Stability Analysis of Slope in Kuranjeri During Kerala Flood 2018 Using Plaxis-3D

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Abstract. Landslide or landslip is defined as a type of mass movement in which a mass of rock, debris or earth down a slope under the direct influence of gravity. In this study Kuranjeri of Thrissur district have been selected where landslides occurred during 2018 Kerala floods. In this case landslide was triggered by incessant heavy rainfall followed by mass movement of debris. An investigation was carried out to discern index properties and soil parameters on the collected soil samples. Limit equilibrium method (LEM) is the most common approach for analyzing slope stability by investigating the equilibrium of a soil mass tending to slide down under the influence of gravity. As a powerful alternative advanced numerical method, Finite Element Method (FEM) quantify factor of safety against slope instability by Strength Reduction Method of Stability Analysis using Plaxis-3D. A comparison is then made between the results of LEM and FEM by in cooperating properties of in-situ soil on slope failures. The analysis result unveils that the infiltration of water into the slope resulted in the failure of the slope on account of reduction of shear strength parameter of the soil.

Keywords: Landslide, Kerala flood 2018, Rainfall, Slope stability analysis, Plaxis-3D.

1 Introduction

1.1 Landslide

Landslides, described as mass movement of soil or rock differs from other types of soil or rock movement (falls, topples or flows) by its shear displacement along one or several rupture surfaces, which are either visible or maybe reasonably inferred [8]. Landslip or landslide is a dynamic phenomenon in the hilly terrains around the world and is a part of ongoing evolution of the landscapes that constitute a major threat to both lives and property worldwide causing long term impact on society as well as nation. The tropical climate, unstable land forms, deforestation and unplanned developmental activities makes the hilly areas of India prone to landslides as an annual and recurring event.

The location of groundwater table in most of the high slopes is deep below the ground surface and the pore-water pressures in the soil above ground water table are negative. This negative porewater pressure is called matric suction when referenced to pore-air pressure which contributes to the stability of unsaturated soil slopes. Hence the effect of rainfall infiltration on slope could result in changing soil suction and positive pore pressure, or main water table as well as raising soil unit weight, reducing shear strength of rock and soil. Generally, unsaturated soil slope failures happen most frequently during rain periods. The infiltration of rainfall will increase the groundwater level and water pressure and decrease matric suction of unsaturated soils.

1.2 Slope Stability

The slope stability analysis is usually carried out to assess the safe and economic design of natural or man-made slopes. Slope stability can be defined as the resistance of an inclined surface to failure by either sliding or collapsing. The choice of analysis technique can be attributed to site conditions and the possible failure mechanism. The traditional concept of slope stability is to evaluate the minimum factor of safety.

Different methods used in the slope stability analysis are limit equilibrium method, limit analysis theorem, numerical modelling etc. Limit equilibrium method satisfies force and/or moment equilibrium of a soil mass above the potential failure wedges. Limit analysis is used due to its physical significance and strict solving range. Numerical modelling has been emerged as a tool based on the application of finite element and upper bound analysis of plasticity limit analysis.

The advantages of adopting numerical techniques (Finite Element) in slope stability problems are,

- failure occurs naturally through the zones within the soil mass in which soil shear strength is unable to withstand the applied shear stresses.
- No assumption needs to be made in advance about the shape or location of the failure surface. There is no concept of slices and hence no assumptions are required for inter-slice side forces.
- The solutions from numerical methods provide information about deformations at working stress levels.
- Progressive monitoring of failure is possible.

1.3 Kerala Flood

Kerala has witnessed one of the worst floods of the century after the great flood of 99 that happened in 1924. In the month of August alone Kerala had recorded excess rainfall of 41% that led to opening of 34 out of 39 dams which resulted in loss of 483 lives and a damage of Rs 40,000 crore. Thrissur district alone received an increase in rainfall around 16%. Thrissur District Administration has informed a loss of Rs 1300 crore. Within the district, 42 villages in and around the Cole fields and on the banks of Conolly canal and Herbert canal was inundated with the Karuvannur river changing its direction. 98 roads in Thrissur was submerged in flood water. 14 landslides were recorded within the district.

1.4 Study Area

In this study, Kuranjeri of Thrissur district have been selected where landslides occurred for the first time in its history during Kerala flood in August 2018. Kuranjeri is a forest area situated in Thekkumkara/ Minaloor Panchayath of Thalapilly Taluk, Thrissur district, Kerala. The study area witnessed one of the largest landslides of the district. The site is located at a latitude of N10˚ 37′ 41.2″ and longitude of E 76˚ 13′ 48.1″. The failure area comprised toe of width 65m with an elevation of 63m. At an elevation of 128m subsidence occurred. During the landslide the soil got displaced to an extent of 500m and resulted in loss of 19 lives. In addition, 4 houses were washed away with severe damage to roads, crops, other material property. Figure 1 shows the landslide that occurred in Kuranjeri.

