Seepage Velocity and Piping Resistance of Coir Fiber Mixed Soils

G. L. Sivakumar Babu[1] and A. K. Vasudevan[2]

Abstract: In the context of sustainable watershed management, natural fibers mixed with soil have applications in irrigation and drainage projects such as river levees, contour bunds, temporary canal diversion works, temporary check dams, soil structures, stream restoration, etc., for controlling seepage. In this study, a number of experiments were carried out for determining the seepage velocity and piping resistance of different types of soils mixed randomly with coir fibers. Three types of soils are used in this study. The experiments were carried out for various hydraulic heads, fiber contents, and fiber lengths. Discharge velocity and seepage velocity of flow of water through soil is calculated in each case and compared with plain soil. It is observed that fibers reduce the seepage velocity of plain soil considerably and thus increase the piping resistance of soil. Regression equations based on experiments are developed for quantifying the seepage velocity and piping resistance considering hydraulic gradient, fiber contents, and fiber lengths. Suitability of coir fibers for field applications with typical examples is also highlighted. The results show that coir fiber mixed soil can be used to increase the piping resistance and reduce seepage velocity in the above mentioned applications.

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Introduction

Sustainable watershed management envisages the use of eco-friendly materials in construction. Coir fiber, derived from coconut, is a natural material available abundantly in a large part of south India and other coastal areas in India, Srilanka, Indonesia, Philippines, Brazil, and other equatorial regions, and is useful in this context. Due to its high lignin content (46%), it is stronger than other natural materials such as jute or cotton. 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. Rao and Balan (2002) synthesized the experimental results in the laboratory as well as field trials. 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 and reinforcing material for the clay dykes and help in early consolidation of the clay, thereby minimizing the chance of early failure. 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. Hence, coir geotextiles require more machinery and processes compared to fiber preparation. Coir fibers can also be used directly in applications such as erosion or seepage control. The suitability of synthetic fibers as random reinforcement material (Gray and Ohashi 1983; Zornberg 2002; Michalowski and Coermark 2003) and natural materials such as coir in applications, for example, of erosion control and strength improvement for a short duration of 2–3 years is established by various researchers (Rao and Balan 2002).

Piping of base soils is a common problem downstream of earth embankments (Sherad et al. 1984) under the influence of upward seepage. 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 canal diversion works, temporary check dams, and soil structures. When the seepage velocity exceeds the critical velocity, piping occurs and the soil in the constructed areas flows out and the structures are weakened. Therefore, effective countermeasures against the piping are needed and the coir fiber mixed soil is useful in this application. Furumoto et al. (2002) reported the use of polyester fiber mixed soil for the construction of river levees and indicated that fibers contributed to increased piping resistance. Vasudevan and Sivakumar Babu (2006) presented a few experimental results on the use of coir fibers in reducing the seepage velocity of soils. Since fibers are distributed throughout a soil mass, they impart strength isotropy and reduce the possibility of formation of weak zones and contribute to improved piping resistance (Sivakumar Babu and Vasudevan 2007). It is noted that literature concerning the uses of these materials in hydraulic applications is very limited and the present work clearly demonstrates that these materials have potential uses and applications in many irrigation projects. Using coir fiber mixed soil (CFMS) for construction of the above structures, the resistance to piping can be provided. Hence an attempt is made in this paper to examine

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the hydraulic behavior of CFMS in terms of seepage velocity and piping resistance.

The specific objectives are as follows: (1) to examine the possibility of using coir fibers for controlling seepage velocity and improving piping resistance of various types of soils using laboratory experiments; (2) to develop a simple approach for quantifying the seepage velocity and piping resistance of CFMS; and (3) to illustrate the effect of fibers on the performance of check dams and sheet pile wall with typical examples.

Theoretical Considerations

Discharge velocity of water flowing through the soil specimen is calculated for different hydraulic gradients using Darcy's law

$$v = ki \tag{1}$$

where v=discharge velocity; and k=coefficient of permeability of soil, which is calculated by using

$$k = \frac{QL}{hAt} \tag{2}$$

i=hydraulic gradient, which can be calculated for various hydraulic heads (h) and length of specimen, L (11.0 cm); A=cross-sectional area of specimen (cm^2); Q=discharge (cm^3) in time t (s); and seepage velocity is calculated by using

$$v_s = v/n \tag{3}$$

where n=porosity of soil, which is calculated from the void ratio of CFMS. For the calculation of void ratio of CFMS, fibers are considered to be similar to soil solid particles (Zornberg 2002)

$$\text{void ratio of CFMS} = \frac{v_v}{v_s + v_f} \tag{4}$$

where v_v=volume of voids; v_s=volume of soil solids; and v_f=volume of fibers

$$v_f = \frac{w_f}{G} \tag{5}$$

where w_f=weight of fibers (g); and G=specific gravity of fibers which is taken as 1.12, and also determined in this study.

