LAYING METHOD OF GEOGRID MATERIAL AND REINFORCEMENT EFFECT OF SOFT GROUND

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ABSTRACT

This paper presents the new laying methods of the geogrid to reinforce a soft ground under embankments. The reinforcement effect by the laying method is considered based on the results of the small model experiments in the laboratory and the finite element method analysis. As a result, it is shown that the proposed method can expect the higher reinforcement effect than the conventional laying methods.

Mechanical viewpoint of the laying method is the higher axial force introduced into geogrid, and we have been able to introduce the axial force by constraining axial displacement at the edges of geogrid. In the proposed laying method, the constraint of the axial displacement was achieved by penetrating the edge of geogrid into the ground.

We have tried the numerical analysis to consider reinforcement effect of saturated clay by reinforcement geogrid. This numerical analysis is used the finite element method based on Biot consolidation governing equation. And the constitutive equation of soil material adopts the hyperbolic model of 3-parameters.

Result of comparing experiment value with analysis value, we have shown that the proposed laying methods can considerably control the lateral flow with sliding failure of a foundation ground under embankments.

1. Introduction

In Japan, many people live as a field of main economic activity on the extremely soft ground. Civil engineer has many technical and economical problems in soft ground which we have to solve to develop infrastructure development such as road works and rail works. For example, on the construction of embankment structure on the soft ground, we have to develop the construction techniques to solve the problem about geotechnical engineering such as a large consolidation settlement and the fracture of a soil material on the foundation ground.

In general, these technical developments are needed many times and costs. On the other hand, in Japan, the cost reduction and the delivery of the new techniques are very important in the construction markets. The net method, laying geogrid on surface of soft ground, is developed to solve these problems, and this method is generally using in the world.

In this study, we notice this net method, and try to the model experiments and the numerical analysis about the laying methods of geogrid and the reinforcement effects.

2. Proposed laying method

The conventional net methods have been expected the constraint effect of deformation by the balance of ground settlement and heaving volume, or we expect the suspension effect based on the tension stress arisen into the geogrid. In conventional methods, the geogrid has been laying flat on the surface of soft ground. On the other hand, when the geogrid is laid on the transverse direction of embankment shown in Fig.1, we have already proposed this method penetrating the edges of geogrid into the ground. In this method, the geogrid on soft ground is constrained the axial displacement, and it is introduced the tensile stress into the geogrid. Namely, the geogrid laid by the method works as a very useful reinforcement material to suspend embankment load.

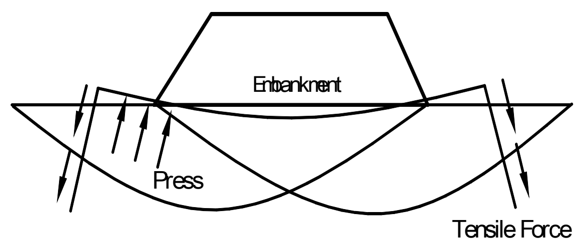

Fig.1 The penetrating method

In order to expect a high reinforcement effect by this method, we need a larger laying width of geogrid than embankment width and we have to make arrangements a large construction area. Therefore, it is not economic and practical method.

In this paper, in order to avoid this economical problem, as the second methods, we examined the method shown in Fig.2 which is laying geogrid in longitudinal direction of embankment. In this laying method, one side of the geogrid edge is fixed by burying under the embankment area; the other side edge of geogrid is penetrated in the ground of non-constructed area.

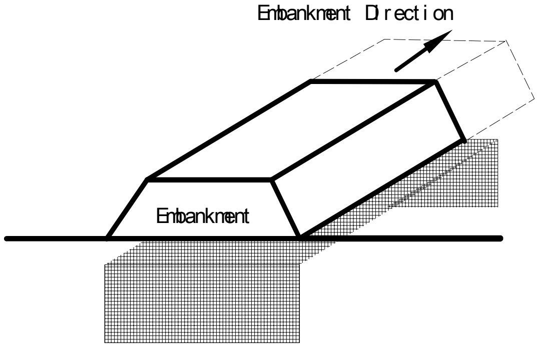

Fig.2 The second methods

3. Small model experiments

3-1 Experimental procedures

We have carried out the small model experiments in two-dimensional plane strain condition as shown in fig.3. The experimental procedures are shown as follows:

(1) We laid the reinforcement nets on the soft ground consolidated by initial pressure of 8.4 KN/m^2.
(2) The net edge was fixed under loading plate (Fig.4), and the other edge was penetrated into the ground in front of the loading plate.
(3) The loading was adopted the stepwise loading, 3.6 KN/m^2 Ç12 times, and the total load was about 42.8 KN/m^2.
(4) The displacements of the measuring points shown in fig.4 continuously were measured during 40 minutes between preserved step loads.