Fig. 1. Shows landslide at Kuranjeri on 16/08/18

Topography. The area consists of dry deciduous vegetation, teak being the major among them. The hill has a slope of 34˚ with a height of 152m from the MSL. Laterite have orange to red colour and clay of white colour. Soils exhibited medium to fine grained texture. A channel was present at the bottom of the failure surface where sand and boulder sized particles were observed.

Geomorphology. The lithology of the terrain includes forest tree underlaid by forest soil followed by 4m thick laterite with fragments of weathered crystalline rock below which weathered bed rock was present as shown in Figure 2. Some clay patches were observed in the site. A newly formed under developed cracks were present just a few meters below the crest.

Fig. 2. Lithology at the site of failure at Kuranjeri

Rainfall. During the occurrence of landslide, Thrissur district marked rainfall as shown in the table below collected from Kerala Agricultural University, Vellanikara.

Table 1. Rainfall Data

Dates	15/08/18	16/08/18	17/08/18
Rainfall (mm)	140.6	253.6	148.4

2 Materials and Methods

For this study a reconnaissance survey was conducted and all the necessary details were collected from the site as well as from the locals from the area. The samples were collected from four locations at 1m depth from ground surface that comprises two from the slide mass portion and two from the unaffected areas at a distance of 15m apart marked as S1A, S1B, S1C and S1D as shown in the Figure 3. Both disturbed as well as undisturbed soil samples were collected from four locations. The undisturbed soil samples were taken with help of sampling tube and was tightly sealed to preserve the natural properties of the soil while transporting. The field density of the soil samples was determined from the site itself. Detailed experimental investigation was conducted to determine the geotechnical properties of the collected soil samples in the laboratory using the standard procedures put forward by Indian Standard codes.

Fig. 3. Location of sample collected

2.1 Experimental investigation

The collected samples were tested in laboratory to classify the soil as well as for determining the shear strength characteristics of the soil. The studies were carried out using the procedures outlined by IS 2720. The soil samples of all four locations had high percentage of sand sized particles of range 52%, 87%, 86% and 67% with fines in it. The fines have intermediate plasticity for the first three locations and low plasticity for S1D. The soils were classified as per the Indian Standard Classification System and they are clayey sand (SC), clayey sand (SC), silty sand (SM), and clayey sand (SC) respectively. The index properties of the soil samples of the four locations are given in the Table 2 below.

Table 2. Index properties of soil samples

PROPERTIES		S1A	S1B	S1C	S1D
Natural water content (%)		3	5	5	5
Field density (kN/m^3)		17	17	18	17
Saturated density (kN/m^3)		23	23	25	24
Specific gravity		2.5	2.5	2.7	2.6
Atterberg limit	Liquid limit (%)	37	44	38	34
	Plastic limit (%)	24	25	25	24
	Plasticity index (%)	14	19	13	11
	Shrinkage limit (%)	17	19	20	22
Particle size distribution	Gravel sized particles (%)	3	1	1	5
	Sand sized particles (%)	52	87	86	67
	Fine sized particles (%)	45	12	13	28

The shear strength parameters of the soil sample were determined by triaxial unconsolidated undrained test i.e. drainage from the soil specimen is not permitted during the application of chamber pressure. The test specimen is sheared to failure by the application of deviator stress. Modulus of Elasticity required for numerical analysis in PLAXIS-3D using Mohr Coulomb model was determined by taking the slope of initial tangent drawn to the stress v/s strain curve with respect to total stress. Theoretical method for the determination of pore water pressure, suggested by Skempton was used to determine the effective strength parameters. The engineering properties of the four soil samples are tabulated as shown below.

Table 3. Engineering properties of the soil samples

PROPERTIES		S1A	S1B	S1C	S1D
Compaction chracteristics	OMC (%)	21	18	12	20
	MDD (kN/m^3)	18	17	18	18
Triaxial	c (kN/m^2)	6	5	14	10
	ϕ (˚)	33	29	33	36
	E (kN/m^2)	10000	17500	25000	18000
	c′(kN/m^2)	4	2	13	9
	ϕ′ (˚)	26	21	27	30

Figure 4 and 5 depicts the modified failure envelope obtained in terms of total stress and effective stress for the four samples. The failure envelopes were drawn for the ultimate stress.

