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Stability Analysis of Slopes at a Landslide Prone Area: A Case Study on the Landslide at Madikere, India

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Abstract. The recurring landslides at Madikeri in India during rainy seasons have created fear among people in this area. In 2018, high rainfall was recorded in Makkandur, Kodagu District, located in the Western Ghats of India. This led to severe landslides, floods and soil displacement. In the present study, the soil in the landslide prone area was analyzed to identify the suitable amendment to improve the slope stability. In-situ and laboratory experiments were conducted on the soil to examine the characteristics of this soil. The soil properties were determined with and without amendments to know the improvement in the factor of safety of the slope. The factors of safety corresponding to two different heights of slopes presented at the site were estimated using the Taylor's stability number. The stability analysis was also performed using GEO5 software tool. Two amendments, fly ash and rice husk ash were studied in different proportions and found that there is considerable increase in the factors of safety with the selected additives.

Keywords: Landslide, Fly ash, Rice Husk Ash, Factor of safety

1 Introduction

Landslides due to excessive rainfall are devastating natural disasters which occur on soil slopes due to seepage of water and causedestruction of a large range of resources (Sassa 1974, 1984; Zêzere et al., 2008; Chang and Chiang 2009; Petley, 2012; Shokouhi et al., 2013; Kim et al., 2013; Promper et al., 2016; Peruccacci et al., 2017; Salvati et al., 2018).Investigations on landslidesare often concluded that the failures occur when the angle of soil slope (i) exceeds the critical angle of the slope (i_c) in saturated conditionor sometimes due to the reduction in shear strength of soil caused by high levels of rainfallwhich increases the pore water pressure within the slope (Bishop, 1973; Brand et al., 1984; Larsen and Simon, 1993; Tsaparas et al., 2002; Craig, 2004.; Chien-Yuan et al., 2005; Dahal and Hasegawa, 2008; Gui & Han, 2008; Niroumand et al., 2012;Tay & Selaman, 2019).

Once the slope failure is started at one part of a slope, it progresses towards the rest of the slope and becomes toughto control at the site (Wang and Sassa 2001, 2003). From the relationship between pore water pressure and occurrence of landslide, it is obvious thatthe presence of an undrained soil layer multipliesthe chances of landslide, if subjected to excessive rainfall (Cogan & Gratchev 2019).When a natural hazard occurs, various kinds of losses occur, but the losses related to buildings, roads, rail tracks, and other infrastructure will be given much focus (Iovine and Parise, 2002; Calcaterra et al., 2008; Calò et al., 2012; Del Soldato et al., 2017). Yet, when rural areas are considered, the major losses are relatedto agricultural fields and land damage which cause threat to the economic development of a country.

The risk analysis for any natural hazard often considers the future damage as it provides the essential basis for strategies related to risk reduction and planning (Van Westen et al., 2006; Vranken et al., 2013). In this regard, an attempt is made to identify the suitable ground improvement technique to avoid future landslides in this area. Two additives, Fly ash and Rice husk ashwere studied in different proportions and the stability analysis was carried out to know the effect of these additives on the stability of slopes. The fly ash addition to the soil increases the strength and stability of a slope up to a height of 14.0 m (Rajak et. al 2019). Rice husk which is obtained from rice milling contains a vast amount of silica and its global annual production is about 108 tons (Alhassan, 2008). As the Rice husk ash (RHA) is an abundantly available agriculture by-product, utilization of RHA in soil stabilization seems to be cost-effective, particularly in the rice-producing countries (Choobbasti et al., 2010). The aim of this paper is to study the influence of addition of fly ash and RHA on the soil strength and factors of safety (FoS) of the slopes. The slope stability analysis was carried out using Taylor's method and using GEO5 software tool.

2 Materials and Methods

2.1 Study Area

The study area is located at Makkandur, Kodagu district located in the Western Ghats of India (Fig. 1). In 2018, high rainfall was recorded (2718 mm as per Karnatak State Natural Disaster Monitoring Center (KSNDM)). This caused severe landslides, flooding and large scale displacement of soil. More than a thousand houses were destroyed, about five thousand people were displaced and at least 16 killed. The average rainfall data of Kodagu district is as shown in Fig.2.

