Dispersive Soils-Characterization, Problems and Remedies

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Abstract - *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. Such soils that are dislodged easily and rapidly in flowing water of low salt concentration are called dispersive soils. 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 in this paper an attempt is made to analyze the basic characteristics, problems and stabilization with suitable additives.*

Key Words*: *Dispersive Soils, Mineralogy, Erodability, Various tests, Remedies, Suggestions

1. INTRODUCTION

Earlier days clays were considered to be non erosive and highly resistant to water erosion, however recent studies on clays found that highly erosive clay soils do exist in nature. The tendency of the clays to disperse or de-flocculate depends upon the mineralogy and soil chemistry and also on the dissolved salts in the pore water and the eroding water. Based on the studies on dispersive soils in the world, clays of alluvial origin, some soil derived from Mud rocks laid down in a marine environment can be dispersive. They are usually found in flood plains and lake bed deposits.

Figure 1: Typical erodible soil

Many earth dams, hydraulic structures and other structures like road way embankments have suffered serious erosion problems and have failed due to the presence of the dispersive soils. Though the problem has been identified in many parts of the world in recent times, design advances and technical preventive measures are yet to be fully developed and practiced. As the scope and magnitude of the problem, due to dispersive soils, is very high it has become one of the major concerns of the geotechnical engineers.

2. BEHAVIOUR OF DISPERSIVE SOIL

Dispersive clays differ from ordinary, erosion resistant clays, because they have a higher relative content of dissolved sodium in the pore water. Ordinary clays have a preponderance of calcium and magnesium dissolved in the pore water. Ordinary clays have a flocculated or aggregated structure because of the electrochemical attraction of the particles to each other and to water. This accounts for these soils' cohesive, non erosive behavior.

2.1 PROPERTIES

Dispersive clays have an imbalance in the electrochemical forces between particles. This imbalance causes the minute soil particles in dispersive clay to be repulsed rather than attracted to one another. Consequently, dispersive clay particles tend to react as single-grained particles and not as an aggregated mass of particles. They are most easily eroded by water that is low in ion concentration, such as rain water. Runoff water has the opportunity to attain ions from land surface contact making it more in ionic balance with the dispersive clays and less erosive. Typically, dispersive clays are low to medium plasticity and classify as CL in the Unified Soil Classification System (USCS)..Other USCS classes that may contain dispersive clays are ML, CLML, and CH. Soils classifying as MH rarely contain dispersive clay fines.

2.2 MECHANISM OF DISPERSION

When the dispersive clay comes in contact with water, the clay fraction behaves more like a single-grained particle with a minimum electrochemical attraction and there by does not adhere or bond with the other soil particles. The inter particle force of repulsion (Electrical surface forces) exceed those of attraction (Van der Waals attraction).

Clay particles are negatively charged as the result of isomorphous substitution or broken edges so they naturally repel each other (like charges repel). However, the presence of adsorbed cations tends to mask this negative charge (repulsion) to varying degrees, depending on the type of cation. small multi-charged cations (i.e. al^{+3}, ca^{+2}, mg^{+2}) are strongly adsorbed by colloids (unlike charges attract), greatly reducing the negative charge. if the negative charge of the colloid is sufficiently reduced, flocculation will occur as represented shown in figure b. if, on the other hand, the colloids are saturated with large weakly charged cations (i.e. na^+, k^+), dispersion will occur as represented in figure a. sodium, a weakly charged cation that encourages dispersion and calcium, a multi-charged cation that encourages flocculation, provide an example of the intricate relationship between soil chemistry and the physical condition of a soil. the importance of the physical condition and the influence of sodium, creates the situation where knowing the concentration of this cation in a soil is essential.

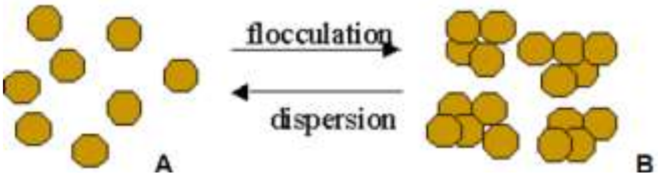

Figure 2: Soil particles in flocculated and dispersed state

The flocculation and dispersion reactions are the result of cation exchange. Cation exchange is the interaction between a cation in solution and another cation on the surface of any surface-active material, such as clay or organic matter The cation exchange that occurs between sodium and calcium on clay mineral surfaces.