Seepage and 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 due to 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 the upward flow of water. The seepage force at this hydraulic gradient can be calculated by using

$$P = \gamma_w hA \tag{6}$$

where P=seepage force at critical gradient; γ_w=unit weight of water; h=critical hydraulic head; and A=cross-sectional area of soil specimen. The experimental results are analyzed using regression analysis.

Table 1. Physical and Mechanical Properties of Single Coir Fiber

Property	Value
Length (mm)	50–200
Density (gm/cc)	1.12
Water absorption (%)	10
Tensile strength (kPa)	1.02*E*5
Modulus of elasticity (kPa)	2.0*E*6

Regression Analysis for Seepage Velocity and Piping Resistance

In many engineering and scientific problems, when there are two or more variables that are inherently related, it is necessary to explore the nature of the relationship. Regression analysis is a statistical technique for analysis and investigating the relationship between two or more variables. If there is only one independent variable it is called a simple linear regression and if the analysis involves more than one independent variable, it is called multiple regression analysis. In this study, there are three independent parameters such as fiber content, fiber length, and hydraulic gradient and hence multiple regression equations are developed for seepage velocity and piping resistance. A polynomial equation for three independent variables is given by

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_1^2 + \beta_3 x_2 + \beta_4 x_2^2 + \beta_5 x_3 + \beta_6 x_3^2 + \beta_7 (x_1 x_2) + \beta_8 (x_2 x_3) + \beta_9 (x_3 x_1) \tag{7}$$

where β_0, β_1, β_2, etc. are called regression coefficients; y=dependent variable; and x_1, x_2, are x_3=independent variables. These coefficients describe the expected change in response to y per unit change in x_i when all the remaining independent variables are held constant. They describe the partial effect of one independent variable when the other independent variables in the equation are held constant. The dependent variable and the independent variables are written in matrix form and the equation coefficients are evaluated. The equations for various types of soils are given in the following sections.

Materials and Experimental Program

Coir fibers of length varying from 40 to 60 mm and 0.25 mm average diameter were used. Tables 1 and 2 present the properties of coir fiber. The following three types of soils were used in this study:

1. Sand passing through 2 mm sieve and retained on 75 μm;
2. Red soil passing through 1.18 mm sieves; and
3. A mixture of sand and red soil in the ratio of 1:1.

The experimental setup used in this study is shown in Fig. 1. It consisted of a tank 40 cm in diameter and 100 cm in height with

Table 2. Chemical Properties of Coir Fibers

Property	Value (%)
Lignin	45.84
Cellulose	43.44
Water soluble	5.25
Pectin and related compounds	3.30
Ash	2.22
Hemi cellulose	0.25

