Inspection and Capacity Assessment of Anchored Slopes

Inspection et évaluation des capacités des pentes renforcées par ancrage

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ABSTRACT: In Taiwan, anchors were first used in the Techi Dam for slope protection in 1970s. Since then, anchors were often used for stabilizing slopes in the construction of roads or communities. Lots of anchor experience of engineering practices have been accumulated in the past 40 years, however, it still remains some problems to be solved. In particular, after the failure of anchored slope at station 3.1K of Highway No. 3 in 2010, the function of existing anchors and the safety of anchored slopes have raised lots of concern. This paper introduces examining items, methods and processes of functional inspection of existing anchors. Also, results of 16 functional inspection of existing anchors in western Taiwan are presented. It is expected that the concepts and suggestions described in this article would be helpful for an engineer in gaining the ability of the analysis of slopes so that the more effective design can be developed for such a problem in the future.

RÉSUMÉ : A Taiwan, les renforcements par ancrages ont d'abord été utilisé dans le barrage Techi pour la protection des talus dans les années 1970. Depuis lors, les ancrages étaient souvent utilisés pour la stabilisation des pentes dans la construction de routes. Beaucoup d'expérience dans les pratiques d'ingénierie d'ancrages a été accumulées au cours des 40 dernières années. Cependant, il reste encore quelques problèmes à résoudre. En particulier, après la rupture d'une pente ancrée à la station 3.1k de la route n^{o}3 en 2010, l'efficacité des ancrages existants et la sécurité des talus ancrées ont soulevé beaucoup d'inquiétude. Cet article présente l'examen des ancrages, des méthodes et des processus de contrôle du fonctionnement des ancrages existants. En outre, les résultats d'inspection de 16 talus renforcés par ancrages existants dans l'ouest de Taiwan sont présentés. Il est prévu que les concepts et les suggestions décrits dans cet article soit utilisable par un ingénieur via l'acquisition d'outils d'analyse des pentes de sorte qu'une conception plus efficace puisse être développé à l'avenir.

KEYWORDS: Landslides, anchor, lift-off test, anchor inspection, maintenance and management.

1 INTRODUCTION

Taiwan's area is approximately 3,600,000 hectare, and of it moderately flat area comprises about 26% while sloped and forested land make up the remaining 74%. Therefore Taiwan is mostly mountainous with lesser plains topography, though in the recent decade with the economic growth and the pursuit of comfort and ease of transportation, the trend of developing public infrastructure such as roadways and public facilities is moving toward hillsides and slopes.

Ground anchoring usage over steep slope has its certain advantages. Ground anchoring technique originated since the 1970s in Taiwan. Since 1988, Northern Taiwan Second Highway construction had begun, as its alignment laid predominantly among mountainous ranges and slopes, this type of method had proved itself to be an effective technique under such natural constraints and coupled with rapid economic growth, many new projects had begun to adopt this method in many sloped terrain community developments. Until today, ground anchorage technique has proven to be a reliable method and have been widely used, as well as the design and field installation has vastly improved since its earlier days. However, there are still many ground anchoring failure instances in recent years, one of which is the quite high profiled case of the 1997 Xizhi Lincoln Mansions disaster and 2010 National Highway No. 3 at 3.1k accident. Both failure cases are considered ground anchoring accidents and attributed to parallel landslide as the cause.

According to Briaud et al.(1998), Bruce and Wolfhope (2007), Liao et al. (2011), Ho et al.(2011), Jeng et al.(2011) and various domestic and foreign ground anchoring case studies, failure instances involved most commonly pre-stressed losses. The main cause of that include 1) free section of tendon(unbounded tendon) rusted and cracked, 2) ground anchoring wedges rusted or had sub-standard quality, 3) Installation did not conform to the specification, as the steel tendon had not gone far enough into the earth, 4) change of terrain layer, and 5) ground cave in at bottom of the bearing plate.

After the National Highway No. 3 incident involving ground anchoring failure, see Figure 1, a complete study had done on ground anchor inspection and assessment. Even so, the findings of the study were routine and not consistent among the investigators. This article will introduce and explain the currently most adopted ground anchoring inspection, procedure, and assessment. In addition, this article will propose a new way of ground anchoring assessment, in hoping to establish a standardized quantitative analysis procedure for professional reference.

