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Restraining effect of geogrid reinforced soil in finite element analysis

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ABSTRACT: Numerical model with dilatancy caused by not only shearing of soil but also the interaction between soil and geogrid is proposed for geogrid reinforced soils. This dilatancy is restrained by adjacent geogrids during deformation of the reinforced soil structure and this is called a restraining effect of the reinforced soil. In order to investigate the importance of the restraining effect in finite element analysis of the reinforced soil, the geogrid reinforced-soil wall is analyzed using this dilatancy model. Comparing this result with that by non-dilatancy model, it may be concluded that the modelings of the dilatancy effects are essential in the analysis of geogrid reinforced-soil.

1 INTRODUCTION

Geogrids are often placed in the soil with multiple layers in practice. For this case, the reinforcing effect is not simply number of layers times as much as that of one layer. This mobilized effect usually exceeds this multiple value and is called a restraining effect of geogrid reinforced soil. It can be considered that this is caused by dilatancy property due to not only shearing of soils but also pulling out the geogrid in the soil. Although there have been many numerical studies on geogrid reinforced soil structures by finite element method with various soils and interaction models (e.g. Ochiai et al.(1987), Ogisako et al. (1988) and Handel et al. (1990)), not many studies have discussed on the restraining effect, quantitatively.

The purpose of this paper is to investigate an importance of considering a restraining effect on finite element analysis of geogrid reinforced soil structures. Here, the dilatancy is taken into account on the modeling of both soils and interaction between geogrid and soil. In order to evaluate the restraining effect on the structures, a finite element analyses of geogrid reinforced-soil wall are carried out using this proposed model in comparison with that by non-dilatancy model.

2 RESTRAINING EFFECT OF GEOGRID REINFORCED - SOIL

Dilatancy property of geogrid reinforced soil may be caused by the shape of geogrid materials in which the soil is partially continuous. When the reinforced soil deforms as the geogrid itself elongates, each geogrid makes the surrounding soil expanded by shearing of soils and it is increased further by the interaction behavior between geogrid and soil. This is illustrated in Fig. 1. This dilatancy is restrained by adjacent geogrids and then the restraining effect is mobilized. Consequently, the stresses of soils are increased and it makes the total reinforcing effect increasing. It is considered that these behavior play very important role for geogrid reinforced-soil structures and should be evaluated in the analysis.

3 NUMERICAL MODELS

In order to take into account the dilatancy behavior described above, the dilatancy is included in the models of not only the soil but also the interaction between soil and geogird. These are summarized as follows:

(1) Soils
The nonlinear behavior with the effect of dilatancy property is assumed on the basis of elasto-plastic constitutive equation. Drucker-Prager's model

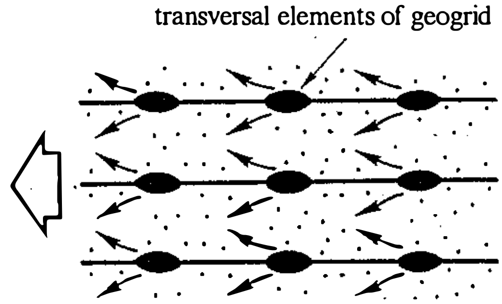

Fig.1 Dilatancy behavior of geogrid reinforced soil.

(Drucker et al. (1967)) with non-associate flow rule is used. In the real construction of geogrid reinforced-soil wall, it is considered that the backfill is well compacted sandy soils, so that the positive constant value of dilatancy is used as a dilatancy angle in the analysis. The relationship between stress increment and strain increment in plane strain condition is shown as follows:

$$\begin{Bmatrix} d\sigma_x \\ d\sigma_y \\ d\tau_{xy} \\ d\sigma_z \end{Bmatrix} = [D]^{ep} \begin{Bmatrix} d\varepsilon_x \\ d\varepsilon_y \\ d\gamma_{xy} \end{Bmatrix}$$

$$= \begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \\ D_{41} & D_{42} & D_{43} \end{bmatrix} \begin{Bmatrix} d\varepsilon_x \\ d\varepsilon_y \\ d\gamma_{xy} \end{Bmatrix} \quad (1)$$

where $[D]^{ep}$ is elasto-plastic constitutive matrix. It is noted that the non-dilatancy model with $D_{13} = D_{23} = D_{31} = D_{32} = D_{43} = 0$ in Eq.(1) is also used in the analysis for the comparative study.

