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A study on the reinforcing effects of geogrids overlaid on pile group for the embankment foundations

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ABSTRACT: The reinforcing effects of geogrids overlaid on pile group driven in a very soft foundation ground were estimated through the simulation of the behavior of field test using finite element method. It was found from analytical and observed results that this reinforcing method largely contributed to improving the safety of the foundation ground under and around embankments. The influences of the interval between piles, the number of layers of geogrids and the stiffness of piles on the reinforcing effects are estimated on the basis of the results of finite element analyses considering consolidation phenomena, too.

1 INTRODUCTION

For constructing embankments on soft foundation ground, geogrids placed in and on the soft grounds were expected to increase the bearing capacity and to reduce the deformation of the ground. The behavior of geogrid-reinforced embankments has been estimated by numerical analyses using finite element method (Hird et al., 1989; Oka et al., 1992; Chai et al., 1993). Though it was found that effect of geogrids without piles did not appear to be large (Ohkubo et al., 1994).

In the case of that the deformation of grounds has to be strictly restricted, the pile group or the deep mixing columns are often applied to such foundation grounds. The effectiveness of the present pile group method in which head of piles were connected to each other by steel bars was estimated (Kudo et al., 1976; Sakamoto et al., 1978). Also, it was reported that steel bars connecting each piles might be not always necessary (Yamamoto et al., 1987).

A field test on the embankment foundation with geogrids, instead of steel bars connecting each piles, overlaid on pile group as shown in Fig.1 was simulated by finite element analysis and it was found that the effectiveness of this reinforcing method appeared to be large (Ohkubo et al., 1995). In this paper, finite element analyses for various embankment foundations with geogrids and pile group are carried out to estimate the influence of the interval between piles , the stiffness of piles and the number of geogrid layers on the reinforcing effects.

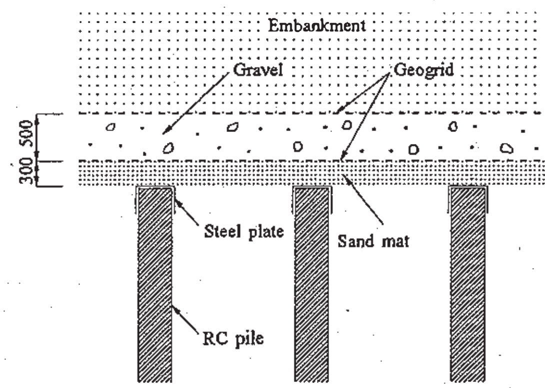


Fig.1 Reinforcing method

2 FINITE ELEMENT ANALYSIS

A embanking work on soft foundation ground reinforced by geogrid and pile group are modelled by finite element method. The behavior of embankment and soft foundation ground are controlled by an elastoplastic model (Nakai et al., 1991, 1992) based on SMP (Spatial Mobilized Plane) theory (Matsuoka et al., 1997) coupled with consolidation theory. The tensile characteristics of geogrid is represented by plane truss elements.

As it is assumed that embankments on soft foundation with pile group in these analyses have semi-infinite length in transverse direction and the major response of piles is provided by the axial stiffness, the three-dimensional pile group foundation system is idealized as a two-dimensional plane strain problem. Consequently, it is

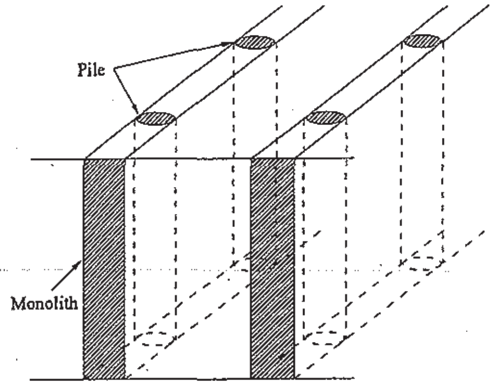


Fig.2 Two-dimensional monolith

Table 1 Material parameters of geogrid

Sectional Area	A(m^2)	2.97×10^{-4}
Elastic modulus	E(tf/m2)	4.00×10^5
Yield strain	(%)	10

Table 2 Stiffness parameters of pile

Parameter		Stiffness of pile	
		Isotropic	Anisotropic
Elastic modulus (tf/m^2)	Ex	5.498×10^5	1.000×10^2
	Ey	5.498×10^5	5.498×10^5
Shear modulus (tf/m^2)	G	2.390×10^5	4.347×10

assumed that the total axial stiffness of two-dimensional monolith used in these analyses shown in Fig.2 is equivalent to that of piles in three-dimensional problem. In order to estimate the influence of stiffness of piles, piles are assumed to have either isotropic stiffness which lateral stiffness is equivalent to axial stiffness, or anisotoropic stiffness which lateral stiffness much smaller than axial stiffness in these analyses. The material parameters of geogrid are listed in Table 1, and the values of the stiffness parameters of pile are listed in Table 2.

