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Evaluation of pull-out resistance of geogrid reinforced soils

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ABSTRACT: Methods for evaluating the pull-out resistance of geogrid-reinforced soil are discussed from the laboratory pull-out tests. The methods are classified into two groups according to the mechanism of pull-out resistance. One is a method which all of the mobilizing processes of the pull-out resistance acting on the geogrid are taken into account. The other is one which the average value of pull-out resistance at the state of maximum pulling force is evaluated. The applications of these methods are also discussed for the design method and the analysis of the reinforced earth structures. Finally, a pull-out test method for geogrid reinforced soils is recommended from the consideration of the characteristics of pull-out resistance.

1 INTRODUCTION

Pull-out resistance is one of the essential behavior in the geogrid reinforced soil structures. Laboratory pull-out tests have been carried out to understand the pull-out resistance of geogrids in soils and recommended to obtain the parameters for the design of geogrid reinforced soil structures. However, the test apparatus, testing procedure and the evaluation method of the test results have not been always established yet.

The purpose of the paper is to present reasonable methods for evaluating the pull-out resistance of geogrid reinforced soils from the laboratory pull-out tests. And a recommendation of laboratory pull-out test is also presented.

2 PULL-OUT BEHAVIOR

In order to understand the pull-out behavior of geogrid reinforced soil in full sizes, a series of full-scale pull-out tests in an embankment of 5.0m in height has been conducted by Ochiai et al.(1988 a). Fig.1 shows a typical test result, in which the geogrid length is 4.0m and overburden pressure is 17.0kN/m^2. When a pull-out force is applied, the force is transmitted from the front to the free end of the geogrid in the soil, thereby the corresponding displacement of the grid junction being caused and distributed on the geogrid. The test results clearly show that the geogrid in the soil is pulled out with the elongation of the geogrid itself. Besides, the value of elongation is different at each grid junction. Such pull-out behavior have to be considered in the evaluation of the pull-out resistance of the geogrid and to be incorporated in the design and analysis of geogrid reinforced soil structures.

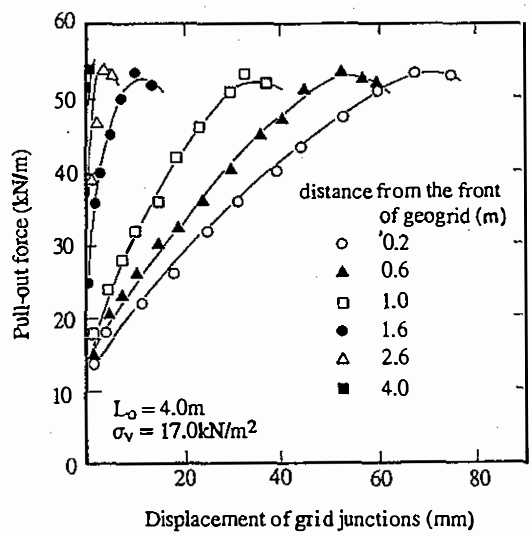

Fig.1 Pull-out behavior of geogrid in embankment.

3 PULL-OUT TEST IN LABORATORY

3.1 Test apparatus and procedure

Test apparatus: Fig.2 shows a sketch of the apparatus used in this study. Pull-out box is a rectangular shape of 0.6x0.4x0.4m. An air pressure bag is used to apply uniform vertical pressure to the surface of the soil specimen. Friction between soil and inside wall of the box is lubricated by means of greased rubber membranes. Dry Toyoura sand, one of the standard sand in Japan, and uniaxial oriented polymer grids are used in the tests. The width of the geogrid is the same as that of pull-out box.