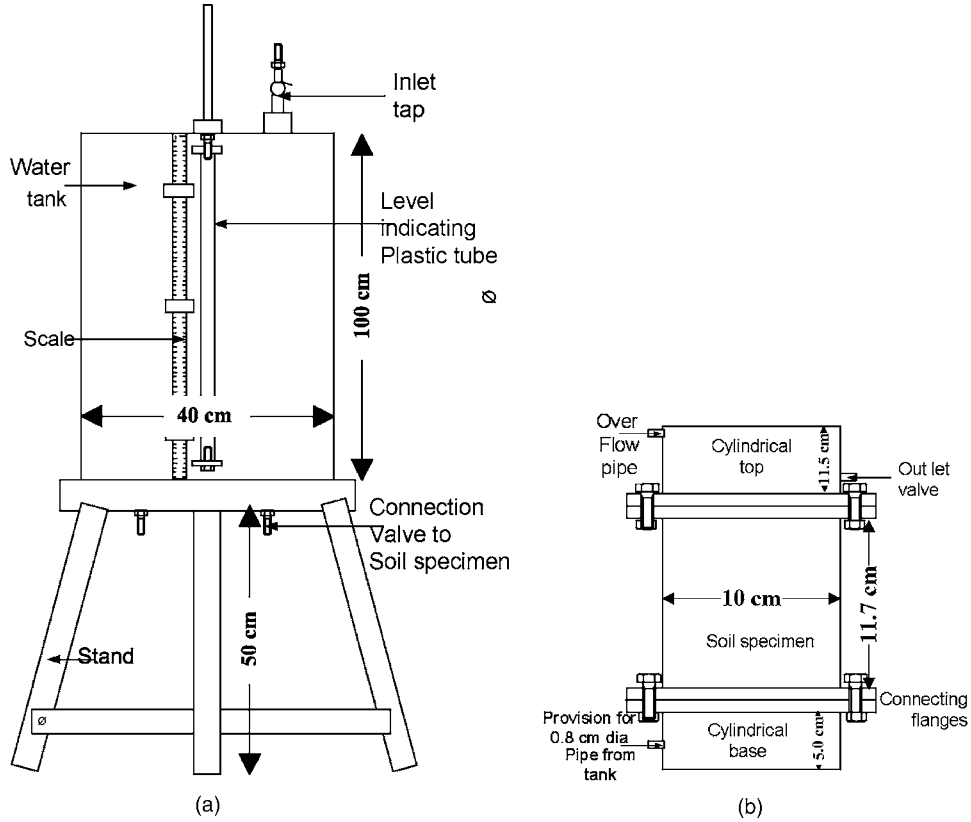

Fig. 1. (a) Water tank (not to scale); (b) scale with not specimen (not to scale)

an attached graduated scale to measure the level of water. The mold for the soil specimen has a diameter of 10 cm and height of 11.7 cm. Dry unit weights of the compacted soil sample and water content used for preparing the soil specimen are given in Table 3. These values are in the typical range for various soils used in the field (HMSO 1957). The required weight of soil for the specified density was mixed with water over a plane glass plate. The fibers of specified weight were spread uniformly over the soil and mixed thoroughly. The CFMS was filled in the cylindrical mold (up to a height of 11.0 cm) in approximately three equal layers and each layer was statically compacted. The mold 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 for different fiber contents (0.25, 0.50, 0.75, 1.0, and 1.50% of dry weight of soil) and fiber lengths (40, 50, and 60 mm).

It was observed that seepage 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. It was observed that for all types of soils critical hydraulic gradient increased with the increase in fiber content. The point corresponding to critical hydraulic gradient was clearly noticeable in the case of clay 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. The following sections present the results of experiments and analysis of test results.

Analysis of Test Results

Sand

The experiments were conducted for fiber contents of 0, 0.5, 1.0, and 1.5% by dry weight of soil. Length and average diameter of fibers in each case was 50 and 0.25 mm. The variation of seepage velocity with hydraulic gradient for various fiber contents is shown in Fig. 2(a). It is clear that fiber parameters such as fiber content and fiber length affect the seepage velocity in addition to

Table 3. Properties of Soils

Sl. numbers	Soil type	Dryunit weight (kN/m^3)	Molding water content %	Uniformity coefficient	Coefficient of curvature	Specific gravity
01	Sand	16.3	10.0	3.9	1.3	2.65
02	Red soil	14.3	17.8	3.6	1.0	2.65
03	Sand (50%)+red soil (50%)	16.0	13.4	3.2	0.8	2.65

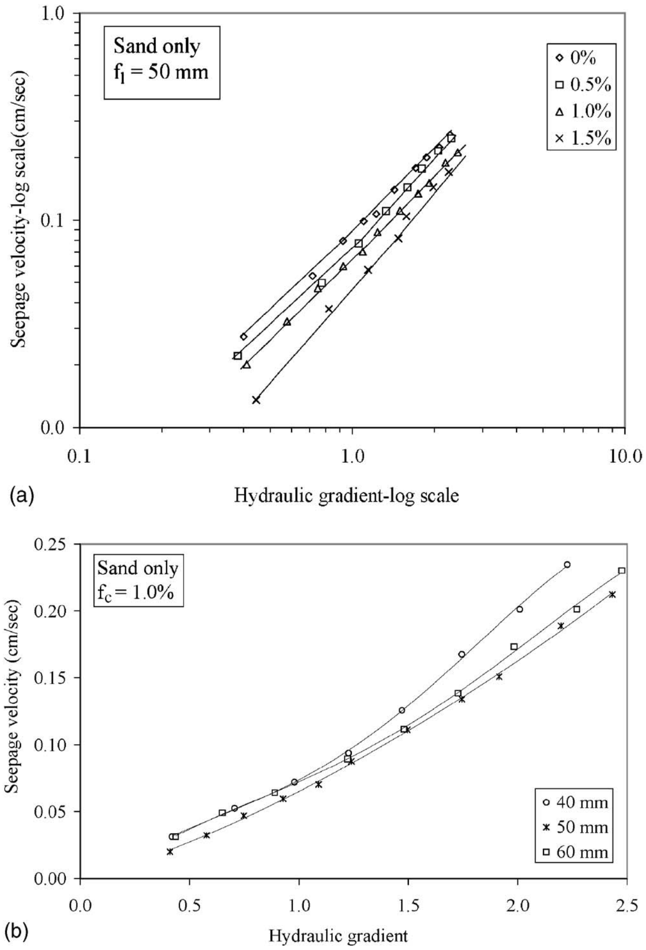

Fig. 2. (a) Seepage velocity versus hydraulic gradient for various fiber contents; (b) seepage velocity versus hydraulic gradient for various fiber lengths

