A STUDY OF A MONITORING METHOD FOR RESIDUAL TENSILE LOAD OF GROUND ANCHOR

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Ground anchoring is one method for maintaining the stability of slope. When under construction, the tension of the anchor is usually managed by a load meter. At that time, the stability of slope is evaluated by checking the tension of ground anchor.

However, there are cases where the measurements of a loadcell do not show a constant value even on stable ground. In addition, it is difficult to set a loadcell to a working anchor. Appropriate monitoring methods have not been established to date as well. In this paper, we have analyzed the characteristics of the measured loadcell values, looking at loadcell data collected on multiple slopes. Moreover, we have developed two new technologies. One is the technology to confirm functions of the loadcell. Another is a method for attaching loadcell to working anchors. Finally, we propose a monitoring method for the residual tensile load.

Key Words: ground anchor, maintenance, monitoring, lift-off test, cut slope, stability

1. INTRODUCTION

The use of ground anchor (hereinafter, anchor) is a deterrence method that is important for managing tension and checking the stability of slope. Figure 1 shows a typical flow of anchor tension. After introducing tension to an anchor at fixation, the tension is reduced due to the effects of soil creeping and relaxation of tendon. After that, anchor tension tends to move toward the constant residual tensile load¹. However, when the ground is excavated, unexpected external forces may be applied to the anchor in some cases. As a result, anchor tension sometimes increases. In addition, there are cases where the tension of anchor does not converge to a constant level affected by geological features of the ground. Therefore, it is important to monitor the tension of the anchor.

Figure 2 shows the flow of anchor tension management in three NEXCO companies (hereinafter, the expressway company)². When anchors are installed, loadcells are set to some of the anchors. After that, anchor tension is measured frequently to maintain and manage the anchors³. After confirming the convergence of anchor tension, the frequency of measuring tension is reduced. Figure 3 shows a typical flow of anchor maintenance⁴. Daily inspections and periodic inspections are conducted mainly visually, while riding on a car. In the maintenance of anchors in service, lifting and jumping out of anchor head are checked by daily and periodic inspections. When an abnormality is observed, there is a concern that the cut slope may have become destabilize due to changes in anchor tension. Therefore, residual tensile load of some of the anchors is checked in the detailed investigation. A countermeasure is then decided based on the results. At this time, if the loadcell installed at the time of construction may be used, it would make the work process more efficient. However, loadcells are exposed to the natural environment and functional decline of the instrument over time⁵ may prevent an accurate measurement. In general, the useful life of a loadcell is said to be between five and ten years⁶. If we replace the loadcell or set a loadcell to a working anchor, it will be necessary to re-tension the anchor. To re-tension
an anchor, the anchor head needs to be removed, which will be burdensome for workers. Methods for attaching and detaching a loadcell to a working anchor have been developed to date. However, the technology can be applied only on specific loadcells and cannot be used for all types. Thus, if the function of loadcell is thought to be deteriorating, in general, the lift-off test is conducted. The lift-off test is conducted by pulling the tendon with a hydraulic jack. However, when the lift-off test is conducted, it is necessary to attach the hydraulic jack to the anchor head in every test. However, it is difficult to continuously monitor the residual tensile load of anchor. Therefore, this method is not realistic.

The Maintenance Manual for Ground Anchor (hereinafter, maintenance manual), states that if the residual tensile force per anchor is more than 80% of the fix tension and less than the design anchor tension, the anchor is evaluated as healthy. However, anchors are generally installed in plurality in slopes. Anchors also have properties to maintain slope stability, although their residual tensile strength varies per individual anchor. Thus, even if the slope is stable, there may be anchors that are rated unhealthy when checking and following the maintenance manual. In addition, even if the ground is stable, there are anchors that sometimes do not show a constant residual tension load. Therefore, it is important to understand what factors cause this phenomenon. In view of this, even if the residual tension load is not healthy in one measurement, it is difficult to evaluate the slope as unstable. Therefore, it is important to evaluate the stability of slope based on the results of observation conducted for a certain time period.

 Monitoring, using loadcells, is typically conducted on about 1/20 to 1/10 of the total number of anchors. The evaluation method for loadcell measurement has not been clearly defined, and an appropriate monitoring method also has not been defined to date.

This study was performed on anchors installed on typical slopes not affected by weather elements, such as frost heaving, to study the monitoring method for the residual tensile load using loadcells. First, we analyzed the characteristics indicated by the measured value of the loadcells. Then, we studied a method for checking the loadcell and examined the applicability of the method to the loadcell attached on the working anchor. There are many nut-type anchors and wedge-type anchors installed in the slopes of expressways. For these working anchors, we developed a method for attaching and detaching loadcell to measure the residual tensile load. We also examined the applicability of this method to working anchors and proposed a method to monitor the appropriate residual tensile load, based on the findings.

