Model Study on Slope Failure Subjected to Rainfall

Karuna Elizabeth Chacko

Dept. of Civil Engineering
Saintgits College of Engineering
Kottayam, India
Rakendu R
Dept. of Civil Engineering
Saintgits College of Engineering
Kottayam, India

Abstract— **Purpose of the paper is to present a scaled model of slope to study the infiltration process subjected to rainfall. To observe the infiltration process on slope, artificial rainfall is applied to model using sprinkler system at a rainfall intensity, ie, 133mm/h. Pore-water pressure (PWP) and displacements are measured using sensors, which are installed within the model at various locations to monitor the changes in suction. The aim is to study the slope movements of the soil water content, pore-water pressures and displacement with and without placing geotextile in the slope. The study tries to predict slope failure caused by monitoring these parameters. Based on these results, the time for first failure can be evaluated.**

Keywords— **slope, rainfall intensity, pore-water pressure, displacement**

I. INTRODUCTION

Kerala has gone through large amount of destruction and damage causing difficulty to human life, due the rainfall that place in monsoon, 2018. Recently, landslide had occurred in many part of the state. The landslide has occurred mainly in mountainous region which consist of debris, rock mass, etc., where now the place is beyond recognition. This landslide has occurred mainly due to the increase in water level beyond the ground level and extreme increase in water level at river banks.

The major occurrence for slope failure is due the change of climate, increase in water level, improper drainage facilities and lack of study at the site. Initially, soil at the toe of the slope saturate faster at a higher rate and then saturate further area of slope which led to slope failure. Slope stability analysis is based on balancing of forces, moments or energy where failure is assumed to occur along slip surface. Fig. 1 shows the slope failure that took place at Kullanpadi-Muttakuzhi at Konni, Pathanamthitta.

The main objective of this paper is to identity the engineering properties of soil opted for slope failure study and to create a laboratory model for understanding slope stability. To study the properties of the slope which happened to fail on providing rainfall at a intensity**,** thereby, to measure pore-water pressure (PWP) and displacement dissipation during failure conditions. Also, to understand slope failures type under rainfall infiltrations is necessary to study. failure that took place at Kullanpadi- Muttakuzhi at Konni, Pathanamthitta.

Anusron Chueasamat et al (2018) has gone through series of test experiments to understand the effects of different combination surface sand layer density and rainfall intensity on the slope failures due to rainfalls. At first water gets accumulated at toe which reduces the effective stress. The generation of PWP values may be the deciding factor for stability of slope. **Edwin Garcia, Taro Uchimura (2007)** presents various scaled model experiments to study the infiltration process on embankments build using silty sand soil subjected to applied artificial rainfall infiltration. Pore-water pressure, water content and displacements transducers were installed within the models at various locations to monitor the changes in suction caused during cycles of wetting and drying processes.

Slavka Harabinova (2017) has presented the paper that deals with the assessment of slope stability on the road before and after the landslide caused by floods. To provide stability of slope, proper remedial method that includes anchorage and geogrid was adopted and better method is adopted based on geological conditions. Factor of Safety is calculated using GEO 5 software to opt for better reinforcing agent. **H. Rahardjo et al (2018)** study was carried out to evaluate the performance of the Geo Barrier System (GBS) which utilizes geobag containing fine material laid over coarse grain material and geogrid reinforcement when subjected to rainfall infiltration. The site was instrumented with gauges, results show that the GBS was effective in maintaining the negative pore-water pressure and the stability of the slope when compared with original slope. **Kuo-Hsin Yanga et al (2018)** has presented a series of numerical simulations of unsaturated slopes with various backfill–reinforcement–drainage systems subject to rainfall infiltration was performed by considering the combined effect of backfill (ie,sand, silt and clay), reinforcement type and rainfall intensity. The stability of the reinforced clay slope substantially decreased due to the loss of matric suction which is higher in sand slope. The influence of sand cushions in improving the stability of reinforced clay slopes was also assessed. Results also indicated that the inclusion of sand cushions, which provide both strength and drainage functions, can effectively enhance the slope stability.

