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STRACTURAL SIMULATION ON AN OPEN-WING-TYPE GROUND ANCHOR

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ABSTRACT: The anchor method involves connecting a structure or a slope with the anchorage zone by using the frictional force between the grouting material and the surrounding ground to stabilize the structure or slope. However, over a long period of time said friction from traditional anchoring methods has been known to decrease, resulting in decreased anchor pullout resistance and ultimately, in anchor pull out. An open-wing type (OW) anchor method developed by our research group is a new type of earth anchor method, in which we use open wings for pullout resistance. Hence, this method can solve problems associated with existing methods. This study suggests an optimum structure for the parts that open in the OW anchor using a numerical analysis, ANSYS (FEM). Three types of 3D analytical models – rotation axis type, bended steel sheet type, and impaction type – are used. The analysis results show the optimum structure to be the impaction type structure, and simulations show that with a base metal yield strength safety factor of 1.5, an OW anchor could generate approximately 4250 N of extreme pullout resistance.

Keywords: Landslide prevention work, Anchor method, OW anchor, Numerical analysis, ANSYS

1. INTRODUCTION

The anchor method employs means for connecting a land retaining structure or a slope with the anchorage zone by using the frictional force between the anchor grouting material and surrounding ground. Examples of the many types of anchor methods include the ground anchor method, earth anchor method, and ground reinforcing method. These are applied at many construction sites for maintaining slope stability, preventing overturning of retaining structures, in earth-retaining walls, etc.

The anchor’s pullout resistance relies on the functionality of the anchor’s main component, grouting material, which is made of mortar. The grouting material works as an adhesive connecting and affixing the anchor via friction to its surrounding ground in the anchorage zone. This friction has been known to decrease over a long time period, ultimately causing the anchor’s functionality to be lost as it is pulled out from its anchorage zone. The open-wing type (OW) anchor method is a new type of earth anchor method [1]. In this method, we use open wings for pullout resistance. Hence, this method can solve the problems that are associated with the existing methods.

This study presents an ANSYS (FEM) numerical analysis to suggest an optimum structure for the opening parts of an OW anchor. Then, using the results of preceding studies, values of the cohesion and, the internal friction angle. And this study determines a range of root depths for which the OW anchor would be well suited to withstand significant pullout resistance and enable practical anchoring.

2. VERIFICATION OF THE OPTIMUM STRUCTURE BY NUMERICAL ANALYSIS

2.1 Method of Numerical Analysis

The pullout resistance of the OW anchor results from wings opened perpendicular to the direction of pull and frictional force between the shaft and surrounding ground. In analysis tool, pullout resistance is expressed load to wings.

In this study, an analysis tool is used to model and compare the pullout resistance of three anchor wing configurations. When the wing or opening parts stresses exceed a criterion, the corresponding load is defined as the extreme pullout resistance for each of the three configurations and the greatest value determines the optimum OW anchor structure.

2.2 Points of Attention for Developing Analysis Model

2.2.1 Section size of analysis model

Ground anchors are used in the casing pipe of a borehole, which is placed underground. Hence, the

OW anchor must fit into the borehole when the anchor wings are not open. For example, consider "shield casing 85" manufactured by TOHO Underground Inc. as a reference [2]. Its outer diameter is 85 mm and the inner diameter is 69 mm. Therefore, the outer size of the model must not be more than 69 mm.

2.2.2 Cost of manufacturing

In the ground anchor method, many anchors of ordinary quality are used. Hence, a cheap material is suitable for fabricating an OW anchor. Therefore, it is preferable that the OW anchor structure is simple and expensive materials are not used.

2.3 Criterion for Judgment of Practical Application of Model

The pullout safety factor is widely used to determine whether the anchor can be used practically. Table 1 lists the pullout safety factors of different ground anchors.

The OW anchor safety factor is related to wing breakage during pullout, which is a primary consideration when considering the practicality of an OW anchor for use. When planning for long time usage of an OW using pullout safety factor, its safety factor should be at least 2.5. But in this study, we use breakage safety factor. Hence, we consider OW anchors with a safety factor of 1.5.

2.4 3D Analytical Model

Three types of 3D analytical models are used in this study. They are the rotation axis type, bended steel sheet type, and impaction type models.

All 3D model have four wings and the angle between shaft and open wing is 60°.

