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Maintenance of a ground anchor based on monitoring of residual tensile loads

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Abstract: Anchors have been used for many years as restraint structures to maintain the stability of slopes. As the restraining effect of such slopes is exerted by the tensile force acting on the involved anchors, investigation of this tensile force is important when maintaining anchors. As multiple anchors are installed on slopes, investigation of numerous anchors is essential to determine the tensile force. This study describes the maintenance of anchors based on the residual-load results obtained using the involved SAAM (Sustainable Asset Anchor Maintenance) system, which uses a compact and lightweight SAAM jack capable of performing lift-off tests on numerous anchors.

Keywords: Ground anchor; Landslide; Maintenance; Monitoring; Tensile load

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1. Introduction

In Japan, numerous ground anchor structures (hereinafter referred to as “anchors”) have been constructed as such restraint structures. More than 60 years have passed since anchors were first introduced in Japan in 1957, and some of these have deteriorated, requiring appropriate maintenance to extend their service life. As anchors use tensile force to maintain the stability of slopes, evaluation of the tensile force is essential when performing maintenance. Investigations of the tensile force acting on anchors have been conducted using methods such as lift-off tests, wherein a jack is installed at the anchor head, and measurements through installation of a load cell at the anchor head. Even if multiple anchors are installed on the slope and anchored with the same tensile force on the same slope, the anchors often do not show the same tensile force due to the influence of the earth behind the structure and other factors [1].

Therefore, when evaluating the residual load of anchors on slopes during maintenance, it is necessary to evaluate the entire slope surface as a “surface” for numerous anchors rather than evaluating each anchor as a “point.” Conventional lift-off test investigations of residual load have used large, heavy center-hole jacks, rendering investigation of numerous anchors difficult. In response to this issue, the authors have developed a compact and lightweight jack that can easily perform lift-off tests (SAAM jack) and proposed the SAAM system to investigate the residual load of many anchors using this jack, making it possible to determine the distribution of residual load on the slope where the anchors are installed [2]. This study presents a method for maintaining anchor slopes by investigating the residual load of anchors using this SAAM system.

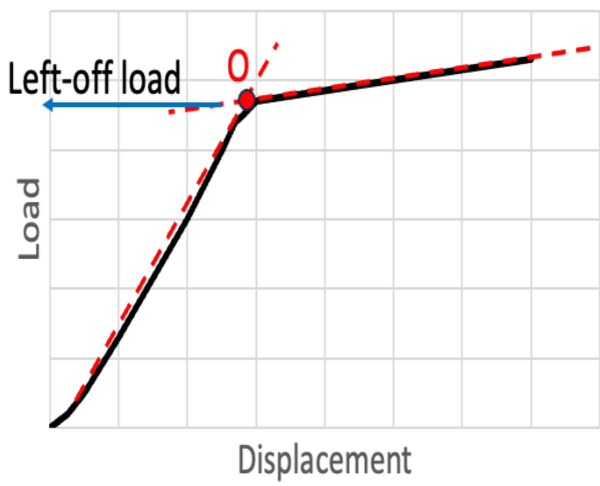
2. Methods

2.1 Residual load of anchor

Lift-off tests and load cell measurements have been used to investigate the residual load of anchors. When determining residual load using the lift-off test, a jack is placed at the anchor head (Figure 1a), a tensile load is applied to the anchor by the jack, and the load–displacement relation shown in Figure 1b is used to determine the residual load. The load–displacement curve presented in Figure 1b shows a linear slope with a steep gradient in the initial stage of loading because of the small displacement of the anchor head. As the tensile load is further increased, "lift-off," in which the anchor head begins to separate from the bearing plate, is observed immediately after the tensile load equals the anchor tension. The residual load of the anchor is considered to be the tensile force at the time of lift-off. However, as it is difficult to confirm lift-off, in which the anchor head floats during the test, the load at the intersection of the straight lines before and after lift-off (point O) was used as the residual load [3].

