Lateral earth pressure acting on the anchored walls installed in cut slopes

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Abstract: To more effectively utilize construction sites for apartments, roads, infrastructure, and so on, excavation works are being performed in sloping ground. In this case, anchored retention walls are mainly selected because of the presence of soil slopes behind the walls and unsymmetrical excavation sections. An instrumentation system has been installed at the anchored retaining walls in the slopes to estimate the lateral earth pressure acting on the anchored walls. As a result of the measurements, the earth pressure diagram acting on anchored walls is presented approximately as a trapezoid. The earth pressure at the ground surface is larger than zero. Also, the earth pressure increases linearly from the ground surface to 15% of the total excavation depth and then is kept constant. Meanwhile, the measured earth pressure is larger than the empirical earth pressure proposed by Terzaghi & Peck (1967). Therefore, the earth pressure acting on an anchored retaining wall installed in a cut slope is larger than that of horizontal ground surface behind wall.

Résumé: À utilisez plus efficacement les chantiers de construction pour des appartements, routes, infrastructure, et ainsi de suite, des travaux d'excavation sont effectués en terre en pente. Dans ce cas-ci, des murs ancrés de conservation sont principalement choisis en raison de la présence des pentes de sol derrière les murs et les sections unsymmetrical d'excavation. Un système d'instrumentation a été installé aux murs de soutènement ancrés dans les pentes pour estimer la pression latérale de la terre agissant sur les murs ancrés. En raison des mesures, le diagramme de pression de la terre agissant sur les murs ancrés est présenté approximativement comme trapèze. La pression de la terre sur la surface au sol est plus grande que zéro. En outre, la pression de la terre augmente linéairement de la surface au sol à 15% de toute la profondeur d'excavation et alors est maintenue constant. En attendant, la pression mesurée de la terre est plus grande que la pression empirique de la terre proposée par Terzaghi et Peck (1967). Par conséquent, la pression de la terre agissant sur un mur de soutènement ancré installé dans une pente de coupe est plus grande que celle de la surface au sol horizontale derrière le mur.

Keywords: Lateral earth pressure, anchored wall, cut slope, excavation, instrumentation.

INTRODUCTION

In order to utilize more effectively underground space for apartments, buildings, geotechnical structures and so on, at urban and slope areas in Korea, excavation work has been performed extensively. The existing buildings or other structures should be protected against the loss of bearing capacity, settlements, lateral movements caused by the adjacent new excavation.

To protect these losses caused by new excavation, earth retention walls composing soldier piles and lagging has been used commonly in Korea. Also, a strut system with wales has been used widely to support the retention wall. Recently, an anchor system is often used instead of the strut system to support the retention wall. The anchor system has advantages to provide wide underground working space for construction work inside excavation area.

To design the earth retention wall supported by strut or anchor system, the lateral earth pressure acting on the earth retention wall should be predicted accurately. Terzaghi & Peck (1967) and Tschebotarioff (1973) proposed several empirical earth pressure diagrams for design of the earth retention walls supported by the strut system. Also, Otta et al. (1982) and Xanthakos (1991) proposed empirical earth pressure diagram for design of the retention walls supported by the anchor system. The empirical earth pressure diagrams have been applied on design retention walls for excavation work without any modification. However, the deformation and earth pressure patterns of earth retention wall are different according to the various field and construction conditions. Also, the deformation and earth pressure patterns of soils may depend on location.

Recently, the excavation work at slope and hill areas has increased to construct apartments in Korea because of overpopulation phenomenon in urban areas. In this case, earth retention walls supported by the anchor system, called the anchored retention wall mainly selected because of the presence of soil slope behind the wall and unsymmetrical excavation section. However, previous studies related to anchored retention walls installed in the cut slope are insufficient to modify and propose an earth pressure diagram in Korea. In order to modify and propose the earth pressure diagram, an instrumentation system is applied in the anchored retention wall installed in cut slope. As the result of the measurements, the earth pressure acting on the anchored retention wall in cut slope can be proposed and compared with empirical earth pressures that have been widely used.

FIELD TEST

Field description

A cut slope with an inclination of one vertical to one horizontal was situated on a construction site of apartment buildings in Pusan, Korea. The cut slope was originally supported by the anchored retention wall with height of 12.5 m. During heavy rain Busan area (530.3 mm) for several days, landslides including partial collapses of the anchored retention wall occurred in soil deposits on August 19, 1993, as indicated on Figure 1.

