Study of a Model Slope Reinforced with Jute

Aniruddha Sengupta and Saurabh Kumar

Department of Civil Engineering, IIT Kharagpur, Kharagpur 721302 India
sengupta@civil.iitkgp.ernet.in,
er.saurabh009@gmail.com

Abstract. This paper presents the results of laboratory model tests and corresponding numerical analyses carried out on a model slope representing an actual embankment, which failed on several occasions after overnight heavy rainfall. A study is performed by reinforcing the slope with thin jute strips of 1 mm diameter. The numerical simulation of the model tests is performed by a commercial program called FLAC. The responses of the model slope with the jute strips are observed under different intensities and duration of rainfall. Significant improvement in the deformation and the factor of safety of the slope is observed both in the numerical analyses and the laboratory experiments when jute strips are utilized as a slope protection measure. The study indicates that the stability of the embankment can be improved significantly at a low cost by reinforcing it with jute strips.

Keywords: Embankment, Physical modelling, Soil reinforcement, Jute strips, Slope failures.

1 Introduction

The repeated failure of the road and the railway embankments in the state of West Bengal in India is the main focus of the present study. Several road and train accidents have occurred in the recent past causing loss of property and human life. Figure 1 shows one such embankment failure adjacent to a highway bridge at a place called Dankuni near Kolkata in West Bengal. In all the cases, the failure occurred after overnight continuous heavy rainfall. The investigating agencies have blamed them on the sudden subsidence of the embankment due to the pore water pressure buildup within the embankment and its foundation [1, 2, 3]. The site inspections in most of the cases revealed formation of several gullies and wet areas on the slope of the embankments by the seepage of the rainwater. This kind of slope failure after prolonged and/or heavy rainfall is not very uncommon throughout the world and several cases have been reported in the literature [4, 5, 6]. But only a very few solutions have been proposed at present on the topic.

One of the major constraints during the rehabilitation of these embankments is that the roadways or the railways located on top of the failed embankments cannot be closed for very long time. The most common remedial measures include construction of filters/drains and rockfill stabilizing berms on the slopes and installation of closely

W. Wu (ed.), *Recent Advances in Modeling Landslides and Debris Flows*,
Springer Series in Geomechanics and Geoengineering, DOI: 10.1007/978-3-319-11053-0_24

spaced piles or sheet pile cutoff wall near the toes of the embankment. Besides above traditional methods, inserting piles and soil anchors on the slope [7, 8] have been also found to be effective ways to stabilize a slope. The roadways and the railways have several hundreds of kilometers of susceptible embankment, but these remedial measures have been implemented only at the places of past accidents, not throughout the whole susceptible area due to exorbitant cost associated with them and/or lack of sufficient funding. This has prompted a fresh look at a cheaper but effective alternative remedial measure to prevent embankment slope failures.

Fig. 1. Embankment Failure adjacent to a bride approach at Dankuni, West Bengal (India)

Jute is a vegetable fiber that is produced from plants in the genus Corchorus. It is one of the most affordable natural fibers. The jute fiber comes from the stem and ribbon (outer skin) of the jute plant. The fibers are first extracted by retting. After the retting process, the stripping begins. In the stripping process, non-fibrous matter is scraped off and the fibers from within the jute stem are grabbed. Jute fibers are composed primarily of the plant materials cellulose and lignin. Jute is a rain-fed crop with little need for fertilizer or pesticides. Jute needs a plain alluvial soil and standing water. The suitable climate for growing jute (temperatures from 20˚C to 40˚C and relative humidity of 70%–80%) is offered by the monsoon climate, during the monsoon season. India is the world's largest producer of jute. In 2011, India produced 2,000,000 tons of jute. Production of jute is concentrated mostly in Indian state of Assam, Bihar, West Bengal and Bangladesh. Beside India and Bangladesh, jute is also produced in China, Vietnam, Myanmar, Thailand, Egypt, Zimbabwe and Uzbekistan. In the past, the utilization of jute fibre, though readily available and cheap, has been limited by its low durability. But recent researches are indicating that the tensile strength, hydrophobicity and resistance against biological and chemical degradations of jute fibres can be significantly enhanced by proper treatment [9]. Properly treated jute can be utilized in the field for long term benefits.

The objective of this paper is to find out the performance of jute reinforced slope in terms of its stability during different rainfall events. In this connection it may be noted that Grimshaw [10], Yoon [11], Hengchaovanic, and Nilaweera [12] have shown that the roots of small plants like certain shrubs and grasses can act as very good soil reinforcements and planting them on the slopes can enhance stability of the slope. Since no field data are available and field tests are discouraged to avoid difficulties associated with the daily operation of the roadways and the railways, it is decided to perform laboratory model tests and numerical modeling of the slope failure mechanisms occurring within the embankment to assess the effect of rainfall on the embankment with and without jute reinforcement. This paper presents the results of laboratory model tests and the corresponding numerical simulation of the scaled model slope with and without jute reinforcements. The jute fibres utilized in the model study are purchased from the local market.

