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Research Article

Interaction between Vetiver Grass Roots and Completely Decomposed Volcanic Tuff under Rainfall Infiltration Conditions

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The important role of vetiver grass roots in preventing water erosion and mass movement has been well recognized, though the detailed influence of the grass roots on soil has not been addressed. Through planting vetiver grass at the Kadoorie Farm in Hong Kong and leaving it to grow without artificial maintenance, the paper studies the influence of vetiver grass roots on soil properties and slope stability. Under the natural conditions of Hong Kong, growth of the vetiver grass roots can reach 1.1 m depth after one and a half year from planting. The percentage of grain size which is less than 0.075 mm in rooted soil is more than that of the nonrooted soil. Vetiver grass roots can reduce soil erosion by locking the finer grain. The rooted soil of high finer grain content has a relatively small permeability. As a result, the increase in water content is therefore smaller than that of nonrooted soil in the same rainfall conditions. Shear box test reveals that the vetiver grass roots significantly increased the peak cohesion of the soil from 9.3 kPa to 18.9 kPa. The combined effects of grass roots on hydrological responses and shearing strength significantly stabilize the slope in local rainfall condition.

1. Introduction

The use of vetiver grass for various applications in erosion and sediment control was developed by the World Bank for soil and water conservation in India in the 1980s [1]. Many literatures reviewed or studied the characteristics of vetiver grass and its application in preventing soil erosion and mass movement [2–9]. Rainfall infiltration is a key factor to control slope stability [10, 11]. In all, the effects of vetiver grass roots on erosion control and mass movement can be summarized as follows: (1) preventing surface erosion through the soil-binding properties of roots, (2) reducing effects of splash erosion through rainfall interception of vegetation canopy, (3) reducing the incidence of shallow slope instability through the anchoring properties of roots, (4) channeling run-off to alter slope hydrology, and (5) providing support to the base of the slope and trapping material moving down the slope.

Hong Kong is a small place and is densely populated; urban development has been carried out over the decades, which has led to enormous pressures on the fragile mountain environment. Most of Hong Kong's crucial rain is brought by the monsoon, which falls in just a few weeks between May and September (Figure 1). In combination with the monsoon climate, very steep slopes, and inherently weak geological conditions, these factors make Hong Kong highly susceptible to erosion and landslides [12–17]. So, vetiver grass, as an important species used for soil bioengineering, is selected in this research to deal with erosion problems and shallow landslides in Hong Kong (Figure 2).

The paper focused on the influence of vetiver grass roots on physical and mechanical properties of soil which has not been addressed, though the important role of vetiver grass roots in preventing water erosion and mass movement has been recognized in recent years. Because the majority of published literatures are based on practical experience or not under such local nature conditions of Hong Kong, there is still a clear need for scientific research concerning the influence of vetiver grass roots on physical and mechanical

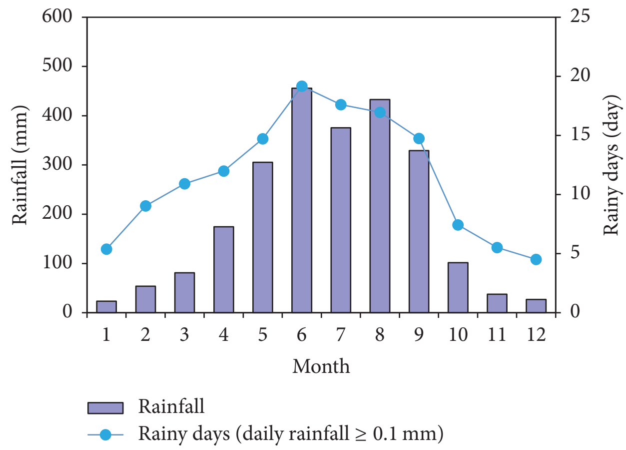

Figure 1: The monthly average of rainfall and rainfall days recorded by the observatory in 1981–2010.