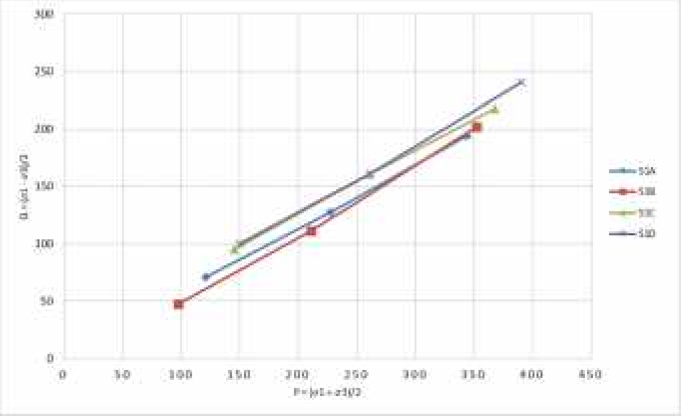

Fig. 4. Modified failure envelope under total stress

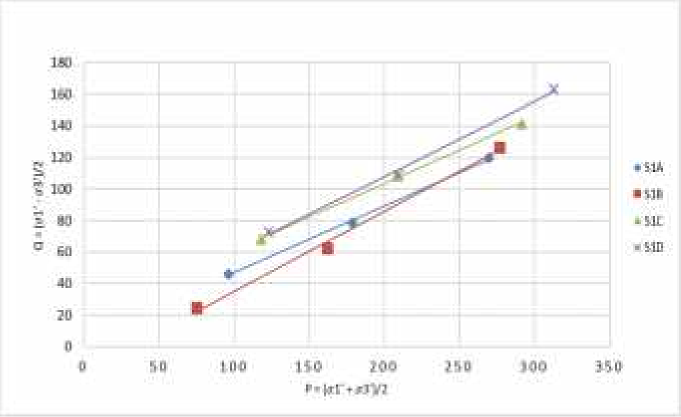

Fig. 5. Modified failure envelope under effective stress

2.2 Limit equilibrium method

Limit equilibrium methods investigate the equilibrium of a soil mass tending to slide down under the influence of gravity. These methods include conventional Limit Equilibrium Method (LEM) like the method of slices, Bishop's modified method, force equilibrium methods etc. Transitional or rotational movement is considered on an assumed or known potential slip surface below the soil or rock mass. All these methods are based on the comparison of forces, moments, or stresses resisting movement of the mass with those that can cause unstable motion. The output of the analysis is a factor of safety, defined as the ratio of the shear strength (or, alternatively, an equivalent measure of shear resistance or capacity) to the shear stress (or other equivalent measure) required for equilibrium. If the value of factor of safety is less than 1.5, the slope is unstable.

Analysis of Finite Slope. If the slope is of limited extent that connect land at one elevation to land that is not far away but is at different elevation, it is called a finite slope. They may exist in nature and man-made. The examples of finite slopes are the inclined faces of earth dam, embankments, and cuts etc. Failure of finite slopes occurs along a surface which is a curve. In stability computations, the curve representing the real surface of sliding is usually replaced by an arc of a circle or logarithmic spiral. The stability of a finite slope can be investigated by a number of methods. Some of them being the Culmann's method of planar failure surface, the Swedish circle method (slip circle method), The friction circle method and the Bishop's method.

The method developed by Swedish engineers is based on the assumption that the rotational angle of sliding during failure is circular. This method requires summing of the moments of all forces acting on the slope, including the gravitational force on the soil mass and the shear stress along the failure surface. If the moments are unbalanced in favour of movement, the slope fails else it will remain stable. The factor of safety can be calculated in this case as the ratio of the moments resisting failure to those causing failure. The analyses were carried out in different trials for different slip circles centred at different points of the Fellinius line drawn. The minimum factor of safety was selected from these trials. The slip circle with minimum factor of safety is called the critical surface. The slip circle is generally divided into 6-12 slices. Normal and tangential components of weight of each slice were found. The factor of safety against sliding is given by equations below.

1. For total stress

$$\text{F. S.} = \frac{cLa+\sum N\tan\varphi}{\sum T} \tag{1}$$

2. For effective stress

$$\text{F. S.} = \frac{c'La+\sum N'\tan\varphi'}{\sum T'} \tag{2}$$

2.3 PLAXIS

PLAXIS 3D is a finite element package intended for three-dimensional analysis of deformation and stability in geotechnical engineering with a full 3D pre-processor that allows CAD objects to be imported and further processed within a geotechnical context. The program is supplied as an extended package, including static elasto-plastic deformation, advanced soil models, stability analysis, consolidation and safety analysis.

