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Evaluation of the Performance of Reinforced Red Coffee Soils Embankments Subject to Rainfall Event

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Abstract

Infrastructure development in Kenya has led to the need for alternative material in slopes and embankments construction. Sourcing of recommended cohesionless material often leads to the destruction of the environmental features such as rivers and involves high extraction and transportation costs. The need for alternative material is the motivation behind this study. The study aims to evaluate the potential of Red coffee soils of Kenya as a backfill material in the construction of slopes and embankments. Provision of sand cushion layers to sandwich non-woven geotextile material has been suggested to overcome the water drainage and stability problems that have been associated with these soils. The study first involved identifying the properties of both the Red coffee soils (RCS) and the river sand that is to aid in drainage. Numerical model SEEP/W was used in evaluating the effect of geotextile inclination on the performance of RCS embankments before the effect of introducing sand cushions of different thickness evaluated. The numerical results revealed that the stability of reinforced RCS decreased with increase in pore water pressure in the embankments due to rainfall infiltration. Provision of sand cushion layers helped improve both the local and global stabilities of the RCS subjected to rainfall infiltration. The results showed that 150mm sand cushion layer was adequate to improve the performance of RCS embankments and reduced the sand consumption in the construction of embankments to 15%.

Keywords: Drainage; Embankments; Non-Woven Geotextile; Red Coffee Soils; Sand Cushion; Slope Stability.

1. Introduction

The design guidelines, AASHTO [1] have recommend the use of coarse grained cohesionless soils as backfill material in reinforced walls and slopes. This is majorly attributed to their low plasticity levels, high frictional values which are helpful in pullout resistance especially when geotextile materials are used to reinforce these structures. Despite the advantages presented by the cohesionless soils, their extraction has proved detrimental to the environment as most of these soils are extracted from river banks or near water bodies as deposits. Patricia [2] reported that sand harvesting along rivers has contributed to the destruction of river banks and drained water points leading to drying of rivers. Backfill material in geosynthetic reinforced structures account for 30-40% of the total cost of the structure [3]. This demonstrates the importance of a cheaper alternative in the construction of earth structures.

In Kenya the availability of RCS which in most construction sites comprises of the largest percentage of waste material can be put into use. However, studies [4, 5] reveal that red coffee soils fall under soils with medium to high plasticity also referred to as marginal soils. In a study that involved 171 failed reinforced soil structures, Koerner [6]

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reported that 61% of the failed structures had used silt and clay as their backfill material with water ingress in the structure contributing to 60% of the failures. Yoo [7] in another study investigated the failure of a segmental GRS wall in Korea after a monsoon season. The investigation revealed that the major contributor to the failure of the wall could be largely attributed to poor quality backfill and rainfall infiltration. For the proper functioning of these structures composed of marginal backfill, studies [8–10] have proposed the need for proper drainage within these structures. Problems with marginal soils has been attributed to their poor drainage and uncertainty in pore water pressure build-up [11]. However, during the construction of geosynthetic reinforced slopes the backfill material is normally compacted within $\pm 2\%$ of optimum moisture content. This brings about the advantage of negative pore water pressure and matric suction in the unsaturated backfill layer. Matric suction in the unsaturated zone enhances the soils' stiffness and shear strength.

Marginal soils reinforced with geotextile have also been associated with poor pullout resistance offered to the non-woven geotextile. Choudhary [12] studied three types of cohesionless soils reinforced with different types of geosynthetics materials. Pull-out tests by use of large direct shear test were conducted to investigate the interface behavior of soil-geosynthetics. Geosynthetics that allowed the penetration of soil particles within themselves such as the non-woven geotextile were found to possess higher soil-geosynthetic inter- face friction angle values than those of woven geotextile. Pull-out interaction coefficients C_i were reported in the range 0.62-1.72. In an effort to improve the pullout resistance of the non-woven geotextile embedded in marginal soils studies [13] were conducted to investigate the effect of providing a thin sand layer to cover the geotextile materials the study reported that the provision of thin sand layer improved the pullout resistance and improved on the deformation of reinforced clays.

Previous studies [6, 14] have suggested that for proper functioning of marginal soils as backfill material, proper drainage should be guaranteed. Efficient drainage in the embankments will minimize the rate of pore water pressure development which subsequently will lessen the rate of shear strength loss. The use of non- woven geotextile has been suggested in the improvement of drainage in marginal backfill embankments due to the advantages of drainage and tensile strength it provides[3, 15]. However, under unsaturated soil conditions non-woven geotextile have been reported to act as barriers contributing to the accumulation of water in the soils above the non-woven geotextile layer [16–18]. Accumulation of water above geotextile layer increases pore water pressure and has been attributed to failures of geosynthetic reinforced structures [9]. This presents the construction industry with dilemma of sticking to the expensive and environmental unfriendly cohesionless soils or address the drainage and stability problems associated with the readily available marginal red coffee soils backfill material.

From the previous studies efforts in the improvement of drainage in marginal backfill embankments is still a topic under investigation. The improvement of the drainage by provision of non-woven geotextile layer has served to some extent improve on the performance of the embankments. However the advantage of the non-woven geotextile has not been fully realized when solely used. This study aimed at improving the performance of the marginal backfill in embankments by working to improve on the drainage of the marginal soils. The study aimed to take advantage of the high conductivity of the river sand to improve on the pullout resistance and improve on the drainage of the marginal backfill embankments when subjected to rainfall event. Specifically this study investigated: 1) the effect of inclining non-woven geotextile on the drainage and stability of the red coffee soils embankment, 2) the optimum sand cushion thickness for improvement of drainage and stability of the RCS backfill embankment. Extreme rainfall was uniformly applied to the modelled embankments and seepage analysis results used in determining the factors of safety during the rainfall event. Results of these study will help provide guidance for the design of RCS embankments.

