Infiltration rate of fiber reinforced soil using mini disk infiltrometer

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ABSTRACT

The infiltration rate of embankment soil is an important parameter that determines its performance against soil erosion, water drainage, and surface runoff. The use of fiber reinforced soil has gained momentum in the recent past as subgrade or in embankment applications and numerous studies have been undertaken to understand its mechanical properties. However, very few studies have accounted the infiltration of water through such fiber reinforced soil. The current study adopts an invasive species, water hyacinth (WH), as a natural fiber to reinforce soil. A series of tests have been undertaken using mini-disk infiltrometer to monitor the infiltration rate of such soil-WH fiber composite. The soil is compacted at two increment densities and the fiber percentage has been varied up to 1.00% of dry weight of the soil. The results indicate that the infiltration rate and the hydraulic conductivity of the soil amended with water hyacinth fiber increases with increasing fiber content, and decreases as the density increases compared to bare soil.

Keywords: Infiltration rate, water hyacinth, fiber reinforcement, minidisk infiltrometer.

1. INTRODUCTION

Twenty first century comes with a wave of industrialization and brings with it the challenge of sustainable development. Soil erosion and slope failure are serious impediments encountered by many countries. In the last few decades a vast range of studies have been conducted to counter the problem of soil erosion and slope failure. A major cause of soil erosion and slope failure is the low hydraulic conductivity of the soil. Higher hydraulic conductivity reduces soil erosion, enriches the ground water table by reducing surface runoff and enhances slope stability by promoting more vegetation (Horton, 1933; Damiano et al., 2010). Several studies have been done on how the mixing of different admixtures and artificial fibers such as geotextiles affect the hydraulic conductivity of the soil (Hafez, 1974; Fernandez et al., 1985; Koerner, 2012). The use of natural fibers in reinforcing soil has caught the attention of many researchers. Several studies have been done on the amendment of natural fiber such as jute, coir, water hyacinth, hemp, flax, sisal etc. in soil to reinforce and improve the strength (Hejazi et al., 2012; Fullen et al., 2007; Cai et al, 2007; Giménez et al., 2014; Bledzki et al., 2012; Prabakar et al., 2002; Tang et al.,2010; Kumar et al.,2015). However, the effect of hydraulic conductivity of soil due to amendment of natural fibers has rarely been studied. The use of water hyacinth (*Eichhornia crassipes*) fiber in improvement of different soil properties are very limited. WH is not only easily available, abundant but also a cheap fiber. WH is mostly considered as an unwanted substance because it grows in water and lowers the oxygen content of water, blocks the sunlight from entering the water bodies, thus depleting aquatic life. Nowadays, thousands of dollars are being spent for removing it. And the removed water hyacinth majorly rots as not much use of it, apart from a component of fodder, is known till date (Ding Jianqing et al., 2001). Therefore, the use of WH in soil amendment is coming into picture.

Many researchers have studied the infiltration mechanism and hydraulic conductivity of the soil using mini disk infiltrometer (MDI) (Vandervaere et al.,1998; Li et al., 2005; Holden et al.,2001). Infiltration is the process by which water present on the ground enters into the soil. A mini disk infiltrometer is an acrylic tube having two chambers namely bubble chamber and reservoir that works on the principle of suction under a certain adjustable pressure. The pressure is adjusted in the bubble chamber by means of a suction control tube dipped into water. The reservoir is filled with water, which is sucked into the soil passing through a sintered steel disk. The aim of this study is to measure the infiltration rate and hydraulic conductivity of a soil amended with water hyacinth (WH) fiber using mini disk infiltrometer (MDI).

2. MATERIAL AND METHODS

2.1 Soil composition and characteristics

The soil used in this study is collected from a site in the IIT Guwahati campus. The specific gravity of the soil was 2.67 determined as per IS-2720-Part 3-1980.

According to the provisions of IS-2720-Part 4-1985 the grain size distribution of the soil was done. The percentage of fine sand, medium sand and coarse sand was 18.85%, 6.50% and 0.11% respectively. The soil mainly consisted of silt (50.24%), and clay (24.30%). The liquid limit (40.49%) and plastic limit (24.79%) of the soil was determined with the help of IS-2720-Part 5-1985. The soil is classified as ML (ASTM D2487-11). The following table summarizes the basic engineering and physical properties of the soil.

