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Rainfall Triggered Soil Slope Stabilized with Vetiver Plant

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ABSTRACT

Rainfall has been identified as one of the main causes for slope failures in areas where high annual rainfall is experienced. Vetiver Plant root systems play a major role in the mechanical properties of soil by increasing soil strength and stability, and by increasing the porosity. Soil root matrix bond the soil slope with the mechanical structure technique stabilization used to mitigate the slope failure. Investigation shows that the root framework causes a decrease of water penetration rate, reduce the rate of rising groundwater table, and expanding in soil shear quality. The root-reinforced soil is expected to be of higher strength as well as higher permeability, which would help to reduce runoff by providing more infiltration, thus improving the slope stability. Vetiver root hedges interact with the soil to provide more shearing strength. Rainfall simulator has been designed in laboratory for the observation of the slope deformation, factor of safety, infiltration and seepage flow inside the slope. Numerical analysis of the slope stabilization with Vetiver Plant subjected to different rainfall intensity has been observed by MIDAS Engineering Software. During heavy rainfall Vetiver hedges are very effective to increase the slope stability, maintain the matric suction and reduce the chances of slope embankment failure.

Keyword : *Rainfall, Vetiver Plant, Soil Slope, MIDAS Software, Slope Deformation, Factor of Safety, Seepage*

1. INTRODUCTION

Slope failure and erosion problems have increasingly become more frequent around the world, causing damage to infrastructure and sometimes leading to loss of people's lives. Rainfall is recognised as major cause of slope instability. A large number of rainfall-induced landslides have happened recently. Uttrakhand disaster 2013 is one of the major example of rainfall induced slope failure. Landslide can also damage transport facilities, infrastructures, railway track. The cost of repairing of the damage occurred from the landslide is also very high. It effects the environment, social activities, health opportunities and employment. Slope geometry, angle, type of soil, rainfall intensities are the factor of the slope failure. Vetiver grass (Vetiveria zizanioides), also known as Chrysopogon zizanioides, is a graminaceous plant native to tropical and subtropical India. The southern cultivar is sterile; it blossoms yet sets no seeds. It is a densely tufted, perennial grass that is considered sterile outside its natural habitat. It is reported that vetiver grows 0.5– 1.5 m high, stiff stems in large clumps from a much branched root stock (Erskine, 1992 & Truong, 1999). The use of vetiver grass hedges against soil erosion increased following several key papers promoting vetiver grass planting as an effective and inexpensive erosion protection measure. Interception of rainfall and evapotranspiration will reduce pore water pressure leading to increase in shear strength. Root fibers reinforce the soil mass, thus increasing its shear strength too. However, vegetation-covered and root-permeated ground surface are normally of higher permeability and infiltration rate (Styczen & Morgan, 1995). This increased infiltration would lead to lower run-off and consequently less erosive energy which is understandably beneficial for erosion control (Curtis & Claassen, 2007). It may also bring about increase in pore water pressure which would subsequently destabilize the slope. In particular, vetiver grass, which is considered one of the deepest roots amongst all plants, in theory, may provide a pathway for water infiltration to a greater depth. When slope embankment subjected to heavy rainfall it reduces the matric suction of the slope, rise in water table, seepage action and failure occurs due to sudden drawdown condition. Vetiver grass planted in rows along the slope contours vetiver is able to quickly form a narrow but very dense hedge. It can grow in very adverse environmental condition also. A correct plantation with plants that has strong rooting systems and roots can improve slope stabilization and reduces soil erosion. In this study, usages of Vetiver grass plant, which can help in erosion control applications on road slopes without hurting aesthetics. Digital tensiometer is instrument to measure the change in matric suction during the rainfall on vetiver stabilized slope. Low suction is responsible for maintaining the slope stability.

1.1 Vetiver Plant

Vetiver Plant Technology, which depends on the use of vetiver grass (Vetiveria zizanioides), was first evolved by the World Bank for soil and water protection in India during the 1980s. Its significant application in agrarian terrains, logical research directed over the most recent 10 years has plainly shown that Vetiver Plantation is additionally one of the best and ease regular strategies for ecological safety. Thus Vetiver grass is presently progressively being utilized worldwide for this reason. Therefore, vetiver grass is known as a marvel grass, a wonder grass and an enchantment grass in different places of the world. Vetiver grass is a lasting ground covering plant which has high adaption capacities and impervious to negative ecological conditions. Vetiver grass has a quick development pace and has solid mass roots. Vetiver is an uncommon plant; has wide scope of attributes, minimal effort prerequisites and simple applications. In numerous examinations and applications it is discovered that Vetiver Plant adequately sustain disintegration. Vetiver Plants can be utilized in; repositories, dams, gardens, pools that contain angles, parkway slants, and to forestall avalanches at ridges. Youthful leaves of Vetiver grass are acceptable wellspring of sustenance for creatures while old leaves are useful for paper mash, mulch, fuel, manure, rooftop spread, and expressions. Underlying foundations of this plant are useful for fragrant oils, drugs and for pesticide. Vetiver grass has a wide scope of utilization and it tends to be utilized in mountain towns to help advancement of the country territory.

