Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943

Advanced Research in Applied Sciences and Engineering Technology

Stability Assessment of Landslide Occurred in India and Its Remedies: A Case Study

Ravendra Prasad Rajak[1,*], Meen-Wah Gui[1]

[1] Department of Civil Engineering, National Taipei University of Technology, Taipei, Taiwan

ABSTRACT

Landslide is a geological process on the surface of the earth, the downward movement of soil mass or rock on the slope region is called a landslide. Natural disaster has always been an important topic of discussion, currently India and many other countries are facing this sort of problem. Through the past study it's seen that there were thousands of landslides occurred in India due to typhoon and heavy rainfall; Kethikal landslide near to Mangalore in India is one of the hazard occurred in 1998 due to heavy rainfall. The total height of the slope is 67 meter and its length is 140.5 meter. Due to this disaster, traffic has been diverted for few days and some houses in the top of the mountain were damaged. The analysis of this slope failure has been done in Plaxis 2D program and found that the cause of failure of the slope is due to the rise of high porefluid pressure and by the field observation found the same cause. In Plaxis 2D, a number of numerical analyses has been done with soil nailing solution and found that the factor of safety of this solution is satisfactory. Soil nailing has been found to be one of the solutions for the treatment of the unstable slope.

Keywords:
Landslide; rainfall; numerical analysis; stability analysis; soil nailing

Received: 28 February 2021 **Revised: 1 April 2021** **Accepted: 26 April 2021** **Published: 14 May 2021**

1. Introduction

Landside has become one of the most serious problems in the present era. The rapid development of the infrastructure and climate change, accounts for maximum mass wastage from landslide on the Earth surface. This ultimately results to exponential loss of life and property [1]. The process of downward movement of soil mass or rock on the slope is called a landslide; this movement takes place due to the low soil shear strength and high slope angles. Generally, landslide occurs in rainy season due to heavy rainfall [2-3], the heavy rainfallgenerates pore-water pressure in soil mass and soil loses its strength. Landslides also occur due to natural hazards too, like tsunami and earthquake [4]. The major manmade activities accounting to construction of roads in hilly areas and development of infrastructure near slopes increases the risk of landslide. The excess rainfall in the mountain area is also one of the main reasons for these hazards. Due to these road transports, rail transport gets blocked for prolonged period and buildings get damaged and cracked.

* *Corresponding author.*
E-mail address: ravindrarec2008@gmail.com

https://doi.org/10.37934/araset.23.1.17

Kethikal is located in Thiruvail village in Dakshin Kannada district of Karnataka in India. The Gurupura River is located just 1.2 km from the landside point. The average rainfall in this area is about 3000 to 4000 mm per year [5]. Kethikal is a bus stop point situated at National Highway number 13 in Vamanjoor village, the total population of the village is 21928 and the total area is about 18.5 square kilometres. The coordinates of the affected site were 12° 55′25″ N and 74° 54′ 40″ E. The village is spread over the mountains. A major landslide occurred in June 1998 at NH-13 near Kethikal bus stop, there was a huge flow of soil mass towards the road. The road was affected for almost200 meters with 60,000 meter cubic materials moved from the adjoining slope [6]. The landslide resulted in road shrinkage by few meters and the blockage disruptive public lives. The site analysis and study revealed that the landslide occurred due to heavy rain fall (1000 mm). A study by Dr. B.M. Ravindra, a Geologist at DMG, Mangalore, has revealed that the highway is bounded by steeper slope made up of laterite clay which resulted to the sliding of the slope. In 2003, Kethikal faced another atrocious landslide. Kethikal is a coastal region and is surrounded by mountains covered with laterite soil, the top layer is made up of weathered laterite and bottom is made up of hard gneiss [7]. These soils are week and highly erosive, they do not have enough strength and sometime they can be used as filling materials for local use.

1. Methods and Materials

1.1. Slope Profile

The unstable slope is located in Kethikal bus stop on National HighwayNo 13. This area is covered by lithomargic clay which possess poor strength and stability, the Kethikal site is also the part of the same soil mass. Through geotechnical testing and field observation, the slope is divided into three layers.

