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EFFECT OF SOIL COMPOSITION ON CRITICAL WATER EROSION SHEAR STRESS[1]

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Abstract – The effects of soil composition on the erodability of saturated cohesive soils were experimentally investigated. The materials consisted of commercial clay minerals mixed with silica flour in different proportions. Slurries of different clay specimens were brought to equilibrium with solutions of various electrolyte concentration and sodium adsorption ratios prior to consolidation. Radio frequency dielectric dispersion was adapted to characterize the materials. Hydraulic erodability was determined by means of a rotating cylinder apparatus. Critical shear stress was obtained by measuring erosion rate as a function of shear stress. The results showed that the structure of the medium has a significant effect on soil erodability. In a low electrolyte concentration high sodium adsorption ratio, montmorillonitic clay is readily dispersed and thus has a lower critical shear stress than illitic or kaolinitic clays.

INTRODUCTION

Most of our knowledge concerning the factors contributing to the erosion of cohesive soils and erosion control has been based on the results of field experiments. The inherent erodability of soils has been related to such soil properties as structure, texture, organic content, pH and permeability [11, 13, 15, 20, 22]. Engineering properties of the soil have also been considered as potential indices of soil erodability [2, 16].

Middleton [13] conducted field studies and found a relationship between erodability of soil and its corresponding dispersion ratio. Anderson [3] introduced the surface-aggregation ratio as a new index of erodability. It is defined as the surface area of soil particles larger than silt divided by the percentage of silt and clay in dispersed soil minus that in an undispersed soil. The index was found to be highly correlated with suspended sediments discharged from watersheds. Yamamoto and Anderson [21] stated that the suspension percentage is largely independent of other erodability indices and that it may serve as a good indication of soil erodability. Smerdon and Beasly [19], Dunn [7] and Carlson and Enger [6] have used the plasticity index (difference between liquid limit and plastic limit) as an index for soil erodability. Although some very valuable data exist

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and good correlations have been developed between these indices and soil erosiveness, it is difficult to understand why such relationships exist. For this reason, more studies, taking the factors affecting erosion into consideration, are needed if valid theories are to be developed on erosion characteristics of cohesive soils.

The purpose of this paper is to determine the effect of type and amount of clay and pore fluid composition on the erodability of soils.

MATERIALS AND METHODS

Soils

The soil used in this study was a local loam. In order to simulate a wide range of conditions, a bulk sample of soil was sieved through a No. 40 sieve to remove the sand fraction. The fraction which was less than 50 μm in diameter was also removed by sedimentation. The remaining materials (stockpile) were then mixed with various clay minerals. The clay additives used were montmorillonite (Na-form volclay bentonite), illite (Grundite®) and kaolinite (Hydrate-R). Most of the soil used contained 40% by weight of clay minerals.

Sample preparation

Samples of stockpile material together with appropriate weighed fractions of clay mineral additives were mixed in bottles containing solutions of various sodium adsorption ratios (SAR) and salt concentration. Samples were agitated from time to time to facilitate complete equilibrium between the soil and solution. Samples were filtered and the soil slurry was then mixed to a uniform consistency and placed into a 3-in. diameter mold and consolidated with increasing load up to 0.75 kg/cm^2. The samples were then ejected from the mold and trimmed to the required height. The effluents obtained during the consolidation process were analyzed for specific electrical conductivity and ionic concentration.

Erosion testing procedure

The erosion testing apparatus used was a rotating cylinder described in detail by Espey [8], Masch *et al.* [12] and Moore and Masch [14] with some modifications [1, 5]. Critical shear stress which initiates erosion was obtained by measuring the erosion rate as a function of applied shear stress.

Soil characterization

In order to examine the effect of type and amount of clay fraction on hydraulic erodability, it was first necessary to characterize the soils. An electrical method which allowed determination of the amount and type of clay without destroying the soil sample was used [4]. This method makes use of the electrical properties of a soil sample such as the magnitude of apparent dielectric dispersion ($\Delta\epsilon_0$). For the soils having 40% by weight of clay minerals, the average $\Delta\epsilon_0$ were 85, 30 and 15 for montmorillonitic, illitic and kaolinitic soils, respectively.