In Chapter 2, we describe the current state of tension management of anchors. The characteristics of measured loadcell value are presented in Chapter 3, and the method for checking loadcell is shown in Chapter 4. Next, we explain a method of attaching and detaching loadcell to the working anchor in Chapter 5. Finally, we propose an appropriate method for monitoring the residual tensile load in Chapter 6.
2. MANAGEMENT OF ANCHOR TENSION

(1) Management of anchor tension on expressway
The standards for expressways state that anchor tensile load should be monitored on more than 1/20 of all anchors that comprise five or more anchors. The anchors monitored to maintain and manage anchors are chosen based on their capability to capture the slope’s tension. Figure 4 shows the general location of the anchors to be monitored. The management of the anchors is conducted by selecting anchors on the main survey line and secondary survey lines on the sliding block. At the time of construction, a loadcell is attached on an anchor, and the measurement is carried out more than once a week. Then, after confirming the convergence of anchor tension, the frequency of measurement is reduced. Anchor tension is measured by loadcell or lift-off tests in the detailed inspections.

(2) Taking measurements using loadcell
Anchors are classified into the nut-type anchor, the wedge-type anchor, and the wedge-nut-type anchor. Figure 5 shows a typical method of installing a loadcell for each type. First, before the tension is introduced, the loadcell is placed between the two plates. Next, the nut of the fixing device is attached. Then, initial tension is introduced using a hydraulic jack, and the loadcell is fixed by tightening the nut. Figure 5(b) shows the installation method for the wedge-type anchor. Figure 5(c) shows the installation method for the wedge- and nut-type anchor. Both types of anchors are installed using the same method. With these anchors, the tendons are fixed by making the wedge bite into the anchor head. In this way, tension is transmitted to the loadcell. Figure 6 shows how tension is measured by connecting the measurement device to the load cell. If the loadcell is attached or replaced on a working anchor, re-tension is needed. This work is a big burden on workers. With anchors installed on expressway slopes, it is common to attach a strain-gauge-type loadcell. If it is necessary to check the measured values of the loadcell frequently over time on such as steep slope, in some cases the M-ring, shown in Figure 7, is used. The M-ring is a magnetostrictive loadcell and has excellent long-term durability. With the M-ring
sensor, the residual tensile load is evaluated by capturing changes in the distortion of the loadcell caused by tension load. There are eight points on the outer rim of the M-ring sensor for measuring the strain. A special device is used for the measurement. The average of measurements at the eight points is considered the residual tensile load. Another type of loadcell that has an excellent long-term durability, shown in Fig.8, is the vibrating-string-type load cell. This loadcell utilizes the principle that natural frequency of the wire changes.

(3) Measurement by lift-off test

The Japan Geotechnical Society standards indicate only the basic method of list-off tests. The evaluation method for the residual tensile load and the loading method have not been sufficiently defined. Therefore, engineers working on-site had to determine many things by themselves, causing the test results to vary, thus posing problems. With expressways, the lift-off test method to be used is determined based on the test results of many anchors. The lift-off test is performed by loading and unloading the anchor head, using a hydraulic jack. The hydraulic load and the displacement of anchor head are then measured. Figure 9 shows how the lift-off test was carried out using a hydraulic jack. The anchor in the figure is a wedge-type anchor. The lift-off test of the wedge-type anchor is conducted by attaching a temporary pooling head to the extra length portion of the anchor head: the temporary pooling head is a device connecting the extra length and tension bar. And then, load is placed on the tension bar.

The hydraulic jack and the displacement of the anchor head are measured in the loading and unloading process. Figure 10 shows the load-displacement curve. The residual tensile load is estimated from the inflection point of the load-displacement curve. At this time, there are three loads that are evaluated as residual tensile load. The load at point A is the load that starts the changes in the linear gradient in the loading process. The load at point B is the load that starts the transition to constant linear gradient. The load at point C is the load that is the intersection of a linear gradient around the change point of the load-displacement curve. Here, point A is defined as "change point 1." Point B is defined as "change point 2." Point C is defined as "tangent method." The general load-displacement curve in the loading and unloading process of the lift-off test shows a route such as point O-point A-point B-point D-point E. In the lift-off test method for expressways, residual displacement sometimes occurs in the first cycle caused by the bite of the fixing device (Fig.10: displacement of O-E). Measurements in the second cycle and after generally show small residual displacements. Therefore, first loading is carried out as preloading, and actual measurements of loading starts from the second cycle.
cycle and thereafter. The residual tensile load is evaluated from the load-displacement curve of the second cycle and after. In addition, the accuracy of the three measurements is compared and verified, and the measured value by the "tangent method" is defined as the residual tensile load.