2. Numerical Program Details

2.1. Seepage Analysis

Finite element model SEEP/W Ver. 2012 was used for seepage analysis in the study. Before seepage analysis is done, the hydraulic properties of geomaterial is required. The hydraulic properties can be derived from the van Genuchten equation or the Fredlund-Xing models which are incorporated in the SEEP/W program. The van Genuchten equation is as expressed in Equation 1 with the Fredlund-Xing equation presented as Equation 2;

$$\theta = \theta_r + (\theta_s - \theta_r) \times [1 + (\alpha \times \psi)^n]^{-(1-\frac{1}{n})} \quad (1)$$

Where θ_r = residual moisture content; θ_s = saturated moisture content; α and n = fitting parameters; ψ = matric suction (kPa);

$$\theta = \theta_r + (\theta_s - \theta_r) \times \left\{\ln\left[e + \left(\frac{\psi}{a}\right)^n\right]\right\}^m \quad (2)$$

Where θ_r = residual moisture content; θ_s = saturated moisture content; α and n = fitting parameters; ψ = matric suction e = base of the natural logarithm, a = represents the air entry suction, n = represents the pore size distribution, and m = represents the model skew.

SEEP/W transient seepage analysis governed by the Richard's equation was used in the study. For a two-dimensional homogenous anisotropic soil, the equation is derived as in Equation 3;

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = \frac{\partial \theta}{\partial t} = m_w \gamma_w \frac{\partial h}{\partial t}, \quad (3)$$

Where h = total hydraulic head; k_x = unsaturated hydraulic conductivity in the x direction; k_y = unsaturated hydraulic conductivity in the y direction; m_w = coefficient of water volume change (slope of the water characteristics curve); γ_w = unit weight of water; θ = volumetric water content.

2.2. Stability Analysis

Stability analysis of the embankments was done using the SLOPE/W program. This involves importing pore water pressure from SEEP/W to determine the factor of safety. The Spencer method, a method that considers both moment and force equilibrium in the factor of safety determination was used. The unsaturated soil shear strength carried out by SLOPE/W implements the Equation 4 as proposed by [19].

$$\tau_f = c' + (\sigma_n - u_a) \tan \phi' + \frac{\theta_w - \theta_r}{\theta_s - \theta_r}(u_a - u_w) tan\phi \quad (4)$$

Where τ_f = shear strength; c' = effective cohesion intercept for a saturated soil; $\sigma_n – u_a$ = net normal stress on the failure plane; σ_n = total normal stress; u_a = pore air pressure; ϕ' = effective friction angle; $u_a – u_w$ = matric suction; u_w = pore-water pressure; θ_w = volumetric water content; θ_s = saturated volumetric water content and θ_r = residual volumetric water content. As is common practice in the design of embankments for long term, effective cohesion of the backfill material was set to c'=0 kPa [20].

3. Materials and Methods

3.1. Materials

3.1.1. Red Coffee Soils

Red coffee soils used in the study was obtained from Juja town in Kenya. The soils were obtained at a depth of 1.5m from the earth surface to minimize the effect of roots and other organic materials that may contaminate it and affect the properties of the soil. Properties of the RCS as obtained from laboratory tests are as presented in Table 1. The RCS was classified as silty clay (CL) according to the Unified Soil Classification System (USCS). The grain distribution curve for the RCS used in the study is presented in Figure 1.

Table 1. Properties of the red coffee soils used in the numerical analysis

Properties	Values
Specific Gravity	2.58
Gravel	0.2%
Sand	9.45%
Silt	51.85%
Clay	38.5%
Liquid limit	48.8%
Plastic limit	27.0%
Plastic Index	21.8%
Type of soil	CL
Hydraulic Conductivity	$1.072 \times 10^{-6} cm/s$
Optimum moisture content	26.2%
Maximum dry density	1337 kg/m^3
Cohesion *C'*	32 kPa
Friction angle φ'	16°

3.1.2. River Sand

River sand was sourced from local dealers in Juja town in Kenya. Properties of the river sand as obtained from the laboratory tests were; specific gravity of 2.68, hydraulic conductivity of 1.43×10^{-4} m/s with cohesion of 0 kPa and angle of friction of 35°. River sand was classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS). Grain size distribution curve for the river sand used in the study is as presented in Figure 1.

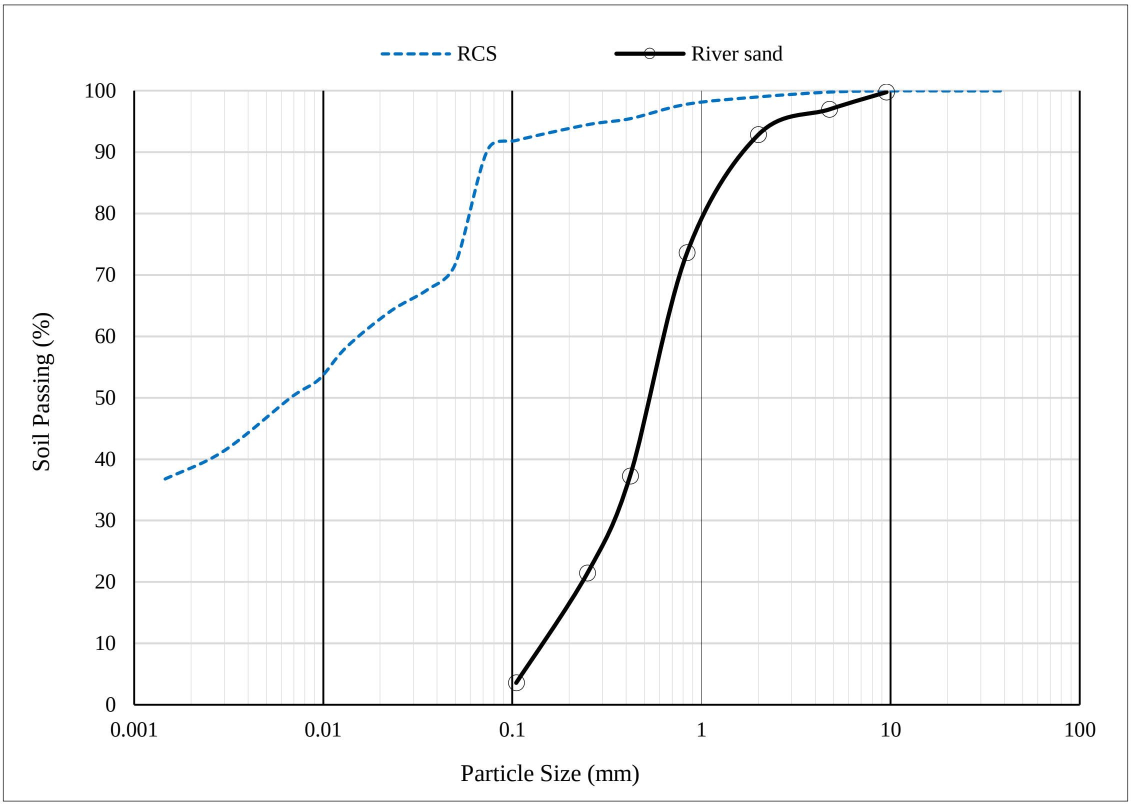


Figure 1. Particle size distribution curves for RCS and River sand used in the study

3.1.3. Non-Woven Geotextile Material

The non-woven geotextile material used in the numerical model was based on the properties as obtained from secondary sources and are as summarized in Table 2.

