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Mechanism of Erosion of Cohesive Sediment: A Review

Tabish Ali[1] and Baldev Setia[2]

[1]M.Tech Student, Department of Civil Engineering National Institute of Technology, Kurukshetra
[2]Department of Civil Engineering National Institute of Technology, Kurukshetra
E-mail: [1]tabishali22@gmail.com

Abstract—*Erosion of cohesive sediment is a complex phenomena and involves various factors comprising effective gravity, dry unit weight, sediment microstructure, particle size distribution, mineralogy, organic content and water chemical condition. The response of cohesive sediment to flow of water has received little attention. In light of this, a study is conducted in the hydraulics laboratory of National Institute of Technology, Kurukshetra. The objective of the study, besides filling up gaps in information, is to make an attempt to establish the effect of certain parameters of cohesive sediment on the erosion process in general and on the incipient motion in particular. The present paper, which is a part of the bigger study, compiles a review of the works by various researchers on the basis of parameters such as shear strength, consolidation pressure, plasticity index, clay content, salinity, compaction water content etc*

1. INTRODUCTION

Research on erosion of cohesionless sediment has been conducted on a large scale during the last century. The hydraulic behaviour of such a sediment on bed and banks of rivers, on account of constriction of flow area around structures like bridge elements, has not only been well understood but also duly quantified. However, in comparison, the response of cohesive sediment to flow of water has received little attention. Erosion of cohesive sediment is a complex phenomenon and involves various factors. This phenomenon is encountered at foothills, plains immediately following the foothills, through embankments and natural streams.

The knowledge of sediment erosion is necessary for study of processes like soil erosion in catchments, depth of scour etc. The behavior of cohesive sediment is highly complicated during erosion with many influential factors involved in it. In the last few decades, numerous studies have been done on the erosion threshold and erosion rate of cohesive sediment by flow with considerable progress achieved. Yet, the phenomenon of cohesive sediment erosion by flow is so complex that the understanding and modelling of the process so far is still inadequate in bridge piers, reservoir sedimentation, river morphological changes etc.

2. LITERATURE REVIEW

This paper presents a review of the work by various researchers on the basis of several parameters:

- Effect of shear strength
- Effect of salinity
- Effect of compaction water content
- Effect of clay content
- Effect of consolidation pressure
- Effect of compressive strength
- Effect of plasticity index

on the erosion mechanism of cohesive soils.

Effect of shear strength:

Shear strength of cohesive sediment is closely related to the resistance to erosion.

Sundborg (1956) suggested that the cohesive force resisting entrainment of a grain is proportional to the shearing strength of the sediment as determined in standard soil tests, and that it acts in a direction opposite to the fluid force.

Dunn (1959) found a linear relationship with shear strength but Partheniades (1965) gave contrary results and concludes that critical shear stress is independent of shear strength.

According to the research work of Abdel-Rahman (1963), the effect of the flowing water on the beds of open channels laid out in pure cohesive soils was found to depend on two main factors:

a) The active force, from the fluid.

b) The passive force, from the soil.

This force was considered to be the vane shear-strength of the bed material.

Kamphuis (1985) concluded that the variation of critical shear stress with unconfined compressive strength and vane shear strength is linear as shown in fig. 1

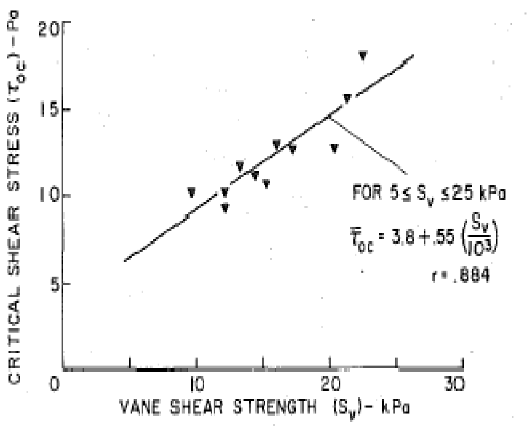

Fig. 1: Critical shear stress Vs Vane shear strength

According to Alaeddin Shaikh et al (1988) the samples that exhibited higher Torvane shear strength had lower values of erosion-rate coefficient. The relationship between erosion-rate coefficient, C, and Torvane shear strength, S_t, of the samples is shown in Fig. 2

The relationship between C and S_t may be expressed as

$$C = 0.157\ (S_t)^{-1.338}$$

Where S_t is in MPa, and C is min $^{-1}$.

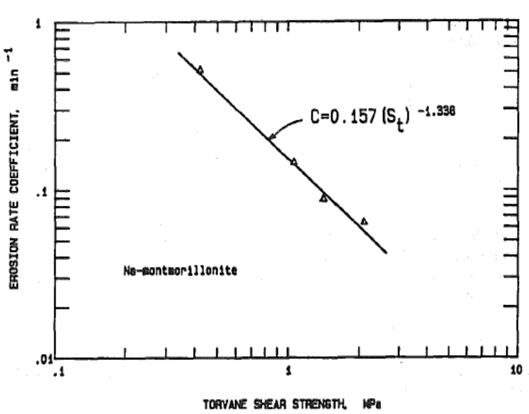

Fig. 2: Erosion rate Vs Torvane shear strength

Effect of salinity:

Arulanandan (1975) found that at high SAR values, the soil critical shear stress for erosion decreases with increasing cation exchange capacity (CEC). At low SAR values, higher critical shear stress is required to detach particles and this increases with rising of CEC value. However, Ariathurai and Arulanandan (1978) described conflicting results: for both high and low SAR values, the erosion rates decrease when CEC increases.

