

Characterization of Dispersive Soils- A Comparative Evaluation between Available Tests

Neetu singh¹, Sameer Vyas², R.Chitra³, Beena Anand⁴

Central Soil and Materials Research Station, Olof Palme Marg, Hauz khas, New Delhi, India^{1,2,3,4}

ABSTRACT: Dispersive soils which occur in many parts of the world are easily erodible and deflocculated in water causing serious problems of stability of earth and earth retaining structures. Earth dams constructed on dispersive soils have suffered internal and surface erosion. The erosion features such as rill and gully marks, channels, internal cavities and tunnels with in the soil mass have been observed in natural slopes of dispersive soils. The failure of slopes due to dispersion of clay particles by seepage water along cracks, fissures and root holes are initiated by erosion of soil. Thus the failure initiated by piping makes the embankments constructed on dispersive soil susceptible.

The mechanism of dispersivity of soils is reasonably well understood. However there is no single method to identify the dispersive soil therefore in absence of proper diagnostic criteria it is difficult to differentiate between dispersive soil and ordinary erodible soils. The available test methods for dispersive soils are Crumb Test, Pinhole test, SCS double hydrometer and chemical analysis of pore water extract. This paper deals with the best possible evaluation of test methods for confirming and characterizing the dispersive soils. The role of surface chemistry responsible for dispersivity is further understood with the help of Sodium absorption ratio (SAR) and mineralogical examination with X-ray diffractometer (XRD). The rationale of using the methods and correlation between the dispersivity determined by various methods has been explained.

KEYWORDS : Dispersive soil, Colloidal erosion, Deflocculation, Dispersivity tests

I. INTRODUCTION

Dispersive soils are highly susceptible to erosion and piping phenomenon and undergo deflocculation in the presence of flowing water[1]. It rapidly erode forming tunnels and deep gullies by a process in which the individual clay particles go into suspension in slow-moving water (colloidal erosion), damaging earth dams, canals, and other hydraulic structures[2].

the failure initiated by piping makes the embankments constructed on dispersive soil susceptible . Dispersive piping in dams has occurred either on the first reservoir filling or, less frequently, after raising the reservoir to highest level.

Dispersive soils contains higher content of dissolved sodium ions in pore-water than ordinary soils, The sodium increases the thickness of the diffused double water layer surrounding the individual clay particles. This causes the repulsive forces to exceed the attractive forces so that the particles readily go into suspension in the presence of water [3]. The sodium ions are adsorbed onto the surface of the clay. It is a large ion with a weak charge. The positive ions bind the negatively charged clay particles together. (Fig.1)

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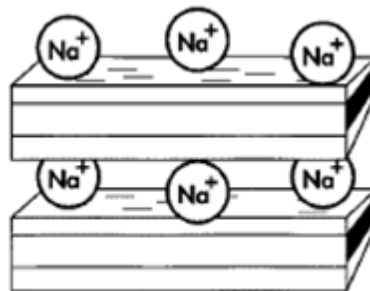


Fig.1 Showing negatively charged clay particle with adsorbed sodium counter ions.

The tendency for dispersive erosion in a given soil also depends on variables such as mineralogy and chemistry of the clay, as well as dissolved salts in the water in soil pores and in the eroding water.

The dispersive mechanism have been reported by various researchers such as Sherard et al., [2], Heinzen and Arulalandan [4], Holmgren and Flanagan [5]. Many slope and earth dam failures, foundation and pavement failures have been observed in these types of soils.

Mechanism of Clay Dispersion:

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 2B**. 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 2A**. 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.