1.2 Rainfall Triggered Slope

Rainfall-triggered landslides are part of the natural process of hill slope erosion and can result in the catastrophic loss of life and expensive property damage in densely populated areas. Rainfall intensity and duration affects the stability of slope. Hilly areas susceptible to high risk of the failure of slope due to heavy rainfall. Topographic factor such as slope angle, slope geometry, type of soil, weather condition along with rainfall causes the failure of slopes. The combination of very poor ground conditions, steep slopes, lack of vetiver grass and heavy rainfall resulted in the landslide and flash floods in the area. Higher intensities of rainfall with the greater duration causes rise in water table, reduces factor of safety of the slope. Section 2 contains detail properties of soil and Vetiver Plant, Experimental and Numerical discussions are described into section 3. Further Factor of Safety and Maximum deformation are calculated & simulated into section 4 as a calculation.

2. PROPERTIES OF SOIL AND VETIVER PLANT

2.1 Properties of Soil

The test soil used for the model study in the laboratory is obtained from the failed embankment near Khalgaon, Bhagalpur (Bihar). Undisturbed tube samples are collected from the sites and brought to the laboratory for determination of the properties. Standard test has been conducted for the soil field test as well as laboratory test. The laboratory specific gravity test result was 2.65 for the sample of the soil. The shear strength of the soil is obtained from the conventional Direct Shear Test. The test shows that cohesion (C') is 0.7 KPa and effective internal angle of friction (ϕ') = 26.8^0 . The hydraulic conductivity of the soil obtained from falling head test is 9.56 x 10^{-4} cm/sec. The sieve analysis test has been performed for the grain size distribution of the soil. The sieve analyses indicate that the soil contains 26.45% fines and the rest is sand. The liquid limit and the plasticity index of the fines are 19% and 7.68%, respectively. The UCSC classification of the embankment soil is SM-SC (silty sand). A summary of all the relevant engineering properties of soil are presented and described in Table 1. The soil-water characteristic curve (SWCC) for the soil is determined by following the standard test method using tensiometers [5,6]. 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.

Table 1. Material Properties of the Soil

Mechanical Properties	Values
Dry unit weight, γ_{dry}	15.6 kN/m^2
Saturated unit weight, γ_{sat}	19.85 KN/m^2
Cohesion, c'	0.7 kPa
Angle of internal friction, φ'	26.8^0
Poisson's ratio, υ	0.24
Modulus of elasticity, E	5225 kPa
Coeff. of permeability, K_{sat}	9.56 x 10^{-4} cm/sec
Plastic limit (PL)	7.68 %
Liquid limit (LL)	19 %
Plasticity index (PI)	11.32 %
Soil Classification	"SM-SC"

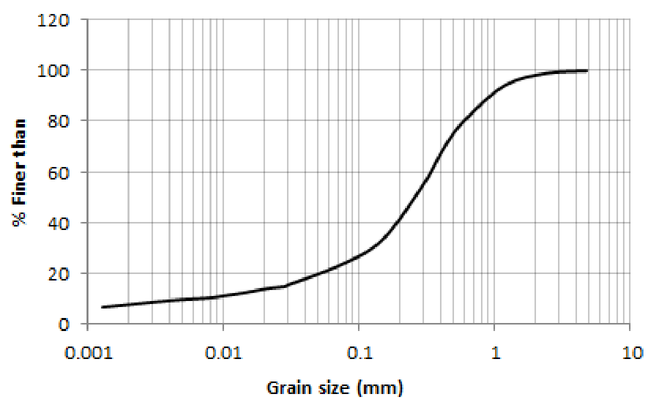

Fig. 1 Sieve Size Analysis Graph

2.2 Properties of Vetiver Plant

The diameter of Vetiver plant is varied from 0.25 to 2.90 mm and Tensile strength of Vetiver plant ranged between 4.32 to 57.93 MPa. Young's modulus varying between 43.20 to 2097.35 MPa. [3,4]. Mechanical properties of the Vetiver grass is given in Table 2.

