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Design of Micropile Walls for Slope Stability Improvement

Anirudhan K. M.[1], Niranjana K.[2]
[1]PG Student, Department of Civil Engineering, Thejus Engineering College, Thrissur
[2]Assistant Professor, Department of Civil Engineering, Thejus Engineering College, Thrissur

Abstract: Many methods to improve factor of safety of slopes are in practice. Micropiles are generally used for seismic retrofit and rehabilitation of foundations. The suitability of usage of micropiles for slope stability of earthen slopes is checked. Series of alternatively battered micropiles, installed to a top beam at the midway of the slope, can retain the potentially unstable mass of soil above the slip circle of slope to the harder strata below. Kakkayam is a spot in Western Ghats of Kerala with high potential slope instability. The possibility of improving factor of safety of the slope using micropiles is analysed.

Keywords:. stability, slope stabilization, micropile, swedish circle

1. Introduction

1.1 Slope Stability

Slopes are either manmade or natural. They are prone to failure due to various factors. Slope failures results in damage of life and property. Mass movements due to slope instability are common in hilly regions.

In Kerala problem of instability of slopes is severe in many parts of Western Ghats. The part of Western Ghats in the eastern region of Kozhikode district, along the downslope of Wayanad Plateau is prone to such mass movements like landslides.

Improving the stability of slopes continues to be a fundamental problem in Geotechnical Engineering. The factor of safety of a slope is the ratio of resisting force preventing failure to that of the driving force causing the failure. There are various methods to evaluate slope stability and to improve it as well. Installation of Micropile groups is one among the methods to improve slope stability

1.2 Micropiles

A micropile is a small diameter drilled and grouted pile that is typically reinforced. The diameter is usually less than twelve inches and this type of pile would be considered a non-displacement pile. Micropiles can be installed at any angle, in places where access is restrictive and in virtually all soil types and ground conditions. Micropiles have been primarily used as foundation support.

Micropiles can be employed in slopes to improve slope stability, as they can take the additional load causing failure through their axial and bending resistance. Possibility of slope stabilization involving the use of micropiles is evaluated in this project. A wall consisting of a line of micropiles placed into the soil mass at alternating batter angles. The micropilesare fixed at the ground surface by means of a concrete cap beam running the length of the wall. The system of micropiles used for slope stabilization is illustrated in the figure Figure 1

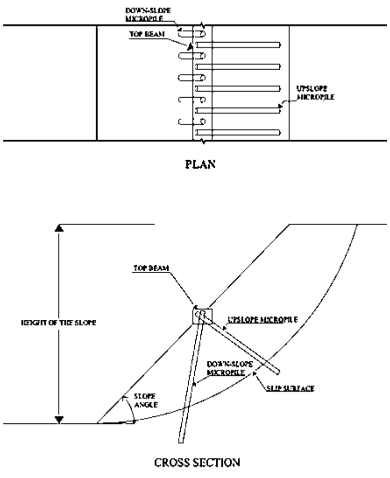

Figure 1: Plan and Cross Section of typical Micropile wall instalation for imroving slope stability (Anirudhan and Niranjana (2017))

2. Previous Literature

2.1 Studies on Micropile Slope Stabilization

Various studies on micropiles have been carried out through years and most of them were based on foundation rehabilitation and seismic retrofit, and later on earth retention structures. Usage of micropiles as slope stabilizing structures was started later and studies available on that topic is comparatively fewer.

U. S. Department of Transportation, Federal Highway Administration (FHWA) published a Reference Manual for Micropile Design and Construction (FHWA SA-97-070) on June 2000. This manual was not provided with the design and construction details of micropiles used for slope stabilization. Later Sebatiniet. al. (2005) had worked on the topic and included it on the updated version of the manual - FHWA SA-05-039. In FHWA procedure, the lengths of the micropiles are fixed by designing them for Bending moment.

