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An application of image processing technique to analyze initial failure behavior in pull-out test

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ABSTRACT

This paper presents a technique employed to detect cracks on failure surface and quantitatively analyze the initial failure behavior of tunnel-type anchorage for suspended bridges in pull-out test. In order to understand the behavior of anchorage, it is imperative to identify failure patterns around the structure where the stress is concentrated. Two-dimensional experiment was performed to observe the initial failure surface directly by naked eyes. This study proposes an analytical method aimed at understanding initial failure behavior in pull-out test by applying image processing technique. A morphological technique and pixel difference method for image segmentation were used to measure features of cracks. The research results show that more precise analysis on the initial failure behavior in pull-out test was possible with images taken solely by a digital camera.

1. INTRODUCTION

Suspension bridges require anchorage in their both ends, except for self-anchored suspension bridges, to secure suspension cables carrying the loads on a bridge. There are three types of anchorages for suspension bridges: gravity type anchorage holding the cable load by its self-weight; tunnel-type anchorage supporting the cable load by friction at the interface between anchorage and the surrounding ground, generally suitable for a relatively fresh rock bed; and cavern type anchorage, a modified tunnel-type anchorage (Hong et al. 2014). Among those three types of anchorages, tunnel-type anchorage, in particular, does not find many application cases in both domestic and foreign projects. Its design concept remains very conservative and is yet to be more studied. As an effort to provide a more rational design concept for tunnel-type anchorage we carried out a series of two dimensional pilot-scale pull-out tests simulating the tunnel-type anchorage constructed in the Ulsan Grand Bridge project. In the experiments, anchorage and the surrounding rock mass were made of a

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mixture of gypsum and sand. In pulling out the model anchorage, strains developing on the model rock mass were measured using LVDT, and a video was taken using a daily using digital camera to visually observe the failure pattern. However, the quantitative evaluation of micro-cracks in initial failure was not possible with naked eyes and the propagation of cracks were difficult to identify because the failures took place instantaneously. In order to overcome the setback of the measurements, an image analysis technique was applied to quantitatively analyze failure patterns.

2. THE IMAGE PROCESSING AND METHODOLOGY

In the recorded images, a lot of noise is generated on the surface due to the influence of the surrounding environment, so that the image preprocessing process is unquestionably required. For the image analysis after preprocessing images, binarization and morphological techniques are performed to detect cracks in model rock mass (Ammouche et al. 2000, Ito et al. 2002, Lee et al. 2007, Otsu 1979). In order to investigate the failure behavior, pixel difference method and the method of tracking specific point are used. (Ilsever and Unsalan 2012) Image acquisition and preprocessing proceed as follows, using Mathematica as image processing tool.

2.1 Image Acquisition

The 2D pull-out test was carried out indoors to minimize the influence of the surrounding environment. Indirect lighting was used to keep the illumination as constant as possible. The SONY HDR-CX500 camera was used as an entry-level digital camera. The frame size was 1440∗1080 and the frame rate was 29.97sec^{-1}. Also, the camera was fixed with a tripod because the camera should be taken without blurring at the same position, and the entire sequence of experiment was taken using a subsidiary digital camera. As shown in Fig. 1, images for each frame were extracted, and each image was subjected to pre-processing and subsequent analysis.

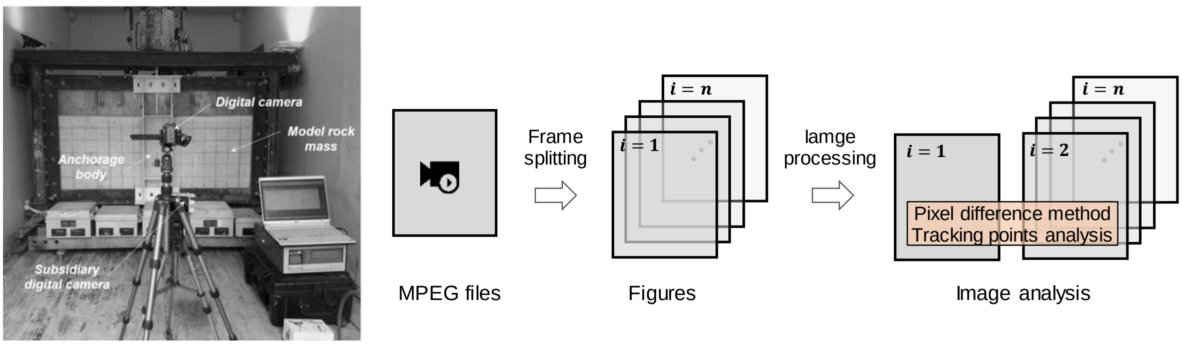

Fig. 1 Experimental apparatus for pull-out test and the flowchart of image processing

