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Experimental Study on Soil Piping and Effect of Coir Geotextiles on Piping Resistance of Soils

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Abstract. Soil piping is a subsurface form of internal erosion. Such types of internal erosions are especially dangerous, because, there may be no external evidence, or only subtle evidence that it is taking place. Such seepage induced failures in the form of piping are generally observed in irrigation and drainage projects for sustainable watershed management such as river levees, contour bunds, temporary check dams, and soil structures. When the discharge velocity exceeds the critical velocity, piping occurs and the soil in the constructed areas flow out, and the structures are weakened. Therefore, effective counter measures are needed to reduce discharge velocity. Hence, an attempt is made to examine the hydraulic behaviour of Coir Geotextiles in terms of discharge velocity and piping resistance. For this study, an experimental model set up was made to determine the mechanism of Soil piping in different types of soils. A number of experiments were carried out for determining the feasibility of using Coir Geotextiles for reducing discharge velocity. The experiments were carried out by placing Coir Geotextiles at different positions within the soil specimen, and also for various hydraulic heads. The discharge velocity of flow of water through the soil is calculated in each case and compared with plain soil. The results show that the Coir Geotextiles can be used effectively to reduce discharge velocity and to increase piping resistance of soils.

Keywords: Discharge velocity, Coir geotextile, Piping resistance.

1 Introduction

Soil piping is the progressive development of internal erosion by seepage which causes the removal of materials. It is usually described as the formation of an open channel, or pipe, within or beneath the soil mass. Piping of loose soils is a common problem in downstream of earthen embankments under the influence of upward seepage. The phenomenon of piping is commonly observed under levees, and involves erosion of soil particles in the land facing zone of levees. Seepage induced failures in the form of piping are generally observed in irrigation and drainage projects such as river levees, contour bunds, temporary canal diversion works, temporary check dams and geotechnical structures. Piping failure is synonymous with sand boiling or a quicksand condition. This type of failure propagates either as a result either of poor construction or of the presence of seepage-enhancing materials. Various researches were carried out using different materials to control this piping erosion. In recent years discrete fibers have been added and mixed into soil to improve the strength behaviour of soil. Maher and Ho (1994) reported that the fiber reinforcement increased the shear strength and ductility of clay. According to Falorca and Pinto (2002), the micro reinforcement of the soil seems to have naturally emerged from the role played by vegetation on the restraint by soil particles by roots due to their tensile strength and frictional properties. It is well established from previous studies that randomly distributed geofibers can improve the shear strength characteristics of soil. Sivakumar Babu and Vasudevan (2008) studied the effectiveness of Coir fiber reinforced soil in controlling seepage. According to them, increase in the fiber content and fiber length increased the critical hydraulic gradient of the soil and reduced the seepage velocity. Das and Viswanadham (2009) described the significant influence of polyester fibers on the piping behavior of embankments constructed with fly ash as a fill material. They reported that long or high-dosage fibers could have a negative effect in controlling seepage through fly ash.

Coir geotextiles have been used in various slope stabilization projects and soil erosion control. Cammack (1988) indicated that coir geotextiles are useful in river bank protection and embankment stabilization. Lekha (2004) presented a field study on the use of coir geotextiles as a filter and reinforcing media for saturated clay dykes in low lying areas and indicated that coir geotextiles serve as an effective filter. Coir geotextiles are manufactured using various processes such as retting the coconut husk, separating it into fibers, making yarn, and then weaving it to obtain the desired type of geotextile. The Coir geotextiles can also be used to increase the piping resistance of soil. They impart strength isotropy and reduce the possibility of formation of weak zones and contribute to improved piping resistance. Hence an attempt is made in this paper to examine the hydraulic behavior of Coir geotextiles in terms of discharge velocity and piping resistance. The specific objectives are as follows: (1) to conduct an experimental investigation on soil piping and to study piping in different types of soil. (2) to evaluate the effects of coir geotextiles on the piping resistance of soils.