2.4.1 The rotation axis type model

Figure 1 shows the rotation axis type model. In this model, wings are attached to shaft by rotation axis (see Fig. 1 (b) and (c)). In this system, the wings open as a result of rotation.

2.4.2 The bended steel sheet type model

Figure 2 shows the bended steel sheet type model. In this model, wings are attached to shaft by steel sheet. In this system, the wings open owing to bending of the steel sheet.

2.4.3 The impaction type model

Figure 3 shows the impaction type model. This model has wings with a round base (see Fig. 3 (b)) and base part that contains a round hole (see Fig. 3 (c)). This type is used to insert wings in a base part and the wings open as a result of the rotation of wings.

Table 1 Safety factor from pull out of ground anchor [3].

Type of anchor		Safety factor
Short span anchor (less than 2 years)		1.5
Long span anchor (more than 2 years)	Normal time	2.5
	During an earthquake	1.5–2.0

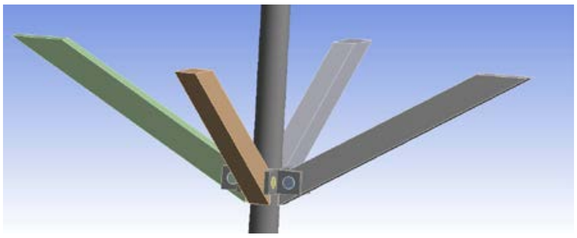

Fig. 1 (a) Rotation axis type model.

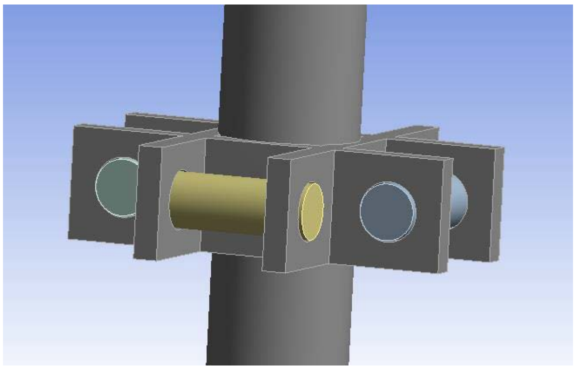

Fig. 1 (b) Rotation axis type model.

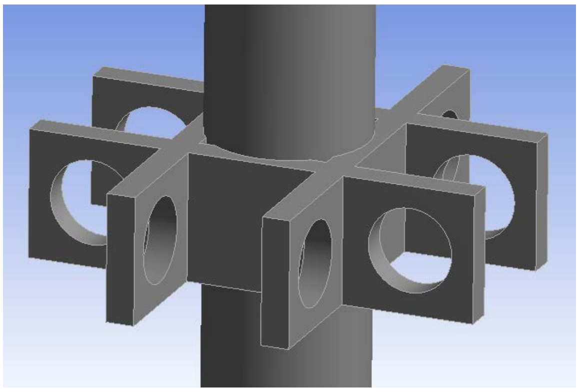

Fig. 1 (c) Rotation axis type model.

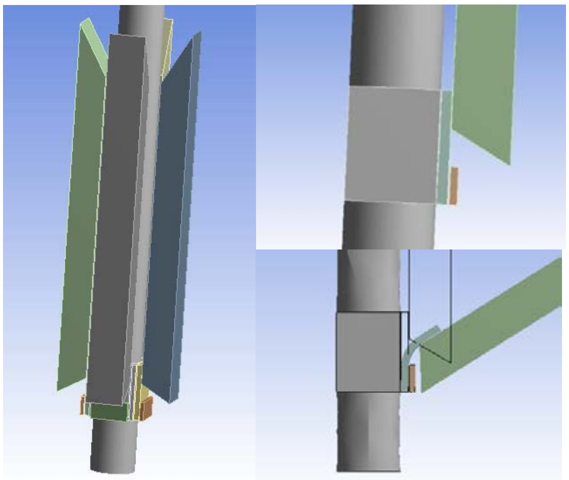

Fig. 2 Bended steel sheet type model.

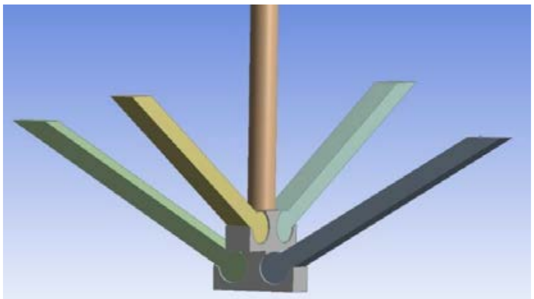

Fig. 3 (a) Impaction type model.