The interface behavior between geogrids and soils is represented by elastoplastic joint elements to allow the relative displacement. Stress-displacement relationship between geogrids and soil in these elements is formulated based on the results of laboratory tests (Hayashi et al., 1989; Nakamura et al., 1994; Alfalo et al., 1994). When the mobilized shear stress at the interface equals or exceeds Mohr-Coulomb failure criterion, a very small value of interface shear stiffness parameter is adopted. The stiffness parameters and the skin friction angle used in joint elements are listed in Table 3.

The nonlinear shear stress-shear displacement characteristics at the interface between pile and soil is represented by hyperbolic model (Kondner et al., 1963). The initial shear stiffness parameter k_{si}

Table 3 Interface parameters for geogrid

Shear stiffness parameter	kss(tf/m^3)	9.35×10^3
Normal stiffness parameter	knn (tf/m^3)	1.00×10^5
Friction angle	δ (deg)	40

Table 4 Parameters on interface for pile

Parameter	Clay	Sand
K_I	2.5×10^4	2.5×10^4
n'	1.0	1.0
R_f	0.87	0.87
δ	20°	30°
knn (tf/m^3)	1.0×10^6	

Table 5 Analytical cases

Case	Interval between piles	Number of layers of geogrid
1a,b	1.75m	—
2 a,b		1
3 a,b		2
4 a,b	3.50m	—
5 a,b		1
6 a,b		2
7 a,b	7.00m	—
8 a,b		1
9 a,b		2

Table 6 Input soil parameters

Parameter	Clay	Sand
$\lambda/(1+e_0)$	0.1966	—
$\kappa/(1+e_0)$	0.0197	—
C_t	—	0.0084
C_e	—	0.0060
m	—	0.30
R_f	2.77	4.70
D_f	—	-0.60
α	0.65	0.85

(=initial tangent stiffness of hyperbolic curve) with normal stress σ_n is expressed by following experimental equation (Janbu, 1963):

$$k_{si} = K_I \cdot \gamma_w \left(\frac{\sigma_n}{P_a} \right)^{n'} \tag{1}$$

where K_I is the stiffness number; n' is the stiffness exponent determining the rate of variation of k_{si} with σ_n; γ_w is the unit weight of water expressed in the same unit as k_{si} ; and P_a is the atmospheric pressure expressed in the same unit as σ_n. Considering the hyperbplic relationship of the interface between piles and soil, the shear stiffness parameter k_s can be expressed from Eq. (1) as follows (Clough et al., 1971):

$$k_s = K_I \cdot \gamma_w \left(\frac{\sigma_n}{P_a} \right)^{n'} \left(1 - \frac{R_f \cdot \tau}{\sigma_n \cdot \tan \delta} \right)^2 \tag{2}$$

where R_f is the ratio of the interface shear strength to the asymptotic shear stress of hyperbolic curve;

δ is the angle of friction. Considering the difference between the surface area of the monolith and that of the pile, the interface shear stiffness parameter used in these analyses is assumed to be 0.31 times higher than that obtained from Eq. (2) unless the shear stress reaches the interface shear strength. Also, the value of the interface normal stiffness parameter between pile and soil is adopted to be the same value between geogrid and soil. The parameters for joint elements which represent the interface behavior between pile and soil are listed in Table 4.