2 Materials Used

The materials used for the study are as follows:

1. Red soil
2. River sand
3. A mixture of sand and red soil in the ratio 1:1
4. Coir geotextile

Red soil was collected from Kadavallur village, Kunnamkulam Thaluk of Thrissur district and River sand was collected from Kumbidi in Pattambi thaluk of Palakkad district. Coir geotextile was purchased from Coir society, Alappuzha. The samples were collected from 1.5 meter depth, and laboratory tests for engineering properties were conducted according to IS methods of testing. Fig.1 shows the materials used for the study.

(a) Red soil (b) River sand

(c) Mixture (1:1) (d) Coir Geotextile

Fig. 1. Materials used for study

The geotechnical properties of the Oven dried red soil were determined and the results are given in Table 1.

Table 1. Geotechnical properties of Red soil

Properties	Results
Natural moisture content (%)	11
Specific gravity (G_s)	2.65
Liquid limit (%)	36
Plastic limit (%)	Non-plastic
Gravel (%)	13.3
Sand (%)	84.6
(Silt + clay) (%)	2.1
Maximum dry density (kN/m^3)	16.5
Optimum moisture content (%)	13
Soil classification	Poorly graded Sand (SP)

From the Particle size distribution curve, the uniformity coefficient, C_u was obtained as 4 and coefficient of curvature, C_c as 1.2 for red soil.

The geotechnical properties of river sand and mixture were also determined and the test results are presented in Table 2.

Table 2. Geotechnical properties of river sand and mixture

Properties	Results	
	River sand	Mixture
Specific gravity (G_s)	2.65	2.65
Gravel (%)	0	5.3
Sand (%)	99.8	93.7
(Silt + clay) (%)	0.2	1
Maximum dry density (kN/m^3)	14.9	18.1
Optimum moisture content (%)	18.1	14
Soil classification	SP	SP

From the Particle size distribution curve of river sand, the uniformity coefficient is obtained as 1.67 and coefficient of curvature as 0.74. Similarly, for mixture the uniformity coefficient and coefficient of curvature are obtained as 2.78 and 0.54 respectively.

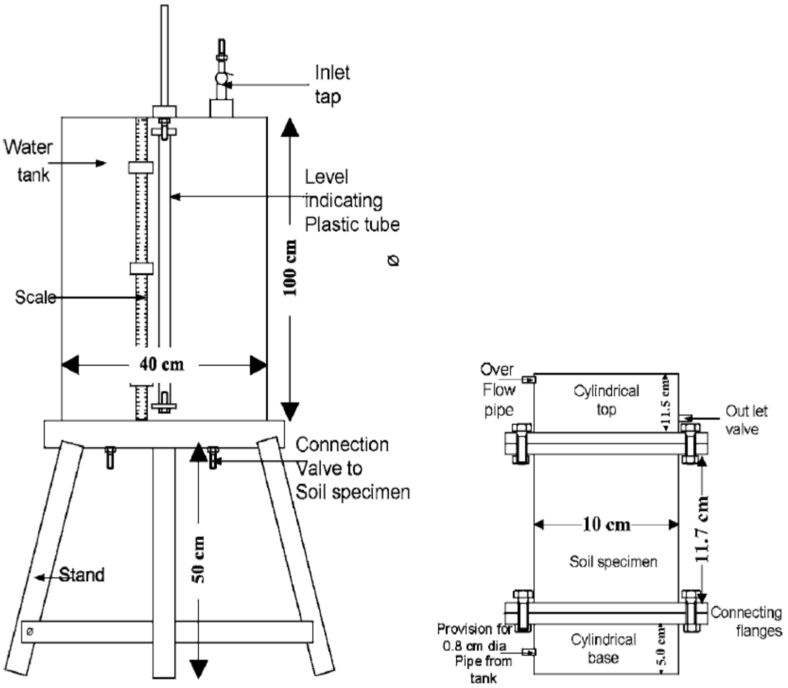
3 Experimental Program

The following three types of soils were used in this study:

1. Red soil passing through 1.18 mm sieve and retained on 425 micron sieve;
2. Sand passing through 2.36 mm sieve and retained on 425 micron sieve; and
3. A mixture of sand and red soil in the ratio 1:1.