2 Properties of the Soil and Jute Reinforcement

2.1 Properties of the Test Soil

The test soil used for the model study in the laboratory is obtained from the failed embankment at Dankuni (West Bengal). Besides bag (loose) samples, three undisturbed tube samples from the mid height of the embankment are collected and brought to the laboratory for the determination of their properties. Several standard laboratory tests are performed to determine the properties and the classification of the soil. The laboratory specific gravity tests indicate that the soil has a specific gravity of 2.63. The saturated hydraulic conductivity ks obtained from the falling head permeability tests is 8.27×10^{-4} cm/s. This value is further used to establish a relationship between the hydraulic conductivity and the suction empirically using Van Genuchten method [13]. The shear strengths of the soil are obtained from the conventional drained direct shear tests. The tests show that the soil has a cohesion (c') of 0.5kPa and an effective internal angle of friction (φ’) of 25.7°. The grain size distribution of the soil is shown in Figure 2. The sieve analyses indicate that the soil contains 23.77% fines and the rest is sand. The liquid limit and the plasticity index of the fines are 21% and 6.45%, respectively. The UCSC classification of the embankment soil is SM-SC (silty sand). A summary of all the relevant engineering properties of the soil is given in Table 1. The soil-water characteristic curve (SWCC) for the soil is determined by following the standard test method [14, 15] using tensiometers. The soil is first dried and then known amount of water is added to it. Every time, the corresponding suction force measured by a tensiometer is noted down. The procedure is repeated for the different water content of the soil. Figure 3 shows the SWCC curve for the embankment soil.

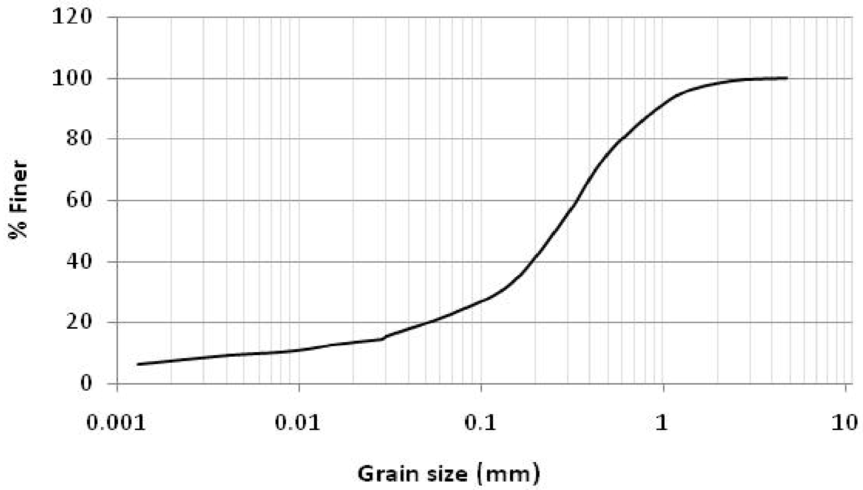


Fig. 2. Grain Size Distribution of the Soil

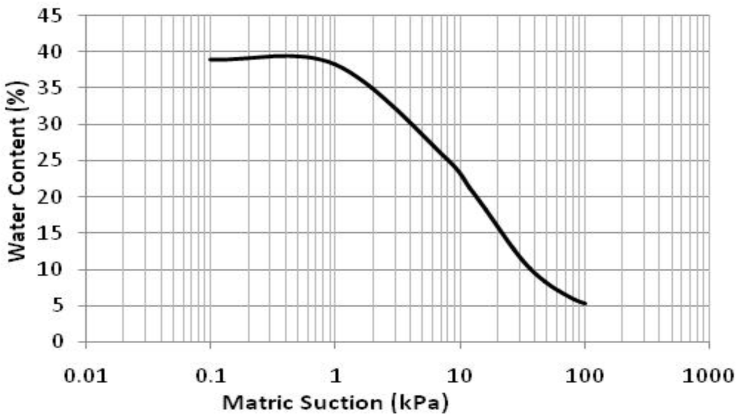


Fig. 3. SWCC Curve of the Soil

Table 1. Material Properties of the Soil

Material Properties	Values
Plastic limit (PL)	14.55%
Liquid limit (LL)	21%
Plasticity index (PI)	6.45%
Soil classification	" SM-SC "
Coeff. of permeability, $K_{sat.}$	8.27 x 10^{-4} cm/sec
Dry unit weight, γ_{dry}	14.5 kN/m^3
Saturated unit weight, γ_{sat}	18.67 kN/m^3
Cohesion, c'	0.5 kPa
Angle of internal friction, ϕ'	25.7°
Modulus of elasticity, E	5110 kPa
Poisson's ratio, υ	0.25

Table 2. Mechanical Properties of Jute Fibres

Material Parameter	Value
Density, ρ	1.35 gm/cc
Young's Modulus, E	20 GPa
Poisson's ratio, υ	0.38
Shear Modulus, G	7.24 GPa
Tensile Strength, T	393 MPa

2.2 Properties of Jute Reinforcement

Thin jute strips or tassels are considered in the present study for the mitigation of the slope. Each jute tassel consists of a number of jute fibres tied to each other at the top. The jute tassels are of 220mm in length and 10mm in diameter. A total of four such jute tassels are placed along the width of the model slope. The spacing between two jute tassels is 100mm. The typical mechanical properties of the jute fibre produced in

India is adopted from Ahmed and Vijayarangan [16] and given in Table 2. The embedment depth of each jute tassel is 200mm. The cross sectional area, the bond area, and the moment of inertia of each jute tassel are 7.86 $\times 10^{-5}$ m^2, 6.3$\times 10^{-3}$ m^2, and 4.91$\times 10^{-10}$ m^4, respectively. The load carrying capacity, the bond skin friction and the bond resistance (bond skin friction x circumferential area/ spacing x factor of safety) for each jute tassel are 31kN, 4933kPa and 1033.2kN, respectively for a factor of safety of 1.5.