The experimental results of Kelly and Gularte (1981) showed that the soil critical shear stress for erosion increases with an increasing salinity. The same conclusion was drawn by Parchure and Mehta (1985).

From three disparate examples studied in the field and the laboratory, Kamphuis (1985) found that the presence of sand in the eroding flow lowers the critical shear stress for erosion of cohesive sediment, increases the erosion volume and erosion rate, and determines where erosion takes place, i.e. at the protrusions of the bed instead of the depressions. Erosion was most rapid when the sand in the eroding flow saltated. The increase in erosion by sand in the eroding flow for constant shear stress is proposed to be explained by abrasion.

Parchure and Mehta (1985) concluded that for practical purposes, the influence of salinity on erosion is important only if it is less than 10 ppt.

Raudkivi (1984) show that the erosion rate of the two kaolins generally decreases with increasing salt (sodium chloride) concentration. In the case of the Bentonite (calben) as shown in fig. 3, the erosion resistance increases with increasing salt concentration initially, and decreases when the salt concentration exceeds 0.01 M. In general, the presence of salt serves to compress the electric double layer of the surfaces and edges of clay particles and results in closer packing of clay particles. This leads to stronger bonding and hence, higher erosion resistance.

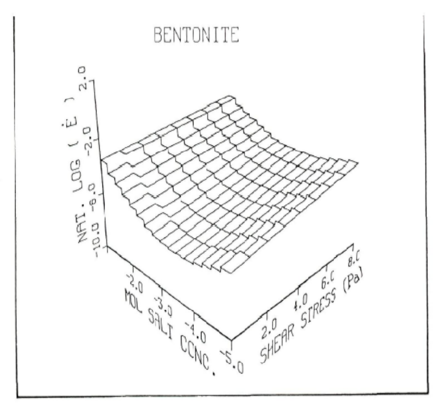

Fig. 1: Salt conc Vs Shear strength

Mehta and Parchure (2000) found that the influence of salt concentration on the erosion rate and bed stability also depends on the composition of the sediment.

Effect of compaction water content:

Martin (1962) has noted the importance of such factors as water content, salt content, and ion exchange on the strength of clay.

Grissinger and Asmussen (1963) found that the erosion resistance of clay soils increased with the time they were kept in a wetted state. The explanation offered for this behaviour was that when clay is first wetted the free water releases the bonds between particles, but as free water is absorbed and the clay minerals hydrate, the bond is strengthened.

While Shaikh et al (1988) concludes that the erosion rate of unsaturated compacted Na-montmorillonite clays was independent of the compaction water content and varied linearly with the tractive stress. He further states that there is no critical shear stress for clays in the sense that one exists for non cohesive soils. Abdel Rehmann's observation that when his clay bed reached stability it was coated with a sticky substance, suggests that the stabilizing process involves some chemical action of the kind suggested by Grissinger and Asmussen.

Ansari (2007) takes antecedent moisture conditions in his experiments. The result of experiments shows that critical shear stress depends upon antecedent moisture condition. It is found that critical shear stress increases with increase in moisture condition.

Mostafa et al (2008) describe their variation with water content by defining a new non-dimensional parameter ξ to combine soil density ρ_b, plasticity PI, and water content w.

Effect of clay content:

The experiment results of Kamphuis (1985) states that the capability of a cohesive soil to resist erosion increases with clay content and plasticity index. The size of the eroded pieces tend to be larger for a soil with a low clay content (high silt and sand content).

Smerdon and Beasley (1961) determined critical shear stress for 11 cohesive soils from Missouri ranging from silty loam to clay by observing them in a tilting flume. He found a linear relationship clay content and critical shear stress. Grissinger (1966) reported that increased concentrations of clay minerals generally induced greater resistance to erosion.

Shaikh et al (1988) gives the relationship between the erosion-rate coefficient and percentage of clay content. The coefficient of erosion rate decreases when the percentage of clay increased as shown in fig. 4 .The clay content of a soil is a measure of the relative importance of the physicochemical properties of clay in resistance to erosion. Therefore, it is expected that the erosion rate increases as the clay content decreases.