To improve stability of the failed slope, a row of stabilizing piles was installed in the slope as shown in Figure 2. The stabilizing piles were designed according to the design method presented by Ito et al. (1981, 1982). 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 with 450mm diameter were drilled by the depth of 1.5 m into the soft rock layer. Steel H-piles (H-300*300*10*15) were inserted into holes and the empty 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 1.5 m as shown in Figure 2. Pile heads were connected by a wale and reinforced concrete capping.

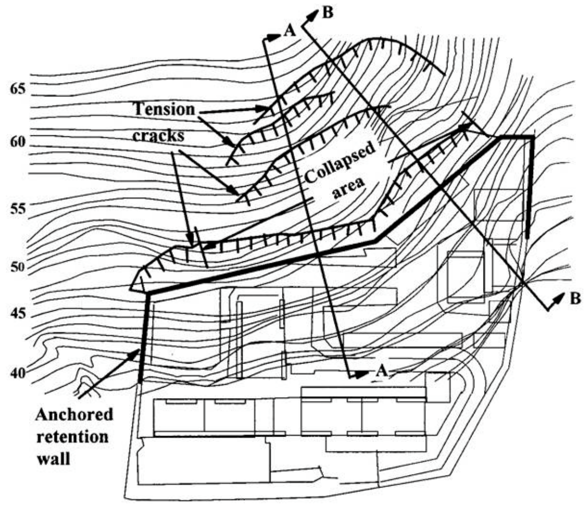


Figure 1. Plan view of landslide outline

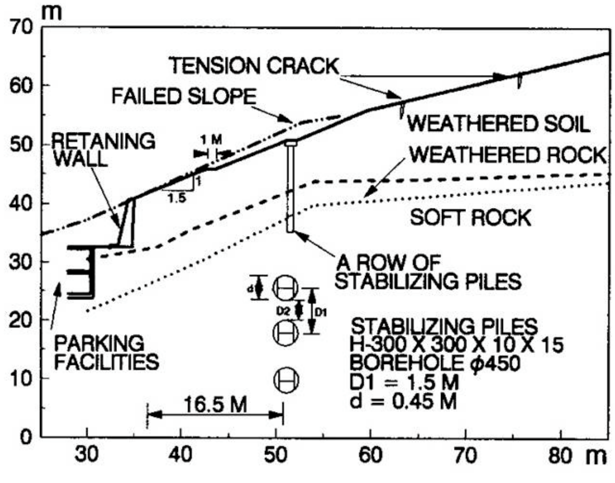
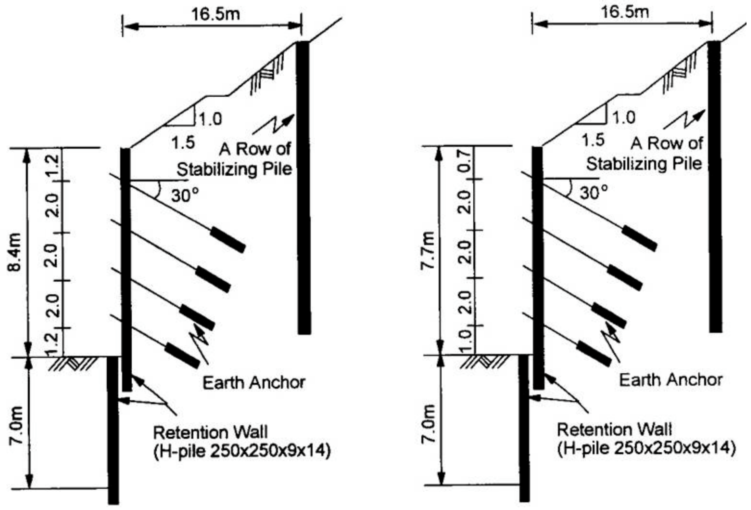


Figure 2. Layout of slope stabilization (section A-A)

A retaining wall with height between 7.7 and 8.4 m was constructed to cut the toe of slope. The retaining wall is composed of an anchored retention wall and a concrete retaining wall as shown in Figure 3. The retaining wall is 16.5m away from the stabilizing piles. 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 2 m 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. The vertical and horizontal intervals of anchors are 2 m and 2 m, respectively, and the inclination of installed anchors is 30 degrees. Permanent anchors were used to maintain the retention effect.