The experimental setup used in this study is shown in Fig.2. The tank is 40cm in diameter and 100cm in height with an attached graduated scale to measure the level of water. The mould for soil specimen has a diameter of 10cm and height of 11.7 cm. The required weight of soil for the specified density was mixed with water over a plane glass plate. The soil was filled in the cylindrical mould in approximately three equal layers and each layer was statically compacted. Then the Coir geotextile was placed in the soil in the mould. The mould was then connected to the water tank. Water was permitted to flow through the sample in an upward direction and discharge was collected in a measuring jar. Discharge under various heads was monitored. The experiment was continued by increasing the head of flow until piping failure of soil occurred. The experiments were conducted by changing the position of the geotextile.

The experiment was first conducted for plain red soil. Then, Coir geotextile was placed inside the specimen and experiments were conducted. Coir geotextile was placed at center at first and the experiment carried out for different hydraulic heads until piping failure. Similarly, by placing geotextiles at top and bottom, the same experiment was carried out. Then, experiment repeated by placing geotextiles at top, center, and bottom, and readings were taken. For all the cases the same test procedure is conducted, and the discharge was measured. It was observed that discharge velocity increased with the increase in hydraulic gradient. When the hydraulic head reached a certain level, small bubbles and local boiling were observed and finally the specimen failed by piping. Hydraulic gradient corresponding to this head was termed critical hydraulic gradient. The point corresponding to critical hydraulic gradient was clearly noticeable in the case of red soil. There was a transition in the nature of curve in the sand. In this case, the point corresponding to critical hydraulic gradient was obtained by considering logarithms on both the axes.



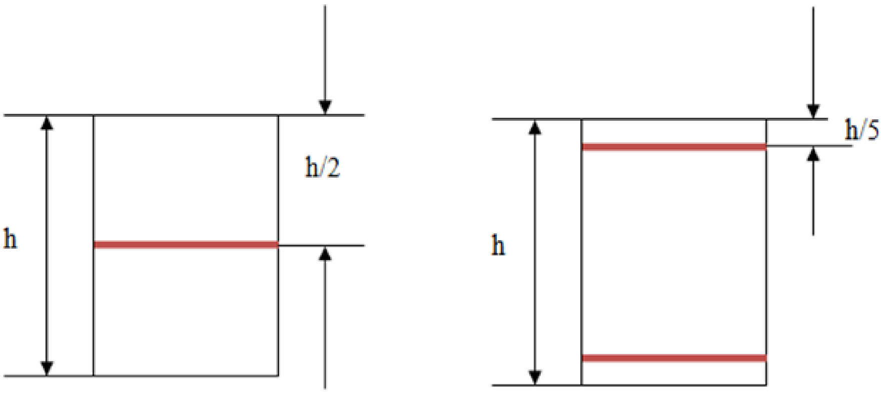
(a) (b)

Fig. 2. (a) Water tank (not to scale); (b) Mould for specimen (not to scale)

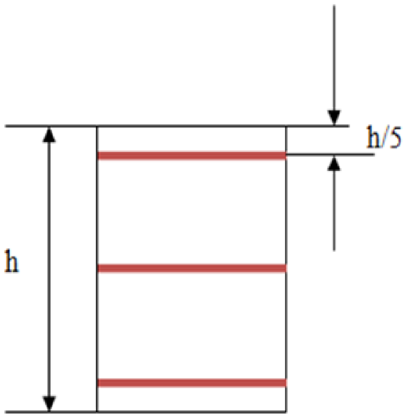
Different positions selected for placing Coir geotextile is given below:

1. At center
2. At top and bottom
3. At top, center, and bottom

Following Fig.3 presents the different positions for placing geotextiles.