Table 1. Engineering Properties of the soil

Sl. No.	Soil Property	Value
1	Specific Gravity	2.67
2	Grain Size Distribution Coarse Sand (4.75mm-2mm) Medium Sand (2mm-0.425mm) Fine Sand (0.425mm-0.075mm) Silt (0.075mm-0.002mm) Clay (< 0.002mm)	0.11 (%) 6.50 (%) 18.85 (%) 50.24 (%) 24.30 (%)
3	Consistency Limits Liquid Limit Plastic Limit Shrinkage Limit Plasticity Index	40.49 (%) 24.79 (%) 23.31 (%) 15.70 (%)
4	Compaction Characteristics Optimum Moisture Content Maximum Dry Density	16.00 (%) 1.70 (g/cc)
5	Shear Strength Parameters Cohesion Angle of Internal Friction	16.89 (kPa) 14.17 ˚

Fig. 1. Embankment failure at a local site inside IIT Guwahati campus.

2.2 Fiber composition and characteristics

The biochemical composition percentages are of great significance to determine the physical properties of a lignocellulose fiber.

Lignin is a highly cross-linked molecular complex that holds together individual cells. The lignin concentration controls the rate of decomposition of organic matter (Berg et al., 1984; Taylor et al., 1989). The standard method of TAPPIT222om-88 (TAPPI Test Methods, 1996) was followed to determine the lignin. Cellulose provides strength to the plant cell walls and thus makes them stable. It is one of the main structural components of the bio-fiber. The total cellulose content of the air-dried water hyacinth fiber was determined by Jenkins method (1930). Hemicelluloses are relatively low molecular weight polysaccharides present in plant cell walls. They remain associated with the cellulose present in the plant cell walls and are responsible for moisture absorption and biodegradation (Rowell & Stout, 2007). Goering and Van (1970) provided a method which was used to calculate the hemicellulose content from the difference between neutral detergent fiber (NDF) and acid detergent fiber (ADF). The percentage of ash present gives us an approximate estimate of the inorganic content in biological mass (McNaught and Wilkinson, 1997). The ash content was determined by the ASTM method E1755-01(ASTM, 2007). Since the water hyacinth was air-dried, it definitely contained some moisture. This moisture content was calculated by oven-drying the fiber at 107^0 C for 1 day. The moisture content of the air-dried sample was found to be 12.89 %. Table 2 shows the basic bio-chemical and physical properties of the water hyacinth fiber. Provisions of IS-2720-Part 3-1980 was followed to determine the specific gravity of the fiber; it was found to be 0.66. The average value for the breaking tensile strength of the fiber was found to be 250 N and this was determined as per the rules of IS-1670-1991.

Table 2. Properties of fiber

	Properties	Quantity
Bio-chemical Composition Of fiber	Lignin	11.14
	Cellulose	35.60
	Hemicellulose	21.18
	Ash Content	11.21
Physical properties of fiber	Specific gravity	0.66
	Thickness of fiber	0.4 mm
	Tensile Strength	245 N

Fig. 2. Overview of water hyacinth fiber

3. TEST PROCEDURE AND PREPARATION OF SAMPLE

The water hyacinth plants were extracted from the water bodies and were air dried until no significant change in moisture content was observed (Prabakar and Sridhar, 2002). The stem of the dried plant was then separated. The water hyacinth fiber obtained was then cut into small pieces of around 2 cm length and 5-7 mm breadth (Fig. 2). After that the cut water hyacinth (WH) fiber was mixed randomly with a locally available silty clay (ML) soil till a uniform soil-WH fiber composite is obtained. Water was added in small increments in the soil fiber composite in predetermined quantities (12.00% of the dry weight of the soil) and was mixed thoroughly. Three samples were prepared for every batch of soil at different WH fiber contents (0.50%, 0.75%, 1.00% of the dry weight of the soil) and densities (0.9 MDD, 1.05 MDD) to inspect the effect of fiber variation and density variation on the hydraulic conductivity of composite respectively. The batches of soil – WH fiber composites were sealed in plastic bags then putted in the desiccator for 24 hours for moisture balance. The soil – WH fiber composite was divided into three equal parts and then each part was compacted into a steel mould of height 17.5 cm and diameter 15 cm one by one. The surface of the soil was then levelled and smoothened to place mini disk infiltrometer- MDI (Fig. 3). Water was then filled in the bubble camber and water reservoir of the MDI and a suction rate of 2 cm was adjusted. Then the MDI was carefully placed on the smooth spot near the center of the mould and at initial time (t=0 seconds) the reading in the water reservoir was noted. The readings were taken after a regular time interval of 60 seconds till about 22-25 ml of water infiltrated into the soil-fiber composite.

