International Journal of GEOMATE, June 2019, Vol.16, Issue 58, pp.110 - 115
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.58.8181
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

CALCULATION FORMULA FOR PULLOUT RESISTANCE EXERTED BY OPEN-WING-TYPE GROUND ANCHOR

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*Corresponding Author, Received: 24 Oct. 2018, Revised: 28 Dec. 2018, Accepted: 15 Jan. 2019

ABSTRACT: Ground anchor systems (also known as earth anchor systems) are installed to stabilize structures or slopes by connecting a structure or a slope to the anchorage zone using the frictional force between grouting material and surrounding ground. However, the pullout resistance of anchors decreases over long periods of time, causing the anchor to finally pulled out from the ground owing to the decreasing friction between grouting material and surrounding ground. An open-wing type (OW) anchor has been developed by our research group as a new type of earth anchor system to address the issues associated with the currently existing methods. The method uses open wings to exert the pullout resistance. Our research group conducts experiments to examine the effects of a number of wings, root depth, and type of ground on the pullout resistance exerted by OW anchors. The experimental results show the reduction rate of maximum pullout resistance exerted by OW anchor compared to that exerted by disk does not change with the values of relative density and root depth under similar ground conditions. In this study, a formula to calculate the pullout resistance exerted by OW anchor is proposed. The developed formula is based on the formula used for calculating the maximum pullout resistance exerted by a disk as an earth anchor model. The proposed formula relies on the results of experiments to evaluate the pullout resistance exerted by OW anchor.

Keywords: Slope collapse suppression method, Ground anchor method, Open-Wing-type anchor, The formula of computation of extreme pullout resistance exerted by OW anchor

1. INTRODUCTION

In recent years, large-scale sediment-related disasters have occurred in Japan causing human injuries. Anchoring methods are used as effective measures to prevent and control landslides. The method involves connecting a land retaining structure or a slope to the anchorage zone using the frictional force between anchor grouting material and surrounding ground. A variety of anchoring systems are used, including ground anchor, earth anchor, and ground-reinforcing methods. They are installed in many construction sites to maintain slope stability, prevent overturning of retaining structures, stabilize earth-retaining walls, etc.

The pullout resistance of anchors relies on the anchor function component and grouting material, which is made of mortar. The grouting material acts as an adhesive to connect the anchor via friction to its surrounding ground. However, it has been known that friction decreases over time, reducing the anchorage bond with the surrounding ground as the anchor is pulled out from its anchorage zone. The open-wing-type (OW) anchor is a new earth anchor technique that has been developed to address the issues associated with the currently existing methods using open wings to increase pullout resistance [1].

The unique design criterion of OW anchors must be incorporated in the original criteria of anchoring systems to ensure the practical application of OW anchors. Thus, developing a formula to calculate the pullout resistance exerted by OW anchor is absolutely imperative. This study presents a formula for the computation of pullout resistance exerted by OW anchors. Experiments were conducted to examine the effects of a number of wings, root depth, and type of ground on the pullout resistance exerted by OW anchors and proposed a calculating formula to express these conditions.

2. LITERATURE REVIEW

2.1 Formula to Calculate Pullout Resistance Exerted by Disk-shaped Earth Anchor

A formula must be derived to calculate the pullout resistance exerted by OW anchor in order to determine the unique design criteria of OW anchors. Hence, the equation to calculate the pullout resistance exerted by disk-shaped earth anchor was used as a reference in this study. Many researchers proposed equations to calculate pullout resistance exerted by disk-shaped earth anchors using earth cone method [2], earth pressure method [3], shearing method [4], and another method proposed by Balla [5], in which the experiment results were based on the assumptions that the sliding surface is determined by $\lambda \equiv D/2B$ ($2B$: diameter of disk, D : root depth of anchor), sliding surface is expressed by a circular arc determined only by the internal friction angle. Katsumi and Nishihara used the sliding surface proposed by Balla as a reference because it is close to the actually measured sliding surface and involves simple calculation procedures compared to other calculation formulas [6]. In their proposed calculation formula, the pullout resistance is calculated based on the vertical component of force perpendicular to the sliding surface that was not considered by Balla.

2.2 Calculation Formula Proposed by Katsumi and Nishihara [6]

Equation (1) was proposed by Katsumi and Nishihara to calculate the pullout resistance exerted by disk-shaped earth anchor.

$$Q = G_1 + T_\upsilon + G_2 \tag{1}$$

where G_1 is the weight of soil mass, T_υ is the sum of the perpendicular components of shear resistance force and perpendicular components of force exerted on a slide plane and G_2 is the self-weight of the anchor.