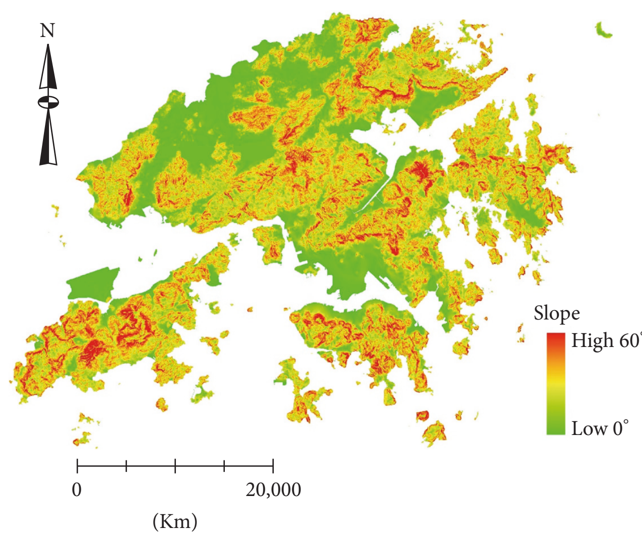

Figure 2: The site and DEM of Hong Kong.

prosperities. In this study, the in situ water content was tested by moisture probe in field. Tests consisting of water content, soil density, grain-size distribution, permeability, and direct shearing were carried out in the laboratory. All items were conducted on rooted and nonrooted soil, respectively.

2. Planting Site and Vetiver Grass Growth

Vetiver grass used in this research has been planted at the Kadoorie Farm of Hong Kong in June. Vetiver grass was planted at spacing of 1 m on a steep slope surface (Figure 3). The slope is 10 m long and has a maximum height of about 10 m. The slope was formed to an angle of 60° by cutting into completely decomposed volcanic tuff.

In order to test its survivability, no water and nutrients were artificially given to the grass during its growth. In 3 months after planting, the grass had grown up to 1.0 m high (Figure 4(a)). Figure 4(b) shows a typical grass roots system. The maximum root depth is 1.1 m and the root diameter ranges from 0.05 mm to 4 mm. Main roots were mostly found within the 25 cm below the ground surface, and for the depth greater than 25 cm from the surface, fibrous roots were mostly found.

Figure 5 shows the development of the grass stem length against time. At the time of field sampling and testing in January, the grass had grown to about 1.8 m tall in a very healthy condition despite the fact that it had been exposed to heavy rain in the summer and a very dry winter.

3. Field and Laboratory Test Results

3.1. Physical Properties. Herein, physical properties include water content, soil density, grain-size distribution, and permeability. All these items were conducted on both rooted soil and nonrooted soil to explore the influences of vetiver grass roots on soil's physical properties.

Water Content. Firstly, soil water content was studied in field on nonrooted and rooted soil. The ML2X moisture probe and data logger produced by detaT company in UK were used

(a) (b)

Figure 3: Panorama of research site (a) before grass planting and (b) during field testing.

(a) (b)

Figure 4: (a) Vetiver stem growth in 3 months after planting. (b) Typical grass root system.

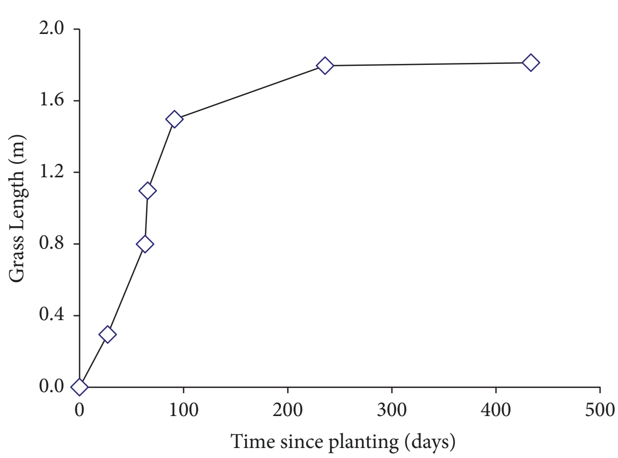

Figure 5: The development of the grass stems length against time.

in this test. The selected testing locations and the measured output voltage value are shown in Figure 6. According to the calibration curves of measured voltage and water content, the mass water content was obtained as shown in Table 1. Soil water content was also tested in laboratory. The soil tested was taken from the sample surface when the sample box was opened in laboratory. The water content was measured by drying method. The results are shown in Table 2.

From the results of the in situ and laboratory water content shown in Table 3, it is observed that vetiver grass roots increased the average soil water content by about 11.63% in field. The increase scale in laboratory testing is 8.26%. It is less than that obtained in field and may be because of the difference of two types of samples in water loss.