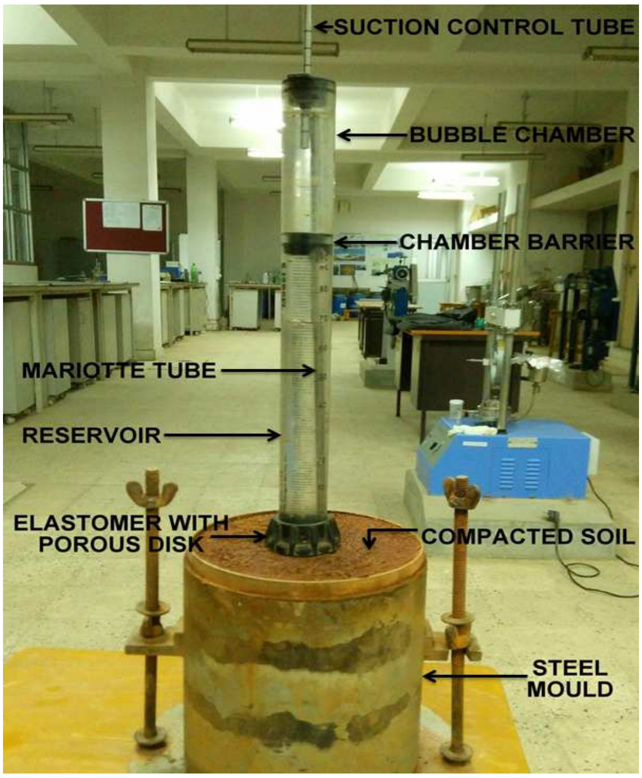

Fig. 3. Experimental setup showing infiltration process

4. RESULTS AND DISCUSSION

The data (cumulative infiltration with time) obtained from infiltration tests with mini disk infiltrometer (Fig. 4.) was analysed and the hydraulic conductivity of the soil was calculated using the spreadsheet provided by the decagon devices (instruction manual MDI, 2016). It was programed based upon the model proposed by Zhang (1997). The measured data of cumulative infiltration is best fitted with the given function:

$$I = C_1 t + C_2 \sqrt{t} \quad (1)$$

Where C_1 (m/s) is related to hydraulic conductivity and C_2 ($m/s^{1/2}$) is related to soil sorptivity. For the case of vertical flow, the sorptivity is negligible and our focus is mainly on hydraulic conductivity, so we have ignored the second term and targeted the first term.

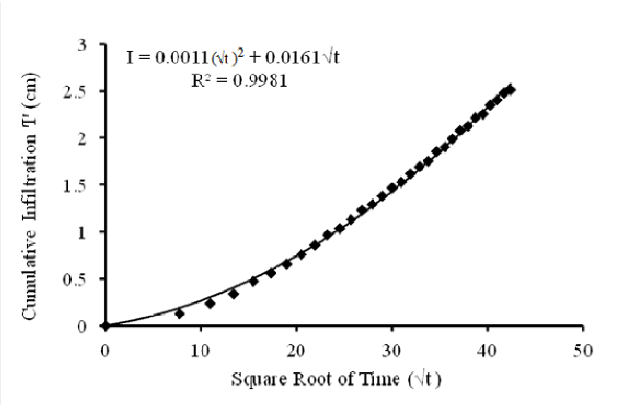

Fig. 4. Cumulative Infiltration vs square root of time plot of soil-fiber composite

The cumulative infiltration vs the square root of time plot of the soil-WH fiber composite has been shown in figure 4. The slope of the curve of the cumulative infiltration vs the square root of time is the parameter C_1. From the figure 4 it has been observed that the cumulative infiltration of the soil-WH fiber composite increases with the decreasing rate i.e. as the time of flow of water into the soil composite increases the infiltration rate decreases. The decrease of the rate of infiltration with time is mainly because of the decrease of the moisture absorption tendency of the soil, as the flow of water continue for long time the void spaces get filled with water, the suction of the soil gets reduced and hence a decline in the tendency of moisture adsorption of the soil is observed.

The hydraulic conductivity of the soil was given by the equation.

$$k = C_1 / A \quad (2)$$

Where C_1 is the slope of the cumulative infiltration vs the square root time plot and A is a value relating the van Genuchten parameters (α, n, m).