G_1 can be obtained by Eq. (2) using the symbols shown in Fig. 1. B is the radius of the disc and D is the root depth.

$$G_1 = \pi B^2 D \gamma F_1(\phi,\ \lambda) \tag{2}$$

Katsumi and Nishihara proposed Eq. (3) to easily set up $F_1(\phi,\ \lambda)$. Fig.2 can be used to set up $f_{11}(\phi), f_{12}(\phi)$ in Eq. (3).

$$F_1(\phi,\ \lambda) = 1 + \lambda f_{11}(\phi) + \lambda^2 f_{12}(\phi) \tag{3}$$

Equation (4) is used to calculate T_υ.

$$T_\upsilon = \pi B^2 D \gamma \left[\frac{c}{D\gamma} F_2(\phi,\ \lambda) + F_3(\phi,\ \lambda) \right] \tag{4}$$

Eqs (5) and (6) were proposed by Katsumi and Nishihara to easily set up $F_2(\phi,\ \lambda)$ and $F_3(\phi,\ \lambda)$. Figs 3 and 4 are used to set up f_{21} and f_{22} in Eq. (5) and $f_{31}$and f_{32} in Eq. (6), respectively.

$$F_2(\phi,\ \lambda) = \lambda f_{21}(\phi) + \lambda^2 f_{22}(\phi) \tag{5}$$

$$F_3(\phi,\ \lambda) = \lambda f_{31}(\phi) + \lambda^2 f_{32}(\phi) \tag{6}$$

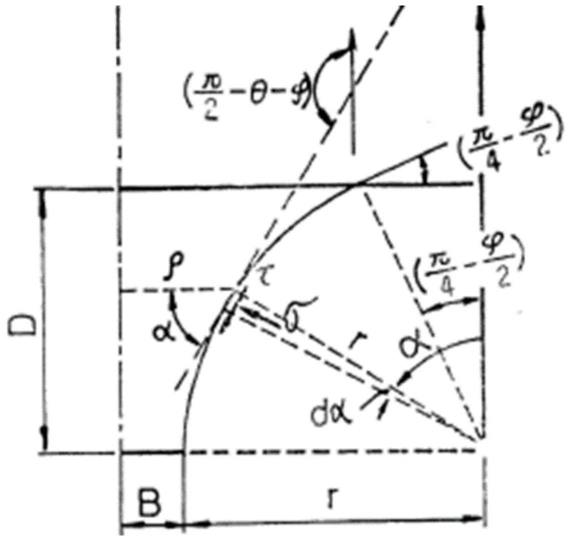

Fig. 1 Stresses acting on the slip line. [6]

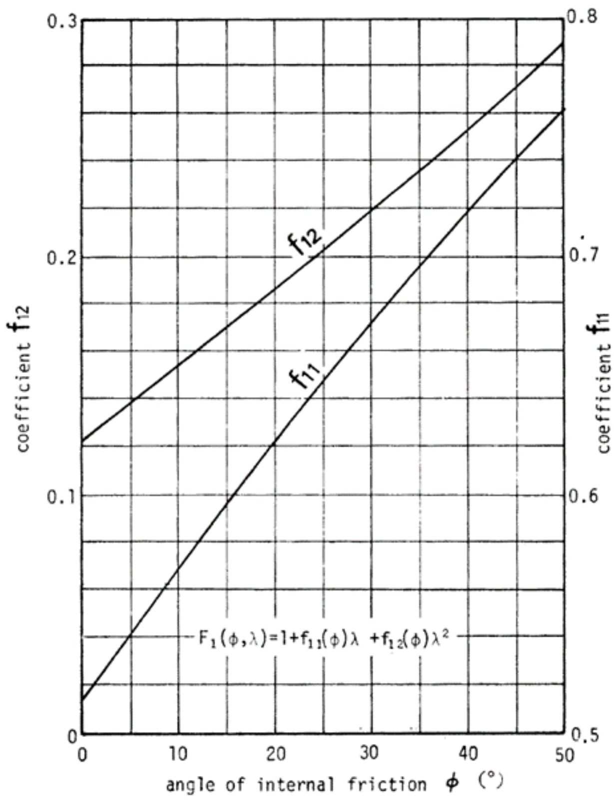

Fig.3 Pullout capacity factor $F_1(\phi, \lambda)$. [6]