Soil Density. The soil used for density testing was taken from the block sample surface when opening the box in laboratory. Ring-knife method was used in this test. Inner diameter of the ring-knife is 61.8 mm and height is 20 mm. Test results are shown in Table 4. It can be found that the average density of soil with roots is 1.81 g/cm^3, which is higher than that of the soil without roots, 1.67 g/cm^3. Using the laboratory water

Table 1: In situ measured voltage of moisture probe and corresponding water content.

Sample types	Voltage tested (mv)	Water content (%)	Voltage tested (mv)	Water content (%)
Rooted soil tested in field	454.00	15.10	580.00	17.73
	453.00	15.08	282.00	11.50
	453.00	15.08	236.00	10.54
	453.00	15.08	647.00	19.13
	458.00	15.18	394.00	13.84
	563.00	17.37	436.00	14.72
	453.00	15.08	402.00	14.01
	438.00	14.76	472.00	15.47
	572.00	17.56	433.00	14.66
	452.00	15.05	339.00	12.69
	491.00	15.87	345.00	12.82
	481.00	15.66	336.00	12.63
	597.00	18.08	316.00	12.21
Nonrooted soil tested in field	294.00	11.75	375.00	13.45
	472.00	15.47	385.00	13.65
	397.00	13.90	321.00	12.32
	341.00	12.73		

(a) Measured locations in the area in which vetiver was planted

(b) Measured locations in the area in which vetiver was not planted

Figure 6: In situ water content locations and corresponding voltage value.

Table 2: Laboratory water content on block samples.

Sample number	Laboratory water content taken from sample surface (%)
Rootedsample_01	21
Rootedsample_02	17
Rootedsample_03	18
Rootedsample_04	21
Rootedsample_05	21
Nonrooted sample_01	17
Nonrooted sample_02	23
Nonrooted sample_03	17

content in Table 3, the dry density of soil was calculated in Table 4. The dry density of rooted soil is 1.51 g/cm^3, about 7% higher than 1.41 g/cm^3 of the nonrooted soil.

Grain-Size Distribution. Grain-size distribution of rooted and nonrooted soils has traditionally been tested combined by sieving and hydrometer methods in laboratory. The results of grain-size distribution are tabulated in Table 5. Figure 7 shows the average grain size distribution of the soil samples with and without roots. It is observed that the percentage of grain size of 0.075~0.005 mm and less than 0.005 mm in rooted soil is higher than that in the nonrooted soil by 18.2% and 39.1%, respectively. It indicates that vetiver grass roots can reduce soil erosion by locking the finer grain in soil.

Table 3: In situ and laboratory water content of soil samples.

	Soil without roots	Soil with roots	Increase in percentage
Average in situ water content	13.33%	14.88%	11.63%
Average laboratory water content taken from sample surface	18.7%	19.8%	8.26%

Table 4: Laboratory soil density and calculated dry density.

Sample number	Laboratory soil density (%)	Average natural soil density (g/cm ^{3})	Calculated dry density (g/cm ^{3})
Rootedsample_1	1.81	1.81	1.51
Rootedsample_2	1.85		
Rootedsample_3	1.86		
Rootedsample_4	1.79		
Rootedsample_5	1.74		
Nonrooted sample_1	1.70	1.67	1.41
Nonrooted sample_2	1.66		
Nonrooted sample_3	1.66		

Table 5: Grain-size distribution of different samples.

Sample number	Gain size (mm)						
	10~5	5~2	2~0.5	0.5~0.25	0.25~0.075	0.075~0.005	<0.005
Nonrooted sample_1	2.7	32.7	12.8	1.9	20.7	19.7	9.5
Nonrooted sample_2	3.7	38.2	12.5	2	16.1	17.2	10.3
Nonrooted sample_3	7.4	25.7	5.3	0.9	10.9	25.9	23.9
Rooted sample_1	2.2	36.1	8.9	1.2	10.5	21	20.1
Rooted sample_2	2	25.6	10.6	1.5	15.8	26.1	18.4
RootedSample_3	1.1	22.2	8.1	1.1	13.3	30.7	23.5
RootedSample_4	3.6	26.3	10	1.7	13.4	25.4	19.6
RootedSample_5	2.7	37.8	7.6	1.1	10.6	20.5	19.7