The Ground Anchor Maintenance Manual [4] provides guidelines for anchor integrity based on residual load and is used for maintenance (Table 1). Figure 2 shows the residual load obtained from the lift-off tests conducted by the authors on 2092 anchors in Japan, classified according to the guidelines for soundness shown in this figure. The results show that the residual load of anchors installed on the slope surface is not uniform after construction, with approximately 40% of the anchors being judged as healthy ("A"), 10% being over-tensioned and therefore judged "C"–"E," and 12% being judged "C" and "D," indicating reduced tension. In general, the residual load of anchors is said to vary depending on the anchor material and the influence of the ground behind the anchors. When performing maintenance based on the evaluation of the residual load of anchors, changes in anchor tension are monitored using load cells or other devices on slopes where the residual load has increased and over-tensioning has been observed. In such cases, it has conventionally been difficult to install load cells on existing anchors; however, with the SAAM system, the load cells can be easily retrofitted [5].

(a)



(b)

Figure 1. (a) Lift-off test situation, (b) Load–displacement relation obtained from a lift-off test

Table 1. Soundness of residual stress

Range of tensile load	soundness	State
0.9Tys	E+	Possibility of failure
1.1Ta	D+	Possiblility of dangerous situstion
Ta	C+	Beyond yolerance
Td	B+	
Pt	A	sound
0.8Td		
0.5Td	B-	
0.1Td	C-	Drastic deteroration of function
	D-	non functional

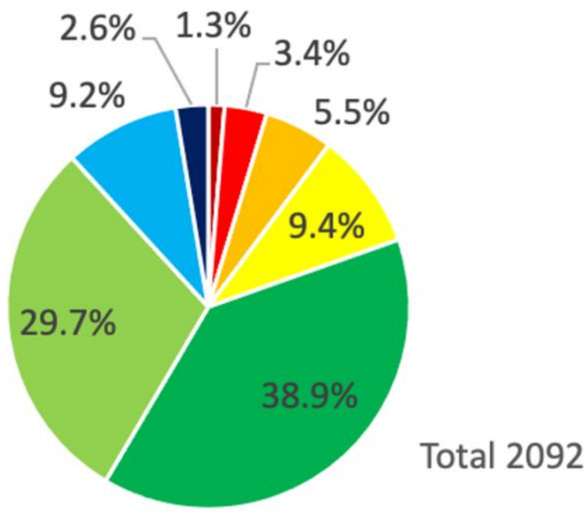


Figure 2. Residual-stress survey results

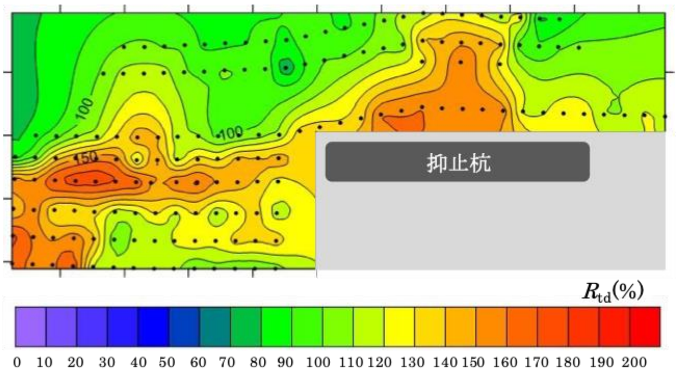
2.2 Residual-load distribution survey

As center-hole jacks are large and heavy equipment, extensive work, involving temporary scaffolding, crane loading and unloading, and road traffic control, is required to conduct the lift-off test. For this reason, the number of lift-off tests surveyed covers approximately 5% of the total slope area. However, as shown in Figure 3a, numerous anchors are installed on the slope, and when maintaining anchors using the residual load, it is necessary to evaluate the entire slope. In response to this, the authors have proposed a survey of residual-load distribution on slopes using the SAAM system, which uses a much smaller and lighter SAAM jack that can quickly perform lift-off tests on many anchors in a short time (Figure 3b). The SAAM system allows lift-off tests to be performed on numerous anchors, thus enabling the residual load over the entire slope surface to be captured as an areal distribution. Figure 4 shows the results of residual-load distribution for 153 anchors installed on the slope shown in Figure 6a, when the numbers of anchors surveyed for the lift-off test were 100%, 50%, 25%, and 5% of the total number of anchors, respectively [6]. The distribution is approximately 100% when the number of lift-off tests is 50%. Furthermore, even when the number of surveys was reduced to 25%, it is possible to capture the distribution trend. However, when the surveyed number is reduced to 5%, it is difficult to evaluate the distribution trend of the slope. This indicates that the survey of approximately 5% performed in traditional lift-off tests is insufficient when maintaining slopes with anchors [7].