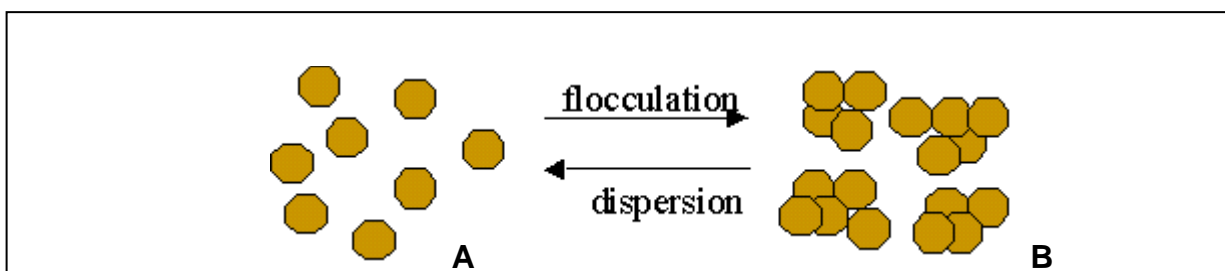


Figure 2: Soil Particles in a Dispersed and Flocculated Condition

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.

Diffuse double layers

Clay particles sometimes behave as colloidal particles in suspension. The diffuse double layer occurs at the interface between the clay surface and the soil solution. It is made up of the permanent negative charge of the clay and the

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cations or counter-ions in the soil solution that balance the negative charge. When the electrical diffused double layers of the two clay particles carrying similar outer charge come close to each other, they repel due to electrostatic repulsion and thus initiated colloidal dispersion phenomenon. Most studies reported in the literature have shown that failures of structures built of dispersive clay soils occurred on first wetting. All failures were associated with the presence of water and cracking by shrinkage, differential settlement, or construction deficiencies. These failures emphasize the importance of early recognition and identification of dispersive clay soils; otherwise, the problems they cause can result in sudden, irreversible, and catastrophic failures.

II. RELATED WORK

First time, Middleton introduced the phenomenon of dispersion as a factor of fine-grain soil erosion. He stated that high percentage of sodium minerals in dispersive soils is the main cause of dispersion. During 1935 to 1938 Volk also realized that soil dispersions the main cause of the destruction of small dams and levees designed by SCS. The dams were generally damaged after first filling [6]. Because classification and routine laboratory tests, such as grain size distribution and Atterberg limits, cannot be used to identify dispersive soils, certain tests have been proposed by researchers and codes. Due to complex mechanisms of dispersion, so far no unique test has been proposed for soil dispersivity. Common tests for determining the degree of dispersion of soils include: Crumb test, double hydrometer test, Pinhole test and chemical tests (Sherard chemical criteria) [7]. These tests have been carried out for each soil in accordance to ASTM.

Dispersive soils cannot be differentiated from ordinary soils by conventional soil mechanics tests. An investigation in which four different laboratory tests for dispersion were performed on a considerable number of soils of diverse origins and properties has provided improved understanding of the properties of dispersive soil and strengthened identification criteria.

The objectives of this study is to established a confirmatory test for identification of soil dispersivity by using interpretation of results obtained from all the four existing soil dispersivity test i.e. Crum test, Pinhole Test, SCS dispersion test and chemical analysis of pore water extract.

III EXPERIMENTAL

Soil samples from four different irrigation projects were collected for this purpose and the following recommended dispersivity tests were conducted as per ASTM & BS standard procedures [8-11].

Crumb test

This test indicates erodibility of clayey soil. This test is generally performed in field for preliminary visual identification of dispersive nature of soils. (Fig.3)