The upper layer is made up of hard laterite and bottom layer have weathered rock and the middle layer contained lithomargic clay which is locally called Shedi soil. The slope has been divided in two part, the upper and the lower slopes, between the upper and the lower slopes there is a 12 m wide road. The height of the upper slope is 12 m and the height of the lower slope is 15 m. The upper slope is steeper than the lower slope. In the analysis the base length of slope is taken to be 140.5m and the total height is 67m, the upper slope angle is $65^o$and the lower slope angle is 55^o. The cross-section of slope is shown in Figure 1:

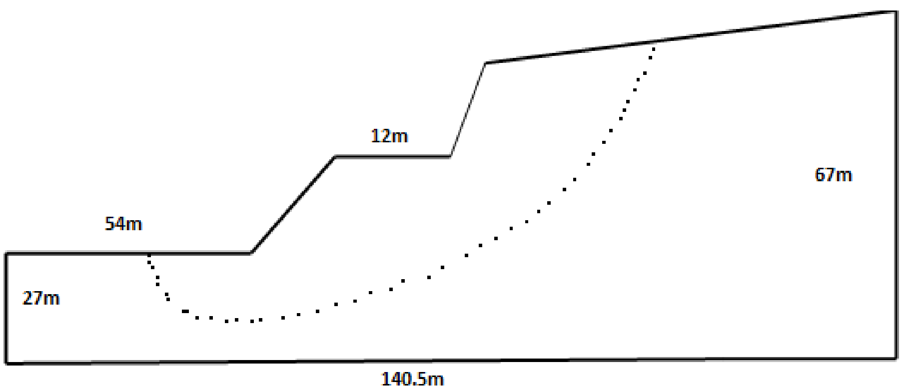

Fig. 1. Slope cross section

1.2. Material Properties

The material properties have been taken from the previous study by[6-7] and are given in Table 1.

Table 1
Strength properties of soil

Property	Upper Layer	Middle Layer	Lower Layer
Unit weight (kN/m^3)	16.07	16.96	17.85
Apparent Cohesion (kPa)	30	45	60
Frictional Angle (ϕ)	9	6	3

Table 2
Slope element dimensions

Slope element	Dimension
Base length (m)	140.5
Wall height (m)	67
Toe height (m)	27
Lower slope angle (Degree)	55
Upper slope angle (Degree)	65
Fill slope angle (Degree)	16
Road length (m)	12

2. Slope Stability Analysis and Results

Stability of the slope depends on the type of material present on and beneath the slope body, strength parameters are the main factor of slope stability and safety. Slope angle is also play important role in the stability of the mass present on slope. The drainage conditions of the materials depend on the type of material present on site. In this problem of analysis undrained loading condition has been chosen for the analysis of the slope stability [8].

2.1. Analysis

For the analysis of this slope, Plaxis 2D numerical analysis software has been used, at the time of analysis Mohr Coulomb model is prepared [9-10] and the undrained materials properties has been chosen as per the materials present in the slope site [7]. The analysis of the slope stability is based on the factor of safety obtained during the analysis, the following equation used to check the stability of slope.

$$\text{Factor of Safety (SOF)} = \frac{ResistingForce}{DrivingForce}$$

A factor of safety can be computed in Plaxis by reducing the mechanical property of soil, this method is called the shear strength reduction method, in this method the strength parameter as cohesion and internal friction angle ϕ are continuously reduced till the process fails. In Plaxis total multiplier ∑Msf value is used to check the factor of safety. Total multiplier is defined as the ratio between strength parameters entered at the time of calculation and reduced till it fails.

$$\sum Msf= \frac{\tan\emptyset\,(intial)}{\tan\emptyset\,(reduced)}=\frac{C\,(intial)}{C\,(reduced)}$$

2.2. Results
2.2.1. Slope stability analysis without water table

In the beginning of the analysis the slope has been considered as dry state [11] and the factor of safety was found as 1.155 which is less safe, in the previous study the slope is safe without pore water. In Fig. 2 the situation of slip circle without the water table is given.