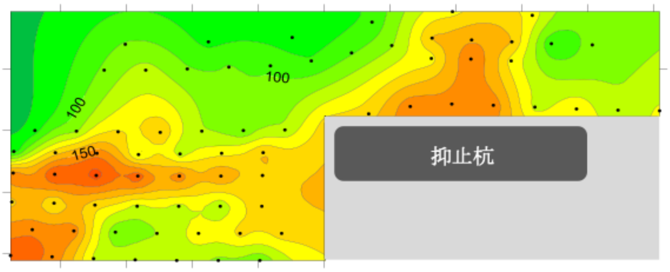
(a)

(b)

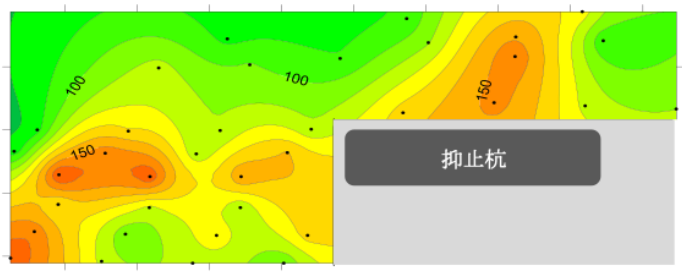
Figure 3. (a) Liftoff test with a center-hole jack, (b) Residual-stress survey using the SAAM system



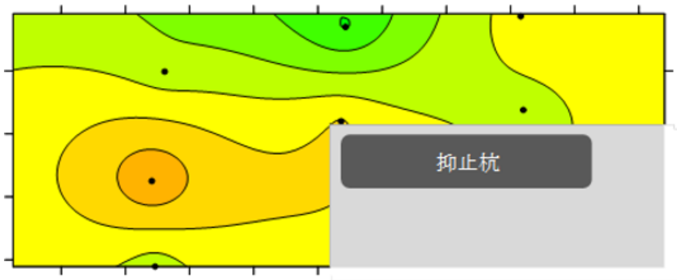
(a) 100%



(b) 50%



(c) 25%



(d) 5%

Figure 4. Residual-Stress Distribution by Number of Investigations

3. Results and Discussion

3.1 Case study of a residual-load distribution in a landslide area

This section presents a case study of a residual load distribution survey conducted using the SAAM system at a site where landslide activity was observed. The objective was to evaluate the soundness of the slope based on the residual load distribution of installed anchors. The survey site shows in Figure 5, is a landslide block measuring approximately 100 meters in width, 120 meters in length, and 15 meters in depth.

Figure 5. Surveyed points

A total of 86 anchors have been installed, with one at the center of each of the three-tiered pressure-receiving structures. The design anchor force (Td) for each anchor is 414.5 kN. At the time of inspection, the tensile force at anchorage (Pt) is approximately 40% to 50% of the design anchor force (Td). Using the SAAM system, lift-off tests were performed on 31 anchors – equivalent to 36% of the toal anchors – to determine the spatial distribution of residual loads.

3.2 Residual Load Characteristics and Implications for Slope Stability

The residual load distribution results obtained from the SAAM system survey are shown in Figure 6. In the residual-load distribution, the region to the left of the side of the center of the slope is in an overloaded state exceeding 0.9 Tys [8]. As shown in Figure 7a, many of the anchors in this area were found to be in various states of damage due to anchor heads falling, rupturing or popping out. Figure 7b shows a situation where an anchor with residual load exceeding 0.9 Tys ruptured and sprung out. Anchors that flew >100 m were also observed at this location. A fiberscope was inserted into the sheath tube to check the depth of anchor breakage and damage to anchors that had ruptured and popped out (Figure 8). The result, as shown in this figure, indicated that the sheath pipe was bent at a depth of approximately 19.5 m near the slip surface; some deformation caused by external compression was observed. It was confirmed that the anchor was affected by the landslide and ruptured due to bending deformation [9].