Howe(2010) conducted studies on Micropile structures for slope stabilization and tried to optimize the location of the structure on the slope and the batter angles of micropiles to be installed towards upslope and downslope.

Later Turner and Halvorson (2013) proposed a simpler design procedure, based on the axial strength of the micropiles, as the design based on the FHWA procedure will result in inappropriately stiff structures.

Anirudhan and Niranjana (2017) designed a Micropile structure to resist slope instability. The instability is measured by means of Swedish circle method and without any surcharge.

2.2 Studies on slope stability analysis of Kakkayam

Arish and Sreekumar (2013) conducted studies on various sites of landslides throughout the Western Ghats of Kerala. Kakkayam was reportedly the region of slope failures in the years 1984 and 2009. They investigated on the triggering factors induced the failure. From their investigation the amount of coarse materials in the soil sample is high and thus the cohesion is very low

3. Study of site conditions

3.1 Site selection

Kakkayam (Arish and Sreekumar (2013)) was reported to be area with history of slop stability failure and potential instability. The location of the site is provided in the Fig. 2 given below. The site is at the co-ordinates N 11^{0}33’24.9”, E 75^{0}54’50.6”.

Figure 2: Location of selected slope – Kakkayam (N 11^{0}33’24.9”, E 75^{0}54’50.6”) (Google maps – imagery)

3.2 Site selection

The geotechnical properties of soil samples collected from the sites are presented in Table. 1

Table 1: Results of laboratory tests conducted on collected soil samples

Parameters		Value
In field Moisture Content (%)		30
Specific Gravity		2.56
Atterberg Limits	Liquid Limit (%)	35
	Plastic Limit (%)	29
	Shrinkage Limit (%)	27
Particle Size Distribution	Gravel (%)	2
	Sand (%)	80

	Clay (%)	9
	Silt (%)	9
Light Compaction	OMC (%)	15.4
	Max. Dry Density (kN/m^3)	17.45
Soil Classification		SM
Strength Properties	Cohesion (kN/m^2)	10.5
	Angle of Internal Friction (Φ)	34^0

4. Slope stability analysis

4.1 Using Swedish Circle Method

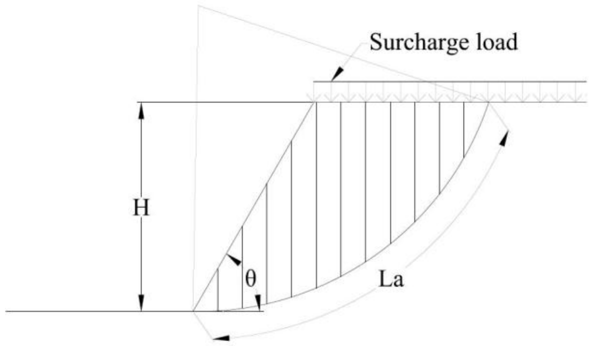

Figure 3: Swedish Circle Method of Slope stability analysis of the slope

The height of the slope is 10m and the slope angle is 600. Swedish Circle Method (Fellinius (1936)) of slope stability analysis is used here for determining t he factor of safety of the slope against sliding. In this method the Factor of Safety (F. S.) of the slope is determined using the Equation. (1) (Fellinius (1936)).

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

Where,
c is the cohesion,
Φ is the angle of internal friction,
La is the length of slip surface,
N is the normal component of each slice and
T is the tangential component of each slice.

The most critical is to be located using a series of trialsApart from slicing the slip circle to 6-12 slices, it is divided into slices of small width dx. The following solutions are obtained by taking toe as origin, (a,b) as centre of slip circle, with radius r. Toe failure is assumed, angle of the slope is θ and height is H and a surcharge load q.