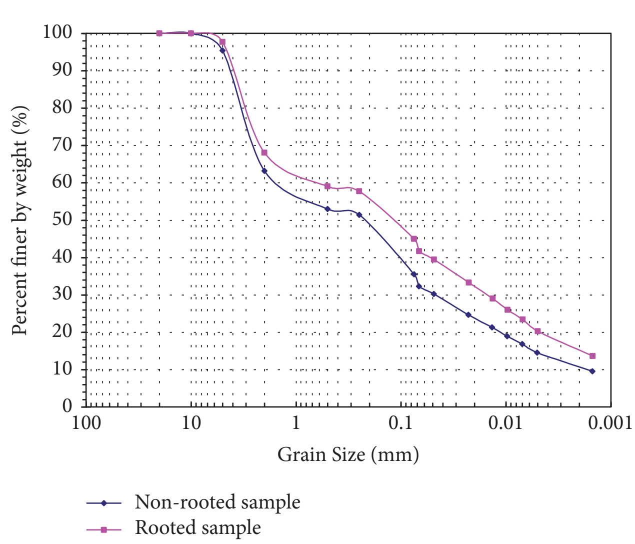

Figure 7: Average grain-size distribution of rooted and nonrooted properties.

Table 6: Densities and moisture content of the soil samples.

Sample	Moisture content	Moist density (kg/m^3)	Dry density (kg/m^3)
Rooted soil	14.9%	1800	1500
Nonrooted soil	13.3%	1700	1400

3.2. Mechanical Properties

Shear Box Test Results. Eight samples, each of dimensions 600 mm × 600 mm × 600 mm, were retrieved at location shown in Figure 3. Five samples were matrix of soil containing vetiver grass roots, whereas the remaining three were "bare" soil.

The soil was identified to be completely decomposed tuff. The densities and moisture content were tabulated in Table 6. Furthermore, the particle-size distribution of each sample was determined by taking samples, and the results are

Table 7: Results of large-scale direct shear test.

Sample number	Designed normal stress/kPa	Displacement/mm	Peak state		Residual state		Root area ratio
			Normal stress/kPa	Shear stress/kPa	Normal stress/kPa	Shear stress/kPa	
Rooted_1	20	16	22.4	32.2	24.5	19.8	1.98%
Rooted_2	40	18	51.3	39.5	42.9	25.4	0.88%
Rooted_3	60	32	71.5	46.6	67.5	41	1.60%
Rooted_4	80	22	82.9	54.4	84.6	41.4	2.45%
Rooted_5	120	16	124.2	76.1	128.4	62.2	2.11%
Nonrooted_1	10	15	10.7	14	9.6	10.4	- - -
Nonrooted_2	80	29	80	45.5	79	34	- - -
Nonrooted_3	120	36	120	63	120.3	54	- - -

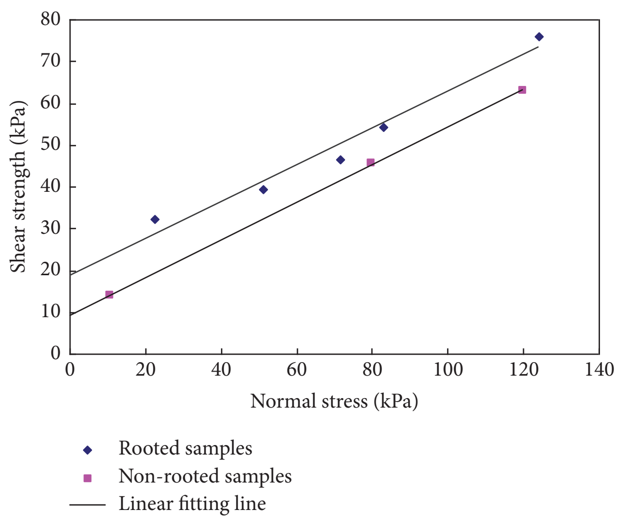

Figure 8: Peak shear strength against normal stress of rooted and nonrooted sample.

