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# Characteristics of geogrid reinforced cohesive soil and its analytical method

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ABSTRACT: The characteristics of interaction between cohesive soil and geogrid is investigated on the basis of the pull-out test results of geogrid in soil. The pull-out resistance acting between cohesive soil and geogrid can be divided into two parts; the one is dependent on a displacement of geogrid while the other is independent of it. The analytical method introducing its characteristics of interaction between cohesive soil and geogrid into a finite element method is proposed and its validity is verified. From the comparison between the analytical values and the experimental values, it is proved that the behavior of reinforced cohesive soil by geogrid can be analysed well by means of the proposed method.

## 1 INTRODUCTION

It is important to grasp the characteristics of the pull-out resistance as an interaction between soil and geogrid in the design and analysis of the geogrid reinforced soil structures. Particularly taking that a soil in the field is used as a soil reinforced by geogrid into consideration, it is supposed to be very important to estimate the pull-out resistance of geogrid in a cohesive soil.

In this paper, first, the characteristics of interaction between cohesive soil and geogrid is investigated on the basis of the pull-out test results of geogrid in soil.

Next, the analytical method introducing its characteristics of interaction between cohesive soil and geogrid into a finite element method is proposed and its validity is verified.

## 2 CHARACTERISTICS OF INTERACTION BETWEEN SOIL AND GEOGRID

### 2.1 *Method of pull-out test*

The apparatus of pull-out test is shown in Figure 1. The dimension of soil box is 600mm in length with 300mm in width and 160mm in height. A geogrid is laid in the center of the soil box and a constant overburden pressure is applied and then the geogrid is pulled out. The rate of pull-out is 1mm/min. The overburden pressures are varied 4 to 5 steps. The displacements of geogrid nodes and the pull-out force of top of geogrid are measured during tests. The geogrids used in tests are FRP geogrid (GB5, GB10) and polymergrid (SR80) whose property is shown in Table 1. And two kind of soil whose property is shown in Table 2 are used in tests.

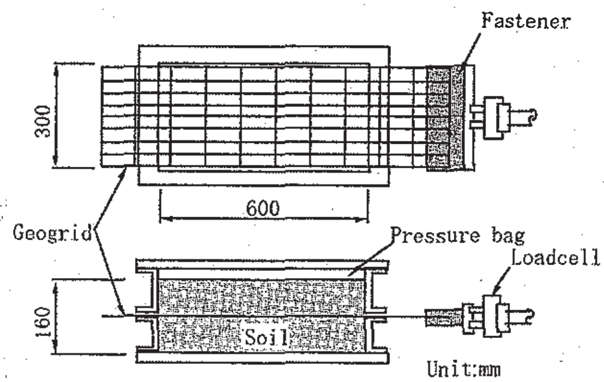



Figure 1. Apparatus of pull-out test.

Table 1. Propert of geogrid.

| Kind | GB5 | GB10 | SR80 |
|---|---|---|---|
| Mesh (mm) | 100×30 | 100×30 | 166×82 |
| Tensile strength (kN/m) | 49 | 98 | 83 |

Table 2. Propert of soil.

| Kind | | Silt 1 | Silt 2 |
|---|---|---|---|
| Grain size (%) | Gravel | 3.1 | 6.4 |
| | Sand | 37.6 | 25.2 |
| | Silt & Clay | 59.3 | 68.4 |
| Wet densit (g/cm$^3$) | | 1.55 | 1.45 |
| Cohesion (kPa) | | 9.6 | 21.9 |
| Angle of internal friction (degree) | | 28.9 | 11.6 |

*2.2 Relationship between pull-out resistance and displacement*

The relationship between pull-out resistance stress and average displacement defined by following equations is shown in Figure 2.

$$\tau = \frac{F}{2A} \quad (1)$$

$$u = \frac{\sum_{i=1}^{n} u_i}{n} \quad (2)$$

Where, F : Pull-out force

A : Area of reinforcing material in soil
$u_i$ : displacement of nodes of geogrid
n : number of nodes of geogrid in soil

The pull-out resistance stress τ increases to some value with almost zero displacement in initial stage. After then τ increases as development of displacement but comes near a constant value. This tendency is also same in different overburden pressures.