Table 2. Properties of the Non-woven geotextile [21]

Properties	Values
Mass per unit area, m_a (g/m^2)	310
Thickness of geotextile, $t_{geotextile}$ (mm)	3
Porosity, n_p	0.92
Saturated hydraulic conductivity in cross plane direction, $k_{sat\ geotextile\ cross}$ (m/s)	0.0035
Saturated hydraulic conductivity in plan direction, , $k_{sat\ geotextile\ plan}$ (m/s)	0.023
Tensile strength in machine direction (kN/m)	21.6

Based on the laboratory tests, the volumetric water content function of sand and the Red Coffee Soils as estimated through the Fredlund and Xing's and those of the non-woven geotextile material as estimated through the van Genuchten-Mualem's model are presented in Figure 2a. The hydraulic conductivity functions of the materials as modelled with sample functions are presented in Figure 2b. The models were constructed based on the soil database in SEEP/W v2012. From the Figure 2 matric suction is observed to be influenced by the volumetric water content of geomaterial. It can be observed that as the volumetric water content of the soils increases matric suction significantly decreases which is in agreement which soil mechanics principles in which soils with high volumetric water content will exert a lower pressure in moving water towards them as compared to dry soils. An important component in the functions is the air entry value which shows the point at which matric suction is adequate to initiate the dying of a saturated soil. RCS has a higher air entry value 15 kPa compared to that of non-woven geotextile and river sand which stands at 0.9 kPa. This is because the amount of flow paths within non-woven geotextile is more thus a lower pressure is required for water movement as compared to RCS with finer particles and lesser flow paths. The curve of the geotextile are steeper showing water is lost at a much faster rate in these geomaterial as compared to RCS. These observations conform to studies [18], which showed that soils with a relatively wider pore-size distribution are marked by relatively less steep characteristic curves because the majority of pores are drained over a relatively wider range of suction.

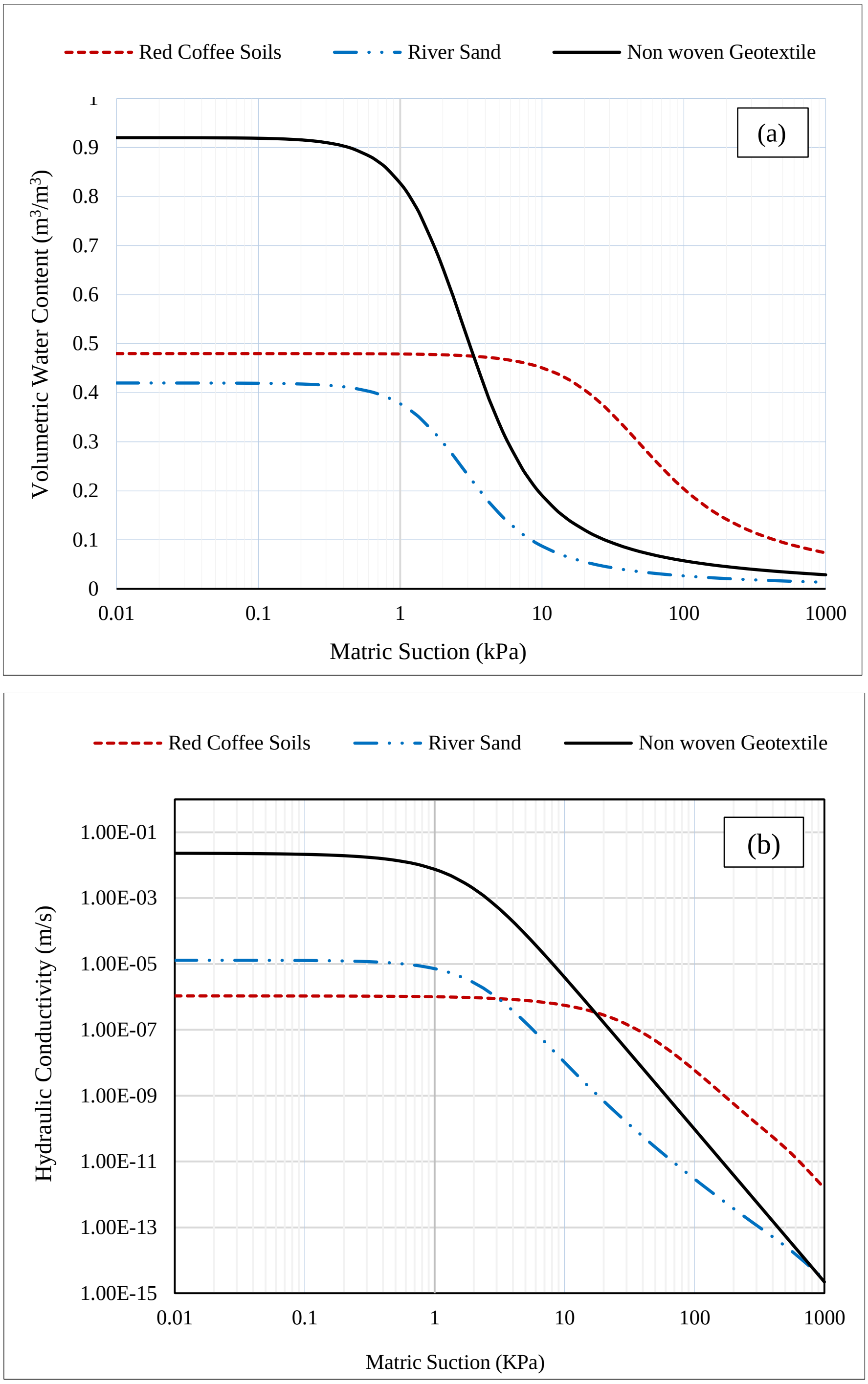


Figure 2. Hydraulic function models of river sand, non-woven geotextile and RCS (a) volumetric water content function curves (b) hydraulic conductivity function curves

3.1.4. Rainfall

Rainfall data for the study was obtained from the meteorological department of Kenya from the year 1991 to the year 2017. Based on the rainfall data an extreme rainfall event of 160 mm/day was recorded for the period. Such rainfall event was reported to last a maximum of 2 days however in our study the rainfall was simulated for a period of 3 days.

