

Dispersive and Erodible Soils – Fundamental differences

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ABSTRACT: Dispersive, erodible and slaking soils are prevalent over wide areas of South Africa. Each of these materials increases the cost of construction, but dispersive soils are likely to lead to far more serious problems, particularly in dam construction. Although frequently similar in surface appearance, the materials are fundamentally different and must be identified and treated differently during construction. This paper summarises the fundamental differences in the materials, discusses current test methods to differentiate between them and reviews techniques for handling them as construction materials.

1 INTRODUCTION

Erosion of soils is a phenomenon that has serious consequences for the agriculturalist, and although not always considered as a significant problem by geotechnical engineers, it can have costly implications. These include environmental problems, siltation and blocking of drains and larger civil engineering structures and costly rehabilitation programmes. The consequences of uncontrolled use of dispersive soils in the construction of earth embankment dams are well documented (Donaldson 1975).

However, for engineering purposes it is important to differentiate between those soils that are merely erodible and those that are dispersive. Construction on or with dispersive soils can lead to far more serious problems than if the material is purely erodible, particularly in earth dam construction when dispersive soils are used unknowingly. Piping failures (various, sometimes conflicting definitions of piping (Richards & Reddy 2007) occur in the literature) as a result of internal erosion of the embankment can result in serious consequences. Other than dams, roads and township infrastructure projects, most civil engineering projects will be founded such that the presence of erodible materials will be accounted for or the material removed, and detailed studies of the nature of the erodible materials would be unnecessary.

Slopes of both transported and residual soils can show evidence of extreme erosion manifested by an irregular surface of channels and gullies created by flowing water (Figure 1). These may even be deep hollows and caverns in certain instances. Erosion and gullying has also been observed in relatively flat

areas on dispersive soils as a result of construction activities. In addition to the non-aesthetic aspect, the eroded material often accumulates at the foot of slopes and in drainage structures blocking surface drains and culverts and requiring regular maintenance. It should be noted that the absence of the typical signs of erodibility at the soil surface does not necessarily preclude the presence of such soils in lower layers in the soil profile. Highly saline conditions can be associated with varying water table conditions at depth.



Figure 1: Typical erodible soil exposure

Three aspects of such erodibility exist: most soils require flowing water to physically remove particles from the exposed surface (erodible soils) while certain soils will deflocculate or disperse in the presence of still or almost still pure water (dispersive soils). Many partially saturated soils may disinte-

grate into smaller particles when soaked in water (slaking soils). It is important that all manifestations of surface erosion in an engineering context are not simply ascribed to a dispersive mechanism as is often noted during discussions.

Erodible soils are best defined as those in which the cohesion (or surface shear strength) when wet is insufficient to resist the tractive forces of rain or runoff water flowing over them (Nascimento & de Castro 1974). Many of these soils do not show any erosion on short slopes, flat slopes or when the rate at which water flows across the slope is insufficient to develop sufficient tractive force. Dispersive soils, on the other hand, are those in which the fine clay component goes into suspension in non-flowing water (Sherard et al 1976a). Slaking soils are those that when dry or partially saturated have considerable soil suction which is totally lost on soaking, an extreme case of being erodible.

This paper assesses the differences between dispersive, erodible and slaking materials and reviews the preliminary identification and test requirements to differentiate between them. Dispersive materials were comprehensively discussed in a paper published in 1985 (Elges 1985) and, despite their potential for leading to serious failures in earth dams and a few localised road failures, little work has been carried out on them since. The majority of the fundamentals discussed by Elges (1985) are not repeated in this paper and reference should thus still be made to this valuable document.

2 DISPERSIVE SOILS

Dispersive soils include only those soils in which the colloidal (or clay) fraction deflocculates and goes into dispersion. This is the result of the repulsive forces (electrical surface charges) between clay particles in the soil exceeding the attractive (van der Waal's) forces (Holmgren & Flanagan 1977; Heinzen & Arulanandan 1977). When this happens, the colloids repel each other and move into the solution, where they remain in suspension and the solution does not clear with time. They can be removed from the structure by the slow movement of water leading to the development of "pipes" or tunnels, in which the water flow velocities increase and failure of the structure occurs. The physico-chemical phenomenon of clay repulsion is the basis of dispersive soils, differentiating them from other types of erodible or slaking materials. Frequently, there is little disintegration of the soil particle itself. It has been noted (Sherard et al 1976a) that materials with less than 10% clay particles may not have enough colloids to support dispersive piping. Standard tests for classifying soils for engineering purposes do not identify dispersivity in fine grained soils (Sherard & Decker 1977).