3. VARIOUS TESTS

The identification of the dispersive soils starts with the field reconnaissance investigations to determine the patterns on the surface. Dispersive clays cannot be identified by the standard laboratory index tests such as visual classification, grain size analysis, specific gravity or Atterberg's limits and therefore, other laboratory tests have been derived for this purpose. The laboratory tests generally performed to identify dispersive clays are the crumb test, the double hydrometer test, the pinhole test, the test of dissolved salts in the pore water and the SAR (sodium absorption ratio) based tests.

3.1 PHYSICAL TEST

The conventional physical tests performed to determine the dispersive clays include crumb, pinhole test and double hydrometer test.

Crumb test is a simple procedure field test to identify dispersive soil behavior in the field, but is now often used in the laboratory as well. The test consists of either preparing a cubical specimen of about 15 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 in about 250 ml of distilled water. As the soil crumb begins to hydrate, the tendency for colloidal-sized particles to deflocculates and go into suspension is observed. Results are interpreted at timed interval of 2 hrs as dispersive, intermediate dispersive or non-dispersive. The crumb test gives a good indication of the potential erodibility of clay soils.

Double Hydrometer test, also known as Soil Conservation Service (SCS) dispersion test, is one of the first laboratory methods developed to assess dispersion of clay soils. The sample should be sent to the laboratory in an airtight container to prevent moisture loss. Testing is performed on specimens at natural water content. The particle size distribution is first determined using the standard hydrometer test in which the soil specimen is dispersed in distilled water with strong mechanical agitation and a chemical dispersant. A parallel hydrometer test is then made on a duplicate soil specimen, but without mechanical agitation and without a chemical dispersant. Criteria for evaluating degree of dispersion using results from the double hydrometer test are:

1. Non Dispersive - % dispersion < 30
2. Intermediate - % dispersion 30 - 50
3. Dispersive - % dispersion > 50

P**inhole test** was developed to directly measure dispersibility of compacted fine-grained soils in which water is made to flow through a small hole in a soil specimen. 1 mm diameter hole is punched or drilled through a 25mm long by 35mm diameter cylindrical soil specimen. Distilled water is percolated through the pinhole under heads of 50, 180, and 380 mm (hydraulic gradients of approx 2, 7, and 15), and the flow rate and effluent turbidity are recorded. The 50, 180, and 80 mm heads result in flow velocities ranging from approx 30 to 160 cm/s at hydraulic gradients ranging from approx 2 to 15.

Table 1: Summary of Pin Hole Test Results

Classification	Head mm	Time min	Flow Rate ml/sec	Effluent Colour Visibility	Hole size after test
D1	50	5	> 1.5	Very distinct visibility	2X
D2	50	10	> 1.0	Distinct to Slightly visible	2X
ND4	50	10	< 0.8	Slight but easily visible	1.5X
ND3	180-380	5	> 2.5	Slight but easily visible	2X
ND2	1020	5	> 3.5	Clear to barely visible	2X
ND1	1020	5	< 5.0	Crystal clear visible	No erosion

Test results can be categorized as mentioned:

D1 & D2 – Dispersive soils

ND4 & ND3 – Intermediate soils

ND2 ND1 – Non dispersive soils

The test was developed by Sherard et al. (1976a) and in the past few years has become a widely used physical test. It is important that the test shall be made on soils natural water content because drying may affect test results for some soils. If the material contains coarse sand or gravel particles, these should be removed by passing the sample through a 2-mm sieve.

3.2 CHEMICAL TEST

Chemical analyses such as ESP and SAR attempt to relate the relative abundance of exchangeable cations to aggregate stability and dispersion. Relationships between soil dispersion and chemical properties such as Exchangeable Sodium Percent (ESP), Sodium Absorption Ratio (SAR), Cation Exchange Capacity (CEC), and Electrical Conductivity (EC) are for a limited range of soils.

Exchangeable Sodium Percent (ESP) is the most common analytical technique used to identify sodic or potentially dispersive soils.

$$ESP = \frac{Na^+}{Na^+ + Mg^{2+} + K^+ + Ca^{2+}} \times 100$$

Criteria to classify dispersive clays using ESP data is as mentioned below:

ESP <7 - Non Dispersive Soils

ESP 7 – 10 - Intermediate Dispersive Soils

ESP >10 - Dispersive Soils

Sodium Absorption Ratio (SAR) is the another parameter commonly evaluated to quantify the role of sodium with respect to dispersion when free salts are present.