3. CHARACTERISTICS OF MEASURED VALUE OF LOADCELL

(1) Loadcell installed on life-size test piece of anchor

Even on stable ground, it is considered that the measurements of loadcell react to environmental changes, such as changes in temperature, even if the level of environmental change does not affect ground stability. Therefore, we checked the characteristics of the measurements taken of loadcell, attached to the anchor, under the condition that earth pressure and other elements do not affect the measurements. Figure 11 shows the VSL method of the wedge type, SFL method of the wedge-nut type, and SEEE method of the nut type. We checked loadcell measurements and temperature of the three anchors. The anchor of VSL method was fixed at 220kN, and a loadcell A1 of the vibrating string type was installed on it. The anchor of SFL method was fixed at 296kN, and loadcell A2 of the strain gauge type was installed. The temperature sensor of the thermocouple was placed close to loadcell A2. The anchor of SEEE method was fixed at 414kN, and a loadcell A3 of the vibrating string type was installed. The measured values of each loadcell and temperature were then recorded at one-hour intervals.

Figure 12 shows the measured value of each loadcell and temperature for one month, after about one year from the construction of the anchor. The measured value of the loadcell increases or decreases with changes in the outside temperature. The maximum increase or decrease width of loadcell A2 of the strain gauge type is about 3kN. In contrast, loadcell A1 of the vibrating string type is 18kN, and loadcell A3 is 16kN.

These measured values are larger than the measured values of the strain gauge type. The increase or decrease width of the measured values of the loadcells is different according to the type of loadcell used. It is considered to be caused by the differences in the temperature correction function of each loadcell. In addition, with the loadcell of the vibrating string type, the difference in anchor and the
difference in the fixed tensions do not influence the increase or decrease of the measured values. Figure 13 shows the relationship between the measured values of loadcell A1 to loadcell A3 and outside temperature. We can see that the measured value of the loadcell has a tendency to increase according to changes in the temperature. The maximum variation width of loadcell A2 of the strain gauge type is 10kN. The maximum variation width of loadcell A1 of the vibrating string type is 18kN. The maximum variation width of loadcell A3 of the vibrating string type is 13kN. The measured values of the vibrating string type are larger than those of the strain gauge type.

Table 1 shows the correlation coefficient between the measured value of loadcell A1 to loadcell A3 and the outside air temperature. The correlation coefficient of each loadcell is more than 0.80, and is high. From these results, if measured values of the loadcell attached to the anchor are not affected by ground pressure, the values of the loadcell change according to changes in the outside air temperature.

In addition, increase or decrease width of the change is different owing to the difference in the temperature correction function of each loadcell type. The values of the loadcell and the value of air temperature show positive correlation.

(2) Measured value of loadcell on working anchors

We checked the characteristics of the measured values of loadcell of anchor at the site. Figure 14 shows slope 1. We analyzed the measured value of the loadcell at slope 1. Slope 1 is a cut slope of an expressway, constructed when the expressway was built. The geology of slope 1 mainly consists of relatively consolidated conglomerate of the Oigawa layer group. The mudstone is interposed therein. The anchors are of the EHD method of wedge nut type and are installed on the grating crib works, because of slope deformation. We attached loadcells of the strain gauge type to two anchors. These loadcells were loadcell B1 and loadcell B2. A small button-type temperature sensor was attached near loadcell B2. It took about three months for the measured values of the loadcell to converge to a constant state after the anchors were fixed. During this period, we recorded at one-hour intervals the measured values of the loadcell and the outside air temperature.

Figure 15 shows the measured values of loadcell B1 and loadcell B2 and the outside temperature for a period of about three months after the anchors were fixed. The measured values of the loadcell converge to a constant state after the anchors were fixed. During this period, we recorded at one-hour intervals the measured values of the loadcell and the outside air temperature.

Figure 16 shows the measured values of loadcell B1 and loadcell B2 and the measured values of the outside temperature for one month after the anchors were fixed. The variation widths of loadcell B1 and loadcell B2 were large for one month after the anchor was fixed, until the changes in the tensions converged. The maximum width of the variation in the second month after the anchors were fixed for loadcell B1 was 10kN, and for loadcell B2 it was 9kN. The maximum width of the variation in the
The measured value of loadcell B1 was 8kN, and for loadcell B2 it was 7kN. Table 2 shows the correlation coefficient of the measured value for load cell B1 and loadcell B2, and outside temperature. The correlation coefficient of each loadcell for one month after the anchor was fixed was as low as 0.30 degrees. In addition, the correlation coefficient of each loadcell in the second month after the anchor was fixed was as high as 0.70 or more. The correlation coefficient of each loadcell in the third month after the anchor was fixed was as high as 0.70 or more. One month after the anchor was fixed the measured value of the loadcell and the outside temperature showed a similar tendency to that of loadcell A2 of the strain gauge type that was attached on real-size specimens of the anchor. The results show that the change in tension has converged.

