Landslide Risk Assessment and Mitigation—A Case Study

A. R. Amashi, A. M. Hulagabali, C. H. Solanki and G. R. Dodagoudar

Abstract Landslides are defined as down slope movement of rock, debris and earth under the influence of gravity. Slide is one of the most common types of hazards on slopes, which might lead to considerable casualties and economic loss. The study and analysis of slope is essential in understanding their performance and, in particular, their stability, reliability and deformations. The aim of the present study is to analyse the typical slope by varying different soil parameters like cohesion, angle of internal friction, water table and also slope geometry such as slope angle and slope height. The stability of the slope is analysed based on numerical simulation using three geotechnical software namely Slope/W, SV-Slope and Plaxis 2D. The study further is directed towards the assessment of stability of landslide along State Highway-72, near Mahabaleshwar, Maharashtra. The analysis of slope is carried out using Slope/W and Plaxis 2D. It was found through the analysis that the slope was unstable under the saturated condition. In an attempt of suggesting suitable remedial measures for the same, soil nailing is provided for the slope and simulation is carried out using Geo-5/Nailed slope software. As a result, the slope was found stable after the application of soil nailing.

Keywords Landslide · Numerical simulation · Factor of safety
Remediation

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B. Adimoolam and S. Banerjee (eds.), *Soil Dynamics and Earthquake Geotechnical Engineering*, Lecture Notes in Civil Engineering 15,
https://doi.org/10.1007/978-981-13-0562-7_27

1 Landslide

1.1 Introduction

Landslides are a serious geologic hazard that involves all varieties of mass movements of hill slopes resulting from the failure of the materials such as rock, soil, debris, artificial fills driven by the force of gravity. These landslides not just cause an extensive damage to the property but also cause loss of lives. The triggering factors responsible for landslides are rainfall, rapid snowmelt, earthquakes and anthropogenic activities. A comprehensive evaluation of slope stability has an essential theoretical and practical significance. Analysis of slope stability has always been an important research content in the field of geotechnical engineering. It develops in an endless stream in the analysis method currently.

1.2 Methodology

Present study deals with analysis of slopes using Limit Equilibrium Method (LEM)-based software namely Geostudio (Slope/W), Geo-5 as well as Finite Element (FE)-based numerical tool Plaxis 2D. The study has been carried out in two parts. First part deals with analysis of a general homogeneous slope by varying different soil parameters and the second part includes the analysis of case study with slope failure. Suitable remedial measures are also recommended and demonstrated for the slope. The input data required to analyse the case study with slope failure is obtained from previously published paper that is mentioned in the later part. Analysis gives a single value of factor of safety (FOS) which is a ratio of available shear resistance to that required for equilibrium.

2 Parametric Study

2.1 Introduction

Based on the principles of soil mechanics, there are three general groups of parameters which determine the strength or instability of slope such as strength of a soil, geometry of a soil and pore water pressure which includes seepage forces. In this study, our approach is to keep some of the parameters constant and to investigate effects of remaining parameters such as slope geometry, cohesion, friction and variation in groundwater table on slope stability. In this manner, we can understand the effects of various parameters on the stability of slopes.

2.2 Simulation

Series of investigations are performed considering slope having simple homogeneous geometry as shown in Fig. 1. The parametric analysis has been carried out using Slope/W, SV-Slope and Plaxis 2D with phi-*c* reduction approach. To validate and obtain more accurate results, three software was used. The variations of FOS values with different soil parameters are shown in Figs. 2, 3, 4, 5 and 6.