3 Laboratory Model Tests

3.1 Test Setup

A test setup has been prepared to conduct the model tests in the laboratory. The main components of the test setup are a test tank made up of plexiglass and a supporting steel frame holding the rain simulator on top of the test tank. The test chamber, having inside dimensions of 1.2m x 1.0m in plan and a height of 0.15m on the front side and 0.80m on the other three sides, is supported directly on two concrete platforms.

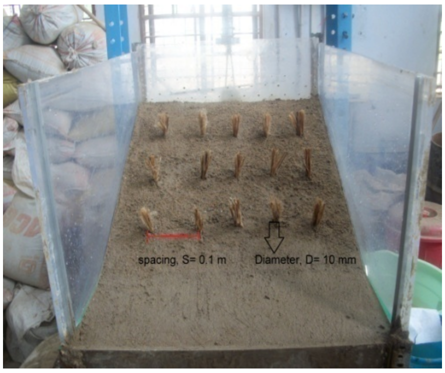


Fig. 4. Front View of a Jute Reinforced Slope

Fig. 5. Rainfall Simulator

The plexiglass walls have a thickness of 16mm. All the joints are glued as well as reinforced with steel angles and the box may be considered to be rigid. Figure 4 shows the laboratory model test setup. A 1:10 scaled model of the actual embankment slope is constructed within the test tank. The embankment slope is constructed with the soil collected from the failed embankment at Dankuni. Due to the symmetry, only one side slope of the embankment is modeled in the laboratory. The slope is prepared in 5 to 6 lifts maintaining a uniform dry unit weight of 14.5kN/m^3. In the laboratory tests, the 1-g scaling law has been utilized. The grain size distribution, the strengths and the density of the soil are modeled same as in the original embankment. Though the slope of the embankment to be provided depends strongly on the shear strength of the embankment material, a 2(H):1(V) slope is most common for the railway and the road way embankments in India [1,2]. However, the field survey done after the embankment failures indicate that the actual slopes are varying between 1.4:1 and 2:1. Typical height of such embankments is between 2m and 5m. Three slope angles, 1.25(H):1(V), 1.5:1 and 2:1 with a height of 0.4m are considered in the laboratory model tests. The finished surface of the slope is prepared by hand modeling tools. At the bottom of the slope, a 0.15m thick foundation of the same soil is provided. The width of the slope is same as the width of the test tank. In the cases of the model slope reinforced with the rows of jute tassels, holes are first dug at the designated places by inserting a 10mm hollow pipe and then the jute reinforcements are inserted in places. Once the jute reinforcements are in place, the holes are backfilled with the same soil as necessary. Four jute tassels at a spacing of 100mm are considered in a row. A total of four such rows are considered. The spacing between the rows is also kept at 100mm. The first row of jute tassels is placed on the slope at 170mm from the toe. The second row of jute tassels is placed on the slope at 270mm from the toe. The third and fourth rows of jute tassels are placed on the slope at 370mm and 470 mm from the toe. After the construction, the slope is fully saturated by adding water. The front and the back sides of the plexiglass test chamber are double walled with a gap in between. The inner walls (the walls adjacent to the slope) are perforated to allow water in and out of the test tank. The gap between the backside walls is continuously filled with water and it is allowed to percolate into the constructed soil slope within the test chamber. The water coming out of the slope is drained away from the front. The water is supplied to the slope continuously throughout the tests to maintain a steady water level at the toe elevation of the slope as observed in the actual field. During the saturation process and during the tests, the pore water pressure/ suction pressures within the constructed embankment are measured by T5-7 tensiometers. In order to study the behaviour of the slope with and without jute reinforcements during different intensity of rainfall, a rainfall simulator has been installed over the test tank. The rainfall simulator (Fig. 5) consists of a centrifugal pump which pumps water from a reservoir to a network of pipes fitted with spray nozzles. The spray nozzles are located in such a way that the whole slope within the tank gets a uniform rainfall. The pressure of water inside the pipes is controlled by a valve. Thus rainfall of different intensity may be simulated by turning the valve appropriately. A rain gauge is used to measure the rainfall intensity and to calibrate the rainfall simulator before the tests. The tests are conducted at 50mm/hr., 100mm/hr. and 150mm/hr. rainfall intensities. These rainfall intensities are significantly higher than the recorded historic highest intensity of rainfall of 32mm/hr. in the area [17]. The deformations along the centerline of the slope are measured at 50 mm interval by a Laser Displacement Transducer (LDT). The development of the matric suction at different points within the slope with and without jute reinforcements at different intensities of rainfall are monitored by the digital tensiometers. The progressive failures and the development of cracks within the slope are also observed after different intensities of rainfall.