Fig..1: Slope failure that took place at Kullanpadi- Muttakuzhi, Konni

A. Scope

- Landslide caused collapse to many structures and roadways due to the movement of water.
- This leads to loss of life and property, damage to natural resources and damage to roads, bridges, etc.
- Properties of soil at various depth can be improved using geotextile agents.
- Non woven geotextile is used to improve drainage facilities and improve capillary barrier effect.

II MATERIALS REQUIRED

Soil was collected from Kullanpadi- Muttakuzhi in Konni, Pathanamttitha district. Soil sample was collected from depth 1m from ground surface. Soil found from the location is laterite soil. Slope subjected to failure is hilly region where rubber, teak and plantation are the main cultivation at that location. Collected soil sample are meant for preparation of laboratory model. Table I shows the preliminary properties of soil collected from site.

TABLE I. PRELIMINARY TEST RESULTS OBTAINED

S.No	Test Preformed	Results
1.	Natural water content	12.24%
2.	Specific gravity	2.51
3.	Percentage of gravel	31%
4.	Percentage of sand	47%
5.	Percentage of silt	4.5%
6.	Percentage of clay	6.5%
7.	Optimum moisture content	21.2%
8.	Maximum dry density	1.667g/cc
9.	Liquid limit	57%
10.	Plastic limit	20%
11.	Plasticity index	37%
12.	Permeability	5.704×10^{-3} cm/s
13.	Soil classification	SP-GP

Coir geotextile of 3mm thickness was collected from Alapuzha Coir Institute. Fig. 2 shows the geotextile collected from Alapuzha Coir Institute.

Fig. 2: Coir Geotextile

III PREPARATION OF LAB MODEL

Model construction is done with samples collected from the site. Slope of the model to be constructed is to be decided, that is, maximum height in which deformation does not take place. Slope is constructed with and without geotextile in order to understand the performances. Soil-Water Characteristic Curve (SWCC) is to be plotted between matric suction and degree of saturation. Here, matric suction can be determined using ASTM D 5298 filter paper method and degree of saturation is determined using Standard Proctor Test.

The slope model is constructed in steel platform with transparent glass surface on front side to observe the failure pattern and note down the initial elapse time. For trail 1, the slope model was constructed at a height of 80 mm and length of 100 mm with toe length of 20 mm and length of 10 mm and thereby, providing a slope angle of 38.6⁰, whereas, for trial 2, model has a height of 75 mm and length of 75 mm with slope angle of 45⁰ and toe length of 20 mm and length of 10 mm. For both the trials slope has a crest width of 50mm. Slope is constructed in layers by compacting soil at maximum dry density with optimum moisture content, that is, construction of slope is done by compacting each soil layers. Water is supplied at a specific height say about 2m. Artificial rainfall can be provided with the help of three spray nozzles which is placed at a distance of 50 cm from each other on providing rainfall intensity of 133mm/h for trial 1 and 2 cases. Fig. 3 gives the model setup arrangement.

Observations are to be made at different rainfall intensities with and without placing geotextile in order to measure positive pore water pressure (PWP) using pressure sensor and displacement of slope using strain sensor affected due to rainfall.