3.2. Method

The finite element model SEEP/W ver. 2012 and SLOPE/W ver.2012 was used in this study. The embankments were simulated as two dimensional (2D). Quadrilateral mesh in elements of height 0.1 m were used in the study. The time increment in the analysis was automatically adjusted between 0.1 second and 100 seconds. With 18 time steps results recorded during the simulation process. To establish initial pore-water condition before simulation of rainfall infiltration, a steady-state seepage analysis with prescribing a unit flux on prescribed unit flux on the surface boundaries was done. The values of prescribed unit flux were adjusted until when matrix suction did not exceed initial soil moisture conditions as obtained from the laboratory results.The non-woven geotextile was modelled as a line with 3 mm interface elements. The volumetric water content data in the simulated model was measured at a distance x=1.2 and 2.4.

In establishing the effect of non-woven geotextile angle of inclination on the drainage and stability of embankments, two dimensional embankments with non-woven geotextile layers inclined at angles of 0°,1°, 3°, 6°,9° and 10.5° in different embankments were modelled. The model with the non-woven geotextile inclined at zero degree is as shown in the Figure 3. Three layers of non-woven geotextile layers were placed 0.75 m apart in the vertical direction, a fourth layer of geotextile of length 1.5 m was maintained at the base of the embankment. This fourth layer was maintained at zero degrees inclination throughout the modelling process. Boundary conditions for the embankments were specified based and a series of transient infiltration analysis in SEEP/W and limit equilibrium analysis using the Spencer method carried out in SLOPE/W. It should be noted as is the standards [14] in the design of slopes the effective cohesion of the RCS was set to 0kPa in the stability analysis.

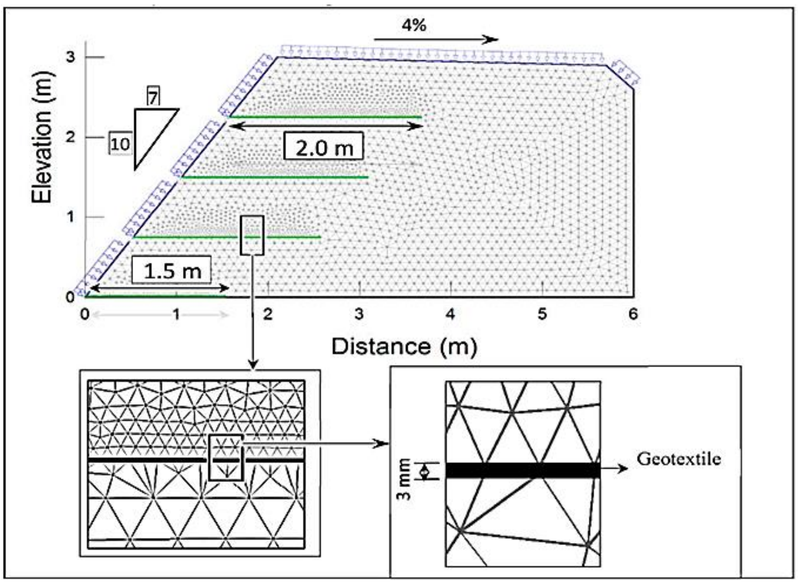


Figure 3. Numerical model setup of the RCS embankment in evaluating effect of geotextile inclination on its performance

After the optimum angle of inclination was obtained, the effect of sand cushion thickness on the drainage and stability of red coffee soils embankments was established by introducing sand layers of different thickness to sandwich the non-woven geotextile layers. The sand layers thickness adopted were 50, 100, 150, 200, 250 and 300 mm. These thickness refer to the thickness on either side of the geotextile material. The numerical model setup is as shown in Figure 4. The non-woven geotextile layer retained their earlier vertical spacing of 0.75 m. The effect of these sand layers on the infiltration and stability was then evaluated.

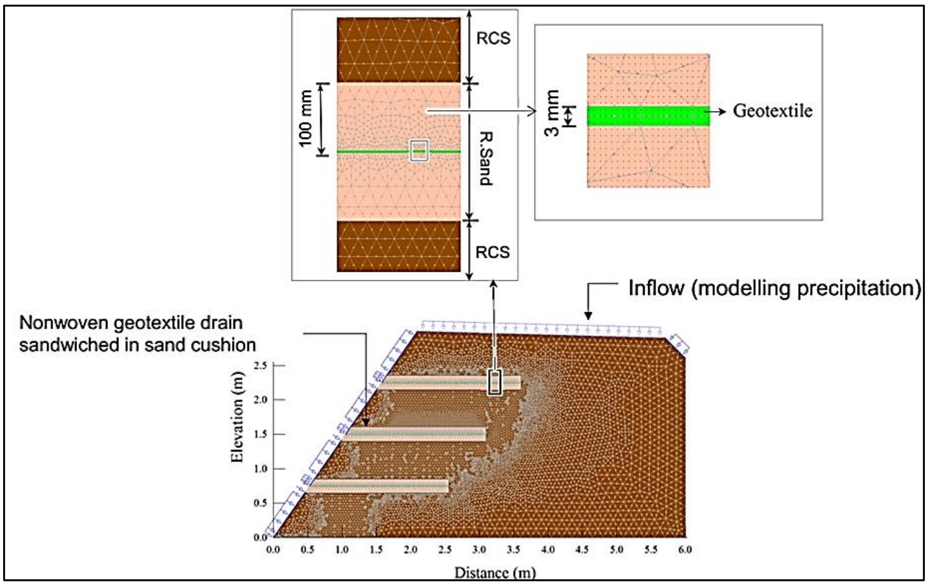


Figure 4. Numerical model setup in evaluating the effect of sand layer thickness on the performance of RCS embankments

4. Results and Discussion

4.1. Effect of Geotextile Inclination on the Performance of RCS Embankments

The effect of inclining non-woven geotextile layers at angles of 0°, 3°, 7.5° and 9° on the pore water pressure profile of RCS is presented in Figure 5.

