Stability of a cut slope reinforced by stabilizing piles

Stabilité d'un talus renforcé par des pieux stabilisants

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ABSTRACT: A row of piles has been constructed to provide successful reinforcement of a cut slope in a construction site of apartment buildings. An instrumentation system has been designed to ensure the stability of the reinforced slope. During cutting works, the behavior of both slope and stabilizing piles is observed precisely. And also the effect of rainfall on the slope stability is investigated during rainy season beginning at June through September. The instrumentation observation represents that the cut slope has been stabilized by contribution of stabilizing effect of piles on the slope stability during not only construction works but also heavy rain.

RESUME: Une rangée de pieux a été mise en place pour assurer un renforcément satisfaisant d'un talus excavé, sur un chantier de construction d'un immeuble d'appartements. Un système d'instrumentation a été mis au point pour s'assurer de la stabilité du talus renforcé. Pendant les travaux d'excavation, le comportement du talus et des pieux est observé avec précision. En outre, l'effet de la pluie sur la stabilité du talus a été étudié durant la saison des pluies, de Juin à Septembre. L'étude des mesures instumentales montre que le talus excavé a été stabilisé par l'effet des pieux sur la stabilité du talus non seulement vis-à-vis des travaux de construction mais également face à l'action de la pluie.

1 INTRODUCTION

Cuts on hillside cause unstability of slope during heavy rain. Most landslides in Korea are initiated on the hillside of long slopes, occurring very quickly with little or no prior warning. Their general patterns are plane failures, which are shallow and parallel to the slope face. Stabilizing piles are available to control such plane failures. Recently, piles have been used in Korea as one of the most useful measures to improve exiting unstability of cut slopes and to maintain stability of the slopes on hillside.

A row of piles has been designed and constructed to provide successful reinforcement of a cut slope, situated on a construction site of apartment buildings. To ensure the stability of the slope throughout the construction sequence for reinforcement of the slope, an instrumentation system, comprising strain gages, inclinometers and standpipe piezometers has been installed into the slope (Hong & Han 1996).

In this paper, the behavior of the slope soil and the stabilizing piles is observed precisely during construction works such as cutting, excavation and anchoring for a retaining walls at the toe of the slope. And also the stability of the reinforced slope is investigated during rainy season beginning at June through September. The effect of rainfall on the stability of the slope is observed during heavy rain.

2 SLOPE STABILIZATION

2.1 Landslide history

A cut slope of one vertical to one horizontal was constructed on a construction site of apartment buildings in Pusan, situated about 432 kilometers southeast of Seoul, Korea. The cut slope was originally supported by an anchored retention wall with height of 12.5m. During heavy rain for several days, however, landslides took place on August 19, 1993, following partial collapses of the anchored retention wall. Fig.1 shows a typical profile of the failed slope and the chain line represents geometry of the failed slope.

The soil layer just below the ground surface is composed of mainly weathered soils approximately 10.3m thick with some colluvial soils. The soils can be described as sandy silts. A layer of bedrock composed of weathered rock and soft rock is below the weathered soils.

Additional boring and direct shear tests using block samples were performed to obtain informations pertaining to the original slope when it failed. It was also assumed that the soil shear strength at the interface between the layers of weathered soils and weathered rocks were significantly reduced due to the excessive displacements, and therefore shear strength parameters of the interface were estimated as $c = 1.1\ t/m^2$ and $\phi = 20^\circ$

2.2 Reinforcements by stabilizing piles

To improve stability of the failed slope, a row of stabilizing piles was constructed in the slope as shown in Fig.1. The stabilizing piles were designed according to the design method presented by the first author (Hong 1986, Ito et al. 1981, 1982).

