Analysis of Effect of Anti-slide Pile on Stability of Slopes

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1 Introduction

Failure of soil slopes can have devastating effects and can lead to loss of both life and property. Hence, it is important to study about and determine methods to reinforce slopes and stabilize them. Anti-slide pile is one such novel measure that is widely used in various parts of the world to stabilize slopes which are susceptible to failure. Several experimental studies and its usage in geotechnical industry have found that it increases safety factor of slope considerably if properly designed. Determination of proper pile parameters like pile embedment length, position and spacing of anti-slide piles is of utmost importance. These parameters should be determined with extreme precision as they play most important role in making this measure effective. The piles are designed for passive earth pressure in soft soil layer and for active earth pressure in lower more stable soil or weathered rocky layers. Thus, the embedded length of piles is a vital issue and attracts unlimited attention. Various researchers have tried to quantify and study pertaining to the influence of existing conditions, soil conditions on the pile parameters. Griffiths et al. [5] used numerical methods to investigate into the effects of pile reinforcement on stability of soil slopes, and his study has some drawbacks which was rectified by Qin et al. [4] who conducted tests on vertically loaded piles to study effect of pile length. Studies conducted in this domain can be grouped as of experimental, review, analytical and numerical analysis or modelling nature. In this study, a soil slope case is considered for analysis which is modelled in GE05 software where modelled slope was reinforced with anti-slide. Then, an attempt has been made to study the effect of parameters like pile spacing,

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pile position and pile spacing on the factor of safety of the slope which have been analysed to determine optimum pile parameters and to calculate forces acting on the critical pile length.

2 Bishop's Method

In this study for the calculation of the factor of safety of the soil slope case considered bishop's method of slices has been adopted. The analysis of the slope model for the FOS was carried out on GE05 2020 soil stability program. This program is used to perform slope stability analysis for embankments, soil slopes, retaining walls etc. (different slope stability calculation methods are available like-Bishop simplified, ordinary method of slices, spencer, etc). ordinary method of slices also called as Fellinius method has been used in this study to compute safety factor of the soil slope [6]. In this method, the slope is divided into a number of slices and each forces on each slices are obtained by solving them for equilibrium using Eqs. 1 and 2. The factor of safety is the ratio of the maximum moment to the estimated moments. Various forces acting on the slices atr shown in the Fig. 1.

$$\sum Fv = W - N\cos(\alpha) - T\sin(\alpha) \tag{1}$$

$$\sum Fh = kW + N\sin(\alpha) - T\cos(\alpha) \tag{2}$$

where FV = vertical forces, FH = horizontal forces, N = normal reaction, W = weight

Fig. 1 Forces acting on slices in Fellinius method
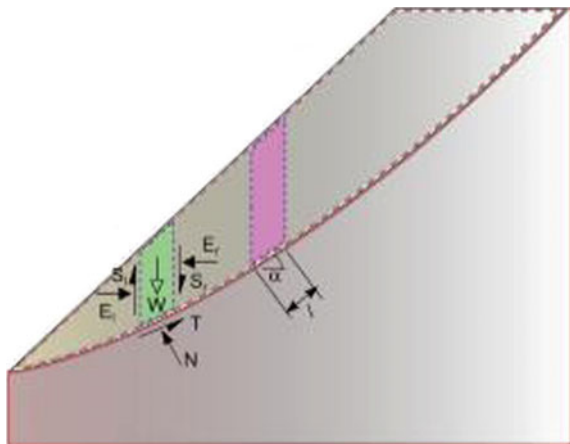
3 Numerical Modelling

In this study, slope case considered consists of three layers of soils and one weathered bedrock. The slope was modelled in the GE05 2020 software interface. The first step in the software is to select the limiting FOS which was considered as 1.5 in this study as shown in Fig. 2. Then, interface coordinates are entered either manually or textually as shown in Fig. 3.

