Staged Pullout Test Method of Reinforced Earth using Hyperbolic Function

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ABSTRACT: Pullout parameters can be defined as the pullout friction angle and the pullout cohesion between soil and reinforcement. And they make an important role in calculating the horizontal length of the reinforcement and the vertical distance of reinforcements in the reinforced earth wall. Pullout parameters are generally determined from pullout curves obtained by pullout test, which is a kind of big model test. However pullout test gives us often inaccurate results because it is very difficult to make repeatedly the model ground with the same property for several tests.

In this study a new test method has been developed, named as a staged pullout test. Present pullout test requires the production of model grounds three times or more for pullout parameters. However in a staged pullout test, only one model ground has been used. Because with one model ground, pullout tests are performed repeatedly, changing the staged vertical loads after stopping a test if reaching about 2cm of pullout displacement. Hyperbolic function has been used as a method of estimating the entire pullout curve from 2cm of pullout curve. And in order to investigate the validity of a staged pullout test, both a present pullout test and a staged pullout test, have been performed about the same properties of model ground made by Korean standard sand and the geogrid has been as a reinforcement. Test results has showed that a staged pullout test has a possibility to be used as a new pullout test method instead of a present pullout test.

1 INTRODUCTION

Pullout parameters, the values of friction and cohesion between soil and reinforcement, make an important role to determine the length of reinforcement and the distance between the upper and lower reinforcements. Here I would like to introduce the equation which obtain the required tensile strength of Geogrid used as reinforcement in case of pullout failure for the design of a reinforcement retaining earthwall.

\[
T_{\text{max}} \leq \frac{2 L_e \cdot (c^* + \sigma_v' \tan \phi^*) \cdot R_c}{F_{S_{pu}}} \tag{1}
\]

where, \(F_{S_{pu}}\): Safety factor against pullout, \(T_{\text{max}}\): Maximum tensile strength of Geogrid, \(L_e\): Effective resistance length of reinforcement, \(R_c\): Area ratio of reinforcement, \(c^*\): Cohesion between soil and reinforcement, \(\sigma_v'\): Vertical stress on the reinforcement, \(\phi^*\): Friction angle between soil and reinforcement

In equation (1) are pullout parameters and should be determined by the pullout test. From equation (1), we can see that the effective resistance length, is inversely proportional to pullout parameters. That is, if the value of pullout parameters is larger, it is possible to make the effective resistance length shorter to satisfy the equation (1). And so it is very important to obtain an accurate pullout parameters for design of reinforcement structures. But pullout test method is not simple and requires a lot of time. Furthermore it is very difficult to make repeatedly the model ground with the same property for several tests because it is a kind of big model test. In this study a new pullout test method has been developed and named as a staged pullout test. In a staged pullout test only one model ground has been used for entire tests. That is, under the first staged vertical load reinforcement is pulled out by about 2cm, measuring pullout force and pullout displacement. In the second or
third stage with the increase of vertical load, the same procedure like the first stage is performed again. And in the final stage, the pullout test has been performed without the limitation of pullout displacement.

Figure 1. Schematic of pullout test apparatus

2 PULLOUT TEST APPARATUS

Test apparatus can perform either the pullout test or the direct shear test, and is composed of soil bin, air compressor bag, fixing part of reinforcement, the load cell and electric motor. The size of soil bin is 60cm long, 40cm wide and 19cm high.

Air pressure bag is used to apply the vertical load and the maximum air pressure available is 2kg/cm². Pullout force is automatically measured by a load cell which has the maximum capacity of 5 ton. Pullout displacement is measured by LVDT at front side of soil bin.

3 COMPARISON OF PULLOUT TEST METHODS

3.1 Conventional Pullout test method (POT)

3.1.1 Test method

Pullout test apparatus is composed of two parts, the upper box and the lower box. At first, soil is filled and compacted into the lower box and then reinforcement is laid down and after the upper box is set, soil is filled and compacted again. One side of reinforcement comes to outside of soil bin, to pull out this part for experiment. Three or four times of tests, changing vertical stresses, should be done to obtain the pullout parameters.

