is not dispersive, different results were obtained based on the type of immersion medium. The use of 0.001N NaOH gives a good indication of dispersive soils if the soil is in fact dispersive. However, the risk of falsely classifying non-dispersive soils, as dispersive is greatly increased as well. Observations during testing found the presence of staining in the solution after two hours. Since the test is essentially a visual indication of dispersivity, it can be highly subjective. It is possible that a non-dispersive soil could be classified as being dispersive due to the staining in the solution and not resulting from fines in suspension. Sodium hydroxide solutions are known to stain (discolour) in the presence of organic matter (SABS 2006).

With regard to the condition of the crumb, the oven-dried crumbs gave the worst indication of dispersivity. This is due to the fact that high temperatures can change the properties of certain clays in the soil, thereby hindering their dispersive properties (Reeves *et al* 2006).

Based on results obtained and observations made during the study, it is recommended that, in order to acquire repeatable and consistent results, the crumb test should be carried out as follows:

- Condition of crumb: Remoulded (air-dried or in situ moisture content)
- Immersion medium: Distilled water
- Observation conditions: Described using current categories but readings taken after one or two hours.

Recommended process for dispersive soil identification

The observations made during this study indicated that the tests currently used for the identification of dispersive soils have significant shortcomings with regard to the procedures, and, in some cases, interpretation of results. Investigations have found that there is no effective standard protocol used for the identification process, which could also be a likely cause of the identification problems.

Based on this investigation, the following process for the identification of dispersive soils is proposed:

- An in situ crumb test (at natural moisture content) should be carried out on site using bottled water as a preliminary screening test. If the results show any evidence of dispersion as discussed by Maharaj (2013), then the soil is likely to be dispersive and should be tested according to the next step. If the results do not show any evidence of dispersion, then the material need not be tested further and is probably only highly erodible or subject to slaking. If there is any doubt or ambiguity regarding the results from the first step, then the next should be followed for more accurate results.
- If the field crumb test shows evidence of dispersion, a laboratory crumb test should be carried out as specified by Maharaj (2013). Samples are to be remoulded and tested in distilled water. Readings/observations of colloidal suspension should be recorded after one hour. If the results for the laboratory crumb test indicate dispersive behaviour, the testing can proceed to the next step of the process. If there is no sign of dispersivity, then it is probable that the material is not dispersive.
- The next step in the identification process is the double hydrometer test. The test is to be carried out as accurately as possible, following the test method proposed by Maharaj (2013). The double hydrometer test is the main indicator test for the dispersivity and carries significant weight if done correctly. If there is doubt regarding the results for the double hydrometer test, then the next step should be followed for clarification/confirmation of the hydrometer results.
- The final step in the process is the chemical analysis of the soil. This should be done by a competent laboratory using the methods prescribed by the Soil Science Society of South Africa (Loock 1990). The full amended test methods are included in Maharaj (2013). Results obtained from laboratories should always be checked and questioned if the client has doubts.

CONCLUSIONS

The dispersion of clay soils in water and its influence on the stability of various engineered structures has been a topic of concern in engineering projects for many years. One of the main problems is the seeming inability (particularly in the road construction industry) to positively identify such soils and thereby to reduce the potential for failure of many engineering structures. The use of non-dispersive soils, which may be identified as dispersive, will result in large increases in construction costs and should be avoided.

Although the causes and consequences of soil dispersion are well understood, the accurate identification of dispersive soils still remains a problem. Many identification methods have been proposed, but none has been completely successful. The identification methods currently used in South Africa to identify dispersive soils include the pinhole, double hydrometer, crumb and chemical tests, which are used in combination. These laboratory tests, however, have been shown to give inconsistent results and the reason for this lies in the actual testing procedures (Maharaj 2013).

Experience from the literature study shows deficiencies in the identification of dispersive soils, and in many cases identification and classification problems appear to be related to inconsistencies in the test methods and testing protocols.

Specific problems with the test methods were thus identified, the methods were modified and implemented, and the following conclusions were drawn:

- The pinhole test was found to be a highly unreliable test. The test method is ambiguous and the test procedure is time consuming with very little of the fundamental problems in dispersive soils being addressed. Investigations into the testing in South Africa have also found that the majority of commercial soils laboratories do not perform the pinhole test.
- The double hydrometer test is a good indicator of dispersivity if done accurately and repeatedly.
- The crumb test is also a good indicator if carried out accurately. However, there is no need for the four classification grades.

- Tests utilised for dispersive soil identification should not be based on methods that require opinions, but should be based on hard evidence instead. For example, crumb test results should state the presence of colloidal suspension or no suspension. There is no benefit in complicating the test by describing 'slightly', 'moderately' or 'heavy' suspension.

In order to identify dispersive soils accurately, the test methods recommended above must be implemented and strictly followed. Repeatability and reproducibility studies on all of these test methods according to recommended protocols, e.g. ASTM E691-11 (ASTM 2011) should also be carried out.

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