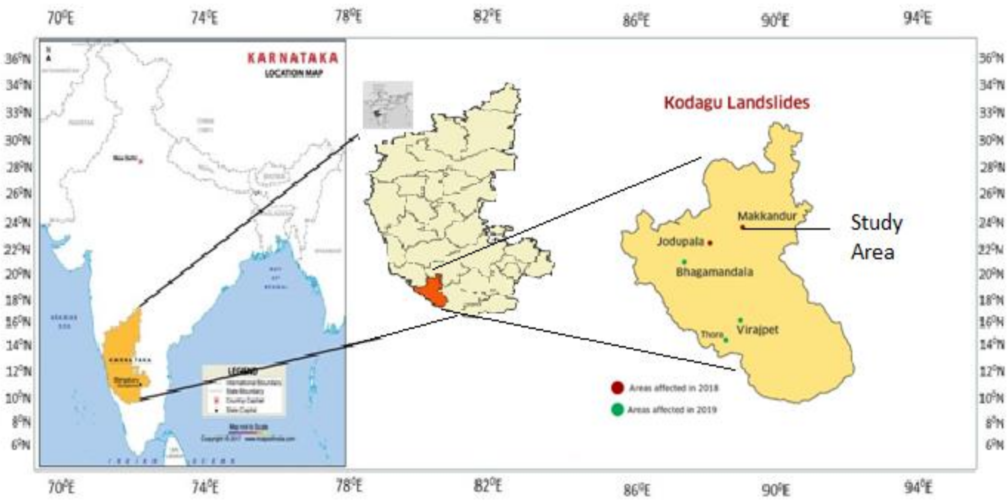


Fig.1. Site location in India map

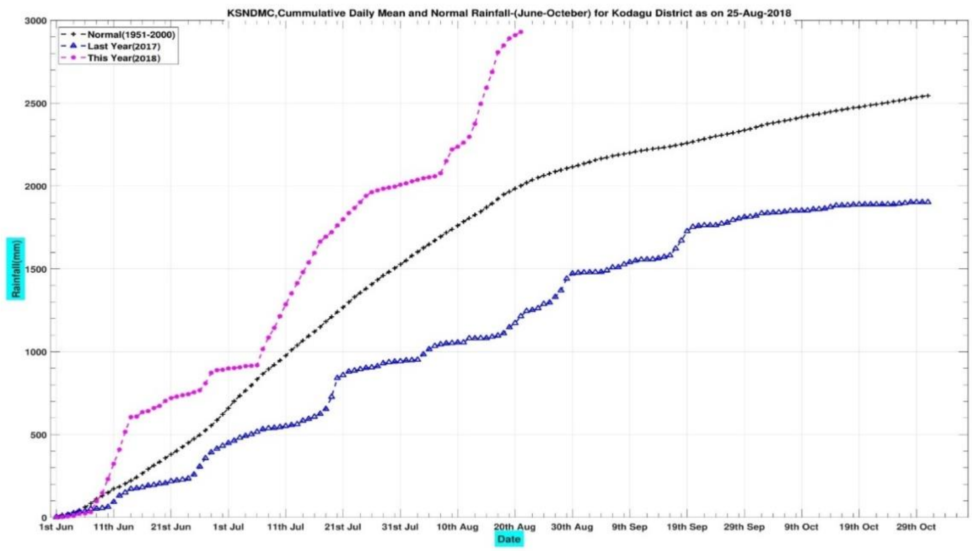


Fig.2. Average rainfall data as per Karnataka state natural disaster monitoring center (KSNDM))

To examine the in-situ properties of the soil at the study area, the soil samples were collected (Fig. 3) at the landslide area. The slope angle and height of the slope were also measured. The slope angles are varying from 45^0 to 55^0 and the heights of the slopes were ranging between 10m to 15.2m. The soil is free from impurities like heavy metals. The in-situ density of soil was determined by core cutter method at 0.5m depth.

