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# New definition of pullout constant

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ABSTRACT: When we design reinforcement structures, pullout friction angle is considered as an important design constant. Pullout resistances are there pullout cohesion, pullout friction and passive resistance. A lot of scholars have tried to find a rational result about pullout constants using pullout experiment apparatus, but they have not obtained the good method yet. Because pullout test is different from the element test such as triaxial test and direct shear test and test results have a lot of difference depending on the pullout test size. Also, it has been observed that pullout constants depend on the vertical stress. Accordingly in this study the new concept angle called the pullout resistance angle, has been defined and it can include the friction, the cohesion and the passive resistance and it depends on the vertical stress such as $\delta = \delta\ (\sigma_v)$. Also, the new method of determining the pullout area has been suggested, which uses the tension curve measured during pullout test. To investigate the new concept, pullout tests using geogrid and standard sand has been performed. From the test results we confirmed the new concept about pullout characteristics will be a good idea.

## 1 INTRODUCTION

In case of reinforced soil, a reinforcement is inserted inside ground and when a load is applied to it, pullout force is occurred within the reinforcement due to relative displacement between the reinforcement and the ground by which it plays its role to enhance the strength of the ground. In Korea, a granite soil, easily found here, has been widely used for backfill material of a reinforced wall. However, little study on pullout friction which is regarded as a critical design constant for granite soil has been performed yet.

This study employed a relatively small pullout tester with 30 cm (L) × 30 cm (W) × 20 cm (H) and carried out pullout test by using the ground material of standard soil and granite soil. Also a geogrid was used for a reinforcement. Comparative analysis on the result of pullout test was followed and a pullout area is one of the important factor to calculate a pullout constant. Accordingly this study adopted the new concept of an area ratio in calculating a pullout area, which is coming from a tensile distribution curve. This method is to calculate the actual pullout area for which a reinforcement receives during pullout test, to get an area ratio after comparing the area within tension force distribution curve with that of the assumption such that max. tension force comes from total length, and with this area ratio to calculate a pullout stress and a corresponding pullout resistance angle.

## 2 NEW DEFINITION OF PULLOUT CHARACTERISTICS

### 2.1 *Pullout resistance angle*

A triaxial test is performed to find out strength properties of a ground after collecting samples from the ground. Internal friction angle and cohesion are calculated from the test result; however, these values are not related to the size of confining stress. On the other hand, a test of pulling out the reinforcement is carried out to get resistance properties between soil and the ground, keeping confining stress increased. This test can not be considered as the element test like triaxial one so that it's not easy to get the unrelated values to the size of confining stress.

Previous efforts have been mainly focused on how to indicate resistance properties between soil and the ground by employing the concept of pullout friction angle and pullout cohesion from these test results. However, in view of previous test results it has been found that pullout friction angle depends on confining stress. This indicates that the more confining stress comes, the lower its value shows.

In this regard, the resistance value between soil and the ground is to be represented by a pullout resistance angle, a new concept of terminology, where as long as this value of pullout resistance angle includes that of pullout friction force, pullout cohesion and passive resistance, it depends on the size of confining stress. Accordingly pullout properties only uses pullout resistance angle which depends on confining stress and can be represented as the following equation (1);

$$\delta = \delta\,(\sigma_v) \tag{1}$$

### 2.2 *Pullout area calculated from pullout force distribution curve*

Max. tension force is used to calculate pullout friction stress from pullout test and it is very important how to determine pullout area in getting an exact pullout resistance angle. The reason lies in the fact that pullout force is not uniformly distributed over the whole reinforcement and this study broadly adopted the two methods in doing so.

Total area method uses the whole area where the reinforcement is installed. This method, however, results in lower pullout resistance angle than an actual value.

Tension force acting on the reinforcement during its pullout test can be obtained. As seen in Fig. 1, tensile strength shows a peak at the certain distance from the area where pullout is initiated and then gradually becomes lower. Pullout area can be obtained in such a way of letting the rectangular area as 100 shown when drawing a line horizontally on the basis of pullout value at the peak area, calculating the area ratio at the lower part of the pullout curve and getting the pullout area by multiplying this area ration by total area.