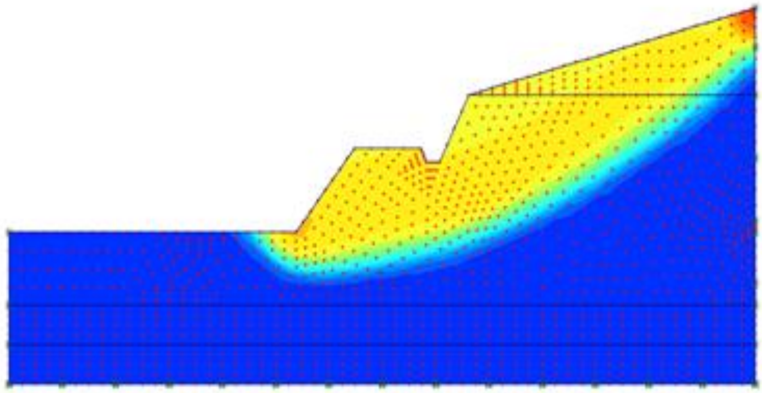

Fig. 2. Slope position without water table, factor of safety is 1.155

2.2.2. Slope stability with water table

In this stage of analysis, the position of water table has been taken and analyzed. The water table has been added at a height of 27 m from the baseand the final factor of safety is 1.005 which confirms the presence of water and instability. In the Fig. 3 we can see the situation of slope failure is base failure. In the analysis there was displacement and the value was 120m, when the analysis has been done without considering water the displacement was 1.3m which is almost similar to the physical condition of the site after landslide and before landslide.

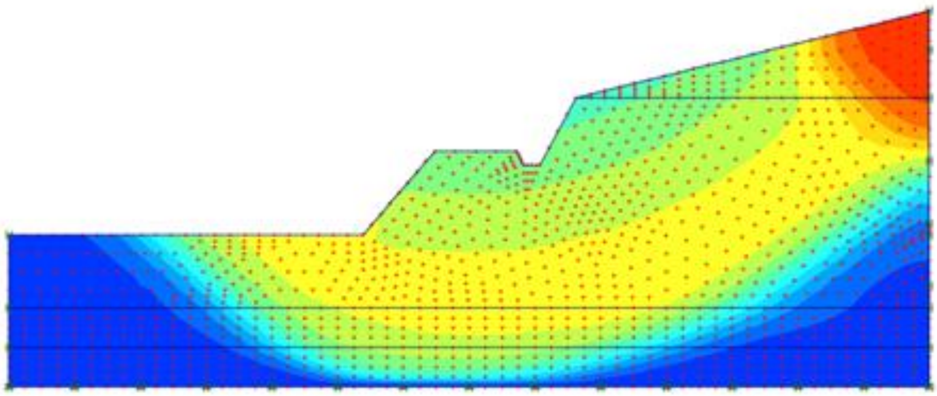

Fig. 3. Analysis result with water table and the factor of safety is 1.005

2.2.3. Slope treatment with soil nailing

Soil nailing is perhaps the most versatile slope mitigation technique, whether the slope is natural or artificial [12-13]. This method of slope treatment is effective, economical and less time consuming. In this technique steel bars are inserted in the soil slope with optimum angle and the bars are sealed with grouting. For soil nail design, American and British codes are used in this analysis. In Fig. 4 the section of soil nailing on a slope is shown.

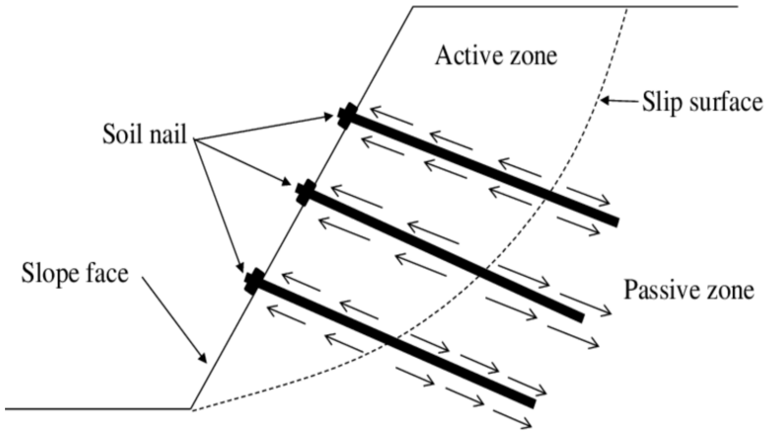

Fig. 4. Mechanism of soil nailing on slope

In the numerical modeling of Kethikal slope, soil nails have been designed as per the U.S. Department of Transportation Federal Highway Administration (FHWA-GEC-007) [14] as given in Table 3.

