Analysis of pull-out behavior of tunnel type anchorage using 2-dimensional scaled model test and image processing technique

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ABSTRACT

In this study, the pull-out behavior of tunnel type anchorage for suspension bridges was observed through scaled model tests and analyzed by means of image processing technique. Since the tunnel type anchorage has few applications in Korea and abroad design techniques such as failure mode and safety factor, therefore, are yet to be clearly established. In this study, scaled model tests were conducted on the test body with simplified shape and structure of the Ulsan grand bridge in Korea. The anchorage body and the surrounding rock mass were made of gypsum mixture and pull-out test was carried out under the plane strain condition. In the 2D model test, focuses were made on direct observation of the failure mode with an aid of LVDTs and a digital camera. It was found that the final failure mode was dominated by the wedge shape. Also, in order to identify the initial failure behavior, the cracks developed in the anchor plate were tracked through image analysis. It was confirmed that failure was initiated at the bottom of the anchor plate. Then cracks advanced to surrounding and propagated to the neighboring rock mass.

Keywords: Tunnel type anchorage, Pull-out test, Scaled model test, Image processing, Failure surface

1 INTRODUCTION

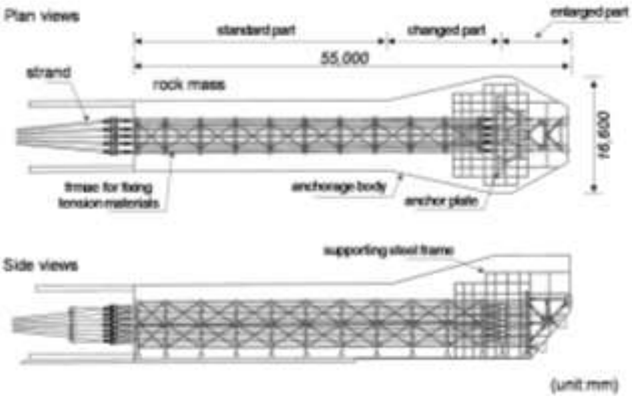
Tunnel type anchorage is one of the anchorage types of suspension bridge where a cable pull load is applied. The tunnel anchorage is a method to excavate the tunnel in the ground and to fill the cable load of the bridge by filling steel and concrete inside. The failure mode is assumed and the stability of activities is examined according to the characteristics of the surrounding rock mass and cross sectional shape of anchorage in the design of tunnel type anchorage. The anchorage design is highly influenced by failure mode of the ground. According to domestic and international applications, a conservative failure mode is applied to the design of tunnel type anchorage. It means that failure mode is assumed to occur along the interface of the adjacent rock mass parallel to the load acting direction. Using this design method, Tunnel anchorage was applied to Ulsan bridge design for the first time in Korea. The purpose of this study is to analyze the pullout behavior and initial failure mode of tunnel type anchorage by the scaled model test of Ulsan grand bridge. Two dimensional model tests were conducted to directly observe the failure behavior and pattern. In the scaled model test, the gypsum mixture was used as model materials and the scale factor was considered to reproduce actual condition. Moreover, we tried to provide quantitative information about failure mode through image analysis of images taken with a digital camera.

2 SCALED MODEL TEST

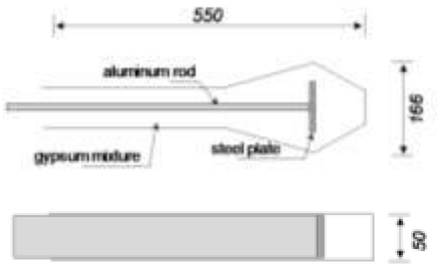
The shape of the tunnel type anchorage was determined based on the design drawings of Ulsan grand bridge (Fig. 1). All the conditions of the in-situ were converted into the scale factor by the dimensional analysis and the site condition was reproduced. In the scaled model test, a mixture of gypsum, sand and water was used as the material of the model test. The mixing ratio of the gypsum mixture was determined through the physical property tests to describe the relative strength of the actual anchorage and the surrounding rock mass.