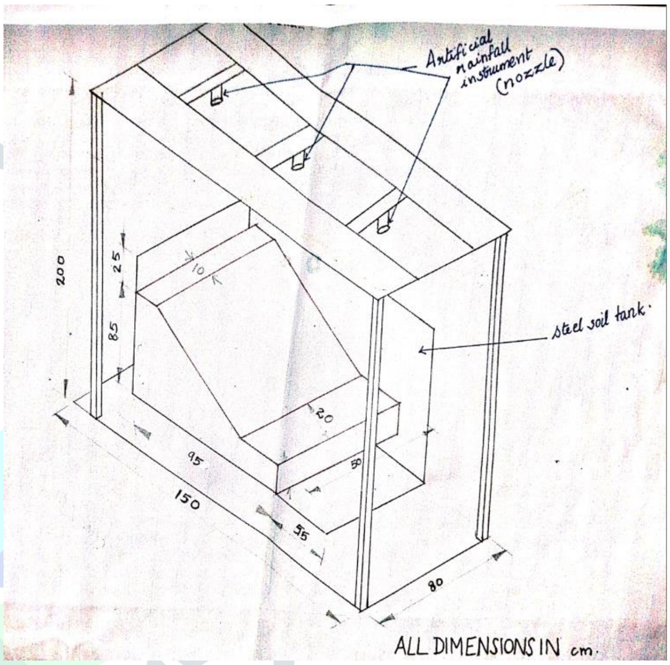

Fig. 3: Model arrangement

IV. INSTRUMENTS USED

A. Pressure sensor

Using MPX10DP pressure sensor, positive pore-water pressure can indicated during initial failure. MPX10 device are silicon piezo-resistive pressure sensors providing a very accurate and linear voltage output, directly proportional to the applied pressure. It can measure a maximum pressure of 10 kPa. These sensors are standard, low cost sensor permit manufacturers to design and add their own external pressure. The pressure sensor is connected to arduino board in order to display the pressure on the system. Fig, 4 shows the MPX10DP pressure sensor connected to arduino board.

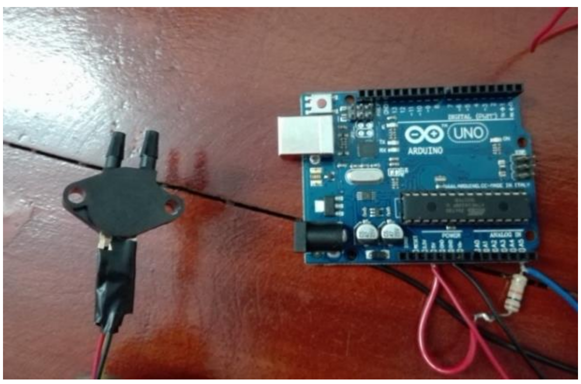

Fig. 4:MPX10DP pressure sensor connected to arduino board

B. Strain sensor

Strain sensor is used to measure the horizontal displacement of the slope by calculating the ratio on change in length to original length. Strain gauge of 120Ω is connected Arduino Uno board. The strain sensor has a gauge length of 10mm. Arduino Uno board act as microcontroller. Programs can be loaded on the arduino computer program. Fig. 5 shows strain sensor connected to arduino board.

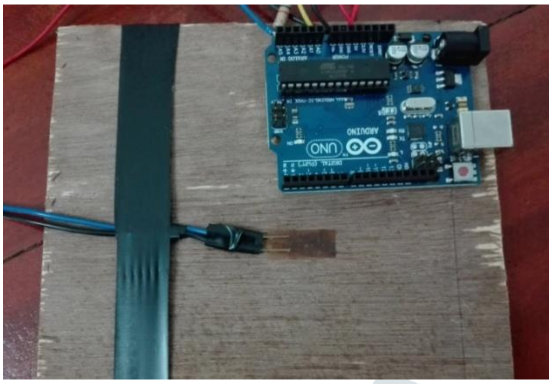

Fig. 5: Strain sensor

V RESULTS ON TEST MODEL

For this test, different cases are to be considered on constructed slope on providing rainfall intensity, that is, 133mm/h.

A. Rainfall simulator

Using spray nozzle irrigation pipe, constant artificial rainfall of 133 mm/h can be provided by 3 spray nozzles to slope constructed. This artificial rainfall gets infiltrated into the soil collected from site leading to slope instability.