The laying length of the nets are 3 types of B=105mm, B=170mm and B=270mm in front of the loading plate. The foundation of the embankment was re-consolidated after filling up Arakida clay mixed with water. The material properties of the foundation are shown in Table 2. The measuring points of the displacement were arranged 4 points on the surface of ground and 2 points at the loading plate as shown Fig.4.

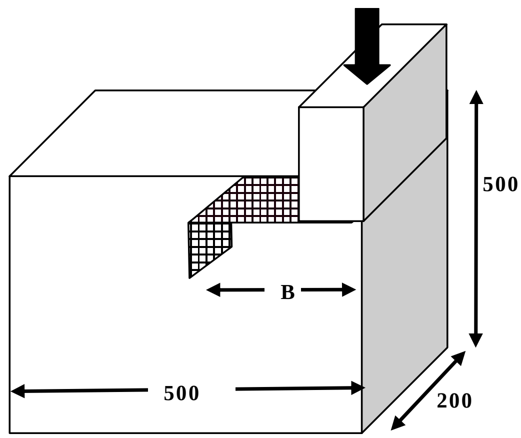

Fig.3 Model experiment

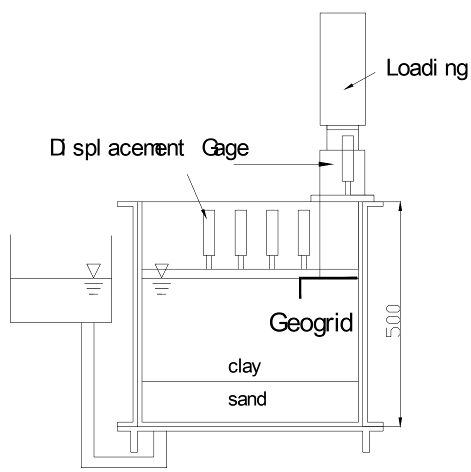

Fig.4 Experimental apparatus

3-2 Experiment result

The experiment case is shown in Table1. Also, we show in the every experiment case about the settlement of the loading plate, where Case-1 is no reinforcement, Case-2 is a laying length of 105mm, Case-3 is 170mm, Case-4 is 270mm. In comparison with Case-1 (no reinforcement) and Case-2 (penetrating method), Case-2 is shown the settlement restraint effect clearly. At the initial loading, the settlement is not dependent on the laying length, and the settlement rate is also small.

But, when the loading is over 17.9KN/m^2 (after about 160 min), the ground of no reinforcement is settled down rapidly. On the one hand, the settlement of *Case.2~Case.4* is comparatively small, and the final settlement is also controlled.

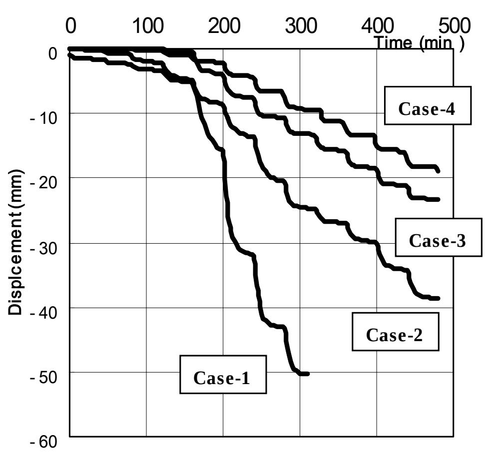

Fig.5 Time-Displacement

Table.1 Test case

Test Case	Laying Length (B)
Case-1	No Reinforcement
Case-2	105mm
Case-3	170mm
Case-4	270mm

4. Consolidation analysis

We try the numerical analysis to consider reinforcement effect of saturated clay by geogrid. The numerical analysis is used the finite element method based on Biot consolidation governing equation. And the constitutive equation of soil material is assumed the nonlinear elastic model.