From these results, it is considered that the measured value of the loadcell changes in different ways owing to various factors, such as ground pressure and the ground where each anchor is fixed. However, their effects are considered to have been reduced after a certain period from construction, and the outside temperature becomes the dominant factor in changing the measured value of the loadcell. Anchors are usually installed in large numbers on the slope. And, while the residual tensile load of anchors varies, the anchor functions to maintain stability of the slope. Even if the anchor slope is stable, some anchors are evaluated as unhealthy according to "the maintenance manual." In this situation, the correlation of the measured value and outside temperature will be used to make the judgment. For example, we will study to determine if the change of tension is due to the temperature characteristics of the loadcell itself, or the effects of ground pressure, and so on.

**Table 2** Correlation coefficient of loadcell and outside temperature (loadcell B1, loadcell B2).

<table>
<thead>
<tr>
<th></th>
<th>Correlation coefficient of loadcell and outside temperature (loadcell B1, loadcell B2)</th>
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<tbody>
<tr>
<td></td>
<td>B1</td>
</tr>
<tr>
<td>One month has elapsed after fixing</td>
<td>0.25</td>
</tr>
<tr>
<td>One month from one month had elapsed after fixing</td>
<td>0.73</td>
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<tr>
<td>One month from two months had elapsed after fixing</td>
<td>0.87</td>
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(3) Effects of differences in the pressure plate

If measured values of the loadcell is affected by outside temperature, the degree of effect is considered caused by the differences in the pressure plate, in addition to the temperature characteristics of the loadcell. Thus, the anchors on slope 2 with different pressure plates, shown in Fig.17, were analyzed for the values of loadcells measured when the change of tension converged after about six months. Slope 2 was constructed by cutting the slope when the dam was constructed. The slope was of fragile geological structure consisting of green schist and black schist belonging to the Sanbagawa metamorphic rocks. Slope deformation was found on slope 2, and the EHD anchors of the wedge and nut type with lightweight pressure consisting of long glass fiber material or the EHD anchors with concrete pressure were installed for reinforcement. Of these, loadcell C1 and loadcell C2 of the strain gauge type were attached on the anchors with lightweight pressure plate. Loadcell C3 and loadcell C4 of the strain gauge type were then attached on the anchors with concrete pressure plate. The small button-type
A temperature sensor was attached near loadcell C1. Then, we recorded the measured values of the loadcell and outside temperature at one-hour intervals.

**Figure 18** shows the changes in the measured value of loadcell C1 to loadcell C4 and outside temperature collected for about one month. The fixed tension load of the four anchors are all 647kN. However, the measured value of loadcell C4 has decreased by 25% or more to the fixed tension load, and the measured value of loadcell C1 has decreased by about 5% to the fixed tension load. This shows that measured values of the loadcells vary. The maximum width of increase and decrease of the measured values of loadcell C1 with the lightweight pressure plate was 22kN. The maximum width of increase and decrease of the measured values of loadcell C1 with concrete pressure plate was 24N. The maximum width of increase and decrease of the measured values of loadcell C3 with concrete pressure plate was 4kN. And, the maximum width of increase and decrease of the measured values of loadcell C4 with the concrete pressure plate was 3N. These values have remained almost constant. **Figure 19** shows the relationship between the measured values of loadcell C1 to loadcell C4, and outside temperature. The maximum width of increase and decrease of the measured values of loadcell C1 with lightweight pressure plate was 25kN. The maximum difference in the increase and decrease of the measured values of the loadcell C2 with lightweight pressure plate was 22kN. The maximum width of increase and decrease of the measured values of the loadcell C3 with concrete pressure plate was 10kN. The maximum width of increase and decrease of the measured values of the loadcell C4 with concrete pressure plate was 9kN. The variation in measured values of the lightweight pressure plate is larger than the variation in measured values of the concrete pressure plate. In addition, we compared the incline of the approximate expression that was determined by the method of least squares to each loadcell. The linear gradient of load C1 and loadcell C2, with the lightweight pressure plate, was found to be steeper than the linear gradient of load C3 and loadcell C4, with the concrete pressure plate. This result shows that the...
rate of temperature change in the loadcell is different according to the type of pressure plate. Table 3 shows the correlation coefficient of the measured values of loadcell C1 to loadcell C4 and outside temperature. Also, the correlation coefficient of each loadcell is as high as 0.70 or more.