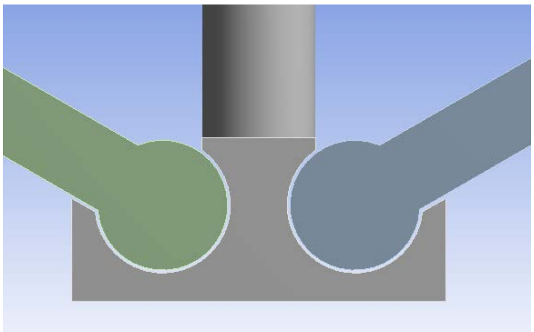

Fig. 3 (b) Impaction type model.

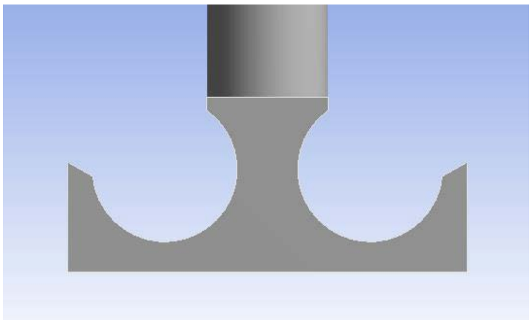

Fig. 3 (c) Impaction type model.

2.5 Analysis Results

2.5.1 The rotation axis type

Figure 4 shows the relationship between the safety factor and the extreme pullout resistance. The optimum structure of the rotation axis type model can generate approximately 3350 N of extreme pullout resistance when it is designed with a safety factor of 1.5. Figure 5 shows a colored distribution of safety factor. Red shows the areas with the lowest safety factor; hence, continuously increasing the load would result in the red parts breaking first.

2.5.2 The bended steel sheet type

It can be concluded that the bended steel sheet type model is not suitable for practical use, because some parts have safety factors less than 1 before the wings fully open. Figure 6 (a) and (b) show the distribution of the safety factor. The factor is low when the color is closer to red.

2.5.3 The impaction type

Figure 7 shows the relationship between the safety factor and the extreme pullout resistance. The optimum structure of the impaction type model can generate approximately 4250 N of extreme pullout resistance when it is designed with a safety factor of 1.5. Figure 8 shows the distribution of the safety factor. The safety factor is low when the color is closer to red. When the load is increased, parts of circle in red break first, owing to the low safety factor.

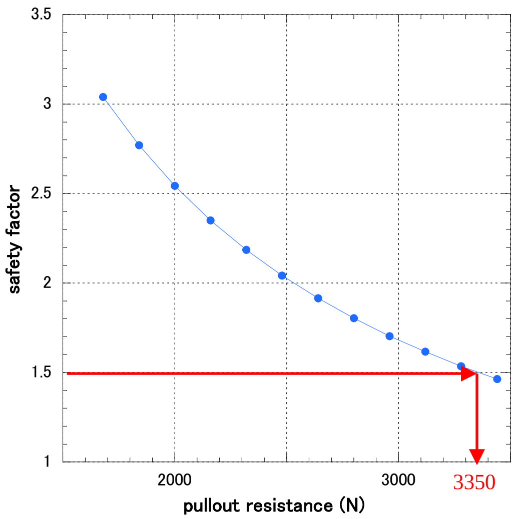

Fig. 4 Relationship between safety factor and extreme pullout resistance of the rotation axis type.

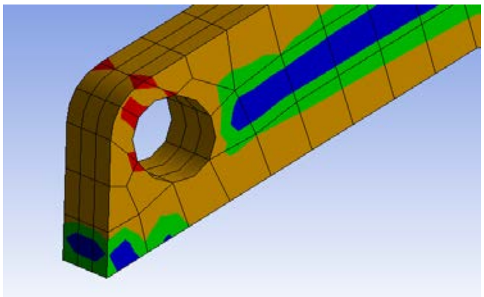

Fig. 5 Distribution of safety factor.