This method was defined as distribution area method and can be regarded as a reasonable logic in consideration of obtaining pullout stress with total area. Area ratio can be calculated as the following equation (2);

$$\text{Area Ratio (AR)} = \frac{\text{Distribution area}}{\text{Total area}} \tag{2}$$

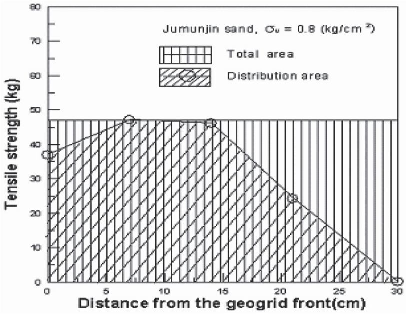
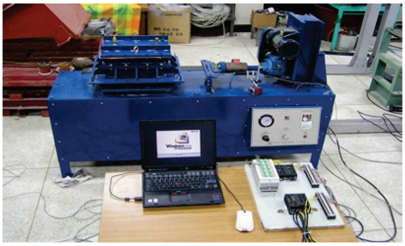



Figure 1. Conceptual drawing of area ratio (standard soil, for, $\sigma_v = 0.8$ kg/cm$^2$).

## 3 TEST

### 3.1 *Pullout tester*

Pullout tester is a relatively small one with 30 cm (L) × 30 cm (W) × 20 cm (H). It is generally consisted of 5 different parts including soil tank, air pressure bag, geosynthetic fiber fixing device, load cell and electric motor.



Picture 1. Pullout tester

At the upper bounding surface, air pressure bag is mounted on the top of soil tank to distribute uniform pressure and pullout resistance is automatically measured by load cell attached to pullout device. And pullout displacement of the reinforcement is measured by LVDT located on the front of soil tank, a loading device is so constructed to add confining stress and upper loading pressure by injecting compressed air with compressor into air pressure bag installed on the upper bounding surface of soil tank, where air pressure is controlled by pressure gauge of regulator.

### 3.2 *Characteristics of standard soil and granite soil*

Jumunjin standard soil and weathered granite soil were used for the model ground. According to soil classification, Jumunjin soil is classified into SP and SM-SC for weathered granite soil. Also direct shear test showed that cohesion of Jumunjin standard soil was 0.016 kg/cm$^2$ and 0.361 kg/cm$^2$ for weathered granite soil and that friction angle was 34.5° and 32.4°, respectively.

### 3.3 *Reinforcement*

The reinforcement applied to this study is an uniaxially drawn geogrid with the following physical properties shown in Table 1.

Table 1. Physical properties of geosynthetic fiber.

| Type of Reinforcement | Max. Tensile Strength (kN/m) | Max. Elongation (%) | Grid Size (mm) |
|---|---|---|---|
| Geogrid | 90.0 | 13.0 | 250 × 17 |

### 3.4 *Contents of test*

Total 6 pullout tests were performed with the same conditions as shown in the following Table 2 according to confining stress and the types of soil.

Table 2. Contents of pullout test.

| Model ground | Reinforcement | Normal stress ($kg/cm^2$) |
|---|---|---|
| Jumunjin Standard Soil | Geogrid | 0.2, 0.5, 0.8 |
| Weathered granite Soil | Geogrid | 0.2, 0.5, 0.8 |

### 3.5 *How to construct model ground and its test method*

Multiple sieving drop tester was used for constructing Jumunjin standard soil ground and the conditions to appear 90% of relative density by using it were as follows; 2.2 mm of the sieve size, 5 sieve layers, 4 cm diameter of an outlet and 70 cm of drop height. And the model ground for weathered granite soil within the soil tank of a pullout box was prepared by adjusting the moisture contents of weathered granite soil to become an optimum contents which has been determined by compaction test, the samples being ready were installed in soil tank and 4.5 kg of a rammer was dropped down from 45 cm height to compact with 4 layers.

As the volume of a pullout box(30 cm × 30 cm × 20 cm) is V = 18,000 $cm^3$ and the compaction has 4 layers, then the required compaction degree can be obtained by compacting 125 times on each layer in order to maintain $E_c = 5.625$ kg · $cm/cm^3$ when 4.5 kg of a rammer is dropped down from the height of 45 cm. And a geosynthtic fiber was compacted to a lower box, that is, up to the 2nd layer and installed at the height of 10 cm, the center of the height of soil tank.