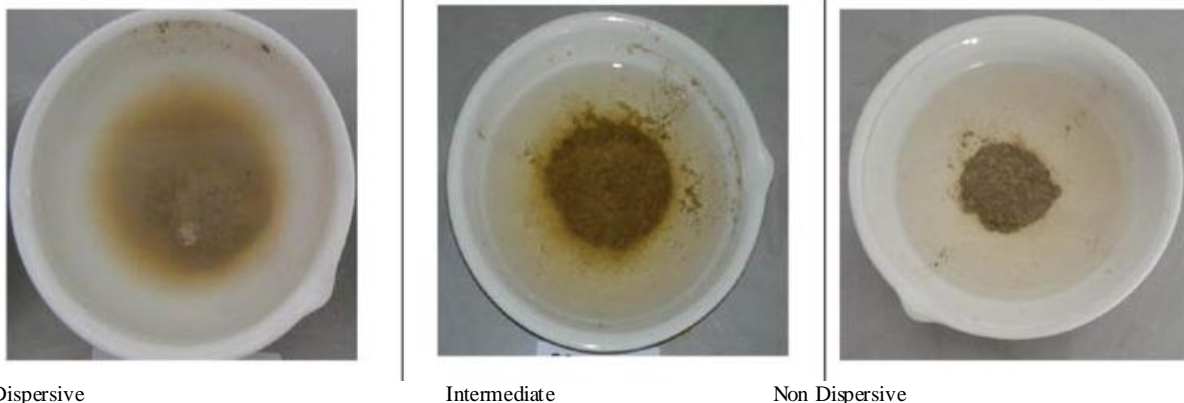


Fig.3 Shows Different Responses of soils During Crumb Test

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Pin Hole Test

In the pinhole test, distilled water is allowed to flow through a 1.0 mm diameter hole drilled through a compacted specimen. The water becomes muddy and the hole rapidly erodes in dispersive clays. For non dispersive clays the water is clear and there is no erosion. (Fig.4)



Fig.4 Pin Hole Test Apparatus

SCS Double Hydrometer Test

The soil conservation service laboratory dispersion test, also known as the double hydrometer test is one of the first methods developed to assess dispersion of clay soils. The current test method was developed in 1937 from a procedure proposed by Volk [12]. The particle size distribution is first determined using the standard hydrometer test in which the soil specimen is dispersed in distilled water with a chemical dispersant. A parallel hydrometer test is then made on a duplicate soil specimen, but without a chemical dispersant. Procedures for performing the test are outlined in USBR 5405. (Fig.5)



Fig. 5. SCS Double Hydrometer Test

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Chemical Tests

The chemical analysis of soils pore water extract was seems to the most reliable methods for characterizing soil dispersivity. The phenomenon of dispersivity is due to the presence of dissolved sodium content in pore water and therefore its percentage was calculated by estimating total dissolved cations (Na, K, Ca& Mg) present in soils pore water extract.To obtain saturation extract, soil is mixed with distilled water until a saturated soil paste with water content near the liquid limit is obtained. The paste is allowed to set for a number of hours untilequilibrium is attained between the salts in the pore water and those on the cation exchange complex. Subsequently, a small quantity of pore water is filtered from the soil paste using a vacuum. This extracted pore water is tested using EDTA titration method (For Ca& Mg) and using flame photometer(For Na & K).(Fig.6)



Fig. 6 Flame Photometer

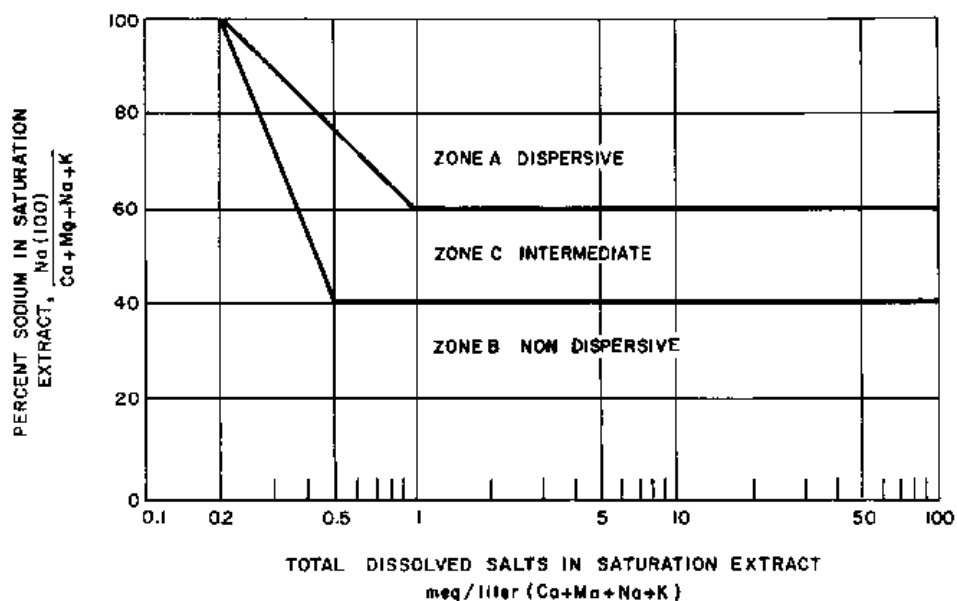


Fig.7. Plot of IDS V/s Percent Sodium

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After plotting the above graph for each samples the results were categorized as follows