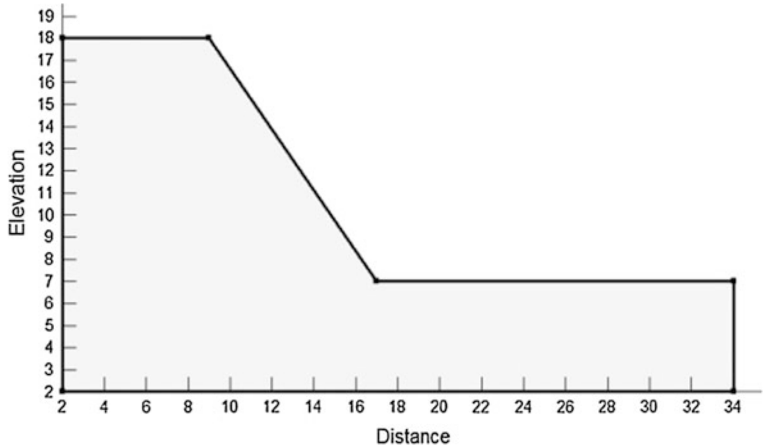

Fig. 1 Slope adopted for parametric analysis

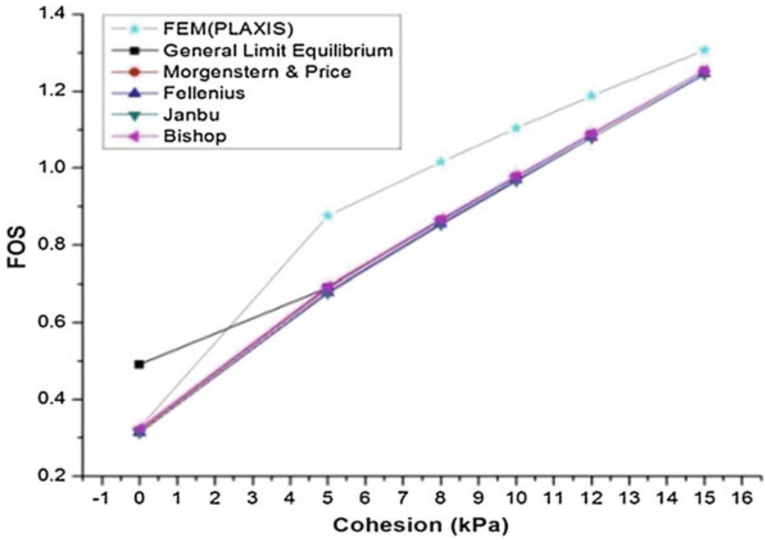

Fig. 2 Variation of cohesion with constant friction angle φ = 25° using Slope/W and Plaxis 2D

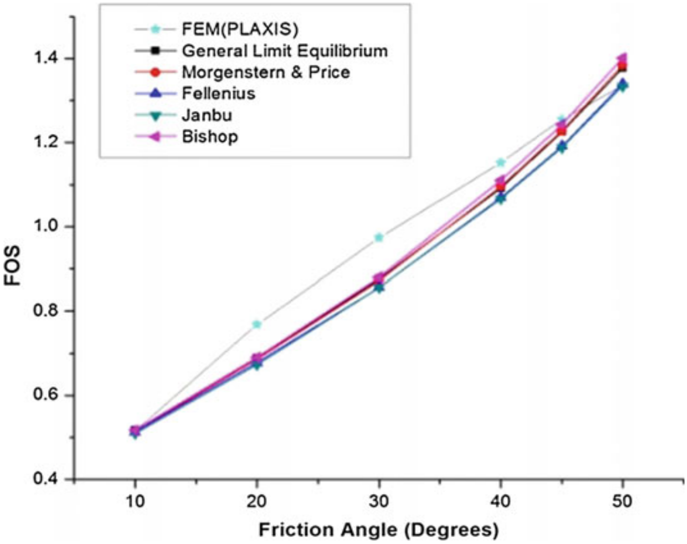

Fig. 3 Variation of friction angle with constant cohesion c = 5 kPa using Slope/W and Plaxis 2D