Then the pull-out resistance mobilized in the stage with zero displacement is defined as $\tau_0$ and the pull-out resistance mobilized after then dependent on a displacement is defined as $\tau_1$. The relationship between $\tau_1$ and u is shown in Figure 3. This relationship is closely resembled by a hyperbola shown as solid lines in Figure 3.

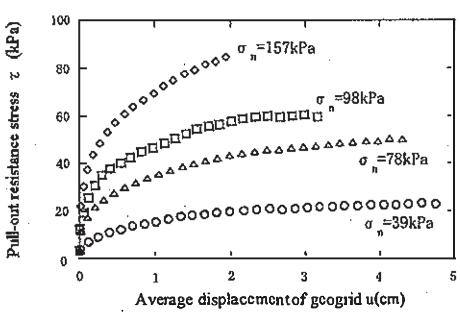



Figure 2. Relationship between pull-out resistance stress and displacement (GB10 : Silt 1).

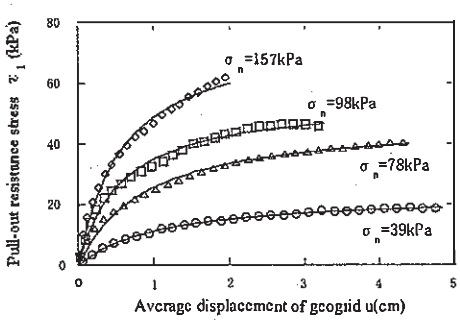



Figure 3. Relationship between pull-out resistance stress $\tau_1$ and displacement (GB10 : Silt 1).

*2.3 Relationship between pull-out resistance and overburden pressure*

The ultimate value of pull-out resistance in the relationship between $\tau_1$ and u shown in Figure 3 is defined as $\tau_{1ult}$. And so, the ultimate pull-out resistance $\tau_{ult}$ is presented as $\tau_{ult}=\tau_0+\tau_{1ult}$. The relationship between overburden pressure $\sigma_n$ and pull-out resistance $\tau_0$, $\tau_{1ult}$ and $\tau_{ult}$ respectively in each case are shown in Figure 4 to Figure 7. It is proved that the relationship between overburden pressure $\sigma_n$ and pull-out resistance $\tau_0$, $\tau_{1ult}$ and $\tau_{ult}$ respectively is almost linear in spite of a kind of reinforcing materials and a kind of soils. That is, a following friction law is concluded between the ultimate pull-out resistance and overburden pressure.

$$\tau_{ult} = c^* + \sigma_n \tan\delta \quad (3)$$

Where, c* is a cohesive component of pull-out resistance $\tau_{ult}$ and δ is a frictional component of it.

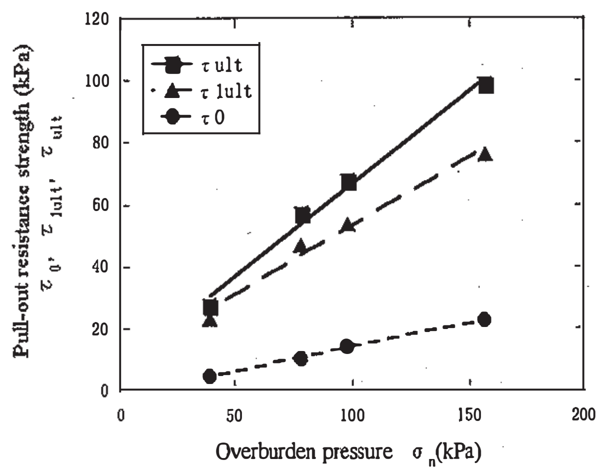



Figure 4. Relationship between pull-out resistance strength and overburden pressure (GB10 : Silt 1).