4-1 Governing equation of consolidation

The derivation of governing equation coupled pore water flow and soil skeleton deformation was first introduced by Biot[1] but the present formulation is elaborated upon in Zienkiewicz et al.[2]. We do not make any reference to the detail on these derivation processes. The governing equation using in this paper is standard type as fallows.

The governing equation about pore water flow can be written by assuming Darcy’s law:

$$\frac{k_i}{\gamma_w}\frac{\partial^2\phi}{\partial x_i^2}-\frac{\partial}{\partial t}\left(\frac{\partial u_i}{\partial x_i}\right)+\chi\frac{\partial\phi}{\partial t}=0 \qquad (1)$$

where u_i is the displacement component in the x_i directions, ϕ is the potential function, k_i is the coefficient of permeability, χ is the coefficient of volume compressibility and γ_w is unit weight of water.

The governing equation of the soil skeleton assuming the elasticity can be written as

$$G\frac{\partial^2 u_i}{\partial x_j \partial x_j}+(G+\lambda)\frac{\partial^2 u_j}{\partial x_i \partial x_j}+F_i=\frac{\partial \phi_p}{\partial x_i} \qquad (2)$$

where G is the shear elastic modulus, λ is the Lame's constant, ϕ_p is the pore water pressure, and F_i is the body force.

To obtain the finite element matrix equations, we used the standard Galerkin's weighted residual method to Eq.(1) and Eq.(2). The geogrid resists only axial force, so we assume as a truss element.

4-2 Constitutive model of soil materials

In this study, the constitutive equation for the structure of soil skeleton was assumed the nonlinear elastic model with 3-parameters, and then the hyperbolic model for shear stress-strain relationship was written as

$$\tau_{oct}=\frac{\gamma_{oct}}{A+B\gamma_{oct}} \qquad (3)$$

where τ_{oct} and γ_{oct} is octahedral shear stress and strain respectively, A and B are material parameters to determine the octahedral shear stress-strain curve of soil material.

The material parameter A and B are related to the initial slope or tangent elastic modulus G_{Ti} and the octahedral shear strength $(\tau_{oct})_{ult}$, i.e. can be written as fallows:

$$G_{Ti}=\frac{1}{2A} \qquad (\tau_{oct})_{ult}=\frac{1}{B} \qquad (4)$$

The value of slope or tangent modulus E_T at a point on the octahedral shear stress-strain curves can be found by differentiating Eq.(3) with respect to ς_{oct} as

$$E_T=2G_T(1+\nu)=\frac{A(1+\nu)}{(A+B\gamma_{oct})^2} \qquad (5)$$

Since the response of soil materials is dependent on hydraulic pressure p' $(=\sigma'_{mm}/3)$ in effective stress, for a given stress path the behavior is often represented by a series of a pair of the parameter (A,B) for different P[3]. However, the normal consolidated clay can assume that the initial slope is nearly constant to P' and the shear strength is dependent on P'. So we assumed to be A = *const* and B = B(p') in Eq.(4).

The correlation between the drained shear strength and consolidation pressure p' for normally consolidation clay was given by

$$(\tau_{oct})_{ult}=mp'=m\frac{\sigma'_{ii}}{3} \qquad (6)$$

where m is the rate of shear strength increase.

Substitution of Eq.(6) and Eq.(4) in Eq.(5) yields

$$E_T = \frac{M(1+\mu)\sigma_{mm}}{(A\sigma_{mm} + M\gamma_{oct})^2} \qquad (7)$$

where M' = 3/m.

We divided the mesh, isoparametric 4-node element, as the two-dimensional plane strain condition. Also, the loading was increased stepwise as 3.6 KN/m^2 x12 times = 42.8 KN/m^2, time interval of at the loading stage is about Δt = 2400sec. within the order estimated by

$$\Delta t = \frac{l^2}{12c_v}, \qquad c_v = \frac{k}{m_v \gamma_w} \qquad (8)$$

where l is representative edge length of a finite element, c_v is coefficient of consolidation, and m_v is coefficient of volume compressibility.

5. Numerical and experimental results

The properties of the material are shown in Table2.