The pullout speed was constant with 1 mm/min during pullout test and pullout force was measured by a load cell connected to a geosynthetic fiber fixing device. On the other hand, one displacement gauge was installed at one side of the geosynthetic fiber fixing device and connected to Data Logger to measure pullout displacement at every 1 second. Also to measure pullout displacement of Geogrid in the soil tank, the holes with 0.1 mm diameter were perforated at the nodes of Geogrid which are 0, 7, 14, 21, and 28 cm apart from the front pullout holes of the pullout box, high strength synthetic fibers with 0.6 mm diameter were attached to a displacement gauge through the rear holes of the pullout box and pullout displacement occurring at the nodes of the grid were measured at every 1 minute (Refer to Figure 2). And friction between a soil and high strength synthetic fiber could be lessened by using copper tubes of 3 mm internal diameter within the soil tank of a pullout box.

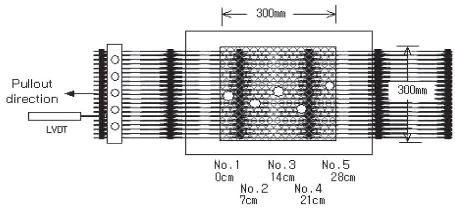



Figure 2. Point of strain gauge on the geogrid in the pullout box.

## 4 RESULTS AND CONSIDERATION

### 4.1 *Relation between pullout force and vertical pullout displacement*

Figure 3 shows the relation between vertical pullout displacement and pullout force as each confining stress increases to be 0.2, 0.5 and 0.8 $kg/cm^2$ when pulling out the strip type and Geogrid reinforcement on the model ground of Jumunjin standard soil and granite soil. As the confining stress increases, a pullout force continues to increase and the type of pullout curve forms different characteristics according to the type of a ground.

It is, therefore, understood that in case of standard sand soil, a pullout force has a tendency to increase continuously according to an increase of a pullout displacement and that a considerably larger pullout displacement is needed until arriving at the peak. However, a granite soil reaches up to 90% of max. pullout force at an initial displacement of 2~3 mm and afterward shows a very slow trend in the rate of increase. These characteristics can be considered in such a way that the particles of a standard sand soil are quickly rearranged even during the pullout process to result in continuous pullout effect, while once a granite soil is pulled out by the effect of cohesive materials, it is rearranged to be considerably weakened in the capacity of restoring its strength. It is, that is, very peculiar to see the fact that a granite soil when

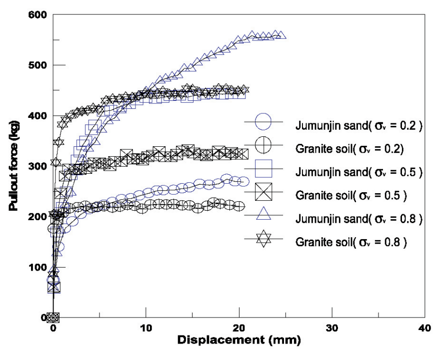



Figure 3. Relation between pullout force and pullout displacement according to confining stress

being used for a reinforcement ground, immediately indicates max. pullout force even in a small displacement.

### 4.2 *Tensile strength distribution of geosynthetic fiber under max. pullout force*

Tensile displacements were measured at the 5 nodes including 0, 7, 14, 21 and 28 cm of Geogrid buried in the soil during a pullout test. After obtaining relative tensile deformation from tensile shift difference, tensile strength was calculated from strength characteristics curve by deformation of Geogrid.

Figure 4 shows the distribution status of tensile strength within Geosynthetic fiber under max. pullout force according to the types of a ground. As seen in Fig. 4, there was a peak at the point 7 cm apart from the front where a pullout was made, ordinary characteristics were shown as going toward the rear and this was similar to either of Jumunjin standard soil or weathered soil. As a whole, the size of tensile strength showed approx. 2.5 times in a standard soil more than in granite soil and this means that a standard soil has larger pullout resistance than that of a granite soil.

### 4.3 *Analysis on distribution area ratio*

Tensile strength induced, when a geosynthetic fiber is pulled out, increases to a certain degree to reach a peak depending on an installation distance at a pullout end and is slightly distributed as the distance becomes more distant. Here in Fig. 5 can we see the area ratio of a standard sand and a granite soil according to their confining stress.

