LABORATORY PULL-OUT TEST OF GEOGRID AND ITS FINITE ELEMENT ANALYSIS

Tanehide TSURUOKA	The Zenitaka Corp.
Norio IWASAKI	The Zenitaka Corp.
○ Sumio TORIUMI	The Zenitaka Corp.
Kyozo TAKAOKA	Mitsui Petrochemical Products Ltd.
Tetsuo YAHABA	Tokyo Printing Ink Mfg.

ABSTRACT

This paper describes about the pull-out resistance of geogrid employing the soil material which was used to build a reinforced embankment in Niigata prefecture, and also refers to the friction coefficient which works between soil and geogrid. According to the verification, the finite element analysis which used joint element method satisfied the experimental result. On the other hand, it was shown that the friction coefficient is gradually decreases with increasing the normal stress.

ジオグリッドの引抜き抵抗試験とその有限要素解析

㈱ 銭高組 技術研究所	鶴岡 胤英
同	岩崎 則夫
同	○ 鳥海 寿美男
三井石化産資㈱	高岡 恭三
東京インキ㈱	矢幅 哲夫

概 要

本論は、新潟県内において築造された補強盛土体の土を使用してジオグリッドと土との間に働く引抜き抵抗力を実験的に求め、その結果を有限要素法にて解析検証した事例について述べたものである。検証によると、解析値は実験値と良く対応することが分かった。また、ジオグリッドと土との間には、引抜きせん断応力に相当する摩擦力が発生していることから、この力がどの程度の物理量であるか摩擦係数をもって表現した。その結果、垂直応力の増加とともに摩擦係数は逐次、減少するという興味ある結果が示された。

LABORATORY PULL-OUT TEST OF GEOGRID AND ITS FINITE ELEMENT ANALYSIS

Tanehide TSURUOKA	The Zenitaka Corp.
Norio IWASAKI	The Zenitaka Corp.
○ Sumio TORIUMI	The Zenitaka Corp.
Kyozo TAKAOKA	Mitsui Petrochemical Products Ltd.
Tetsuo YAHABA	Tokyo Printing Ink Mfg.

INTRODUCTION

It is not yet sufficiently made clear with respect to the effect of reinforcement of geogrid. The reason is that since reinforced earth structure was introduced into Japan it is not so long and is not yet established a proper design method which agrees with Japan's soil. This paper describes about the pull-out resistance of geogrid employing the soil material which was used to build a reinforced embankment, and briefly discusses about the result of finite element analysis by which a discontinuity between soil and geogrid was expressed.

The authors, on the otherhand, tried to find out the friction coefficient which works between soil and geogrid under an arbitrary normal stress.

Table 1 Soil Sample

Gravel (Over 2000μ) (%)	35.8
Sand ($74 \sim 2000\mu$) (%)	48.3
Silt ($5 \sim 74\mu$) (%)	15.9
Maximum Grain Size (mm)	19.1
Wet Dnsity γ_t (g/cm ³)	1.9
Dry Density γ_d (g/cm ³)	1.7
Moisture Content (%)	12~13

SOIL MATERIAL AND PULL-OUT TEST DEVICE

The soil material is a crushed muck which was produced due to tunnel excavation work in Niigata prefecture. The test sample is the soil which passed the sieve size of 19.1mm. To be agreed with the moisture content of reinforced embankment at site, the soil sample was controled and adjusted by adding or subtracting the water. Table 1 shows the grain size and physical constant. The soil sample widely contains gravel, sand, silt fraction, and the wet density was estimated by carrying on the soil compaction test. On the compaction test, it was used a rammer of 2.5kg, and was tried several times to be agreed with the wet density of reinforced embankment at site.

Fig.1 Pull-Out Test Device

The machinery and tools, being employed in the pull-out test, is an oversized shear apparatus which equipped a circular shear box of 300mm in diameter and 200mm in height. So it can directly shear the specimen which

contains coarse aggregate (see Fig.1). To convert the shear force P into the tensile force T , the steel frame which transmits T was fitted on the tip of steel bar which transmits P , and to lay the geogrid of 180mm in width between upper and lower shear box the aperture of 25mm was made by two steel plates. Here, the upper and lower shear box is fixed each other. The plates were also used to prevent the scattering of soil sample during the pull-out test. As the test condition, the geogrid was pulled-out in the rate of 1mm per a minute under UU condition. The normal stress, σ_n , of 0.2, 1.5, 2.0 kg/cm² was individually applied.

