Performance of Geosynthetic Reinforced Steep Soil Slopes at the onset of Rainfall Infiltration

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Abstract. The frequency of rainfall triggered landslides is increasing across the world. Infiltration of rain water into the slopes with low permeable soil increases the pore pressure and reduces the stability of slopes. Also, in the recent past Kerala experienced many rainfall triggered landslides. One of the most efficient way to prevent rainfall triggered landslides would be the usage of composite geosynthetics which can combine the functions of pore pressure dissipation and reinforcements. In the present study, soil is collected from a nearby site where landslide has occurred and the geotechnical characterisation of the soil was carried out. An attempt was made to investigate the performance of steep soil slope with and without the geosynthetics when subjected to rainfall, numerically. The study highlights the importance of use of a composite geogrid in reinforced soil slopes composed of locally available marginal soil.

Keywords: Reinforced soil slopes; Marginal backfills; Composite geogrid; Rainfall; Geosynthetics.

1 Introduction

Slope instability during rainfall is one of the major concerns in geotechnical engineering. The rain water infiltrating into the slopes with low permeable soil results in the development of excess pore water pressure, thereby reducing the stability of slopes during the rainfall. The soil properties and rainfall intensities are the most important parameters affecting the slope stability during rainfall [1]. Rain water infiltrating into the soil decreases the strength and leads to instability of natural soil slopes during monsoon season.

The stability of soil slope is increased by placing reinforcement within the soil mass. The provision of reinforcement within the soil slope enables the construction of steep soil slopes. The applications of reinforced soil slope is commonly seen in the construction of highway embankments and in places where the right of way is limited. One of the methods for the remediation or reconstruction of failed slopes is to provide reinforced soil slopes. The tendency of using the slide debris soil for the remediation is increasing, as the granular fill materials are rarely available at the remediation site. Also, the transporting high quality fill may prove to be uneconomical. Generally, granular soil with good permeability and frictional characteristics are preferred for the construction of reinforced soil slopes. Most of the design guidelines mandated the usage of soil with less than 15% fines (passing 75μ) in reinforced soil applications like mechanically stabilized earth walls. However, NCMA guidelines permits soil up to 35% fines (passing 75μ) with proper drainage considerations. Any soil which does not meet the requirements of an ideal backfill soil is termed as 'Marginal soil'. [2]

A database of 171 failed reinforced soil structures were reported by Koerner [3].The failure was characterized by excessive deformation or actual collapse. Around 61% of failures were due to the use of fine grained silt and clay in reinforced sections. There are a number of case studies reported on failure or inadequate performance of reinforced soil structures [4] which indicate that the presence of fine grained soil is the primary cause for the failure. The presence of excess silt and clay particles reduces the permeability of backfill thereby increasing the potential of pore water pressure buildup during rainfall infiltration. However, some studies on satisfactory performance of reinforced soil slopes with marginal soil are also reported [5]. The main reason for the satisfactory performance in these cases was suitable drainage provisions. The presence of permeable reinforcements enhances the pore pressure dissipation. On the contrary, low tensile stiffness and higher elongation of permeable reinforcement (geotextile) has limited its use as a reinforcing material [6].

Kelly and Naughton [7] reported that the enhancement of short term interface shear strength was achieved in case of a novel geogrid with in-plane drainage capability. Studies on the utilisation of dual function geosynthetics to provide reinforcement and drainage on a 2V:1H slope made of silty sand (SM) soil [8] indicate the potential application of such materials in enhancing the slope stability during rainfall. However, very limited studies have been reported on the influence of wetting of hybrid geosynthetic reinforced soil slope due to rainfall infiltration.

Heavy rain followed by severe landslides and slope failures were observed in Kerala during June-August 2018. Most efficient way to prevent rainfall- triggered landslides and damages would be the usage of hybrid geosynthetics or geocomposites[9]. In the present study, soil was collected from a nearby site where landslide had occurred and the geotechnical properties of the soil were determined. Numerical studies were carried out using the properties obtained from the experiments. The utilization of a composite geogrid which has the capacity of providing reinforcement as well as drainage in reinforced soil slope composed of locally available soil is attempted in the present study.

2 Materials

2.1 Soil

During June – August 2018 many rainfall triggered landslides were observed in Kerala. The soil used for the study was collected from a landslide area near Ambayathode, Kannur district in Kerala. Basic index tests of the collected soil were carried out. Based on the tests conducted, soil is classified as "Lean clay" (CL) as per Unified Soil Classification system (USCS). The optimum moisture content and maximum dry density of soil were determined from standard Proctor test. The coefficient of permeability corresponding to OMC and Maximum dry density was found to be 1.4x 10^{-7} m/s. The strength properties of soil at OMC and corresponding maximum dry density were determined performing direct shear tests. The tests was performed at a shear rate of 1.25 mm/min. The value of cohesion intercept and angle of internal friction were observed to be 14 kPa and 32° respectively. The properties of the collected soil are shown in Table. 1.