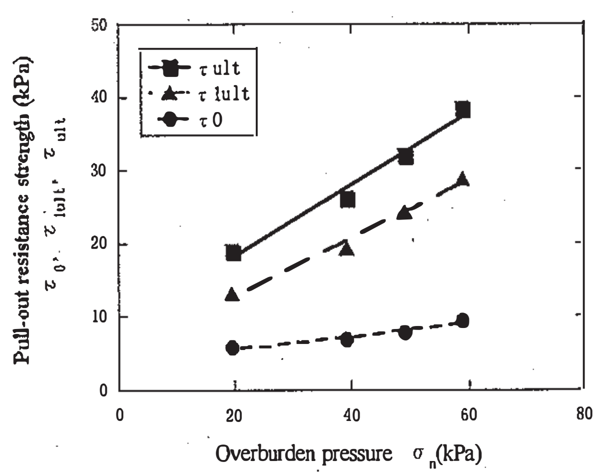



Figure 5. Relationship between pull-out resistance strength and overburden pressure (GB5 : Silt 1).

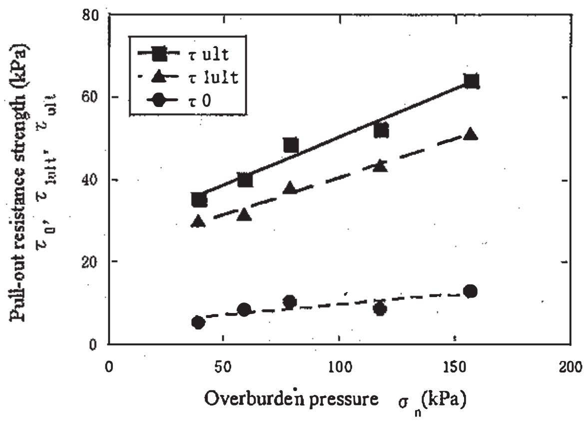



Figure 6. Relationship between pull-out resistance strength and overburden pressure (SR80 : Silt 1).

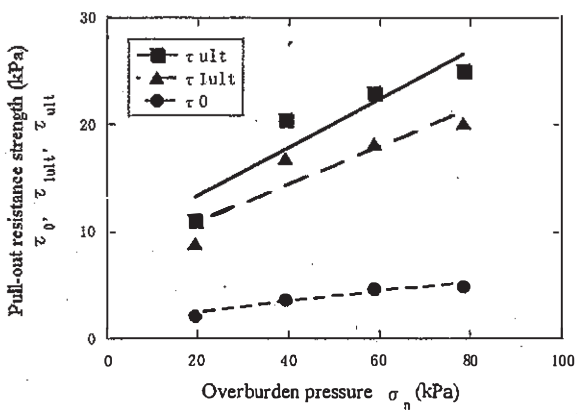



Figure 7. Relationship between pull-out resistance strength and overburden pressure (GB5 : Silt 2).

## 3 ANALYTICAL METHOD OF GEOGRID REINFORCED SOIL

The relationship between the pull-out resistance acting on a geogrid and the displacement of geogrid can be closely resembled by a hyperbola as mentioned above. The method introducing this relationship into the analytical method by FEM is investigated.

In the analysis by FEM a geogrid is represented by a plane truss element which transmits only an axial force, and joint elements are set between soil and geogrid in order to express the pull-out resistance acting between both as shown Figure 8 (Ogisako et al. 1998). The relationship between the pull-out resistance and the displacement abovementioned is introduced into the joint element.

The following relationship is concluded between a shear stress τ acting in joint element and a displacement u.

$$\tau = K_s u \tag{4}$$

The shear stiffness $K_s$ in above equation is defined as following because the pull-out shear resis-

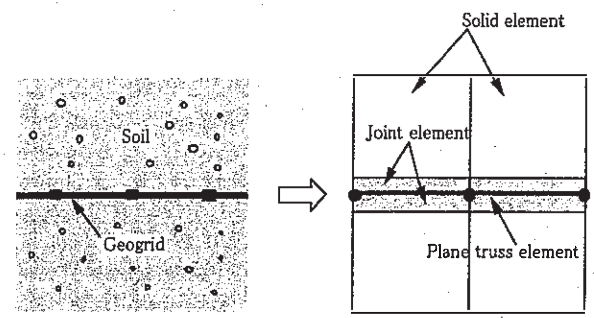



Figure 8. Modeling of interaction between soil and geogrid.

tance acting between soil and geogrid increases to $\tau_0$ with zero displacement and after then the relationship between $\tau_1$ and displacement u can be closely resembled by a hyperbola as shown Figure 3.