The analytical cases are listed in Table.5, in which 'a' and 'b' attached to the case number mean the difference of pile stiffness, 'a' denoting isotropic stiffness piles and 'b' denoting anisotropic stiffness piles. The input soil parameters used in these analyses are summarized in Table.6. Fig.3 shows the finite element mesh of Case3 for example. The final height of the embankments consisted of 5 lifts at a filling rate of 0.18m/day is equal to 4.5m. For the cases with one layer of geogrid (Case2, 5 and 8), geogrids are usually placed at the location of 0.3m high from the ground surface. Also, for the cases with two layers of geogrids (Case3,6 and 9), upper

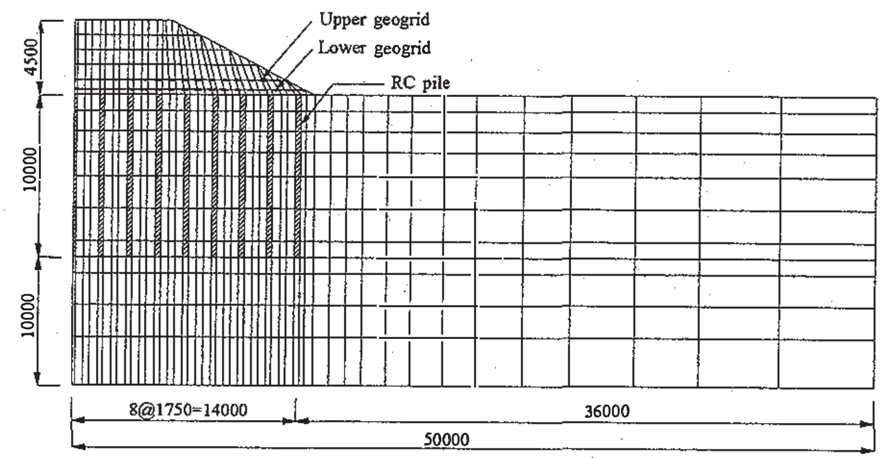


Fig.3 Finite element mesh (Case3a,b)

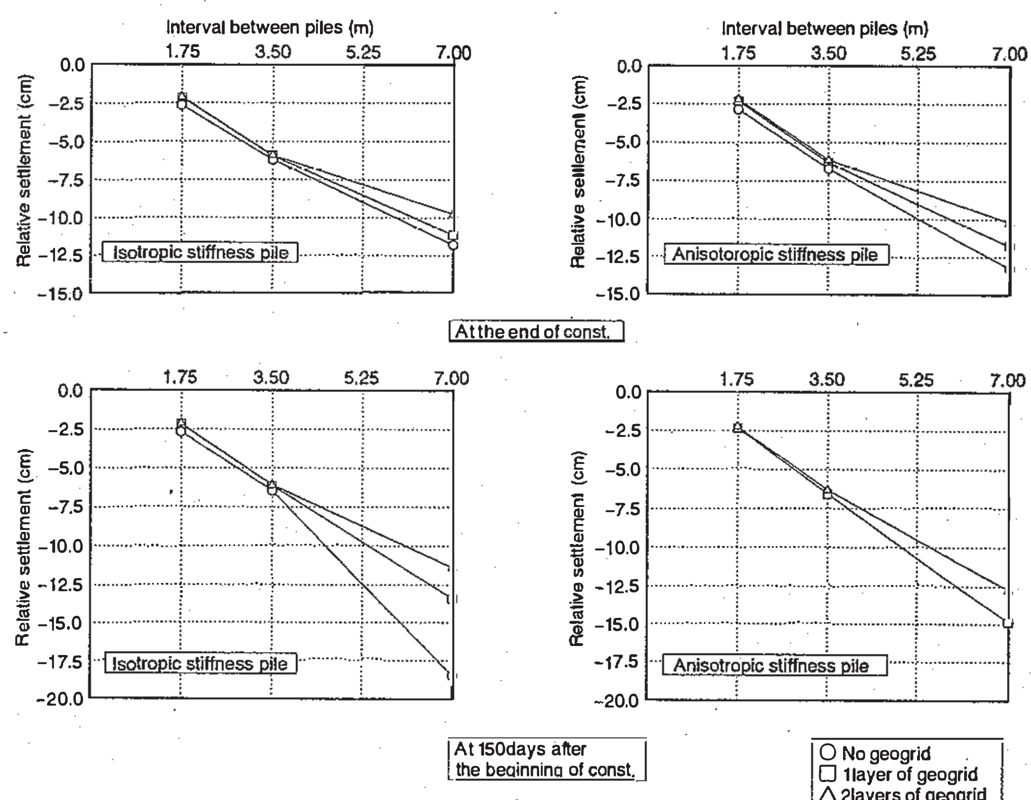


Fig.4 Relative settlement with pile interval

geogrids are placed at the location of 0.9m high from the ground surface. The vertical and lateral displacement are restrained at the bottom surface and at both the bottom surface and the sides, respectively. Drainage is permitted at the top and the bottom surface of the clay elements considering the consolidation phenomena.