(a) section AA (b) section BB

Figure 3. Anchored retention walls installed in cut slopes

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

Ground condition

Figure 2 shows a typical profile of the failed slope and the chain line represents geometry of the failed slope. As shown in Figure 2, the ground is composed of weathered soils, weathered rock and soft rock from ground surface. The soil layer just below the ground surface is composed of mainly weathered soils approximately 10.3m thick with some colluvium soils. The soils can be described as sandy silts or silty sand with gravels. The shear strength parameters of weathered soils are $c=1.35 t/m^2$ and $\phi=25.5^{\circ}$, respectively. The weathered rock below the weathered soils is very intact. The soft rock is mainly composed of andesite rocks, which include fissures and joints (Kang et al. 1993).

FIELD MEASUREMENTS

Instrumentation and construction sequence

To ensure the slope stability and to monitor the earth pressure acting on the anchored retention wall throughout the construction sequence for cutting the toe of slope, instrumentation with inclinometer, load cell and water level meter (standpipe piezometer) was designed to observe the behaviour of anchored retention wall at section AA and section BB. Figure 4 shows the schematic cross-sectional view of instrumentation system.

To measure the horizontal displacements of anchored retention wall and slope behind wall, two inclinometers were installed inside the wall and in the backside slope of 0.45 m from wall, as illustrated in Figure 5. To measure the anchor force of anchored retention wall, the load cells were installed around the anchor tendon at anchor head in each 1st to 4th level anchors. Also, to measure the ground water level around anchored retention wall, water level meter was installed in the backside slope of 3 m from wall, as illustrated in Figure 5.

The instrumentation was carried out to investigate the earth pressure and horizontal displacement of wall in excavation stages. Table 1 illustrates the excavation stages and schedule used at section AA and section BB.

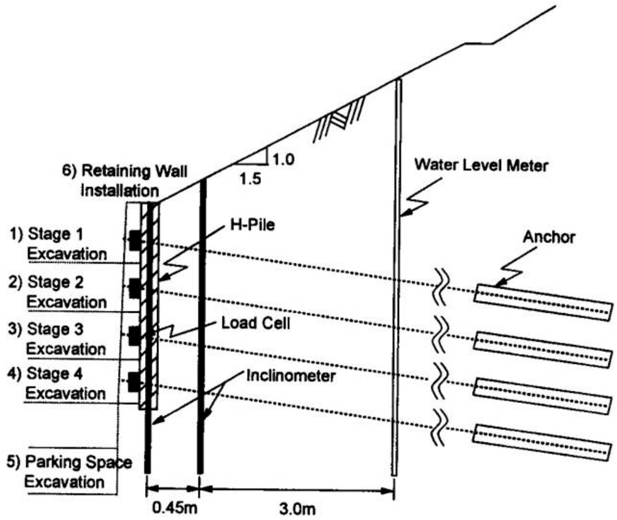


Figure 4. Cross-sectional view of instrumentation system

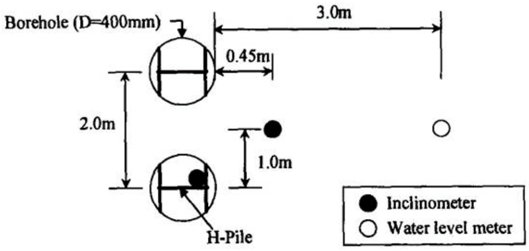


Figure 5. Plan view of instrumentation system

Table 1. Construction sequence of excavation work in each section

Stages	Section AA	Section BB
1st excavation stage	02/15, 1st level excavation (GL-2.2 m) 03/11, 1st level anchor installation	02/15, 1st level excavation (GL-1.7 m) 03/11, 1st level anchor installation
2nd excavation stage	03/16, 2nd level excavation (GL-4.2 m) 03/26, 2nd level anchor installation	03/16, 2nd level excavation (GL-3.7 m) 03/26, 2nd level anchor installation
3rd excavation stage	03/30, 3rd level excavation (GL-6.2 m) 04/05, 3rd level anchor installation	03/30, 3rd level excavation (GL-5.7 m) 04/05, 3rd level anchor installation
4th excavation stage	04/17, 4th level excavation (GL-8.4 m) 04/20, 4th level anchor installation	04/17, 4th level excavation (GL-7.7 m) 04/20, 4th level anchor installation
Concrete retaining wall construction stage	06/15, Installation of concrete wall 06/22, Removing the form of wall	06/29, Installation of concrete wall 07/04, Removing the form of wall