SAR of the pore water:

$$SAR = \frac{Na+}{\sqrt{0.5\ (Ca + Mg)}}\ meq/L$$

SAR method is not applicable if free salts are not present. Specifically there is a relationship between electrolyte concentration of the soil pore water and the exchangeable ions in the clay adsorbed layer.

Cation Exchange Capacity (CEC) can either be obtained by summing the amounts of the common exchangeable cations present (these are determined individually) or by a single laboratory test in which the total cation exchange capacity is determined. Soils with an ESP value greater than 15% are considered highly dispersive and those with low CEC (15 meg/100g clay) have been found to be completely non – dispersive at ESP value of 6% or less.

Another soil property that governs susceptibility of a soil to dispersion is the Total Dissolve Solids (TDS) in relation to the salt content of the water affecting the structure. The higher the sodium percentages in the saturation extract relative to the TDS, the greater the susceptibility of the sodium saturated clays to disperse. The percentage sodium , which is the ratio between sodium and TDS in the saturation extracted, may also give an indication of the dispersion potential. The percentage sodium is defined as:

$$Na\ \% = \frac{Na^+}{TDS} \times 100$$

Where TDS = $Na^+ + K^+ + Ca^{2+} + Mg^{2+}$

With all units expressed in meg/l of saturation extract.

Electrical Conductivity (EC) of a solution is a measure of the ability of the solution to conduct electricity. The EC is reported in either milliohms per centimeter or the equivalent decisiemens per meter. When ions (salts) are present, the EC of the solution increases. If no salts are present, then the EC is low indicating that the solution does not conduct electricity well. The EC indicates the presence or absence of salts, but does not indicate which salts might be present. For example, the EC of a soil sample might be considered relatively high. No indication from the EC test is available to determine if this condition was from irrigation with salty water or if the field had been recently fertilized and the elevated EC is from the soluble fertilizer salts. To determine the source of the salts in a sample, further chemical tests must be performed.

3.3 PHASE ANALYTICAL METHOD

Phase analytical techniques are used to determine the exact composition of soils i.e. their mineral and the order of arrangement. These techniques include XRD (X Ray Diffraction) test and SEM (Scanning Electron Microscopic) tests.

XRD (X Ray Diffraction) TEST is perhaps the most widely used X-ray based analytical techniques for characterizing materials. The X ray analysis helps in identifying the types of minerals present in soil samples .When an X-ray beam hits a powder – fined ground sample and is diffracted, we can measure the distances between the planes of the atoms that constitute the sample by applying Bragg's Law, :$n\lambda = 2d\sin\theta$, where the integer n is the order of the diffracted beam, λ is the wavelength of the incident X-ray beam, d is the distance between adjacent planes of atoms (the d-spacing), and θ the angle of incidence of the X-ray beam.

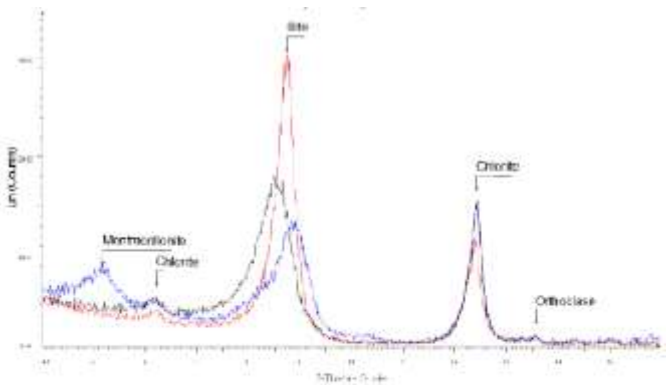

Figure 3: XRD pattern of clay minerals

SEM (Scanning Electron Microscopic) Test is one of the ideal tools available for the measurement of fabric of clays because of its higher resolution capacity together with large depth of focus and also it is possible to get the three dimensional view of the arrangement of the particles. The scanning electron microscope is operated at 20kV and is of the type FEI Quanta 200. First the entire area of the fractured surface is scanned under low magnification and then, the chosen representative areas are magnified to get the clear picture of the micro fabric arrangement.Seven days cured compacted samples were taken for this study so that there is sufficient time for the development of the cementatious bonds. The samples were split apart in the direction opposite to that of the compaction, and a cube of 10mmx10mmx10mm is obtained in the undisturbed state as the fractured surface provides the details of the crystals present.

