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PERFORMANCE OF XANTHAN GUM ON INTERNAL EROSION CHARACTERISTICS OF DISPERSIVE SOILS

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Abstract

The main aim of this study is to assess the erodibility of dispersive soil treated with xanthan gum by using the Hole Erosion Test (HET). Two types of dispersive soil mixed with 0.5, 1, 1.5, and 2% of Xanthan gum were tested for various curing days (7, 28, 60, and 90 days). Hydraulic shear stress and erosion rate are the key parameters that were evaluated for treated soils. From the results, it was observed that increments in hydraulic shear stress and decrement in erosion rates were observed for all curing days with various admixture concentrations. The rate of improvement in erosion rate was significant for the addition of 1% XG

Keywords*— Soil Stabilization, Xanthan Gum, Internal Erosion, Dispersive Soil, eco-friendly materials.*

INTRODUCTION

Towards the safety of earthen dams, slopes, and dikes, erosion is a commonly existing issue in civil and geotechnical engineering. Erosion is mainly of two types: Surface erosion and Sub-surface (Internal) erosion. Majorly research is primarily focused on surface erosion, which occurred by overtopping of earthen structure, rainfall, overland flow, gully and rill erosion, erosions [1-2]. Studies towards subsurface erosion are overlooked as surface erosion contributes to subsurface erosion. Though, subsurface erosion indirectly contributes to an increase in water pressure in soil and leads to a decrease in shear strength of the soil. Which tends to raise in erodibility, seepage force causing failures, detachment of soil particles in the core and piping erosion [3-4]. Reports reveal that after overtopping, internal erosion or piping failures are accountable for earthen dam failures [5]. Piping erosion has primarily been identified as a severe threat to homogeneous embankment dams over the world as it starts with a fissure or minor crack in the embankment and ends up with a pipe along with the earthen structure. Many investigations were carried out to know the erosion characteristics and cracks in earthen dams [6-8]. Wan and Fell (2004) [9] studied the erosive behaviour of various soils through cracks by using a series of the hole and slot erosion tests. The results reveal that 37% of earthen dams are failed by piping due to the presence of dispersive properties of soils present in the core of the structures. Internal erosion or piping is very rapid, if the soil is cohesionless sand with uniform size and has a low plasticity index, or well-graded cohesionless sand with less plasticity and very less percentage of clay, or if soil is a dispersive soil which falls under D1 or D2 by pinhole test. It is very strategically important to improve the erosive and dispersive resistance of soils in a very useful and eco-friendly manner. Dispersive soils available in many forms like clays, silts, and sands, are the leading cause of failure in earthen dams and embankments incidents over the world [10-12]. Globally, Problems associate with dispersive soils is very common related to water retaining structures. The presence of sodium montmorillonite mineral in soil chemistry and more exchangeable sodium cations made soils quickly erode when they come in contact with each other. Dispersion of these soils is related to many factors like mineral composition, structure, surface-exposed, and depends on exposed fluid. Earlier understanding is necessary to employ these types of soils as they are a threat to many earthen hydraulic structures. When such a variety of soil presents while construction, soil replacement is a better idea, but it is more time consuming and uneconomical. Considering the drawbacks, soil improvements by chemical admixtures are proven as an effective way to deal with dispersive soils. Many kinds of research work on these soils with many traditional admixtures like cement, lime fly ash, and gypsum and reduce dispersivity and increase the strength of theses soils [13]. But due to the rise in carbon footprints and many environmental concerns, researchers are working towards eco-friendly and cost-effective admixtures to treat theses soils. The application of biopolymers in geotechnical engineering works gives the most significant results in the field. As they showed a considerable increment in the strength of various soils and the increases in strength different from soil to soil, type of biopolymer employed, the concentration of biopolymer, and testing conditions [16]. Even though the application of biopolymers shows many successful results in soil improvement, the literature on the application of biopolymers on erosion properties of dispersive soil was not studied much.