Table 1. Properties of the soil collected

Soil parameter	Value
Soil classification (USCS)	CL
Sand sized (%)	41.3
Silt sized (%)	27.3
Clay sized (%)	31.4
Max. dry density (kN/m^3)	16.6
Optimum moisture content (%)	20.35
Shear strength parameters	
Cohesion (kN/m^2)	14
Friction angle (°)	32

2.2 Reinforcement

The reinforcement materials used in the present study was a composite geosynthetic. The performance was compared with a conventional geogrid as well. Composite geosynthetic is a combination of two geosynthetic materials possessing reinforcement and drainage characteristics. In the present study, a combination of geogrid and non-woven geotextile is selected and referred herein as a composite geogrid. The ultimate tensile capacity of geogrid and composite geogrid used in the present study was 50 kN/m at 12 % strain. The in-plane permeability of composite geogrid was 2.23x10^{-3} m/s.

3 Numerical modelling of reinforced soil slopes subjected to rainfall

The effect of inclusion of composite geogrids in marginal fill subjected to rainfall was studied numerically using Geostudio 2018. The analysis was carried out on a soil slope of 10 m height with an inclination of 68° (2.5V:1H). The geometry is fixed in such a way to avoid the influence of side boundary effects. The geometry of the slope adopted in present the study is shown in Fig.1. The initial ground water table was considered at the toe of the slope as shown in the Fig. 1. To study the effect of rainfall on the performance of reinforced soil slope, rainfall intensity of $3.59\text{x}10^{-7}$ m/sec was selected, this typically represents the highest rainfall in Kerala during 2018 [10]. Numerical analysis was carried out for a duration of 5 days with rainfall simulated for 2 days. The performance of soil slopes were studied at the onset of rainfall and during the rainfall. Three models were analysed in the present study. One is unreinforced soil slope (UR) without any reinforcements. The other two are reinforced soil slopes reinforced with geogrid (RS-G) and composite geogrid (RS-CG) respectively. The length of reinforcement in reinforced slopes were based on the Federal highway administration (FHWA) guidelines, i.e., length of reinforcement equal to 0.7 times the height of soil slope with a vertical spacing of 750 mm was adopted.

Each analysis was studied in two phases. In the first stage, the effect of infiltration was studied using SEEP/W. The pore water pressure profiles obtained from SEEP/W were imported to SLOPE/W and factor of safety at different instances of time were computed.

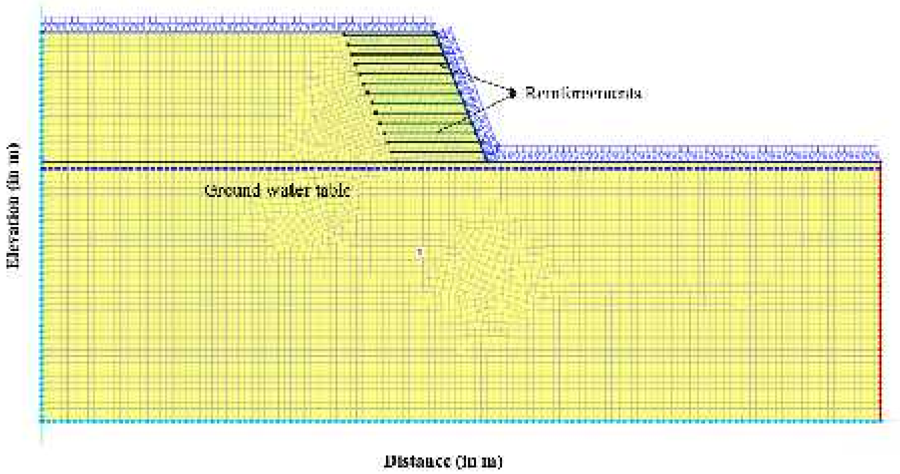


Fig. 1. Geometry of the reinforced soil slope adopted for the present study

3.1 Seepage analysis

The influence of rainwater infiltration into the unreinforced (UR) and reinforced soil slopes (RS-G and RS-CG) were investigated using a finite element program SEEP/W. The infiltration of rainwater into the soil slope is described by transient flow, as the hydraulic head changes with time. The unsteady transient flow through an unsaturated soil mass is governed by Richard's equation,