(1) in the case of $\tau \leqq \tau_0$

$$K_s = \infty \cong 10^{11} (kN/m^2/m) \tag{5}$$

(2) in the case of $\tau > \tau_0$

$$K_s = \left(1 - \frac{\tau_1}{\tau_{1ult}}\right)^2 K_{si} \tag{6}$$

Where, $K_{si}$ is an initial shear stiffness.

And a following friction law is concluded between the pull-out resistance $\tau_0$ and $\tau_{1ult}$ and overburden pressure.

$$\tau_0 = c_0{}^* + \sigma_n \tan\delta_0 \tag{7}$$

$$\tau_{1ult} = c_1{}^* + \sigma_n \tan\delta_1 \tag{8}$$

From a procedure above, the characteristics of pull-out shear resistance between soil and geogrid obtained from pull-out tests can be introduced into FEM analysis.

## 4 ANALYSES OF GEOGRID REINFORCED COHESIVE SOIL GROUND

FEM analyses for the model experiments of geogrid reinforced cohesive soil ground (Ogisako & Ryokai 1998) are performed by means of the proposed analytical method above. From the comparison between the analytical values and the experimental values, a validity of the analytical method is investigated.

### 4.1 *Outline of model experiment*

The apparatus of model experiment is shown in Figure 9. The dimension of soil box is 1500mm in length with 300mm in width and 800mm in height. A geogrid with L in length is laid in the depth with D of soil ground and a vertical load with 100mm width is applied. The soil used in experiments is silt

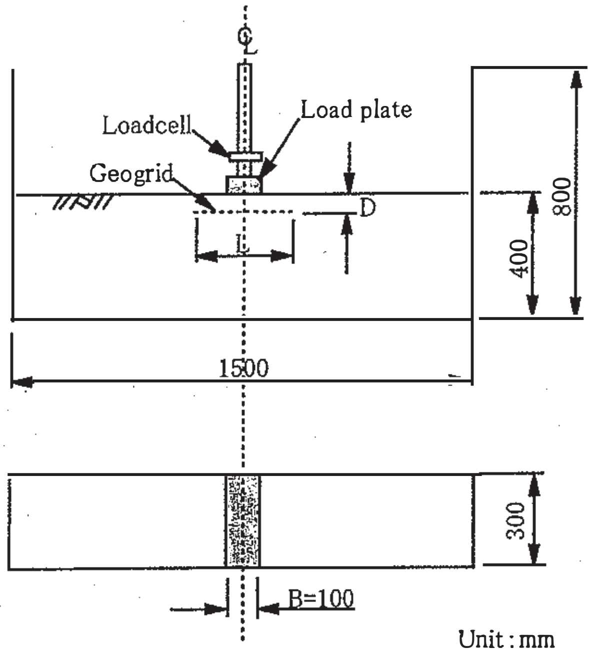
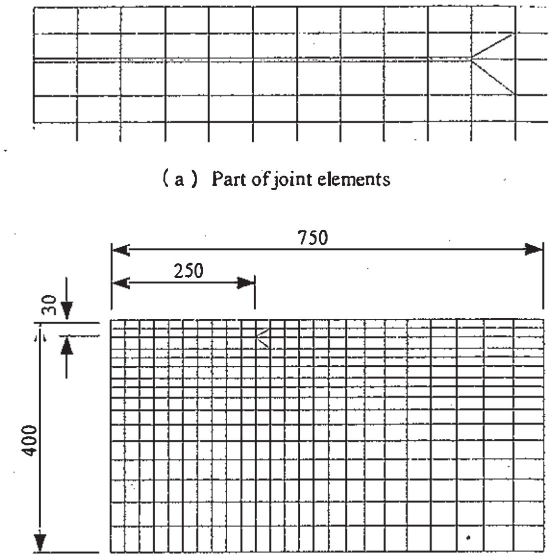



Figure 9. Apparatus of model experiment.