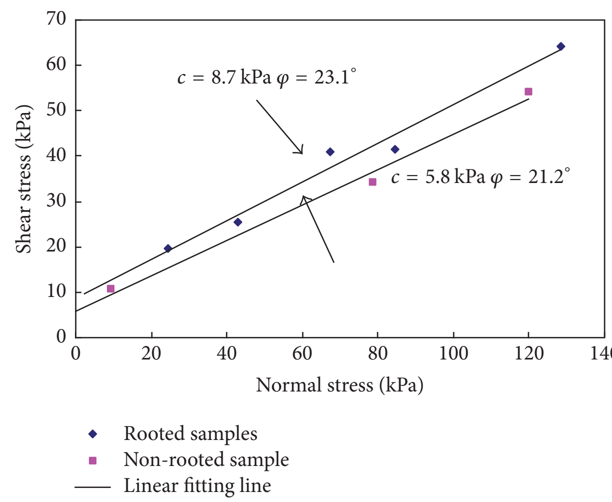

Figure 9: Residual shear strength against normal stress of rooted and nonrooted sample.

depicted in Figure 7. The soil is rather fine with some gravel. The coefficient of uniformity is approximately 5.

The shear strength obtained is plotted on the y-axis with the corresponding normal stress on the x-axis. Based on the test results (Table 7), the soil cohesion and frictional angle were obtained (Figures 8 and 9).

As shown in Figure 8, the peak cohesion of rooted soil is 18.9 kPa and the nonrooted soil is 9.3 kPa. Vetiver grass roots increased the cohesion by 103% in this study. The peak friction angles of rooted and nonrooted soils are nearly the same, which are 23.7° and 24.2°, respectively. The results of residual strength are shown in Figure 9. The residual cohesions of the rooted and nonrooted soils are 8.7 kPa and 5.8 kPa and their corresponding friction angles are 23.1° and 21.2°.

3.3. Application to Slope Safety. Vetiver grass was used to stabilize the slope. The effect of roots on slope stability is therefore analysed here. As revealed by shearing box testing, the grass roots can increase the soil strength. On the other hand, vetiver grass also changed the soil permeability. Finer particles were well reserved in the rooted soil in case of rainfall conditions. This will certainly influence the soil water characteristic curve (SWCC). In this study, the SWCC is evaluated using the soil's particle-size distribution. Soil permeability function is generated for rooted and nonrooted soils. As a result, the soil water contents in slope under the same rainfall conditions are different. The slope stability will therefore be different for rooted soil and nonrooted soil.

A slope is selected in this study. The slope angle is 45°. This is mainly because the 45° slope is mostly distributed in Hong Kong (Figure 2). The vetiver grass rooted soil is 3 m deep in vertical direction. The particle-size distribution of rooted and nonrooted soils as shown in Figure 7 is adopted to evaluate SWCC (Figure 10) for grass slope and nongrass slope, respectively. The soil strength as presented in Figure 8 is adopted for the rooted and nonrooted soils. The rainfall intensity of 7.62×10^{-7} m/s was used in the model. The preset