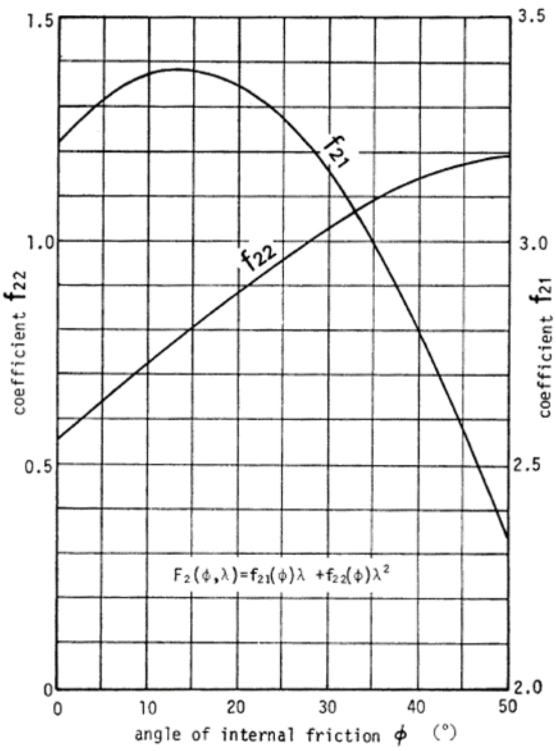

Fig.3 Pullout capacity factor $\boldsymbol{F}_2(\boldsymbol{\phi}, \boldsymbol{\lambda})$. [6]

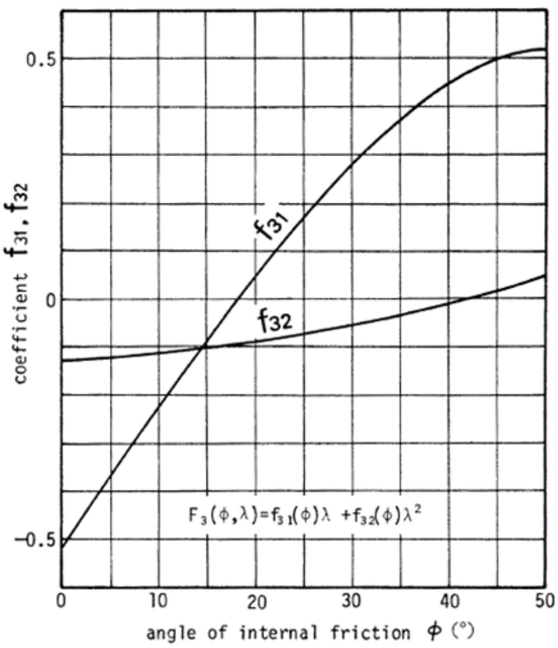

Fig.4 Pullout capacity factor $F_3(\boldsymbol{\phi}, \boldsymbol{\lambda})$. [6]

3. EXPERIMENTS TO ESTIMATE PULLOUT RESISTANCE OF OW ANCHOR

3.1 Experimental Method

The influence of a number of OW anchor wings was examined to evaluate the pullout resistance exerted by OW anchor. Five OW anchors with different numbers of wings (two, three, four, six, and eight wings) and a disk were used in this experiment. Three experimental conditions are listed in Table 1.

Table 1 Specifications of three experimental conditions

Experimental conditions	Condition 1	Condition 2	Condition 3
Type of soil	Decompose -ed granite soil	Toyoura sand	Toyoura sand
The maximum particle size (mm)	2	0.25	0.25
Relative density (%)	100	80	35
Root depth (mm)	200	200	400
Moisture content (%)	10	0	0

When the experiment was conducted using decomposed granite soil, widespread shearing of soil was detected reaching the top of the soil. Thus, a large soil tank was used to prevent shear planes from reaching the wall surface of earth tank. A cylindrical soil tank with a bore diameter of 800 mm and a height of 600 mm was used in the experiment conducted using decomposed granite soil, as shown in Photo 1. Model ground with a bore diameter of 800 mm and a height of 200 mm was formed in this soil. When the experiment was conducted using Toyoura sand, a smaller acrylic soil tank was used compared to that used in the decomposed granite soil experiment because the influence and size of shear bands developed in Toyoura sand are less than those developed in decomposed granite soil. An acrylic soil tank with a width of 600 mm, depth of 400 mm, and a height of 400 mm was used, as shown in Photo 2.

Photo 1 Soil tank.

Photo 2 Acrylic soil tank.