3. ANALYTICAL RESULTS

Analytical results are evaluated on the settlement of the ground surface, axial stress and lateral displacement of piles at the end of construction and 150days after the beginning of construction, and on the strain of geogrids at the end of construction for the case of isotropic and anisotropic piles.

In the case of the pile interval of 7.0m without geogrids and anisotropic stiffness piles (Case7b), the foundation ground failed just after the end of the construction of the embankment. Therefore, the analysis for this case was finished at that time.

Fig.4 shows the relationships between the interval between piles and the maximum relative settlement between the ground surface and the top of piles. It is found that reinforcing effects of geogrids appear in all analytical cases. In the cases of pile interval of 1.75m and 3.5m, reinforcing effects of one layer of geogrids is equivalent to those of two layers of geogrids. However, in the case of pile interval of 7.0m, reinforcing effects of geogrids, especially two layers of geogrids, appear to be large.

Fig.5 shows the distribution of axial stress at the top of piles. In the case with the pile interval of 7.0m, axial stress acting at the top of pile increase when geogrids are overlaid on pile. Therefore, it is considered from these figures that most of embankment loads are supported by piles in the pile

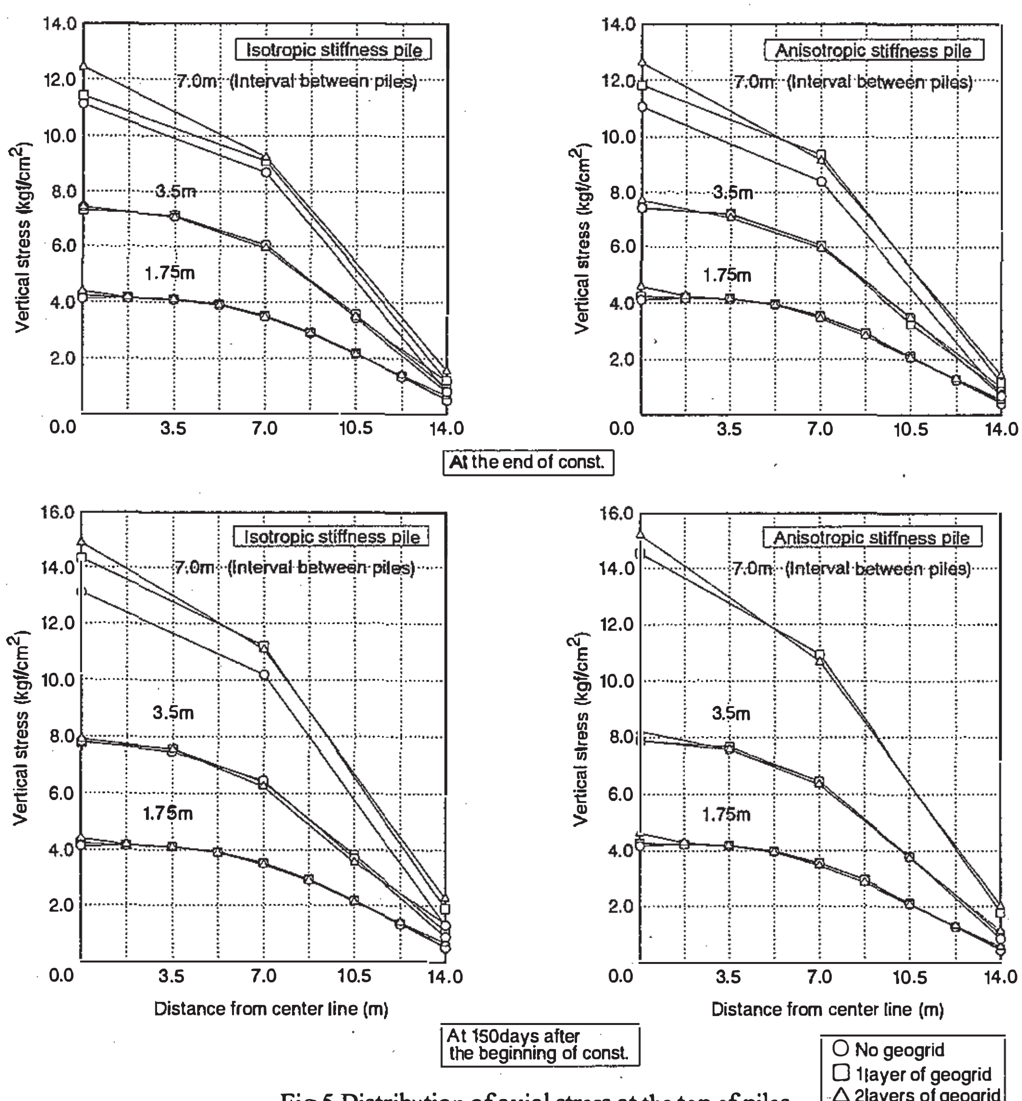
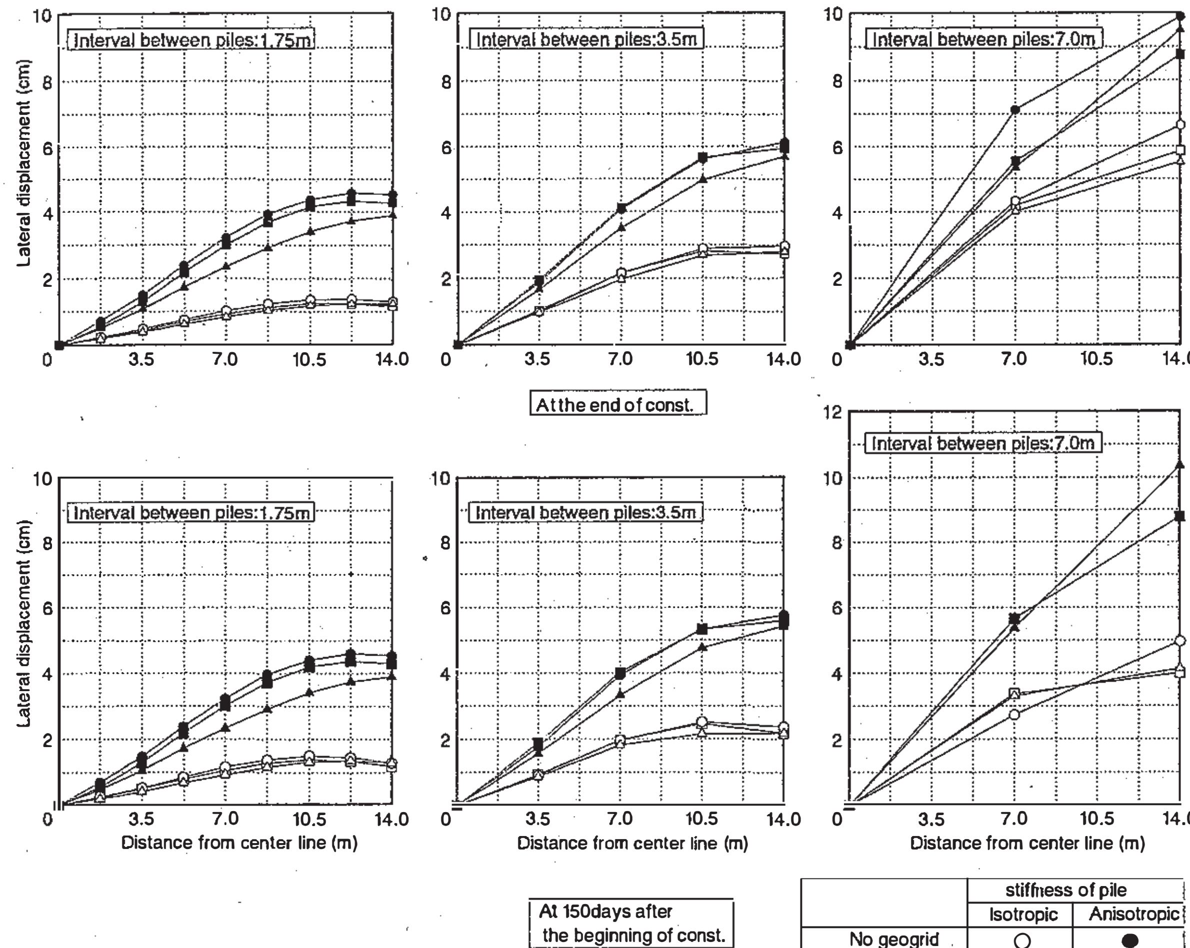
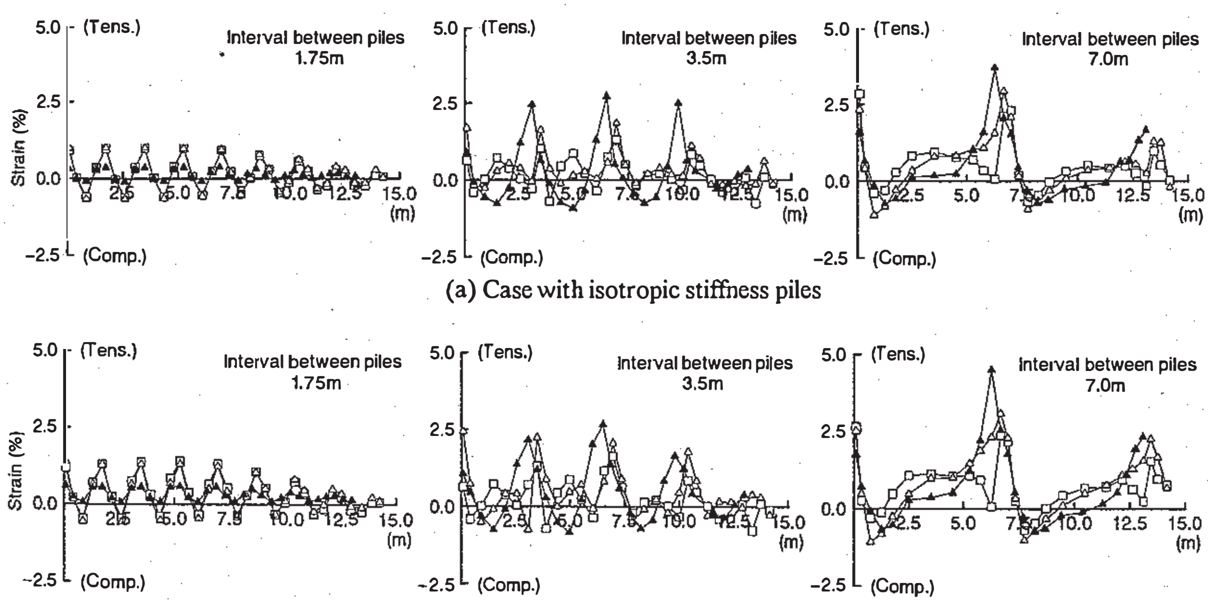