After specifying the interface details soil parameters are entered, here in this slope case soil considered is silt with low plasticity, clayey sand, sandy clay, sandy clay
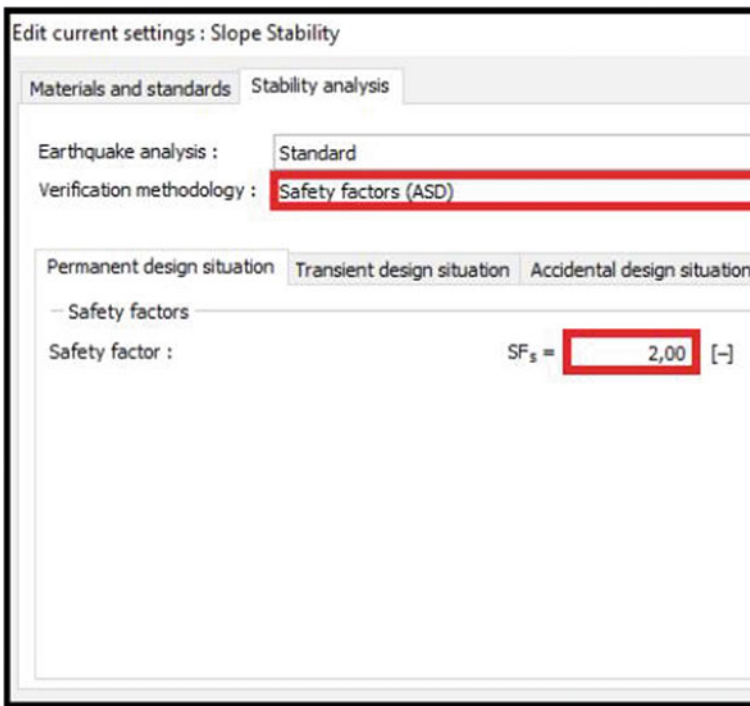
Fig. 2 Specifying limiting FOS

		Interface 1				Interface 2				Interface 3				Interface 4	
▸	1	0,00	0,00	▸	1	38,71	8,72	▸	1	36,78	7,82	▸	1	0,00	-0,40
	2	10,00	0,00		2	50,00	8,72		2	50,00	7,82		2	50,00	-0,40
	3	20,00	4,66												
	4	30,00	4,66												
	5	36,78	7,82												
	6	38,71	8,72												
	7	40,00	9,32												
	8	50,00	9,32												

Fig. 3 Interface coordinates

and weathered slate as bedrock. The parameters are entered and soil are assigned on the interface. A surcharge is also assigned on the slope of 25 kN/m^2 as shown in Fig. 4. The ground water table was also applied in the slope to introduce effects of pore water pressure and effective stress. The coordinates of GWT is shown in Fig. 5.

Now pile parameters are defined. Anti-slide pile defined is of circular cross section in one row. The diameter of the pile is 0.66 m, and the initial length is 9 m. It is initially positioned at the toe of the slope. It is difficult task to identify a general position of the pile for maximum stability of slope. Pile position is a case dependent parameter, but piles must cross the imaginary slip surface. One of the major aim of the study is to determine the ideal position of the pile. Now, the slope interface can be seen in Fig. 6.
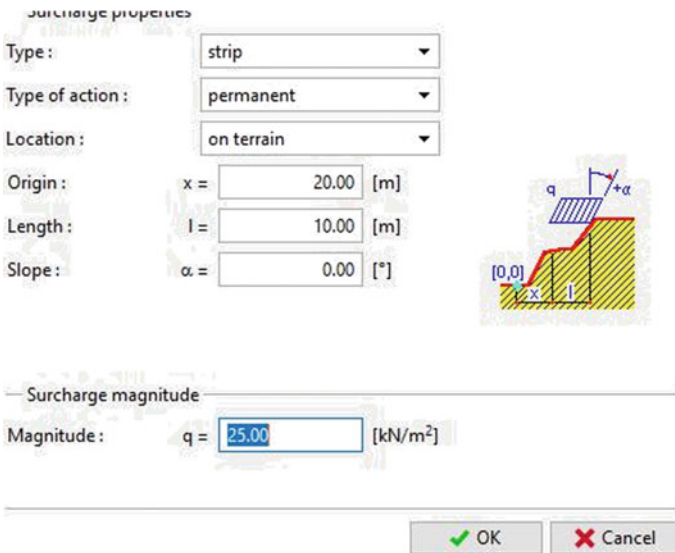