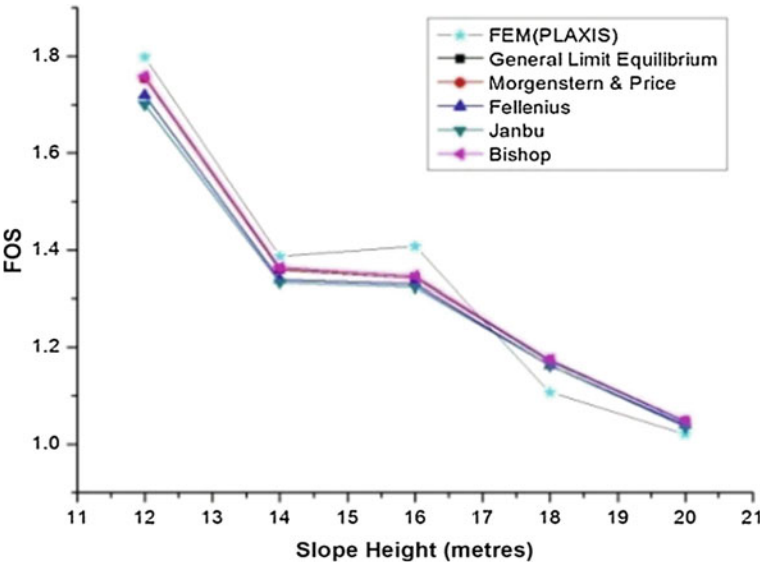

Fig. 4 Variation of slope height with c = 10 kPa, φ = 30° using Slope/W and Plaxis 2D

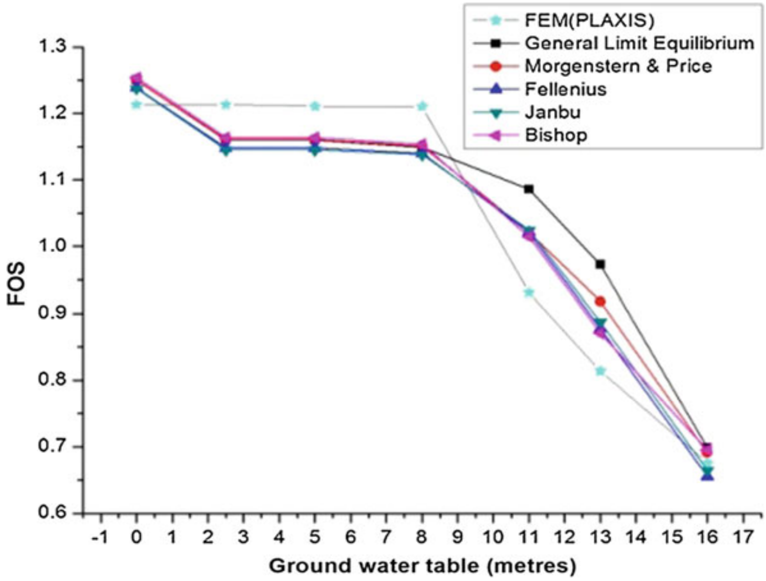

Fig. 5 Variation of groundwater table using Slope/W and Plaxis 2D

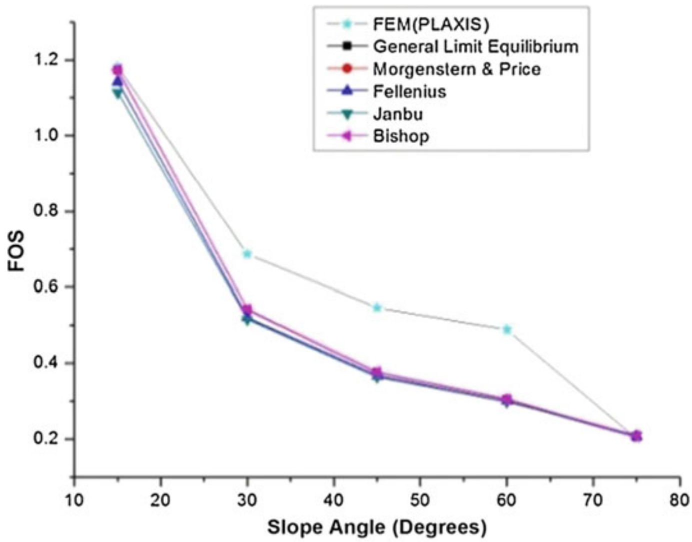

Fig. 6 Variation of slope angle with $c = 2$ kPa, $\varphi = 15°$ using Slope/W and Plaxis 2D