Table 3
Strength parameter of nail and nail grout

Name	Unit	Mild steel nail (Fe415)	Nail Grout
Axial stiffness (EA)	kN/m	2.0E9	3.0E7
Pre-stressed force (Nc)	kN	600	-
Length of nail (L)	m	18	4
Diameter of nail bar	m	0.03	-
Spacing of nails (S)	m	1.5	-
Nail angle form horizontal	degree	20°	

Table 4
Strength parameter of nailed slope facing

Name	Unit	Slope facing
Axial stiffness (EA)	kN/m	6.3E6
Flexural rigidity (EI)	kNm^2/m	4.7E5
Diameter (D)	m	0.53
Weight (w)	kN/m/m	2.1
Poisson ratio (υ)	-	0.17

Above nail and grout property has been taken with optimum angle [8] and numerical analysis has been done in Plaxis 2D and the factor of safety found 1.29. With this factor of safety, the deformation is 0.20m. The analysis result is shown in Fig 5.

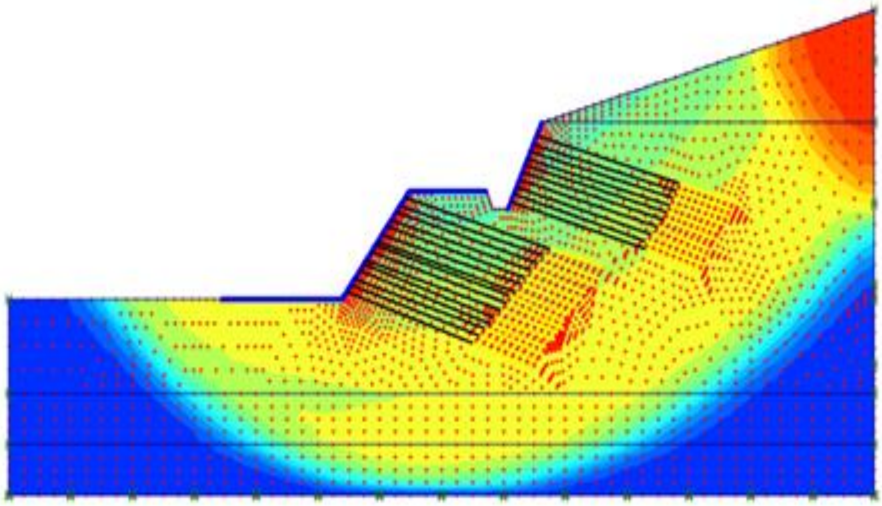

Fig. 5. Analysis output with factor of safety 1.29

Table 5
Calculated results of factor of safety with different conditions

Conditions	F.O.S.	Meshing type
Analysis without treatment and no water table	1.149	Fine mesh
Analysis without treatment and no water table	1.155	Coarse mesh
Analysis without treatment with water table	1.005	Fine mesh
Analysis with nail and with water table (Nail spacing 1.5m)	1.29	Medium mesh
Analysis with nail and with water table (Nail spacing 2.5m)	1.25	Medium mesh
Analysis with nail and with water table (Nail spacing 1.5m)	1.26	Fine mesh

3. Conclusions

In this study we have seen that before failure there was slow downward movement of slope materials every year, just before failure a tension crack has been found. Therefore, the downward slip of slope was due to the yearly rainfall, and that just after the failure of the slope the measurement has been taken there was horizontal displacement of about 100m.

A number of simulations have been done in numerical analysis and various factor of safety have been obtainedunder different boundary conditions. The slope without considering water is found safe as per factor of safety analysis, when the water table has been raised in the slope then factor of safety becomes less than one. To remediatethe failure, slope treatment by soil nails has been assumed in both the upper and lower slopes in the numerical modeling and the factor of safety was found to be 1.29 which is safe even during heavy rainfall. The study concluded if the spacing between nails reduced, the factor of safety increased and factor of safety reduced with increasing the spacing between nails. Through this simulation we come to know that the soil nailing will be the best solution for unstable slopes in India as well as in other countries.

Acknowledgement
I would like to express my special thanks of gratitude to Professor Raghvendra Singh, Department of Civil Engineering, Ujjain Engineering College, Ujjain, India, who helped me through by providing me the data and important information related in this research work.

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