In this study, Xanthan Gum is used as a biopolymer to improve the erosion resistance of dispersive soils. From Double Hydrometer test (DHT), Pinhole Test (PT) dispersive characteristics of soils were determined. Further Chemical Testing was done to know soil chemistry. Finally, to assess erosion rate and hydraulic shear stress, a series of HET were conducted. HET was more economical, less time taking, and a more efficient method to evaluate erosion in embankment dams.

MATERIALS AND METHODS

Dispersive Soils

The soils employed with this study were collected from Karnataka and designated as KN and TN samples. Samples are collected in a disturbed state and processed. After preparing soil were undergone a series of engineering properties and dispersive properties like a double hydrometer test (DHT), Crumb test (CT), Cylindrical dispersion test (CDT) and Pinhole test (PT) were conducted, and the results were tabulate in table 1. Chemical analysis like Sodium Absorbed Ratio, Percentage Sodium, Total Dissolved Solids, Electronic Conductivity, and pH tests were conducted as per [12] and tabulated in Table 2.

TABLE 1 Geotechnical Engineering and Dispersive properties of collected sample

Constrains	**Units**	**TN Sample**	**KN Sample**
Specific Gravity	-	2.53	2.63
Sand (S)	%	38	29
Silt (M)	%	47	23
Clay (C)	%	15	48
Liquid Limit (W_L)	%	42	68
Plastic Limit (W_P)	%	26	29
Plasticity Index (PI)	%	16	39
Shrinkage limit (SL)	%	17	12
Free Swell Index (%)	%	25	60
Optimum Moisture Content (%)	%	15.3	19.2
Maximum dry density	kN\m^3	17.8	16.8
Unconfined Compressive Test	kPa	210	360
CT		D1	D1
PT		D2	D1
DHT	%	35.17	68.3
CDT		TYPE D	TYPE D

TABLE 2 Chemical Analysis on soil

Compounds	**TN Sample**	**KN Sample**
Na^+ (meq/lit)	109.3	174.56
K^+ (meq/lit)	35.6	13.6

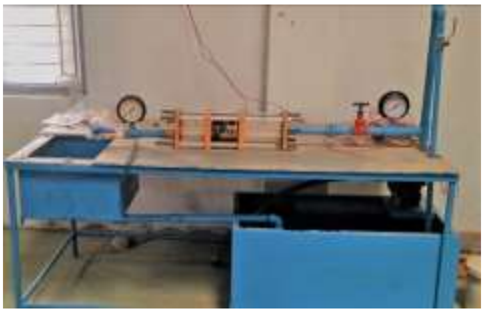
Ca^{2+} (meq/lit)	41.25	36.9
Mg^{2+} (meq/lit)	16.82	14.53
TDS (meq/lit)	197.52	239.35
PS (%)	53.6	72
SAR (%)	20.6	34.4
Electronic Conductivity (mS/cm)	20.6	21.5
pH	7.8	8.2

Xanthan Gum

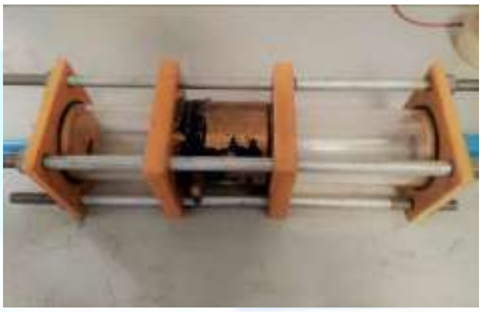
Xanthan used in this study is procured from the Ghajana traders in Karnataka. It is a pale white, non-hazardous, edible material and has a pH of 7.3 and viscosity of 1630 cps. Xanthan Gum used in this study as it has a pseudo-plastic nature and proven as an eco-friendly stabilizer in many civil engineering works.