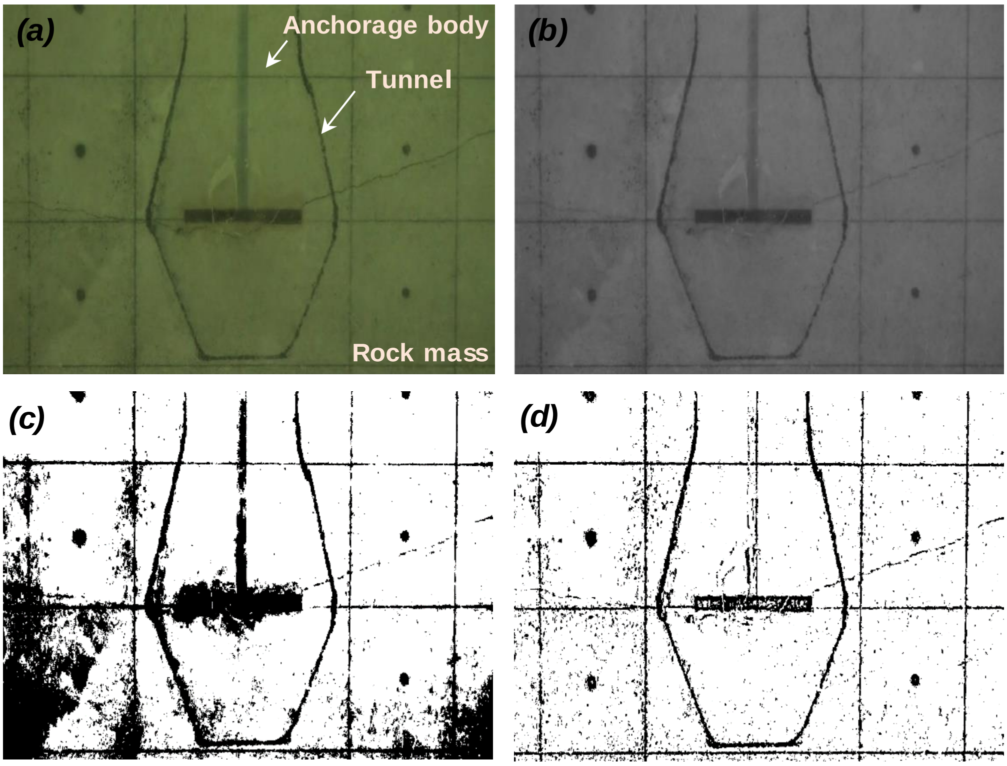

Fig. 2 Example of image preprocessing

2.2 Gray scale

First, the multichannel image is converted to grayscale to simplify image processing as shown in Fig. 2 (b). Grayscale images are often used for image analysis because of their low complexity. And eliminates the heterogeneity of the image due to illumination through shading correction.

2.3 Thresholding and Binarization

The shaded image is converted into a binarized image with a fixed threshold value. With fixed thresholds it is difficult to identify cracks in the central part of the anchorage body and cracks occurring in the rock mass. Therefore, the threshold is adjusted locally to adjust the structure to be identifiable as shown in Fig. 2 (c) (Rosin and Loannidis 2003).

2.4 Extra thresholding and Morphological structure extraction

Additional correction is performed to extract the morphological structure of cracks. When a part with cracks is binarized as shown in Fig. 3 (b), the black dots around cracks can be recognized as a crack as well. Therefore, the threshold value is additionally adjusted for this region to be corrected as in Fig. 3 (c). In this state, the morphological structure of cracks is extracted and cracks are recognized as Fig. 3 (d). Through this process, the final morphological shape is recognized as cracks and used for image analysis.