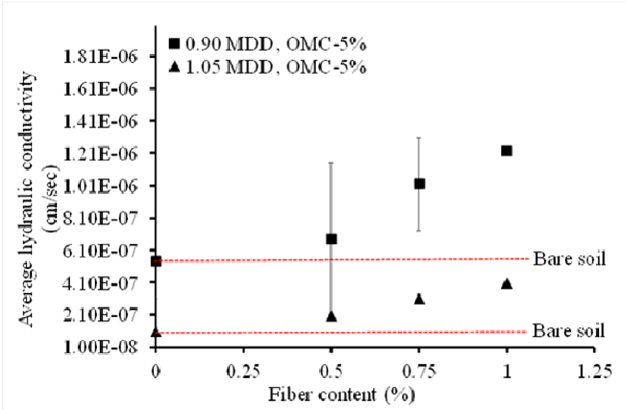

Fig. 5. Variation of average hydraulic conductivity of soil-WH fiber composite with fiber content.

The hydraulic conductivity of the soil-WH fiber composite was determined as the average hydraulic conductivity. Three test samples for each fiber content and compaction state were tested to determine the average hydraulic conductivity of the soil fiber composite. Standard deviation of these three samples were calculated to assess the deviation in each plotted point. The variation of average hydraulic conductivity with fiber content and density is shown in figure 5. From figure 5 it has been observed that with the increase of fiber content the average hydraulic conductivity of the soil-WH fiber composite increases as compare to that of bare soil. The average hydraulic conductivity increases with increasing rate upto fiber content of 0.75% and after that increases with a decreasing rate. One of the possible reasons for increase in hydraulic conductivity could be the preferential water flow through the soil-fiber interface. The standard error bar provided in each measure point indicates the variation of each point with the average value.

The average hydraulic conductivity of the soil –WH fiber composite decreases as the density of the soil fiber composite increases. The hydraulic conductivity decreases with increase in density of composite. This is mainly due to decrease in void spaces or void ratio of soil composite and higher packing of soil particles. Due to this, the water flow path of the soil fiber composite, gets blocked and hence there is a decrease in hydraulic conductivity.

5. CONCLUSIONS

One of the most important characteristics of soil is its hydraulic conductivity. The hydraulic conductivity is a property of soil related to slope stability and soil erosion, etc. Silty clay (ML) soil sample was reinforced with water hyacinth (WH) fiber and the effect of this reinforcement on hydraulic conductivity of the soil was studied. To determine the hydraulic conductivity of the soil-WH fiber composite, infiltration test was carried out using mini disk infitrometer (MDI). The tests were conducted with two density variation (0.9MDD and 1.05MDD) and mixed with varying fiber content (0.50 %, 0.75 %, 1.00 %, by weight of dry soil). The results of the tests indicate an increase in hydraulic conductivity due to amendment of the WH fiber. Moreover, hydraulic conductivity of the soil increases on increasing the WH fiber content, whereas it decreases on increasing the density of the soil. One of the possible reason could be the preferential flow of water through the soil-fiber interface. On the other hand, increasing the soil density decreases the void spaces or void ratio of the soil, which results in blockage of flow path and consequently reduces infiltration.