Sample Preparation for the Hole Erosion Test

From the results obtained from the crumb test, pinhole test, and double hydrometer tests, 1% XG is taken as optimum [12]. Xanthan gum of 1% was mixed with two types of soils at an OMC. It was mixed manually and compacted into a standard compaction mold in 3 layers to achieve MDD. Compaction was undergone using automatic standard proctor apparatuses, to ensure proper bonding between the layers, each layer was scratched. All samples were cured at 24 c in air tied covers to arrest the moisture loss. After desired curing days, compacted samples were drilled with a 2mm hole along with the sample and assembled in HET apparatuses, as shown in figure 1. Constant pressure was applied through the inlet, and a change in pressure at the outlet is measured. Variation in hydraulic pressures is due to a change in hole diameter, and turbidity is measured from the outlet. The test was conducted for 45min or until the core sample is washed outed or when the turbidity of out sample decreased. After the final analysis, the geometry of the hole is calculated by pouring wax through the hole to know the final volume of the hole shown in figure 1.



(a)



(b)

(c)

(d)

Fig 1: Hole Erosion Test process (a) Experimental Setup of HET (b) HET testing cell; (c) compacted soil with initial hole diameter; (d) final hole diameter after testing

Empirical Equations used in interpret HET results.

Soil erosion properties were measured using a Hole erosion test apparatus developed by Wan and Fell [8-9].

$$\dot{\varepsilon} = k_{er}(\tau - \tau_c) \quad (1)$$

Where $\dot{\varepsilon}$ = Rate of erosion for a unit surface area of the hole at a given time t (kg/s/m^2); τ = hydraulic shear stress throughout the hole at any given time 't' in Pa; k_{er} = soil erosion coefficient (s/m); and τ_c = critical shear stress of the soil in Pa.

At any given time, the diameter of the hole is calculated by equations 2 & 3 for laminar flow and turbulent flow conditions.

$$\emptyset_t = \left(\frac{16Q f_L}{\pi \rho_w g s}\right)^{\frac{1}{3}} \quad (2)$$

$$\emptyset_t = \left(\frac{16Q^2 f_T}{\pi^2 \rho_w g s}\right)^{\frac{1}{5}} \quad (3)$$

Where $\emptyset_t$ = hole diameter at any given time t (m); Q = flow rate along hole at any given time t (m3/s); f_L = friction factor for laminar flow; f_T = friction factor for turbulent flow; g = acceleration due to gravity g (m/s^2); s = hydraulic gradient throughout the hole at any given time t; ρ_w = eroding fluids density (kg/m^3).

Equations 4 and 5 are used to calculate the erosion rate (ε_t) and hydraulic shear stress (τ_t).

$$(\varepsilon_t) = \frac{\rho_d}{2}\left(\frac{d\emptyset_t}{dt}\right) \quad (4)$$

Where ε_t = Erosion Rate in (kg/s/m^2); ρ_d = soils dry density (kg/m^3);

$$(\tau_t) = \frac{\rho_w g s \emptyset_t}{4} \quad (5)$$

Results and Discussion

Compaction Characteristics of XG treated soil

Void ratio and density of soil are the prime factors controlling shear stress and soil permeability. Still, achieving certain densities for various mixtures was not easy, as soil fines and biopolymer characterization and viscosities lead to different densities. From figure 2, it was observed that the addition of XG to dispersive decreases MDD from 1.83 to 1.63 g/cc for the TN sample and 1.71 to 15.8 g/cc for the KN sample. However, the OMC of treated soil increased 15.3 to 18% for the TN sample and 19.2 to 21.8 for the KN sample same result was observed in literature also [12].

Effect of XG on dispersive properties of soil

The Double hydrometer analysis test was performed according to ASTM D 4221, 2000a. With reference to the DHT results, it was observed that the TN sample falls under intermediate dispersive soil (36%), whereas the KN sample is identified as highly dispersive soil (71%). From figure 3, it was evident that the addition of XG to both soils decreased the dispersion ratio from 71% to 18% for the KN sample and 36% to 15% for the KN sample. A decrement in dispersion ratio is due to the rheological effect, which arrests the water movement in between soil grains, and 1% XG is treated as optimum [12].