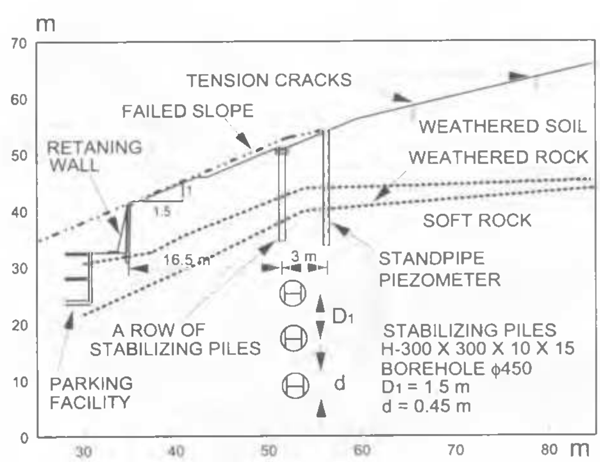


Figure 1. Design to control the landslide

After installation of stabilizing piles, the slope was modified to an inclination of one vertical to one and half horizontal with two soil berms. For an installation of stabilizing piles directly below the second soil berm, the holes of 450mm diameter were drilled by the depth of 1.5m into the soft rock layer. Steel H-piles (H-300×300×10×15) were inserted into the boreholes and the left spaces around H-piles in the holes were filled by cement grouting to prevent corrosion of steel piles.

The piles installed in a row at center-to-center intervals of 1.5m as shown in Fig.1. Pile heads were connected by a wale and reinforced concrete capping.

A retaining wall with height of 8.4m was constructed to cut the toe of the slope. The retaining wall is composed of an anchored retention wall and a concrete retaining wall as shown in Fig.2.

The anchored retention wall consists of soldier piles with concrete lagging and anchors. The soldier piles (H-250×250×9×14) installed into the bored holes at intervals of 2m were surrounded by cement grouting to prevent corrosion. Four rows of the anchors, having different free lengths and bond lengths, were designed to have sufficient resistance against pull-out or fracture. Permanent anchors was used to maintain the retention effect.

Based on the concept that half of the initial anchor load previously determined in anchored retention wall section would be lost with the passage of time, installation of the additional concrete retaining wall of about 8.4m in height directly at the front face of the anchored retention wall shown in Fig.2 was proposed to ensure the long-term stability of the slope.

2.3 Construction sequence

Fig.2 illustrates the cross sections of the slope controlled by stabilizing piles and retaining walls with anchors. Construction works for stabilization of the cut slope on hillside can be divided into four stages as follows:

(1) stage Ⅰ : slope modification
(2) stage Ⅱ : toe excavation
(3) stage Ⅲ : underground excavation
(4) stage Ⅳ : after construction

During stage Ⅰ, the slope was modified to an inclination of one vertical to one and half horizontal with soil berm after installation of stabilizing piles below second soil berm.

During stage Ⅱ, anchored retention wall was constructed by excavating the toe of the slope after installation of soldier piles with lagging.

During stage Ⅲ, underground excavation was performed in front of the anchored retention wall to provide underground parking facilities. Concrete retaining wall was constructed at the end of this stage.

Stage Ⅳ begins right after all construction works.

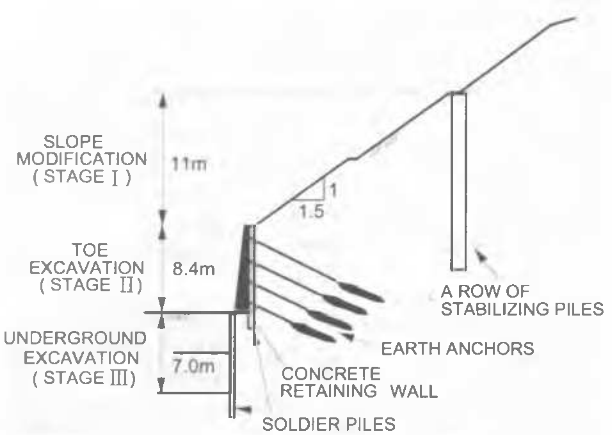


Figure 2. Construction stages

3 INSTRUMENTATION

To ensure the stability of the failed slope, an instrumentation comprising strain gages, inclinometers and standpipe piezometers was designed.

The stabilizing piles were instrumented with strain gages, as illustrated in Fig.3(a). Strain gages were installed at intervals of 1.5 m from pile top to tip, as illustrated in schematic diagrams in Fig.3(a).

Wheatstone Bridge type strain gages were used to ensure durability against temperature and humidity. The strain gages were installed in type of full bridge. Strains of piles were measured by use of transducer with switch box. Several strain gages did not work, however, since they were damaged during construction works.