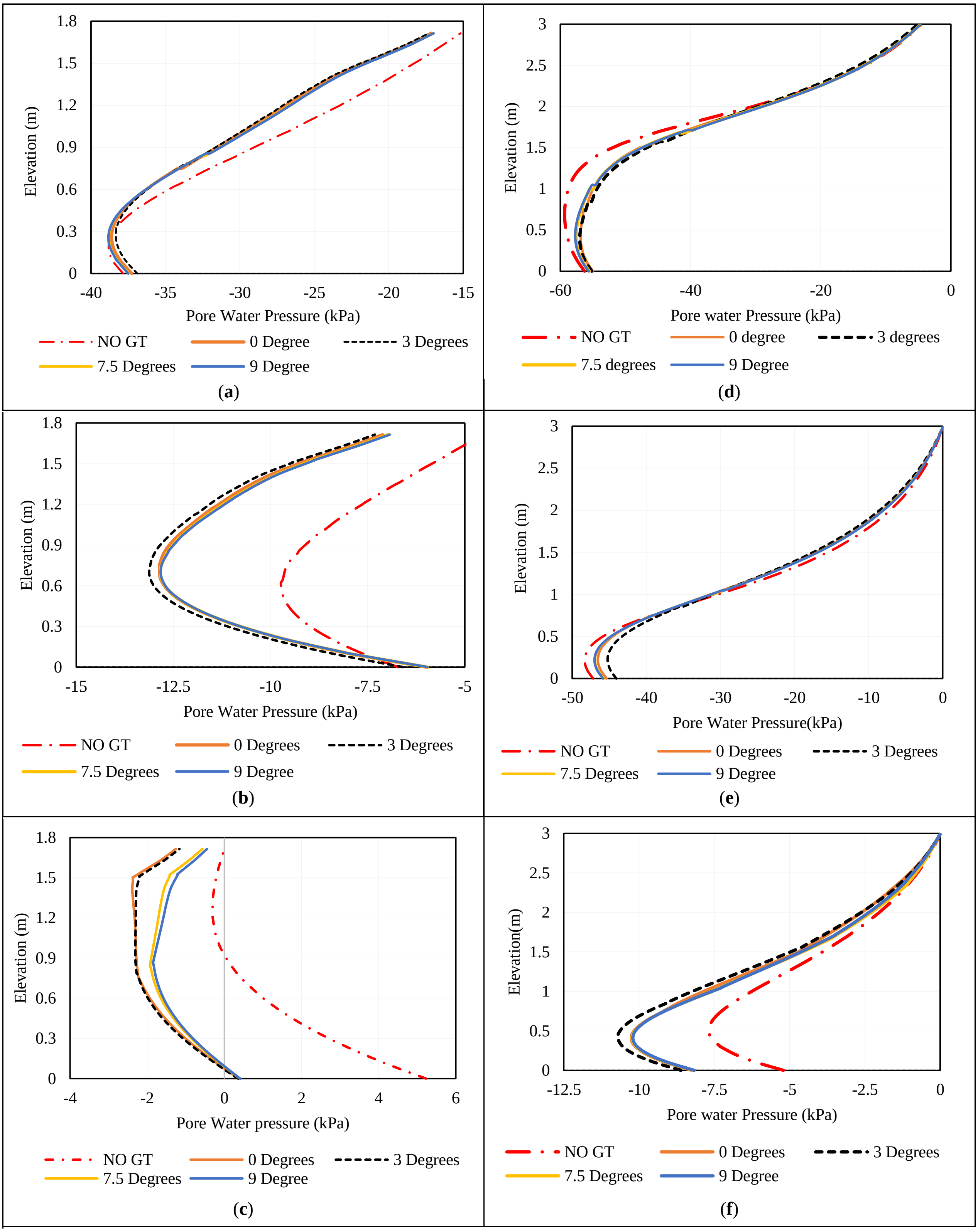


Figure 5. Pore water pressure profiles of embankments with inclined geotextile layers measured at (a) x=1.2m day 1 (b) x=1.2 m day 2 (c) x=1.2 m day 3 (e) x=2.4 day 1 (e) x=2.4 m day 2 (f) x=2.4 m day 3

From the figure increase in pore water pressure within the embankments with increase in time can be noticed. This is attributed to the dissipation of matric suction in the RCS contributed by the increase in volumetric water contents within the embankments with the advancement of time and continued rainfall event. The advantage of non-woven geotextile on the performance of the RCS embankments can be seen in Figure 5. The embankments reinforced embankments irrespective of their inclination angle performed much better with lower pore water pressures within their pore water pressure profiles. This is because the presence of non-woven geotextiles provided a drainage effect on the RCS embankments attributed to the high hydraulic conductivity of the non-woven geotextile as compared to a RCS.

Inclining the non-woven geotextile layers has an effect on the pore water pressure developments in the RCS embankment though to a small extent. Increasing the non-woven geotextile angle of inclination from the conservative angle of zero degree up to an angle of three degrees resulted in the reduction of the rate of pore water pressure development in the embankment. This was attributed to the slope created by the inclination. Initially when the non-woven geotextile layer was placed at zero degrees inclination (horizontal placement) water accumulated above the non-woven geotextile until the soil layer just above the non-woven geotextile became saturated a point when water now transited to the non-woven geotextile and was drained through the non-woven geotextile layers. However, with the inclination instead of the water accumulating above the non-woven geotextile it begun to flow due to the slope created. The rate of flow above the layer was however very low due to the low hydraulic conductivity of the RCS. A three degree angle of inclination was observed to be the optimum angle of inclination an angle beyond no significant improvement on the pore water pressure development was observed. This clearly demonstrates that inclining the non-woven geotextile material at an angle of three degrees makes it more effective as a drainage material as compared to not inclining the material at all and not providing the non-woven geotextile material in the RCS embankment. Iryo [21] reported similar results on the performance of sandy backfill when inclined and he reported an optimum inclination of 10% in the sand backfill embankments.