The result of instrumentation

Anchor force

Figure 6 shows the variation of anchor force measured from the load cell placed at anchor head during excavation at section AA. As shown in Figure 6, the pre-stressed anchor force was decreased during excavation and installation of anchor. The decrease of anchor force was generated with time by redistribution of stress due to deflection of retention walls during excavation. However, the anchor force was kept constant or varied little after 4th level excavation and installation of 4th level anchor. These performances of anchor force appear to be in a state of stable equilibrium. After installation of concrete retaining wall, the anchor force was increased slightly and then decreased again. The temporary increase of anchor force was attributed to holding deflection of anchored retention wall due to installation of concrete wall.

Figure 6(a) shows the variation of the 1st level anchor force. The anchor force measured by load cell is 52.1 ton after the 1st level excavation, while the jacking force of 55 ton adds on the anchor. Also, the anchor force is reduced to 47.8 ton just after jacking free. After the 2nd level excavation and installing the 2nd level anchor, the anchor force is rapidly reduced to 35.2 ton. However, the anchor force is kept constant after the 4th level excavation and installing the 4th level anchor. After installation of concrete retaining wall, the anchor force has increased by 2 ton and has slightly decreased. Figure 6(b) shows variation of the 2nd level anchor force. The anchor force is 51.3 ton after the 2nd level excavation. The anchor force is reduced to 46.1 ton just after jacking free. After the 3rd level excavation and installing the 3rd level anchor, the anchor force is reduced to 43.7 ton. From the 4th level excavation to installation of concrete wall, the variation of anchor force is similar to the variation of the 1st level anchor force. Figures 6(c) and (d) show variations of the 3rd level, and 4th level anchor force, respectively. The 4th level anchor force is decreased rapidly after jacking free. After 4th level excavation, the variation of anchor force is similar to the variation of the 1st level anchor force.