2.1 Materials of model test

In order to reproduce the field in the scaled model test, the scale factor should be calculated through the dimensional analysis of all the elements of the actual site and the model material suitable for the scale factor should be used. In case of considering the stability of tunnel made of hard rock, the method to reproduce the actual situation through the scaled model test is reliable in many studies (Hobbs 1968). In this study, the scale factor is determined as shown in Table 1.



(a) Actual



(b) Schematic of 2-D model test

Fig. 1. Plan and side views of tunnel-type anchorage body (Yooshin Co., Ltd., 2010)

A mixture of gypsum, sand and water was used to form the target rock mass and the internal material of tunnel. This material has the advantage that various strengths can be produced according to the weight ratio (Coquard and Boisetelle 1994). Experiments were performed on the physical properties of the gypsum: sand: water. The curing period of the gypsum mixture was determined to be 7 days. The mixing ratio was determined as shown in Table 2 to describe the physical properties of the actual rock mass and the inside material of tunnel according to the scale factor.

Table 1. Scale factors of model tests in comparison to the actual design of the Ulsan Grand Bridge

Physical properties	Dimension	Scale factor
Length	[L]	0.01
Time	[T]	0.1
Density	$[ML^{-3}]$	0.57
Mass	[M]	5.74×10^{-7}
Acceleration	$[LT^{-2}]$	1
Strength	$[ML^{-1}T^{-2}]$	5.74×10^{-3}
Young's modulus	$[ML^{-1}T^{-2}]$	5.74×10^{-3}

Table 2. Mixing ratios of the materials in the model test

In-situ	Model test	Mixed ratio of model materials (wt%)			
rock mass density (kN/m3)	material density (kN/m3)	model	gypsum	sand	water
27.0	15.5	rock model	27	49	23
		anchorage body	20	57	23

2.2 Experimental method of scaled model test

The model rock mass used for the scale model test was constructed with a size of 1800Wx700Hx50D corresponding to 1/100 of the actual size. The experimental view is shown in Fig 2. The pull-out test was carried out at a speed of about 2.0 mm / min until the model rock mass was destroyed. LVDTs were installed at same intervals in the upper part of the model rock mass and the pull-out load were measured through the load cell installed on the anchorage. Also, in order to observe deformation of the model rack mass, the grid and tracking points were marked on the surface of rack mass at 10cm intervals. The test types are shown in Table 3, and the pull-out behavior according to the size of the anchor plate was investigated.

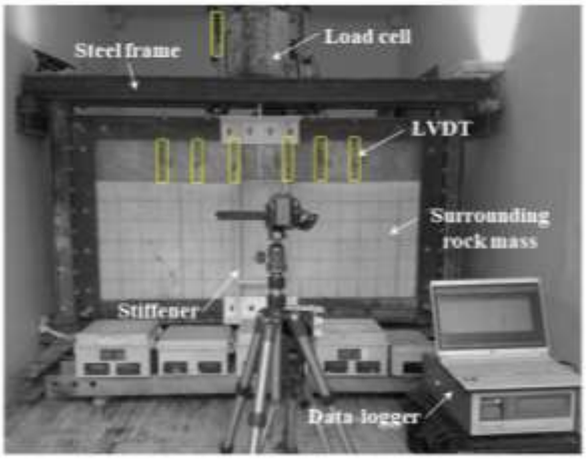


Fig. 2. Experimental setup of the 2D model test

Table 3. Cases of model test with different anchor plate lengths

Classification	Length of anchor plate (mm)	Y-axis boundary condition
Case 1	110	Plane strain state
Case 2	73	Plane strain state

3 IMAGE ANALYSIS

Since the noise is generated on the surface of rack mass due to the influence of the surrounding environment, the preprocessing of the image is required. In order to detect the micro cracks on the failure surface, the method proposed in the previous study was used (Ito et. al 2002, Seo and Chung 2018). We tried to quantitatively analyze the pull-out behavior through pixel difference and point tracking of preprocessed images. Using Mathematica image processing tool, frame-by-frame images were extracted and image-processed. Converts multi-channel images to grayscale and then adjusts threshold values to convert them to binary images. In addition, the threshold value is partially adjusted so that the anchorage and surrounding rock mass can be reliably separated. The area used for image analysis after preprocessing is shown in Fig 3. The Ω_1 region is to investigate propagation of cracks. The crack thickness was measured in pixel units by calculating the distance change between the tracking points of each frame.