To measure the horizontal movements of stabilizing piles and slope soil across the open space between piles, two inclinometers were installed as shown in Fig.3(b). The pile deflection was measured by the inclinometer which is installed in piles. The other inclinometer was installed inside potential plastic zone across the open space between the piles, as illustrated in Fig.3(b).

The inclinometer access PVC standpipe was installed between 14.5m and 15.5m deep. They were placed in holes that were grouted up with cement milk.

The Casagrande standpipe piezometer was installed in slope as illustrated in Fig.1. Porous plastic tips manufactured by GI were used. These tips were connected Via 30mm OD PVC tubing to the ground surface.

Piezometric pressure at the tip was indicated by the head of water which developed inside the standpipe. The water level was determined by lowering a dipmeter probe from the top of the tube until an audible signal was received. The piezometer was installed backside of 3m from stabilizing piles as shown in Fig.1.

4 EFFECT OF GROUNDWATER ON SLOPE STABILITY

4.1 Relationship between rainfall and landslide

Rainfall is the most significant factor affecting on landslides in Korea. Annual rainfall is high and seasonal averaging from 1,100mm to 1,400mm. The heavy but seasonal rainfall is produced either by movable troughs of low air pressure (seasonal rain front) or tropical low pressure (typhoons) during the rainy season from June to September.

Kim et al. (1992) have classified the landslide events in South Korea into three categories such as 'minor', 'severe', and 'disastrous' as shown in Fig.4.

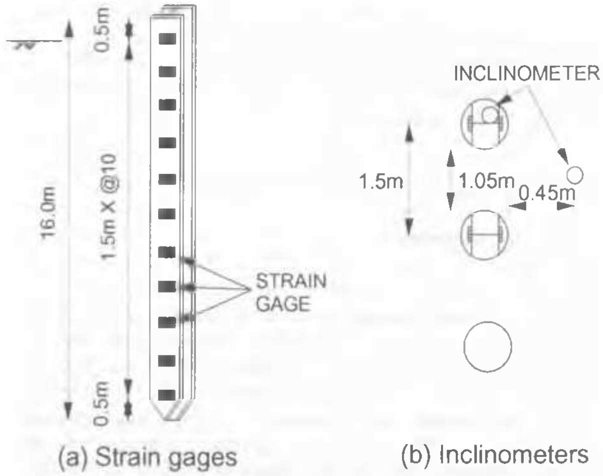


Figure 3. Instrumentation system

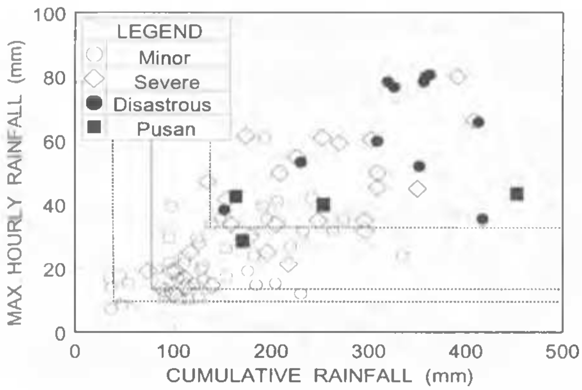


Figure 4. Relationship between landslide event and rainfall

Based on the data in Fig.4, Kim et al. (1992) have suggested the means of a warning system for prediction landslide disastrous as following: A minor event can occur when not only peak hourly rainfall is over 10mm but also two-day cumulative rainfall over 40mm. A severe event can occur when not only peak hourly rainfall is over 15mm but also two-day cumulative rainfall over 80mm. A disastrous event can occur when not only peak hourly rainfall is over 35mm but also two-day cumulative rainfall over 140mm.

The landslide events, which occurred in Pusan for recent ten years from 1982 to 1991, are plotted on Fig.4 and compared with the landslide events presented by Kim et al.(1992). As shown in Fig.4, the landslide events for recent ten years in Pusan were severe or disastrous. Heavy rainfall in Pusan is usually produced by typhoons, Therefore, the landslides occurred in Pusan are mainly governed by the intensity of daily rainfall at failure, as like the typical pattern in southern area in South Korea.

4.2 Relationship between rainfall and groundwater

The standpipe piezometer was available to investigate the variation of ground water level as known in the previous study (Hong & Han 1996). According to the previous investigation, the groundwater level did not grow so sensitively during heavy rain. Even through there were several heavy rains, in which daily rainfall was more than 50mm and the cumulative rainfall was more than 150mm, the groundwater level was not changed so much.