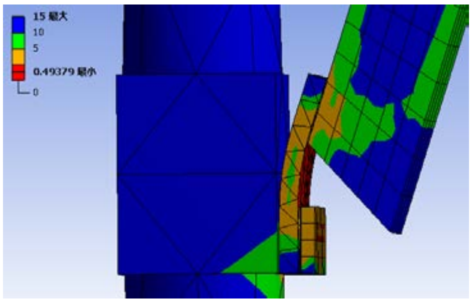

Fig. 6 (a) Distribution of safety factor.

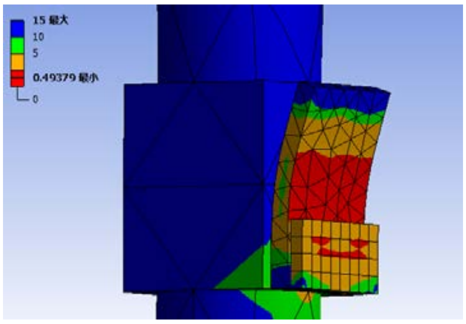

Fig. 6 (b) Distribution of safety factor.

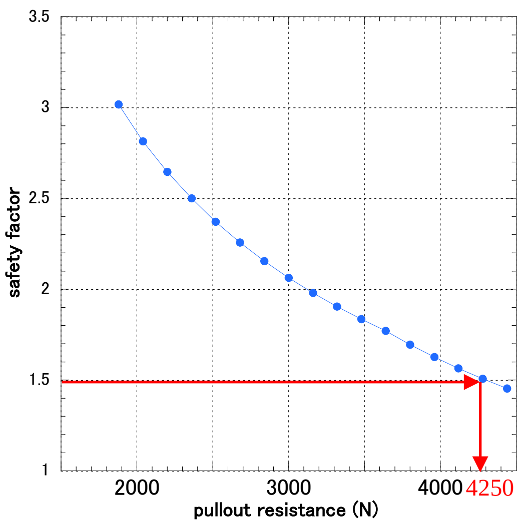

Fig. 7 Relationship between safety factor and extreme pullout resistance of the impaction type.

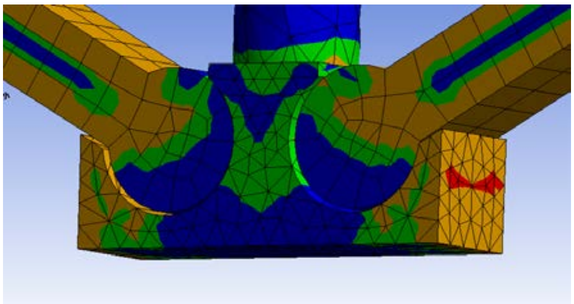

Fig. 8 Distribution of safety factor.

3. STUDY ON MAXIMUM ROOT DEPTH OF THE OPTIMUM STRUCTURE

3.1 Estimation of Maximum Root Depth When Using Optimum Structure

The optimum OW anchor structure was the impaction type, owing to the greatest value of extreme pullout resistance. To calculate the maximum root depth that can be withstood by said pullout resistance, we use the results of preceding studies, values of cohesion, and internal friction angle. For estimation and comparison, a formula for the computation of pullout resistance exerted by a disk is used. Then, a series of experiments was conducted to investigate the relationship between the actual pullout resistance exerted by an OW anchor and the actual pullout resistance exerted by disk.

3.2 Formula for Computation of Pullout Resistance Exerted by Disk-shaped Earth Anchor

Katsumi and Nishihara (1978) suggested a formula for computing the extreme pullout resistance exerted by a disk as a model of an earth anchor [4]. The formula is based on the formula for computation suggested by Balla [5], Matsuo [6] - [8], Mors [9] and can be expressed as Eq. (1),

$$Q = G_1 + T_v + G_2 \qquad (1)$$

Where G_1 is the weight of the soil mass, G_2 is the self-weight of the anchor, and T_v is the summation of the perpendicular component of the shear resistance force that is exerted on a slide plane and the perpendicular component of the force that is perpendicularly exerted on a slide plane.

3.3 Experimental Estimation of Pullout Resistance of OW Anchor

The relationship between the pullout resistance exerted by the OW anchor and a disk was investigated experimentally (Fig.9).