Fig. 3.Collection of soil samples at landslide affected area

2.2 Properties of soil

The index and engineering properties of soil samples were as per IS 2720. The in-situ density and moisture content of the soil determined by core cutter method are 1.9 g/cc and 25% respectively. The in-situ dry unit weight is 14.91 kN/m^3. The wet sieve analysis was carried out as per IS 2720 and the fines were analyzed using hydrometer analysis. The composition of the soil is 0.75% gravel, 40.25% sand and 59% fines. It is classified as clay of intermediate plasticity (CI) as per Indian Standard classification. The physical properties of soil are specified in the Table 1.

2.3 Properties of amended soil

To examine the influence of admixtures on the factor of safety of slopes, two industrial wastes, fly ash and rice husk ash were selected. The admixtures of 5% and 10% were mixed with the soil samples, the properties of these mixtures are as given in the Table 1.

Table 1. Properties of soil with and without additives

S. No.	Soil Parameter	Soil Alone	Soil amended with 5% Fly Ash	Soil amended with 10% Fly Ash	Soil amended with 5% Rice Husk Ash	Soil amended with 10% Rice Husk Ash
1	Specific Gravity	2.70	2.69	2.67	2.64	2.61
2	Maximum Dry Unit weight (kN/m^3)	18.89	17.54	16.48	16.88	16.58
3	Plastic Limit (%)	24.44	23.21	22.10	23.89	22.36
4	Liquid Limit (%)	39.8	37.8	36.6	38.2	36.9
5	Shrinkage Limit (%)	9.21	9.68	10.57	11.28	11.9
6	OMC (%)	16.98	18.45	20	18.52	19.1
7	Unconfined Compressive Strength (q_u) (kN/m^2)	70.60	92.80	97.09	90.22	94.14
8	Undrained Cohesion ($C_u = q_u/2$) (kN/m^2)	35.3	46.4	48.54	45.11	47.07
9	Shear strength parameters from Triaxil Test (UU Test)	C = 28 kN/m^2 Ø = 22^0	C = 32 kN/m^2 Ø = 28^0	C = 38 kN/m^2 Ø = 32^0	C = 33 kN/m^2 Ø = 20^0	C = 36 kN/m^2 Ø = 18.5^0

2.4 Stability analysis of slopes

The heights of slopes in the study area are varying between 10 m and 15.2 m. Hence the factors of safety were estimated for 10 m and 15.2 m height slopes using Taylor's method. As the slope angles are varying between 45^0 to 55^0, an average value of 50^0 was taken for the analysis. The factors of safety of the slope were also estimated using the GEO5 software tool using the Bishop's method. As the degree of saturation varies with depth, the bulk unit weights at different depths were calculated and the slope is prepared using the interface option in the GEO5 software tool. The soil slope was divided into different zones depending on the degree of saturation and the pore pressure ratio (Ru) was given as 0.5.

3 Results and Discussions

The estimated factors of safety using Taylor's method for slopes of heights 10 m and 15.2 m with and without the admixtures are shown in Tables 2 and 3. The results of slope stability analysis carried out on the slopes using GEO5 software tool are shown in Figs 4 and 5. From the values of factors of safety obtained, it was observed that the addition of 5% fly ash to the soil, considerably increases the factor of safety and there is only a minimal increase in factor of safety with 10% fly ash when compared with 5% fly ash. A similar trend was followed for the rice husk ash when compared with the results corresponding to 5% and 10% rice husk ash. It was also observed that the factors of safety are less for a slope of 15.2 m height when compared with a 10 m height slope. Hence, it is evident that the addition of fly ash / RHA to the soil improves the stability of soil slopes in the study area.