(a) Part of joint elements

(b) General view Unit : mm

Figure 10. FEM mesh of model experiment (in the case of L/B=5 and D/B=0.3).

1 whose property is shown in Table 2. And the used geogrid is FRP geogrid whose tensile strength is 12 kN/m and tensile stiffness is 392 kN/m.

A settlement of load plate, a vertical displacement at a surface of ground and a strain of reinforcing material are measured during experiment.

### 4.2 *Condition of analysis*

(1) Analytical models and cases

The analyses are performed for the cases that a length of geogrid stays in L/B=5 and a laying depth varies D/B=0.3 to 1.0. And both the cases used the analytical method considered the interaction between soil and geogrid abovementioned (hereafter called the proposed method) and the cases used a method in which the interaction is not considered that is, soil is represented by a solid element and a geogrid is represented by a plane truss element only (hereafter called an ordinary method) are performed.

An example of the analytical models is shown in Figure 10. In analyses two dimensional plane strain condition is assumed and as the boundary condition a horizontal direction is fixed and a vertical direction is free in sides, both direction is fixed in bottom.

(2) Input parameters

As a stress-strain relationship Duncan-Chang's non-linear elastic model (Duncan & Chang 1970) is used. In this model an elastic modulus is indicated as a following equation.

$$E=\left\{1-\frac{R_f(1-\sin\phi)(\sigma_1-\sigma_3)}{2c\cos\phi+2\sigma_3\sin\phi}\right\}^2 KP_a\left(\frac{\sigma_3}{P_a}\right)^n \tag{9}$$

Where, $\sigma_1$ : Major principal stress

$\sigma_3$ : Minor principal stress

c : Cohesion

$\phi$ : Angle of internal friction

$P_a$ : Atmospheric pressure

$R_f$ : Failure ratio

K, n : Constants determined experimentally.

The input parameters are determined from triaxial compression tests (UU tests) results as shown in Table 3. And the parameters for the interaction between soil and geogrid are determined from pull-out tests results as shown in Table 4.

### 4.3 *Analytical results*

(1) Strain of geogrid

The relationship between strain of geogrid and settlement of load plate is shown in Figure 11 and Figure 12. In these figures the strains at the position of a center, a middle (10 cm apart from a center) and a edge (20 cm apart from a center) of geogrid are

Table 3. Input parameters of soil.

| K | n | $R_f$ | c (kPa) | $\phi$ (degree) | Poisson's ratio | Density (kN/m$^3$) |
|---|---|---|---|---|---|---|
| 560 | 0.44 | 0.90 | 9.6 | 28.9 | 0.333 | 15.2 |

Table 4. Input parameters of interaction between soil and geogrid.

| Initial shear stiffness (kN/m$^2$/m) | Vertical stiffness (kN/m$^2$/m) | $c_0$* (kPa) | $\delta_0$ (degree) | $c_1$* (kPa) | $\delta_1$ (degree) |
|---|---|---|---|---|---|
| 6791 | $10^{11}$ | 0.0 | 22.0 | 1.0 | 24.8 |

shown respectively. Figure 11 indicates the comparison between the analytical values by the proposed method and the experimental values, while Figure 12 indicates the comparison between the analytical values by an ordinary method and the experimental values. The analytical values by the proposed method increase as a settlement increases. Its tendency is same as the experiments and the analytical values agree well with the experimental values quantitatively. On the other hand, the analytical values by an ordinary method differ from the experimental values that is, the strain at the edge decreases as a settlement increases and the strain at the center is overestimated and the strain at the edge is underestimated.

