Design of geocell stakes along slopes using analogy of laterally loaded piles

Prashant Guda, Yashodeep Patil, Suraj Vedpathak, Gautam Dalmia & Shahrokh Bagli
Strata Geosystems (India) Pvt. Ltd.,India

ABSTRACT: Geocells with low aspect ratio are recommended to prevent erosion of slopes of soil embankments. Steel stakes / pins are generally used to hold these geocells in position. Generally anchor stakes are designed for pullout; however this procedure is inappropriate where in-filled geocells placed along a slope are subject to net sliding forces along the slope in a direction perpendicular to the anchored stake. A close similarity can be drawn to laterally loaded piles.

Anchor stakes normally used are 8mm diameter mild steel rods, 450mm length. By a thumb rule, the anchor stake length should be at least thrice the depth of geocell. However diameter of the stake as well as embedment length and spacing of the stakes will depend upon several factors, primarily the undrained shear strength of the embankment material, besides the density of the in-fill material and weld spacing of the geocells which would manifest as net sliding forces. This Paper considers the net sliding forces parallel to the slope and provides a mechanistic approach to the analysis to determine the adequacy of the embedment length of the stake and as a corollary, the number of stakes required to take up the net sliding forces, limiting the deflection of the stakes and thereby limiting deflection of the geocell sysyem down the slope.

The analysis deliberated here is analogous to laterally loaded long piles.

Keywords: Anchor stakes, geocells, slopes, erosion control, length of stakes, number of stakes, net sliding force, maximum deflection, laterally loaded long piles analogy

1 INTRODUCTION

A geocell is a three dimensional cellular confinement system with varied applications inter alia including load bearing and erosion control. Erosion along an earth embankment slope may be because of several factors, essentially rain water run-off, wind and water seepage from with the soil mass. In order to prevent erosion of soil along the slope, geocells are installed along the slope surface. The cells of the geocell are in-filled with vegetative soil, gravel or lean concrete. The vegetative soil infill within the geocell prevents soil erosion and promotes vegetation which gives an aesthetically pleasing look. Because of the slope, a net sliding force acts on the entire geocell system. In order to hold the geocells on the slope against the net sliding force, anchor stakes / pins are spiked into the slope. An anchor may or may not be provided at the top of the slope. The net sliding force is distributed among the anchor stakes and the anchor trench at the top (if at all provided). Tendons are used to maintain the geometry of the geocells while installing the geocells on the slope surface. The anchor stakes are normally 8mm diameter mild steel rods having an inverted U-shape at the top to hold on to the geocell brim. Quite often, anchor stakes are designed for pullout capacity, but the net sliding force acts laterally to the anchor stakes. Therefore, anchor stakes should be designed for lateral loads rather than for pullout. The Authors recommend using the analogy of laterally loaded piles for design of anchor stakes. A typical cross section of slope erosion protection using geocells is shown in Figure 1.

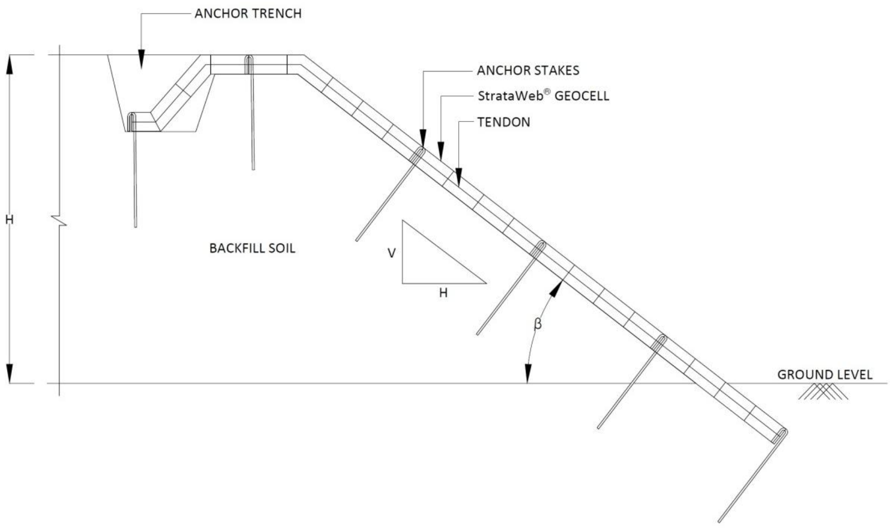

Figure 1. Typical cross section of embankment slope with geocell for slope erosion protection

2 DESIGN OF ANCHOR STAKES

Design of anchor stakes considering pull-out capacity of anchor stake is inappropriate since the net sliding force acting on the geocell acts perpendicular to the anchor stakes as in laterally loaded piles. Hence anchor stakes are designed analogous to laterally loaded piles and their capacity is determined accordingly. The net sliding force acting laterally to the anchor stakes is shown in Figure 2.