B. Failure situation

1) Case 1- Slope angle= 38.6⁰, Rainfall intensity= 133mm/h: On considering, case 1, with rainfall intensity of 133 mm/h. There is sudden increase of pore-water pressure (PWP) within 15 minutes after applying rainfall. PWP gradually increases leading to initial failure in the slope. Due to the downward infiltration of the rainfall, maximum or initial failure was experienced at the head or crest of the slope, further leading to sliding surface of the slope. PWP value was measured as a value near to zero and as the initial failure was observed as 1kPa with elapse time of 50 minutes. Initial elapse failure is shown in Fig 6. In this case, test was conducted for 3 hours and there was a vertical settlement of 20 mm from the initial position, which under the case of failure as shown in the Fig 7. Fig 8 shows the failure in slope after 3 hours. From the strain gauge, value for strain is obtained as 0.00075 and corresponding horizontal displacement is obtained as 0.9 mm which determined from formula, strain = $\frac{horizontal\ displacement}{original\ length}$

⇒ strain x original length = horizontal displacement

⇒ 0.00075 x 1200 mm = 0.9 mm

Fig. 6: Initial failure in slope at 50 minutes

Fig. 7: Progress in failure on PWP increase at 133mm/h rainfall intensity

Fig. 8: Failure of slope after 3 hours

2) Case 2- Slope angle= 45⁰, Rainfall intensity= 133mm/h, without geotextile: Now, considering, Case 2 for the slope with slope angle 45⁰, thereby providing rainfall intensity of 133 mm/h to the slope. Here also, due to the downward infiltration of the rainfall, maximum or initial failure was experienced at the head or crest of the slope, further leading to failure at sliding surface of the slope. PWP value was measured as a value near to zero. As the initial failure was observed, PWP is observed as 1kPa with an elapse time of 30 minutes. The slope experienced a horizontal displacement of 0.6 mm at middle of toe and centre of slope with a strain of 0.000631 having slope length of 950 mm, that is, strain in case 2 is observed as 0.000631. Therefore, strain x original length = change in length, that is, 0.000631 x 950 mm = 0.6 mm. Fig. 9 shows the initial failure of slope and fig. 10 Failure of slope after 3 hours

Fig. 9: Initial failure of slope at 133 mm/h rainfall intensity for slope angle 45⁰

Fig. 10: Failure of slope after 3 hours at 133 mm/h rainfall intensity

3) Case 3- Slope angle= 45 ^{0}, Rainfall intensity=133mm/h, With geotextile: On considering, this case by constructing slope of 45⁰ on providing 75 mm thick geotextile in two layers, each at 30 cm from the base of slope. Rainfall intensity of 133 mm/h was supplied to the slope. Due to the downward infiltration of the rainfall, initial failure was experienced at the crest of the slope. PWP value was measured as a value near to zero. As the initial failure was observed, PWP is observed as 1kPa with an elapse time of 50 minutes. From the observation, it is seen that initial failure for elapse time increases by 20 minutes on providing geotextile to the slope with same slope angle. The slope experienced a horizontal displacement of 0.43 mm between the toe and centre of slope with a strain of 0.000453 having slope length of 950 mm. Therefore, strain x original length = change in length, that is, 0.000453 x 950 mm = 0.43 mm. Fig 11 shows the initial failure of slope on stabilizing with 75mm thick geotextile at 133mm/h rainfall intensity.

Fig. 11: Failure of slope on stabilizing with 75mm thick geotextile at 133mm/h rainfall intensity

C. Failure type

Failure types for both the cases are considered as surface slide failure because of the sequence of failure progressed to upper part of slope. Surface slide failure was experienced at both the cases because of the weak structural surface and high rainfall intensity, that is, I =133 mm/h. There will be decrease in effective stress due to the accumulation of rainwater at the base and further increase in its level. At first some soil is mixed with lots of rainwater flows from the toe as the seepage pressure grow till the first crack occurred Rainwater gets accumulated at base of slope because rainwater was drained vertically downward from surface to base. Excess rainwater at base and further increase in pore-water pressure (PWP) eventually led to vertical settlement or development of initial failure and horizontal displacement of slope. This is observed due to the decrease in effective stress. PWP gradually increases due the lack of proper drainage.