4. ACTIVITIES ENCRASING DISPERSION

Following are the major activities that help in erosion of soil:

1. Overgrazing
2. Removal of top soil
3. Excavation in dispersive soil
4. Poor compaction of sodic soil
5. Concentration of runoff

5. PROBLEMS OF DISPERSIVE SOILS

Dispersive soils are not suitable as foundation material or as fill material in the construction of structures. Using dispersive clay soils in hydraulic structures, embankment dams, or other structures such as canal lining, roadway embankments can cause serious engineering problems if these soils are not identified and used appropriately. This problem is worldwide, and structural failures attributed to dispersive soils have occurred in many countries.

5.1 STRUCTURAL PROBLEMS

The problems associated with the structures are:

1. Dam embankment failure
2. Tunnel erosion
3. Canal failure
4. Piping failure

5.2 CONSTRUCTION PROBLEMS

Major construction problems due to dispersive soils are listed as:

1. Collapse of fill
2. Pipes and Cables failure
3. Breaching Septic trenches

5.3 DEVELOPMENTAL PROBLEMS

Now a days the landscape developments are considered to be emerging field of area. The problems associated with it due the dispersive soils are:

1. Erosion of external soil slopes
2. Internal erosion
3. Extreme turbid water (never settles)
4. Sediment deposits

6. REMEDIES

At present, due to increased land use pattern there is more concern about the economy. In practice, soils with low bearing capacity, low stability, high settlements, excessive swelling or shrink properties are usually encountered. It has become necessary to make such soils suitable for construction by increasing the strength, reducing compressibility, swelling or shrinkage and increasing the durability of soils by altering the properties and making it stabilize for developmental work.

6.1 PHYSICAL STABILIZATION

It includes the change in physical state of soil to make it stable. Following are the methods of physical stabilization:

1. Identifying and avoiding disturbance to areas with dispersive subsoil.
2. Minimizing excavation of dispersive soils.
3. Not allowing water to pond on the soil surface, or exposed subsoil.

4. Keeping sodic sub-soils buried under topsoil.
5. Maintaining vegetation cover.
6. Precise compaction.
7. Top soiling.
8. Sand filters and sand blocks

6.2 CHEMICAL STABILIZATION

It is a chemical process where original structure of minerals breakdown to form a new stabilize mineralogical arrangements. It is also called as chemical amelioration.

HYDRATED LIME (CALCIUM HYDROXIDE) has been widely used to prevent piping in earth dams. Rates of application have varied depending on soils and degree of compaction used in construction. Only around 0.5 –1.0% hydrated lime is required to prevent dispersion, however difficulties with application and mixing necessitate higher rates of application. The strength of the clayey soil increases with increase in lime content up to certain limit, called optimum lime content which depends on clay content and reactive silica. It is observed that the lime treatment reduces the settlement and improves the strength.

GYPSUM (CALCIUM SULPHATE) is more effective than lime for the treatment of dispersive soils as it increases the electrolyte concentration in the soil solution as well as displacing sodium with calcium within the clay structure. Gypsum is less commonly used than hydrated lime in dam construction and other works due to its lower solubility, and higher cost. Studies show that in construction, a minimum of 2% by mass of gypsum be used.

ALUM (ALUMINIUM SULPHATE) effectively used to prevent dam failure and protect embankments from erosion. Limited data suggests mixtures of 0.6 –1.0% (25% solution of aluminium sulphate) to 1.5% of the total dry weight of soil may be appropriate. Alum is however highly acidic (pH 4-5), and thus alum treated soils will need to be capped with topsoil in order to establish vegetation. Soil testing is required to establish appropriate application rates for soils. Long chain of polyacrylamides helps to increase aggregate stability, reduce dispersion and maintain infiltration rates in dispersive.