Fig. 4 Defining surcharge on the slope

Fig. 5 Ground water table coordinates

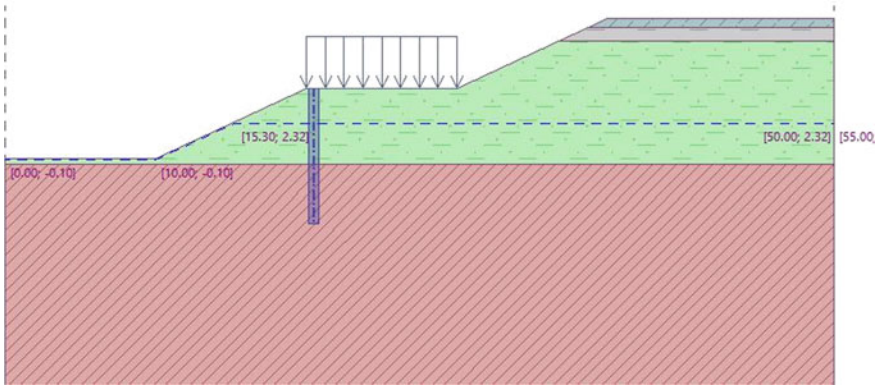| No. ▲	x [m]	z [m]
1	0.00	-0.10
2	10.00	-0.10
3	15.30	2.32
4	50.00	2.32
5	55.00	2.32

Water type: GWT

GWT points

Fig. 6 Final slope model in the software

Thereafter finally defining all the necessary parameters the analysis for FOS is undertaken in this case by bishop's method of slices. The FOS obtained is compared to limiting FOS value for slope stability. A three-dimensional view of the slope interface can be seen in Fig. 7.
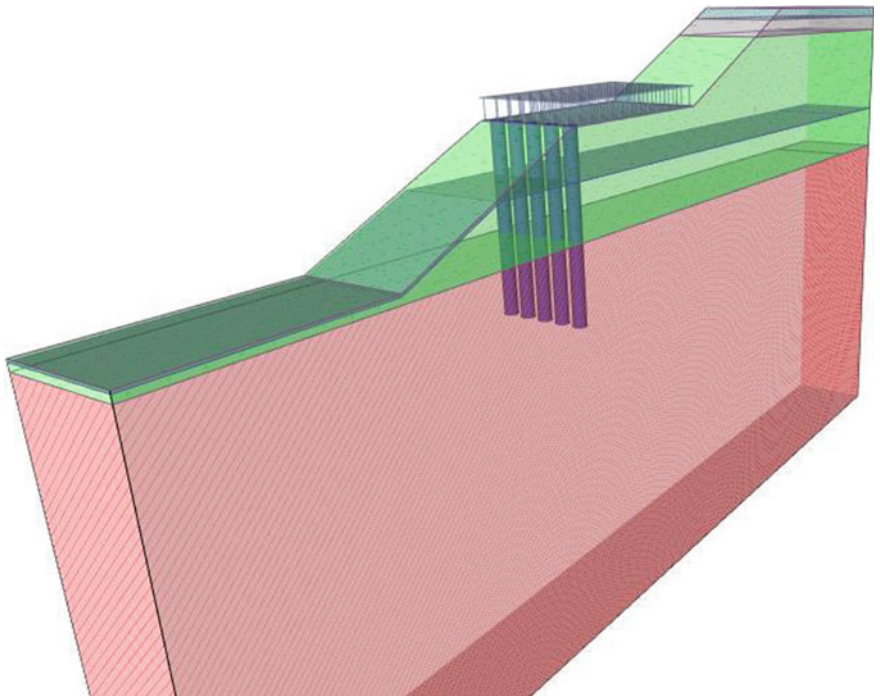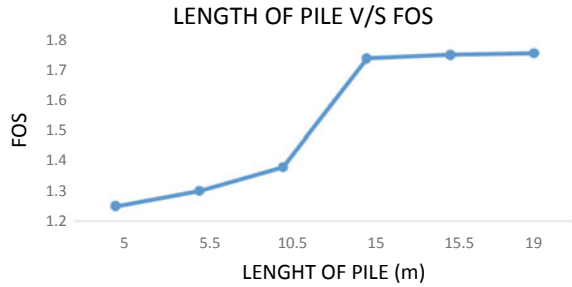