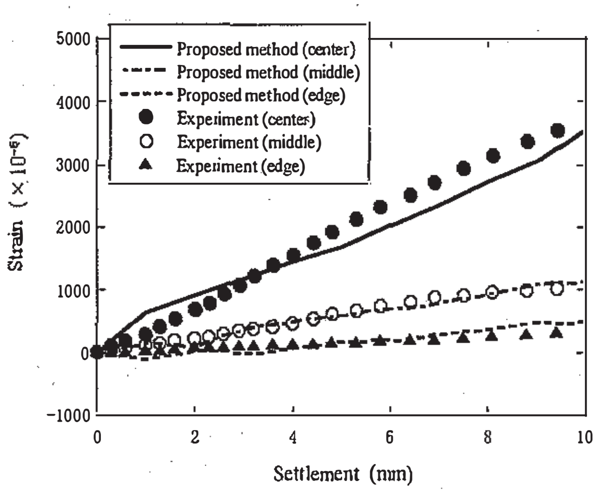



Figure 11. Relationship between strain of geogrid and settlement of load plate (comparison between analytical values by proposed method and experimental values in the case of L/B=5 and D/B=0.5).

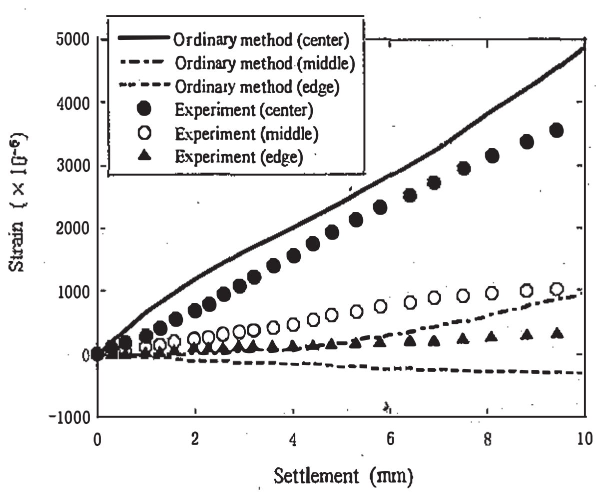



Figure 12. Relationship between strain of geogrid and settlement of load plate (comparison between analytical values by ordinary method and experimental values in the case of L/B=5 and D/B=0.5).

The distributions of the strain of geogrid in each settlement of load plate respectively are shown in Figure 13 and Figure 14. The analytical values by the proposed method in shown Figure 13 is larger at the center and is smaller at the edge, so its tendency is same as the experiments. The analytical values also agree well with the experimental values quantitatively. On the other hand, the analytical values by an ordinary method are overestimated at the center and underestimated at the edge.

The tendency abovementioned is also same in other cases. Accordingly it is supposed that the proposed analytical method is able to estimate the strain of geogrid in the experiment both qualitatively and quantitatively than an ordinary method.

(2) Deformation

The comparison between the analytical values by the proposed method and the experimental values in a distribution of a displacement at a ground surface is shown in Figure 15 and Figure 16. The ground settles near by the load plate and heaves up apart from

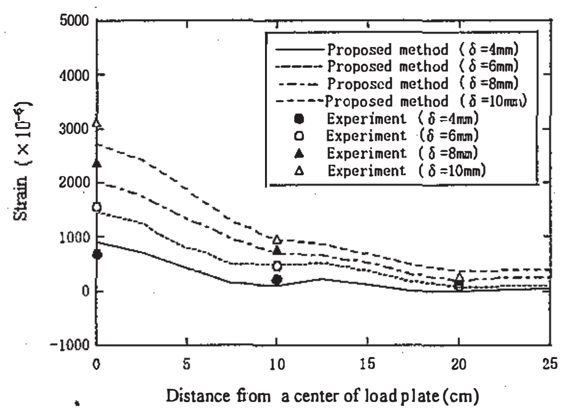



Figure 13. Distribution of strain of geogrid (comparison between analytical values by proposed method and experimental values in the case of L/B=5 and D/B=0.5).