hydraulic gradient. Seepage steadily increased as the gradient is increased. In all the cases, the seepage velocity decreased with the increase in fiber content and contributed to the increase in piping resistance. With the increase in fiber content, the increase in critical hydraulic gradient (i.e., the gradient at which piping failure occurs) was observed. To investigate the effect of fiber length on seepage velocity experiments were carried out with fibers having lengths of 40, 50, 60 mm length. Fig. 2(b) shows the seepage velocity versus hydraulic gradient response for various fiber lengths. It was observed that seepage was less with 50 and 60 mm fibers. Experiments were also carried out with 25 and 75 mm long fibers. However it was observed that if the length of fibers is less, i.e., 25 mm, the fiber content had no effect on discharge and, similarly, if the fibers had greater length (75 mm), seepage was not reduced substantially.

Red Soil

Experiments were carried out with five different fiber contents (0, 0.25, 0.5, 0.75, and 1.0). Fig. 3(a) presents the variation of seepage velocity with hydraulic gradient for various fiber contents. From Fig. 3(a), it can be noted that seepage velocity suddenly increased once piping was initiated. Unlike the previous case, the hydraulic gradient at which piping occurs was clearly observed. The results also show that critical hydraulic gradient increased as the fiber content is increased. The threshold value of critical hy-

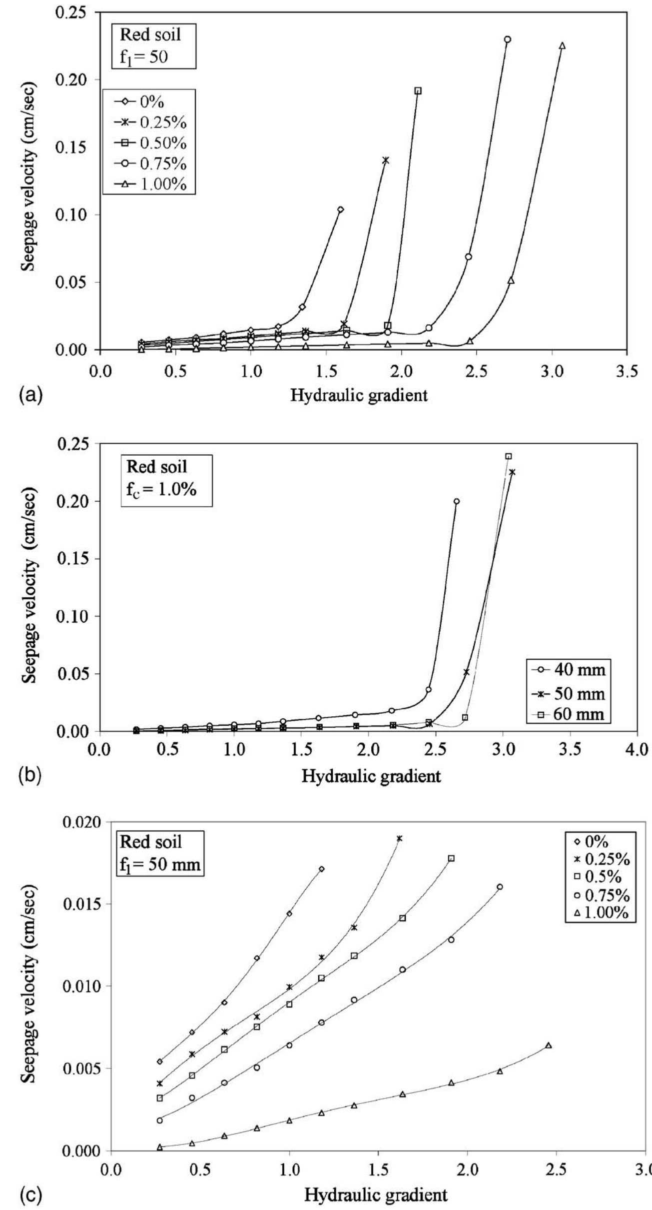

Fig. 3. (a) Seepage velocity versus hydraulic gradient for various fiber contents; (b) seepage velocity versus hydraulic gradient for various fiber lengths; and (c) seepage velocity versus hydraulic gradient for various fiber contents (until piping failure occurs)

draulic gradient is observed to be at a fiber content of 1.0%. At a fiber content of 1.5%, mixing of fibers with soil and filling the soil-fiber mix in the mold was difficult as the number of fibers required for 1.5% was high. The effect of fiber length on seepage velocity was also examined for red soil [Fig. 3(b)]. Experiments were also carried out with 25 and 75 mm long fibers and the optimum length of fibers for maximum seepage reduction was found to be 50–60 mm, which is similar to the case of sand. Fig. 3(c) presents an expanded view of seepage velocity versus hydraulic gradient variation at low seepage velocities (0–0.02 cm/s). This brings out the effects of fibers at different hydraulic gradients and fiber contents more clearly. It is evident that the response leading to critical hydraulic gradient is a function of fiber content.