PLAXIS is intended to provide a practical analysis tool for use by geotechnical engineers who are not necessarily numerical specialists. Quite often practicing engineers consider non-linear finite element computations cumbersome and time consuming. The PLAXIS research and development team has addressed this issue by designing robust and theoretically sound computational procedures, which are encapsulated in a logical and easy-to-use shell. As a result, many geotechnical engineers world-wide have adopted the product and are using it for engineering purposes.

The safety analysis in PLAXIS is determined by Phi-c reduction which is executed by successively reducing the strength parameters of the soil until the collapse of the soil occurs. The reduction of these parameters is controlled by total multiplier ΣMsf which is equal to the ratio of the available strength over strength at failure.

2.4 Stability analysis of slope

For both the analyses the slopes were considered to be finite as well as homogenous for all the four samples. The LEM analyses were carried out in different trials for different slip circles centered at different points of the Fellinius line drawn graphically. The critical failure surface was converted into circular form and analysis was carried out. For FEM analysis, the geometry of slope and the necessary soil parameters were entered required to analyse the slope. The soil was modelled as Mohr- Coulomb model and the meshing was carried out by using fine option in order to attain greater accuracy. Many numbers of trials were carried out using different depth of wetting.

3 Results and Discussions

Both the analytical and numerical analysis was carried out for all the four samples considering the height of the hill slope to be 89m inclined at an angle of 34˚. The analysis was carried out in terms of both total stress as well as in effective stress condition. For the analysis the water table was not taken in to consideration. Table 4 and 5 tabulates the factor of safety obtained for LEM and FEM in terms total stress and effective stresses respectively.

Table 4. Factor of Safety Obtained in terms of Total Stress

Type of analysis		Factor of safety			
		S1A	S1B	S1C	S1D
LEM	Swedish method	1.069	0.822	1.144	1.277
FEM	PLAXIS-3D	1.097	0.9356	1.177	1.266

Table 5. Factor of Safety Obtained in terms of Effective Stress

Type of analysis		Factor of safety			
		S1A	S1B	S1C	S1D
LEM	Swedish method	0.798	0.592	0.903	0.991
FEM	PLAXIS-3D	0.813	0.6026	0.949	1.024

Figure 6 represents slip surface divided into 12 slices for Swedish circle method of analysis

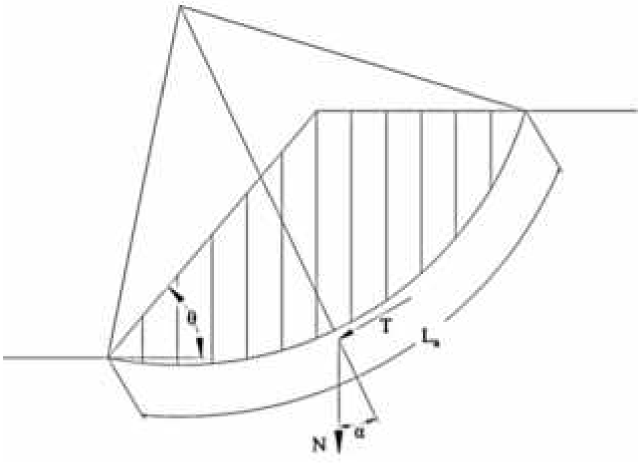

Fig. 6. Swedish circle method of analysis

Figure 7 is the resulting plot of the incremental displacement of S1B obtained from PLAXIS-3D that shows a good impression of the failure mechanism.

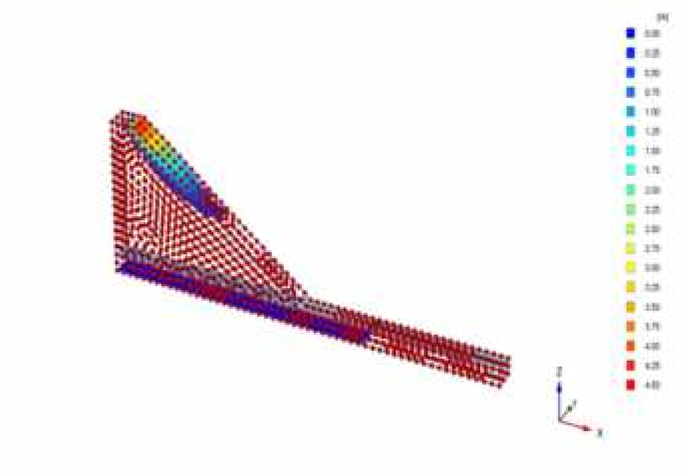

Fig. 7. Shadings of total incremental displacement indicating the most applicable failure mechanism obtained for S1B using PLAXIS-3D