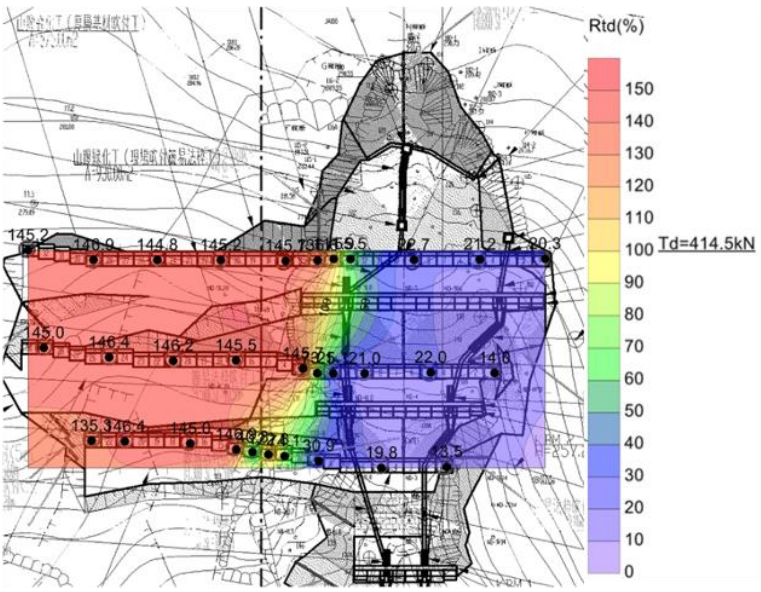


Figure 6. Residual-stress distribution

Figure 7. Anchor popping out

(a) (b)

Figure 8. (a) Fiberscope survey, (b) Deformation status in sheath

Thus, using the SAAM system to conduct lift-off tests on numerous anchors and determine the distribution of residual load on the slope, it is possible to identify areas of over-tensioning on the slope and use these results to identify the extent of landslide activity on the slope for future maintenance and management.

4. Conclusion

The following is a summary of the anchor maintenance method based on the residual tensile force survey using the SAAM system on slopes where anchors have been installed:

- The SAAM system is effective in the maintenance of anchors installed on slopes because it can perform lift-off tests on numerous anchors.
- When surveying the residual-load distribution, surveying 5% of the total is insufficient, and the survey should be >25%.
- By conducting lift-off tests on >25% of the survey points and understanding the residual-load distribution of the slope, it is possible to identify the areas that would, in all likelihood, be affected by landslide activity.
- Anchors with a large degree of over-tensioning with a residual tensile force of >0.9 Tys may be at risk of rupturing and popping out.

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References

[1] Mitsuru Yamazaki and Toshinori Sakai: Evaluation of Relationship Between Decrease in Tensile Load of Ground Anchors and the Geological Conditions, 9Th Int. Conf. on Geotechnique , Construction Materials and Environment, 34-39, 2019, ISBN: 978-4-909106025 C3051

[2] Toshinori Sakai, Yuji Fukuda, Yoshihiro Tsunekawa, Naoaki Yamazaki and Kyoji Yanagawa, The lift-up test for ground anchor using SAAM jack, 43rd Japan National Conference on Geotechnical Engineering, 1361-1362, 2008 (in Japanese)

[3] Yu Fujiwara and Toshinori Sakai: A Study of Lift-off Test Method for Ground Anchor, Journal of JSCE , 4(1), 106-117, 2016, https://doi.org/10.2208/journalofjsce.4.1_106

[4] Public Works Research Institute and Japan Anchor Association: Inspection and Maintenance Manual for Ground Anchor, 2008

[5] Yu Fujiwara and Toshinori Sakai: A Study of a Monitoring Method for Residual Tensile Load of Ground Anchor, Journal of JSCE , 4(1), 134-151, 2016, https://doi.org/10.2208/journalofjsce.4.1_134

[6] Yu Fujiwara and Toshinori sakai: The study on health evaluation method of ground anchors expanding “point to surface”, Journal of the Japan Society of Civil Engineers, 75(4), 460-474, 2017, DIO https://doi.org/10.2208/jscejge.73.460 (in Japanese)

[7] Toshinori Sakai and Yu Fujiwara: Evaluation of Slope Stability Based on Monitoring of Residual Loads on Ground Anchors Using the SAAM System, 7th Int. Conf. on Geotechnique , Construction Materials and Environment, 10-18, 2017, ISBN: 978-4-9905958-8-3 C3051

[8] Toshinori Sakai: The Change of the tensile load of Anchor and Damage of Anchors at the Time of the Heavy Rain, Journal of Geotechnical Engineering, 66(4), 26-29, 2018 (in Japanese)

[9] Toshinori Sakai: Breakage Properties of Ground Anchors under Bending Deformation, 13th Int. Conf. on Geotechnique , Construction Materials and Environment, 2 -9, 2023, ISBN: 978-4-909106100 C3051