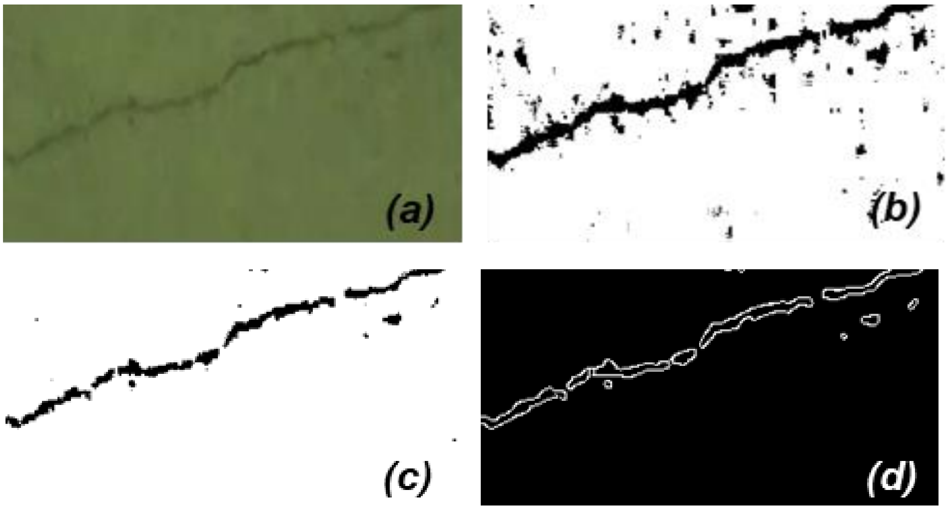

Fig. 3 Example of morphological determination of cracks

3. FAILURE BEHAVIOR ANALYSIS RESULTS

The failure mode varies slightly depending on the condition of the material used for the model rock mass, the shape of the structure, etc. in the pull-out test. Through pull-out test of tunnel-type anchorage, the failure mode can be divided into two types, wedge type and compressive type. In this study, image analysis is performed on three cases as shown in Table.1, and quantitative analysis results of cracks propagation and the extent of failure for two representative failure types are presented. Image analysis was performed using the preprocessed images described in advance, and the results were analyzed for the areas shown in Fig. 4. The Ω_1 region is an area for investigating the propagation of cracks. For the Ω_2, Ω_3 regions the cumulative pixel variation was investigated to observe the failure extent in the anchorage body. The thickness of cracks was measured in units of pixel number by calculating changes of the distance (*D*) between the tracking points of each frame.

Table. 1 Conditions of pull-out test in image analysis

Test case	Type of failure surface	Length of anchor plate (cm)	Shape of anchor plate	Property ratio[1] (m_1/m_2)	Pull-out direction
Case 1	Wedge type failure	11	Symmetry	2	Vertical
Case 2	Wedge type failure	11	Symmetry	1.5	Vertical
Case 3	Compressive failure	7.3	Symmetry	2	Vertical

[1] The property ratio of model rock mass to anchorage body: m_1 is compressive strength of model rock mass, m_2 is compressive strength of anchorage body

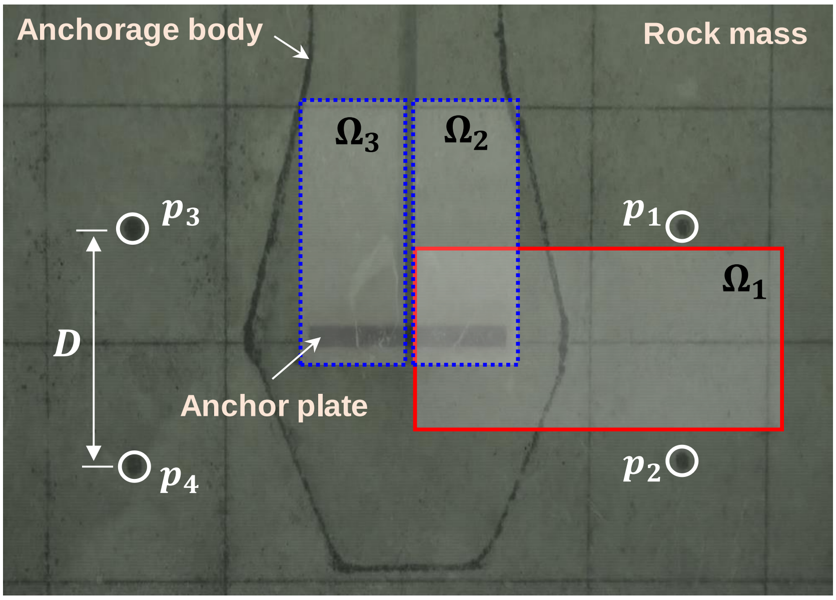

Fig. 4 The definition of calculation area for image analysis (Ω_1 : purpose of observing propagation of crack, Ω_2, Ω_3 : purpose of observing failure inside anchorage body, $p_1 \sim p_4$: tracking point)