CALCIUM CHLORIDE is chemically $CaCl_2\ 2H_2O$. It is a highly soluble salt which supplies soluble calcium directly. Its reactions in sodic soil are similar to those of gypsum:

$Na_2CO_3 + CaCl_2$ Û $CaCO_3 + 2\ NaCl$ (leachable)

SULPHURIC ACID is chemically H_2SO_4. It is an oily corrosive liquid and is usually about 95 percent pure. Upon application to soils containing calcium carbonate it immediately reacts to form calcium sulphate and thus provides soluble calcium indirectly. Chemical reactions involved are:

$Na_2CO_3 + H_2SO_4$ Û $CO_2 + H_2O + Na_2SO_4$ (leachable)

$CaCO_3 + H_2SO_4$ Û $CaSO_4 + H_2O + CO_2$

PYRITE (FeS_2) is another material that has been suggested as a possible amendment for sodic soil reclamation. Reactions leading to oxidation of pyrite are complex and appear to consist of chemical as well as biological processes. The following sequence has been proposed for the oxidation of pyrite by Temple and Delchamps (1953). The first step in the oxidation is nonbiological and iron II sulphate (ferrous) is formed

$2\ FeS_2 + 2\ H_2O + 7\ O_2$ Û $2\ FeSO_4 + 2\ H_2SO_4$

This reaction is then followed by the bacterial oxidation of iron II sulphate, a reaction normally carried out by Thiobacillus ferrooxidans,

$4\ FeSO_4 + O_2 + 2\ H_2SO_4$ Û $2\ Fe_2(SO_4)_3 + 2\ H_2O$

Subsequently iron III sulphate (ferric) is reduced and pyrite is oxidized by what appears to be a strictly chemical reaction.

$Fe_2(SO_4)_3 + FeS_2$ Û $3\ FeSO_4 + 2\ S$

Elemental sulphur so produced may then be oxidized by T. thiooxidans and the acidity generated favours the continuation of the process

$2\ S + 3\ O_2 + 2\ H_2O$ Û $2\ H_2SO_4$

Summary: $4\ FeS_2 + 2\ H_2O + 15\ O_2$ Û $2\ Fe_2(SO_4)_3 + 2\ H_2SO_4$

POLYACRYLAMIDES however the effect is highly variable between various polyacrylamide products and the chemical and physical properties of the soil. Further advice and laboratory testing should be conducted before using polyacrylamides to protect earth dams from piping failure

POZZOLAN is a finely divided siliceous, or siliceous and aluminous, material which by itself possesses little or no cementing value. In the presence of moisture, however, it will chemically react with lime at ordinary temperatures to form cementing compounds. Natural pozzolans from different geographical regions nevertheless have diverse properties due to their respective chemical compositions which could lead to varying results in the products treated by these additive materials. Test studies shows that addition of 5% pozzolan has maximum reduction in % dispersion.

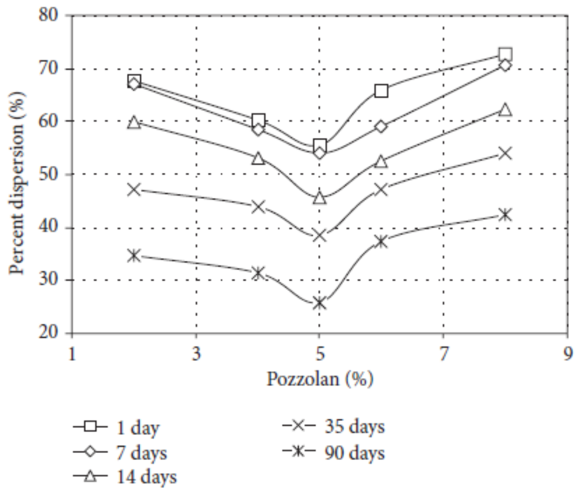

Figure 4: Graph % dispersion with Pozzolan content

PORTLAND CEMENT has also been used extensively in treating clays in the construction industry. Because of the existence of lime in most cements, the latter would not be any better than the former if used alone as additive in stabilizing dispersive clays. For this reason and the fact that, when used alone, certain pozzolans also have not been effective in the treatment of dispersive clays. 2-4% of cement is ideally added to reduce maximum dispersion.