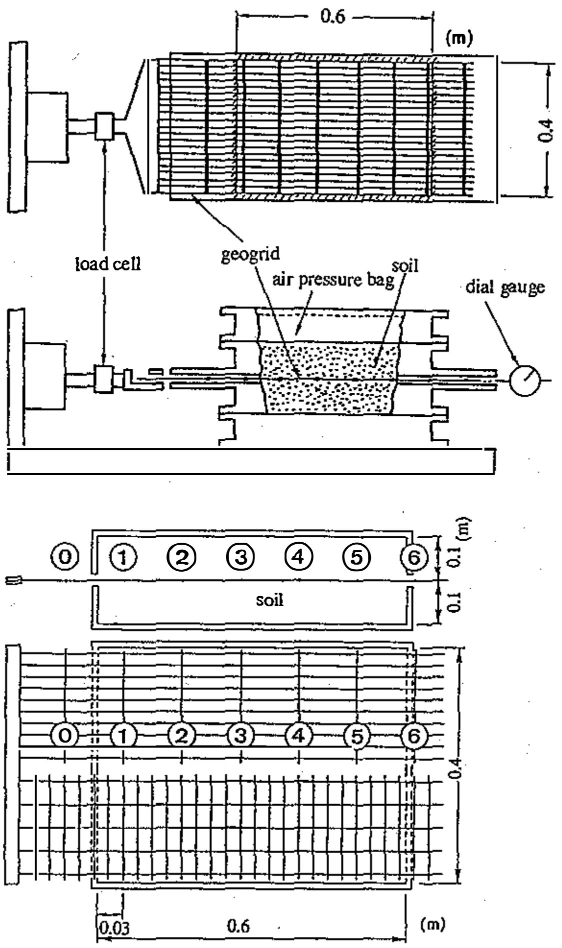

Fig.2 Pull-out test apparatus and the measurements.

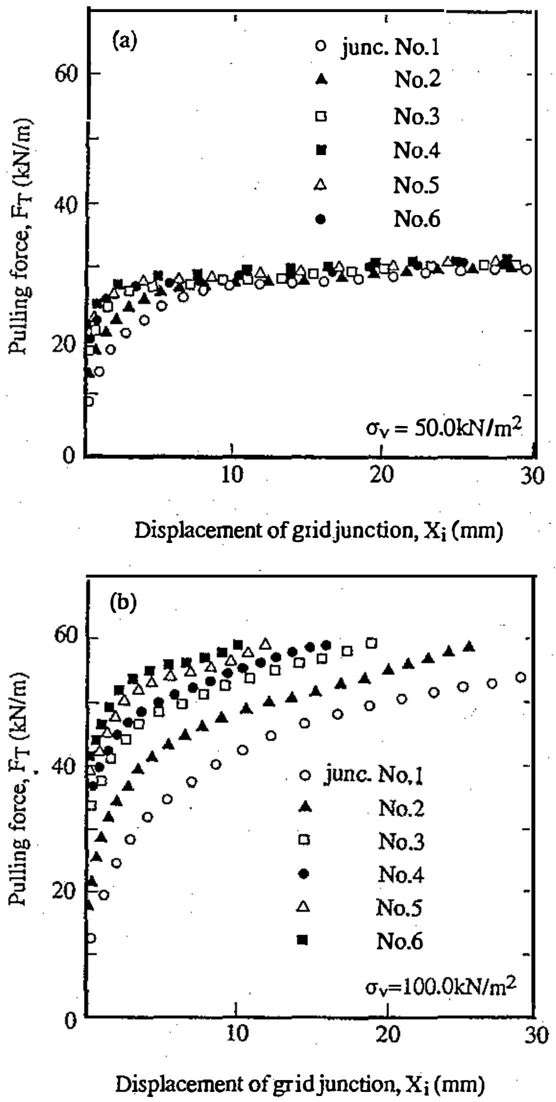

Fig.3 Pull-out force - displacement relations in each grid junction.

Test procedure: Sand is poured into the pull-out box through multiple sieves in order to make the homogeneous soil specimen. After embedding the geogrid on the sand poured in the lower part of the box, the upper part is fastened to the lower part with a spacer plate and then additional sand is filled in the box. The tests are carried out in the way of pulling the geogrid out in sand with constant speed of 1.0mm/min by means of screw jack under constant vertical pressure. The pull-out force is measured using a tension load cell at the front of the geogrid and the displacement in each grid junction is also measured by using stainless steel wires which is the technique developed by Ochiai et al.(1988 a).

3.2 Test results

The relations between the pulling force and the displacement at each geogrid junction are shown in Fig.3(a),(b) for the cases of σ_v = 50.0kN/m^2 and 100.0kN/m^2, respectively. The former case is that the geogrid is wholly pulled out with a slight elongation, while the latter is that the pulling force reaches the strength of the geogrid with a considerable amount of elongations. These results clarify that the geogrid is pulled out as the geogrid itself elongates, especially for large vertical stress. It is noted that this behavior is exactly the same as that of field pull-out test described above.