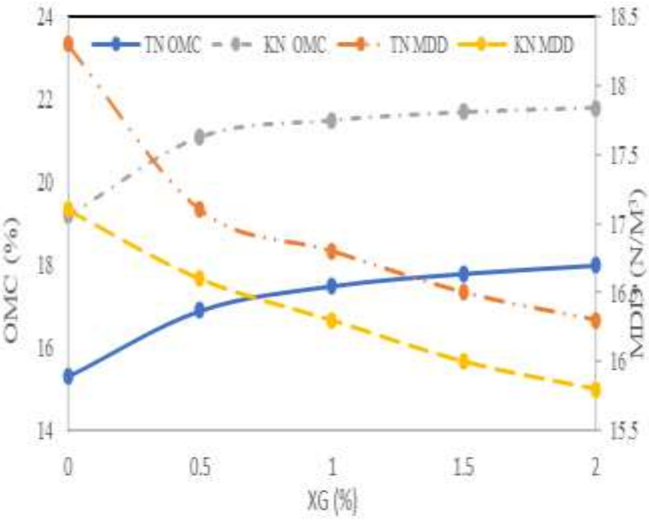


Fig. 2 OMC and MDD curves for XG treated soil

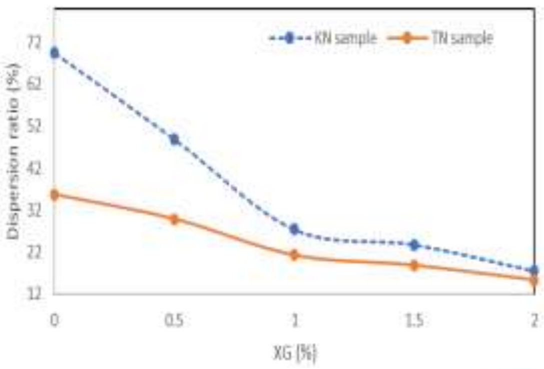


Fig.3 Disparity of dispersion ratio (%) vs Xanthan Gum (%) of TN and KN samples.

From the pinhole test, it was observed that erosion resistance of XG treated soil increases with every combination of XG with all curing days. From table 3&4, it is found that the addition of 1% XG to soils changes its nature from highly dispersive (D1) soil to non-dispersive (ND2) soil for both samples for 7-day curing period. Further increase in curing periods soils sample can take high hydraulic heads and high flow rate with moderate to clear effluent on the outlet with minor to no disturbance in initial hole diameter. The improvement in erosion resistance is because of XG being a vicious nature which coated to soil grains, arrest the movement of water, and helps in reducing the repulsive forces [12].

TABLE 3: Results from Pinhole test with 1% XG treated TN sample

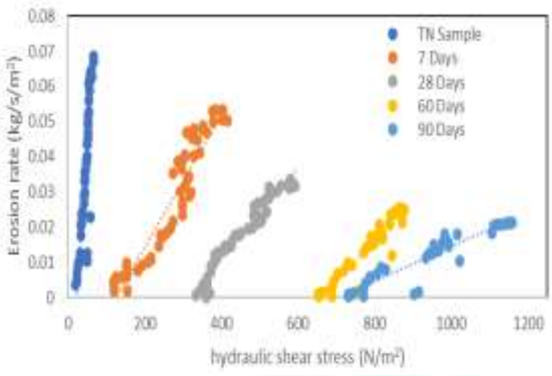
Constraints	1-day	14-day	28-day	90-day
Head of water in mm	50-180	380	360-1080	1080
Flow rate in ml/sec	2.65	3.68	3.43	3.21
Effluent color	Mostly cloudy	Moderate to clear	Moderate to clear	Clear
Resulting Hole diameter	2.1	2.38	1.15	1.16
Soil classification	ND3	ND2	ND1	ND1