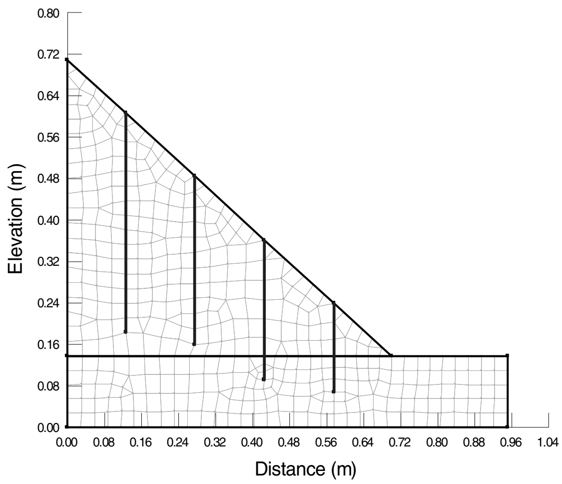


Fig. 6. Modeling of the slope & the Reinforcements

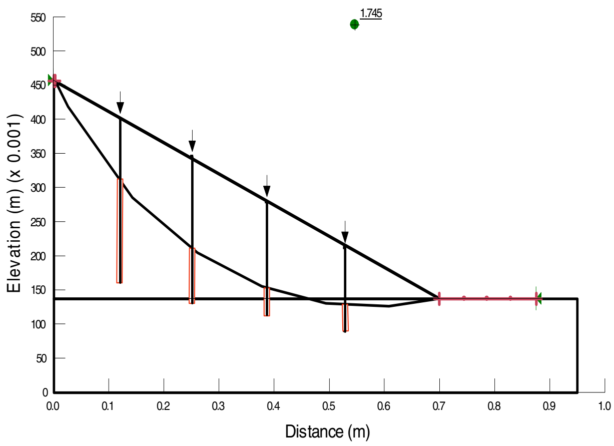


Fig. 7. A Typical Slip Surface

4 Numerical Analysis

The behavior of the scaled model slopes tested in the laboratory is numerically evaluated by a commercial finite element software called GEO-STUDIO [18]. The SEEP/W, SLOPE/W and SIGMA/W modules of the program are utilized to study the behavior of the slope. A plane strain condition is assumed for all the analyses. The soil slope is discretized in the numerical analyses by the standard two dimensional quadrilateral and triangular elements (Fig. 6). The material properties assumed for the soil in the numerical analyses are given in Table 1. The jute reinforcements are modeled as anchor elements (Fig. 6). The anchor elements are one-dimensional axial elements. The anchors can yield in tension or compression, but they cannot sustain a bending moment. The numerical program utilized in this study is two-dimensional; the three-dimensional effect of regularly spaced elements (anchors) is accommodated by scaling their material properties in the out-of-plane direction. The properties of the jute reinforcements are given in Table 2. The boundary conditions in the stress analyses assume that the nodes on all the sides are on roller and the nodes at the bottom are fixed in all directions.

Before the stability analyses of the slope, the initial conditions of the pore-water pressures are obtained by a transient seepage analysis using the SEEP/W program. The result of the transient analysis is then imported into the stability analysis model. The negative pore water pressure distribution within the slope is computed under a given intensity and duration of rainfall. Before the transient seepage analysis is carried out, a steady-state analysis is done to achieve a hydrostatic condition within the slope and the foundation. In the transient analyses, the infiltration rate is determined by dividing the amount of rainfall in an event by the total duration of the rainfall event and applied to the slope boundary as a surface flux. The transient analysis is carried out for the different infiltration rate and the results are recorded at 2.4 hours interval. The transient analysis program, SEEP/W, is formulated on the basis that the flow of water through both saturated and unsaturated soil follows Darcy's law. The Darcy’s law is also applied to the flow of water through unsaturated media. The only difference is that under the unsaturated flow condition, the hydraulic conductivity is no longer a constant, but varies with the changes in the water content and indirectly varies with the changes in the pore-water pressure. The general governing differential equation for a two-dimensional seepage is expressed as:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial V}{\partial t} \tag{1}$$

where, H = total head, k_x, k_y = hydraulic conductivity in the x and y directions, Q = applied boundary flux, V = volumetric water content, and t = time. This equation states that the difference between the flow (flux) entering and leaving an elemental volume at a point in time is equal to the change in the storage of the soil media.

The program is formulated for the conditions of constant total stress (σ); that is, there is no loading or unloading of the soil mass. It also assumes that the pore-air pressure, u_a, remains constant at an atmospheric pressure during the transient processes. This means that (σ-u_a) remains constant and has no effect on the change in the volumetric water content. The changes in the volumetric water content are consequently dependent only on the changes in the (u_a-u_w) stress state variable, and with u_a remaining constant, the change in the volumetric water content is a function of only the pore-water pressure (u_w) changes. As a result, the governing differential equation (Eqn. 1) used in the SEEP/W finite element formulation reduces to the following:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = m_w \gamma_w \frac{\partial H}{\partial t} \tag{2}$$

where, m_w and γ_w are the slope of the storage curve and the unit weight of water. The SLOPE/W program considers the unsaturated shear strength conditions when the suction pressures exist or the pore-water pressures are negative. The following equation for the shear stress as proposed by Vanapalli, et. al. [19] based on the soil water characteristics curve is utilized in the present study.

$$\tau = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)\left[\left(\frac{\theta_w - \theta_r}{\theta_s - \theta_r}\right)\tan\phi'\right] \tag{3}$$

where, c' = effective cohesion of the soil, σ_n = normal stress, u_a = pore-air pressure, u_w = pore-water pressure, φ' = effective friction angle of the soil. In the above equation, θ_w is the volumetric water content, θ_s is the saturated volumetric water content, and θ_r is the volumetric water content at the residual condition. When the water content is at saturation ($\theta_w = \theta_s$), 100% of the suction contributes to the strength. When the water content is at the residual value ($\theta_w = \theta_r$), the suction makes no contribution to the strength. Thus the water content function is used in essence to apportion the suction contribution to the strength. The above equation (Eqn. 3) is used in the present analyses for the computation of the stresses. The above equation is similar to that proposed by Lu, et al. [20, 21]. The factor of safety is then calculated by

$$FS = \frac{\Sigma \tau_r}{\Sigma \tau_m} \tag{4}$$

where, $\Sigma\tau_r$ is the summation of the resisting shear stresses computed from the Mohr-Coulomb equation and the corresponding material parameters. $\Sigma\tau_m$ is the summation of the mobilized shear stresses.