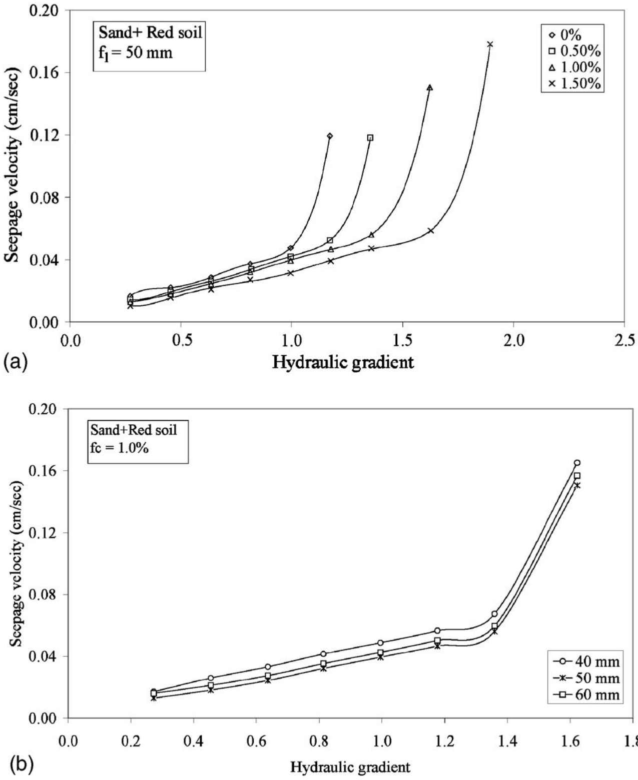

Fig. 4. (a) Seepage velocity versus hydraulic gradient for various fiber contents; (b) seepage velocity versus hydraulic gradient for various fiber lengths

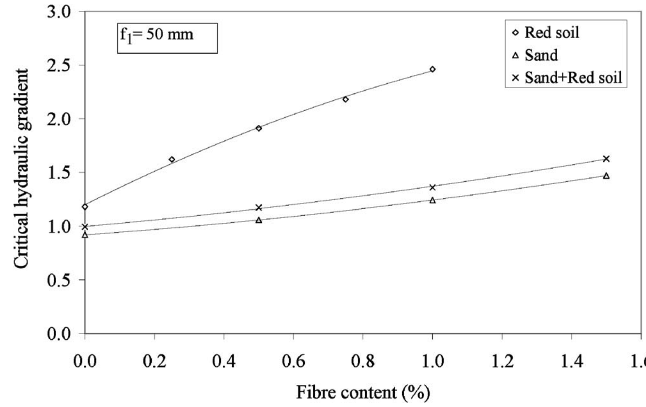

Fig. 5. Critical hydraulic gradient versus fiber content for various soils

Mixture of Sand and Red Soil

Sand and red soil, which were used in the above experiments, were mixed properly in dry conditions in the ratio of 1:1 and used for experiments. Mixing and sample preparation was similar to other soils. Experiments were carried out with four different fiber contents (0, 0.5, 1.0, and 1.5%). Fig. 4(a) presents the variation of seepage velocity against hydraulic gradient for various fiber contents and it is clear that fibers reduce the seepage similar to the trends observed in previous cases. Similarly to red soil, clear piping failure was also observed for this soil. The critical hydraulic gradient was found to be lower than that observed in red soil. Fig. 4(b) presents the seepage velocity versus hydraulic gradient for various fiber lengths. It is clear that seepage velocity is found to be minimum with 50 mm fibers, similar to other types of soils in this experimental setup.

Critical Hydraulic Gradient and Piping Resistance

Values of critical hydraulic gradient for various fiber contents are presented in Table 4 and Fig. 5. From the results, it is clear that critical gradient increases as fiber content increases. Due to mixing of soil with fibers, the critical hydraulic gradient increased resulting in an increased value of seepage force and piping resistance. Piping resistance of soil with various fiber contents is calculated using Eq. (6) and is presented in Table 4 and Fig. 6. Results show that piping resistance of soil increases as fiber content increases.