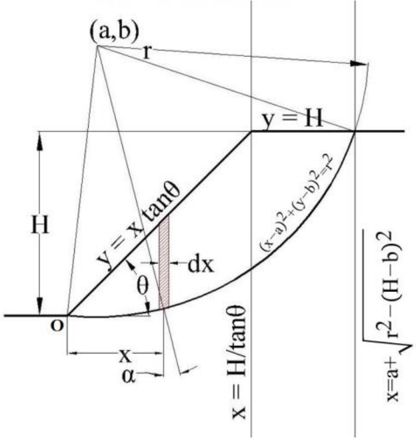

Figure 4: Calculating Factor of safety using integration

From the figure 4 we can found that L_a in equation 1 is

$$L_a=\left\{\cos^{-1}\left\{\frac{b-H}{r}\right\}+\sin^{-1}\left\{\frac{a}{r}\right\}\right\}\times r \tag{2}$$

And ΣN and ΣT can be found using

$$\sum T=\int_0^{\frac{H}{\tan\theta}}\left\{\left[x\tan\theta-\left(b-\sqrt{r^2-(x-a)^2}\right)\right]\times\gamma\times\left[\frac{x-a}{r}\right]\right\}dx \\ +\int_{\frac{H}{\tan\theta}}^{a+\sqrt{r^2-(b-H)^2}}\left\{\left\{\left[H-\left(b-\sqrt{r^2-(x-a)^2}\right)\right]\times\gamma+q\right\}\times\left[\frac{x-a}{r}\right]\right\}dx \tag{3}$$

$$\sum N=\int_0^{\frac{H}{\tan\theta}}\left\{\left[x\tan\theta-\left(b-\sqrt{r^2-(x-a)^2}\right)\right]\times\gamma\times\left[\frac{\sqrt{r^2-(x-a)^2}}{r}\right]\right\}dx \\ +\int_{\frac{H}{\tan\theta}}^{a+\sqrt{r^2-(b-H)^2}}\left\{\left\{\left[H-\left(b-\sqrt{r^2-(x-a)^2}\right)\right]\times\gamma+q\right\}\times\left[\frac{\sqrt{r^2-(x-a)^2}}{r}\right]\right\}dx \tag{4}$$

Using the equations 2, 3 and 4 above the solutions for varying trails of slope stability analysis with slip circles centered at different values of (a,b).

The analysis resulted that the F. S. of the existing slope is 1.06. The total driving forces (ΣT) is equal to 351.16kN and total resisting force is equal to (cLa+ΣNtanΦ) 361.36 kN

5. DESIGN OF MICROPILE SYSTEM

Design of micropile soil stabilization was carried out by the design procedure proposed by FHWA manual FHWA SA-05-039 by Sabatini et. al. (2005). Turner and Halvorson (2013) proposed a simpler method of design, in which the structure is designed for resolved axial loads acting on the micropile. Turner and Halvorson (2013) and Howe (2010) carried out various studies and optimized the values for positioning of micropile top beam and determination of batter angles.

The design of micropile slope stabilization system is carried out through the following steps

5.1 Additional force for which the micropile system is to be designed

As discussed in the above section the sum of resisting forces should be equal to the product of factor of safety and the driving forces. Thus the additional force required for the design is calculated by Equation (5) given below

$$AF=FS_T\times DF-RF \tag{5}$$

Where,
AF is the additional for required,
FST is the target factor of safety,
DF is the total driving force and
RF is the total resisting force
Additional force required is found to be 160.50 kN

5.2 Position of Top Beam on the slope

In order to avoid creation of slip surfaces with factor of safety less than the targeted factor of safety above the position of the system of micropile, as illustrated in the figure (Fig. 5) (Anirudhan and Niranjana (2017)), the micropile should be above the midway of the slope from the toe. In economic consideration, the position of top beam should be such a way that the length of micropile above the slip surface must be the minimum.

Considering these aspects and the recommendations made by Turner and Halvorson(2013) stating that it is ideal to make the position of the top beam to be between 50% to 75% of the slope from the toe.

The position of top beam is determined to be at the 75% of the slope.