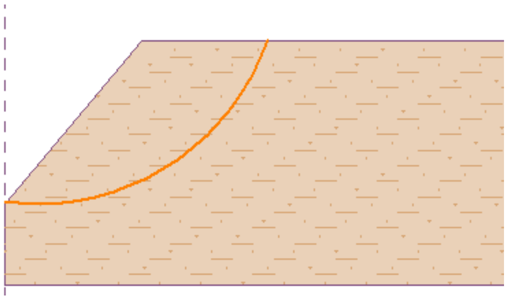
Table 2. Factors of Safety for 10mheight slope using Taylor's method

S. No.	Material of slope	FoS
1	Soil Only	1.29
2	Soil amended with 5% Fly Ash	1.95
3	Soil amended with 10 Fly Ash	2.04
4	Soil amended with 5% RHA	1.90
5	Soil amended with 10% RHA	1.94

Table 3. Factors of Safety for 15.2 m height slope using Taylor's method

S. No.	Material of slope	FoS
1	Soil Only	0.93
2	Soil amended with 5% Fly Ash	1.24
3	Soil amended with 10 Fly Ash	1.32
4	Soil amended with 5% RHA	1.21
5	Soil amended with 10% RHA	1.24

From the Tables 2 and 3, it can be observed that the factors of safety, estimated for 10 m slope stabilized with fly ash and rice husk ash are above 1.5. But the factors of safety, estimated for 15.2 m slope stabilized with the same additives have not improved the factors of safety above 1.5. From this analysis, it was understood that the selected additives are effective only for the slopes of height upto 10 m and beyond which it requires additional reinforcement to achieve higher factors of safety.



(a)

Slope stability verification (Bishop)
Sum of active forces : F_a = 633.91 kN/m
Sum of passive forces : F_p = 881.51 kN/m
Sliding moment : M_a = 9508.70 kNm/m
Resisting moment : M_p = 13222.66 kNm/m
Factor of safety = 1.39 < 1.50
Slope stability NOT ACCEPTABLE

(b)

Slope stability verification (Bishop)
Sum of active forces : F_a = 598.70 kN/m
Sum of passive forces : F_p = 1205.32 kN/m
Sliding moment : M_a = 8980.44 kNm/m
Resisting moment : M_p = 18079.77 kNm/m
Factor of safety = 2.01 > 1.50
Slope stability ACCEPTABLE

(d)

Slope stability verification (Bishop)
Sum of active forces : F_a = 598.70 kN/m
Sum of passive forces : F_p = 1148.43 kN/m
Sliding moment : M_a = 8980.44 kNm/m
Resisting moment : M_p = 17226.45 kNm/m
Factor of safety = 1.92 > 1.50
Slope stability ACCEPTABLE

(c)

Slope stability verification (Bishop)
Sum of active forces : F_a = 598.70 kN/m
Sum of passive forces : F_p = 1084.18 kN/m
Sliding moment : M_a = 8980.44 kNm/m
Resisting moment : M_p = 16262.65 kNm/m
Factor of safety = 1.81 > 1.50
Slope stability ACCEPTABLE

(f)

Slope stability verification (Bishop)
Sum of active forces : F_a = 598.70 kN/m
Sum of passive forces : F_p = 1055.77 kN/m
Sliding moment : M_a = 8980.44 kNm/m
Resisting moment : M_p = 15836.53 kNm/m
Factor of safety = 1.76 > 1.50
Slope stability ACCEPTABLE

(e)

Fig. 4. Stability Analysis of 10m height slope using GEO5 (a) cross section of the slope (b) Soil alone (c) soil + 5% fly ash (d) soil + 10% fly ash (e) soil + 5% RHA (f) soil + 10% RHA