Dispersive soils in South Africa appear to be restricted to areas where the annual rainfall is less than 850 mm and particularly where the materials are derived from mudrocks (Bell & Walker 2000). This is not supported by the information provided in Elges (1985) where numerous problems on a wide range of materials, some of which are from much wetter areas are discussed. Essentially dispersive soils are derived from rocks that are low in calcium and magnesium and usually contain sodium rich minerals such as albite and amphibole. Most granites have this type of composition and have been found to be dispersive. Elges (1985) noted that most dispersive soils contain smectite or illite clays, with kaolinitic materials generally being non-dispersive. The sodium in the soil can be derived during the natural weathering process of certain rock types, from materials deposited under marine or saline conditions (eg, many mudrocks) or from dissolution, leaching and deposition of sodium in the soil profile during recent geomorphologic processes. This obviously has an influence on the type and location of sodium in the material (Dye 1979). Sherard et al (1977) noted that most of the dispersive clays encountered by them consist of alluvial clays in the form of flood-plain deposits, slope wash, lake bed deposits and loess deposits. They also noted that some clay-stones and shales deposited under marine conditions were found to have the same pore water salts as dispersive clay and their residual soils were dispersive.

Elges (1985) identified the Exchangeable Sodium Percentage (ESP) as the most reliable method of identifying dispersive clays although it was based on work carried out by Harmse (1980) in which a combination of pH, conductivity, Sodium Adsorption Ratio (SAR), ESP and Exchangeable Magnesium Percentage (EMgP) are employed (Figure 2). This has been generally implemented in southern Africa, together with the Pinhole Test, which had not been investigated fully at the time of Elges' paper. However, Bell & Walker (2000) carried out an extensive investigation in KwaZulu Natal using a range of tests and confirmed what had been suspected for some time, that no one technique is suitable for the positive identification of dispersive soils (Richards & Reddy 2007).

They expanded on a rating scheme proposed by Bell & Maud (1994), in which a number of tests are carried out and the results weighted, the weighting depending on the tests considered to be the most reliable. The method of assessment with the highest rating was the plot of ESP versus CEC proposed by Gerber & Harmse (1987). The assessments of dispersivity obtained from the crumb test, double hydrometer test, SAR and pH are also used. This rating system was then modified (Bell & Walker, 2000) to include results from the pinhole test (Sherard et al

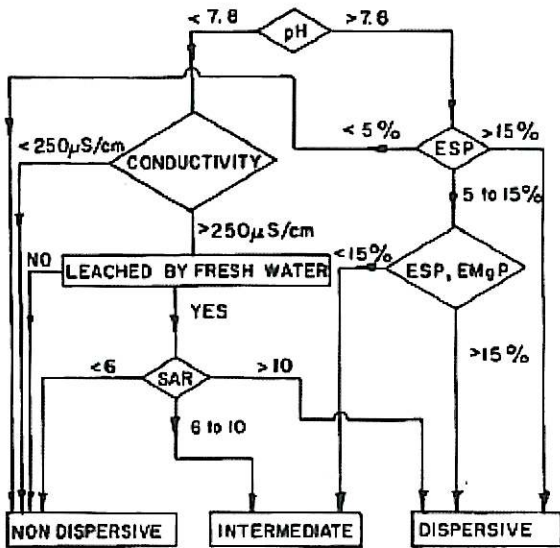


Figure 2 Chemical evaluation of dispersive soils (Harmse 1980)

1976b; BSI 1990), the remoulded crumb test (Reeves et al 2006), the SAR value and the dispersivity charts of Sherard et al (1976a) (this includes the sodium percentage and the total dissolved salts shown in Figure 3) and Gerber & Harmse (1987) (Figure 4 based on ESP and CEC). This allows the incorporation of both physical and chemical factors, broadening the basis for classification. The sum of the individual ratings is used to identify the potential dispersivity (Table 1).