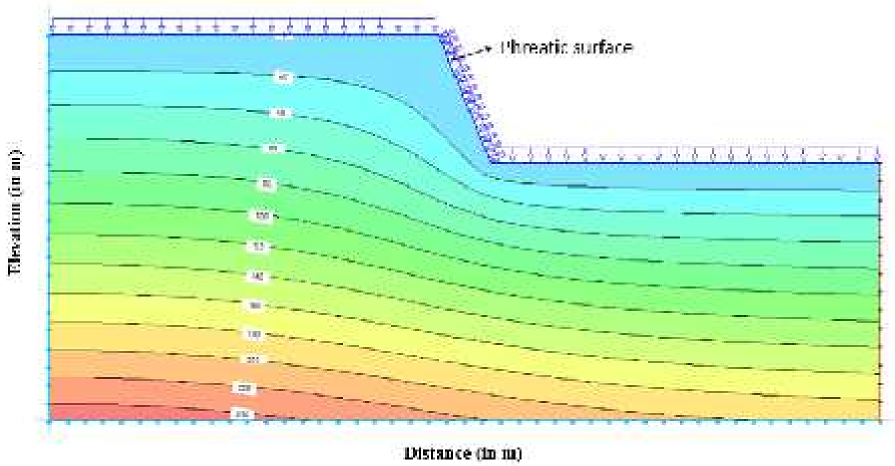
$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right)+q=\frac{\partial \theta_w}{\partial t} \qquad (1)$$

$$\frac{\partial \bar{\ }_{w}}{\partial t} = m_{w}^{2} \circ {}_{w} g \frac{\partial h}{\partial t} \qquad (2)$$

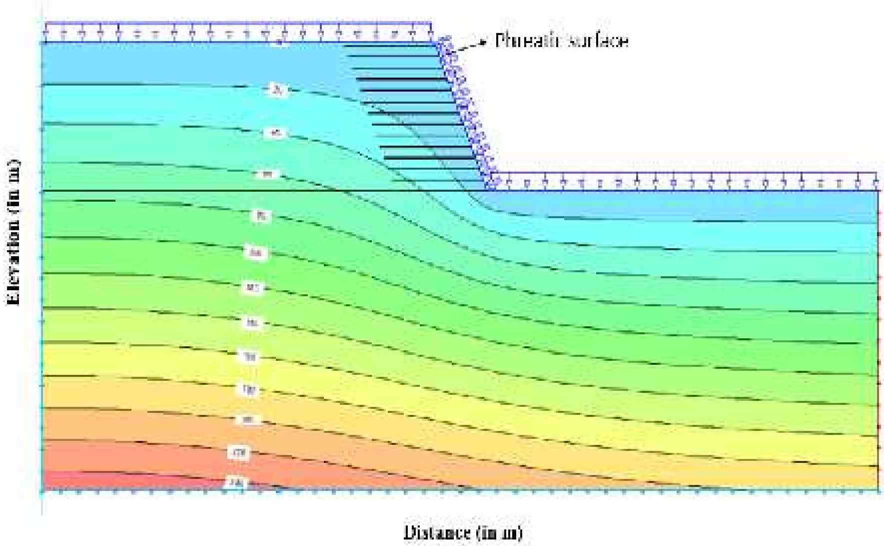
Where h is the total hydraulic head, k_x and k_y are the unsaturated hydraulic conductivity in x and y direction respectively, m_w is the co-efficient of volumetric water change equal to the slope of soil water characteristic curve, Θ_w is volumetric water content, ρ_w is the density of water, g is acceleration due to gravity and t is time.

The effect of infiltration was studied by applying boundary influx equal to the rainfall intensity of $3.59x10^{-7}$ m/s on the surface and along the slope. The rainfall was simulated for a duration of 2 days. The nodal flux, Q = 0 m^3/s was adopted to simulate no flow conditions along the bottom and the left boundary of the slope. Total head equal to the height of water table was assigned to the right boundary. Initial water table was considered at the toe of the soil slope and the initial maximum negative pore water pressure was limited to 50 kPa. Initial pore water pressure was limited to 50kPa to ensure that the pore water pressure generated above the water table are realistic[11].The soil domain was described by using saturated/unsaturated model. In case of wetting of unsaturated soil mass, the volumetric water content and hydraulic conductivity is non-linear function of soil suction. The saturated/unsaturated model is capable of solving non-linear function. The soil water characteristic (SWCC) of the collected soil was predicted using the particle size distribution of the soil by curve fitting option available in the software. The hydraulic conductivity which varies with soil suction was estimated using Fredlund and Xing method for corresponding SWCC and saturated permeability. For model with composite geogrid (RS-CG) composed of geogrid and non-woven geotextile, the material was assigned to the line elements. The properties of non-woven geotextile adopted were k_{sat} were $2.23X10^{-3}$m/s (In plane) and $2.5X10^{-5}$m/s (cross plane).The analysis was carried out using quadrilateral and triangular mesh.