The parametric study shows that as the cohesion and internal friction increase, FOS increases but as water table, slope height and slope angle increase the FOS decreases. The FOS varies linearly as the cohesion increases but it is not the same with other parameters like slope height, slope angle, water table and friction angle. The values of FOS obtained from different LEMs such as Bishop, Fellinius, Janbu and Morgesteron price (M-P) methods showed almost same results with less than 10% variations, whereas General Limit Equilibrium (GLE) method tends to overestimate the FOS. The analysis was also carried out using SV-Slope, and the results were within acceptable limits.

3 Case Study SH72 Mahabaleshwar

3.1 Study Area

The study area is chosen from the previous research work by M. Ahmad et al. 2013, which was focused on State Highway (SH-72) between Poladpur and Mahabaleshwar which is a part of the Deccan traps. The SH-72 connects the famous hill station in Mahabaleshwar, located in Satara district of Maharashtra and lies at a distance of about 120 and 285 km from Pune and Mumbai, respectively. The study area falls between latitude 17° 52′ 30″–18° 00′ 00″ and longitude 73° 26′ 15″–73° 41′ 15″ (Ahmad et al. 2015). The area is prone to weathering action, formation of soils and presence of bole beds in between two consecutive basaltic flows; in addition to this, joints, sub-vertical-to-vertical slopes, heavy rainfalls, etc., lead to slope instability. The area falls under Seismic Zone III. The basalts found in this area are fine-grained, massive and jointed in nature (Kainthola et al. 2012).

3.2 Numerical Simulation

The data required to carry out the analysis of this area is obtained from the previous paper published by Ahmad et al. (2013). They carried out the slope stability analysis using Slide-6 numerical tool. The details are as follows; five different types of soil have been identified on the basis of physical nature and colouration. Through field survey, they have considered a general slope having maximum height as 15 m above the road and the average slope angle of 70°. To assess the impact of five different soils, 4.5 m soil bed on the top of the slope and about 3 m soil layer has been taken above the slope in their study (Ahmad et al. 2015). The five different geo-engineering soil properties are independently applied on the slope as shown in Fig. 7 and analysed using Geostudio and Plaxis 2D. The aim of this study is to analyse the stability of the slope having basaltic soil formations and the effect of these soil on slope stability (Tables 1 and 2).