3.1 Wedge type failure

The failure of rock mass during the pullout test often occurs in an extremely short time, and it is not easy to investigate the initial failure behavior. Especially in the case of micro cracks occurring at an early stage, it is often difficult to know even a file recorded sequentially. Therefore, to observe the failure transition, the pixels corresponding to parts of morphologically determined cracks were examined frame by frame and the variation of them was investigated. Fig. 5 (a) shows the result by pixel difference method in each frame. The variation rate of the pixel number represents the ratio of pixels changed in one area. From about 10th frame, failure occurred in the anchor plate and in the tunnel, and then rapid pixel change after that is the effect of cracks in rock mass. From the variation of the pixel number, it can be assumed that cracks first propagated to rock mass after the initial failure in the vicinity of the anchor plate and in the tunnel. Thereafter, a constant pullout loading is applied, and the variation of pixel number is continuously increased. In order to minimize the noise in images, the median filter was applied in the preprocessing process is shown in Fig. 5 (b). The median filter is advantageous in that the deterioration of the edge is relatively small among the nonlinear filtering algorithms (Cho et al. 2010, Pratt 1978). Since the edge detection is important for cracks, the median filter was applied. As shown in Fig. 5 (b), the noise is removed, and the number of pixels is counted lower, but the tendency is still similar. With the application of the median filter, tendency of the initial failure is slightly different. It is considered that the application of the median filter increased the detection rate of initial fine cracks.

Fig. 5 (c) shows the results when the properties of anchorage body and rock mass are different. In this case, wedge type failure was also observed, and it can be deduced that the failure propagation progressed to the rock mass near the anchor plate and in the tunnel. The failure pattern resembled closely case1. Also, the result of removing the noise shows a similar tendency (Fig. 5 (d)). If failure mode cannot be observed with naked eyes due to influence of measurement equipment or experimental environment, it is possible to quantitatively evaluate failure propagation in the way proposed above.