Fig. 7 A 3-D view of soil slope model on GE05 2020 interface

Fig. 8 Effect of length of
pile on FOS of slope

LENGTH OF PILE V/S FOS

4   Results and Discussion

After undertaking the analysis of proposed soil slope reinforced with row of anti-
slide piles, various observations were made. The variation of soil slope was studied
in reference to the change in length of piles, spacing of pile and position of pile.

4.1   Influence of Length of the Pile

Length of the pile is a very important parameter that has greatest influence in the
stability of slope and economy of the project. The effect of embedded pile length
on the factor of safety of the slope reinforced with piles is shown in Fig. 8. As
expected, the factor of safety of the slope reinforced with one row of anti-slide piles
shows significant increase with increasing length of pile. When the embedment length
exceeds a limiting value (in this case 15 m), safety factor approaches a constant value.
This value at which safety factor approaches persistent value is termed as limiting
pile embedment length, and this is the optimum pile length for design for stability
of the slope.

4.2   Influence of Spacing of Piles

The effect of pile spacing on the factor of safety is shown in Fig. 9. On decreasing the
spacing of piles leads to compaction of soil in between piles which in turn increases
stiffness of soil leading to increase in safety factor ultimately. As pile spacing is
reduced safety of soil slope keep on increasing but an optimum value should be
adopted for design considering the existing stability of slope. Because excessive
reduction in spacing may be uneconomical, so an optimum pile spacing should be
selected depending upon existing conditions.
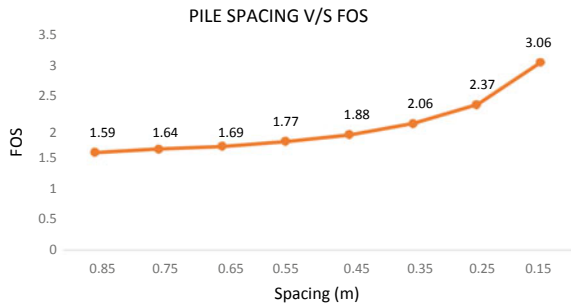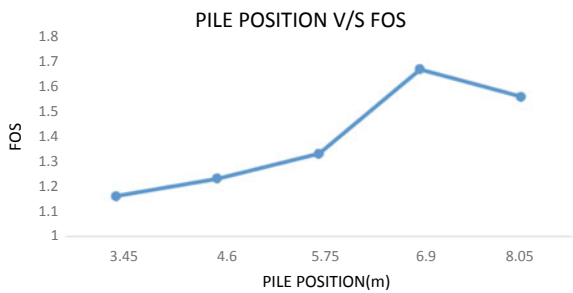
Fig. 9 Effect of pile spacing on FOS

PILE SPACING V/S FOS

FOS values: 1.59, 1.64, 1.69, 1.77, 1.88, 2.06, 2.37, 3.06

Spacing (m): 0.85, 0.75, 0.65, 0.55, 0.45, 0.35, 0.25, 0.15

Fig. 10 Influence of pile positioning on FOS

PILE POSITION V/S FOS

PILE POSITION(m): 3.45, 4.6, 5.75, 6.9, 8.05

4.3 Influence of Pile Positioning

The influence of pile position on FOS is shown in Fig. 10. Initially, pile was positioned at the toe of the slope where an FOS of 1.17 was observed. Then moving the pile position up away from the toe the FOS increases. Factors affecting pile position include ground water table, soil and slope. The FOS is maximum when the pile is 7 m away from the toe then FOS decreases because at 7 m the pile is adequately positioned to balance the effects of water table and soil.