- Soil with water soluble Sodium Percentage below 40 meq/lit. are categorized in Zone B (Non Dispersive)
- Soil with water soluble Sodium Percentage between 40-60 meq/lit. are categorized in Zone C (Intermediate)
- Soil with water soluble Sodium Percentage above 60 meq/lit. are categorized in Zone A (Dispersive)

Sodium absorption ratio (SAR)

The SAR is a ratio of the concentration of sodium ions to the concentration of calcium plus magnesium ions. The Sodium absorption ratio (SAR) of the soil solution adequately defines the soil sodicity problem and has a marked influence on the physical soil properties. Sodium adsorption ratio, SAR, is defined by the equation:

$$SAR = Na^+ / \sqrt{(Ca + Mg)^{++} / 2}$$

where all concentrations are in meq / litre.

XRD tests

X-ray diffraction analysis (XRD) 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 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-spacings), and θ the angle of incidence of the X-ray beam.

IV. RESULTS & DISCUSSION

The four soil sampled from different project were analyzed for dispersivity using all the four tests method. The results of crumb test, SCS double hydrometer, Pin hole tests and chemical analysis of pore water extract are presented in table 1, 2, 3 & 4 respectively.

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Table-1
Result of Pinhole Test

Sample No.	Depth (m)	Particulars of water	Hydraulic Head in mm								% Erosion	Remarks for hole dia	Inference
			50	100	180	250	380	600	1020				
1.	0.5-2.0	Discharge in ml/sec	0.47	0.57	0.55	0.86	1.02	1.24	1.65	5.40	No Change	Non Dispersive	
2.	0.3-2.8	Discharge in ml/sec	0.28	0.32	0.39	0.52	0.75	1.09	1.69	5.4	2 times	Intermediate	
3.	0.3-3.0	Discharge in ml/sec	0.18	0.31	0.44	0.61	0.78	0.90	1.07	1.9	No Change	Non Dispersive	
4.	0.2-1.8	Discharge in ml/sec	0.53	0.79	1.03	1.50	1.70	1.97	2.53	3.87	No Change	Non Dispersive	

Table-2
Result of SCS Double Hydrometer

Sample No.	Depth (m)	Percent Finer (0.005 mm aperture size)		Percent Dispersion	Inference
		Without dispersing agent	With dispersing agent		
1.	0.5-2.0	7.1	16.9	42.0	Intermediate
2.	0.3-2.8	22.0	37.2	59.1	Dispersive
3.	0.3-3.0	10.4	64.7	16.1	Non Dispersive
4.	0.2-1.8	10.3	31.4	32.8	Non Dispersive

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Table-3
Result of Crumb Test

Sample No.	Depth(m)	Grade of Reaction	Reaction	Inference
1.	0.5-2.0	I	No reaction, no sign of cloudy water	Non Dispersive
2.	0.3-2.8	II	Slight Reaction	Intermediate
3.	0.3-3.0	I	No reaction, no sign of cloudy water	Non Dispersive
4.	0.22-1.8	I	No reaction, no sign of cloudy water	Non Dispersive

Table-4
Results of Chemical Analysis of Pore Water Extract

Sample No.	Millequivalent per litre				Total Na+K+Ca +Mg Milliequivalent per litre	% Sodium	Dispersion Zone	Remarks
	Sodium	Potassium	Calcium	Magnesium				
1.	3.23	0.45	1.0	0.2	4.88	66.2	A	Dispersive
2.	1.78	0.61	0.6	0.8	3.79	46.1	C	Intermediate
3.	5.13	0.26	0.3	0.4	6.09	84.24	A	Dispersive
4.	4.14	1.07	0.4	0.6	6.21	66.7	A	Dispersive