The slope stability analysis is performed using four well known limit equilibrium methods, that is, Morgenstern & Price method, Janbu's method, ordinary method of slice and Bishop's simplified method [18]. The above limit equilibrium methods are different in how they are handling the four inter-slice forces to make the equilibrium equations determinate. The Morgenstern & Price method allows one to define the relationship between the inter slice forces and satisfies both the force and the moment equilibrium equations. The Janbu's simplified method assumes the inter slice forces to be horizontal and satisfies the force equilibrium equations only. The ordinary method of slice or Fellenius method assumes no inter-slice forces and satisfies the moment equation only. The Bishop's simplified method assumes the inter slice forces to be horizontal and satisfies only the moment equilibrium condition. In the present analyses, the minimum factor of safety obtained by applying the above four methods is reported for each case. Fig. 7 shows a typical slip surface predicted by the numerical analyses for the case of a jute reinforced model slope.

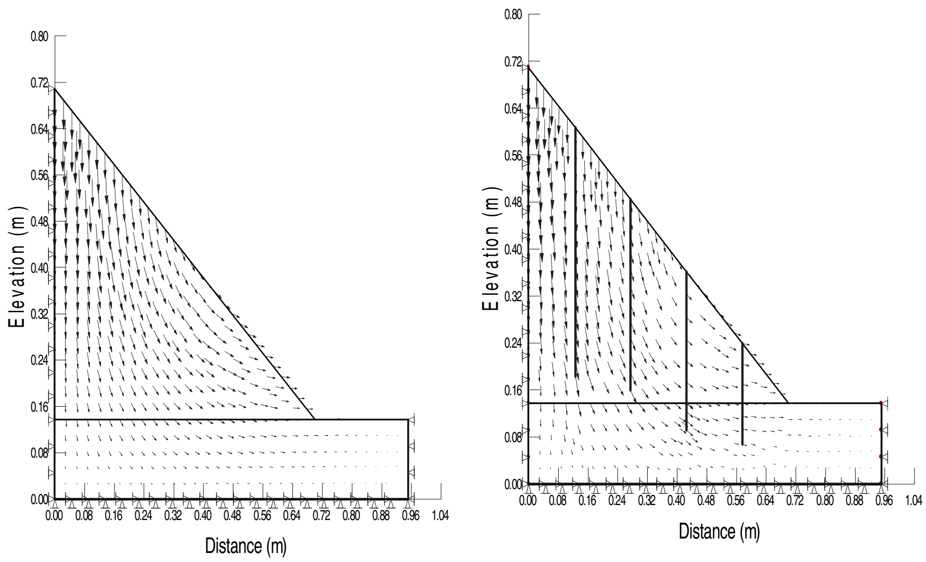
5 Results and Discussions

The maximum deformations within the three slopes (2:1, 1.5:1 and 1.25:1) under fully saturated condition with and without jute reinforcements as obtained from the laboratory model tests and the numerical analyses are shown in Table 3 below. The laboratory model tests in general show more deformations than the values predicted by the numerical analyses. However the differences between the two are not significant. The results of both, laboratory model tests and numerical analyses, show that the slope deformations reduce significantly with the inclusion of the jute reinforcements in the slope. For 2:1 slope, the maximum deformation reduces from 12.5mm to 4.4mm with the inclusion of four rows of jute reinforcements. For 1.5:1 slope, the deformation reduces from 17.7mm to 9.6mm. For 1.25:1 slope, four rows of jute reinforcements reduce the maximum deformation from 33.8mm to 18.5mm. These reductions in the slope deformation are significant. Figures 8(a) and (b) show the deformations (in the vector form) of the 1.25:1 slope without and with four rows of jute reinforcements from the numerical analyses. The formation of the slip plane is quite prominent in the case of slope without any reinforcement. But for the case of slope with jute reinforcements, the slip plane is not properly forming. The development of the suction pressures within a slope without and with jute reinforcement and their subsequent reduction at different intensities of rainfall are of interest. In the laboratory model tests, the suction pressures at different elevations along the middle of the slope at a depth of 50mm from the surface are measured with the electronic tensiometers. Figure 9 below shows graphically the reduction of the suction pressures measured for a 2:1 unreinforced slope during 50, 100 and 150mm/hr. intensities of rainfall over 30minutes of duration. The experimental results are also compared with those predicted numerically.

In general the suction pressures measured during the tests are higher than those predicted by Geo –slope using Vanapalli, et al s' equation and SWCC curve developed for the same soil. The numerical analyses indicate that the suction pressures reduce to zero after 12mins, 15mins and 24mins of 50mm/hr, 100mm/hr and 150mm/hr rainfall but the model tests show a suction pressure between 5-7kPa remains even after 30minutes of rainfall.