The area ratio as seen in Fig. 5 shows a similar tendency regardless of the type of a soil. However as the larger a confining stress is, the larger its ratio shows; therefore, the ratio is known to us as being dependent on a confining stress. The following equations (3) and (4) show how to calculate the area according to a confining stress by using regression analysis.

- standard soil ground : $AR = 33.35\sigma_v + 56.59$ (3)
- granite soil ground : $AR = 29.25\sigma_v + 56.49$ (4)

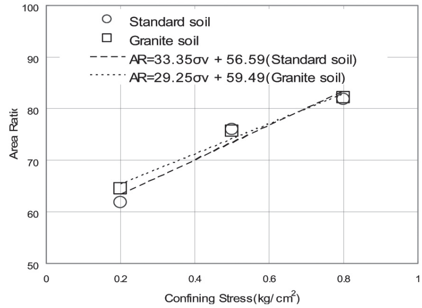



Figure 5. Confining stress-area ratio.

### 4.4 *Pullout resistance angle*

A pullout resistance angle was defined in the equation (1) as a value depending on a confining stress. Based on this concept, pullout resistance angles were calculated by the total area method and the distribution area method according to each confining stress. The results were shown in Fig. 6. The pullout resistance angles were significantly decreased according to the size of a confining stress. Also more larger angles were shown in the distribution area method than in the total area method. And the unique internal friction angle of a standard soil or a granite soil was indicated in a boldly slotted red line. An internal friction angle was not dependent on the size of a confining stress and thus indicated in a horizontal line. For the case of the distribution area method, a pullout resistance angle showed a bigger valve than that of an internal friction angle of the ground under a low confining stress, and as a confining stress became larger, it started to show a small value and showed even more smaller one than that of an internal friction angle in case 0.8 kg/cm$^2$ of a confining stress. The followings are the equations indicating a pullout resistance angle as the function of an confining stress by incorporating regression analysis.

- standard soil ground: $P.A = -41.40\ \sigma_v + 51.08$ (5)
- granite soil ground: $P.A = -38.38\ \sigma_v + 49.47$ (6)

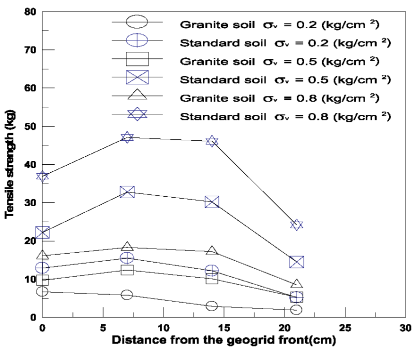



Figure 4. Tensile force distribution on geosynthetics in maximum pullout force.

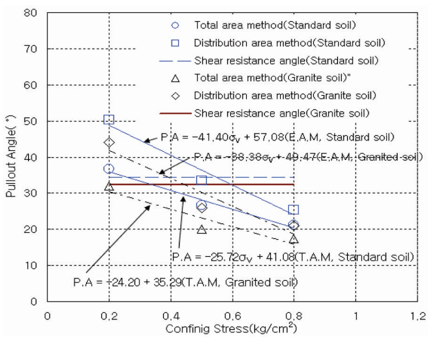



Figure 6. Pullout resistance angle distribution as confining stress.

## 5 CONCLUSION

This study adopted the concept of a pullout resistance angle, a new terminology on a pullout constant. Based on this concept of a pullout resistance angle, the pullout test has been carried out for a standard soil and a granite soil, and the following conclusions have been reached.

1. There was no significant difference in a distribution area ratio regardless of the type of a soil. However, as the larger a confining stress is, the greater an area ratio becomes; therefore, it has been known as the area ratio's dependence on a confining stress.
2. For the case of the distribution area method, a pullout resistance angle showed a bigger valve than that of an internal friction angle of the ground under a low confining stress, and as a confining stress became larger, it started to show a small value and showed even more smaller one than that of an internal friction angle in case 0.8 kg/ $cm^2$ of a confining stress.
3. New concept of a pullout constant has been introduced and a reasonable test result to a certain degree has been achieved; however, it is suggested that more extensive studies utilizing various types of soil and geosynthetic fiber are to be continued further in the near future.

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