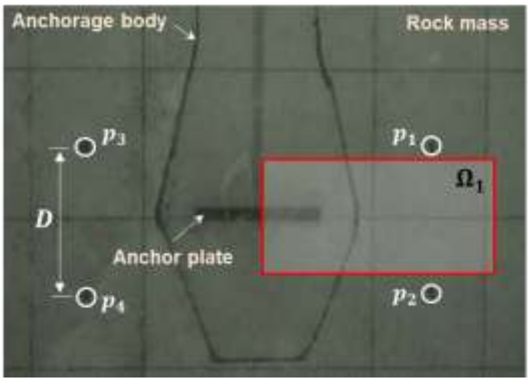


Fig. 3. The definition of calculation area for image analysis(Ω_1: purpose of observing propagation of cracks, p_1~p_4: tracking points)

4 THE RESULTS OF MODEL TEST AND IMAGE ANALYSIS

4.1 Case1

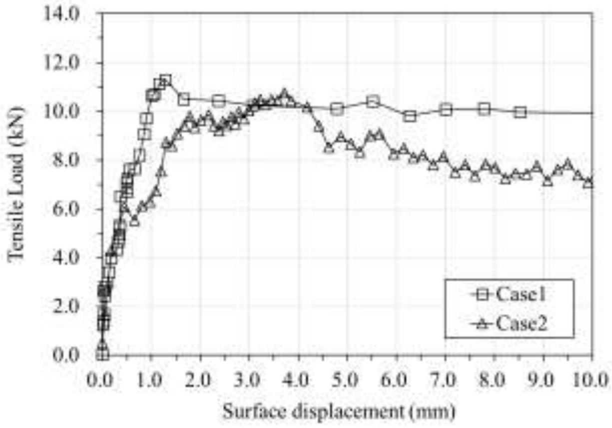
Case1 shows the same scale of anchorage as the actual tunnel type anchorage, and the result is shown in Fig 4(b). According to the pull-out load, initially the anchor plate drop out of inner materials of the tunnel, and fine cracks occurred at the bottom of the anchor plate. Subsequently, the materials at both ends of the anchor plate were destroyed. Until the pull-out load of about 4.0 kN, it was close to the elastic behavior due to the local failure, and wedge-shaped failure developed along with plastic deformation to a load of about 7.5 kN.

Fig 5(a) shows the results observed with the LVDT installed on the surface of rock mass. It is a measurement of the surface displacement by the load step and it is similar to the failure surface inside the rock mass in Fig 4.

4.2 Case2

Fig 4(b) shows the case where the length of anchor plate is reduced 1.5 times than case1. In other words, the length of the anchor plate is smaller than the inside diameter of the tunnel. Overall, the same pattern as case1 was shown. Elastic behavior up to approx. 4.0kN followed by nonlinear plastic deformation with increasing load up to maximum load of 10.8kN. In this case, the cracks occurred at the end of the anchor plate was propagated to the model rock mass, and the final failure mode was a wedge shape. The asymmetrical shape of the left and right side of model rock mass is considered to be due to heterogeneous mixing of model material.

In case 2, it is seen that the displacement profile at the surface of rock mass and the failure mode in the internal rock mass are similar (Fig 5(b)).