Table 3. Comparison of the Maximum Deformation of the Saturated Slopes obtained from the Numerical Analyses and the Laboratory Model Tests

Slope	Maximum Deformation (mm)							
	Without Jute Reinforcement		With 2-rows of Jute Reinforcements		With 3-rows of Jute Reinforcements		With 4-rows of Jute Reinforcements	
	Exp. Value	Num. value	Exp. Value	Num. value	Exp. Value	Num. value	Exp. Value	Num. value
2:1	12.5	9.8	10.6	7.6	8.5	5.6	4.4	2.3
1.5:1	17.7	14.6	16.6	13.7	13.4	7.8	9.6	4.6
1.25:1	33.8	25.8	29.2	22.4	24.8	14.6	18.5	11.8



(a) (b)

Fig. 8. Deformation Vector of a 1.25:1 Slope obtained from the Numerical Analyses (a) without and (b) with 4-Rows of Jute Reinforcements

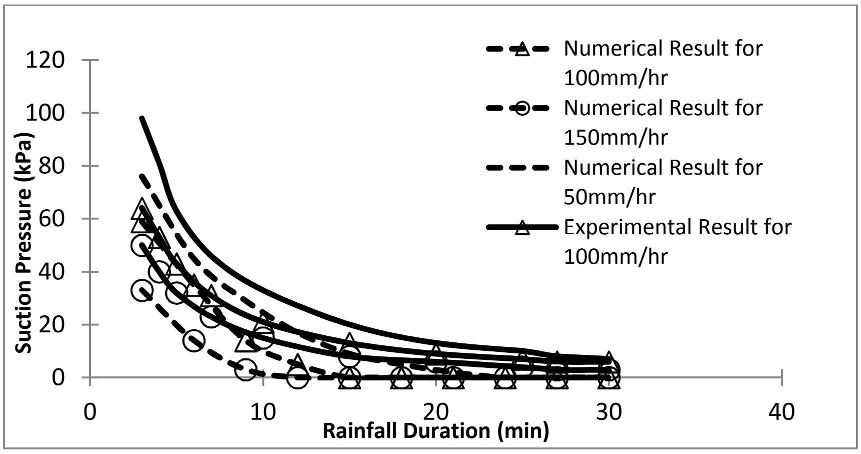


Fig. 9. Suction Pressures in a 2:1 Unreinforced Slope at Different Intensities of Rainfall

Figure 10 shows graphically the reduction of the suction pressures measured for a 2:1 slope with 4-rows of jute reinforcements during 50, 100 and 150mm/hr. intensities of rainfall over 30minutes of duration. The experimental results are also compared with those predicted numerically. In general the suction pressures are higher with 4-rows of jute reinforcement as compared to those for the unreinforced slope. The suction pressures at the end of 30minutes of rainfall are between 10-14kPa for 4-rows of jute reinforced slope corresponding to 5-7kPa for the unreinforced slope. The numerical analyses of 4-rows of jute reinforced slope indicate that the suction pressures reduce to zero after 18, 21 and 30minutes of 50, 100 and 150mm/hr. of rainfall as compared to 12, 15 and 24minutes of 50, 100 and 150mm/hr. rainfall in case of the unreinforced slope. The results clearly show that the jute reinforcements not only reducing the deformation of the slope but also increasing the overall suction pressures within the slope.

Though the deformation of the slope is a very important factor especially for the railway embankments, but these embankments are designed by traditional limit equilibrium methods which are based on stresses, that is, factor of safety approach. The minimum factor of safety requirement for these embankments under a saturated or flooding condition is 1.2 [1, 2]. These embankments are typically not designed to retain water as they remain in moist to dry condition throughout the year except during rainy seasons (July to September). The historical maximum rainfall intensity in this part of the world (lower Gangetic basin) is 32mm/hr [17]. Since the rainfall data are incomplete and not available for sufficient years, the rainfall intensities for this study are very conservatively assumed to be 50mm/hrs, 100mm/hrs and 150mm/hr. The factor of safety for the 2:1 slope for theses three rainfall intensities up to a maximum duration of 30 minutes are computed numerically and shown in Fig. 11 below.

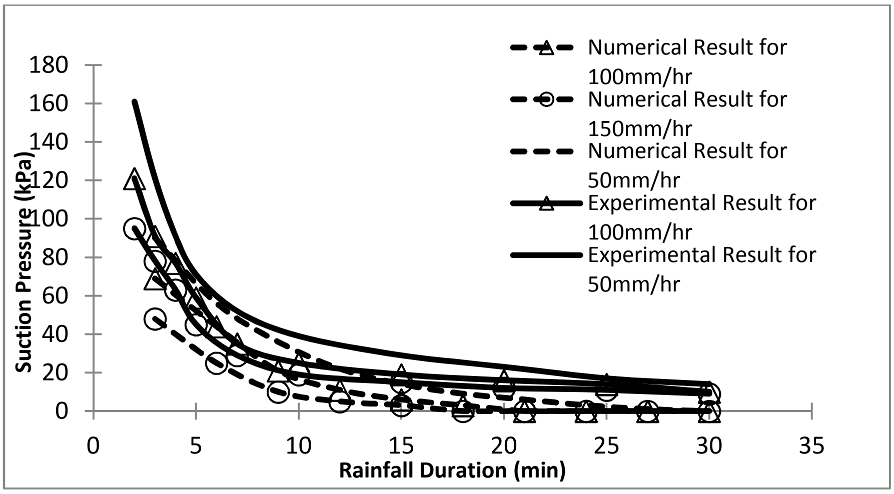
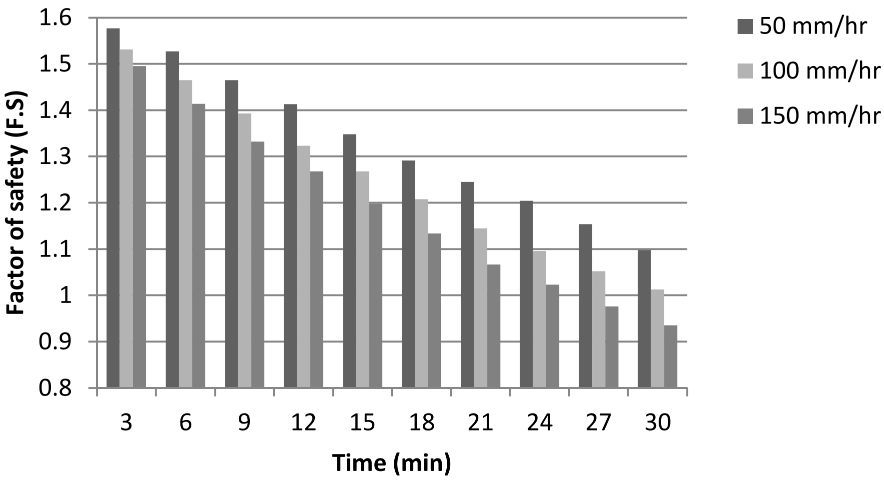