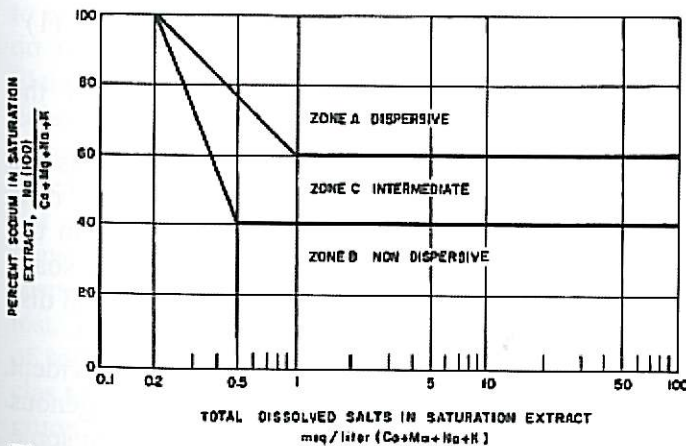


Figure 3 Potential dispersivity chart (Sherard et al 1976a)

It should be noted that the interaction between the clay minerals and the water solution in the material voids and pores is very important. If the pore water has a high concentration of dissolved salts, the effect on the dispersion of the soil can be significantly reduced. This must be borne in mind when comparing laboratory test results with field conditions. Distilled water is generally used in the laboratory whereas river and ground water may have a wide range of dissolved salts of varying concentration.

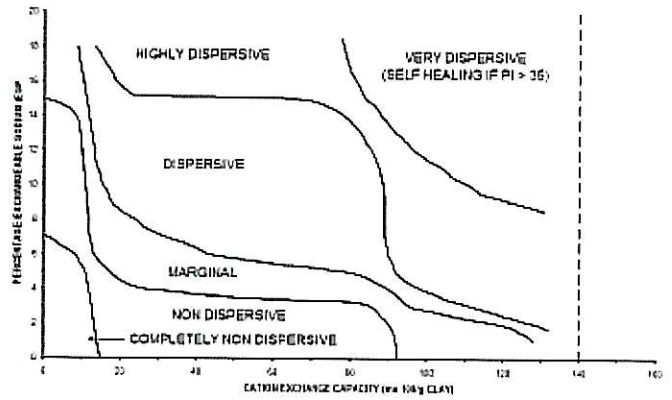


Figure 4 Potential dispersivity based on ESP and CEC (Gerber & Harmse 1987)

It is also important that soil samples collected for dispersive soil tests (particularly the Crumb and pin-hole tests) should be retained at their natural moisture content. There is significant evidence to suggest that drying of the material influences the results.

In the experience of the author, a number of so-called dispersive soils may not be dispersive but only slaking or erodible. By definition, the colloid component of a dispersive soil must go into suspension on soaking, although this can be affected by the SAR, salt concentration in the water and the pH. Crumb tests on undisturbed crumbs of known dispersive soils have shown that the crumb seldom disintegrates fully, but the water in the beaker becomes cloudy and remains cloudy – the clays do not settle out, as is the case with slaking materials. Crumb tests can be carried out in distilled water or in a solution of 0.001N sodium hydroxide, depending on the method followed. Sherard et al (1976a) note that no useful correlations were found using the weak sodium hydroxide solution. Recent investigations by the author, however, have indicated that a number of South African materials showed no apparent dispersion in distilled water but gave a distinct cloudy appearance in the sodium hydroxide solution. It is thus suggested that both techniques are used locally, until more data is available.

One specific problem soil was investigated in the 1980s. Distress affected a dam in Zimbabwe and the normal sodium testing showed no significant sodium content. During a visit to the dam, the author noted that the area was well known for its lithium deposits, particularly the lithium mica, lepidolite. Testing of the material indicated a high lithium content. Bearing in mind that the reactivity order of the metal alkalis is $Li > Na > K > Rb$, etc, this immediately identified the cause of the high dispersivity, confirmed by testing for lithium by Prof Harmse at the University of Potchefstroom. This indicates the importance of the local geology in material identification and the necessity for experience in potentially problematic materials.

Table 1: Rating criteria for identification of dispersive soils (Bell & Walker, 2000)

Test	Class and weight- ing	Description of dispersivity			
		Dispersive	Moderate	Slightly	Non-dispersive
Pinhole test	Class Rating	5	3	1	0
CEC vs ESP	Class Rating	Highly dispersive 4	Dispersive 3	Marginal 1	Non-dispersive 0
Crumb test	Class Rating	Strong reaction 3	Moderate 2	Slight 1	No reaction 0
SAR	Class Rating	> 2 2	1.5 - 2.0 1		< 1.5 0
TDS vs % Na	Class Rating	Dispersive 2	Intermediate 1		Non-dispersive 0
	Total dispersiv- ity rating	Highly > 12	Moderately 8 - 11	Slightly 5 - 7	Non-dispersive < 4

In the field the first indication of dispersive soils is the presence of highly eroded, gullied and channelled soil slopes *that contain tunnels and internal cavities*. This is not necessarily foolproof and other indicators should be assessed. A common indicator in areas where a variety of trees (Dye 1979), but especially mopane trees (*colophospermum mopane*) in the northern areas of South Africa, occur is that the trees tend to be multi-stemmed with badly stunted growth. Local vegetation could be affected differently and note should be made of differences in growth form or rate of the vegetation species compared with other areas.