From these results, we consider that the measured values of the loadcell may be affected by the temperature characteristic of the pressure plate, in addition to the temperature characteristics of the loadcell. There are various types of pressure plates. The actual temperature characteristic of the pressure plate will become evident by analyzing the measurements of the other pressure plates.

4. CHECK METHOD FOR LOADCELLS

(1) Checking loadcell function attached to real-size anchor specimen

Loadcells are exposed to the natural environment. For this reason, the loadcell functions may degrade over time. Therefore, the measured value of a loadcell on a working anchor may not represent the correct tension of the anchor. We conducted the lift-off test on the strain gauge type loadcell A2 attached to a real-size anchor specimen by using the center hole jack, used in constructions, as shown in Fig.20. We then checked the characteristics of the normal loadcell by comparing the load-displacement curve of the lift-off test. The lift-off test was carried out following the test method established for expressway lift-off tests. The first cycle of lift-off tests was carried out as pre-loading. From the load-displacement curve of loadings for the second cycle and after, the load points obtained by the "tangent method" were then evaluated as the residual tensile load.

Figure 21 shows the load-displacement curve obtained by the lift-off test. The path from point A-point B shows where the change in linear gradient begins unloading, in relation to the distance between the hydraulic jack load and displacement. On the other hand, the path from point A'-point B' shows where the change in linear gradient begins to where it becomes constant during loading and until unloading in relation to the distance between the hydraulic jack load and displacement. When comparing the two pathways, we can confirm that each curve is about the same in form. From this result, the function of a loadcell may be checked by comparing the load-displacement curves of the hydraulic jack and the measured value of loadcell and checking the followability of the curves. On the other hand, from the comparison of both measured values, the measured value of the "tangent method" of the lift-off test was 182kN (point C), and the measured value of the loadcell was 181kN (point A'). In the Japan Geotechnical Society standards, the residual tensile load of the anchor evaluated by the lift-off test is defined as the load when the anchor head begins to lift away from the plate (displacement of 0.1mm – 1.0mm). This phenomenon is typically called "lift-off". Lift-off was confirmed at point A. Point A is "change point A" when the load-displacement curve begins to change, as shown in Fig.21. The load value of point A is the same as the load value of point A' of the loadcell, and this load is considered the residual tensile load of the anchor. However, it is difficult to directly confirm the lift-off point in actual lift-off tests, or to capture the point where the linear gradient of the load-displacement curve changes. Therefore, the residual tensile load is generally evaluated from the point obtained by the "tangent method". Thus, when checking the loadcell, if point C is evaluated as the residual tensile load, and if point A' is the load that is captured by the loadcell, it is important to understand that the load difference between point C and point A' occurs owing to the difference in the measurement methods.
(2) **Function check of loadcell attached to working anchors**

Slope 3, shown in Fig.22, is an expressway slope with a geological structure consisting mainly of rock and gravel sandstone of the *Nosugawa* layer group. Functions of loadcell D1 to loadcell D8 installed in slope 3 were evaluated. Loadcell D1 to loadcell D4 are attached to SMC anchors. Function tests were conducted on these loadcells after about two years from construction. Loadcell D5 to loadcell D8 are attached to SFL anchors. Function tests were carried out to these loadcells about five years had passed after construction.

**Figure 23** shows the changes in the measured values of loadcell D1 to loadcell D8. The measured value of the loadcell shows a tendency to change, fluctuating within a narrow range.

The amplitude width has become greater after January 29, 2008. When we checked the inside of the switch box that contained the measurement instrument of the loadcell, we found stains and mold. Therefore, it was possible that data were not recorded correctly because of instrument failure. It was assumed that incorrect measurement might be notable in loadcell D1 that showed large increases or decreases in amplitude. Measured values of loadcell D2 were missing after June 9, 2008, possibly due to failure of the measurement instrument. As to the changes in load during the observation period, the measured values of loadcell D3 and loadcell D4 showed a nearly constant value.

However, the measured values of loadcell D5 to loadcell D8 decreased after August 31, 2008. We also confirmed a significant increase in measured value of loadcell D1, which might have been caused by soil pressure to the anchor. On these eight anchors with loadcells, we checked the function of the loadcells similar to the function check carried out on the real-size specimen of the anchor. In order to
simplify the tests, we used the SAAM jack as shown in Fig.24. The SAAM jack\textsuperscript{18)} is lightweight and compact, and has high test accuracy.