(2) Interaction between soil and geogrid

As described above, the dilatancy behavior is caused by not only shearing of soil but also the interaction between soil and geogrid. Likewise, the pull-out behavior may be assumed to be the dominant behavior for the deformation of the geogrid reinforced-soil structures as discussed in the paper by Ochiai et al.(1988). In order to model the interaction behavior between these two materials, the joint element which is the same formulation developed by Ghaboussi(1973) is used and this is formulated as

$$\begin{Bmatrix} d\tau \\ d\sigma \end{Bmatrix} = \begin{bmatrix} k_{ss} & k_{sn} \\ k_{ns} & k_{nn} \end{bmatrix} \begin{Bmatrix} du \\ dv \end{Bmatrix} \quad (2)$$

where k_{ss} and k_{nn} are shearing and normal parts of the stiffness, respectively and both k_{ns} and k_{sn} show the effects of dilatancy. The constitutive 2x2 matrix is defined by the results of the pull-out test in laboratory. The joint element without considering the dilatancy effect has been used by Ogisako et al.(1988) for geogrid reinforced-soil walls based on the laboratory pull-out test. The same test results are used herein the study with respect to the effect of dilatancy in the interaction behavior. Drucker-Prager type of the elasto-plastic formulation is also applied in the interaction model. For the comparative study, the non-dilatancy model with $k_{ns} = k_{sn} = 0$ in Eq.(2) is also used in the analysis.

Table 1 Material parameters for soils

	Unit weight (tf/m³)	Cohesion (tf/m²)	Friction angle φ (deg.)	Dilatancy angle ψ * (deg.)	Elastic modulus (tf/m²)	Poisson's ratio
Backfill	1.8	0.0	40	10	1000	0.33
Foundation	0.8	0.0	35	5	1000	0.33

*: $\psi = \phi - 30$

4 ANALYSIS OF GEOGRID REINFORCED-SOIL WALL

4.1 Summary of analysis

In order to evaluate the restraining effect on the structures, a finite element analysis of geogrid reinforced-soil wall is carried out using above dilatancy models. Finite element mesh with each scale and boundary conditions are shown in Fig.2, in which not only the backfill but also the foundation ground are included in the analysis. The height of the wall is 8m and eight layers of geogrids are placed with the equal length of 6m and the equal spacing of 1m between two geogrids. In the analysis, the loading of step-by-step construction process of backfill is taken into consideration. In order to verify the restraining effect in the reinforced soil structures, not only the case (Model A) by using proposed dilatancy model but also the one (Model B) which does not include the effect of dilatancy for both soil and the interaction are analyzed.

The rest of all the models such as wall, geogrid, and the interaction between wall and geogrid are exactly the same as those used in the paper by Ogisako et al.(1988). Polymer grid is used as a geogrid and is modeled by truss element with nonlinear characteristics of tensile force-strain relations in air. The wall is assumed to be multiple number of concrete panels and is modeled by beam element with linear elastic assumption.

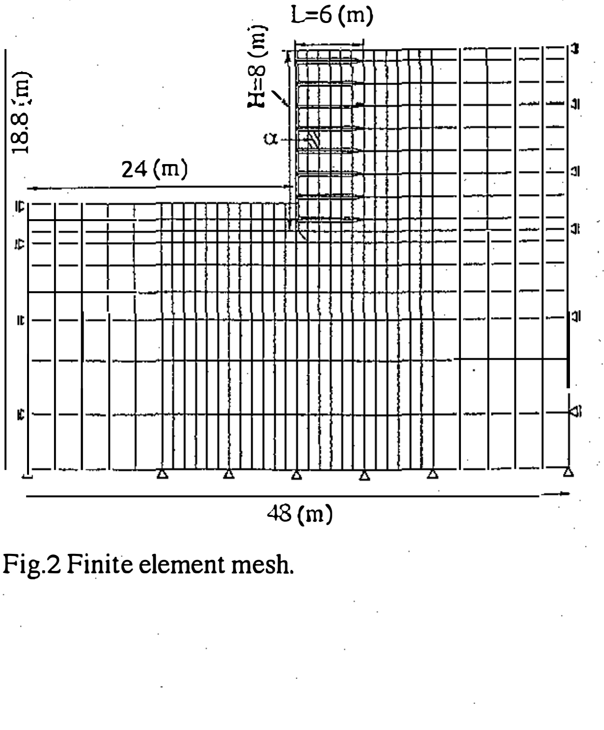

Fig.2 Finite element mesh.