3.2 Experimental Results

The experimental results are shown in Figs. 5-7. Fig. 5 shows the results by the experiments conducted using decomposed granite soil (with 100% relative density and 200 mm root depth). Fig. 6 shows results obtained using Toyoura sand (with 35% relative density and 400 mm root depth). Fig. 7 shows the results obtained using Toyoura sand (with 80% relative density and 200 mm root depth). The maximum pullout resistance was determined for each experimental condition. It found that the highest pullout resistance was achieved when the experiment was conducted using the disk in all experiments and the second highest pullout resistance was obtained using OW anchor with eight wings. In addition, the maximum pullout resistance decreases as the number of wings of OW anchor decreases.

The experimental results were compared to determine the relationship between the maximum pullout resistance and a number of wings. Fig. 8 shows the reduction rate of maximum pullout resistance exerted by OW anchor compared to that exerted by disk when the experiments were conducted using decomposed granite soil (with 100% relative density and 200 mm root depth), Toyoura sand (with 35% relative density and 400 mm root depth), and Toyoura sand (with 80% relative density and 200 mm root depth). Different values of pullout resistance were obtained when Toyoura sand was used owing to the different values of relative density and root depth. However, regardless of the sand physical properties, the reduction rate of maximum pullout resistance determined by the number of wings was comparable with that obtained by disk. Accordingly, the reduction rate does not change with the values of relative density and root depth under similar ground conditions. Furthermore, lower reduction rate was obtained in decomposed granite soil than in Toyoura sand. This can be attributed to the difference in the values of cohesion and inter frictional angle. Thus, the reduction rate of maximum pullout resistance is dependent on the number of wings when OW anchors are used, while it depends on the ground condition and ground strength parameters when using disks.

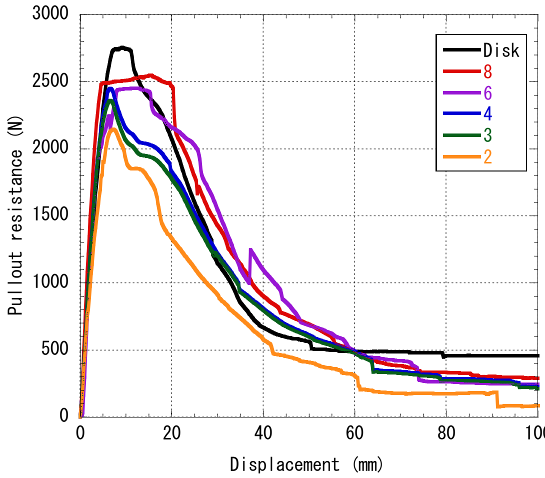

Fig. 5 Condition 1 results.

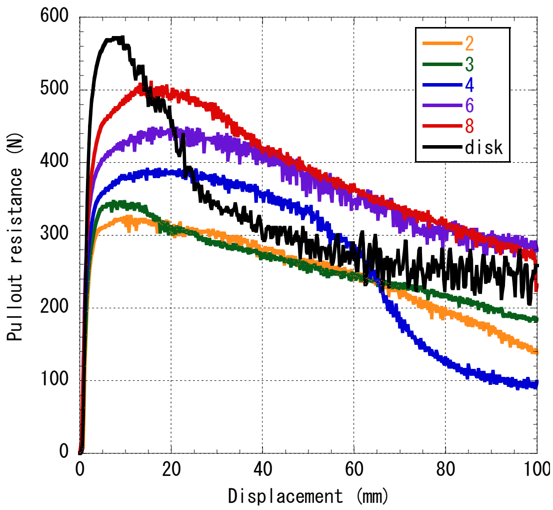

Fig. 6 Condition 2 results.

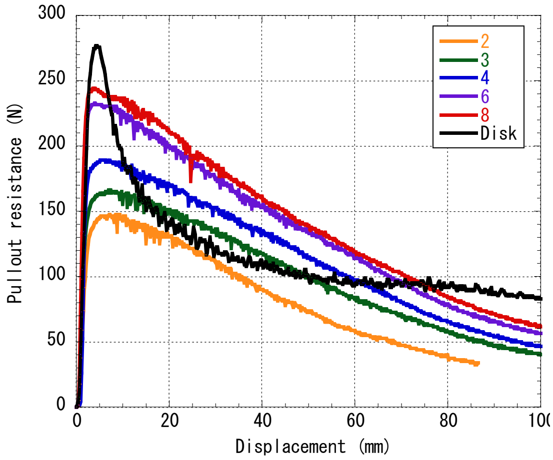

Fig. 7 Condition 3 results.