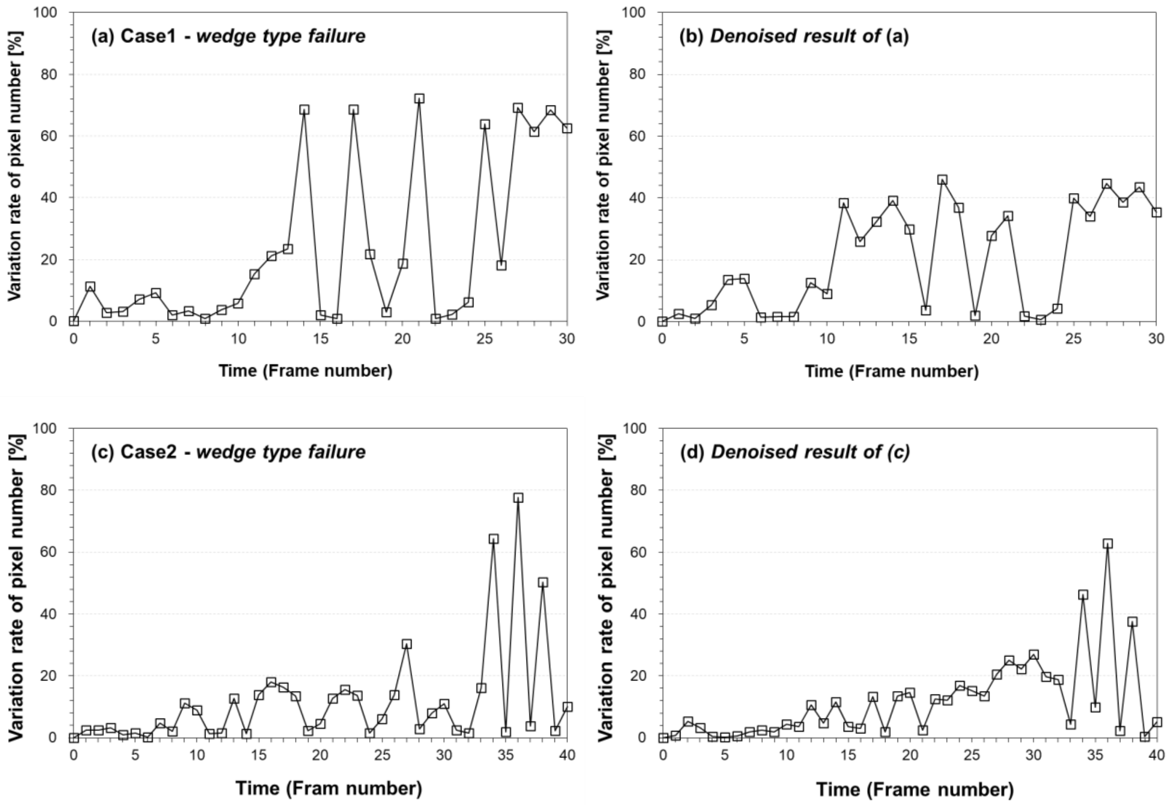

Fig. 5 The pixel variation results for wedge-type failure

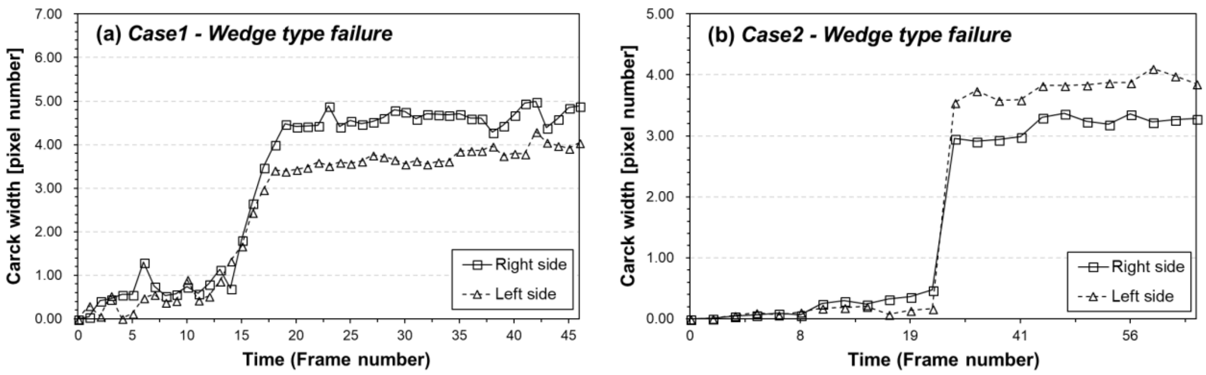

Fig. 6 The result of crack thickness estimated using tracking point

When the wedge type failure occurs, the failure pattern in left and right side of rock mass are different. Cases 2 and 3 have the same wedge type failure, but the failure patterns of rock mass are slightly different. To compare failure extent the coordinates of the tracking points marked on the model rock mass were extracted and the distances between the two points were calculated. As cracks occur, the distance changes, so the thickness of cracks between tracking points can be measured in unit of pixels. We investigated the failure patterns of the left and right rock mass at a distance from the anchor plate. The results of estimating the crack thickness by tracking the coordinates of p1 ~ p4 are shown in Fig. 6. As shown in Fig. 6 (a), the failure occurs at a place where the thickness of the crack increases sharply, and the failure extent of left and right-side rocks can be compared over time. In Case 1, the thickness of cracks in the right-side rock was larger and in Case 2, the thickness of left-side cracks was larger. Therefore, even the rock mass of same composition shows that the extent of failure in the left and right side of rock mass might be different due to the non-uniformity of the mixed materials.

3.2 Compressive failure

When the tunnel-type anchorage is broken in accordance with compressive failure type, the failure effect does not reach the rock mass, and materials inside the tunnel is compressively broke. The case 3 represents the compressive failure type. In the case of compressive failure, the total failure behavior was considered by examining the cumulative pixel variation rather than comparing the pixel variation for each frame. Fig. 7 shows the cumulative pixel variation for regions 2 and 3. At the beginning of the failure, the stress is concentrated in the vicinity of the anchor plate, so that the cumulative pixel variation of the two regions is similar, but the variation of pixel number in the region 2 increases over time. Even in the same pullout loading, the extent of failure in the tunnel is different, and it can be validated quantitatively through the cumulative variation of the pixel number.