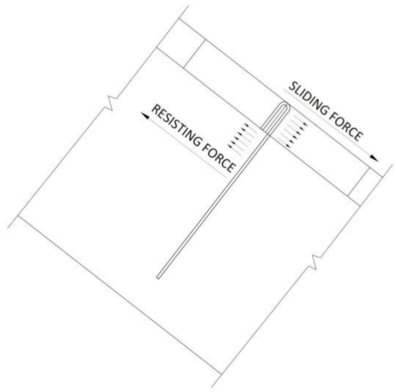

Figure 2. Net sliding force acting laterally on the anchor stake

Anchor stakes resist lateral loads perpendicular to the stake by mobilizing lateral resistance of soil around it as shown in the Figure 2. Considering the pile analogy, there are various methods to calculate lateral loading capacity of piles. The governing parameters include type of pile, geometry of pile and soil properties. Ultimate load analysis is carried out by either Broms' method or Meyerhof's method. Elastic solution according to Matlock and Reese (1960) is generally used for determining lateral load capacity of vertical piles which are embedded in granular soils.

In this Paper, Broms' method has been used to determine lateral load carrying capacity of anchor stakes embedded on a sloped embankment.

2.1 *Broms' method*

Broms (1) provided a simplified solution based on assumptions of shear failure in soil in case of short piles, and bending in the pile governed by plastic yield resistance of the pile section in case of long piles. Furthermore, Sabrena, J. O. and Md Zoynul (2) have used simplified solution for a layered soil system. A major advantage of Broms' method is that it determines the lateral capacity of short and long piles (both free head and fixed head) in cohesionless as well as cohesive soils. As per theory, piles can be divided in two types as short and long piles. Short or rigid piles are those which are rigid such that they move in the direction of the load by rotation or translation. Long or flexible piles are those where the top will rotate or translate without allowing movement of the bottom of piles.

In this Paper, analysis has been carried out for anchor stakes used on highways embankment constructed from cohesive soils, or c soils. Broms' charts for short and long piles embedded in c soils are shown in Figure 3.

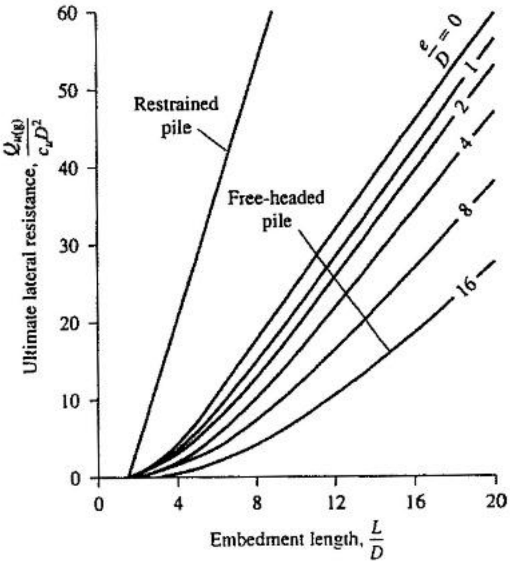

Figure 3. Broms' solution for ultimate lateral resistance of short piles in c soils

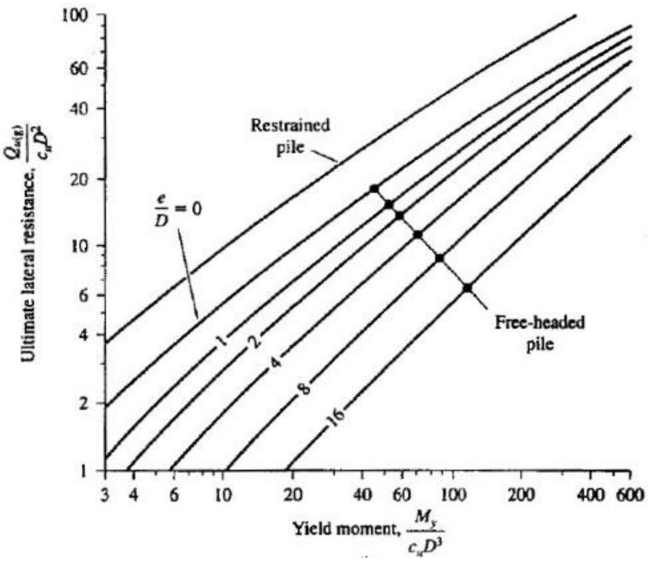

Figure 4. Broms' solution for ultimate lateral resistance of long piles in c soils

For erosion solutions along slopes, depth of geocells is commonly 75mm. Hence for the purpose of analysis, the Authors have considered depth of geocell considered is 75mm. The total length (L) of the anchor stake considered is 450mm and the diameter (D) is 8mm. By virtue of the soil infill within the cells of the geocells, stakes are assumed as restrained. Considering the chart for Broms' solution for ultimate lateral resistance of long piles in cohesive soils, lateral loading capacity of anchor stakes is calculated as follows:
Assuming that the embankment has a minimum undrained cohesion (c_u) value of 45 kPa.