Tensile forces acting at each grid junction are calculated from the strain between adjacent grid junctions using the index curve of load-strain relation of the geogrid, as proposed by Ochiai et al.(1988b). Fig.4 shows the distribution of tensile force acting on the whole length of geogrid at any pulling forces, in which σ_v = 100.0kN/m^2. The tensile force decreases from the front of geogrid towards the free end in the curve like S-shape. The same distribution curve is also investigated for different vertical stresses. It is noted that the slope of the tangent at a point on the distribution curve may be considered to be the pull-out resistance stress at the point on the geogrid.

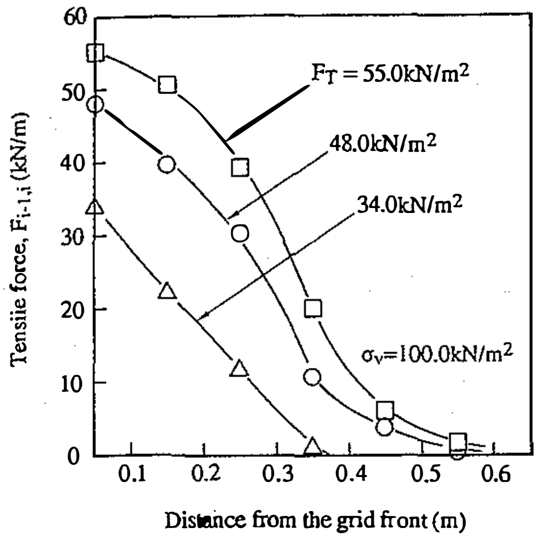

Fig.4 Distributions of tensile force on the geogrid.

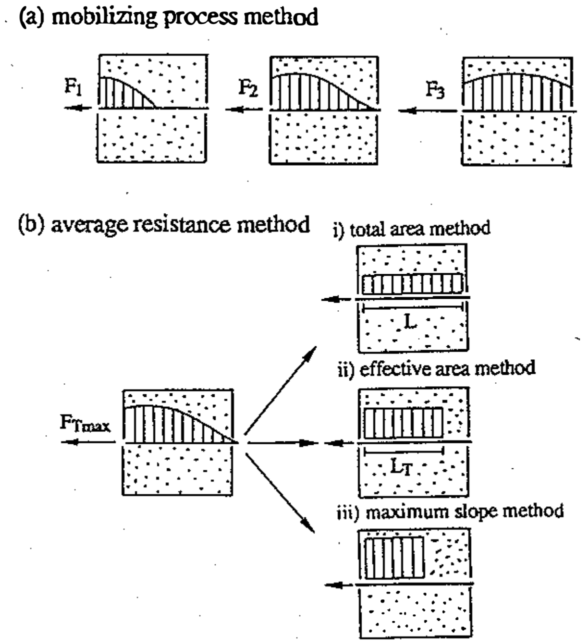

Fig.5 Basic concepts on the evaluation method of pull-out resistance.

4 EVALUATION METHOD

From practical use such as design and analysis of geogrid reinforced-soil structures, the pull-out resistance should be expressed in the stress unit. Thus, the evaluation methods of the pull-out resistance in stress unit are discussed herein.

The tensile force distributes along the geogrid as shown in Fig.4, and the shapes of the distribution curve depend on the pulling force and vertical stress. Based on this pull-out mechanism, the evaluation methods of pull-out resistance are classified into two groups as illustrated in Fig.5. One is the method which all the mobilizing processes of pull-out resistance at any pulling forces are used for the evaluation as shown in Fig.5(a), which is called the mobilizing process method. The other is that the distribution curve at the maximum value of pulling force is adopted and average values are used for the evaluation. This is called the average resistance method, and is classified into three methods based on the determination of the average values as shown in Fig.5(b). First one is the total area method, in which the pulling force at the front and the whole area of the geogrid in the pull-out box are used for the evaluation. The second is the effective area method which use effective force and area for evaluating the pull-out resistance. The third is the maximum slope method using a slope of the tangent at a point on the distribution curve.

The mobilizing process method is applied to the deformation analyses of the geogrid reinforced soil structures. On the other hand, the average resistance method is used in the limit analyses of the reinforced soil structures, which include most of the design method currently being employed.

Both the mobilizing process method and the average resistance method are implemented in the evaluation of pull-out resistance from the laboratory test results.