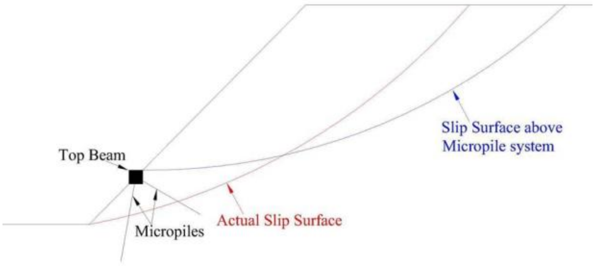

Figure 5: Effect of micropile installation below the midway of the slope. (Anirudhan and Niranjana (2017))

5.3 Upslope and Downslope batter angles

The length of increases, as the down-slope batter angle increases. Hence from the economic point of view, down-slope batter angle is limited to 100. Turner and Halvorson (2013) recommend the upslope batter angle to be between 25 to 35 degrees.

The batter angles were selected as 10 degrees from vertical for down-slope and 30 degrees from vertical for upslope micropiles.

5.4 Spacing of Micropiles

To avoid plastic flow of soils between piles the spacing between individual micropiles should be between 0.4m and 0.55m(Turner and Halvorson(2013)).

Here it is fixed as 0.4m and thus the spacing between micropile pairs consisting upslope and down-slope battered micropiles is 0.8m

5.5 Cross Section

Sabatini et. al.(2005) provided the cross sectional details of micropiles in FHWA manual. Type-A is usually used for slope stabilization purposes. The nominal yield stresses of micropiles available are 552 N/mm2. The yield strength for each cross section is provided in FHWA manual. As this strength is higher than that of maximum expected shear load, API N80 casing with 177.8mm diameter and 12.6mm thickness is selected as casing. Grout of 27N/mm2 compressive strength is taken. The total diameter of pile including grout is taken as 230mm.

5.6 Length of Micropiles

As the piles are battered at 10 degree and 30 degree respectively towards the down-slope and upslope, the length of pile above slip surface for any pile positioned at any point of slope with any angle is determined by by plotting the conditions as shown in the figure(Fig. 6).

From the figure, for a slope of angle θ and height H with the toe centered at O(0,0) and the slip surface centered at (a,b) with a radius of r

We have the equation for line OP as

$y = x \tan\theta$

(6)

Equation of slip circle is,

$$(x-a)^2 + (y-b)^2 = r^2$$

(7)

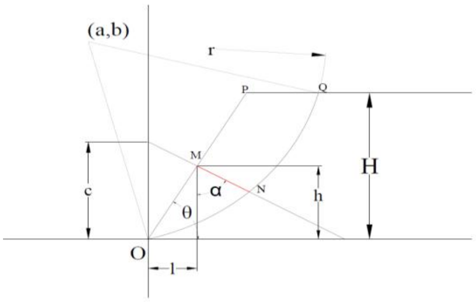

Figure 6: Determination of length of micropiles above slip surface

We have to find the length of pile above slip circle MN, with a batter angle α and with position of M at (l,h)

Let the equation for line passing through axis of pile be

$$y= m x+ c$$

(8)

$$m = \tan (90+ \alpha)$$

(8a)

$$c=h\left[\frac{1}{\tan\alpha\tan\theta}+1\right]$$

(8b)

To find postion of N($x^{|}$,$y^{|}$), which is a common point on the slip surface and the line through axis of pile, Equation 5 is substituted in Equation 4.

$$(x-a)^2+ ((m x+ c)-b)^2 = r^2$$

or

$$x^2\{m^2+1\} + x\left\{2\left(m\left[c-b\right]-a\right)\right\} + \left\{b^2+\left(c-b\right)^2-r^2\right\}= 0$$

(9)

$x^{|}$ is found by solving Equation 6.