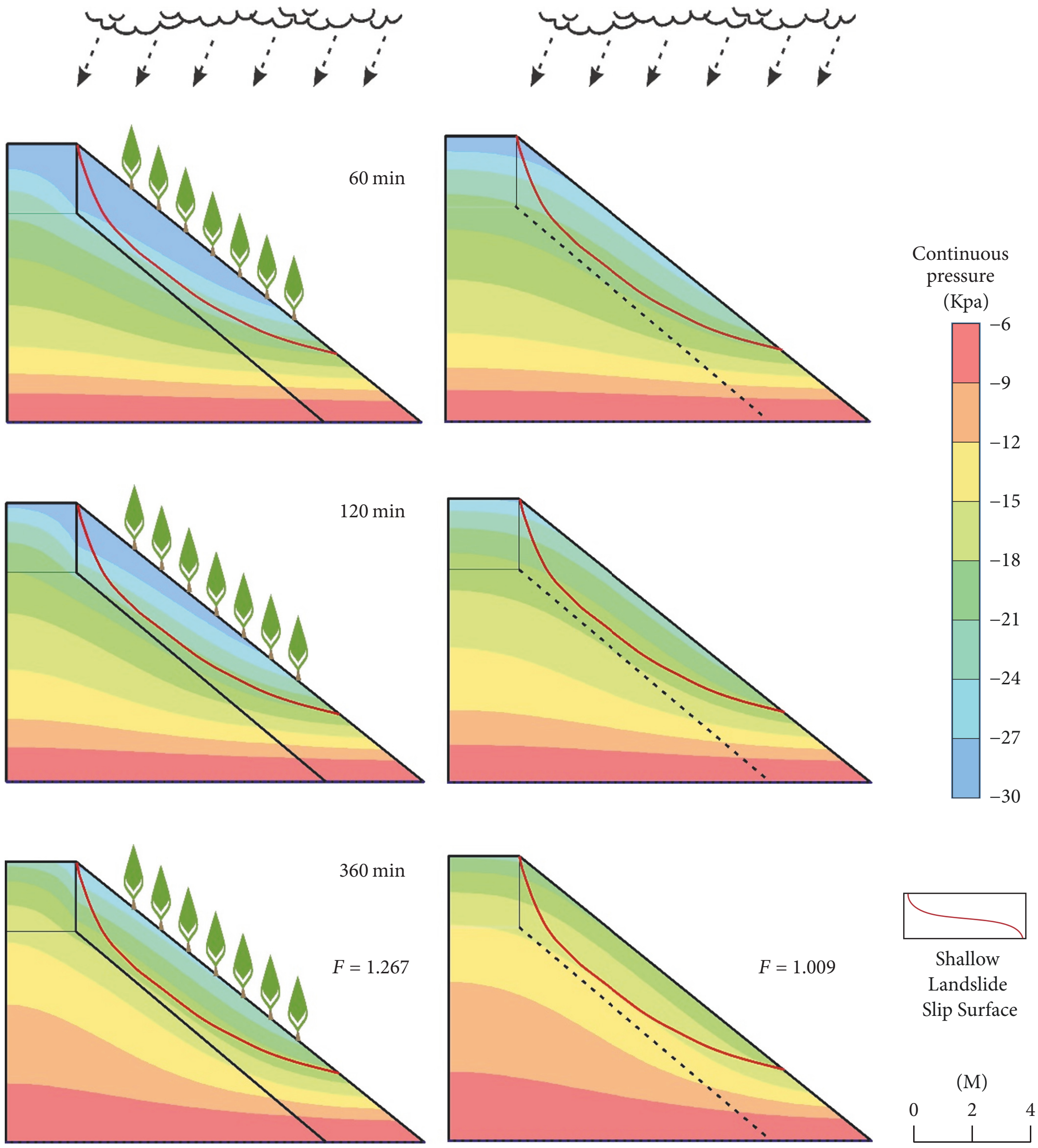

Figure 10: Hydrological responses to rainfall and slope stability for nonrooted and rooted slopes.

slip surface was defined in the slope to constitute the base of the comparison between nonrooted and rooted slopes.

Figure 10 shows the results of rooted and nonrooted slopes under rainfall conditions. The rainfall intensity used in this study is calculated from the monthly average of rainfall and rainfall days recorded by the observatory in 1981–2010 (Figure 1). It was found that the rainfall firstly infiltrated into the nonrooted slope is quicker than the rooted slope. It causes the soil in the nonrooted slope to be higher in water content than the rooted slope. The metric suction was evolved in the slope stability analysis. With increasing the soil water content, the soil strengths decrease. The grass root can enhance the soil strength. In this model, the peak strength for nonrooted and rooted soil was adopted in the slope. The data results clearly show that the grass root can increase the slope's stability.

4. Conclusions

This study highlights the influence of vetiver grass on soil properties and associated slope stability. It was firstly found that, under the natural conditions of Hong Kong, growth of the vetiver grass roots can reach 1.1 m depth after one and a half year from planting. Vetiver grass roots can increase the soil water content and density. The vetiver grass roots can reduce soil erosion by locking the finer grain. Grain-size distribution analysis shows that the percentage of grain size of 0.075~0.005 mm and that less than 0.005 mm in rooted soil is higher than those of nonrooted soil by 18.2% and 39.1%, respectively.