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The results of SAR of all the four samples are presented in table 5

Table-5

Sample No.	Sodium Absorption Ratio (SAR)
1	4.16
2.	2.13
3.	8.68
4.	5.91

The results presented in table no.1-4 clearly shows dispersive/intermediate trend for sample no,2, however for remaining samples, a disagreement shown between these four tests. The results of chemical analysis presented in table no.4 however observed to be different from other engineering tests.

The results of sodium absorption ratio (SAR) presented in table 5, also in agreement with results of table 4, which shows dispersive nature of three soil samples.

In view of the different out come of above mentioned engineering and chemical test, a XRD study was also conducted for further confirmation regarding dispersivity of soil sample no.2 compare this with the XRD pattern of standard clay samples.

The observations are presented in fig. 8 & 9

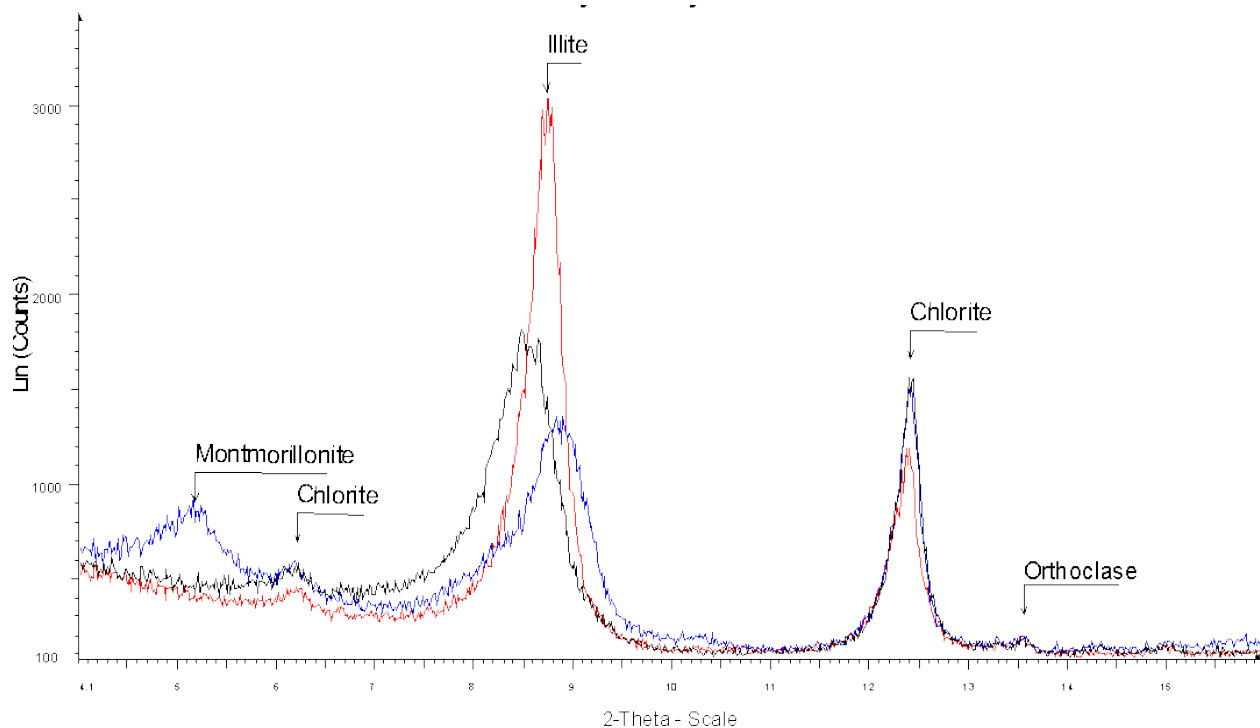


Fig.8 XRD pattern of clay minerals