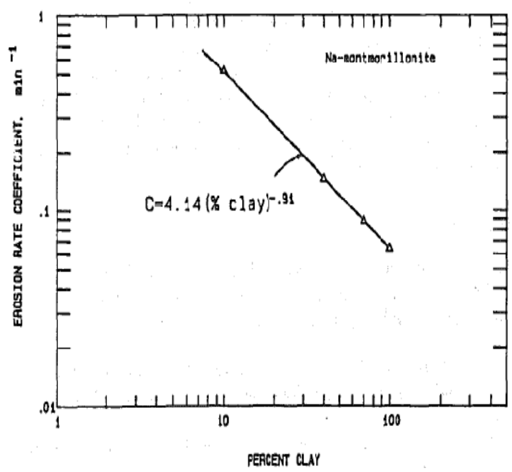

Fig. 2: Erosion rate coefficient Vs % clay

Jain and kothyari (2005) reported that the dimensional critical shear stress increases with an increase in clay percentage in the bed material. Mostly comparable values are obtained for critical shear stress of cohesive sediments determined through measurements on the initiation of motion and estimated through backward extrapolation of the plot between shear stress and rate of erosion to the zero rate of erosion.

Effect of consolidation pressure:

Kamphuis (1985) performed experiments and concludes that the shear stress required to initiate erosion of a cohesive soil, increases with consolidation pressure. For the clay tested in this study, results indicate that if the consolidation pressure is greater than approximately 200 kPa, the soil may be considered safe from erosion under normally expected, naturally occurring flow conditions. The relationship is shown in fig. 5

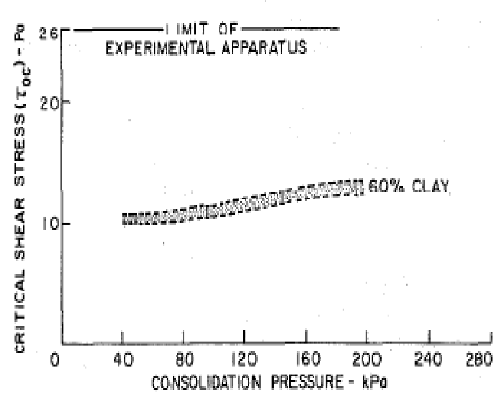

Fig. 3: Critical Shear strength Vs Consolidation pressure

Effect of compressive strength:

Flaxman (1963) found that the compressive strength of unconfined saturated and undisturbed samples of the sediment was a good indication of the shear stress it would withstand without excessive erosion

Kamphuis (1985) made observations and concludes that the variation of critical shear stress with unconfined compressive strength and vane shear strength is linear. The relationship is shown in fig. 6

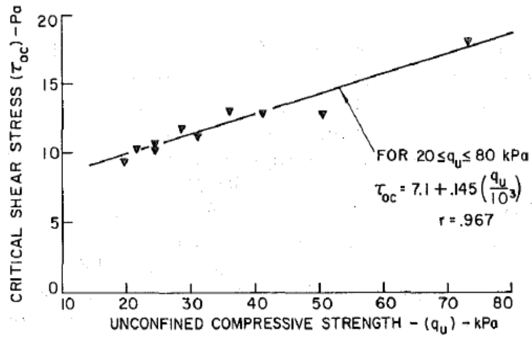

Fig. 6: Shear stress Vs Unconfined compr. Strength

Effect of plasticity index:

Smerdon and Beasley (1961) determined plasticity index for 11 soils from Missouri. The experiments were performed in a flume and the soil used was thoroughly mixed, lumps were broken, and foreign matter was removed as the soil was placed in the flume. A linear relationship was observed between plasticity index and critical shear stress. Flaxman (1963) observed that some channels in sediment with small or negligible plasticity index were stable and therefore resistant to erosion indicating that plasticity index alone was not an adequate indicator of erosion resistance or critical shear stress.

Kamphuis (1985) found that the capability of a cohesive soil to resist erosion increases with plasticity index. He gives the following graph as shown in fig. 7

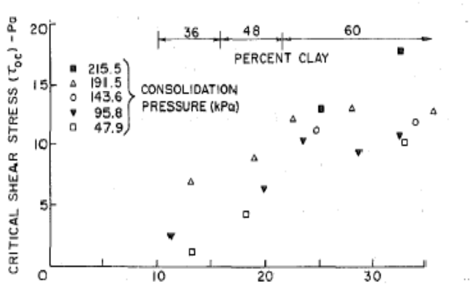

Fig. 7: Critical shear stress Vs plasticity index

Ansari (2007), on the basis of his experimental results concluded that the critical shear stress is found to increase with the increase in the plasticity index and antecedent moisture content of the cohesive sediment. It has also been found to decrease with the void ratio.

Mostafa et al (2008) defines new non-dimensional parameter ξ to combine soil density ρ_b, plasticity PI, and water content w, and is defined as:

$$\chi = \frac{\mathrm{LI}}{S_G - 1},$$

The relationship between the soil parameter χ and the relative nondimensional erosion resistance has been found to follow the Gamma distribution.

3. SUMMARY

In the present paper, an effort has been made to understand the behavior of erosion of clayey soils. Works of previous researchers have been studied and analysed to understand the mechanism of erosion resistance. Most of the relationships are usually described in terms of the parameters that are used in soil mechanics, but are not important from the hydraulics point of view. It is suggested that soil- water interaction criteria should also be adopted by researchers to study the behaviour of cohesive soils in future.

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