Another early indication of potentially dispersive soils is that the soaked (normal 4 day or longer) California Bearing Ratio (CBR) test gives very low strengths (< 3%) even with relatively high unsoaked strengths, which is also shown up by excessive CBR swells.

It is recommended that all of the tests required by the Bell & Walker (2000) rating system be applied to potentially dispersive materials. The designer should be directly involved with the testing at is essential that the results of the crumb and pinhole tests are observed directly.

3 ERODIBLE MATERIALS

Significant work was done on erodible materials in the mid 1960s (Dos Santos & de Castro 1966; Nascimento & de Castro 1974). This was primarily related to minimising erosion damage to road slopes and the main properties affecting erodibility were identified as grain size, swelling and petrification (cohesion resulting from some sort of "cementation" and not apparent cohesion resulting from soil suction. The presence of petrous cohesion (petrification) marks the difference between slaking materials and erodible materials.

Erodible materials thus lie between those materials that are dispersive as a result of high sodium contents and those prone to slaking as a result of a lack of water resistant cohesion. This probably includes dispersive type materials (ie cohesive soils) that have calcium or magnesium saturated clays and not sodium saturated clays. Erosion of these materials is thus a result of the tractive forces of the water flowing over the material (or through the material if adequately wide cracks or flow paths exist) exceeding the ability of the material to resist erosion. This erosion resistance is essentially the shear resistance (S) given by Coulombs law

$$S = C + s \tan f \quad (1)$$

with C the cohesion, s the normal stress and f the angle of internal friction.

It should be noted that the C component is the petrous cohesion discussed previously and it is clear that, if in slaking materials discussed in the following section, this cohesion decreases on soaking and without any normal stress, the material disintegrates.

The presence of these materials is often evident in road cuttings where a relatively homogenous material only starts showing signs of erosion some distance from the top of the slope, as the water flowing over the slope gains velocity, and the traction force exceeds the erosion resistance of the slope part of the way down the slope.

De Castro (1964) and Nascimento & de Castro (1974) studied a number of tropical soils and identified simple swell and water absorption tests to classify the materials. It is interesting to note that a number of other workers (Heinzen & Arulanandan 1977; Rosewell 1977) have used swell tests to identify dispersive soils, but in a different context. Only the swell test has been applied in South Africa by the author on an ad hoc basis, with promising, but unpublished results.

It is suggested that this approach be investigated further for application in South Africa.

Sherard et al (1976a) note that, in the pinhole test, most soils either do or do not erode. Few soils give intermediate results and there are few exceptions of low sodium soils that erode rapidly (Sherard et al 1976b). It is proposed that under the relatively low hydraulic heads and consequent flow rates (0.305 to 3.05 m/s), the tractive force required to remove particles from non-dispersive but erodible materials is not achieved. Higher flow rates may provide more information in this regard and should perhaps be applied. Sherard et al (1976a) refer briefly to this threshold velocity for erodible non-dispersive soils but mostly in relation to there being no threshold velocity for dispersive materials – they disperse in still water.

4 SLAKING MATERIALS

Slaking soils have not been addressed in the literature to any extent as a specific type of erodible soil. The slaking of mudrocks and other rocks and partly weathered rocks has been investigated by a number of workers (Franklin & Chandra 1972; Olivier 1979; Venter 1980). Although slaking has been defined as the degradation of materials by alternating cycles of wetting and drying (Reeves et al 2006), many soils when exposed to water slake immediately, and do not necessarily require alternating wetting and drying.