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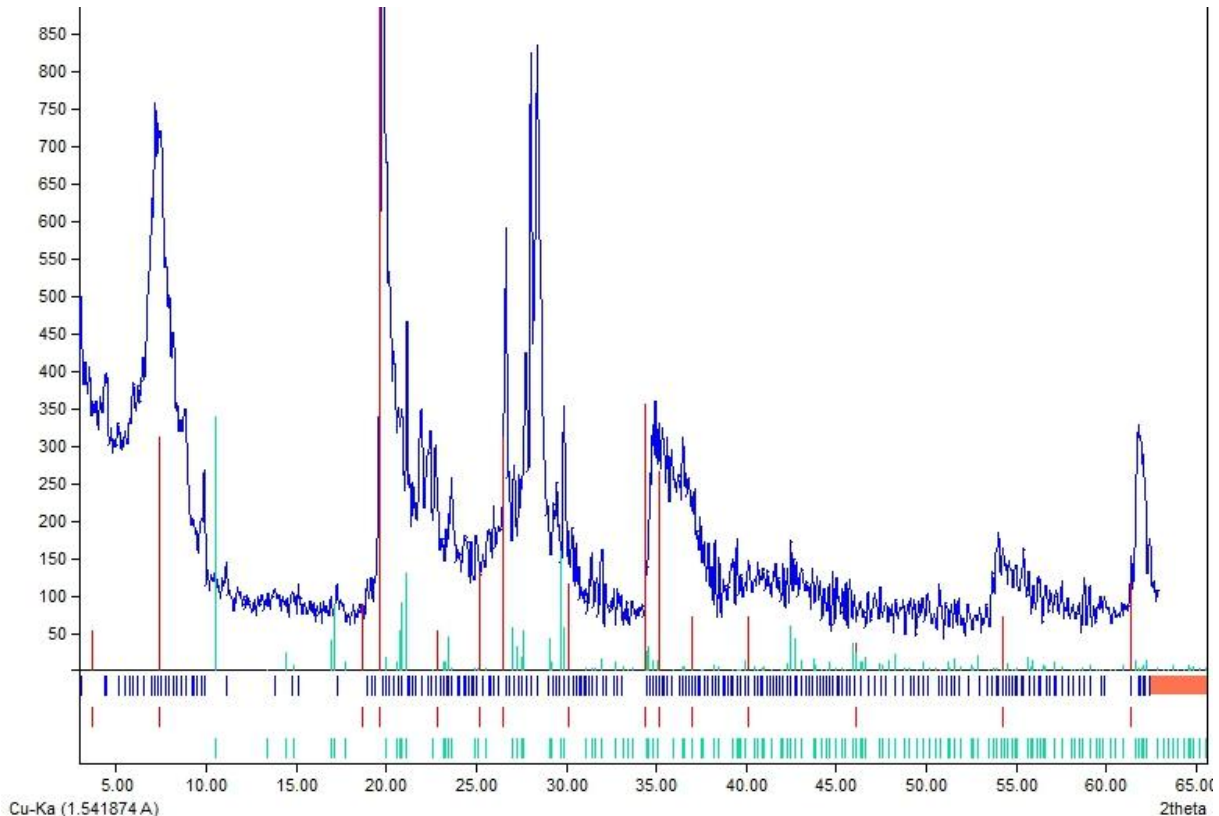


Fig.9 XRD pattern of Dispersive sample no.2

V. CONCLUSION

The results of different tests conducted on all the four soil samples indicated different outcome on dispersivity criteria and shows very little agreements with each other. The observation of engineering tests were found to be different from chemical tests. The SAR results also in agreement with the chemical analysis results. The dispersivity is a surface phenomena and certain clay minerals are responsible for this, therefore a XRD analysis was also conducted to confirm the presence of clay minerals responsible for dispersivity. In order to reach any conclusion regarding, a detail analysis of all the available tests are need to be conducted on large numbers of soil samples with known dispersive history. The XRD analysis with detail interpretation of types of minerals present need to be further investigate,

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