Therefore, the groundwater level in this slope could not affect the behavior of piles and slope. The wetting front rather than the groundwater level may affect so much the behavior of piles and slope, since the driving force of slope is increased by increase of the weight of soil above the wetting front.

5 THE BEHAVIOR OF PILES AND SLOPE

5.1 Behavior of piles

Fig.5 shows the distribution of the horizontal deflection of pile measured by the inclinometer installed in the pile as shown in Fig.3(b). Fig.5(a) represents the pile deflection corresponding to each construction stages such as soil modification, toe excavation and underground excavation, while Fig.5(b) represents a typical case of the variation of the pile deflection during heavy rain.

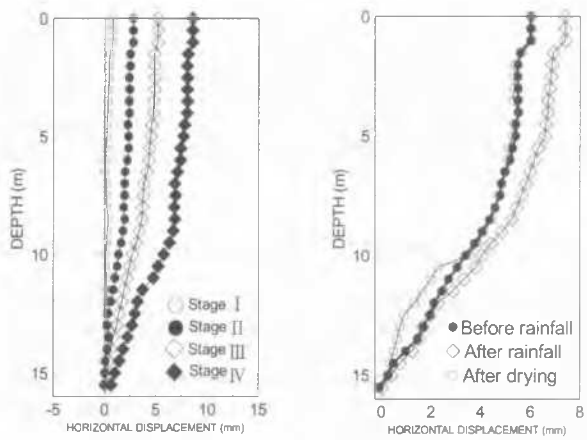
The maximum deflection was measured at pile head and the deflection angle at pile head was zero as shown in Fig.5. This means that the pile head is under unrotated head condition.

The deflection of piles in Fig.5(a) grew gradually by lateral earth pressure which was developed on piles due to cutting and excavation.

The deflection of piles increased also during heavy rain as shown in Fig.5(b), since the lateral earth pressure increased by increase of the weight of soil above the wetting front due to infiltration of rain during heavy rain. The pile deflection decreased again, however, when the soil above the wetting front was dried.

On the other hand, Fig.6 shows the distribution of bending stress developed on piles. The bending stress of piles was measured by the strain gages installed in piles as shown in Fig.3(a). A typical case of the variation of bending stress developed on piles during heavy rain is shown in Fig.6.

The distribution of bending stress represents that the pile above the weathered rock layer is subjected to lateral earth pressure due to driving force of slope, while the pile in the ground below the soil layer is subjected to subgrade reaction against pile deflection.



(a) During construction works

(b) During heavy rain

Figure 5. Pile deflection

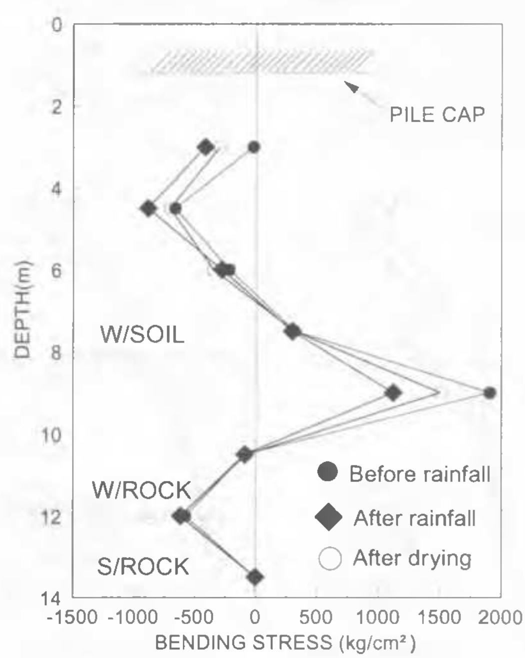


Figure 6. Bending stress on piles

Fig.6 represents also that the bending stress on piles increased during heavy rain. Of course, the bending stress decreased again when the soil above the wetting front was dried as like the pile deflection in Fig.5(b) decreased.

Therefore, the results of Fig.5(b) and Fig.6 illustrates that the piles shows elastic behavior during heavy rain.