As anchor stakes' top portion is embedded in geocell, considering the analysis for restrained piles,

$$\text{Yield moment} = \frac{\mathrm{M_y}}{\mathrm{c_u D^3}}$$

where,

$$M_y = SF_y$$

S = section modulus of the pile (stake) section

$$S = \frac{\pi}{32} D^3$$

$$S = 5.03 \times 10^{-8}\ \mathrm{m}^3$$

F_y = yield stress of the pile material

$$F_y = 250\ \mathrm{MPa}$$

Hence,

$$M_y = 0.0125\ \mathrm{kNm}$$

$$\text{Yield moment} = \frac{0.0125}{45 \times 0.008^3} = 542.53$$

From Figure 4,

Ultimate lateral resistance is given as,

$$\frac{Q_{u(g)}}{c_u D^2} = 100$$

$$Q_{u(g)} = 100 \times 45 \times 0.008^2$$

$$Q_{u(g)} = 0.288\ \mathrm{kN}$$

Similar analysis has been carried out with combinations of various undrained cohesion values for the embankment soil and diameter of the anchor stakes. The load carrying capacities are captured in Table 1 for 8mm, 10mm and 12mm diameter steel bars as anchor stakes in embankment soils with various undrained cohesion values.

Table 1. Lateral load carrying capacity of anchor stakes for 8mm to 12mm diameter

Undrained Cohesion (kPa)	Lateral load carrying capacity of Anchor Stakes (kN)		
	8mm diameter	10mm diameter	12mm diameter
20	0.13	0.20	0.28
25	0.16	0.25	0.36
30	0.19	0.30	0.43
35	0.23	0.35	0.5
40	0.26	0.40	0.57
45	0.29	0.45	0.64
50	0.32	0.50	0.72

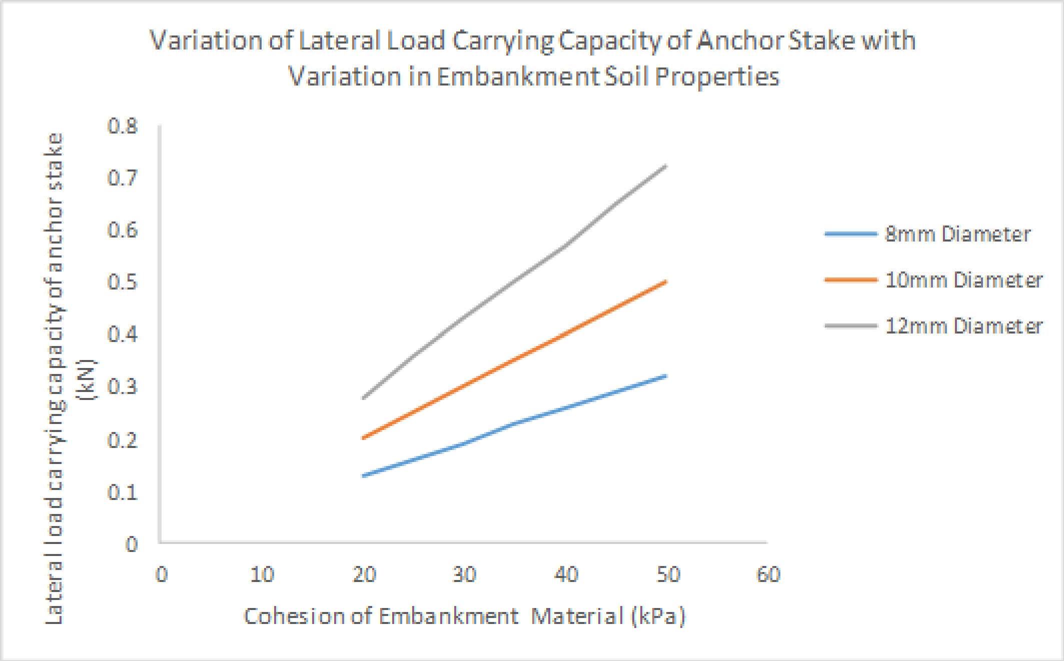

Figure 5. Variation of lateral load carrying capacity of anchor stake with variation in cohesion of embankment soil

Figure 5 illustrates how lateral load-carrying capacities of anchor stakes vary with the undrained cohesion values of embankment soils for 8mm, 10mm and 12mm diameter anchor stakes. It may be noted that the lateral load carrying capacity of anchor stake significantly increases with the increase in diameter of anchor stake as well as with increase in the undrained cohesion of the embankment material.

3 CONCLUSION

The Paper proposes the laterally loaded pile analogy to determine the capacity or adequacy of anchor stakes to hold the erosion protection geocell system along an embankment slope. Computations with pile analogy are more realistic than those based on pull-out capacity of an anchor stake, since the net sliding force from the geocell is parallel to the slope, and perpendicular to the anchor stake. The method takes into account the diameter of the stake as well as the undrained shear strength (cohesion) of the soil within which it is embedded. The proposed method will provide site specific and safe solutions which also facilitate optimisation from cost considerations.

REFERENCES

1. Broms, B. B., 1965, Design of Laterally Loaded Piles, Journal of SMFED, ASCE, No. SM3, pp. 79-99.
2. Sabrena, J. O. & Md Zoynul, A. 2012. Use of Broms' charts for evaluating lateral load capacity of vertical piles in a two layer soil system, 1st International Conference on Advances in Civil Engineering 2012 (ICACE 2012), CUET, Chittagong, Bangladesh.