Laboratory Evaluation of Permeability Characteristics of Cocologs

[1]K.P.Indulekha, [1]P.K.Jayasree, [2]K.Balan,[1]L Dhanesh and [3]J S Vinod

[1]Department of Civil Engineering, College of Engineering Trivandrum, Kerala, India.
[2]Department of Civil Engineering, Rajadhani Institute of Engineering and Technology, Trivandrum, Kerala, India.
[3]Faculty of Engineering and Information Sciences, University of Wollongong, NSW-2522, Australia.
indulekhakp@gmail.com, jayasreepk@cet.ac.in, drkbalan@gmail.com, dhan76859@gmail.com, vinodjs@uow.edu

Abstract.
Coir geo textiles have a wide applicability for control of bank erosion and soil stabilization. Cocologs are densely packed coconut fibers wrapped in coir net. Cocologs, which are made out of coir fibres have proven to be an erosion control product along river banks. This paper presents the laboratory experimental results on the permeability behaviour of cocologs. The permeability of cocologs is a critical parameter in the design of cocolog stabilised geostructures. In this study, the experiments to determine the permeability of cocologs were carried out in a modified permeability test apparatus. The effect of different parameters such as the density of cocolog, opening size (d) of outer cover, hydraulic gradient and orientation of cocologs on the permeability of cocolog was investigated. It is found that, the permeability of cocologs varies from 20 mm/s to 85 mm/s for density variation of 220 kg/m^3 to 100 kg/m3. A 76% reduction in flow velocity was observed for density variation from 100 kg/m^3 to 220 kg/m^3. The opening size of outer net covering of cocologs has less significance regarding the prediction of permeability value of cocologs for a d/L ratio (ratio of opening size to length of cocolog) above 0.010. It was seen that the density of cocolog has a significant influence on the permeability of cocologs. Furthermore, an empirical relationship was developed to determine the permeability of cocologs considering the effect of different parameters.

Keywords: Cocologs,permeability, coir geotextile; density,coir fibers

1 Introduction

Cocologs are strong and flexible logs made of coir geotextile or polypropylene net filled with cocofibers. They are biodegradable products that have been proven to be erosion control materials along the river banks. The spurs constructed with cocologs degrades after 3 to 4 years, and by that time strong vegetation will be established along river banks, capable of arresting the erosion from bank completely. In the recent past a lot of experimental investigations were carried out on various aspects of coir geotextiles in controlling erosion (e.g. Balan and Rao, 1996; Lekha, 2004). Coir geotextile has the capacity to conserve soil and moisture and is biodegradable (Joy et al., 2011, Sumi et al., 2018) in nature, leaving no unwanted residues in the ecosystem. As they biodegrade, no harmful substances are left in the environment, on the other hand, the addition of organic matter enhances the soil fertility (Manilal et al., 2010; Anil et al., 2011,). Coir geotextiles retain 20% of their original tensile strength (Anggraini et al., 2015) even after one year in the soil. It is also seen that, coir geotextiles exhibited no damage in wet condition for 167 day. Rao and Balan (2000) demonstrated that the major strength loss takes place in 4 to 8 months in coir yarns.

Coir geotextiles have a natural ability to retain moisture and protect from the sun's radiation just like natural soil (Cassady and Bright, 1995) and unlike geo-synthetic materials, they provide good soil support up to three years, allowing natural vegetation to get established. The life of coir geotextiles in the field typically lasts for two to five years under exposed conditions (Rickson, 2006). The ability of coir fibers to absorb water four to five times their weight and to degrade with time are the prime properties which give them an edge over synthetic geotextiles for erosion control purposes (Rickson, 2006; Bhattacharya et al., 2010; Kumar and Midha,2018). Geotextiles made of coir fibre degrade due to microbial action in the soil and because of continuous actions of rain and sunlight. Various studies indicate that a coir fibre could retain 19-56% of its initial strength in the field (Lekha, 2004; Vishnudas et al., 2005; Karthika, 2016).

Recently field experiments were conducted using cocologs along the banks of the Manimala River in Kerala, India and the variations of velocity and sediment erosion/deposition against time were analysed. This was done by constructing spurs with cocologs at an interval of 20 m at an angle of 45^o (Anil et al., 2011) along the river bank. Natural vegetation was seen growing on the rear side of spurs predominant with reed and locally grown vegetation covered the soil along the river bank within a period of 14 months. After 30 months, the spurs started biodegrading and by that time strong vegetation capable of arresting the erosion of the bank completely, was covered all over the river bank.