There are four experiment models. The first is the open-wing ground anchor with four wings opened at 45°. The second is the same anchor with the wings opened at 60°. The third is at 90°. The fourth is the disk. The projected lengths of each wing on the horizontal plane are all the same as the radius of the disk. Figure 10 shows the pullout resistance exerted by the OW anchor and the disk. Experimental results show that an OW anchor with four wings opened at 60° exerts 58% of the pullout resistance exerted by the disk.

3.4 Calculation of Root Depth

Figure 11 shows the flow chart of the method of calculation of the root depth when using the impaction type OW anchor. The results are shown in Table 2. The root depth of the optimum structure varies between 79 cm and 156 cm when the cohesion value varies between 0–10 and the internal friction angle varies between 15° and 45°.

Fig. 9 Image of the experiment.

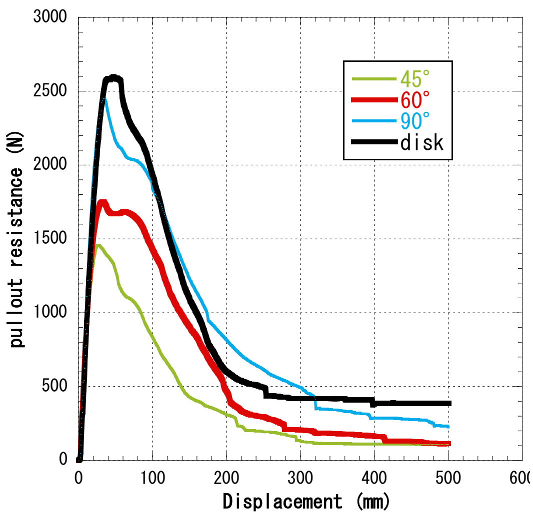

Fig. 10 Pullout resistance exerted by OW anchor and disk.

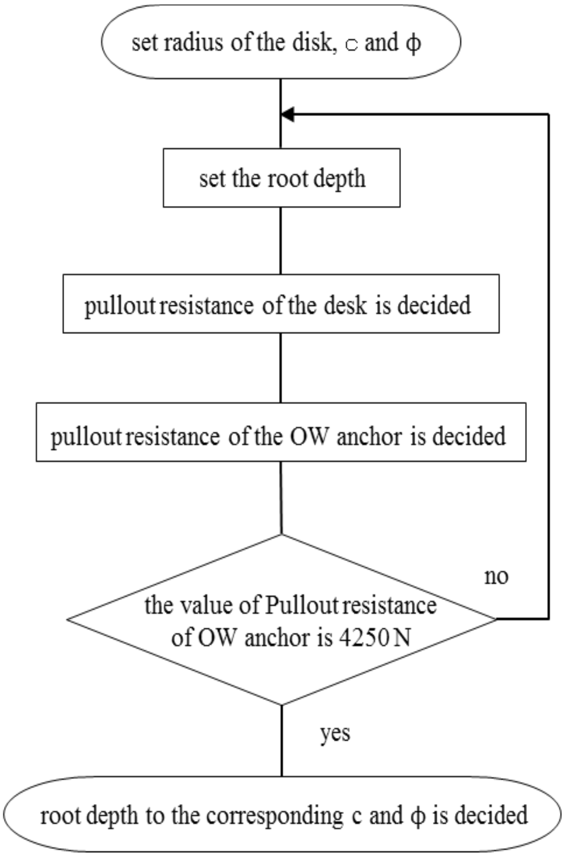

Fig. 11 Method of calculation of root depth.

Table 2 Root depth when using impaction type OW anchor.

c (kN/m^2)	ϕ (°)	D (cm)
0	15	156
	30	102
	45	83
5	15	146
	30	99
	45	81
10	15	138
	30	95
	45	79

4. CONCLUSION

4.1 Summary

The optimum structure is the impaction type structure, and it can generate approximately 4350 N of extreme pullout resistance. The root depth of the optimum structure varies between 79 cm and 156 cm when the cohesion value varies between 0 kN/m^2-10 kN/m^2 and the internal friction angle varies between 15°-45°.

4.2 Future works

It is conceivable that for some use cases, especially in applications with shallow root depths, an OW anchor type, as described and proposed in this study, could be used as a substitute for the existing ground reinforcing type anchors. However, as the root depths increase and approach 2 m, the OW anchor type would not provide the holding abilities of existing ground reinforcing type anchors. For greater root depth applications, it would be essential to improve the proposed OW anchor model or propose a new model that would be capable of exerting more extreme pullout resistance.

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