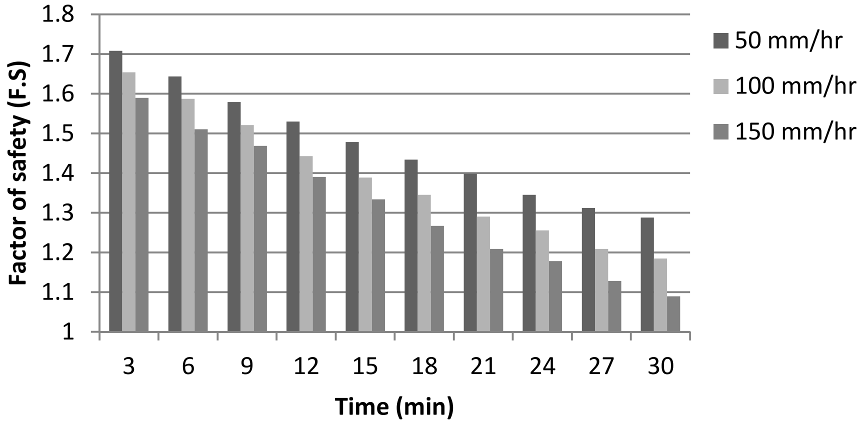
Fig. 10. Suction Pressures in a 2:1 Slope with 4-Rows of Jute Reinforcements at Different Intensities of Rainfall

The theoretical factors of safety of the saturated slopes with and without jute reinforcements are given in Table 4 below. Table 4 shows that a typical 2:1 unreinforced slope is barely stable after 30minutes of 50mm/hr intensity of rainfall. But the same slope reinforced with 4 rows of jute reinforcements will yield a factor of safety of 1.5 even after 30 minutes of continuous 50mm/hr rainfall.

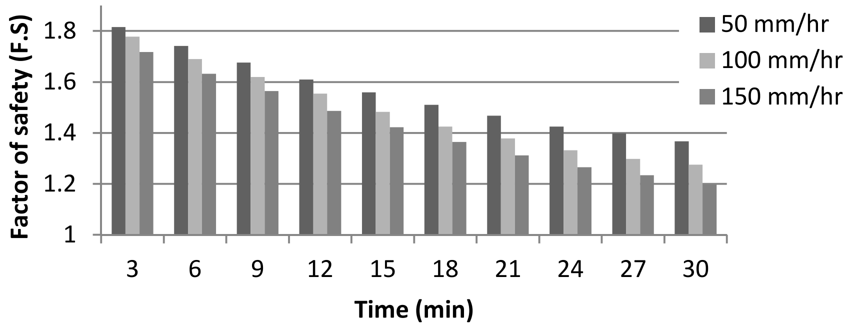


(a)

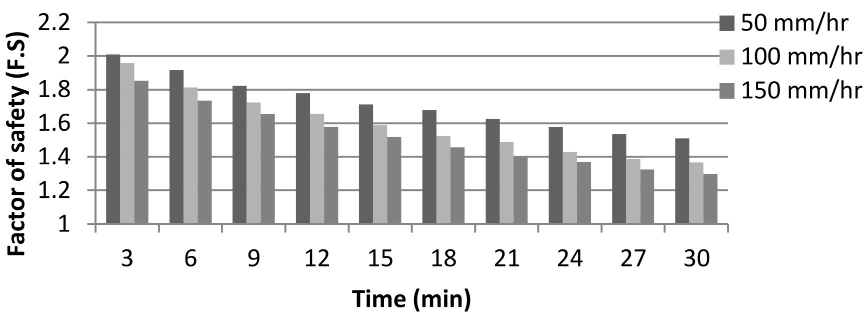
Fig. 11. Factor of Safety of 2:1 Slope for Different Intensity and Duration of Rainfall (a) without Reinforcement, (b) with 2-Rows, (c) with 3-Rows, and (d) with 4-Rows of Jute Reinforcements



(b)



(c)



(d)

Fig. 11. (*continued*)

Table 4. Variation of the Factor of Safety with respect to the Slope and the Jute Reinforcement

Slope	Factor of Safety			
	Without Jute Reinforcement	With 2-Rows of Jute Reinforcements	With 3-Rows of Jute Reinforcements	With 4-Rows of Jute Reinforcements
2:1	0.973	1.133	1.239	1.336
1.5:1	0.826	0.982	1.106	1.232
1.25:1	0.686	0.775	0.879	1.061

The above table shows that the 1.25:1 saturated slope will not be stable with or without jute reinforcements. The 1.5:1 and 2:1 saturated slopes, though not stable without any jute reinforcements, will meet the minimum factor of safety requirements with 4-rows of jute reinforcements.