Shear box test results do show that the vetiver grass roots significantly increased the peak cohesion of completely decomposed volcanic tuff by 103% from 9.3 kPa to 18.9 kPa. To evaluate the effect of grass roots on slope stability, a numerical modeling was performed. It illustrates that the grass roots can prevent the rainfall water infiltration by locking the finer grain, which is of benefit for slope stabilizing. It was therefore demonstrated that the combined effects of grass roots on hydrological responses and shearing strength can stabilize the slope.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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References

[1] P. N. V. Truong and R. Loch, "Vetiver system for erosion and sediment control," in *Proceeding of the 13th International Soil Conservation Organization Conference*, 2004.

[2] O. Babalola, S. C. Jimba, O. Maduako, and A. O. Dada, "Use of vetiver grass strips for soil and water conservation in Nigeria," in *Proceedings of the Third International Conference on Vetiver and Exhibition: Vetiver and Water*, China Agriculture Press, Guangzhou, China, October, 2003.

[3] N. Dudai, E. Putievsky, D. Chaimovitch, and M. Ben-Hur, "Growth management of vetiver (Vetiveria zizanioides) under Mediterranean conditions," *Journal of Environmental Management*, vol. 81, no. 1, pp. 63–71, 2006.

[4] O. Babalola, S. O. Oshunsanya, and K. Are, "Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays, L) yields," *Soil & Tillage Research*, vol. 96, no. 1-2, pp. 6–18, 2007.

[5] S. Donjadee and T. Tingsanchali, "Soil and water conservation on steep slopes by mulching using rice straw and vetiver grass clippings," *Agriculture and Natural Resources*, vol. 50, no. 1, pp. 75–79, 2016.

[6] E. Gnansounou, C. M. Alves, and J. K. Raman, "Multipleapplications of vetiver grass-a review," *International Journal of Environmental Sciences*, vol. 2, pp. 125–141, 2017.

[7] C. Ghosh and S. Bhattacharya, "Landslides and erosion control measures by vetiver system," in *Disaster Risk Governance in India and Cross Cutting Issues, Disaster Risk Reduction (Methods, Approaches and Practices)*, I. Pal and R. Shaw, Eds., pp. 387–413, Springer Singapore, Singapore, 2018.

[8] H. Liu, L. Yao, C. Lin, X. Wang, W. Xu, and H. Wang, "18-year grass hedge effect on soil water loss and soil productivity on sloping cropland," *Soil & Tillage Research*, vol. 177, pp. 12–18, 2018.

[9] J. K. Raman and E. Gnansounou, "A review on bioremediation potential of vetiver grass," in *Waste Bioremediation, Energy, Environment, and Sustainability*, S. Varjani, E. Gnansounou, B. Gurunathan, D. Pant, and Z. Zakaria, Eds., Singapore, 2018.

[10] M. Zhang, Y. Yin, and B. Huang, "Mechanisms of rainfall-induced landslides in gently inclined red beds in the eastern Sichuan Basin, SW China," *Landslides*, vol. 12, no. 5, pp. 973–983, 2015.

[11] M. Zhang and M. J. McSaveney, "Is air pollution causing landslides in China?" *Earth and Planetary Science Letters*, vol. 481, pp. 284–289, 2018.

[12] E. W. Brand, "Landslides in Hong Kong," in *Proceedings of the Eighth Southeast Asian Geotechnical Conference*, 1985.

[13] S. W. C. Au, "Rain-induced slope instability in Hong Kong," *Engineering Geology*, vol. 51, no. 1, pp. 1–36, 1998.

[14] F. C. Dai, C. F. Lee, J. Li, and Z. W. Xu, "Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong," *Environmental Geology*, vol. 40, no. 3, pp. 381–391, 2001.

[15] K. T. Chau, Y. L. Sze, M. K. Fung, W. Y. Wong, E. L. Fong, and L. C. P. Chan, "Landslide hazard analysis for Hong Kong using landslide inventory and GIS," *Computers & Geosciences*, vol. 30, no. 4, pp. 429–443, 2004.

[16] K. K. S. Ho, "Managing the uncertainties of natural terrain landslides and extreme rainfall in Hong Kong," in *Landslide Science and Practice*, pp. 285–302, Springer Berlin Heidelberg, Berlin, Germany, 2013.

[17] L. Gao, L. M. Zhang, and R. W. M. Cheung, "Relationships between natural terrain landslide magnitudes and triggering rainfall based on a large landslide inventory in Hong Kong," *Landslides*, pp. 1–14, 2017.