4.4 Bending Moment and Shear Force on the Anti-slide Pile

Critical embedment length is the length of pile at which safety factor is maximum for the slope and remains constant further increasing pile length. The bending moment and shear force values are obtained and plotted in Figs. 11 and 12. The maximum bending moment value obtained is 93.57 KNm while maximum shear force is 43.23 kN. Calculation of forces is important for the design of pile as suitable shear and tensile reinforcement must be provided in the pile to prevent it from failure.

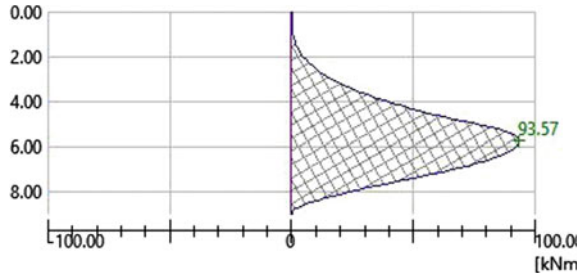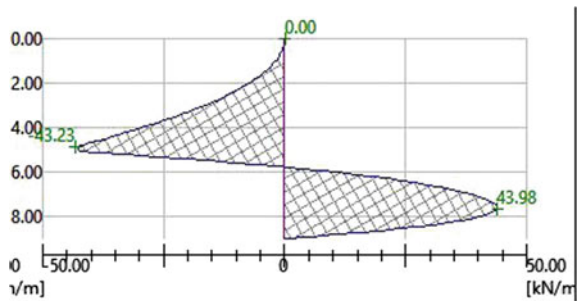**Fig. 11** Bending moment
diagram of anti-slide pile

Fig. 12 Shear force diagram
of anti-slide pile

4.5   Earth Pressure on the Pile

Pressure on the anti-slide pile embedded in the soil has also been computed and
plotted below. Both passive and active pressures have been plotted. Maximum pres-
sure obtained to be acting on the pile is 70.67 kPa. Active force acts on the pile from
the higher part of slope. It weakens the slope. Passive force acts against the landslide
and helps the pile to stabilize the slope. In case the passive force is equal to zero,
it means that the slope in front of the pile is not stable and it is necessary to solve
its stability separately [7–9]. The difference between the active and passive force is
which the pile must transfer to reach the required safety factor of the slope (Fig. 13).

Fig. 13 Pressure diagram of
the anti-slide pile
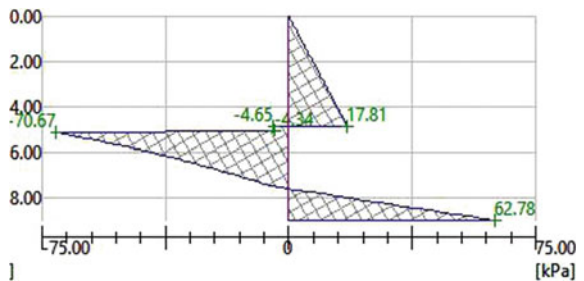
5 Conclusion

In this study, it can be concluded that usage of anti-slide piles increases safety of slope considerably and anti-slide piles can serve as a good measure to improve stability of soil slopes on unstable soils. It can be observed from the results obtained in the above study that the safety factor increases on increasing pile length and becomes constant when pile length exceeds critical embedment length. Also, the safety factor shows a steady increase upon decreasing pile spacing as reduced spacing stiffens the soil in between two piles. Hence, optimum pile length would be around 10–15 m and optimum spacing for single row of pile for this case will be around 0.65–0.55 m. The pile position of anti-slide pile is also an important parameter which has significant influence on the stability of slopes. Results show that increasing distance of piles from toe of slope tends to decrease safety factor initially up to a certain distance and then starts showing decrement.

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