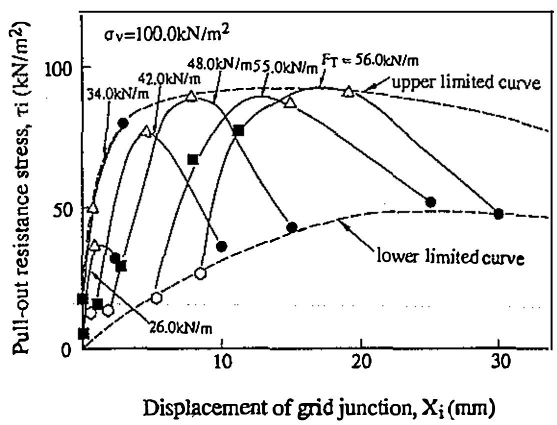

Fig.6 Distributions of mobilized pull-out resistance (mobilizing process method).

4.1 Mobilizing process method

In the case of the geogrid through where the soil on either side of the reinforcing materials is partially continuous, the resistance effect of the ribs at right angle with the direction of pulling is assumed to be transferred to the junctions in a concentrated manner. Thus, the resistance mobilized on each junction plays a great role than that mobilized on each rib. It may be, therefore, considered that the pull-out resistance will concentrate and act on each grid junction. This concentrated pull-out resistance is evaluated as the difference of the tensile forces in each two adjacent junctions and is defined as follows:

$$T_i = F_{i-1,i} - F_{i,i+1} \qquad (1)$$

where $F_{i-1,i}$ is the tensile force acting on the geogrid between junction (i-1) and (i). The pull-out resistance in stress unit per unit width at each grid junction is calculated from the concentrated resistance and the distance of each two adjacent junctions. This is formulated by the following equation:

$$\tau_i = T_i / d \qquad (2)$$

where τ_i is a pull-out resistance stress mobilized on the geogrid between each two adjacent junctions, and "d" is a distance of the two junctions. The resistance stresses, τ_i, are plotted against displacement of grid junction at a given pulling force in Fig.6. The stress changes with the displacement in a shape of convex distribution, and two limit curves, upper and lower curves, are drawn along the distribution curve. Coulomb friction law is applied to the limit curves at any level of displacement, thus the mobilizing process of friction behavior being obtained. This is directly applied to deformation analyses by finite element method as an interaction property between soil and geogrid (Ochiai et al. (1988 a)).

4.2 Average resistance method

Most of the design methods for reinforced soil structures are based on the limit equilibrium method, in which the interaction property between soil and reinforcing material has been evaluated by the average resistance method. However, the method for evaluating the average resistance has not been always consistent. Fig.7 shows the test results, where the distribution of tensile force at each maximum pulling force in the tests with different vertical stresses are shown. There are three ways for evaluating the average pull-out resistance from the test results, as described above. They are summarized as follows:

(a) Total area method: $$\tau_{av} = \frac{F_{Tmax}}{2BL} \qquad (3)$$

The average pull-out resistance is calculated by Eq.(3), in which F_{Tmax} is the maximum value of pulling force at the front of the geogrid, and L and B are the length and width of the geogrid, respectively. This method may give a reasonable average value of the pull-out resistance when the geogrid is wholly pulled out with a slight elongation. But when there exists non-displaced part near the free end of the geogrid, an underestimated value of the resistance may be obtained compared with the real value. Advantage of this method is that only the pulling force at the front of geogrid is necessary to be measured.

(b) Effective area method: $$\tau_{av} = \frac{F_{Tmax} - F_r}{2BL_T} \qquad (4)$$

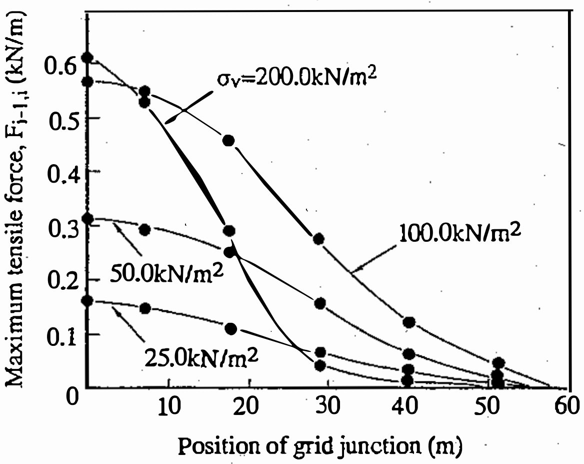

Fig.7 Distributions of tensile force at maximum pull-out force for various vertical pressures.