Figure 1. National Highway No. 3 at 3.1k accident

2 INSPECTION ITEMS AND PROCEDURE

Ground anchoring inspection and assessment is aimed to analyze and understand the performance of existing anchors and the impact to the site and its surrounding.

2.1 *Inspection items*

Currently there are some initial inspection items including: exterior inspection, anchor head inspection, endoscopy inspection and Lift-off test, the four major itemswill be explained in detail later.

2.2 *Inspection procedure*

Inspection procedure is as indicated in Figure 2. First gather basic data from all sloped terrains for ground anchor index, then remove all outgrowth on the slope, and check the entire ground anchors for outside appearance, pressure bearing integrity and water seepage status. According to the gathered data and inspection results, select the most typical anchor in characteristics of all achors, remove the concrete casing to examine the anchor head and steel tendon closely, and record findings. After examining the anchor, use the findings to select partial ground anchors for endoscopy inspection to exam steel tendon corrosion and proceed with Lift-off Test, in order to understand the existing ground anchor Residual load(Tr). Lastly, based on sloped terrain basic data and findings of various test results, evaluate in totality the ground anchors current capacity. If ground anchor capacities no longer meet the requirement of original specifications or there are other anomalies present which render the anchors inappropriate for continuing usage, then a proposal is required to improve or remediate the situation, including refurbishment, remedy, reinforcement or reconstruction as required.

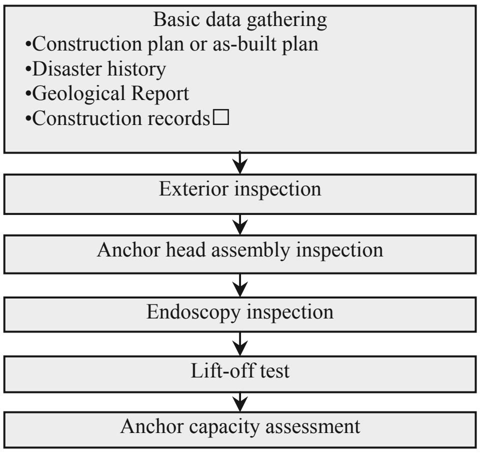

Figure 2. Ground anchor capacity assessment flowchart

3 CAPACITY INSPECTION METHOD

Various inspection category results can be used to provide as the basis for evaluating the capacity of anchors, summary of each categories is as follows:

3.1 *Exterior inspection*

Prior to knocking off the ground anchor concrete protected seats, obtain as-built drawings to mark off each and every anchors with numeric identifications. Visually inspect, investigate and record all anchor protected seats and load bearing structure system conditions. Visual inspection should emphasize on 1) anchor head protected seat hammer knocking test and the quality of sound whether solid or hollow, 2) visually inspect exterior of anchor protected seat for any damages, 3) between anchor head and load bearing structure, look for any sign of separation, rotation, or even detachment, 4) Whether subsoil below shows sign of cave-in for the load bearing structure and 5) anchor head proximity has sign of efflorescence or ground water seepage, and all visual inspection should be carefully documented.

3.2 *Anchor head assembly inspection*

Anchor head assembly includes locking mechanism(wedges and screw head), load bearing plate and angle plate, as such parts tend to have anomalies. When inspecting anchor head assembly, carefully select a representative anchor head, after the removal of concrete protected seat, visually inspect the corrosive state of the anchor heads. After removal of anchor head protected seat the following category of items need to be recorded: load bearing plate dimension, angle plate dimension, load bearing plate angle, anchor head dimension, steel tendon style and remaining length data.

At this stage visual inspection should emphasize on 1) anchor head wedges and steel tendon corrosion, 2) anchor head assembly and water seepage condition and 3) steel tendon interior shortening, and all inspection should be recorded in detail.

3.3 *Endoscopy inspection*

Endoscopy can be used to inspect the backside of anchor head and free section of steel tendon, to determine whether the steel tendon is corroded, broken or free section has water inside. Entire inspection process should be video recorded to allow further inspection and study back in the lab. The equipment used is as shown in Figure 3.

Besides inspecting steel tendon status, this stage should measure the steel tendon length of free section. The measuring technique is to use a stainless steel rod to insert into the anchor free section portion until the rod can not be inserted further, as Figure 4 indicated. Then record the length of the rod which was inserted, as such length can be taken as the exposed section length.