RESULTS AND DISCUSSION

Effect of clay type

In order to evaluate the effect of clay mineralogy on hydraulic erodability, the critical shear stress was plotted vs the dielectric dispersion for different pore fluid compositions. Such plots are shown in Figs. 1 to 4. It is seen that the effect of clay type varied with pore fluid composition. At a high pore fluid concentration, as shown in Fig. 1, critical shear stress increased with increasing $\Delta\epsilon_0'$ for low values of SAR. In other words, at high concentration of pore fluid, montmorillonitic soils had a higher resistance than illitic or kaolinitic soils. The effect was more pronounced at low SAR, while at high SAR the critical shear stress was independent of clay type.

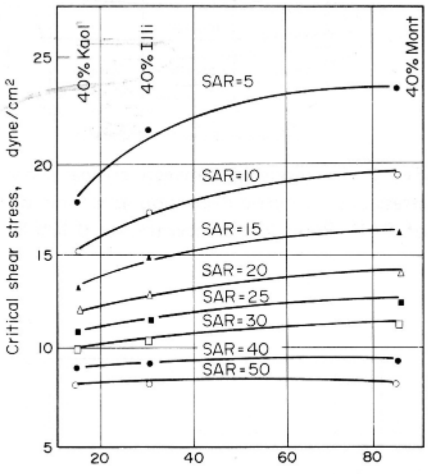

Fig. 1. Relationship between critical shear stress and dielectric dispersion as a function of SAR. Pore fluid concentration 0.250 N.

At very high salt concentration and low SAR, all three clay types were flocculated. In such a condition, very little osmotic swelling took place, and the binding between the particles and/or the aggregates was very strong. It is quite possible that a flocculated montmorillonitic soil shows a higher critical shear stress than kaolinitic soil. This may be due to the high specific surface area and cation exchange capacity of the montmorillonite, in which all exchange sites are wholly satisfied with divalent ions and produce a very thin and strong double layer. As the proportion of monovalent to divalent ions increased, structure of montmorillonitic soil shifted from a flocculated structure to a less flocculated condition. In this transitional structure, montmorillonite showed significant osmotic swelling to decrease its strength against erosion but the cohesion between clay particles was still high enough to produce equal or even higher critical shear stress than flocculated illitic or kaolinitic soil.

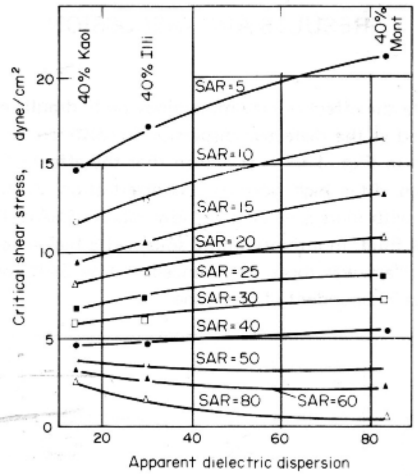

Fig. 2. Relationship between critical shear stress and dielectric dispersion as a function of SAR. Pore fluid concentration 0.125 N.

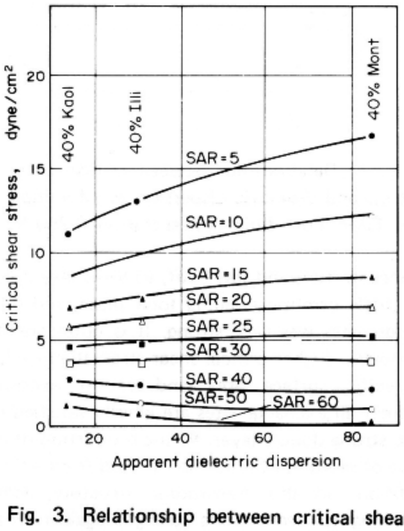

Fig. 3. Relationship between critical shear stress and dielectric dispersion as a function of SAR. Pore fluid concentration 0.050 N.

As the concentration decreased, montmorillonitic soil showed higher critical shear stress than kaolinite only if SAR was low. It is seen in Figs. 2 and 3 that for a pore fluid concentration of 0.125 N, normal for any values of SAR above 50, montmorillonite showed lower resistance to erosion than kaolinite. The threshold SAR for a concentration of 0.05 N was 25. At very low concentration, as seen in Fig. 4, regardless of the value of SAR, the critical shear stress of montmorillonitic soil was less than kaolinitic soil.