TABLE 4: Results from Pinhole test with 1% XG treated KN sample

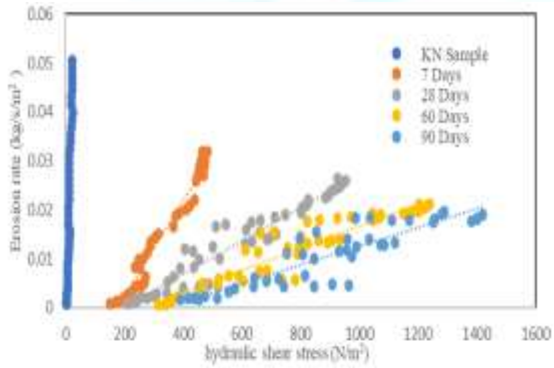
Constraints	1-day	14-day	28-day	90-day
Head of water in mm	180	380	1080	1080
Flow rate in ml/sec	2.35	3.14	3.86	3.56
Effluent color	Moderate to clear	Moderate to clear	clear	Clear
Resulting Hole diameter	2.6	1.6	1	1
Soil classification	ND3	ND2	ND1	ND1

Effect of Xanthan Gum on Erosion Rate and Hydraulic Shear Stress

An increase in XG concentration to dispersive soils assists with diminishing in erosion rate of the two soils for all combinations. Furthermore, the soil has shown higher resistance at higher hydraulic heads. From the figure 4, it is understood that HET of TN sample and KN sample with 0% of XG has an erosion rate of 0.068 and 0.0505 kg/s/m^2, respectively and maximum hydraulic shear stress of 67 and 22.5N/m^2 respectively. Moreover, with the mixing of 1% XG to soil sample expanded the erosion resistance of the TN sample from 0.068 to 0.043, 0.031, 0.0249, 0.0218 for 7, 28, 60, and 90 days curing period respectively, as appeared in figure 4. Comparable research results were seen for KN sample likewise as it increments from 0.0505 to 0.032, 0.0265, 0.0219, 0.0208 kg/s/m^2 for 7, 28, 60, and 90 days curing period as appeared in figure 4a. As curing period increases, the erosion rate of soil decreased due to the gain in resistance towards hydraulic shear stress for TN sample and the increments were observed to be 67 to 404, 592, 877, and 1158 N/m^2 for 7, 28, 60, and 90 observation days. respectively which is appeared in figure 4a. Similarly, for KN sample also the hydraulic shear stress increased like the TN sample and the increments were observed to be 22.5 to 483, 927, 1205, and 1421 N/m^2 for 7, 28, 60, and 90 curing days respectively appeared in figure 4b. Because of the strong interactions that happen between XG and soil particles, erosion rate decreased.



(a)



(b)

Fig.4 Erosion rate and hydraulic shear stress of 1% XG treated soils at various curing days (a) TN sample, (b) KN sample.

Being a viscous material, XG surrounds soil particle and dissolve repulsive forces present in particle surface by direct bonding happening between the groups of (–OH) and carboxyl group (–COOH). As the curing period increases, all the repulsive forces present in soil decreases and readily bonds with other particles by filling the pore gaps [12,16].

CONCLUSIONS

This present study explores the performance of XG on TN and KN samples, to assess its internal erosion characteristics, then the resulting conclusions were given.

The addition of XG increases OMC and decrease in MDD of both TN and KN samples. It is due to the viscous property of XG, which holds more water in valances and decreases MDD.

From dispersive testes by PT and DHT, it was observed that the addition of 1% XG performs better to reduce the dispersivity of soil and increase in erosion resistance.

From HET results, as curing day increases, soil samples show higher resistance towards hydraulic stresses from 67 to 1158 N/m2 for TN and 22.5 to 1583 N/m2 for KN samples. Decrements in erosion rate were also observed from 0.505 to 0.028 kg/s/m2 for KN sample and 0.068 to 0.02166 kg/s/m2 for TN sample.

Compare to the TN sample, and the KN sample performs better with addition XG. It is due to the higher clay content present in KN samples, which fill pore spaces and helps in strong bonding between XG and soil particles.

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