Field exposures of slaking soils appear similar to erodible and dispersive soils at first glance, but do not show evidence of piping and tunnelling. Slaking is a result of swelling of the individual particles (or possibly compression of air in voids (Reeves et al 2006)), which is simulated clearly when a lump is placed in potable water. The material disintegrates rapidly into smaller particles of gravel, sand and silt without any fines going into suspension in the water as the apparent cohesion is lost. This apparent cohesion is primarily the effect of soil suction (capillary) forces holding the particles together when dry or partly saturated. On saturation these forces are lost and the individual soil particles separate from each other.

Typical examples of such materials are weathered and residual mudrocks, certain alluvial soils, and a single case of the development of a large "sinkhole" in a deep fill constructed from Karoo dolerite on a highway has been investigated by the author. The material used was non-dispersive but slaked to a silty material almost immediately on immersion in distilled water. Leakage of a culvert resulted in water flow through the material, which caused a collapse of the overlying pavement structure (about 3 m in diameter) within 24 hours of the start of the rainfall.

No specialised test methods are necessary to identify these materials. A crumb test in which the crumb disintegrates rapidly (usually within 60 s) and the surrounding solution (0.001N NaOH) remains clear is indicative that the material is probably not dispersive. Turbidity of the solution indicates that it is probably dispersive and additional testing should be carried out. If there is any doubt, it is best that at least the ESP and SAR are tested.

By their nature, slaking soils can be used in the construction of embankments for roads and other structures, as the propensity to slake is reduced once they have been enclosed, specifically with the outer extremes constructed with other (non-slaking) materials.

5 TREATMENT

The means of treating the different types of soil discussed depend on the cause of the problem and the possible use of the material. Successful treatment requires that the dispersive, erodible or slaking potential of the material be recognised and identified. The presence of exchangeable sodium in the clay minerals is critical for the dispersive process to occur and this can be replaced by calcium by treating the material with lime ($\text{Ca}(\text{OH})_2$), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or even ground limestone (CaCO_3), depending on the nature of the soil, the environment and the potential problem. Pinhole tests on numerous dispersive soil samples treated with 1% to 4% hydrated lime have, without exception, indicated that the material was non-dispersive after treatment. The addition of high quantities of lime could result in cracking (resulting from shrinkage) that could exacerbate water flows in certain materials and actually compound the problem. Care needs to be exercised in this regard.

Erodible soils are not a problem as a subgrade material but present challenges on steep and/or long slopes. Treatment or prevention of damage in these cases is best done by limiting the velocity at which water moves over the slope as well as the quantity of flowing water. Techniques such as revegetation, the installation of flow retarding structures or removal of as much water as possible from the slope are the most cost-effective and practical solutions.

Slaking materials are probably one of the most difficult problems in road engineering to control. When exposed in slopes, they will disintegrate continuously until they are protected by an overlying layer of slaked material (which is also highly erodible) or unless they are protected by a layer of topsoil and vegetation. A solution that has been used in South Africa is to cut the slope as steep as possible (subject to stability considerations) to minimise the exposed area of slaking material, and

then maintain the drain at the bottom of the slope regularly.

The addition of calcium based compounds to erodible and slaking materials may have no direct effect through replacement of sodium cations, but treatment with lime will certainly modify and strengthen the material (increase the C component in the Coulomb equation) in the short term, at least.

As in all good construction, all erodible materials (irrespective of their fundamental classification) should be compacted uniformly in thin layers to as high a degree as possible to reduce their permeability as well as to minimise the possibility of their containing potential flow paths for water. The upper portions of compacted layers should be lightly scarified prior to placement of the following layer to remove any flat interfaces. It is also generally recommended that compaction be carried out at 2% to 3% above optimum moisture content (Donaldson 1975; Elges 1985).

Control of water around embankments and drainage structures when dispersive or erodible soils are used in construction is imperative. One of the challenges is obtaining a high degree of compaction adjacent to structures and culverts and thus it is important to ensure that leakage from culverts and drains as well as the possibility of erosion and water access at culvert inlets is carefully attended to.

6 CONCLUSIONS

Many southern African soils have dispersive, erodible or slaking potential. These can have a significant influence on the performance of roads, earth embankments and dams and township infrastructure, if not identified timeously and the necessary precautions taken.

This paper has attempted to differentiate among the different types of erodibility, as each of them has different identification techniques, consequences and preventative treatment options. It is important that the specific type of erodibility is identified and the correct precautions taken.

An aspect that has become obvious from the research in developing this paper is that the state-of-the-art has progressed little since the original paper presented by Elges at the 1985 Problem Soils Conference, and from the number of queries regarding potentially dispersive materials, it appears that additional research should be carried out.

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