Figure 25 shows the load-displacement curve of loadcell D1, loadcell D3, and loadcell D4. Point A to point B is the route of the hydraulic jack and displacement. Point A’ to point B’ is the route of the measured value of loadcell and displacement. Both routes take about the same path. For loadcell D1 and loadcell D3, the value of hydraulic jack is slightly higher than the value of the loadcell. For loadcell D4, both values are almost identical. The measured value of point C of the “tangent method” is 944kN. The measured value at point A’ of loadcell is 873kN. The difference is caused by the differences in the measurement methods used in measuring each value. Followability can be seen in the measured values of loadcell D1 and loadcell D3; however, both loads of the measured values are not a match. In such cases, it is important to adjust the calibration coefficients of loadcells based on the measured values of the lift-off test\textsuperscript{19}).

Figure 26 shows the load-displacement curve of loadcell D8. Point A-point B is the route of the hydraulic jack and displacement. Point A’-point B’ is the route of the measured value of loadcell and displacement. The
two routes do not show followability. Therefore, an accurate measurement for loadcell D8 may not be obtained because of the functional decline of loadcell and fixing device defects.

Table 4 is a summary of the function check results of each loadcell. Function checks for loadcell D1 to loadcell D4 were performed about two years after the loadcells were attached. These loadcells may be working normally because followability between the hydraulic jack load and the measured value of loadcell was confirmed. On the other hand, function checks were performed on loadcell D5 to loadcell D8 about five years after the loadcells were installed. Followability could not be seen for the measured values of loadcell D5 to loadcell D8. From this result, it is possible that the loadcells are not functioning properly.

The function check may be performed with relative ease by using the SAAM jack by comparing the load-displacement curve of the measured values of hydraulic jack and loadcell.

5. METHOD FOR ATTACHING / DETACHING LOADCELL TO / FROM WORKING ANCHOR

(1) Issues and method for attaching / detaching loadcell to / from working anchor

When a function check finds that a loadcell’s function has declined, the loadcell must be replaced. When doing so, the tension load on the anchor must be completely released, and the fixing devices removed and reattached when replacing the loadcell. It is important to reload tension by using a hydraulic jack, used in constructions. This work may be difficult depending on the conditions of the site. On the other hand, when attaching a loadcell to a working anchor for the first time, the extra length of tendon may not be enough for re-tensioning. In addition, if the working anchor is in a hypertonic state the tendon may be drawn into the ground when unloading and it may be difficult to recover it to the original position. Furthermore, with wedge-type anchors, because the anchor head is fixed by a wedge, it may be difficult to remove the anchor head and perform unloading. To address these issues, we developed a new method that will make it easy to attach or detach loadcells to working anchors.

When attaching a loadcell to an working anchor, an adjuster that matches the anchor head is used in each method, to ensure the extra length of tendon needed as shown in Fig.27. Figure 28 shows the process of attaching the loadcell to a nut-type anchor. Figure 29 shows the loadcell attached to a working nut-type anchor. As shown in Fig.28(2), the adjuster is attached to the extra length of tendon of the anchor head. Next, as shown in Fig.28(3), the loadcell is placed on the pedestal. Then, as shown in Fig.28(4), load is installed using the SAAM jack and...
the anchor is fixed by tightening the new nut. And then, as shown in Fig.28(5), the old nut is loosened. This will transmit tension to the loadcell, and measured values may be checked by connecting the measurement apparatus. When removing the loadcell, a hydraulic jack is fixed to the loadcell again by tightening the existing nut. After that, the new nut is loosened, and then the loadcell is removed. On the other hand, Fig.30 shows the attaching procedures for the wedge anchor. First, as shown in Fig.30(1), the anchor head is attached for re-tensioning. The excess length of this anchor head is threaded. Next, as shown in Fig.30(2), the adjuster is attached to the tendon of anchor head. Then, as shown in Fig.30(3), the loadcell is attached on the pedestal. Following that, as shown in Fig.30(4), a new nut is attached. Finally, as shown in Fig.30(5), tension is loaded using the SAAM jack to lift the existing nut, and the anchor is fixed with the new nut.21) Figure 31 shows the method of attaching the wedge-nut-type anchor. First, as shown in Fig.31(2), the extra length is ensured by joining the anchor head and adjuster. The tendon of anchor head is threaded. Next, as shown in Fig.31(3), the loadcell is attached on the pedestal. Following that, as shown in Fig.31(4), a new nut is attached. Finally, as shown in Fig.31(5), tension is loaded using the SAAM jack to lift the existing nut, and the anchor is fixed with the new nut.21)
(2) Verification of applicability to working anchor and monitoring of residual tensile load

We verified the applicability of the attaching and detaching methods of loadcell to anchors already installed on expressway slopes. To SEEE anchor and VSL anchor, we attached a strain-gauge-type loadcell. In each test, we performed lift-off tests before and after attaching the loadcell and before and after detaching the loadcell. We also checked the function of the loadcell after attaching the loadcell and before detaching the loadcell. The lift-off test was performed by using the SAAM jack to facilitate the task and according to the test methods set for expressways. In addition, to check if the loadcell on the working anchor is functioning correctly, we attached a button-type temperature sensor around the loadcell and measured the outside temperature, as temperature could change the measured value. In addition, humidity could be another factor that could change the measurements. Therefore, humidity was measured using a humidity sensor, and we studied the relationship of the measured values of the loadcell.