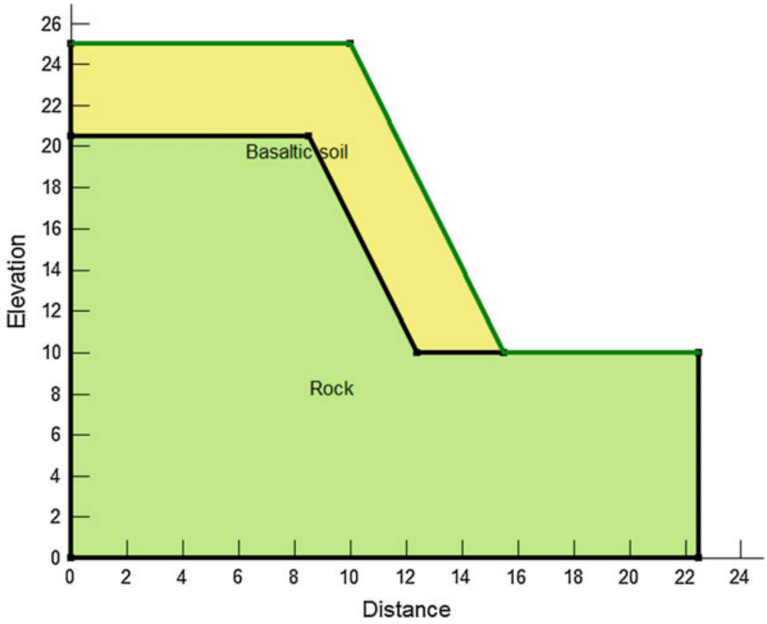

Fig. 7 Geometry of slope

Table 1 Properties of soil

Soil sample	Cohesion (kPa)		Friction angle (°)		Density (kN/m^3)	
	Dry	Wet	Dry	Wet	Dry	Wet
S1	70	35	23	18	18	19.5
S2	44	27	17	13	17.5	18.5
S3	62	83	18	17	19	20
S4	88	52	27	22	22	24
S5	60	31	19	16	19.5	22.5

Table 2 Rock soil sample details

Parameters	Dry	wet
Average density (kN/m^3)	27	28.5
Average cohesion (MPa)	11.6	8.4
Average friction angle (°)	37	30
Average Young's modulus (GPa)	40.1	36.3
Average Poison's ratio	0.24	0.22

3.2.1 Simulation Using Slope/W and Plaxis 2D

The results of slope stability analysis along SH-72 Mahabaleshwar by using Slope/W and Plaxis 2D under dry and saturated condition are given in Figs. 8 and 9.

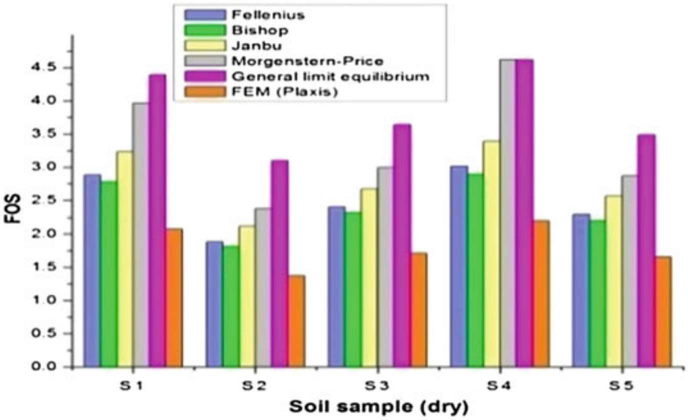

Fig. 8 Simulation using Slope/W and Plaxis 2D under dry condition

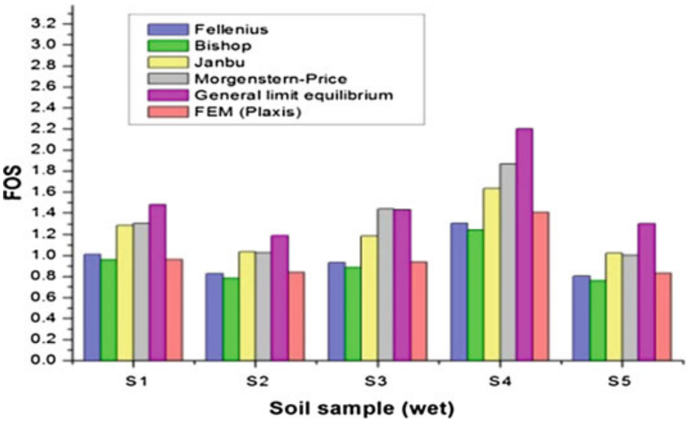

Fig. 9 Simulation using Slope/W and Plaxis 2D under wet condition

The results obtained through the analysis say that the LE methods such as Fellenius, Bishop and FE method showed FOS values with less variation whereas Janbu, GLE and M-P overestimated the FOS values. It is observed that the resultant FOS obtained from the stability analysis is more than 1 for all 5 soil samples under dry condition which implies the slope is stable. In wet condition, the FOS obtained is less than 1 for soil samples S2, S3, S5 which indicates that they are unstable and FOS values are nearly equal to 1 for sample S1 which says it is critically stable. The FOS obtained for soil sample S4 is greater than 1 and is found to be stable.