Table 4. Piping Resistance of Soils for Various Fiber Contents

Type of soil	Sl. number	Fiber content (%)	Critical hydraulic gradient	Critical hydraulic head (cm)	Piping resistance (N)
Sand	01	0	0.92	10	7.9
	02	0.5	1.06	12	9.2
	03	1	1.24	13	10.7
	04	1.5	1.47	16	12.7
Red soil	01	0	1.18	13	10.2
	02	0.25	1.62	18	14.1
	03	0.5	1.91	21	16.5
	04	0.75	2.18	24	18.8
	05	1	2.46	27	21.2
Red soil (50%)+sand (50%)	01	0	1	11	8.6
	02	0.5	1.17	13	10.2
	03	1	1.36	15	11.8
	04	1.5	1.36	15	11.8

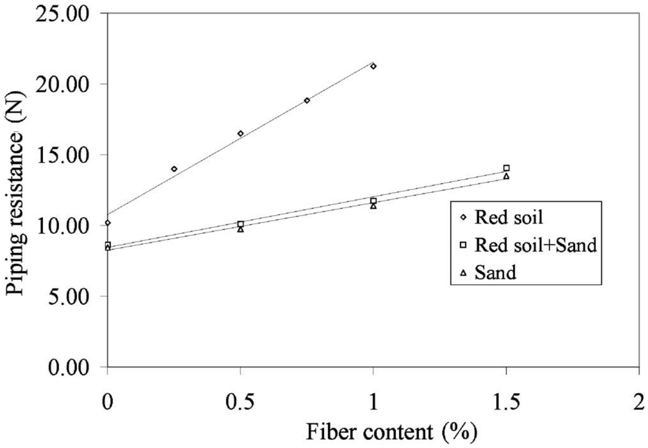

Fig. 6. Piping resistance versus fiber content for various types of soils

Regression Analysis

Regression Equations for Seepage Velocity

Regression equations for seepage velocity for all types of soil are given in the following sections.

Sand Alone

Based on 49 data points of the experimental observations, a multiple polynomial regression equation for seepage velocity is obtained. The degree of agreement between the experimental and predicted values is calculated from the term R^2 called the coefficient of determination, which is an index of the reliability of the relationship. A regression equation that lies close to all the observation points gives a high value of R^2 (i.e., $R^2=1.0$). For Eq. (8), the R^2 value is found to be 0.97. It is given by

$$\nu_s = -0.01499 + 0.1142(f_c) - 0.0203(f_c)^2 - 0.00159(f_l) + 0.000037(f_l)^2 + 0.0712(i) + 0.0263(i)^2 - 0.00173(f_c f_l) - 0.000433(f_l * i) - 0.0151(i * f_c) \quad (8a)$$

where f_c=fiber content in percentage by dry wt of soil; f_l=fiber length (mm); and i=hydraulic gradient. It is clear from Eq. (8*a*) that the regression coefficient for the fiber content is higher than the corresponding coefficients for the other two parameters, indicating that the fiber content is the major controlling factor for seepage velocity. In order to determine the accuracy of the equation, experimental and predicted results of seepage velocity are plotted as indicated in Fig. 7. Both experimental and predicted values are close to each other. For simplicity, considering only linear terms, seepage velocity (with R^2 value for this equation of 0.92) can be expressed as

$$\nu_s = -0.003 - 0.01213 * (f_c) - 0.0003 * (f_l) + 0.10249 * (i) \quad (8b)$$

Fig. 7 also indicates the predictions obtained from the simplified equation.

Red Soil

Based on the results of 65 data points, a regression equation for seepage velocity is given by

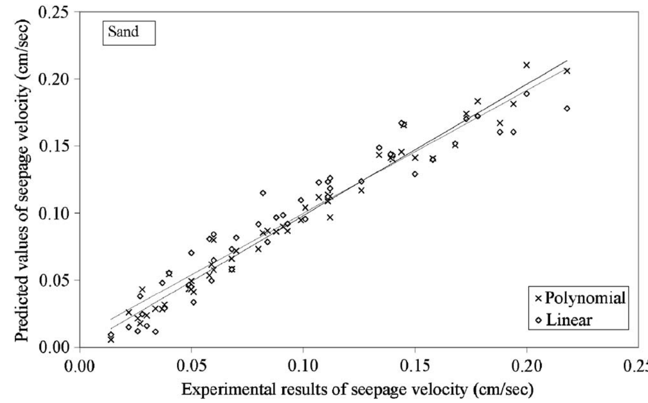

Fig. 7. Experimental versus predicted values of seepage velocity

$$\nu_s = -0.00125 + 0.0992(f_c) - 0.0157(f_c)^2 - 0.00157(f_l) + 0.0000315(f_l)^2 + 0.0158(i) + 0.0087(i)^2 - 0.00169(f_c * f_l) - 0.000123(f_l * i) - 0.0074(i * f_c) \quad (9a)$$