PULL-OUT RESISTANCE FORCE OF GEOGRID

The pull-out resistance force of geogrid into a soil mass was assumed as a sum of the friction resistance of longitudinal member and the bearing capacity of latitudinal member: However, it may also contain an adhesion resistance in the component of the friction resistance. In Fig.2, it is shown a general concept of the pull-out resistance force of geogrid. The sum of the resistance force which works in a micro-cross section may be given as

$$\Delta \tau = \Delta \tau_f + \Delta \tau_b \quad (1)$$

in which $\Delta \tau$ = sum of the component of pull-out resistance force which works in a micro-cross section; $\Delta \tau_f$ = component of the friction and/or adhesion resistance force which works in a longitudinal member; $\Delta \tau_b$ = component of the bearing capacity which works in a latitudinal member. If an equilibrium between pull-out force and pull-out resistance force is expressed as

$$\Delta p = 2 \cdot \Delta A \cdot \Delta \tau \quad (2)$$

in which Δp = component of the pull-out force which acts on the tip of geogrid; $2 \cdot \Delta A$ = sum of the micro-cross section on the upper and lower surface of geogrid, the stress which occurs into the specimen can be rewritten as

$$\tau_f = P / 2 \cdot A \quad (3)$$

in which τ_f = pull-out shear stress of geogrid (kg/cm²); P = pull-out force (kg); $2 \cdot A$ = sum of the laying area of geogrid ($A=505.6\text{cm}^2$). On the other hand, instead of Eq.3, the P can be expressed as

$$T = P / B \quad (4)$$

in which T = pull-out force per a unit width (kg/cm); B = width of geo-

Fig.2 Concept of pull-out Resistance Force of Geogrid

Fig.3 Pull-Out Shear Stress and Shear Deformation

Fig.4 Pull-Out Shear Stress,
Shear Stiffness and Normal Stress

Fig.5 Anchoring Effect
Due To Latitudinal Member

grid into the specimen ($B=180\text{mm}$).

In Fig.3, the relationship between τ_f and shear deformation, $\delta\tau$, is shown. The Fig.3 presents that no clear peak point of τ_f can be found on any normal stress condition, σ_n . Therefore, it was assumed that the 15% of the original diameter of soil specimen is equivalent to the peak value of $\delta\tau$, which means maximum shear deformation, $\delta\tau_{\max}$: The peak value is expressed as $\delta\tau_{\max}=300d \times 15\%=45\text{mm}$, and that the peak value of 45mm indicates the maximum pull-out shear stress, $\tau_{f\max}$. Fig.4 shows the relationship between τ_f and σ_n . As a linear formula of τ_f , we obtain

$$\begin{aligned}\tau_f &= C_f + \sigma_n \cdot \tan \phi_f \\ &= 0.26 + \sigma_n \cdot \tan 10.2\end{aligned}\quad (5)$$

in which τ_f = linear formula of pull-out shear stress (kg/cm^2); C_f = cohesion (kg/cm^2); σ_n = normal stress (kg/cm^2); ϕ_f = angle of shear resistance (deg).

In Fig.5, it is shown an interesting state which the latitudinal member fixes soil sample. According to the experimental observation, it seems that the most of the pull-out resistance force is sustained by the latitudinal member of geogrid.

SHEAR STIFFNESS FOR JOINT ELEMENT

The shear stiffness, K_s , which expresses a shear character for joint element was estimated as the inclination of a line passing one second of maximum pull-out shear stress, $\tau_{f\max}$. As a linear formula of K_s (see Fig.4), we obtain

$$\begin{aligned}K_s &= A + B \cdot \sigma_n \\ &= 0.18 + 0.061 \cdot \sigma_n\end{aligned}\quad (6)$$

in which K_s = linear formula of shear stiffness (kg/cm^2); A = initial shear stiffness (kg/cm^2); B = increment of shear stiffness. On the other hand, the compression stiffness, K_n , which expresses a compression character for

joint element, was estimated as follows: It was first assumed that the compression displacement, which momentarily occurred when σ_n of 0.2, 1.5, 2.0 kg/cm² was individually applied to the specimen, is equivalent to the normal deformation, δ_n . Then the relationship between σ_n and δ_n was plotted to make a linear equation. After that, K_n was estimated from the inclination of the line plotted. As a linear formula of K_n , we obtained

$$K_n = A + B \cdot \sigma_n \quad (7)$$

$$= 0.14 + 1.897 \cdot \sigma_n$$

in which K_n = linear formula of compression stiffness (kg/cm²); A = initial compression stiffness (kg/cm²); B = increment of compression stiffness.