Cocologs are made from bunches of coir fibre bundled in pressed condition in tubular enclosures of knotted coir yarn. Commercially available cocologs are of diameters ranging from 0.3 m to 0.6 m and of lengths 3 m to 6 m. The densities of cocolog vary from 110 kg/m^3 to 180 kg/m^3. Normally, an outer coir net with a rectangular opening mesh of size (d) of 0.05 m x 0.05 m is provided for a 3 m and 6 m long (L) cocolog. Different categories of cocologs are available and hence the selection of proper and appropriate cocologs for a specific application is very crucial. Both physical and hydraulic properties of cocologs are to be analysed carefully and accurately for their effective application at a site. Although several test methods are available for studying the, behavior of geotextile/soil filtration systems (Cazzuffi et al., 1999; Nanayakkara, 2005; Recio and Oumeraci, 2008; Rawal et al., 2010; Paul and Tota-Maharaj, 2015), none are available for testing the water flow through a cocolog. The permeability of natural fibers is one of the most difficult geotechnical parameters to be evaluated because of its wide distribution range (Nahar et al., 2010; Cazzuffi et al., 2016; Miszkowska and Koda, 2017).

Hence, the objective of the study is to determine the permeability of cocologs and to analyse the physical and hydraulic characteristics of cocologs under varying parameters like density of coir fibers, opening size of outer cover and orientation of cocologs.

2. Materials and Method

Cocolog was prepared by filling coir fibers inside the outer covering made into a cylindrical shape of diameter 30 mm to achieve the desired density. Cocologs of different densities ranging from 100 to 215 kg/m^3 were prepared for testing as shown in Fig. 1. Polypropylene nets of different opening sizes were used as outer coverings for cocolog models. An Outer Covering (OC) net of thirteen different properties (OC1 to OC13) was used for cocolog preparation to study the effect of opening size on the permeability of cocologs. The mesh size of the outer net is an important physical property of cocolog, as it affects the packing density of the coir fibers. The mesh size of the outer net covering was measured using overhead projector method (IS 15868, 2008). By ratio proportion method, the mesh size of the specimens was determined. The wide width strip tensile strength was determined on 200mm×200mm samples as per ISO 10319:2015.A permeability apparatus was designed and fabricated in accordance with the ISO 11058:2011(E) and ASTM (D 4491:2015; D 4716:2014; D 6574:2013) standards to measure the permeability of cocologs. The schematic diagram showing the dimensions of the apparatus is shown in Fig. 2.The flow rate through the cocologs is very high, hence the constant head permeability test was used. The apparatus was fabricated to maintain a maximum constant head of 300 mm to a minimum head of 50 mm. The water was supplied to the apparatus through an inlet pipe from an overhead storage tank. Constant head was maintained in the apparatus by adjusting the control valve provided in the external inlet pipe. The apparatus consists of 3 parts- (a) the inlet unit, (b) the specimen container and (c) the outlet unit. The specimen container is a separate arrangement made in the apparatus to hold the cocologs in the horizontal and vertical directions as shown in Fig. 2. The specimens(cocologs) prepared were of diameters of 30 mm and length 200 mm. Water was allowed to pass through the inlet unit in to the cocolog specimen and it was collected in a measuring jar placed near the outlet unit. The quantity of flow was measured with respect to time.

The flow velocity v20 for each specimen was determined (EN ISO 11058:2011) according to the formula shown in Equation (1).

$$v_{20} = \frac{VR_T}{At} \quad (1)$$

Where V is the water volume measured in m3, R_T is the correction coefficient for water of temperature of 20ºC, A is the exposed area of the specimen in m2 and t is the time measured to achieve the volume V in seconds. The permeability of cocologs k_c was calculated using Equation (2).

$$k_c = \frac{VLR_T}{Ath} \quad (2)$$

Where k_c is the coefficient of permeability (mm/s), V is the volume of water discharged (mm^3), L is the length of flow (mm), A is the exposed area of specimen (mm^2), t is the time of discharge (s), h is the difference in head (mm) and R_T is the temperature correction factor. Statistical Package for the Social Sciences (SPSS) tool was used to find out the significant parameters affecting the permeability of cocologs. R, R square, coefficients, residuals, statistics, histogram and normal PP plot of regression standardized residual were analyzed to get an idea about dependent and independent terms. Multiple linear regression analysis was used to find out the relationship that exists among variables.