Figure 6 shows the variation of factor of safety with change in angle of inclination of the non-woven geotextile layers. There is a general decrease in factor of safety of the embankment with accumulated rainfall. Initially the factor of safety of the reinforced embankments were lower compared to those of the unreinforced embankment. This can be attributed to capillary barrier effect a phenomena that is characterized by accumulation of water above the non-woven geotextile layers of the top most layer. This effectively increased the pore water pressure and reduced the matric suction of the soils in the region where the geotextile materials were located consequently reducing the shear strength of RCS. However, with time as the rainfall flux passed through the RCS zone the regions above the geotextile became saturated this allowed the accumulated water to transit into the non-woven geotextile layer. The non-woven geotextile material now acted as drainage layers, dissipating pore water pressure and thus improved the shear strength of the soils in the reinforced embankments. The unreinforced embankment recorded a continuous rapid decline in the factors of safety of the embankment because of the non-existence of drainage layers to help dissipate the pore water pressure in the embankments. Corresponding to low pore-water pressure in the reinforced embankments with non-woven geotextiles inclined at three degrees, the embankment with a three degree inclination angle recorded the highest factors of safety during the rainfall event. Subsequent decrease in the factors of safety with increase in inclination can be attributed to the accumulation of water just above the non-woven geotextile layer, with an increase in water content the material just above the non-woven geotextile layer begin to slide contributing to a weaker zone just above the layer. A three degree angle was thus found to be a balance of overcoming the effects of capillary barrier and drainage before the volumetric water content above the non-woven layer increases.

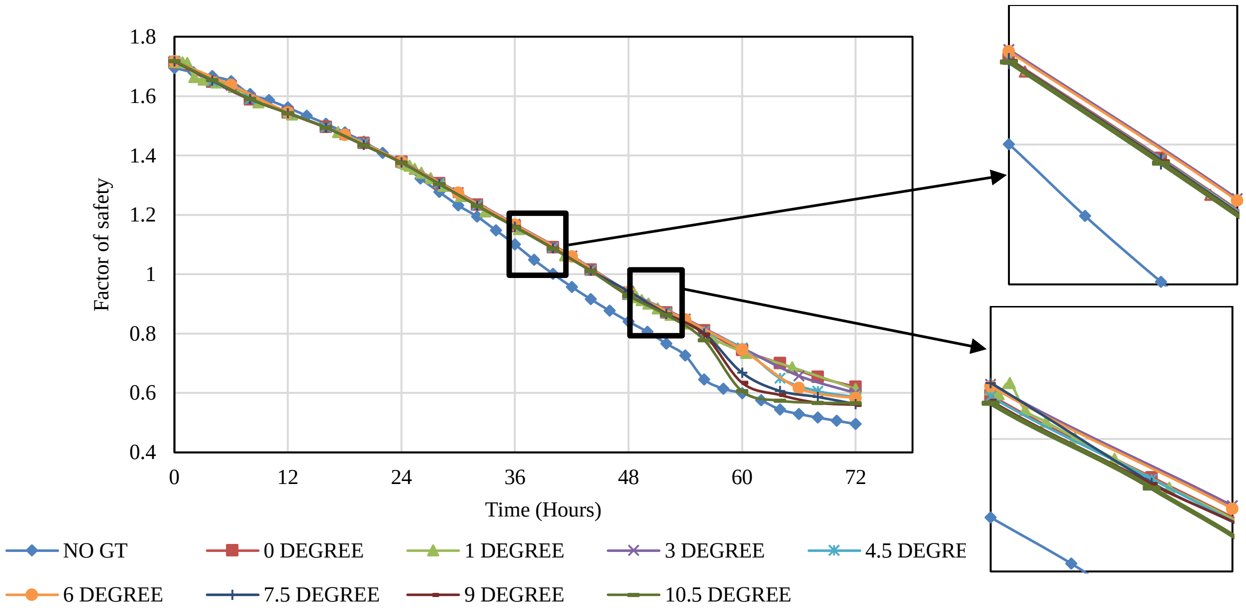
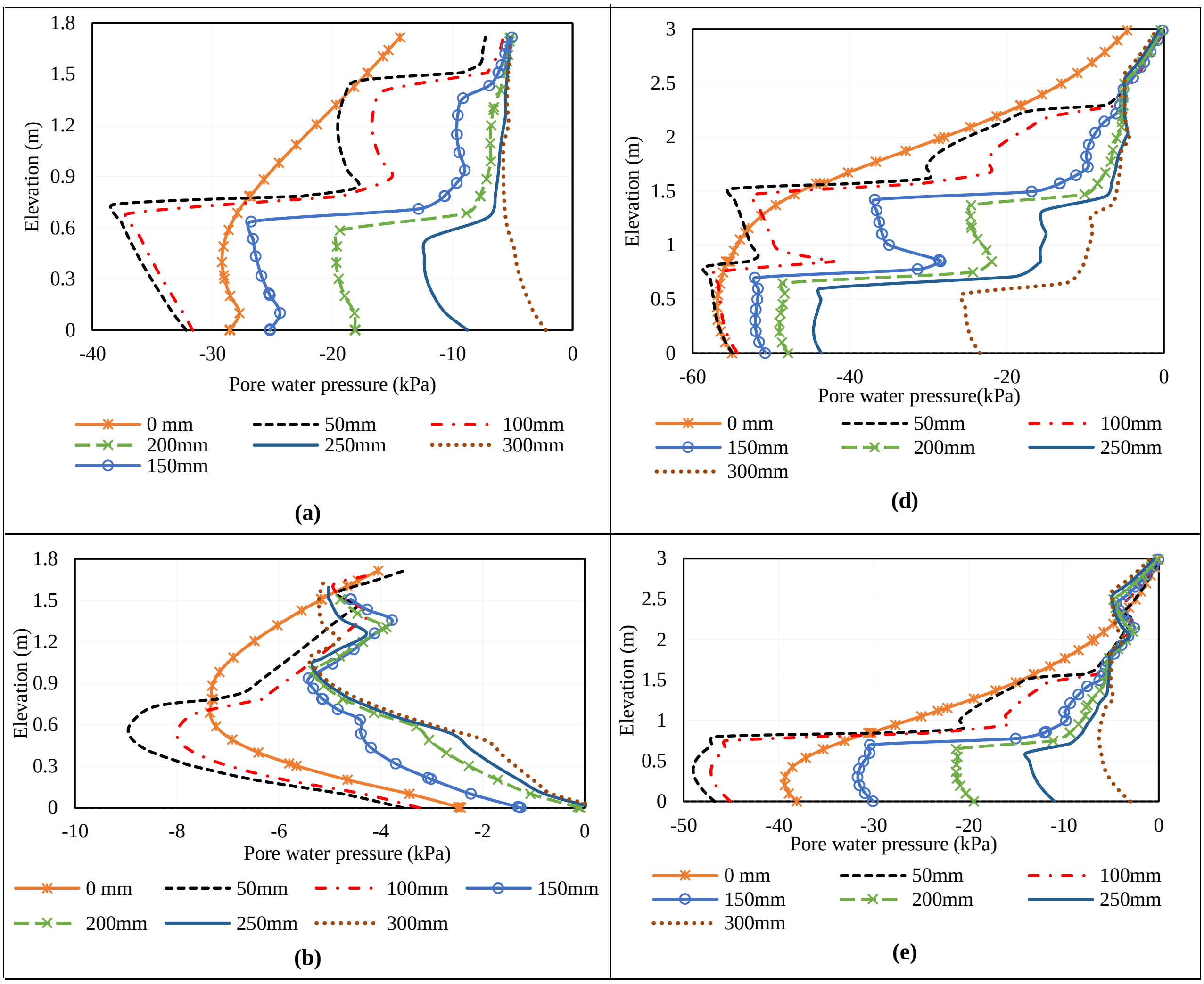