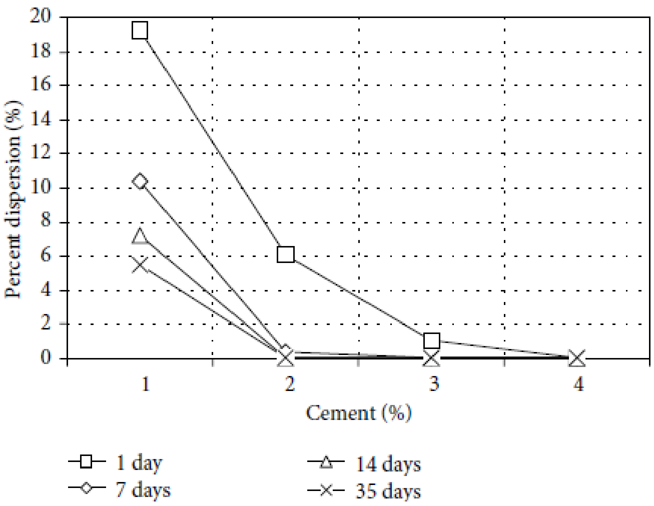

Figure 5: Graph % dispersion with cement content

6.3 DESIGN MEASURES FOR STABILIZATION

When dispersive clays are detected in a site investigation and verified by testing, defensive measures must be incorporated into the design. The designer must base any special design features on the severity of the dispersive characteristics of the soil.

For Embankment if non dispersive soils can be located, designate that borrow source for construction of the entire embankment. If the volume of non dispersive soils in the borrow area is not adequate to construct the entire embankment, the construction plans should designate non dispersive materials as a blanket for the embankment. The blanket thickness should be 12 inches. The blanket protects the underlying dispersive clays from drying cracks and erosion by rainfall. The most effective design measure for preventing internal erosion of earth fills is a sand chimney filter. Sand diaphragms around the conduit are an effective method of controlling internal erosion in that area. Placement of dispersive soils into specified zones of an embankment may be incorporated in the design if the zone is not relied upon as a barrier to seepage or internal erosion.

For Wastage storage pond liners and excavated slopes dispersive soils can be over excavated and replaced or blanketed with non dispersive soils to the lines and grades required on the construction plans. This is the recommended design feature for waste storage ponds. Chemical amendments may be used to treat exposed dispersive soils on excavated slopes. This treatment is not recommended for waste storage ponds.

6.4 OTHER MEASURES FOR STABILIZATION

In some localities cheap acidic industrial wastes may be available which can be profitably used for sodic soil improvement. Press mud, a waste product from sugar factories, is one such material commonly used for soil improvement. Press mud contains either lime or some gypsum depending on whether the sugar factory is adopting carbonation or a sulphitation process for the clarification of juice. It also contains variable quantities of organic matter. Sand filters prevent dam failure by trapping entrained sand and silt, blocking the exit of the tunnel and preventing further tunnel development (Sherard *et al.* 1977). Richley (1992 and 2000) developed the use of sand blocks to prevent tunnel erosion during installation of an optical fibre cable in highly dispersive soils. The sand blocks work slightly differently to the sand filters in that they allow the free water to rise to the surface through the sand. The use of sand blocks has recently been modified by Hardie *et al.*, (2007) to prevent re-initiation of tunnel erosion along an optical fibre cable.

7. CONCLUSIONS

Dispersive soils which occur in many parts of the world are easily erodible and segregate in water pose serious problems of stability of earth and earth retaining structures. The mechanism of dispersivity of soils is reasonably well understood. Visual classification, Atterberg's limits and particle size analysis do not provide sufficient basis to differentiate between dispersive clays and ordinary erosion resistant clays. Pinhole test and double hydrometer test are the only two tests that plays an important role to identify the dispersive soils. This paper explores the characterization, problems due to dispersive soils and their remedial measures to stabilize it. It has been concluded that dispersivity ascertained from strength tests is more reliable.

Dispersive soils erode under small seepage velocity leading to problems of stability of earth and earth retaining structures. No concurrences exist in identifying dispersivity of soil by all the four tests. It has to be arrived at by consensus of test results. The Double Hydrometer test and Chemical analysis of pore water extract test are more conservative in showing the dispersion of soil. The pinhole test is more reliable as it simulates field conditions. The crumb test gives a good indication of the soil for potential tendency to erosion. The strength of dispersive soil increases with increase in lime, alum and gypsum content up to certain limit.

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