5.2 Behavior of slope

Fig.7 shows the distribution of the horizontal deformation of soil measured by the inclinometer installed in potential plastic zone between piles as shown in Fig.3(b). Fig.7(a) represents the soil deformation corresponding to the pile deflections of each construction stages, while Fig.7(b) represents a typical case of the variation of the soil deformation during heavy rain. The soil across the open space between piles deformed rapidly during excavation at the toe of slope as shown in Fig.7(a). However, additional deformation was not measured after construction of concrete retaining wall. This result illustrates that the soil between piles was restrained by the arching action of the soil.

The soil deformation increased also during heavy rain as shown in Fig.7(b). The behavior shows same to the behavior of the pile deflection as shown in Fig.5(b). The soil deformation decreased again, however, when the soil above the wetting front was dried. This result illustrates that the soil shows elastic behavior during heavy rain as like the piles.

6 EFFECTS OF PILES ON SLOPE STABILITY

Fig.8 shows the variation of maximum movements of pile and soil. After construction of slope stabilization, movements of pile and soil became constant, but the soil movement was larger than the pile movement. This means the soils between piles are restrained by the arching action of the soil between piles. The maximum movement of pile increased linearly during construction, while the maximum movement of soil increased linearly during only initial slope modification. After then the movements of pile and soil becomes almost constant within 30mm, which can be treated as elastic behavior.

Judging from the measured movements of piles and soil, it is supposed that the behavior of the stabilizing piles and the slope is elastic.

The slope movement could be restrained within quiet low movement by the effect of the stabilizing piles. Therefore, it is inferred that the stabilizing piles are effective to control landslides in Korea.

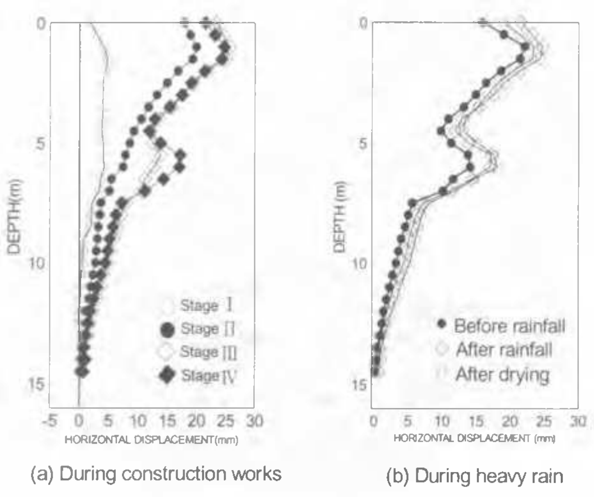


Figure 7. Soil deformation

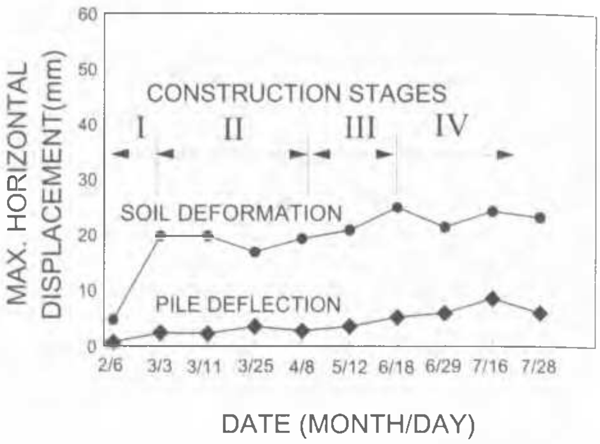


Figure 8. Variation of maximum horizontal displacement

7 CONCLUSIONS

Piles have been used successfully as a measure to stabilize a failed cut slope. The stabilizing effect of piles could be confirmed by an instrumentation observation. The horizontal deflection and bending stress developed on the piles could be measured, respectively, by the inclinometers and strain gages installed in piles, while the horizontal deformation of the slope soil could be measured by the inclinometer installed in the soil across the open space between piles.

The stabilizing piles designed by the presented design method can have sufficient effect on the slope stability during not only construction works such as cutting and excavation but also heavy rain in rainy season from June to September. The groundwater level does not grow so sensitively during heavy rain. The behavior of piles and slope is affected by the wetting front rather than groundwater level during heavy rain. The stabilizing piles and the slope soil show elastic behavior during heavy rain.

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