(a) at Center of specimen (b) at top and bottom



(c) at top, center and bottom

Fig. 3. Different positions for placing geotextile within the specimen

3.1 Piping resistance

Seepage force acts in the direction of flow, i.e., in the upward direction, for the present case. Piping resistance of soil acts in the direction opposite to seepage force. Hence for equilibrium, piping resistance should have a magnitude equal to that of seepage force and the line of action of these two should be the same. The soil is under equilibrium just before failure as piping starts. Once this equilibrium is disturbed, failure of soil mass occurs due to piping. Hence piping resistance of soil is equal to the seepage force at which soil particles start lifting due to upward flow of water.

The seepage force at this hydraulic gradient can be calculated by using,

$$P = \gamma_w h_c A \tag{1}$$

where, P = seepage force at critical gradient, Υ_w = unit weight of water, h_c= critical hydraulic head and A= cross sectional area of the soil specimen.

3.2 Piping test

Experiments were carried out by placing Coir geotextiles at different positions in the three types of soils. Four stages of piping initiation were identified as,

1. First visible movement
2. Heave progression
3. Boil formation
4. Total heave

Red soil. Piping test was carried out in plain red soil, and also by placing geotextiles at different positions. When the piping test was conducted in red soil, as the hydraulic head was increased, small bubbles were formed initially. On further increase in hydraulic head, local boilings and heave was formed; and finally the specimen failed by piping. The following Fig.4 shows the pictures of piping failure observed in red soil.

Fig. 4. Piping failure observed in red soil

Fig.5 presents the variation of discharge velocity with hydraulic gradient in the case of red soil for different positions of Coir geotextile within the specimen. From Fig.5, it can be noted that discharge velocity suddenly increased once piping was initiated. The hydraulic gradient at which piping occurs was clearly observed for different hydraulic heads until piping failure. At that point, small bubbles and local boilings were clearly visible in red soil specimen.

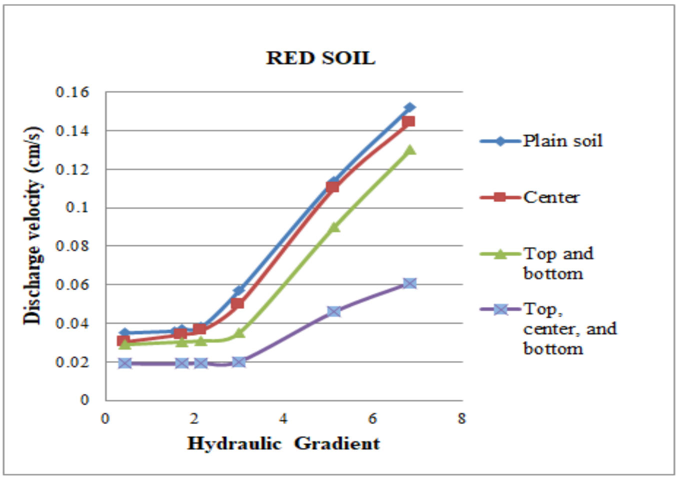


Fig. 5. Discharge velocity versus hydraulic gradient graph of red soil

Discharge velocity reduced and the Critical hydraulic gradient increased as the number of layers of geotextile increased. It was found that the least discharge velocity was observed when coir geotextile was placed at the third position, ie., top, center, and bottom; and this considerably increased the piping resistance of red soil.

River sand. The same test procedure was conducted, and the discharge was measured for plain river sand. Then experiments were repeated by placing geotextiles at the three different positions and discharge was monitored in all the cases. The four stages of piping initiation development were observed in river sand also. The bubbles and boils formed were more compared to that observed in red soil. But, the heave formed was small compared to red soil. Fig.6 shows the piping failure observed in river sand.