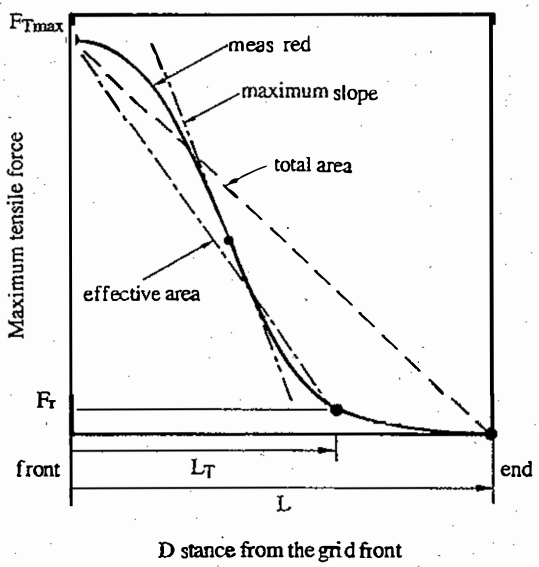

Fig.8 Sketches of the evaluation methods of the pull-out resistance

The resistance is calculated by Eq.(4), where L_T is the effective length of the geogrid and (F_{Tmax} - F_r) is the effective tensile force which correspond to L_T as shown in Fig.8. A reasonable average pull-out resistance may be always obtained from this method, because the effective force and area for the interaction between soil and geogrid are used in the evaluation. However, in order to determine the effective length, L_T, the displacements of each grid junction in soil have to be measured in the test as well as the pulling force at the front of geogrid. It is noted that the effective area method agrees with the total area method when the whole of geogrid is totally pulled out.

(c) Maximum slope method: $$\tau_{av} = \left(\frac{dF}{dL}\right)_{max} \qquad (5)$$

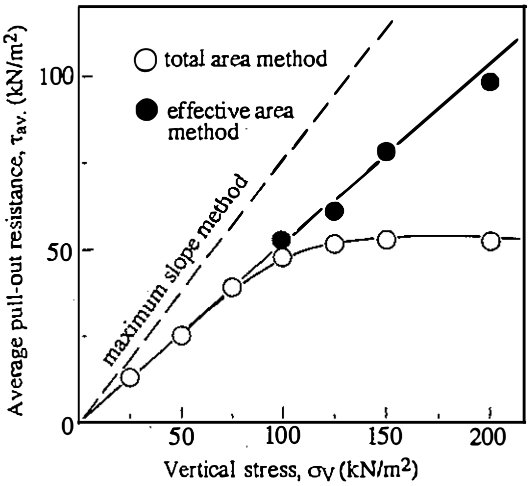

Fig.9 Maximum pull-out resistance - vertical stress relations (average resistance method)

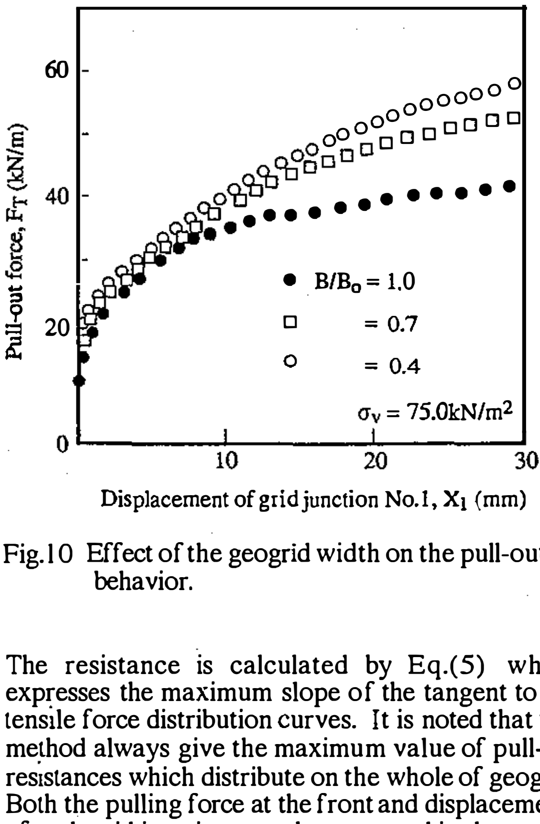

Fig.10 Effect of the geogrid width on the pull-out behavior.