When the finite element analysis was carried out, other experimental constants such as c_f , ϕ_f were used (see Eqs.5).

STATIC FRICTION COEFFICIENT

As mentioned above, between soil and geogrid under an arbitrary normal stress works a pull-out shear stress, τ_f , when a pull-out force, P, acts on the tip of geogrid. This means that between soil and geogrid occurs a friction resistance force, R_f , which is equivalent to τ_f . Here, we try to estimate the R_f in fundamental physics. Referring to Fig.6, a physical solid, which has a mass, m, under an arbitrary drag force, N, exists on a plane, and it considers a situation that the solid is pulled by a force, F, along the plane. First, when the solid was pulled by F'' , no the solid moved for the direction of F'' : The situation is that both F'' and R'' is under an equilibrium condition: Hence, the equilibrium equation is expressed as $F'' = R''$. Then, although the F was increased, the solid does not move yet. However, when the F reached to F' , the solid start moving for the direction of F' : The F' is called maximum static friction force, and the equilibrium condition becomes $F' = R'$. Finally, when the solid is moving on the plane, the frictional resistance force gradually decreases from R' to R_d : The R_d is called kinetic friction force, and the equilibrium condition becomes as $R_d < R'$.

Here, we know a physical composition as follows:

$$F = R, \quad F \text{ or } R = \mu \cdot N$$

Fig.6 Concept of Physical Friction Force

Fig.7 Friction Coefficient and Normal Stress

$$\therefore 1/\mu = N/F \text{ or } R \quad (8)$$

in which F = tensile force (kg); R = friction force (kg); N = drag force (kg); μ = friction coefficient (non-dimension).

Utilizing Eq.8, we can evaluate the μ which occurs between soil and geogrid during the pull-out test, as (see Fig.3)

$$1/\mu = \sigma_n / \tau_{\text{max}} \quad (9)$$

In Fig.7, the relationship between $1/\mu$ and σ_n is shown. As a linear equation of $1/\mu$, we obtain

$$\begin{aligned} 1/\mu &= A + B \cdot \sigma_n \\ &= 0.56 + 1.407 \cdot \sigma_n \quad (\text{to be non-dimension}) \end{aligned} \quad (10)$$

in which $1/\mu$ = reciprocal of friction coefficient; A = initial friction coefficient; B = increment of friction coefficient. Referring to Fig.7, it was shown an interesting result that μ gradually decreases with increasing of σ_n .

ANALYSIS OF PULL-OUT RESISTANCE OF GEOGRID

To verify if the experimental constants which were obtained in the pull-out test of geogrid are properly reflected in finite element analysis, the pull-out test of geogrid is reemerged analytically. The constants which are used in analysis are shown in Table 2: In this verification, the normal stress of 1.5 kg/cm^2 was chosen.

Table 2 Constant Used in Analysis

Material	Experimental Constant
Soil Sample	$\gamma_s = 1.9 \text{ (g/m}^3\text{)}, C = 0.14 \text{ (kg/cm}^2\text{)}$ $\phi = 34.9 \text{ (deg)}, E = 136.0 \text{ (kg/cm}^2\text{)}$ $\nu = 0.33, \sigma_v = 15.0 \text{ (kg/cm}^2\text{)}$ $E_p = 0.0 \text{ (kg/cm}^2\text{)}$
Joint Element	$K_s = 0.27 \text{ (kg/cm}^2\text{)}, K_n = 2.99 \text{ (kg/cm}^2\text{)}$ $C_t = 0.26 \text{ (kg/cm}^2\text{)}, \phi_t = 10.2 \text{ (deg)}$
Geogrid	$A_g = 0.528 \text{ (cm}^2\text{)}, E_g = 3.5 \times 10^4 \text{ (kg/cm}^2\text{)}$ $\sigma_{yg} = 2.27 \times 10^2 \text{ (kg/cm}^2\text{)}$ $E_{og} = 2.8 \times 10^4 \text{ (kg/cm}^2\text{)}$