6 Conclusions

From all the model tests performed in the laboratory and corresponding numerical analyses, it is clear that the inclusion of the jute reinforcements on a slope significantly reduces the deformation of the slope in a fully saturated condition. The jute tassels act as tensile reinforcements and increase the resistance along the probable slip surfaces. Consequently, the stability of the soil slope is improved.

Both the model tests and the numerical analyses indicate that planting four rows of jute reinforcements on the slope increase the overall suction pressures within a slope and significantly improve the stability of the slope as compared to the slope without and with 2- rows and 3-rows of jute reinforcements.

The deformations of the slope computed by the numerical analyses are found to be reasonably close to those observed in the model tests performed in the laboratory. Both show that the maximum deformation/ settlement may be reduced by more than half by planting four rows of jute reinforcements on the embankment slopes.

The results confirm that the plantation of jute strips or tassels in the slope may significantly improve the slope stability and may be considered as an environment friendly and a low cost slope stabilization measure.

References

1. RDSO: Rehabilitation of Weak Formation between Gour Malda and Malda Town on Malda Division Eastern Railway. Consultancy Report No: GE-20, Geotechnical Engineering Directorate, RDSO, Lucknow, India (1998)
2. RDSO: Rehabilitation of Unstable Formation between Gour Malda and Jamirghata Stations, Malda Division, Eastern Railway. Consultancy Report No. RDSO/2011/GE:CR-0157, Geotechnical Engineering Directorate, RDSO, Lucknow, India (2011)

3. Sengupta, A.: Numerical Study of a Failure of a Wall. Intl. J. of Geotechnical & Geological Engg. 30, 1025–1034 (2012)
4. Fowze, J.S.M., Bergado, D.T., Soralump, S., Voottipreux, P.: Rain-triggered landslide hazards and mitigation measures in Thailand: From research to practice. Journal of Geotextiles and Geomembranes 30, 50–64 (2012)
5. Au, S.W.C.: Rain-induced slope instability in Hong Kong. Engineering Geology 51(1), 1–36 (1998)
6. Fourie, A.B.: Predicting rainfall-induced slope instability. Proceedings of the Institution of Civil Engineers –Geotechnical Engineering 119(4), 211–218 (1996)
7. Ausilio, E., Conte, E., Dente, G.: Stability analysis of slopes with piles. Comput. Geotech. 28, 591–611 (2001)
8. Rowe, R.K., Poulos, H.G.: A method for predicting the effect of piles on slope behaviour. In: Proc. 3rd Intl. Conf. on Numerical Methods in Engineering 3, Aachen (1979)
9. Saha, P., Manna, S., Sen, R.K., Roy, D., Adhikari, B.: Durability of lignocellulosic fibers treated with vegetable oil–phenolic resin. Carbohydrate Polymers 87, 1628–1636 (2012)
10. Grimshaw, R.G.: Vetiver grass—its use for slope and structure stabilizatioon under tropical and semitropical conditions. In: Vegetation and Slopes, pp. 26–35. Institution of Civil Engineers, London (1994)
11. Yoon, P.K.: Important biological considerations in use of vetiver grass hedge rows (VGHR) for slope protection and stabilization. In: Proc. Int. Conf. on Vegetation and Slopes, Oxford, England (1994)
12. Hengchaovanich, D., Nilaweera, N.: An assessment of strength properties of vetiver grass roots in relation to slope stabilization. In: Proceedings of the First International Conference on Vetiver, pp. 153–158. Office of the Royal Development Projects Board, Bangkok (1996)
13. Van Genuchten, M.T.: A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44, 892–898 (1980)
14. ASTM: Standard guide for measuring matric potential in the vadose zone using tensiometers. ASTM Standard D3404-91. American Society of Testing materials, West Conshohoken, PA (2004)
15. Fernando, M.A.M.: Nature of soil–water characteristic curve for plastic soils. Journal of Geotechnical and Geoenvironmental Engineering (ASCE) 131(5), 654–661 (2005)
16. Ahmed, K.S., Vijayarangan, S.: Elastic property evaluation of Jute-glass fibre hybrid composite using experimental and CLT approach. Indian Journal of Engineering and Material Sciences 13, 435–442 (2006)
17. IMD: Monsoon 2012: A Report. IMD MET Monograph No. 13/2013, Pai, D.S., Bhan, S.C. (eds.) National Climate Centre, Indian Meteorological Department, Government of India, Pune, India (2012)
18. GEO-SLOPE Intl. Ltd.: Seepage Modeling with SEEP/W: An Engineering Methodology. 2007 edition. GEO-SLOPE Intl. Ltd., Calgary (2007)
19. Vanapalli, S.K., Fredlund, D.G., Pufahl, D.E., Clifton, A.W.: Model for the prediction ofshear strength with respect to soil suction. Canadian Geotechnical Journal 33(3), 379–392 (1996)
20. Lu, N., Wayllace, A., Oh, S.: Infiltration-induced seasonally reactivated instability of a highway embankment near the Eisenhower tunnel, Colorado, USA. Engineering Geology 162, 22–32 (2013)
21. Lu, N., Sener-Kaya, B., Wayllace, A., Godt, J.W.: Analysis of rainfall-induced slope instability using a field of local factor of safety. Water Resources Research 48, W09524 (2012), doi:10.1029/2012WR011830