$$x^{|}=\begin{cases}\dfrac{-B - \sqrt{B^2-4AC}}{2A} & ,\text{for } \alpha < 0\\ l & ,\text{for } \alpha = 0\\ \dfrac{-B + \sqrt{B^2-4AC}}{2A} & ,\text{for } \alpha > 0\end{cases}$$

(10)

Where,

$$A = \{m^2 + 1\}$$
$$B = \{2(m[c-b]-a)\}$$
$$C = \left\{b^2+\left(c-b\right)^2-r^2\right\}$$

(10a)

$y^{|}$ is found from substituting the value of $x^{|}$ in Equation 4. Length of micropile above slip surface $L^{|}$ is found using Equation 8 below

$$L^{|}=\sqrt{(x^{|}-l)^2+(y^{|}-h)^2}$$

(11)

The Additional Force (AF) required is assumed to be acting as a Uniformly Distributed Load (UDL) throughout the upslope pile, above slip surface. The piles are assumed to be rigidly connected by means of top-beam and fixed below slip surface. The force acting as UDL will be resolved into axial components and the bond length needed for both the piles in a pair to maintain fixity below slip surface is determined.

The Additional Force (AF) for the pair will be the force required to stabilize the entire spacing between two pair. Thus an $AF^{|}$ is found where,

$$AF^{|}=AF\times\text{Spacing between pairs}$$

(12)

$$AF^{|}=175.75\times0.8=140.36\text{kN/m}$$

Assuming the required force to be acting throughout the upslope micropile, above the slip surface as an UDL

$$AF_{UDL}= \frac{AF^{|}}{L^{|}_{U}}$$

(13)

Where,

AF_{UDL} is the Magnitude of Uniformly Distributed Load,

$AF^{|}$ is the total additional force required for a micropile pair,

$L^{|}_{U}$is the Length of Upslopemicropile above slip surface

The axial load on upslope micropile is found to be 189.11kN and for down-slope micropile, it is 74.69kN.

The grout to ground bond strength values are provided by Bruce et. al. (2005). For sandy soils the allowable bond srtressfallis 70kN/m2. The length of the micropile to be extended below slip surface is given by Equation (10)(Turner (2013))

$$L_{req}= \frac{P}{f_{all}\pi D}$$

(14)

Where,
Lreq is the length to be extended below slip surface
P is the axial load,
fall is the allowable bond strength,
D is the diameter of the pile (Here it is 0.229m)

The length, $L_{req\text{-}up}$ to be extended below slip surface for upslope is 3.50 m and Lreq-down for downslope micropile is 1.60 m.

For upslope the total length required is 6.80 m. For downslope the total length required is 6.90 m. The iullustration of the design is given in the figure (Figure. 7)

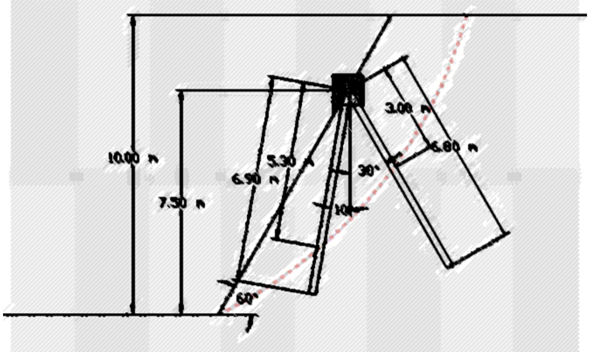

Figure.7. Design of Micropile slope stabilization system.

The factor of safety achieved with the instalation of micropile system is computed as 1.51.usingPlaxis 3D software

6. CONCLUSION

The soil characteristics of Kakkayam were studied and found that the composition of the soil is governed by sand and the soil has a lesser value of cohesion.

Geo5 software is used and the existing factor of safety of the slope is 1.06.

A system of micropiles was designed so as to improve the stability of the slope to a targeted value of 1.5 and the dimensions of the components of the system were determined that the value of Factor of Safety is increased to 1.51.

Aemperical equation to calculate length of pile above slip surface is found

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