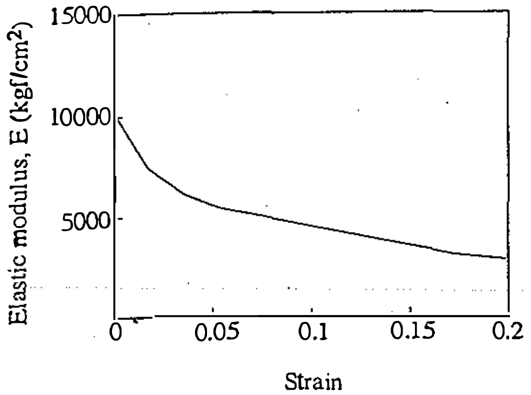

Fig.3 Strain dependency of elastic modulus of geogrid.

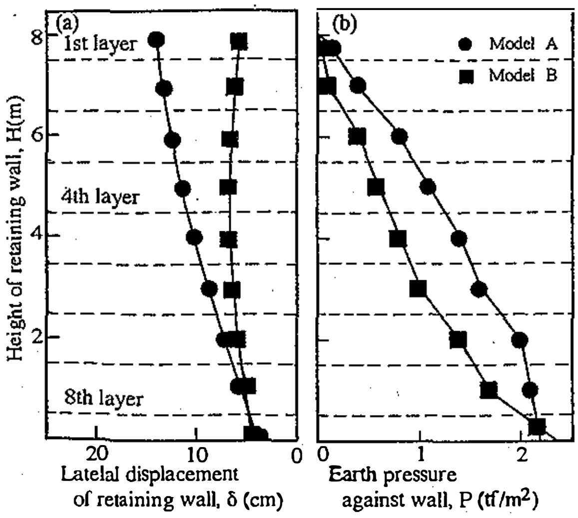

Fig.4 Lateral displacements of the wall and lateral earth pressures against wall.

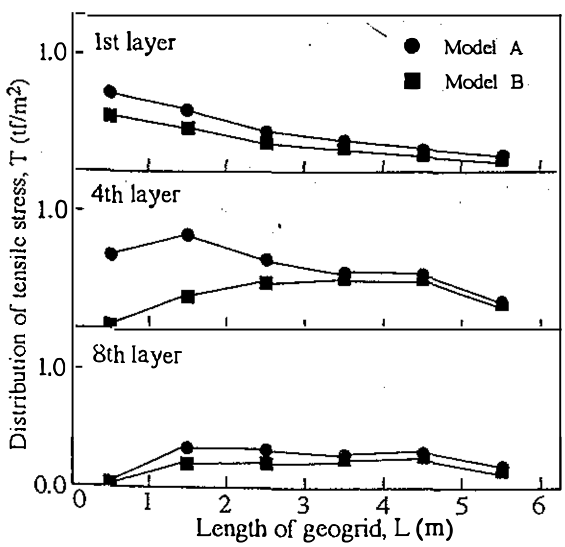

Fig.5 Distributions of tensile stresses of geogrids.

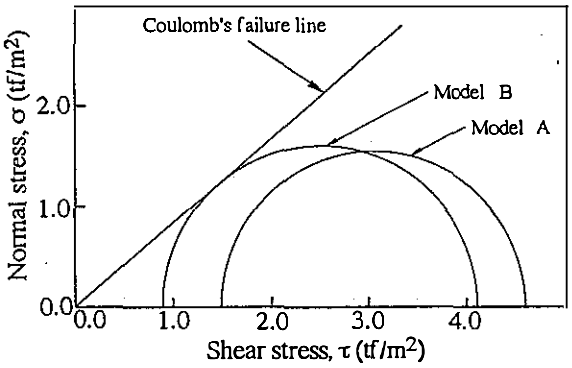

Fig.6 Comparison of stress condition between Model A and Model B.

Material parameters for soils are shown in Table 1. Here, the dilatancy angle, $\psi = \phi - 30^{\circ}$ which ϕ is the friction angle is used from laboratory test results. The strain dependent elastic modulus of geogrid is obtained from tensile force - strain relation in the air and this is shown in Fig.3. The elastic modulus of the wall is 2.45×10^7 tf/m2. The cross section areas of both geogrid and wall are $0.0012 m^2$ and $0.18 m^2$, respectively. For the interaction model, the parameters k_{ss}, k_{nn}, k_{ns} and k_{sn} are determined by the method proposed by Ochiai et al.(1988) with elasto-plastic theory based on Drucker-Prager's model.