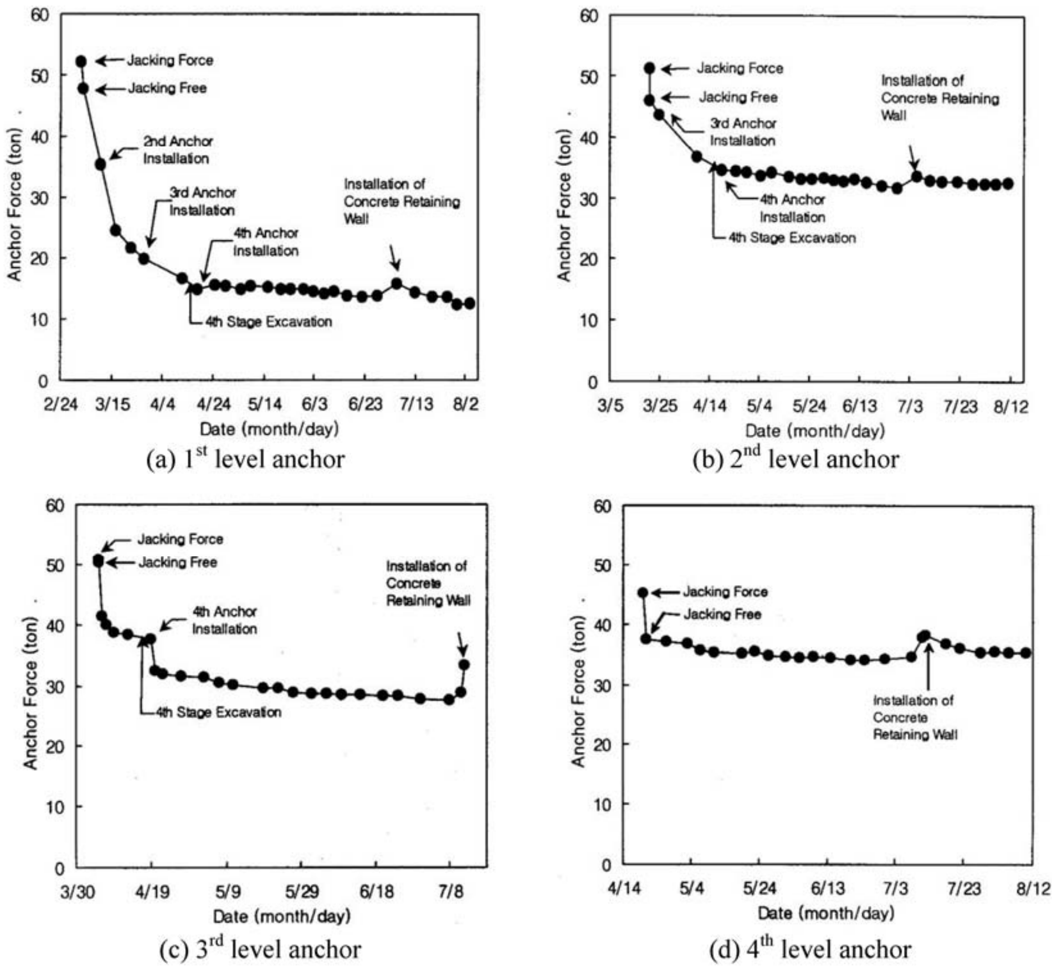


Figure 6. Variation of anchor force

Horizontal displacement

Figure 7 shows the horizontal displacements of anchored retention wall and slope behind wall measured by inclinometers during excavation at section AA. Figure 7(a) illustrates the horizontal displacement of anchored retention wall. The horizontal displacement of 107.4mm is occurred at the upper part of wall after the 1st level excavation. After installation of the 1st level anchor, the horizontal displacement is rapidly reduced to about 75mm influenced by the pre-stressed anchor force. As the anchor is installed in each excavation stage, the horizontal displacement is controlled by anchor force. However, the horizontal displacement at only ground surface is increased for three months after the final excavation. Figure 7(b) illustrates the horizontal displacement of slope behind the wall. The horizontal displacement of 114.7 mm occurred at the ground surface after the 1st level excavation. The horizontal displacement of slope is increased gradually with process of excavation. The horizontal displacement of the slope is not influenced by the anchor force in each excavation stage. Also, the horizontal displacement of the slope is increased largely at not only ground surface and but also underground.

EARTH PRESSURE ACTING ON ANCHORED RETENTION WALL

Earth pressure considering surcharge load

The apparent earth pressure acting on the anchored retention wall was calculated from anchor forces in each excavation stage by use of the split method of the middle point (Flaate 1966). The earth pressure can be calculated by dividing the anchor force measured from load cell by length between wales. The calculating equation of earth pressure in each excavation stage is shown in Equation 1.