Endoscopy inspection should emphasis on 1)steel tendon corrosion level, 2)steel threads loosened condition, 3) free-section concrete condition, 4) any concrete casting pipes and 5) interior moisture level or any water seepage, all inspection processes should be done carefully and in detail.

3.4 *Lift-off test*

After locking in load bearing of ground anchors, it’s possible that due to creep at the bond end, wedges not properly function which would reduce or increase the loading capacities. To measure the change of loading capacities after lock-in, typical lift-off test is conducted, as shown in Figure 5. Lift-off test is aimed at finding the remaining load capacity of anchor(Tr), and the reason being when tensile load is greater than the anchor remaining capacty, anchor will demonstrate obvious displacement increase, from which can be taken to evaluate the remaining capacity of ground anchors, as shown in a standard test curve in Figure 6. Ground anchor residual load(Tr) divided by ground anchor original designed load capacity (Tw) is the remaining load capacity ratio.

Figure 3. Equipment installation and operation

4 GROUND ANCHOR CAPACITY ASSESSMENT PROCEDURE AND CASE STUDY

For the purpose of quantitative assessment on the ground anchor capacities, and with regard to the ground anchors performance on the sloping terrain application is the goal of this procedure. Based on the inspection and assessment items, this article shall introduce a new set of ground anchor capacity assessment procedure, in hoping to establish a standardized way to quantitatively evaluate and assess ground anchoring. Such procedure shall comprised of exterior inspection, anchor head inspection, endoscopy inspection and lift-off test. The findings based on Table 1 distribution is point based. The total score will then be carried to Table 2 to evaluate (β) and classification. Sloped terrain performance and ground anchoring total capacity shall be classified based on Table 2 standards. Ground anchoring total performance assessment classified as A or B grade, respectively, will be given corresponding effective rehabilitation to ensure the full and reliable capacity of the ground anchors.

Figure 4. Free section exposed portion length investigation

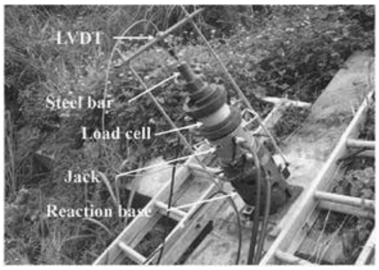

Figure 5. Lift-off test installation

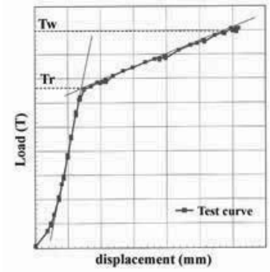

Figure 6. Lift-off test curve diagram

Table 1. Score of anchor capacity assessment

item	scoring	Content of inspection	Weight	subtotal
Exterior inspection	10	Buckled or detached.	0	
		Greater than 2mm separation from bearing plate or water corrosion is severe.	0.25	
		Anchor head protected seat and bearing plate separation is less than 2mm.	0.50	
		Anchor head protected seat surrounded by water seepage, efflorescence or anchor seat outside is slightly damaged or water corrosive level is moderate.	0.75	
		No observable anomalies or water quality is normal.	1.0	
Anchor head assembly inspection	15	Assembly came apart(clamp became loosened, steel tendon shrinkage or broken)	0	
		Anchor head surface appeared rusted and cracked, spread over 50% of the surface, steel tendon section is deformed due to corrosion.	0.25	
		Anchor head surface appeared rusted and cracked, but spread less than 50% of the surface.	0.50	
		Slightly corroded or water seepage. Anchor head appeared rusted, but the depth of the rust is quite thin, not measurable or lesser than 0.1mm.	0.75	
		No corrosion or water seepage is present.	1.0	
Endoscopy inspection	30	Steel tendon broken or steel threads became loosened and completely rusted.	0	
		Steel tendon appeared dark brownish, the surface already appeared corral-like or lumpy or rusted surface spread over 90%.	0.15	
		Steel tendon appeared dark brownish, the surface is rough, but not appearing corral-like or lumpy or rusted surface is between 50~90%.	0.45	
		Steel tendon appeared light brownish, but the surface is smooth and shining or rusted surface is between 10~50%.	0.75	
		No anomaly presence or rusted surface is below 10%.	1.0	
lift-off test	45	Detached, steel tendon broken or Tr=0.	0	
		Tr>1.2Tw or Tr≦0.2Tw	0.33	
		0.2Tw<Tr≦0.5Tw	0.67	
		0.5Tw<Tr≦0.8Tw	0.75	
		0.8Tw<Tr≦1.2Tw	1.0	
Single ground anchor capacity assessment(β)				
Total score of anchor capacity assessment(α)				