REFERENCES

1. Álvarez-Mozos, J., Abad, E., Giménez, R., Campo, M. A., Goñi, M., Arive, M., Díez, J., Casalí, J., & Diego, I. (2014). Evaluation of erosion control geotextiles on steep slopes. Part 1: Effects on runoff and soil loss. *Catena*, *118*, 168-178.
2. Carsel, R. F., & Parrish, R. S. (1988). Developing joint probability distributions of soil water retention characteristics. *Water Resources Research*, *24*(5), 755-769.
3. Damiano, E., & Olivares, L. (2010). The role of infiltration processes in steep slope stability of pyroclastic granular soils: laboratory and numerical investigation. *Natural hazards*, *52*(2), 329-350.
4. Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in polymer science*, *37*(11), 1552-1596.
5. Fernandez, F., & Quigley, R. M. (1985). Hydraulic conductivity of natural clays permeated with simple liquid hydrocarbons. *Canadian Geotechnical Journal*, *22*(2), 205-214.
6. Fullen, M. A., & Booth, C. A. (2007). Contributions of biogeotextiles to sustainable development and soil conservation in developing countries: the BORASSUS Project. *WIT Transactions on Ecology and the Environment*, *106*.
7. Ghazizade, M. J., & Safari, E. (2016). Analysis of Desiccation Crack Depth in Three Compacted Clay Liners Exposed to Annual Cycle of Atmospheric Conditions with and without a Geotextile Cover. *Journal of Geotechnical and Geoenvironmental Engineering*, 06016024.
8. Hafez, A. A. R. (1974). Comparative changes in soil-physical properties induced by admixtures of manures from various domestic animals. *Soil Science*, *118*(1), 53-59.
9. Hejazi, S. M., Sheikhzadeh, M., Abtahi, S. M., & Zadhoush, A. (2012). A simple review of soil reinforcement by using natural and synthetic fibers.*Construction and building materials*, *30*, 100-116.
10. Holden, J., Burt, T. P., & Cox, N. J. (2001). Macroporosity and infiltration in blanket peat: the implications of tension disk infiltrometer measurements.*Hydrological Processes*, *15*(2), 289-303.
11. Horton, R. E. (1933). The role of infiltration in the hydrologic cycle. *Eos, Transactions American Geophysical Union*, *14*(1), 446-460.
    a. Indian Standards publications.
12. IS-2720 (Part 4), 1985, Methods of test for soils, Grain Size Analysis, New Delhi: Bureau of
13. IS-2720 (Part 5), 1985, Determination of liquid and plastic limit, New Delhi: Bureau of Indian
14. Jianqing, D., Ren, W., Weidong, F., & Guoliang, Z. (2001). Water hyacinth in China: Its distribution, problems and control status. *Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes. Canberra, Australia*.
15. Koerner, R. M. (2012). *Designing with geosynthetics* (Vol. 1). Xlibris Corporation.
16. Kumar, D., Nigam, S., Nangia, A., & Tiwari, S. Improvement in CBR Values of Soil Reinforced with Jute Fiber.
17. Li, X. Y., González, A., & Solé-Benet, A. (2005). Laboratory methods for the estimation of infiltration rate of soil crusts in the Tabernas Desert badlands.*Catena*, *60*(3), 255-266.
18. Methacanon, P., Weerawatsophon, U., Sumransin, N., Prahsarn, C., & Bergado, D. T. (2010). Properties and potential application of the selected natural fibers as limited life geotextiles. *Carbohydrate Polymers*, *82*(4), 1090-1096.
19. Miller, C. J., & Rifai, S. (2004). Fiber reinforcement for waste containment soil

liners. *Journal of Environmental Engineering*, *130*(8), 891-895.

20. Mohanty, K., Jha, M., Meikap, B. C., & Biswas, M. N. (2006). Biosorption of Cr (VI) from aqueous solutions by Eichhornia crassipes. *Chemical Engineering Journal*, *117*(1), 71-77.
21. Muramoto, S., & Oki, Y. (1983). Removal of some heavy metals from polluted water by water hyacinth (Eichhornia crassipes). *Bulletin of Environmental Contamination and Toxicology*, *30*(1), 170-177.
22. Prabakar, J., & Sridhar, R. S. (2002). Effect of random inclusion of sisal fiber on strength behaviour of soil. *Construction and Building Materials*, *16*(2), 123-131.
23. Prabakar, J., & Sridhar, R. S. (2002). Effect of random inclusion of sisal fiber on strength behaviour of soil. *Construction and Building Materials*, *16*(2), 123-131.
24. Šimůnek, J., Angulo-Jaramillo, R., Schaap, M. G., Vandervaere, J. P., & Van Genuchten, M. T. (1998). Using an inverse method to estimate the hydraulic properties of crusted soils from tension-disk infiltrometer data. *Geoderma*,*86*(1), 61-81.
25. Sivakumar Babu, G. L., & Vasudevan, A. K. (2008). Seepage velocity and piping resistance of coir fiber mixed soils. *Journal of irrigation and drainage engineering*, *134*(4), 485-492.
    a. Standards publications.
26. Tang, C. S., Shi, B., & Zhao, L. Z. (2010). Interfacial shear strength of fiber reinforced soil. *Geotextiles and Geomembranes*, *28*(1), 54-62.
27. Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. *Geotextiles and Geomembranes*, *25*(3), 194-202.
28. Zhang, R. (1997). Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. *Soil Science Society of America Journal*, *61*(4), 1024-1030.