The R^2 value for the above equation is 0.95. It is evident that fiber content is the major controlling factor for seepage velocity. A simplified seepage velocity equation ignoring the higher terms (R^2 value for this equation is found to be 0.71) is

$$\nu_s = 0.00829 - 0.00884 * (f_c) - 0.000031 * (f_l) + 0.005683 * (i) \quad (9b)$$

Mixture of Red Soil and Sand

Similar to the earlier results, based on the results of 40 experimental observations, the equation for seepage velocity (with R^2 value of 0.99) *is* given by

$$\nu_s = 0.004527 + 0.1697 * (f_c) - 0.00529 * (f_c)^2 - 0.00308 * (f_l) + 0.0000597 * (f_l)^2 + 0.0324598 * (i) + 0.008661(i)^2 - 0.00318 * (f_c * f_l) - 0.0000317 * (f_l * i) - 0.01029 * (i * f_c) \quad (10a)$$

The corresponding simplified relationship (with R^2 value of 0.92) is

$$\nu_s = 0.006895 - 0.00624 * (f_c) - 0.0000231 * (f_l) + 0.0398 * (i) - \quad (10b)$$

From the above equations, it is clear that fiber content and fiber length are the main factors which control the seepage velocity of soil.

Regression Equations for Piping Resistance

As indicated earlier, piping resistance corresponds to seepage force at critical hydraulic gradient and is a function of fiber parameters, namely fiber content and fiber length. For the data presented in Fig. 6 (data pertaining to 50 mm length fibers) the regression equations are presented below.

The regression equation (with R^2 value of 0.99) for piping resistance of sand is given by

$$P = 7.95 + 1.99 * (f_c) + 0.78 * (f_c)^2 \quad (11)$$

Similarly, for red soil and mixture of red soil and sand, the relationships (with R^2 values of 0.99 for both the equations) are given by

$$P = 10.37 + 14.31 * (f_c) - 3.62 * (f_c)^2 \quad (12)$$

$$P = 8.668 + 2.55 * (f_c) + 0.655 * (f_c)^2 \quad (13)$$

The above results clearly demonstrate that the use of fibers for the increase of piping resistance is a viable approach and the mechanism of improvement is attributable to the increase of overall shear resistance of fiber mixed soil at various strain levels. This aspect has been brought out in the experimental and analytical studies presented by Sivakumar Babu and Vasudevan (2007) and Sivakumar Babu et al. (2008).

Applications

Two different types of applications with coir fibers relevant to the results of the study are given in the following sections.

No. 1. Check Dam

Check dams are small barriers which are constructed using soils across the direction of water flow of shallow rivers and streams for the purpose of water harvesting. These structures are popular in India and other countries. The small dams retain excess water flow during monsoon rains in a small catchment area behind the structure. The major environmental benefit is the replenishment of nearby groundwater reserves and wells. The water entrapped by the dam, surface, and subsurface, is primarily intended for use in irrigation during monsoons and later during the dry season, but can also be used for livestock and domestic needs. Excessive seepage through the body of the dam is one of the important problems faced by dam engineers. Coir fibers mixed in soil can be used efficiently in reducing the seepage and is a cost effective and eco-friendly solution, and can be used in localities where coir is sufficiently available. The compaction of soil can be done with conventional methods. The following example illustrates the benefit of coir fibers in reducing the seepage through the body of a check dam made up of typical red soil. It should be noted that these structures are constructed using soils that are similar in composition to the soil in the present study. The seepage is calculated using the analytical methods of Dupuit, Schaffernak, and Casagrande described in Das (1983) and the results are compared.

Example

The data pertaining to a temporary dam used for water conservation purposes, constructed with red soil used, are as follows; dry density of soil=14.3 kN/m^3; molding water content=17.8%; height of water surface from the base of the dam=1.8 m, base width=10.0 m; top width=2.48 m; side sloping angle, β=28°; and free board=0.2 m. The bottom of the dam is assumed to be an impermeable surface. The flow is assumed to take place only through the body of the dam between the base and phreatic line. Fig. 8 gives the calculated discharge in cubic meters per second per meter length of the check dam using different analytical methods for various fiber contents (0, 0.25, 0.5, 0.75, and 1.0%) for a hydraulic gradient of unity. It is clear from the results that the