The resistance is calculated by Eq.(5) which expresses the maximum slope of the tangent to the tensile force distribution curves. It is noted that this method always give the maximum value of pull-out resistances which distribute on the whole of geogrid. Both the pulling force at the front and displacements of each grid junction must be measured in the tests.

These three methods are implemented in the evaluations of the average resistance from the results of pull-out tests. Fig.9 shows the relations between the average pull-out resistance, τ_{av}, and the vertical stress, σ_v, which are evaluated by the three methods. The resistance by the maximum slope method is constantly larger than that by the other two methods, so that the overestimated value of pull-out resistance may be predicted at all times by the method. In the comparison of the results by the total area method and that by the effective area method, the evaluated values by the two methods are almost equal for the range of small vertical stress which the geogrid is wholly pulled out with a slight elongation. When the vertical stress becomes large, the values by the total area method are constantly smaller than that by the effective area method. For the case of breaking the geogrid under large vertical stress, these are determined from the strength of geogrid.

The resistance values by the effective area method can be arranged on a straight line through the origin, so that the Coulomb friction law can be assumed for the results based on the method which is capable to predict a reasonable value. Here, it is noted again that the total area method gives the same result as the effective area method when the vertical stress is small which the geogrid is wholly pulled out with a slight elongation. This means that a pull-out test should be carried out under the condition of small vertical stress and the average value of pull-out resistance is evaluated by the total area method.

5 RECOMMENDATION OF LABORATORY PULL-OUT TEST

5.1 Influence of geogrid width on test result

The pull-out resistance is remarkably influenced by the width of geogrid in the pull-out test box. Three different widths of B/B_0 = 1.0, 0.7 and 0.4 are examined, where B is a width of the geogrid and B_0 is that of the pull-out test box. The test results are shown in Fig.10 as a relation between the pulling force and the displacement of grid junction No.1 shown in Fig.2. There exist obvious differences between the results of $B/B_0 = 1$ and that of $B/B_0<1$, and the tensile force per unit width increases with the decrease of B/B_0-value. The differences are considered to be due to the side resistance of geogrid in soil which is negligible for geogrid reinforced structures. Therefore, the pull-out tests should be conducted under the condition without the influence of the side resistance of geogrid, thus the test condition of $B/B_0 = 1$ being recommended.

5.2 Recommendation of test procedure

(1) In laboratory pull-out tests for reinforced soil, deformation of specimen should not be restrained during the test;
  (a) Flexible air pressure bag is used to apply the uniform vertical stress.
  (b) Friction between the specimen and the side of pull-out box is lubricated by some ways such as the use of greased rubber membrane.

(2) Parameters obtained from the laboratory tests should be independent on the scale of specimen;
  (a) Width of geogrid in pull-out box is always the same as that of the box.

(b) Length of geogrid in pull-out box depends on the evaluation methods of test results;

b-1) For the total area method: length which elongation of the geogrid itself in soil can be neglected.

b-2) For the other methods: length which the elongation of geogrid itself is occurred in soil.

(3) Measurements in tests depend on the evaluation methods;

(a) For the total area method: pulling force and displacement at the front of geogrid.

(b) For the other methods: pulling force at the front and displacements at each grid junction.

6 CONCLUSIONS

Basic idea for evaluating the pull-out resistance of geogrid reinforced soil was discussed from the test results. The following remarks may be drawn:

(1) When the geogrid laid in soil is subjected to a pulling force, the geogrid is either pulled out along the whole of geogrid or broken. These behavior depend on the magnitude of the vertical stress and the length of the geogrid.

(2) Two different evaluation methods of pull-out resistance stress were presented, which were the mobilizing process method and average resistance method, respectively.

(3) The mobilizing process method may be applied to the deformation analysis by finite element method.

(4) The average resistance method, three types of the method were defined. They are the total area method, effective area method and the maximum slope method, and are mainly used to the limit equilibrium design method.

(5) For the practical uses, pull-out tests with small vertical stress is recommended and the total area method is useful for evaluating the average resistance from the test results.

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