3.3 Remediation

The highway that is part of study area remains closed due to frequent landslides that occur in small and large slopes during monsoon caused due to heavy rainfall and vibrations produced by the traffic. In the present study, an attempt is made to demonstrate the application of remedial measure (soil nailing) for the mitigation of landslide using LE-based software tool Geo-5 (Nailing). Soil nailing is provided to stabilize the slope with different types of basaltic soils formed due to weathering on the surface of hills. The analysis is carried out for three field conditions, i.e., under dry condition, wet condition and simulation of earthquake (pseudo-static) in dry and wet condition. The horizontal and vertical acceleration coefficients considered for pseudo-static analysis are $k_h = 0.15$ and $k_v = 0.075$. Properties of soil nails are nail diameter 25 mm, spacing 1.2 m, yield strength 0.28 MPa, ultimate bond 120 kPa, length 1.5 m. The variation of results for different LE methods for soil samples 1–5 is shown in Fig. 10.

The resultant FOS obtained from slope stability analysis using Geo-5 (Nailing) tool with Bishop Method is around 2–3 after providing soil nailing. The provision of soil nailing is shown in Fig. 11.

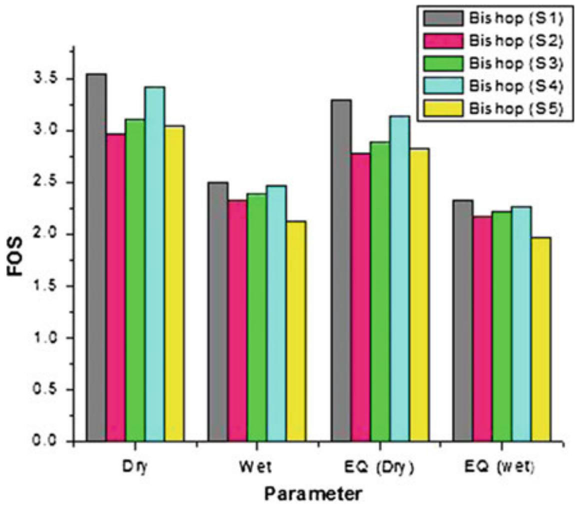

Fig. 10 FOS values after remediation

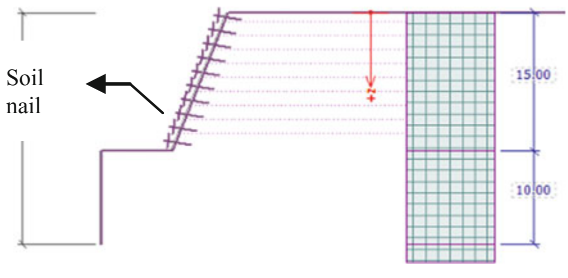

Fig. 11 Provision of soil nailing

4 Conclusions

- The parametric study shows that as the cohesion and internal friction increase, FOS increases, but as the water table, slope height and slope angle increase the FOS decreases. The FOS varies linearly by increasing the value of cohesion, whereas for the other parameters, the FOS does not vary linearly.
- When we compare FOS values using Limit Equilibrium Method and Finite Element Method, later method gives higher FOS values.
- The FOS obtained from Bishop Method and Ordinary Fellinius Method is almost similar, whereas GLE, Janbu's and M-P methods overestimate the FOS values.
- From the analysis of case study, it was found that the slope was unstable or on the verge of failure. Hence to increase the stability of the slope, suitable remedial measure was demonstrated.
- The FOS values obtained after providing remediation were around 2–3 and slopes were found stable.

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