Figure 6. Variation of factors of global factor of safety with change in geotextile inclination angle

4.2. Effect of Sand Layers Thickness on the Performance of RCS Embankments

Figure 7 presents the pore water pressure profiles of the embankments with varying sand cushion thickness with changes in days are shown. At the end of day one, the embankment whose non-woven geotextile layers were not sandwiched between non-woven geotextile layers recorded the lowest rates of pore water pressure within their profiles with the embankments whose non-woven geotextile layers were sandwiched with the thickest sand layer of 300 mm recording the highest values of pore water pressures within their profiles. This is attributed to the difference in the initial matric suction of the sand and RCS in the embankment, because the loss of matric suction is attributed to the increase in the volumetric water content of the soil, RCS with a much lower hydraulic conductivity (1.072×10^{-8} m/s) and high matric suction (60 kPa) took a much longer time for the loss of matric suction and development of significant pore water pressure in the initial stages. On the other hand sand with a high hydraulic conductivity and low matric suction (3.5 kPa) took much lesser time for pore water pressure development and this strongly explains the high pore water pressure values in the early stages of the rainfall event. The initial high pore-water pressure development rates in embankments with sand cushion was also attributed to the fact that, part of the sand layers were exposed to the rainfall on the sloping part of the embankment. This made the sand layers to act as a medium through which rain water made its way into the embankment.

However with advancement of time as the water flux passed through the embankments, pore water pressure of both soils significantly increased. With an increase in the volumetric water content in the upper parts of the embankment the advantage of sand layer cushions was exhibited. Sand cushions effectively started working as drainage layers. Embankments with thicker sand cushions recorded lower pore water pressure values within their profile as compared to embankments with thin sand cushions which recorded higher values of pore water pressure values within their profiles. This can be attributed to the increased pathways for water drainage that is provided by the coarse grained sand soil unlike the RCS which provided lesser flow path ways due to finer soil particles thus thicker sand layers further increased the drainage paths which proportionally reduced with the decrease in sand layer thickness. Generally the pore water dissipation increased with increase in sand cushion layer thickness, similar results were reported by [14]. Considering the pore water pressure profiles and sand thickness, sand cushion thickness greater than 100 mm on either side of the non-woven geotextile layer adequate served to dissipate the pore water pressure in the embankments.



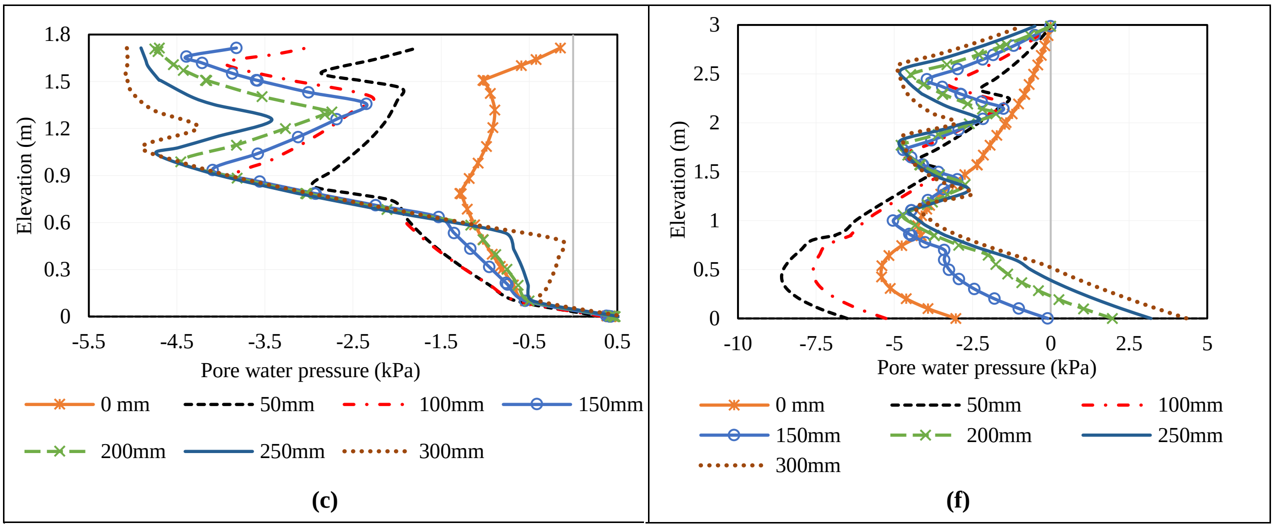


Figure 7. Pore water profiles of embankments with change in sand layer thickness at end of: (a) day one x=1.2m from toe; (b) day two x=1.2 m; (c) day three x=1.2 m; (d) day one x=2.4 m from toe (e) day two x=2.4 m and (f) day three x=2.4 m