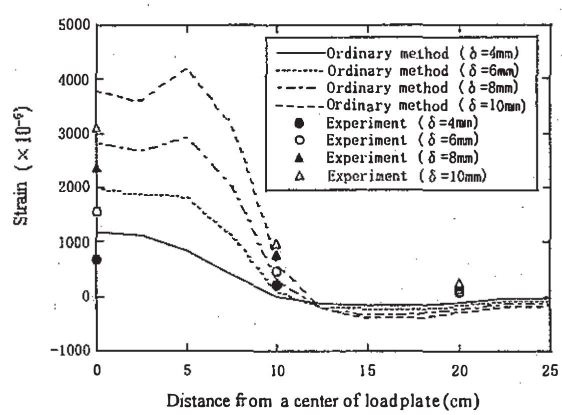



Figure 14. Distribution of strain of geogrid (comparison between analytical values by ordinary method and experimental values in the case of L/B=5 and D/B=0.5).

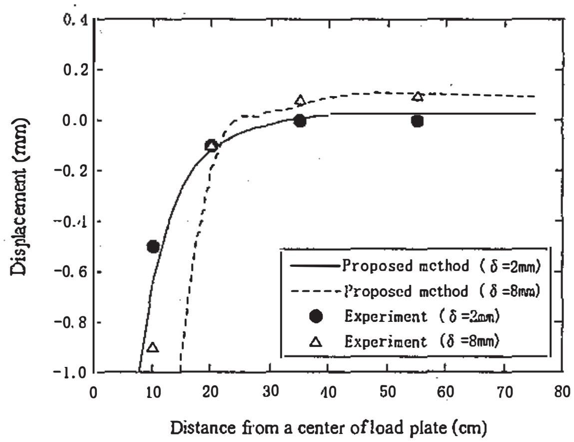



Figure 15. Distribution of displacement at a ground surface (comparison between analytical values by proposed method and experimental values in the case of L/B=5 and D/B=0.5).

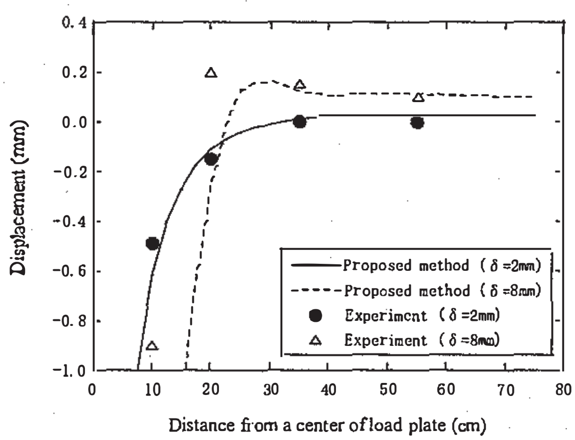



Figure 16. Distribution of displacement at a ground surface (comparison between analytical values by proposed method and experimental values in the case of L/B=5 and D/B=0.8).

the load plate as a settlement of the load plate increases. Particularly in the case that a laying depth of geogrid is deep, a magnitude of heaving becomes large at the side of the load plate as a settlement increases. Such tendency agrees well with the experiment. Further the analytical values also agree well with experimental values quantitatively.

## 5 CONCLUSIONS

The interaction characteristics between cohesive soil and geogrid is investigated on the basis of the geogrid pull-out test results. Further the analytical method introducing its interaction characteristics into finite element method is proposed and its validity is verified. The following is concluded.

1. The pull-out resistance acting between cohesive soil and geogrid can be divided into two parts; the one is dependent on a displacement of geogrid while the other is independent of it. And the relationship between the former and the displacement can be closely resembled by a hyperbola. Further the linear relationship is concluded between the ultimate strength of pull-out resistance and the overburden pressure.

2. As the method that can be taken the interaction between cohesive soil and geogrid into consideration, the analytical method introducing the characteristics of pull-out resistance obtained from the pull-out tests into finite element method is proposed and is applied to the model experiments of the geogrid reinforced cohesive soil ground. From the comparison between the analytical results by the proposed method and those by an ordinary method, it is proved that the analytical values of the geogrid strain and the displacement at a ground surface by the proposed method agree with the experimental values better than an ordinary method. Accordingly the validity of the proposed analytical method is verified.

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