3.1.2 Some problem in POT

Three or more pullout tests are needed to obtain the pullout parameters. Accordingly Three or more model grounds are used, but because pullout test apparatus is mostly very big, it is very difficult to make repeatedly a model ground with the same property.

3.2 Staged pullout test (SPOT)

3.2.1 Test method
SPOT uses only one model ground for pullout tests. The test is performed in the order of the loading of vertical stress, 1-stage pullout test, suspension, the loading of another vertical stress, 2-stage pullout test and suspension etc. The test method can be summarized as follows,

1) Vertical forces should be beforehand determined. In this study, 0.2, 0.5, 0.8 \( \frac{g}{\mu} \) of vertical forces have been used.
2) After making one model ground, 0.2 \( \frac{g}{\mu} \) of vertical stress has been applied on a model ground and 1-stage pullout test has been done until the pullout displacement reached 2cm.
3) After 1-stage pullout test, the vertical force and pullout force has been cleared perfectly.
4) Now for 2-stage pullout test, the vertical stress has been increased to 0.5 \( \frac{g}{\mu} \) and then the second test was performed. The test has been performed until the pullout displacement reaches 2cm like as the 1-stage test.
5) Again for 3-stage pullout test, the vertical force has been increased to 0.8 \( \frac{g}{\mu} \) and then the third test has been performed. Because the third test is the final stage, the pullout test has been performed without the limitation of pullout displacement.
6) The full pullout curve has been estimated from the pullout curve until 2cm pullout displacement using hyperbolic function.

3.2.2. Some problem in SPOT

Because the test is performed repeatedly about the same model ground, the reinforcement should suffer the repeated pullout force and so it has a possibility for the strength of reinforcement to be weakened due to the plastic strain.

4 EXPERIMENT FOR COMPARISON OF TWO TEST METHODS

In order to investigate the validity for a new pullout test method, the comparison tests have been planned and performed. Here a standard sand has been used and Geogrid has been used as reinforcement to make a model ground. Model ground has a 90% of relative density.

4.1 The standard sand and Geogrid

Table 1 shows the geotechnical properties of the standard sand and Table 2 shows the maximum tension strength, the maximum elongation rate and size of Geogrid used as a reinforcement.(Fig. 2)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Soil</th>
<th>Gs</th>
<th>Water content</th>
<th>Maximum Density (g/ cm³)</th>
<th>Minimum Density (g/ cm³)</th>
<th>Density of model ground (g/ cm³)</th>
<th>Realative density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard sand</td>
<td></td>
<td>2.67</td>
<td>0.2</td>
<td>1.654</td>
<td>1.398</td>
<td>1.612</td>
<td>90</td>
</tr>
</tbody>
</table>

Figure 2. Dimensions and shape of geogrid used for tests
4.2 Experiment contents

Table 3. shows test conditions which have been done in POT and SPOT test. Because POT test is a general pullout test, Three model grounds named A-1, A-2 and A-3, have been used and fully pulled out until it shows a yield failure. SPOT is a new staged pullout test suggested in this study. Only one model ground, named B-1, has been used for three pullout tests.

Table 3. Test conditions

<table>
<thead>
<tr>
<th>Test</th>
<th>Test No.</th>
<th>Vertical force (kg/cm²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>POT</td>
<td>A-1</td>
<td>0.2</td>
<td>Full pullout test</td>
</tr>
<tr>
<td></td>
<td>A-2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-3</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>SPOT</td>
<td>B-1</td>
<td>0.2, 0.5, 0.8</td>
<td>1) In case of 0.2, 0.5kg/cm²: about 2cm of pullout displacement &lt;br&gt;2) In case of 0.8kg/cm²: Full pullout</td>
</tr>
</tbody>
</table>

4.3 Estimation of full pullout curve by hyperbolic function

Because the test is finished at the pullout displacement of about 2cm in SPOT, full pullout curve should be estimated from the 2-cm pullout curve. Hyperbolic function like equation(2) has been used for estimating a full pullout curve.

\[ P_d = \frac{\delta}{m + n\delta} \quad (2) \]

where, \( \delta \): Pullout displacement, \( P_d \): Pullout force at \( \delta \), \( m, n \): Hyperbolic constants.