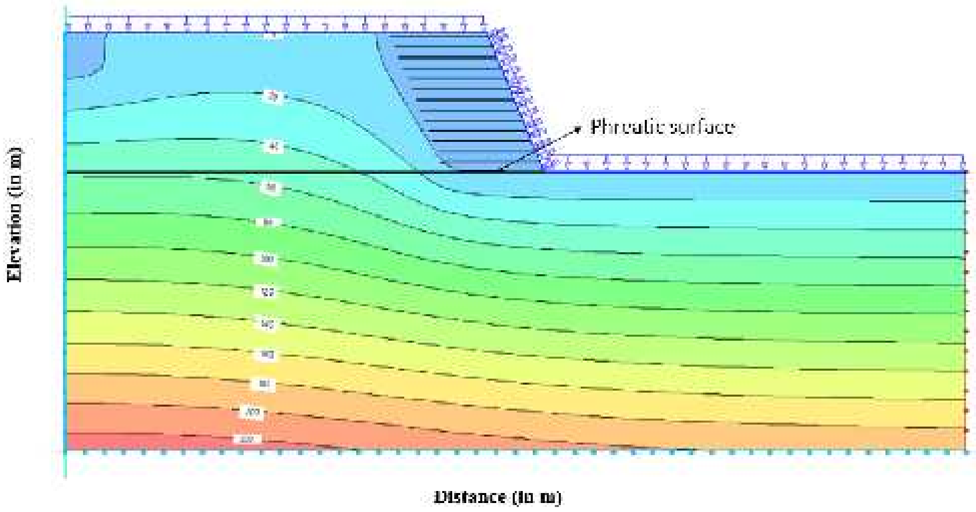
Figure. 2shows the pore water distribution for model UR, RS-G and RS-CG at the end of 2 days for the given rainfall conditions. As shown in the Fig. 2,there is a build-up of excess pore water pressure in case of unreinforced (UR) and slope reinforced with only geogrids (RS-G). On the contrary, for the slope reinforced with composite geogrid, the pore water pressure buildup is less compared to other two cases. Also, it can be observed that the rise in ground water level is significant in case of UR and RS-G, whereas the ground water table remains unchanged even at the end of 24 hours of rainfall. Figure.3 shows the normalized pore water pressure at a distance 5mbehind the toe for cases UR, RS-G and RS-CG. Normalized pore water pressure defined by ratio of porewater pressure (u) and product of unit weight of soil (γ) and height (h) of slope. As shown in the Fig. 3, there is almost 6 times reduction in the normalized pore water pressure of unreinforced soil slope when reinforced with composite geogrid layers. The results demonstrate the effectiveness of composite geogrid in providing drainage and pore pressure dissipation during rainfall event.



(a) Unreinforced soil slope (UR)



(b) Soil slope reinforced with only geogrid (RS-G)



(c) Soil slope reinforced with composite geogrid (RS-CG)