It is known that for higher intensity of rainfall for a longer duration leads to higher wetting depth. In the month of August, the study area had received incessant rainfall continuously. Table 6 tabulates the factor of safety obtained without wetting as well as wetting depth at 1m, 2m, 3m, 4m, 5m and 6m

Table 6. Slope stability analysis results of PLAXIS-3D for different depths of wetting

WETTING DEPTH (m)	Factor of safety			
	S1A	S1B	S1C	S1D
0	0.8340	0.6040	1.086	1.111
1	0.8125	0.5998	0.9237	1.006
2	0.8114	0.6000	0.9225	1.004
3	0.8114	0.6009	0.9228	1.004
4	0.8115	0.6008	0.9221	1.005
5	0.8082	0.5990	0.9197	1.000
6	0.8056	0.5979	0.9176	0.9978

The decrease in factor of safety is comparatively more prominent from a depth of 4m to 5m. Figures 8, 9 and 10 represents the results of strength reduction analysis carried out in PLAXIS-3D without wetting depth and at depth of wetting 4 and 5m respectively for S1D.

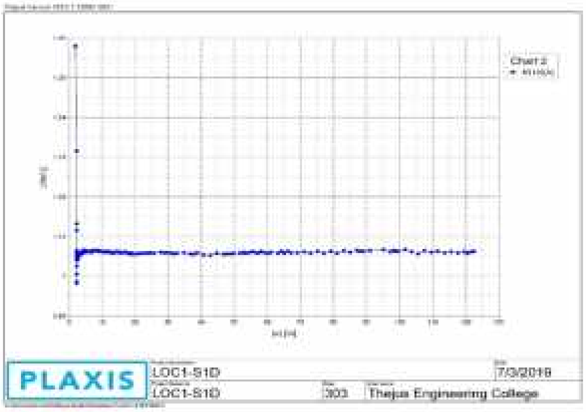

Fig. 8. Analysis without wetting for S1D using PLAXIS-3D

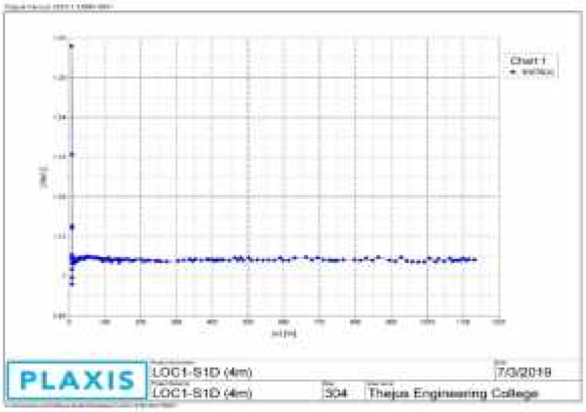

Fig. 9. Analysis with 4m wetting for S1D using PLAXIS-3D

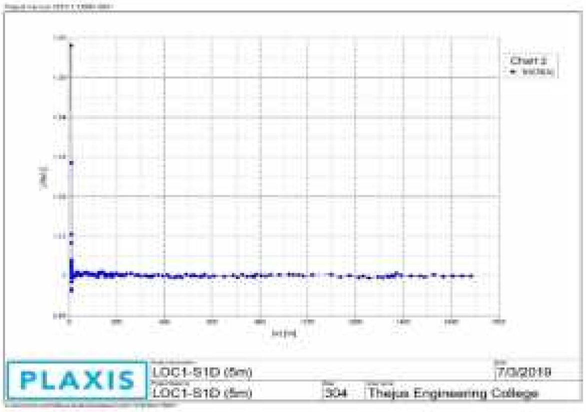

Fig. 10. Analysis with 5m wetting for S1D using PLAXIS-3D

4 Conclusions

For the first time in the history of Kuranjeri landslide occurred in the month of August during Kerala flood of 2018. The study area had received comparatively excess rainfall with longer duration nearly 16% for the month of August compared to the previous years. Hence the effect of rainfall infiltration on slope resulted in changing positive pore pressure as well as raising soil unit weight thereby reducing shear strength of soil.

The results obtained from both the LEM and FEM analysis of slope stability were found to be in close agreement. The factor of safety obtained from the LEM and FEM analysis shows that the four slopes were having low factor of safety. The decrease in the factor of safety can be attributed to the fact that the shear strength parameters get reduced with infiltration due to introduction of pore pressure which results in the reduction of the strength parameters. The wetting depth of the study area was found to be between 4 to 5m.

By providing suitable conventional or bio engineering methods that couples with proper drainage for the diversion or collecting arrangement of the rainwater may help to reduce the future slope failures.

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