If hyperbolic constants, \( m \) and \( n \), are calculated from 2 cm- pullout curve, The extra pullout curve can be estimated from equation (2).

5 EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Pullout curves of POT and SPOT

Figure 3. shows pullout curves of POT done at three reinforcing model grounds which have vertical stress of 0.2, 0.5, 0.8[kg/cm²]. Figure 4. shows pullout curve of SPOT done at one reinforcing ground with three staged vertical stresses. From SPOT pullout curves we can see the process of starting again after stopping the test at about 2cm of displacement.
5.2 Calculation of hyperbolic constants

Figure 5. shows the relationship between $Dz$ and $Dz/P$ from POT test results and the regression line. Figure 6. shows the relationship between $Dz$ and $Dz/P$ from SPOT test results and the regression line. From the regression analysis, we can obtain a slope and an intercept of the linear equation. The intercept means the value, $m$ and the slope means the value, $n$ of hyperbolic equation. Hyperbolic constants has been calculated and shown in Table 4. The value of $m$ was not dependent on vertical stress, but the value of $n$ had a greater value as the vertical stress was smaller.

<table>
<thead>
<tr>
<th>Vertical stress (kg/ cm$^2$)</th>
<th>POT</th>
<th>SOPT</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$m$</td>
<td>$n$</td>
<td>$m$</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0052</td>
<td>0.0020</td>
<td>0.0121</td>
</tr>
<tr>
<td>0.5</td>
<td>0.0116</td>
<td>0.0008</td>
<td>0.0038</td>
</tr>
<tr>
<td>0.8</td>
<td>0.0146</td>
<td>0.0004</td>
<td>0.0044</td>
</tr>
</tbody>
</table>

5.3 Comparison between measured curve and estimated curve at POT and at SPOT

Figure 7. shows us the measured curve and the estimated curve using hyperbolic function on POT. Figure 8. shows us the measured curve and the estimated curve using hyperbolic function on SPOT. From the figures, it can be seen that the estimated curve has a good agreement with the measured curve. Accordingly it is thought that it is possible to estimate the full pullout curve, using 2cm of pullout test result and hyperbolic function.
Figure 5. Hyperbolic constants at POT

Figure 6. Hyperbolic constants at POT
Figure 7. Measured and estimated curves at POT

Figure 8. Measured and estimated curves at SPOT

Figure 9. Comparison between a estimated by SPOT and a measured by POT
### 5.4 Comparison between the measured pullout curves at POT and the estimated pullout curves at SPOT

As shown in Table 3, for comparison of two pullout test methods, POT and SPOT were performed on the reinforced model ground with 90% of relative density using Korean standard sand.

Figure 9. shows the comparison result between the measured pullout curve from POT and the estimated pullout curve from SPOT. There is a little difference between POT and SPOT but we can judge that they are similar values from the practical point of view. It is thought that the main reason which shows a little difference between two test methods is the difference of property of model grounds. The initial slope of pullout curve has a greater value on SPOT than POT. Differently from the judgement that reinforcement embedded into soil will be weakened due to repeating pullout force, SPOT give little effect on the weakening of reinforcement in this experiment.

Accordingly we see that it is possible to use the staged pullout test as a new pullout test. However it is thought that this test method should be checked through continuing experiments by various kinds of soil and geosynthetics. Just as it was discussed, because it is very difficult to make the same property of model grounds on a large scale of pullout apparatus, SPOT suggested in this study will gives a good chance to choose as a new pullout test, to obtain pullout parameters to the geosynthetics engineer.

### 6 CONCLUSION

In this study a new pullout test, named a staged pullout test, has been suggested. In a staged pullout test only one model ground is needed and so it is a very convenient test method. In order to investigate the validity of a new test method, two kind of tests, a general pullout test and a new staged pullout test, have been planned and performed for comparison. It has been conformed that from the comparison tests, a staged pullout test method could be used as a new test method instead of a conventional one. However the repeating pullout forces, applied on a reinforcement, can make reinforcements weakened due to plastic strain. Accordingly it has been thought that continuous study should be done for various geosynthetics and soils.

### REFERENCES