Fig. 2. Pore pressure distribution at the end of 24 hours of rainfall

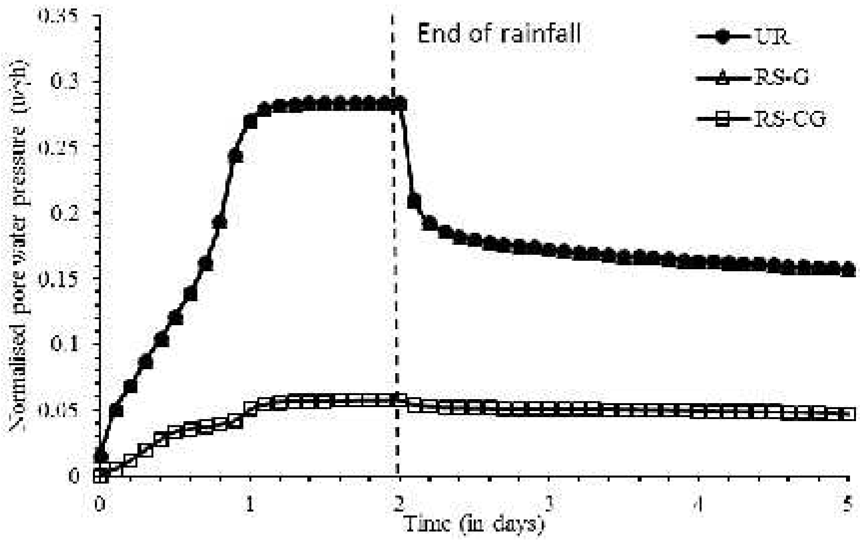


Fig. 3. Variation of normalised pore water pressure (u/γh) with time

3.2 Stability analysis

Limit equilibrium approach - SLOPE/W was adopted to determine the factor of safety for unreinforced and reinforced slopes. The pore water pressure profile at every instant of time was imported from SEEP/W to compute the factor of safety during rainfall. The factor of safety was computed using the Morgenstern-Price method. The potential sliding mass was defined using entry and exit method. The soil domain was defined by modified Mohr-Coulomb failure criteria which incorporates negative pore water pressure in the unsaturated region during the factor of safety computation. Figure. 4 shows the factor of safety for unreinforced (UR), soil slope reinforced with geogrid (RS-G) and soil slope reinforced with composite geogrid (RS-CG). It is observed from the Fig. 4, that the unreinforced soil slope (UR) and soil slope reinforced with only geogrid (RS-G) which was initially safe (FOS > 1.5) at the onset of rainfall reaches an unstable condition (FOS < 1.5). The soil slope reinforced with composite geogrid remains stable (FOS > 1.5) during the rainfall infiltration. Although the pore water pressure profile was similar in case of unreinforced (UR) and soil slope reinforced with only geogrid (RS-G) the factor of safety was slightly higher during the rainfall. This is can be attributed to the presence of geogrid. The change in factor of safety during the rainfall is attributed to loss of suction. The reduction in factor of safety is not very significant in case of (RS-CG) as the non-woven geotextile present in composite geogrid allows drainage and aids in keeping the reinforced section in unsaturated state. From Fig. 4, it can concluded that the presence of non-woven geotextile along with geogrid aids in maintaining the slope in drained condition. Thus, results demonstrate the effectiveness of composite geogrid in providing drainage and pore pressure dissipation during rainfall event.

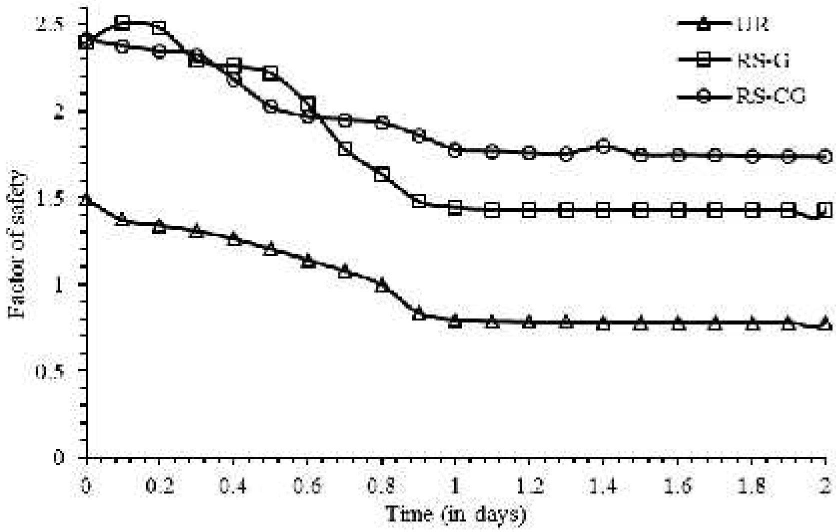


Fig. 4. Variation of factor of safety with time

4 Conclusions

In the present study, performance of an unreinforced (UR), geogrid reinforced (RS-G) and composite geogrid reinforced (RS-CG) soil slopes with locally available soil at the onset of rainfall infiltration was investigated. Based on the analysis and interpretation, following conclusions can be drawn:

The composite geogrid was found to be very effective in dissipation of pore water generated in the locally available low permeable soil during rainfall. This was found to be very clear from the pore pressure distribution of UR, RS-G and RS-CG soil slopes. There was 6 times reduction in the normalised pore water pressure of unreinforced soil slope when reinforced with composite geogrid layers.

The factor of safety was found to be higher for models RS-G and RS-CG compared to UR. This is due to reinforcement function. From stability analysis, it was observed that the factor of safety decreases at the onset of rainfall infiltration. However, the rate of decrease was found to be negligible and the slope was found to be safe for soil reinforced with composite geogrid. This is attributed to the inplane drainage capacity of composite geogrid which helps in dissipation of pore pressure developed during rainfall infiltration.

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