Remark: 1. If any of the items in categories 1,2,3,4 assessed a score of 0, such ground anchor shall be deemed as defective, and the total score of the anchor shall be zero.
2. When a sloped terrain of which 1/3 of the ground anchors inspected has reach over 90% rusted surface under the examination of endoscopy, but the lift-off test revealed remaining capacity falls into the range 0.8Tw<Tr≦1.2Tw, additional investigations in the field and test data is recommended to determine whether the slope may have a tendency to slide.

Table 2. Ground anchor assessment classifications

Individual capacity assessment		Total capacity assessment	
β	class	α	class
0	X. Defective		
β□30	A. Worst	α□30	A. Worst
30<β□55	B. Unacceptable	30<α□55	B. Unacceptable
55<β□80	C. Acceptable	55<α□80	C. Acceptable
80<β	D. Normal	80<α	D. Normal

Ground anchor inspection items will be measured with apparatus, which is the best and most direct way to understand the existing conditions of the anchors and remaining bearing capacities. These values usually will be referred to while performing sloping reinforcing analysis. Of course the anchor capacity cannot and should not base solely on the lift-off test result. There are other factors such as ground condition below the anchors for possible cave-ins, steel tendon or anchor head surface appeared rusted and cracked. When a sloped terrain of which 1/3 of the ground anchors inspected has reach over 90% rusted surface under the examination of endoscopy, but the lift-off test revealed remaining capacity falls into the range 0.8Tw<Tr□1.2Tw. Such conditions should be cross referenced with other data like field observations and inspections and evaluate in totality whether the slope has a tendency to slide. This article brings forth various anchor evaluations by which will address the possible different scenarios that might be overlooked otherwise. In order to validate the practicality of Table 1, this article takes 16 slopes and conduct a simulating calculation for them. The results are as shown in Table 3 and 4. The results and classifications are consistent, thus prove the validity of this assessment procedure and its practicality.

Table 3. Case study of Single ground anchor capacity assessment

No. of anchors	S4-1	S4-2	S4-3	S4-4	S4-5
Exterior inspection	7.5	7.5	7.5	7.5	7.5
Anchor head assembly inspection	11.25	11.25	11.25	11.25	11.25
Endoscopy inspection	22.5	30	22.5	30	30
Lift-off test	33.75	45	33.75	45	45
β	75.0	93.8	75.0	93.8	93.8
α	86.3				
Class of lift-off test	C	D	C	D	D
Class of β	C	D	C	D	D
Class of α	D				

5 CONCLUSION

Based on collected statistical data, 90% ground anchor failure are resulted at the anchor head proximity and free section part of the steel tendon. This article had gathered data which initially showed free section was not completely filled with concrete for nearly 85% of the ground anchors being examined, therefore making it the most prevalent shortcoming. To avoid anchors becoming defective which leads to disaster, anti-corrosive remedy should be done promptly.

This article only took 16 areas of sloping terrain to gather data on ground anchors for inspection and assessment as explained previously. This evaluation procedure demonstrates that the four categories assessment: inspecting the exterior aspect of the anchor, the anchor head examination, endoscopy inspection and lift-off tests is a logical process in finding shortcomings. In the future it is bound to have additional data available added to and revised upon, and would become a valuable systematic way for the engineering industry to adopt widely across.

Table 4. Case study of anchored slope capacity assessment

Slope No.	lift-off test			Total capacity	
	Amounts	Tr(%)	Class	Scoring	Class
S1	6	88.2	D	83.9	D
S2	5	77.8	C	55.3	C
S3	6	35.6	B	38.9	B
S4	5	88.2	D	86.3	D
S5	5	65.5	C	77.2	C
S6	4	35.6	B	54.2	B
S7	3	52.9	C	60.2	C
S8	3	70.2	C	63.6	C
S9	4	43.3	B	62.9	C
S10	3	85.1	D	87.9	D
S11	3	108.6	D	74.7	C
S12	8	69.5	C	64.8	C
S13	7	71.2	C	61.6	C
S14	5	55.6	C	62.0	C
S15	8	53.5	C	68.4	C
S16	7	47.7	B	52.9	B

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