In Fig.8, a model for the analysis is shown. Referring to Fig.8, each of two plane discontinuities (joint elements) was linked on the upper and the lower surface of geogrid which contacts soil material. In Fig.9(a) through (e), it is shown a state that the geogrid is pulled out for the direction of pull-out force, T . First, Fig.9(a) shows that the σ_n of 1.5 kg/cm^2 is applied on the upper shear box. Then, in

Fig.9(b) through (e), the T of $0.0, 5.0, 10.0, 15.0, 20.0 \text{ kg/cm}$ is individually applied on the tip of geogrid. Referring to Fig.9(a) through (e), we can observe the geogrid which is gradually pulled out from the shear box.

In Fig.10, the tensile strain, ϵ_g , which were obtained in both pull-out

Fig.8 Analysis Model

Fig.9 Pull-Out Test of Geogrid

test and finite element analysis, are shown: However, on the pull-out test, it became impossible to measure the ϵ_g since the elongation capacity of the strain gauge which stuck on the longitudinal member of geogrid is until 2%, so ϵ_g until 2% is shown in Fig.10.

Referring to Fig.10, the analyzed strain, which was expressed as a linear function, sufficiently covers the measured strain: Therefore, we knew that the experimental constants are properly reflected in analysis.

Fig.10 Pull-Out Force and Tensile Strain

CONCLUSION

We carried out the pull-out resistance test of geogrid employing the soil material which was used to build a reinforced embankment. The constants, which were obtained in pull-out test, were applied to finite element analysis to verify if the constants are properly reflected in the analysis. As the gist in this study, the following matters are obtained:

1. As a linear equation of the pull-out shear stress of geogrid, it is

obtained

$$\begin{aligned}\tau_t &= c_t + \sigma_n \cdot \tan \phi_t \\ &= 0.26 + \sigma_n \cdot \tan 10.2 \text{ (kg/cm}^2\text{)}\end{aligned}$$

2. As a shear and compression stiffness for the joint element, it is obtained

$$\begin{aligned}K_s &= A + B \cdot \sigma_n \\ &= 0.18 + 0.061 \cdot \sigma_n \text{ (kg/cm}^2\text{)} \\ K_n &= A + B \cdot \sigma_n \\ &= 0.14 + 1.897 \cdot \sigma_n \text{ (kg/cm}^2\text{)}\end{aligned}$$

3. It seems that the most of the pull-out resistance force is sustained by the latitudinal member of the geogrid.
4. As a linear equation of the static friction coefficient, it is obtained
- $$\begin{aligned}1/\mu &= A + B \cdot \sigma_n \\ &= 0.56 + 1.407 \cdot \sigma_n \text{ (to be non-dimension)}\end{aligned}$$
5. Friction coefficient, μ , is gradually decreases with increasing the normal stress, σ_n .
6. It was verified if the experimental constants are properly reflected in finite element method. The result showed that the analyzed strain sufficiently covers the measured strain. Therefore, as a method for analytically expressing the pull-out resistance of geogrid, it was shown that the joint element method is one of very useful techniques.

REFERENCE

- R.E.Goodman, C.S.John: Finite Element Analysis for Discontinuous Rocks, Numerical methods in Geotechnical Engineering Edited by C.S.Desai and J.T.Christian, Chap.4, pp155~160, 1977, McGraw Hill Inc.
- D.T.Bergado, A.Bukkanasuta and A.S.Balasubramaniam: Laboratory Pull-Out Tests Using Bamboo and Polymer Geogrids Including a Case Study, Geotextiles and Geomembranes, Vol.5, No.3, 1987
- T.Tsuruoka, N.Iwasaki, S.Toriumi, K.Takaoka: Finite Element Analysis of Steep Reinforced Embankment Using Geogrid (II) - Pull-Out Resistance Test of Geogrid -, pp.228~229, Proc. of The 44th Annual Conference of The Japan Society of Civil Engineers, 3, 1989