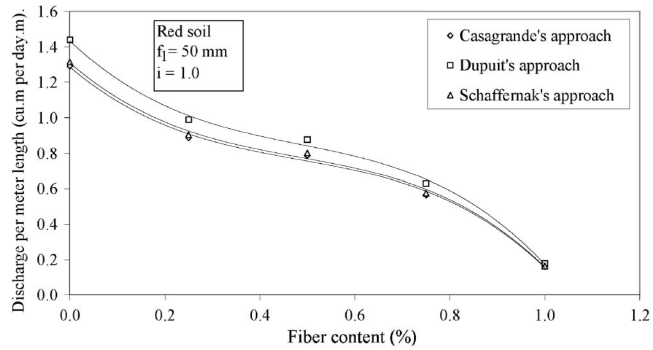

Fig. 8. Discharge per unit length versus fiber content for typical coir fiber reinforced check dam by various methods

seepage reduces as the fiber content increases. Hence it can be concluded that coir fibers are effective in controlling the seepage through the body of a check dam.

No. 2. Sheet Pile Wall

Sheet pile walls are used both as permanent and temporary structures. During the construction of water front structures sheet piles (as a temporary structure) are used for making artificial islands, cofferdams, etc. Failure due to piping is a major cause for the failure of sheet piles in such cases. The following example illustrates the application of coir fibers for increasing the factor of safety against piping for such a sheet pile.

Factor of safety (FS) against piping (Das (1983) for a sheet pile wall is illustrated as

$$FS = \frac{i_{cr}}{i_{exit}} \quad (14)$$

where i_{cr}=critical hydraulic gradient obtained for different fiber contents from experiments; and i_{exit}=maximum exit gradient which is obtained by using the relationship given by Harr (1962) and is given as

$$i_{exit} = \frac{H}{3.14D} \quad (15)$$

where H=maximum hydraulic head and D=depth of penetration of sheet pile wall. Eqs. (14) and (15) from the literature are based on the assumptions that the sheet pile wall is embedded in a permeable layer and an impermeable layer is available at a shallow depth. Das (1983) provided a review of the above literature and indicates that a factor of safety of 3–5 against piping is satisfactory.

Example

A sheet pile wall having the following details is used for the construction of a cofferdam: embedded depth, D=2.0 m; u/s water depth=2.5 m; and d/s water depth=0.5 m. After dewatering the site, soil deposit on the downstream side of the sheet pile is replaced with CFMS and compacted. The factor of safety against piping with the original soil and fiber mixed soil is calculated using Eq. (14). The results are presented in Fig. 9. It is clear that as the fiber content increases the factor of safety against piping failure.

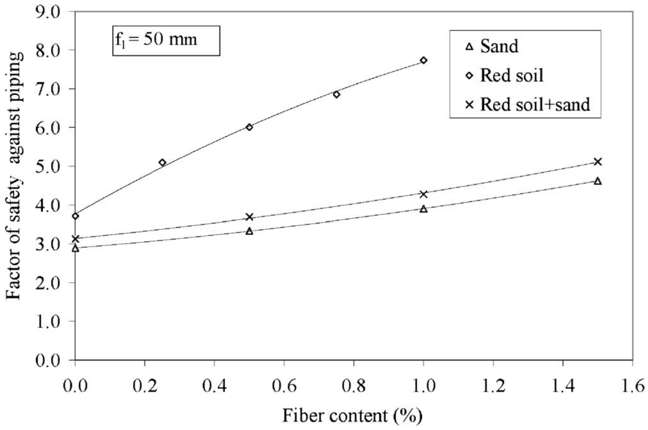

Fig. 9. Factor of safety against piping versus fiber content for various types of soils

Concluding Remarks

Based on the experimental observations and discussion of the test results and analysis, the following conclusions are made:

1. As the fiber content increased seepage velocity decreased and piping resistance of soil increased. This was observed for all three types of soils;
2. In the experimental study, seepage velocity was observed to vary as the fiber length changed. The least value was observed when fiber length was 50 mm;
3. Inclusion of coir fibers in soil reduced the lifting of individual soil particles when water flowed in the upward direction through the soil mass. Piping failure due to lifting of soil particles is found to occur in CFMS at high gradients, whereas plain soil failed at comparatively low hydraulic gradients. This was clearly visible for red soil and also for red soil-sand mixture; and
4. The proposed regression equations provide an understanding of the variation of seepage velocity and piping resistance of CFMS at various hydraulic gradients, fiber contents, and fiber lengths. It is clear from all the equations that fiber content is the major controlling factor.

The effectiveness of coir fibers mixed in soil is demonstrated with reference to typical applications in check dams and sheet pile walls. Similar applications of these materials to control seepage and increase resistance against piping in the construction of river levees, temporary canal diversion works, stream restoration, and other similar soil structures are possible.

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