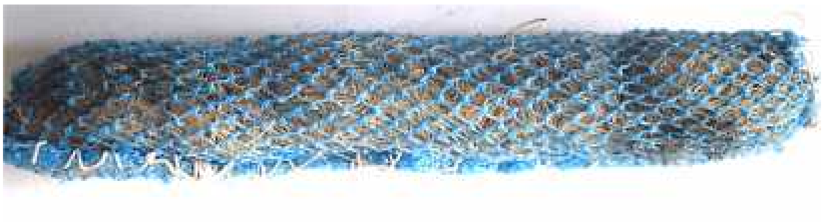

Fig. 1. A sample cocolog prepared for testing

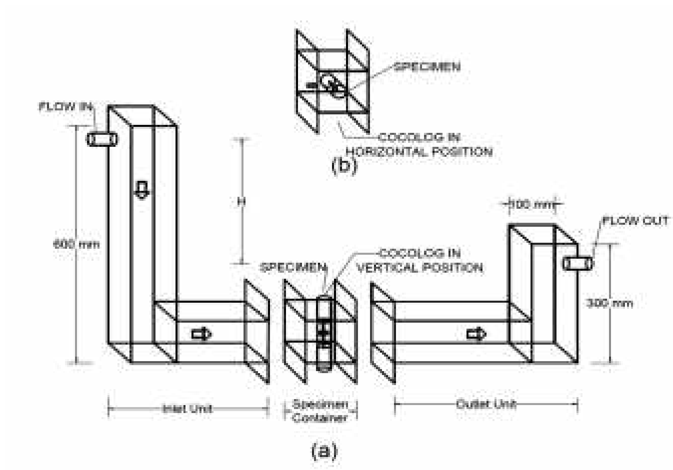

Fig. 2. Schematic representation of permeability apparatus

3. Results and discussions

3.1. Physical properties

The length of the coir fibers used for the cocolog preparation ranges from 37 mm to 280 mm and the coir fibers could be classified under the grade of 3F (Ravi, Indian coir, a reference book,2007).The average length of cocolog fibers in a bundle was 220 mm, and had an effective diameter varying from 0.2 mm to 0.35 mm. Polypropylene nets of different opening sizes ranging from0.50 mm to13 mm with different tensile strengths were used as the outer covering of cocolog model as shown in Table 1.

3.2. Hydraulic Properties

3.2.1 Effect of density on the permeability of cocologs

The effect of density on the permeability of cocologs is presented in Fig.3. It was observed that the density has a significant influence on the permeability of cocologs. As expected, the permeability decreases with increase in the density of the cocologs. The permeability characteristic of fibers is mainly influenced by the pore space among the fibers. Higher the pore space, greater will be the flow of water through the cocologs, which indicates that the permeability of cocolog is high. As the density of cocologs increases, the fibers inside the cocolog gets more closely packed reducing the pore space inside the fibers causing a decrease in the flow of water. From the experiment results, it is found that, the permeability of cocologs varies from 20 mm/s to 85 mm/s for density variation of 220 kg/m^3 to 100 kg/m^3. A 76% reduction in flow velocity was observed for density variation from 100 kg/m^{3}to 220kg/m^3. Flow velocity in the rivers could be controlled at any percentage below 76% by proper selection of densities of fibers inside the cocologs.

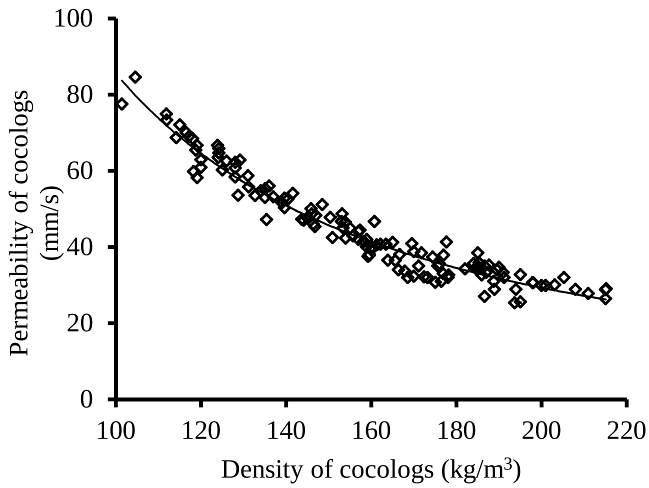

Fig. 3. Variation of permeability of cocolog for different opening size of outer net cover with trend line

3.2.2. Effect of orientation on permeability of cocologs

In the field, cocologs can be placed either horizontally or vertically against the flow. The effect of permeability on horizontal and vertical orientation of cocologs was also evaluated in the study. The apparatus was modified for both horizontal and vertical orientations of cocologs, as shown in Fig.2, for assessing the variation of permeability. The same cocolog specimens were tested in horizontal as well as vertical orientations. The variations of some of the samples tested are presented in Fig.4. It is found that the orientation of cocolog has negligible influence on the permeability of the cocolog. This clearly indicates that it is the pore space among the fibers that mainly controls the permeability of the cocologs. So cocologs can be placed in any orientation either horizontally or vertically during the construction of bank protection works, which will not affect the efficiency of cocologs.