Figure 8 presents the variation of the global factors of safety of the embankment with change in sand cushion thickness. There was a general decline in the factors of safety of the RCS embankments with the increase in the rainfall duration as earlier explained this is because of the increase in pore water pressure in the embankments with time. It was observed that in the early stages of the rainfall event the factors of safety of the embankments with sand cushion layers decreased with increase in the sand cushion thickness. This is attributed to the initial matric suction of sand (-3.5 kPa) and RCS (-60 kPa). The lower matric suction value of sand was rapidly lost as the rainfall flux infiltrated through the RCS embankment. A lower matric suction contributes to the reduction in the shear strength of the sand as can be derived from equation 4 and this consequently reduces the factor of safety of the embankment. RCS with a higher matric suction took significant time for the matric suction to be dissipated thus the high initial factors of safety for the embankments with small sand cushion thickness. However, as the rainfall flux infiltrated through the embankment the contribution of the sand cushion in the strength of the soil was demonstrated. Sand cushions acted as drainage layers dissipating pore water pressure thus better factors of safety as compared to embankments with smaller sand layers. With the advancement of time it was observed that the thicker the sand cushion the higher the factor of safety values recorded for the embankments.

At 36 hours the factors of safety curves of the different embankments with sand cushions converged. This marked the point at which most parts of the RCS zones became saturated. Due to the high volumetric water content in the RCS layers, the shear strength of the embankment was not dependent on the matric suction of the RCS but was now largely dependent on the drainage and effective shear provided by the sand cushion layer. This explains the change in the curve trends after the convergence, with the embankments having thicker sand layers now recording the best trends in the local factors of safety of the embankments. The trend continued till the end of the rainfall event with the factors of safety of the embankments increasing with increase in the sand layers thickness. An introduction of a 50mm sand layer increased the 72 hours factor of safety of the embankment from 0.567 to 0.916 signifying a 61% increase in the global factors of safety. A sand layer thickness of 100 mm improved the global factor of safety of the RCS embankments from the unstable factor of 0.255 when without sand layers to the stable factor of safety of 1, a further increase to 150 mm sand cushion layer improved the factor of safety of the embankment to 1.01 a 78% increase in the factors of safety. It was also observed that with increase in sand layer thickness the rate of factor of safety decline becomes low. The rate of factor of safety decline stagnated earlier with increase in drainage layers thickness. This presents another advantage of the sand cushion layers in marginal soils embankments. The results are in agreement with findings of [16].

Of importance to the construction industry is the good drainage and stability of the embankments. An embankment composed of purely RCS though reinforced with geotextile is prone to failure at around 39 hours since the factor of safety values fall below 1. The same failure faces embankments with sand layers of thickness 50mm and 100 mm which are prone to failure at around 54 and 60hours respectively. A sand layer thickness of 150mm is thus determined to be adequate in the construction of RCS embankments and effectively reduces the amount of river sand used in the embankment construction to a meagre 15%.

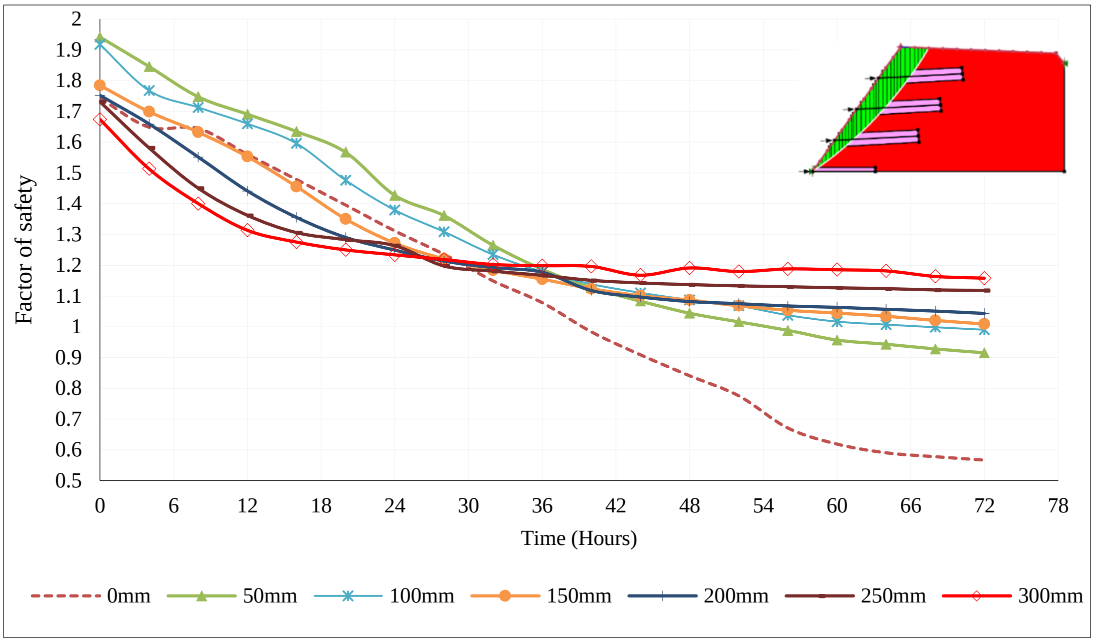


Figure 8. Factors of safety of RCS embankments with varying sand cushion thickness

5. Conclusions

The behavior of red coffee soils embankments was numerically investigated in this study. The effect of rainfall on the stability and pore water pressure development was evaluated. From the study it is concluded that.

1. Non-woven geotextiles inclined at three degrees in red coffee soils embankments made them more effective in draining and dissipation of pore water pressure and became more effective when the soils interface region became saturated.

2. Pore water pressure in RCS embankments have a high influence on the stability of embankments. Inclusion of sand layers to sandwich non-woven geotextile material improved drainage in the Red coffee soils embankments consequently enhancing strength and stability of the RCS embankments, a thickness of 150mm on either side of the geotextile was found adequate. A sand layer of 150 mm thickness sandwiching the non-woven geotextile effectively reduced the amount of sand required to a meagre 15% saving the sources of the natural resources in construction.

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8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

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