a) Monitoring residual tensile load of nut-type anchor

The loadcell was attached by using the method to attach / detach loadcell to a nut-type anchor constructed using the SEEE method. The measured values of the loadcell was monitored. The working anchor monitored was F-50TA, installed in a concrete retaining wall. The design force of the anchor was 297kN, the length 15.5m, and the fix length was 3.0m. First, we performed the lift-off test to evaluate the residual tensile load of the working anchor. As a result, the residual tensile load of anchor was 225kN. After that, the loadcell of the strain-gauge type was attached to this working anchor. Then, tension equal
to the current tension was installed to fix the anchor. Figure 32 shows the load-displacement curve obtained by the function check carried out after the loadcell was attached. Point A-point B is the route of the hydraulic jack and the displacement. Point A'-point B' is the route of the measured value of the loadcell and displacement. Tracking can be seen on both routes, and the loadcell is working properly. The value measured by the "tangent method", point C is 231kN. The measured value of the loadcell, point A', is 218kN. The difference between the two measured values is 13kN. With the nut-type anchor, the end part of PC composite steel line is crimped by threaded mansion. For this reason, the variation in tension of each PC steels is considered small. Also, the difference in the two measured values is considered small, because the change point appears relatively clearly. We monitored the loadcell for about one month after the loadcell was attached, checking the measured values. The loadcell was then removed. Figure 33 shows the load-displacement curve obtained by the loadcell function check, before the loadcell is detached. The route point A-point B is the route of the hydraulic jack and the displacement. Point A'-point B' is the route the measured value of loadcell and displacement. In both routes, followability can be seen, and the loadcell is properly working at the time the loadcell is removed. The value measured by the "tangent method", point C, is 226kN. The measured value of loadcell, point A' is 212kN. The difference between the two measured values is 14kN. The lift-off test was conducted after the loadcell was detached, and at this time, the residual tensile load was 230kN. The results showed that the differences between the measured values of loadcell and lift-off test, before and after the loadcell was attached or detached, were not large. Thus, the attaching and detaching of loadcell were properly performed.

Figure 34 shows the changes in the measured values of the loadcell and outside temperature collected for about one month from attaching to detaching the loadcell. The maximum width of the variation in outside temperature is 18 degrees. The maximum fluctuation width of the measured value of the loadcell is 3kN. The correlation coefficient of the two measured values is 0.85, which is high. Figure 35 shows the relationship between the measured value of the loadcell and outside temperature. The maximum width of the variation is 3kN. This indicates that the loadcell is working properly during the monitoring period. On the other hand, Figure 36 shows the changes in the measured values of the loadcell and humidity in the same period. The maximum fluctuation width of humidity is 50%RH. The correlation coefficient between the measured values of loadcell and humidity is -0.11. Figure 37 shows the relationship between the measured values of the loadcell and humidity, and the maximum width of variation is 7kN. The result does not show a correlation between the measured value of the loadcell and humidity.

b) Monitoring of residual tensile load of wedge-type anchor

We attached the loadcell to the VSL-type anchor and monitored the measured values of the loadcell. The type of working anchor was E5-4, and it was installed in a concrete pressure plate. The design anchor force was 406kN. The anchor length was 33.4m. The anchor fixed length was 4.6m. First, we performed the lift-off test to confirm the residual tensile load of the working anchor, and confirmed that the residual tensile load was 538kN. After that, the loadcell of the strain gauge type was attached to this working anchor. Then, this anchor was fixed by installing a high tension of about 30kN, to provide clearance by floating the working anchor head. Figure 38 shows the load-displacement curve obtained by the function check of the loadcell carried out after the loadcell was attached. Point A-point B is the route of the hydraulic jack and the displacement. Point A'-point B' is the route of the measured value of the loadcell and displacement. In both routes, followability can be seen, and the loadcell is working properly when the loadcell is attached. The measured value obtained by the "tangent method", point C, is 564kN. The measured value of loadcell, point A', is 537kN. There is a difference of 27kN between the two measured values. For the wedge-type anchor, many PC steel wires are fixed by the wedge of the anchor head. Therefore, the influence of eccentricity of the load and such, are considered according to the difference in tension of each PC steel wire. In some cases, the change point of the load-displacement curve shows a stronger curvature in comparison with the nut-type anchor. Therefore, the difference between the two measured values is larger than that of the nut-type anchor that has a change point, which appears relatively clearly than the wedge type.