Fig. 6. Piping failure in river sand

There was a transition in the nature of curve in the sand. In this case, the point corresponding to critical hydraulic gradient was obtained by considering logarithms on both the axes. Fig.7 presents the variation of discharge velocity with hydraulic gradient in river sand on logarithmic scales for different positions of Coir geotextile within the specimen.

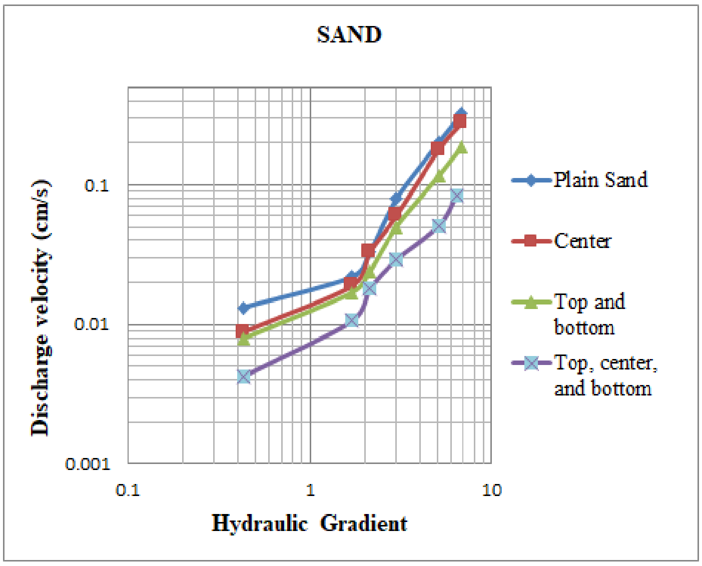


Fig. 7. Discharge velocity versus hydraulic gradient of river sand in logarithmic scales

Discharge velocity steadily increased as the hydraulic gradient is increased. When the geotextile was placed inside the specimen, the discharge velocity reduced and critical hydraulic gradient increased. But when compared to red soil, the reduction in discharge velocity is less in river sand. The increment in critical hydraulic gradient is also less when compared to red soil. But, in river sand also, the least discharge velocity was observed when geotextile was placed in the third position, ie., at top, center, and bottom, which indicates that maximum piping resistance is obtained in river sand when geotextile was placed at top, center, and bottom.

Mixture. The same test procedure was conducted, and the discharge was measured. The four stages of piping initiation development were observed in mixture also. Bubbles and local boils were formed. But, the heave formed was small compared to red soil. Fig.8 presents the variation of discharge velocity with hydraulic gradient in mixture on logarithmic scales for different positions of Coir geotextile within the specimen.

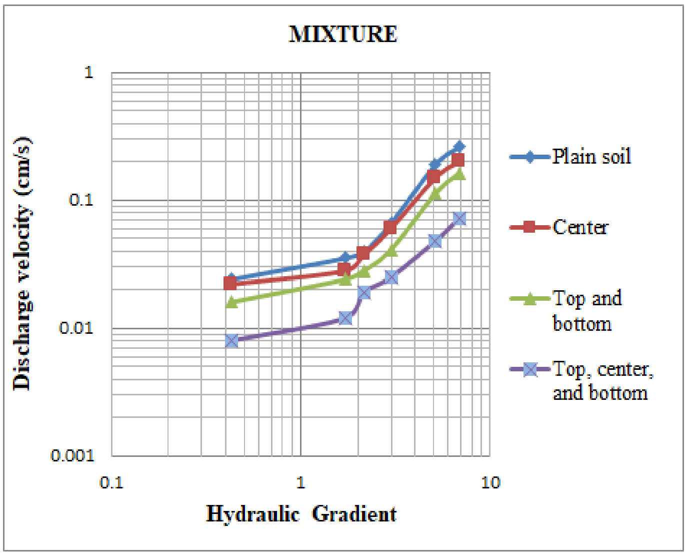


Fig. 8. Discharge velocity versus hydraulic gradient of mixture in logarithmic scales

In mixture also, it can be observed that, as the hydraulic gradient increases, discharge velocity also increases, and it has a sudden increase once piping was initiated. As the number of layers of geotextile increased, the discharge velocity reduced and critical hydraulic gradient increased. This considerably increased the piping resistance of mixture. Reduction in discharge velocity is less in case of mixture when compared to red soil, but more when compared to river sand. Similarly, in the case of critical hydraulic gradient, the increase in critical hydraulic gradient is more when compared to river sand, and less when compared to red soil.