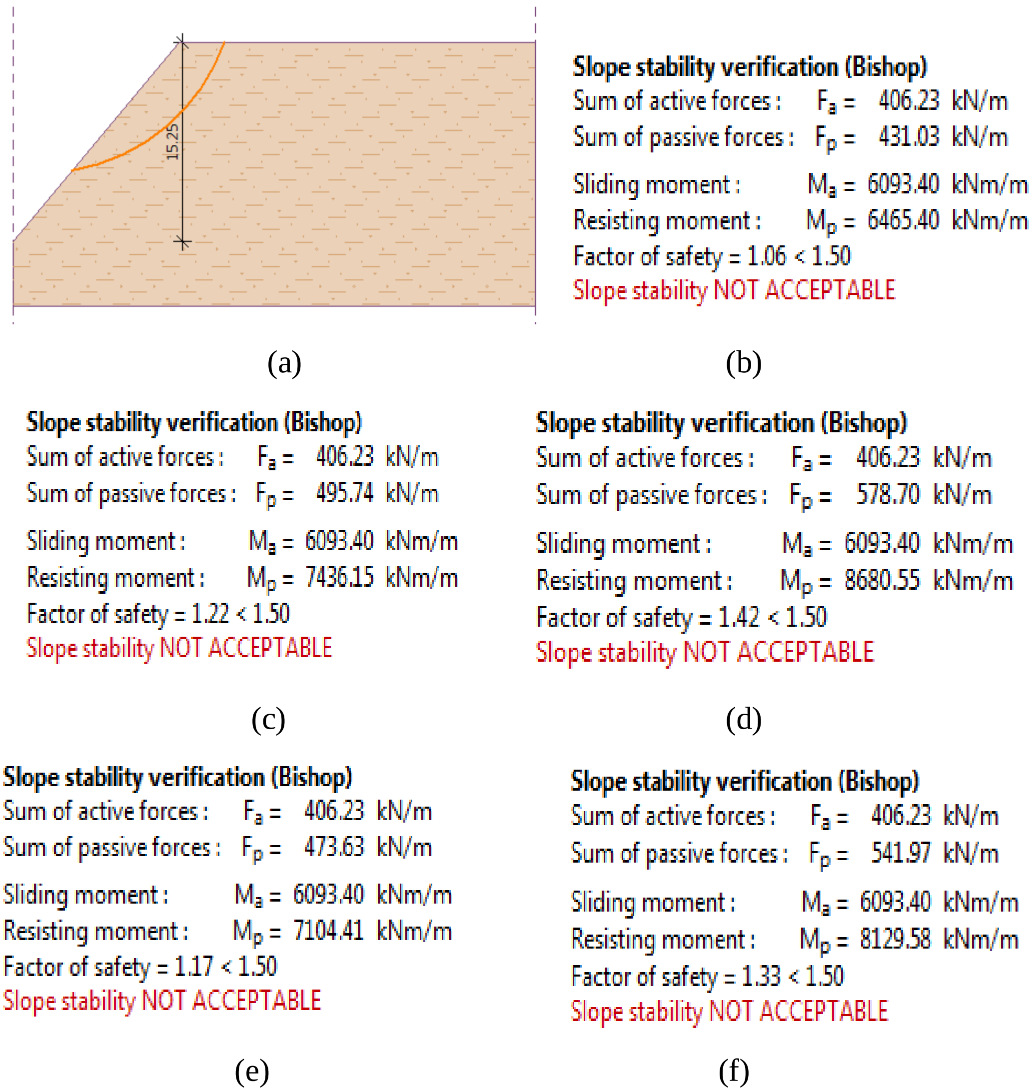


Fig. 5. Stability Analysis of 15.2m height slope using GEO5 (a) cross section of the slope (b) Soil alone (c) soil + 5% fly ash (d) soil + 10% fly ash (e) soil + 5% RHA (f) soil + 10% RHA

4 Conclusions

The landslide prone area located at Makkandur, Karnataka State, India was studied to know the effect of addition of admixtures on the stability of existing slopes at this location. The additives, fly ash and rice husk ash were added in different proportions and the changes in the soil properties were observed. With the addition of fly ash and rice husk ash, the unconfined compressive strength of soil increased significantly. The factors of safety were estimated for 10 m and 15.2 m height slopes using Taylor's method and using GEO5 software tool by considering the field conditions. It was observed that for the existing slope of 10 meters, the factors of safety have considerably increased with the addition offly ash and rice husk ash.But for 15.2 m slope, the estimated factors of safety of using both the methods were less than 1.5. Hence it can be concluded that addition of fly ash or rice husk ash is effective for slopes of height upto 10m and for slopes of height beyond 15 m needs soil reinforcement either in the form of soil nails or Geosynthetics to achieve a factor safety above 1.5. The stability analysis carried out with and without additives is useful to select suitable admixture to improve the slope stability of soil presented at the site. Thus, this research work is useful to design the ground improvement techniques at the area studied to avoid landslides in the future.

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