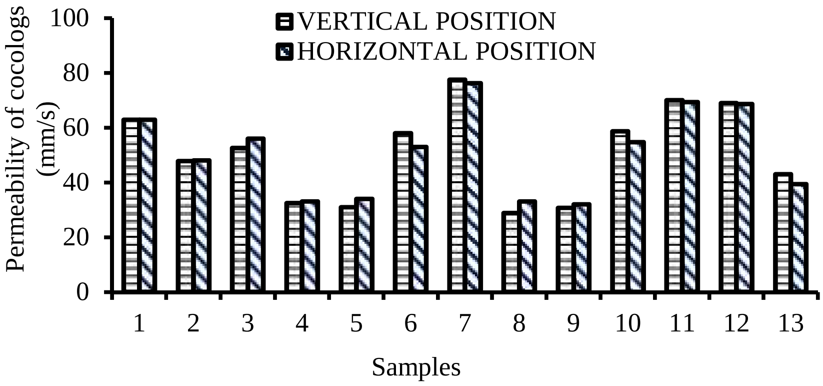

Fig. 4. Variation of permeability of cocolog for horizontal and vertical orientation

3.2.3 Effect of outer net covering on permeability of cocologs

The cocologs are commercially available with an outer covering of 50 mm x 50 mm mesh opening. In the laboratory, the cocolog specimens were prepared with various outer coverings OC1 to OC13 with different mesh openings ranging from 0.33 mm to 13 mm selecting suitable scale ratio to study the effect of mesh opening on permeability. The physical properties of the outer net covering are shown in Table 1. The tensile strength of the outer net cover varies from 0.62kN/m to 7.22kN/m. The variation of permeability with density for different outer covers is shown in Fig.5. The opening size of the outer net coverings of cocologs exerts some influence on the permeability of cocologs when it is lesser than the pore space of the cocologs. The permeabilty of cocologs increases with an increase in the opening size of outer nets up to a d/L ratio of 0.01 is shown in Fig. 6. Thereafter, an increase in the mesh opening size of outer cover did not increase the permeability of cocologs. The outer covering only served the function of holding the cocofibers.