Table.2 Material properties of soil

Density of soil(g / cm^3)	2.69
Water content (%)	40
Poison's ratio	0.25
Modulus of elasticity(MPa)	10
Coefficient of compression (normal consolidation)	0.05~0.2
Coefficient of compression (over consolidation)	0.0153~0.0155
Strength increment ratio	0.49~0.59
Coefficient of consolidation (cm^2)	0.3-D2~ 0.4-D2

Also, *Fig.6~Fig.8* are compared the analysis results with experiment results about the settlement of loading plate. The analysis value is comparatively inferred to the experiment value. In particular, Fig.6 (with no reinforcement net) is shown Time-displacement relationships, and the analysis value is comparatively similar to the experiment value. But, about between Fig.7 and Fig.8 using the nets, the errors may be observed, because the analysis value is slower than experiment value on loading interval which shows a rapid settlement. In other words, the generation of the sliding surface is slow. Therefore, in the analysis, the reinforcement effect using the nets is ideally generated from initial stage. On the other hand, in the experiment, when the net is laid, it is generated loose. So we think that it is difficult to generate the reinforcement effect at initial stage.

In this regard, as it is shown by experiment value in Fig.7 and Fig.8, we are able to assume that in former part of loading the settlement rapidly advances, but the settlement rate doesn't advances in latter part. Except for the problem of this experiment, we consider that the error between analysis and experiment value result from the different causes. In particular, the constitutive law of soil which we conveniently use, we are not able to express sufficiently the complicated the constitutive formula of clay with the consolidation, and it is necessary to use the advanced constitutive law based on the critical state theory for us.

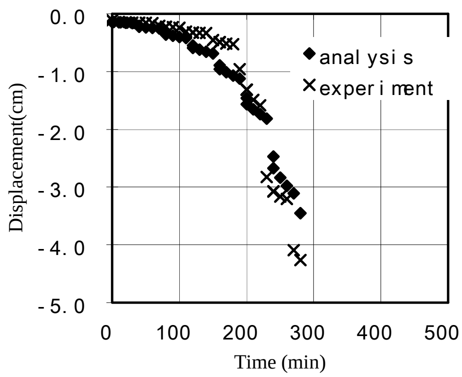

Fig.6 Time-displacement: part1

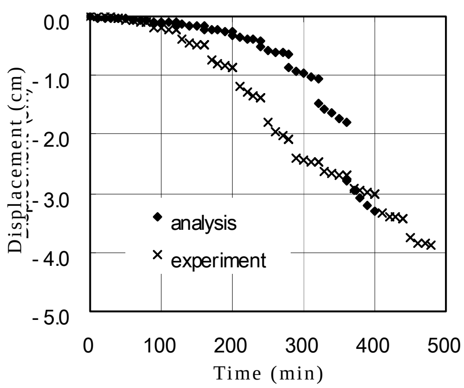

Fig.7 Time-displacement: part2

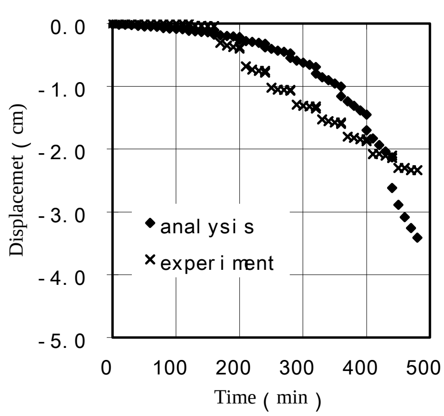

Fig.8 Time-displacement: part3

6. Conclusion

The main results of the proposed net methods can be summarized as follow.

(1) We carried out the small model experiment about the laying method using geogrid on the surface of soft ground. As a result, it was clear that we have the restraint effect by penetrating the edge of geogrid into the ground.

(2) The reinforcement zone is the proper value, and we are needed the design considering economical problem, construction cost and constraint of site.

(3) In comparison with analysis value and experiment value using the consolidation analysis program, we aren't able to get the deformation as the continued sliding surface is completely formed in the ground.

(4) In the range of the sufficiently controlled construction condition, we showed that the analysis results are able to predict the actual phenomenon on the observed deformation.

As challenges for the future, about deformation of soil skeleton structure at the numerical analysis, the effect of the strain is also important, but we try to consider preferentially on the relation between the increasing strength of saturated clay and the constitutive law using the consolidation progress.

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