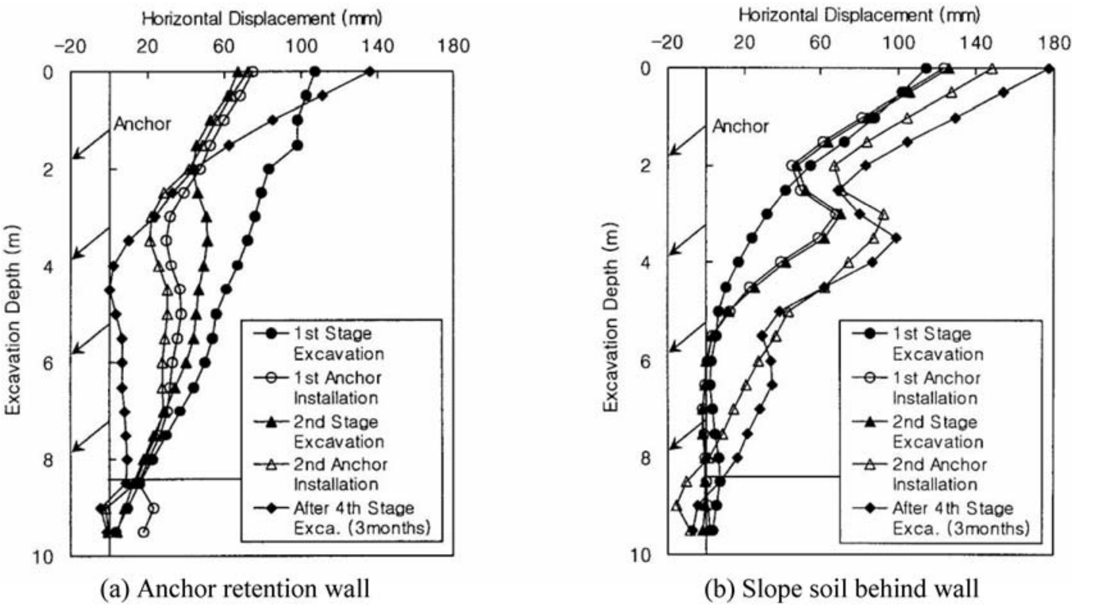


Figure 7. Variation of horizontal displacement

$$P = \frac{Q \cdot \cos\phi}{L \cdot B} \tag{1}$$

where, P is the earth pressure (t/m2), Q is the anchor force measured from load cell (ton), ϕ is the installation angle of anchor (^{o}), B is the horizontal interval of anchor, and L is the vertical interval of anchor.

To estimate the apparent earth pressure acting on anchored retention wall, the maximum anchor forces in each excavation stage were applied. Based on the maximum earth pressures in each stage, the apparent earth pressure diagram can be proposed as shown in Figure 8. The proposed earth pressure diagram of the anchored retention wall installed in cut slope was a trapezoidal shape. As shown in Figure 8, the earth pressure diagram has two characteristics. First, the earth pressure at the ground surface is larger than zero. Second, the earth pressure is increased linearly from ground surface to a certain depth, and kept constant under a certain depth.

Based on the Figure 8, the schematic diagram of apparent earth pressure can be represented in Figure 9. As shown in Figure 9, the earth pressure diagram can be divided into two parts. A part is the earth pressure of rectangular shape occurred in surcharge load caused by slope soil behind the wall. B part is the active earth pressure of trapezoidal shape.

An increased earth pressure at certain depth is represented as αH. As shown in Figure 8, the value of α is approximately 0.15. The total width of earth pressure is represented as P. P is represented by use of Rankine's (1857) active earth pressure and vertical surcharge pressure. Therefore, P is written in the form of Equation 2.

$$P = \beta K_a (q + \gamma H) \tag{2}$$

where, q is the surcharge load caused by slope soil behind the wall, K_a is the coefficient of active earth pressure, γ is the unit weight of soil, and H is the total excavation depth.

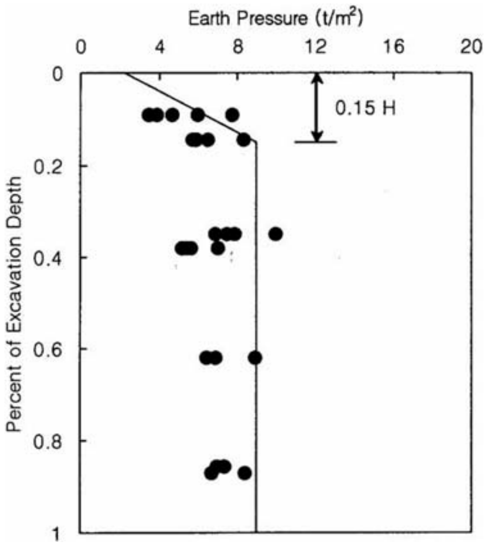


Figure 8. The measured earth pressure

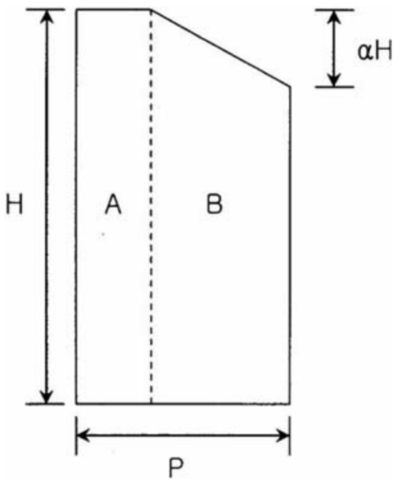


Figure 9. Schematic diagram of apparent earth pressure

Figure 10 shows the earth pressure calculation method considering surcharge load caused by slope soil behind wall. As shown in Figure, the soil mass weight of ACD is loaded uniformly at the line AC. That is, the soil mass weight of ACD is equal to the surcharge load. Therefore, surcharge pressure can be calculated by use of the above mentioned method, and the surcharge pressures in section AA and section BB are 5.64 t/m^2 and 5.17 t/m^2, respectively. Also, the active earth pressures by surcharge pressure in each section are 2.2 and 2.3, respectively. These values of the active earth pressure by surcharge pressure are similar with the value of earth pressure at ground surface.