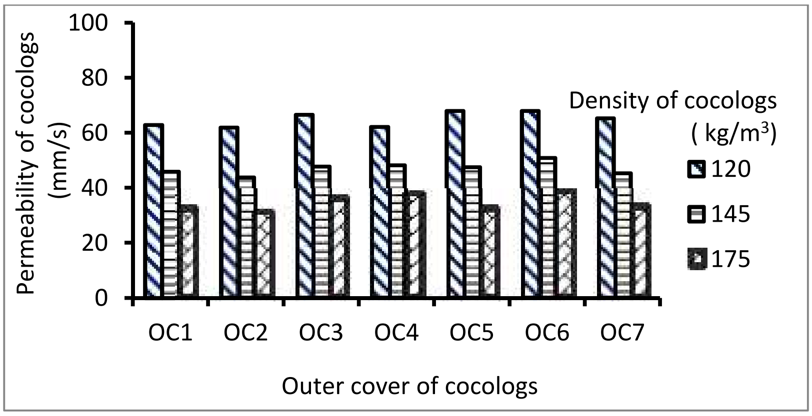

Fig. 5. Variation of permeability with opening size for three densities

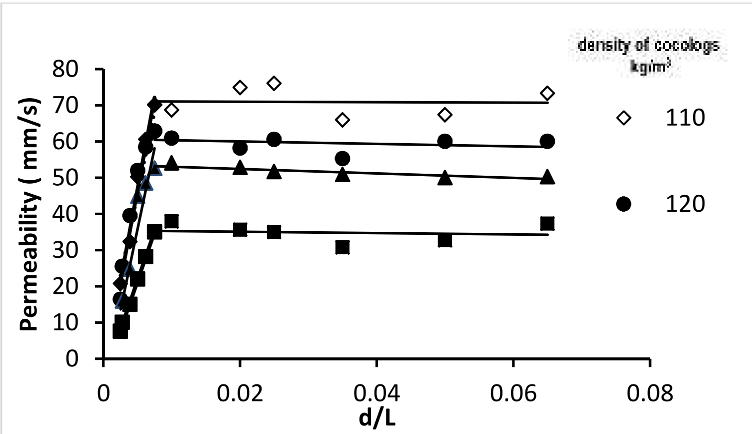

Fig. 6. Effect of opening size on permeability of cocologs

Table 1 Physical properties of cocolog specimens

Specimen	*Mesh size (d) (mm x mm)*	*Diameter of yarn (mm)*	*Tensile strength (kN/m)*	*d/L*
OC1	1.5 x 1.5	0.020	2.42	0.008
OC2	7 x 7	0.090	0.62	0.035
OC3	8 x 2	0.200	2.68	0.040
OC4	13 x 13	0.320	2.31	0.065
OC5	5 x 5	0.440	5.24	0.025
OC6	2 x 2	0.290	2.51	0.010
OC7	10 x 10	0.390	7.22	0.050
OC8	0.50 x 0.50	0.050	2.58	0.0025
OC9	0.55 x 0.55	0.067	3.40	0.0027

OC10	0.66 x 0.66	0.075	4.12	0.0033
OC11	0.78 x 0.78	0.033	1.32	0.0039
OC12	1.00 x 1.00	0.065	1.29	0.0050
OC13	1.24x 1.24	0.034	2.82	0.0062
Length of the Cocolog (L) = 200 mm				

3.3. Regression analysis

In this paper, an attempt was made to statistically analyse the effect of density and d/L (ratio of opening size to length of cocolog) on the permeability of cocologs. Regression analyses were carried out for samples with d/L ratio above 0.01, as the commercially available cocologs were above the d/L ratio of 0.16. From the experimental results of 134 tested samples, the permeability was taken as the dependent variable and d/L and density as independent variables. Experiment results show that a power relation exists between the dependent variable and independent variables which was then converted to a linear relation by taking logarithmic values of dependent and independent variables. A multiple linear regression analysis was carried out using SPSS software. Among the various methods of regression analysis, the backward regression method (BRM) gave more accurate results. In SPSS, variables can be entered or removed from the model depending on the significance (probability) of the F value. A variable is entered into the model if the significance level of its F value is less than the entry value (<=0.05) and is removed if the significance level is greater than the removal value (>=0.10). *R* value of 0.967, indicates a good level of prediction. R^2 value of 0.933 means that independent variables explain 93.3% of the variability of the dependent variable. The p-value calculated for D/L is higher than 0.05; therefore, d/L is insignificant and is removed in back propagation algorithm. Hence the variable d/L was excluded. Thus Model with only density as independent variable predicts the dependent variable more accurately. The regression model obtained is

$$\mathbf{k_c = 104860\ (\rho_c)^{-1.54}} \quad (3)$$

Where, k_c is the permeability of cocologs in mm/s and ρ_c is the density of cocologs in kg/m^3. The *p* value of d/L obtained was 0.127 which is above 0.05 and hence it is insignificant, whereas the independent variable density with *p* value 0 shows it to be defining the permeability of cocolog. The regression analysis results demonstrate that the opening size has less importance in predicting the permeability values of cocolog. This is also graphically proved in Fig.6 which shows a horizontal trend for variation of k_c with d/L for different densities. The best fit relation between the density and permeability is given by a power equation. Validation of newly developed equation was done using independent data of different opening size and densities. Fig. 7 shows the parity plot showing the relation between the actual and predicted permeability values for the independent data set. Histogram of the residuals with a normal curve superimposed is shown in Fig 8, the residuals look close to normal. The residual plot obtained from SPSS is shown in Fig.9. The pattern show here indicates no problems with the assumption that the residuals are normally distributed at each level of Y and constant in variance across levels of Y. This empirical relationship can predict the realistic permeability values effectively.