Table 2. Mechanical Properties of Vetiver Grass

Growing Period (month)	Shear Strength (kPa)
2	11.02
3	11.89
4	14.42
5	17.60
6	15.06

3. RESULT AND DISCUSSIONS

The results obtained from experimental and numerical analysis of the model slope is presented in terms of maximum deformation, Factor of Safety, maximum rise in water table. 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 vetiver grass in the slope. The maximum deformation of the slope angle 26.8^0 is obtained for the different intensities of the rainfall 50 mm/hr, 100 mm/hr, 150 mm/hr and 200 mm/hr of different duration 5 min, 10 min, 15 min, 20 min, 25 min and 30 min. The formation of the slip plane is quite prominent in the case of slope without any Vetiver Plant. But for the case of slope with Vetiver Plant, the slip plane is not properly forming. The development of the suction pressures within a slope without and with Vetiver and their subsequent reduction at different intensities of rainfall are observed. Several experiments has been performed on laboratory model slope, the suction pressures at different elevations along the middle of the slope at a depth of 60 mm from the surface are measured with the digital tensiometer. The factor of safety of the slope, rise in water table and matric suction of the model slope is observed throughout the experiment. Factor of Safety has reduced drastically from 1.31 to 0.758 for the 100 mm/hr rainfall intensity of duration 30 min. Vetiver Plant of diameter 1.5 mm planted in 3 rows with the spacing of 10 cm has reduced the deformation significantly from 42.5 mm to 21.3 mm.

3.1 Experimental 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 1.6 m x 1.2 m in plan and a height of 0.20m on the front side and 0.90 m on the other three sides, is supported directly on two concrete platforms. Nozzle is attached with the rainfall pipe at outlet. The rainfall simulator consists of centrifugal pump which pumps water to a network of pipes fitted with two spray nozzles. The spray nozzles are located in such a way that the whole slope within the box gets uniform rainfall. The pressure of water inside the pipe is controlled by a controlling valve. Thus rainfall of different intensity can be simulated by controlling the valve. To measure the different rainfall intensities a rain gauge is used. The tests are conducted at three different rainfall intensities 50mm/hr., 100mm/hr., 150mm/hr and 200 mm/hr. The whole setup with rainfall simulator along with the rain gauge is shown in Fig. 2.

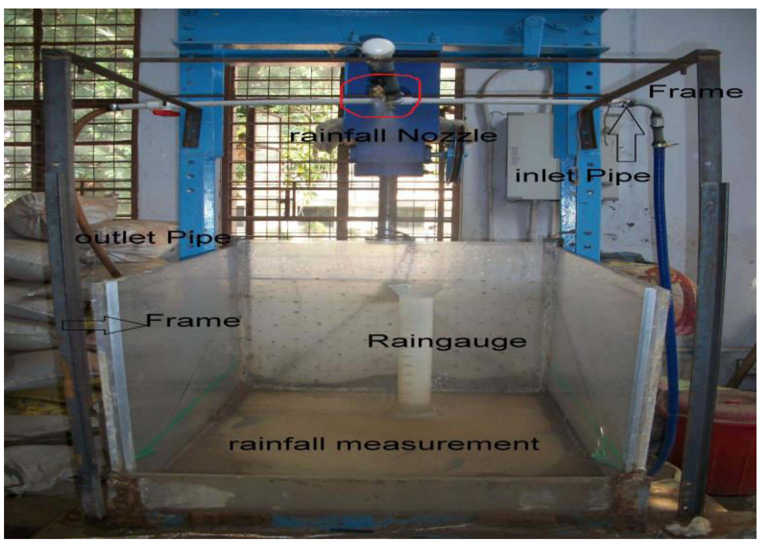

Fig -2 Rainfall Simulator

3.1 Numerical Modeling

Numerical analysis of the slope is done with the help of MIDAS GTS NX software. GTS NX is a comprehensive finite element analysis software package that is equipped to handle the entire range of geotechnical design applications including deep foundations, excavations, complex tunnel systems, seepage analysis, consolidation analysis, and embankment design, dynamic and slope stability analysis. A plane strain condition is assumed for all the analyses. The slope incline is discretized in the numerical examinations by the standard two dimensional quadrilateral and triangular components. The material properties accepted for the soil in the numerical investigations are given in Table 1. The Vetiver Plant are demonstrated as anchor elements. The anchor elements are one-dimensional. The Vetiver can yield in tension and compression but can not sustain Bending Moment. The numerical program used in this investigation is two-dimensional; the three-dimensional impact. The properties of the Vetiver Plant is given in Table 2. The boundary condition in the model is nodes on all sides are considered as roller and nodes at bottom is fixed in all directions.