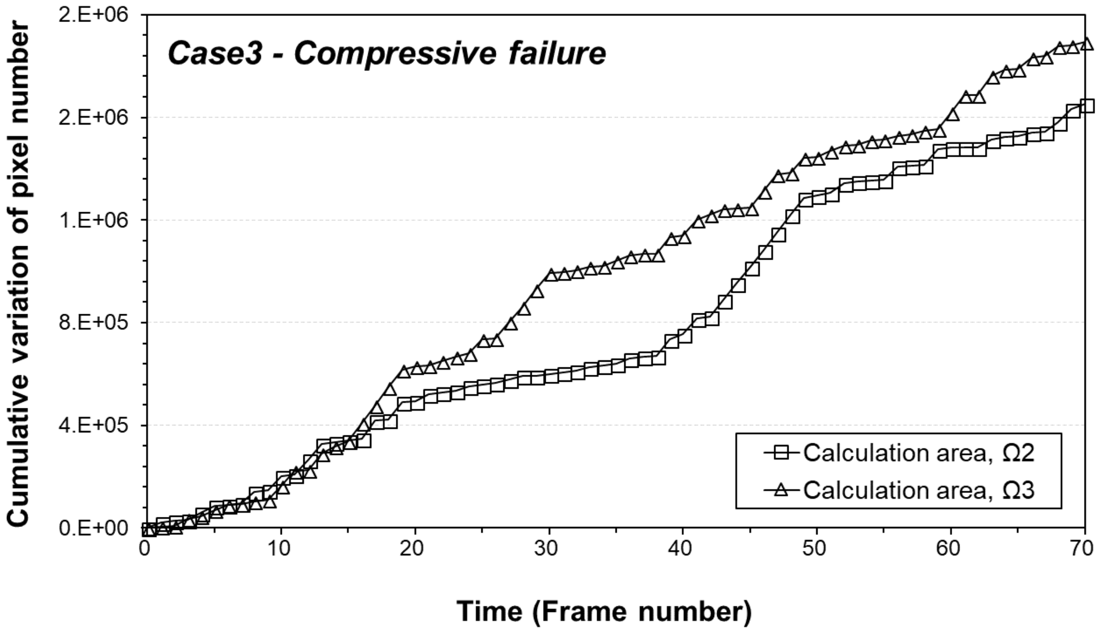

Fig. 7 The cumulative pixel variation curves for compressive failure

4. CONCLUSIONS

In this paper, we applied image processing technique to the quantitative analysis of failure surface in 2D pull-out test of tunnel-type anchorage. The strain of target materials against pullout loading is generally interpreted with the load-displacement curve in the pull-out test. However, since the visual observation of the failure mode is the main object in the case of the two-dimensional experiment, it is additionally required to detect fine cracks and analyze them quantitatively. We propose a method of analyzing the failure surface photographed by a digital camera through image processing. In the image analysis, images that have undergone the preprocessing process were used. This is to eliminate the non-uniformity of illumination caused by the test site and the noise existing on the surface of materials. A fully preprocessed image has a great effect on increasing the detection rate of cracks. The purpose of this study is to apply image analysis technique to failure behavior analysis in pull-out test. There is some case which failure occurs instantaneously due to the characteristics of the material, or micro cracks cannot be observed with the naked eye. Therefore, applying image analysis technique to the pull-out test, we can provide more information about visible analysis beside the result by measurement equipment.

The main conclusions are as follows. In the case of wedge type failure, it is quantitatively expressed through the variation of pixel number that cracks transfer from the structure where the stress is concentrated to the surrounding rock mass. The thickness and the extent of failure were estimated by using the tracking points. If we increase the number of tracking points, the results can be predicted precisely. In the case of compressive failure, materials inside the tunnel is compressed and cracks occurs. Materials inside the tunnel is uniformly broken around the anchor plate at the initial failure. Since the shape and materials inside the tunnel are not completely homogeneous, the failure patterns of the left and right sides of the tunnel are different.

The limitation of this paper is that there may be errors in crack detection due to non-uniform illuminance at the test site. As more accurate analysis become possible through further studies, it is expected that the relationship between the variation of pixel number and pullout loading can be inferred and utilized in pull-out test.

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