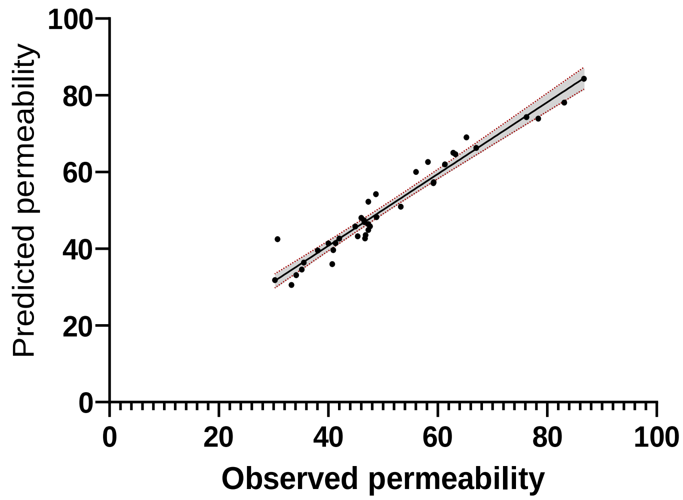

Fig. 7. Scatter plot of observed permeability and predicted permeability with band showing 95 % confidence interval.

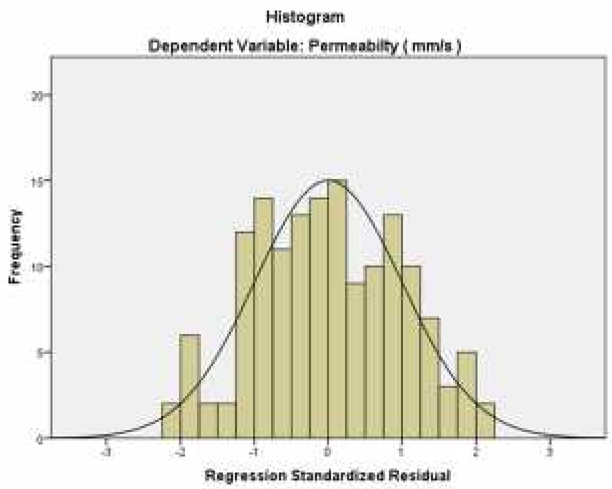

Fig. 8. Histogram

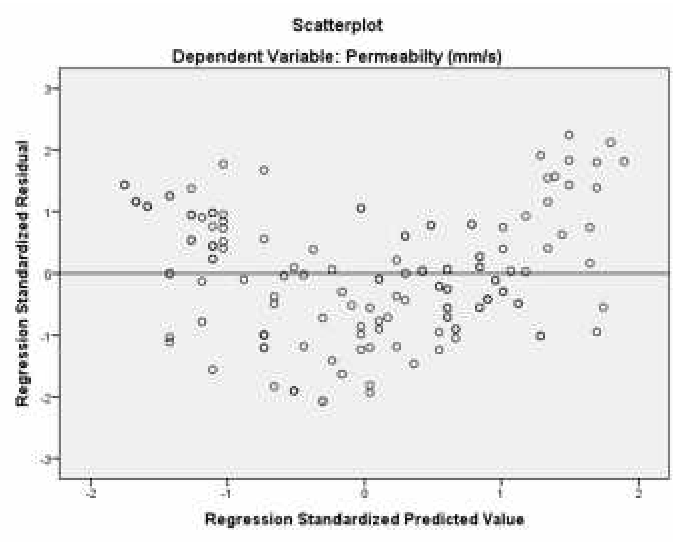

Fig. 9. Residual plot

4. Conclusion

This study investigated the variation of permeability of cocologs under various parameters such as density, orientation, and type of outer covering using a physical model test. The scaled model of the cocologs was tested in a newly devised permeameter following ISO standards. The following conclusion can be drawn from the intensive laboratory experiments.

1. The horizontal and vertical permeability of cocologs are the same. The orientation of cocologs has no influence in the permeability. Thus, cocologs can be placed either horizontally or vertically in site, which will not affect the performance of cocologs.
2. The opening size of outer net covering of cocologs has less significance regarding the prediction of permeability value of cocologs for a d/L ratio above 0.010. Thus, the opening size of outer net covering can be made of any size just enough to hold the coco fiber inside the cocologs, provided they do not obstruct the flow through the coir fibers. A sharp change in the permeability value of cocologs was observed when the opening size was reduced than the pore space i.e., for a d/L ratio less than 0.01.
3. The density of cocologs is the only influencing parameter that affects the performance of cocologs. A power equation was developed to predict the permeability of cocologs. The regression value of 0.946 indicates the suitability of this equation in the estimation of permeability of cocologs.

The estimation of permeability properties helps in the successful selection of cocologs for erosion control on river banks. Further studies are required to focus on the evaluation of clogging characteristics of cocologs embedded in the surrounding soil subjected to different drainage conditions for their use in the field.

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