4 Result Analysis and Discussions

Values of critical hydraulic gradient and critical hydraulic head for different positions of geotextile within the soil specimen are presented in Table 3. Due to placing of geotextiles inside the specimen, critical hydraulic head and critical hydraulic gradient were increased resulting in an increased value of seepage force and piping resistance. Piping resistance of soils with different positions of geotextile in the soil samples is calculated using Eq.(1) and is also presented in Table 3. There was an increase in critical hydraulic gradient of 1.4 for red soil, 0.8 for river sand, and 1 for mixture. Maximum piping resistance obtained in all soil samples when geotextile was placed at top, center, and bottom. Discharge velocity was reduced and this contributed to increase in piping resistance. There was an increase in Piping resistance from 15.7 N to 28.27 N in case of red soil sample. At the same time, there was an increase in Piping resistance from 16.5 N to 23.56 N in case of river sand sample and increase from 16.5N to 25.92 N in case of mixture. The piping resistance increased more in case of red soil and the least in case of river sand.

Table 3. Critical hydraulic gradient and piping resistance of soils

Type of Soil	Position of Geotextile	Critical Hydraulic head (cm)	Critical Hydraulic Gradient	Piping resistance (N)
Red soil	Plain soil	20	1.7	15.7
	Center	26	2.2	20.42
	Top and bottom	33	2.8	25.92
	Top, center, and bottom	36	3.1	28.27
River sand	Plain soil	21	1.8	16.5
	Center	23	2.0	18.06
	Top and bottom	26	2.2	20.42
	Top, center, and bottom	30	2.6	23.56
Mixture	Plain soil	21	1.8	16.5
	Center	26	2.2	20.42
	Top and bottom	30	2.6	23.56
	Top, center, and bottom	33	2.8	25.92

Following Table 4 gives an overall analysis of the test results obtained from piping test conducted in all the soil samples.

Table 4. Test result analysis

Type of soil	Percentage increase in piping resistance compared to plain soil		
	Center	Top and bottom	Top, center, and bottom
Red soil	30	65	80
River sand	10	24	43
Mixture	24	43	57
Type of soil	Percentage reduction in discharge velocity compared to plain soil		
	Center	Top and bottom	Top, center, and bottom
Red soil	10	20	50
River sand	3	7	30
Mixture	6	12	36

Reduction in discharge was found more in red soil and least in river sand. Hence the increase in piping resistance is also more for red soil and least in river sand. Mixture occupies an intermediate position.

5 Conclusions

The following conclusions are drawn based on the interpretation of experimental data:

1. Four stages of piping initiation development were identified in all soils as, first visible movement, heave progression, boil formation and total heave.
2. The discharge velocity decreased by placing Coir geotextile and contributed to the increase in critical hydraulic gradient and piping resistance.
3. When the hydraulic head reached a certain level, small bubbles and local boiling were observed and finally the specimen failed by piping. Bubbles observed were more in case of river sand than mixture and red soil. Heave formation was observed more in red soil.
4. Reduction in discharge was found more in red soil and least in river sand. Hence the increase in piping resistance is also more for red soil and the least in river sand. Mixture occupies an intermediate position.
5. Maximum percentage reduction in discharge velocity was obtained as 50% in red soil, 30% in river sand, and 36% in mixture.
6. Maximum piping resistance was obtained in all the soil samples when geotextile was placed at top, center, and bottom. Maximum percentage increase in Piping resistance was obtained as 80% in red soil, 43% in river sand, and, 57% in mixture.

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