Figure 39 shows the changes in the measured value of the loadcell and outside temperature for about one month. The maximum fluctuation width of the outside temperature is 22degrees, and this temperature is greater than the anchor of the SEE method. The maximum decrease in width of the measured value of the loadcell is 7kN. The correlation coefficient of the two measured values is high at
Figure 40 shows the relationship between the measured value of the loadcell and outside temperature, where the maximum width of variation is 10 kN. This result shows that the loadcell was properly working during the monitoring period. On the other hand, Fig. 41 shows the changes in the measured value of the loadcell and humidity in the same period. The maximum increase or decrease width of the humidity is 50%RH. The correlation coefficient of the measured values of the loadcell and humidity is -0.61. Figure 42 shows the relationship between the measured value of the loadcell and humidity, and the maximum width of the variation is 18 kN. This result does not show a clear correlation between the measured value of loadcell and humidity.

c) Applicability of the attaching and detaching method of the loadcell to the working anchor

We verified the applicability of the attaching and detaching method of the loadcell to the working nut-type anchor and the working wedge-type anchor. We confirmed that the loadcell was functioning properly during the period between attaching and detaching the loadcell, when the measurements were taken. Therefore, the method of attaching and detaching the loadcell by using the SAAM jack to a working anchor poses no problem. Because the anchor slopes sometimes become unstable, some cases require monitoring of tension load after construction. As shown in Fig. 43, monitoring can be continued by using the function check and the method for attaching and detaching the loadcell. In addition, we could not find a significant correlation between the measured values of the loadcell and humidity value.

6. CONCLUSION

The measured value of the loadcell sometimes changes due to various factors, such as ground pressure and the environment. Therefore, it is important to evaluate the measured values appro-
appropriate. This study was performed on anchors that were installed in typical slopes not affected by frost heaving, and such. We analyzed the characteristic of the measured value of the loadcell. And then, we studied the method for carrying out function checks on loadcell. In addition, we studied the method for attaching and detaching loadcells to working anchors. As a result, we found the following:

(1) The measured value of loadcell attached to a real-size anchor increased and decreased in response to the changes in the outside temperature. The measured value of loadcell and outside temperature showed a high correlation. In addition, the measured values showed that the increased or decreased width is different according to the temperature correction function of each type of loadcell. The measured value of the loadcell and outside temperature also showed a positive correlation.

(2) The correlation between the measured loadcell values and outside temperature is low in the period when the tension load change to converge after the anchor was fixed. However, we found that the correlation tended to become high after the convergence of tension. This result indicates that if the correlation between the measured loadcell value and outside temperature changes during monitoring, it is possible that the tension variation is caused by the temperature characteristic of the loadcell or by ground pressure. Therefore, this correlation may be used to decide what causes the changes in the tension.

(3) The measured value of loadcell change may be affected by the pressure plate, and such, in addition to the temperature characteristic of the loadcell.

(4) The loadcell is exposed to the natural environment, and therefore, its function declines over time. When the lift-off test is conducted by using a SAAM jack, the function check of loadcell can be conducted with relative ease by comparing the measured values of the load of the hydraulic jack and loadcell.

(5) When checking the function of loadcell, the difference between the measured value obtained by the "tangent method" and the measured value of "change point 1" is caused by the difference in the method of measuring the value, and it is important to understand this. In addition, with the wedge-type anchor, the curvature point of the load-displacement curve tends to be larger than the curvature point of the nut-type anchor. Therefore, the difference in the two measured values tends to become large.

(6) We developed a method for attaching and detaching the loadcell to a working anchor by using the SAAM jack, and we verified the applicability of this method to the working anchor. From the result of the function check of the loadcell after it is attached and before it is detached, we confirmed that the loadcell is functioning properly. In addition, from the results of measurement for a certain period of time, we confirmed that the loadcell is functioning properly. Therefore, there appears to be no problem in applying this method to the working anchor.

7. CLOSING REMARKS

In this study, we were able to determine the characteristics of the measured value of loadcell that had not yet been verified. In addition, we found it possible to check the function of loadcell and to exchange the loadcell installed on a working anchor. In particular, the residual tensile loads of working anchors had to be evaluated by carrying out lift-off tests, which typically require time and effort. The results show that this method will reduce the burden of tension management of anchors. If we can show a method of quantitative evaluation of the tension convergence based on this characteristic, maintenance may be improved. Incidentally, in the actual tension management, it is necessary to set the frequency of measurement that can capture the correlation coefficient.

In previous studies, we obtained knowledge on evaluating the slope health from the survey of many anchors. Efficient and effective maintenance of anchor may be carried out by combining the monitoring method proposed in this paper to that knowledge.

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