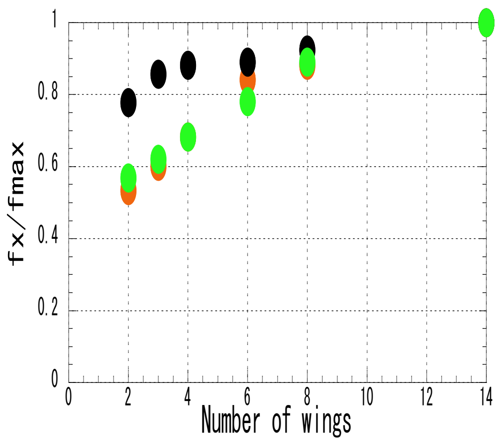

Fig. 8 Reduction rate of maximum pullout resistance

4. FORMULA TO CALCULATE MAXIMUM PULLOUT RESISTANCE EXERTED BY OW ANCHOR

A formula to calculate the maximum pullout resistance exerted by OW anchor was derived using the results obtained from soil tank experiments and based on the formula proposed by Katsumi and Nishihara to calculate the pullout resistance exerted by disk-shaped earth anchor. As discussed above, the reduction rate of maximum pullout resistance exerted by OW anchor is comparable with that obtained by disk anchors, which depend on the value of cohesion and inter frictional angle. Hence, the formula proposed by Katsumi and Nishihara can be updated to derive an original formula to calculate the maximum pullout resistance of OW anchor by incorporating the number of wings, cohesion, and inter frictional angle into the formula developed by Katsumi and Nishihara. When OW anchors with a large number of wings (6 wings, 8 wings, etc.) are used, the soil mass surrounding the OW anchor is approximately equal to the case of disk anchors with less pullout resistance exerted by OW anchor compared to the case of disk because of the reduced amount of soil released through the wing gaps. However, this concept cannot be applied if OW anchors with a fewer number of wings (2 wings, 3 wings, etc.) are used. For example, that the apparent sliding surface in case of OW anchor with two wings differs from that shaped by disk as the amount of soil in the apparent contact area surrounding the OW anchor depends on the number of wings. Thus, the reduction rate of maximum pullout resistance exerted by OW anchor cannot be unconditionally expressed using the number of wings. Hence, a formula to calculate the maximum pullout resistance exerted by OW anchor is derived by multiplying the coefficient that depends on the type of ground and number of wings by the formula f developed by Katsumi and Nishihara to calculate the maximum extreme pullout resistance exerted by disk anchors.

The maximum pullout resistance exerted by OW anchor can be calculated by Eq. (7).

$$Q = a_n(G_1 + T_\upsilon + G_2) \tag{7}$$

where G_1 is the weight of soil mass. T_υ is the sum of perpendicular components of shear resistance force exerted on a slide plane and the perpendicular components of force perpendicularly exerted on a slide plane. G_2 is the self-weight of the anchor. a_n is coefficient depend on the number of wings of OW anchor. a_n is the corresponding reduction rate of maximum pullout resistance determined by a number of the wing when compared to disk for a specific type of ground. Fig. 8 can be used to determine a_n.

5. CONCLUSIONS

Our research group conducts experiments to evaluate the pullout resistance exerted by OW anchor. Five OW anchors with different numbers of wings and a disk were used in this experiment and three experimental conditions are used. The experimental results show the reduction rate of maximum pullout resistance exerted by OW anchor compared to that exerted by disk does not change with the values of relative density and root depth under similar ground conditions.

In this study, a formula to calculate the pullout resistance exerted by OW anchor is proposed. The developed formula is based on the formula used for calculating the maximum pullout resistance exerted by a disk as an earth anchor model proposed by Katsumi and Nishihara. The proposed formula relies on the number of wings of OW anchor.

6. FUTURE RESEARCH

As mentioned in the previous section, the formula developed to calculate the maximum pullout resistance exerted by OW anchor is achieved by multiplying the formula proposed by Katsumi and Nishihara by a coefficient. However, incorporating the relationship between the number of wings, cohesion, and inter-frictional angle into the developed formula can potentially result in more flexible calculation procedures of the maximum pullout resistance without relying on the ground condition and number of wings. Hence, our future research will focus on investigating the relationship between the number of wings, cohesion, and inter-frictional angle using experiments or computer simulations.

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