Comparison with the empirical earth pressure

Figure 11 shows that the measured earth pressure is compared with Rankine's active earth pressure considering surcharge load. As shown in Figure 11, the measured earth pressure is equal to Rankine's active earth pressure. However, the measured earth pressure is larger than the empirical earth pressure proposed by Terzaghi & Peck (1967). That is, the values of β in the Equation 2 are 1.0 in case of the measured pressure and 0.65 in case of the empirical pressure.

The sliding force in slope soil behind the walls is increased with a decrease of the passive earth pressure due to excavation. Therefore, the earth pressure acting on anchored retention wall installed in cut slope is larger than that of horizontal ground surface behind wall. That is, the sliding force caused by excavation in slope soil is larger than that of horizontal ground surface.

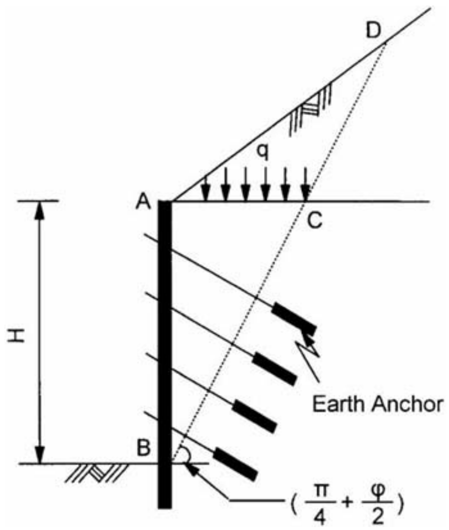


Figure 10. Earth pressure calculation method

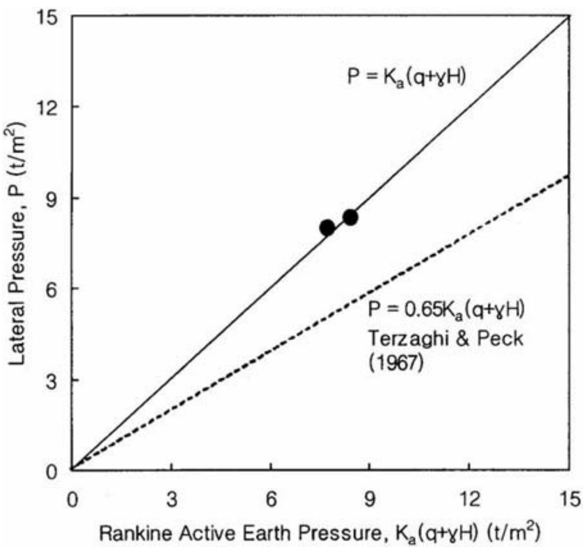


Figure 11. Comparison with the empirical earth pressure

CONCLUSION

In order to propose the earth pressure diagram, an instrumentation system was applied in anchored retention wall installed in cut slope. Based on the result of the measurements, the earth pressure acting on the anchored retention wall in cut slope could be proposed and compared with empirical earth pressure. The following conclusions could be drawn:

(1) The anchor force is decreased during excavation and installation of anchor. The decrease of anchor force is generated with time by redistribution of stress due to deflection of retention walls during excavation.

(2) The proposed earth pressure diagram is a trapezoidal shape. The earth pressure at the ground surface is larger than zero. Also, the earth pressure is increased linearly from the ground surface to the 15% of total excavation depth, and the kept constant below that depth.

(3) The measured earth pressure is larger than the empirical earth pressure proposed by Terzaghi & Peck (1967). Therefore, The earth pressure acting on anchored retention wall installed in cut slope is larger than that of horizontal ground surface behind wall.

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