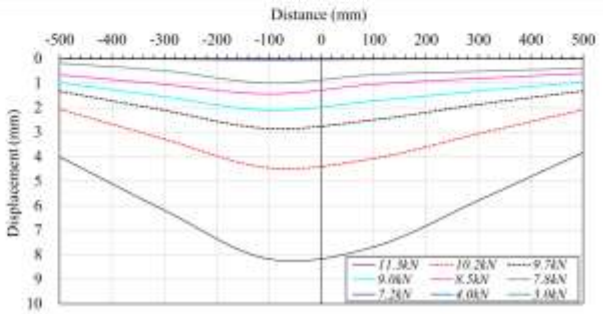


(a) Load-displacement curve

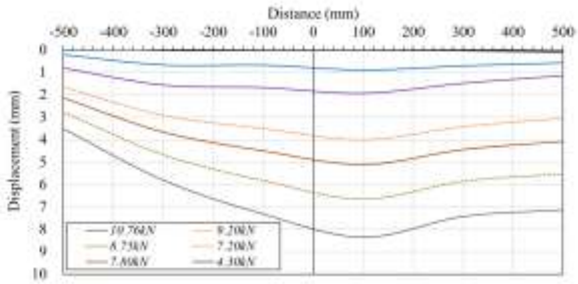
(b) Case1

(c) Case2

Fig. 4. The results of model tests



(a) Case1



(b) Case2

Fig. 5. The results of failure surface by LVDT

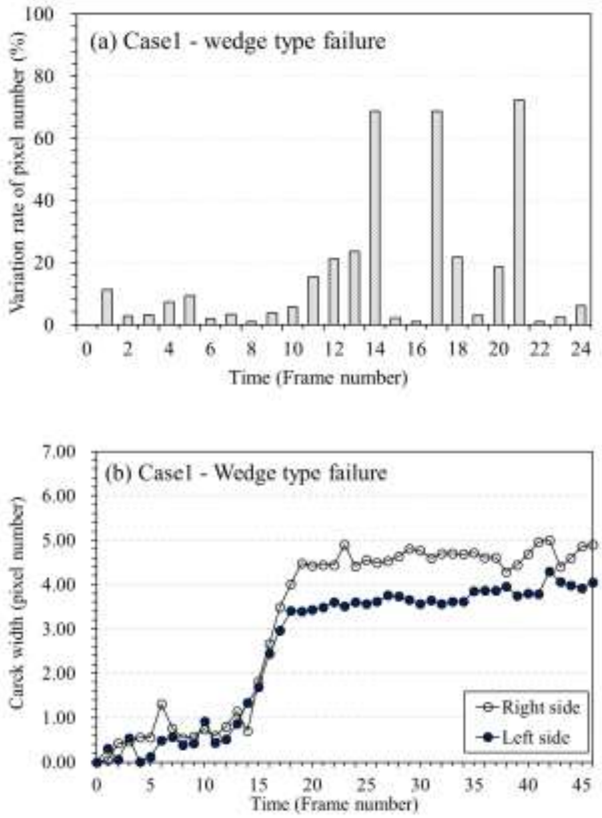


Fig. 6. The pixel variation and crack thickness results of case1

4.3 The result of image analysis

Through the image analysis, it was possible to quantitatively analyze crack propagation in wedge failure as in case1 or case2. As a result of examining the area Ω_1, it can be seen that the pixel changes abruptly at the initial stage of destruction as shown in Fig 6(a). Compared with the frame-by-frame images, the amount of pixel variation increased due to cracks in the anchor plate, inside the tunnel, and in the surrounding rock mass. In reality, it is hard to observe the crack propagation visually because the cracks occurs instantaneously, but it is found that the cracks are propagated sequentially through the image analysis. Also, Fig 6 shows the measurement of the distance change of the tracking point and the thickness of the crack and the point of occurrence of the failure. As shown in Fig 6, it can be seen that the result measured with the displacement meter is similar to that at the time of occurrence. In the case of image analysis, it is measured in pixel units, so that it is possible to measure a minute change from the displacement meter.

5 CONCLUSION

In order to analyze the pull-out behavior of the tunnel type anchorage, two dimensional scaled model tests were carried out and the initial failure behavior was analyzed using image analysis. In this study, we focused on: initial failure behaviors under the given conditions, direct observation of the failure mode, and the effect of the length of anchor plate. The main conclusions are as follows.

Subjected to pull-out loads, the scaled model tunnel type anchorage of the Ulsan grand bridge exhibited a wedge type failure. The results of digital image analysis confirmed that, at the onset of the pull-out test, failure was initiated at the both ends of the anchorage plate: cracks then were propagated to its surrounding anchorage body, and finally to the rock mass. The image analysis allowed more accurate observation of failure modes than LVDTs in a high resolution digital camera or in a low noise environment because it measures in pixel units. Image analysis techniques can be a useful tool to quantitatively analyze the initial failure behavior in the event of momentary failure. The scaled model test of two dimensional tunnel type anchorage conducted in this study was found to be effective enough to evaluate the initial failure behavior and sequential failure modes under the pull-out loading, although there remains some limits that do not exactly reflect the actual 3-dimensional effects.

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