4.2 Results and discussions

Fig.4(a) shows the distribution of the lateral displacement of the wall at the end of constructing the backfill for both Model A and Model B, while the distribution of lateral earth pressure against the wall is shown in Fig.4(b) for both the cases. Fig.5 shows the comparisons of the mobilized tensile stresses in the embedded geogrids for first, fourth and eighth layer from the surface of the backfill, respectively. According to these results, the earth pressure against the wall for Model B is underestimated because of not taking into account the dilatancy, and this causes the less lateral displacement compared to that by Model A. As a result of these behavior, the tensile stress of the geogrid for Model A is larger than that of Model B especially in the middle of the backfill at the wall.

In order to investigate the difference of the stress condition in the backfill between Model A and Model B, the stress Mohr's circle for element α as indicated in Fig.2 at the end of constructing the backfill are shown in Fig.6 with Coulomb's failure line. The stress state for Model A does not reach to the failure while that for Model B is already in failure.

In order to evaluate the stability of the backfill after completing the loadings, the stability ratio, F_{sr}, is defined in Fig.7. The value F_{sr} is always larger than or equal unity ($F_{sr} \geq 1$), in which $F_{sr} = 1$ means the failure condition in the element, and besides the more

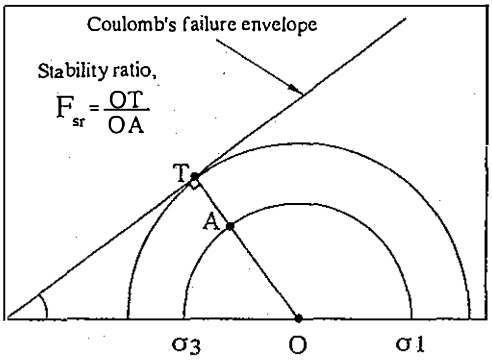

Fig.7 Definition of stability ratio, F_{sr}.

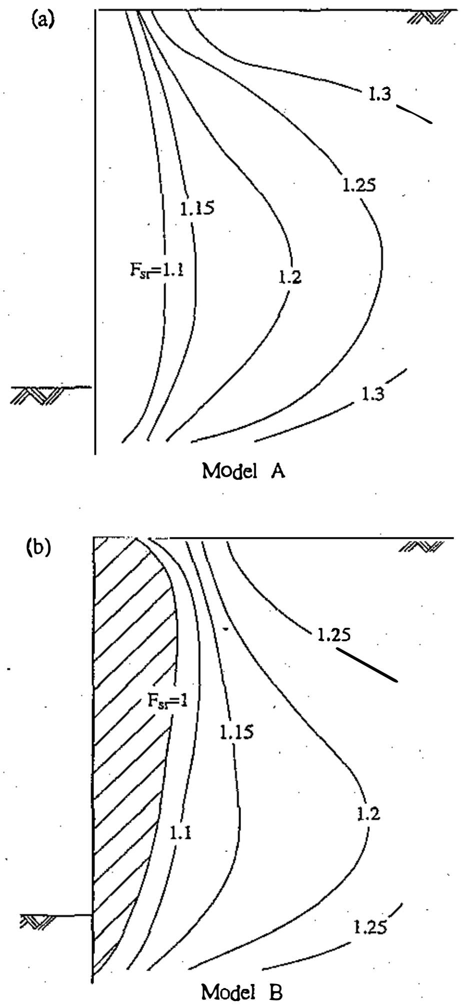

Fig.8 Contour lines of F_{sr} in the backfill.

the values increase the more the stability of the backfill is expected. Fig.8(a),(b) show a contour of this ratio, F_{sr} in the backfill for both Model A and Model B. Fig.8(a) shows the contours for Model A while that for Model B is shown in Fig.8(b). Comparing these two results, the backfill around the wall shown as shaded area becomes $F_{sr} = 1$ for Model A, while the ratio for the same area for Model B is still more than unity. Based on these results, it is considered that the effect of the reinforcement is increased further by restraining the dilatancy by geogrids, which was called the restraining effect, and the Model B can evaluate this behavior. It may be concluded, therefore, that the effect of dilatancy for not only the soil but also the interaction between geogrid and soil is necessary to consider for the geogrid reinforced soil structures.

5 CONCLUSIONS

In order to investigate the necessity of considering the restraining effect on finite element analysis of geogrid reinforced soil structures, the dilatancy was taken into account in the models of not only the soils but also the interaction between soil and geogrid. The importance of this restraining effect was verified by conducting the finite element analysis of geogrid reinforced-soil wall, quantitatively. It is concluded that the modelings of the dilatancy in not only the soil but also the interaction between soil and geogrid are indispensable for the sake of evaluating the restraining effect.

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