VI. CONCLUSION

- The preliminary tests of samples were completed. Soil chosen were identified which lies in different soil classification. Soil was classified as SP-GP (soil of poorly graded sand and gravel) with 31% of gravel, 47% of sand, 4.5% of silt, 6.5% of clay.
- For both the trials, there was a gradual increase in PWP around 15 minutes on providing rainfall intensity I= 133 mm/h.
- Failure was initially experienced at head and graduated to sliding surface of the slope.
- Surface slide failure was experienced at both the trials because of the weak structural surface and high rainfall intensity.
- It was observed that rainwater gets infiltrated almost straight towards the foundation.
- There will be decrease in effective stress due to the accumulation of rainwater at the base and further increase in its level.
- At first some soil is mixed with lots of rainwater flows from the toe as the seepage pressure grow till the first crack occurred.
- PWP gradually increases due the lack of proper drainage.
- It was observed that elapse time for initial failure increases by 20 minutes on providing 75 mm coir geotextile in two layers for same slope angle.
- On providing coir geotextile, elapse time can be increased with shows that geotextile act as a drainage material.

REFERENCES

[1] A. Sharma, P. T. Raju, V. Sreedhar, H. Mahiyar, "Slope Stability Analysis of Steep-Reinforced Soil Slopes Using Finite Element Method," Geotechnical Applications, vol. 13, pp. 163-171, June 2019.
[2] A. Chueasamat, T. Hori, H. Saito, T. Sato,, Y. Kohgo, "Experimental tests of slope failure due to rainfalls using 1g physical slope models," Soils and Foundations, *vol.* 58(2), pp. 290-305, April 2018
[3] H. Rahardjo, Y. Kim, N. Gofar, E.C. Leong, C.L. Wang, J. L.H. Wong, (2018) "Field instrumentations and monitoring of GeoBarrier System for steep slope Protection," Transportation Geotechnics, vol. 208(23), pp. 345-354, June 2018
[4] S. Sun, S. Li, L. Li, S. Shi, J. Wang, J. Hu, C. Hu, "Slope stability analysis and protection measures in bridge and tunnel engineering: a practical case study from Southwestern China," Springer, vol. 87(39), pp. 1-17, August 2018.
[5] S. Harabinova, (2017) "Assessment of Slope Stability on the Road," Elsevier, vol. 190, pp.390 – 397, 2017.
[6] K. H. Yanga, J. N. Thuo, V. D. A. Huynh, T. S. Nguyen, F. H. M. Portelinha, "Numerical evaluation of reinforced slopes with various backfill reinforcement-drainage systems subject to rainfall infiltration," Elsevier, vol. 20(6), pp. 457-471, 2017
[7] S. Naidu, K. S. Sajinkumar ,T. Oommen, V. J. Anuja, R. A. Samuel, C. Muraleedharan, "Early warning system for shallow landslides using rainfall threshold and slope stability analysis," Elsevier, vol. 10, pp.1-12, 2017.
[8] H. Moayedi, B. B. K. Huat, T. A. M. Ali, A. Asadi, F. Moayedi, M. Mokhberi, "Preventing landslides in times of rainfall: case study and FEM analyses," Disaster Prevention and Management: An International Journal, vol. 20 (2) , pp.115 – 124, 2017.
[9] S. Pramusandi, I. A. Rifa, K. B. Suryolelonob, "Determination of unsaturated soil properties and slope deformation analysis due to the effect of varies rainfall," Procedia Engineering, vol. 125, pp. 376 – 382,2015
[10] M. Heibaum, "Geosynthetics for waterways and flood protection structures - Controlling the interaction of water and soil," Geotextiles and Geomembranes, vol. 42(4), pp.374-393, 2014.
[11] E. Garcia, T. Uchimura, "Study of failure mechanism in embankments Induced by rainfall infiltration by monitoring Pore water pressures and water contents," Elsevier, vol. 74(152), pp. 125-135, 2007
[12] R. P. Orense, P. S. Shimoma, K. Maeda, I. Towhata, "Instrumented Model Slope Failure due to Water Seepage," Journal of Natural Disaster Science, vol. 26(1), pp. 15-26, 2004.
[13] P. S. H. Poh, B. B. Broms,lope Stabilization Using Old Rubber Tires and Geotextiles," Journal of Performance of Constructed Facilities, vol. 9(1),pp.76-79,1995.