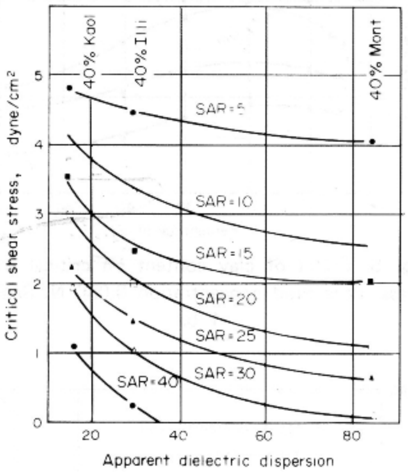

Fig. 4. Relationship between critical shear stress and dielectric dispersion as a function of SAR. Pore fluid concentration 0.005 N.

Effect of clay content

The effect of clay content on hydraulic erodability was also studied for three types of clay. The amounts of clay used were 5, 10, 20, 30, 40 and 60%. The tests were performed at pore fluid concentrations of 0.05 N and 0.005 N. The results are shown in Figs. 5 and 6. It can be seen from these results that, except at high SAR, resistance to erosion in general increased with increasing clay content up to 20%. At high clay contents, approx. 20%, the critical shear stress was independent of clay percentage.

At a very low SAR (between 1 and 5), regardless of the amount of clay, montmorillonitic soils showed higher resistance to erosion, whereas at higher SAR, kaolinitic soils resisted erosion more than montmorillonitic soils. It is also interesting to note that at high SAR the maximum critical shear stress was obtained for 20–30% of the clays. Samples of higher clay content showed lower critical shear stress. The reason may be that for such structural conditions the higher clay content increases the amount of swelling and consequently the critical shear stress is reduced.

It can be concluded from the results of this investigation that the resistance of soils are

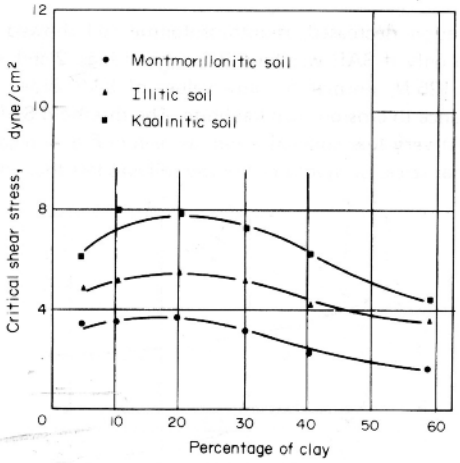

Fig. 5. Effect of clay content on critical shear stress. Pore fluid concentration 0.050 N, SAR = 1-5.

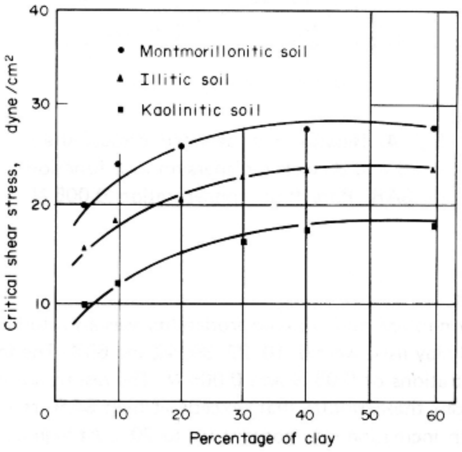

Fig. 6. Effect of clay content on critical shear stress. Pore fluid concentration 0.050 N, SAR = 50-60.

strongly dependent on the type of clay minerals, amount of clay and type and concentration of ions in pore fluid. When the soil structure is flocculated, montmorillonitic soils show higher critical shear stress than other types of clay. However, when the soils are in a deflocculated state, kaolinitic and illitic soils are more resistant to erosion than montmorillonitic soils.

Although the results reported in this paper support the work of other investigators such as Liou [10], Sherard *et al.* [18] and Wischmeire and Mannering [20], they do not agree with some other results. According to Sargunam [17], regardless of the composition of pore fluid, the critical erosion shear stress of kaolinitic soil is less than montmorillonitic soil. A similar conclusion was also reported by Grissinger [9]. It should be noted that Grissinger [9] examined the rate of erosion which is a different concept than critical shear stress studied by Sargunam [17]. Therefore a higher rate of erosion in kaolinite may not support the lower critical shear stress. Since Sargunam [17] worked with Yolo loam, which is high in Mg and Ca, he was not able to make soil samples with very high SAR in pore fluid. Thus his speculation on soil behavior at high SAR was based on extrapolation of the curves of critical shear stress vs SAR.

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