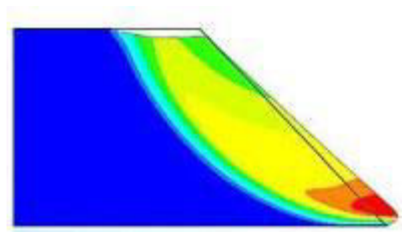

Fig. 3 A Model Slope Failure After Rainfall

Table 3. Maximum Deformation (cm) of the Model Slope Angle of 26.8^0 with Vetiver Plant

Deformation (cm) / **Rainfall Intensity** (mm/hr)	**Duration of Rainfall**					
	5 min	**10 min**	**15 min**	**20 min**	**25 min**	**30 min**
50	1.5	2.14	2.78	3.18	3.4	3.9
100	2.9	3.24	3.5	3.8	4.2	4.5
150	3.2	3.65	3.90	4.15	4.6	5.1
200	3.6	3.82	4.45	4.9	5.4	5.75

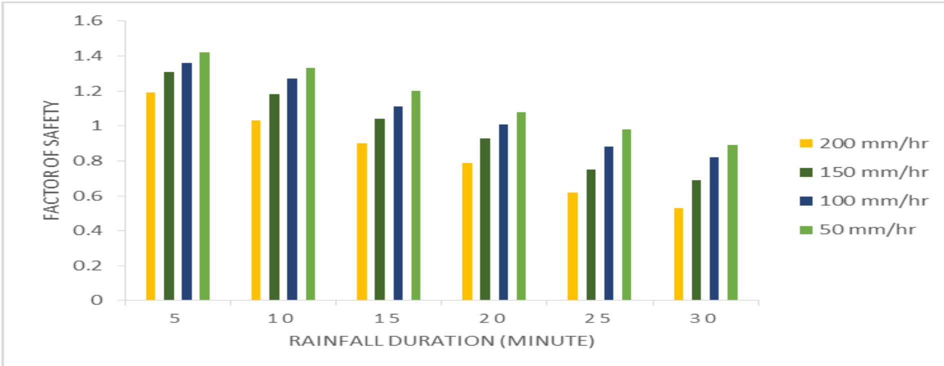

Fig. 4 Factor of Safety of Model Slope Angle 26.8^0 without Vetiver Plant for different Intensity and Duration.

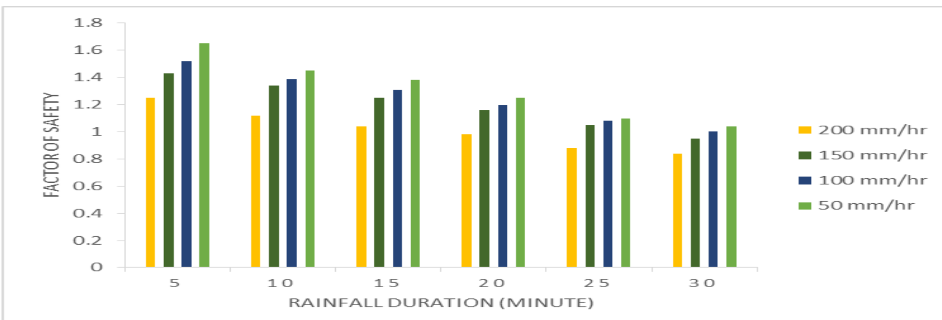

Fig. 5 Factor of Safety of Slope Angle 26.8^0 with Vetiver Plant for different Rainfall Intensity and Duration.

4. CONCLUSION

Model test has been performed in laboratory as well as numerical analysis has been done by MIDAS GTS NX finite element based software. It is clear that Vetiver Plant is reducing the deformation of slope and increasing the Factor of Safety in the saturated condition. The Vetiver root acts as a fiber reinforcement to the soil and provide Tensile as well as shear resistance. Stability of the soil slope is improved. Both model test and numerical analysis indicates that planting Vetiver Plant increases the matric suction of the slope. It also helps to increase the permeability of the soil, avoid the sudden drawdown condition. Vetiver also helps to reduce the cracks appear into the slope during the rainfall.

The deformations and Factor of Safety of the slope computed by the numerical analysis are reasonably closed to the experimental values found for model slope. Both results shows that maximum deformation is reduced by more than half after planting Vetiver Plant on the slope embankment. The results confirms that planting the Vetiver Plant on the slope embankment significantly improve the slope stability. The impact of using Vetiver Plant is cost effective considering slope stabilization measure and environment friendly. The scope of this approach can be further utilize into different domain like Railways embankment, Highway embankment and Hills slopes region. This methodology can be used further to enhance the slope protective techniques for fascinated researcher.

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