Fig.5 Distribution of axial stress at the top of piles



	stiffness of pile	
	Isotropic	Anisotropic
No geogrid	○	●
1layer of geogrid	□	■
2layers of geogrid	△	▲

Fig.6 Distribution of lateral displacement at the top of piles



(a) Case with isotropic stiffness piles

(b) Case with anisotropic stiffness piles

□ 1layer of geogrid
△ 2layers of geogrid (Lower)
▲ 2layers of geogrid (Upper)

Fig.7 Distribution of strain of geogrids interval up to 3.5m, and geogrids contribute to transfer vertical stress acting on the foundation grounds between piles to the top of piles.

Fig.6 shows the distribution of the lateral displacement on the top of piles. It is found that the longer the pile interval is, the larger are reinforcing effects of geogrids. Especially, in the case of anisotropic piles which have lower lateral stiffness, the reinforcing effects of geogrids appear to be large. Also, it is found from these figures that residual displacements are little after the end of the construction for the case with geogrids.

Fig.7 shows the distribution of the strain of geogrids. For all analytical cases, large tensile strain of the geogrids occurs near the top of piles , and small compressive strain occurs between piles. The longer the pile intervals are, the greater is the tensile strain of upper geogrids located on piles. Therefore, in comparison with the reinforcing effects of one layer of geogrids, those of two layers of geogrids appear large if pile intervals become larger.

4. CONCLUSIONS

A series of finite element analyses for reinforced embankment foundation ground were done on the influence of the interval between piles and the number of geogrid layers overlaid on pile group. The principal conclusions drawn from these analyses may be summarized as follows:

1) The reinforcing effects of geogrids on the maximum relative settlement between pile and foundation ground surface suddenly appear to be significant if the value of the pile interval reaches a certain value (=7.0m in these analyses).

2) Geogrids, especially two layers of geogrids, overlaid on pile group, especially anisotropic stiffness piles, contribute to reduce the lateral displacement at the top of pile. Therefore, the effects by geogrids are similar to those by steel bars connecting each piles.

3) The reinforcing effects of two layers of geogrids are remarkable in comparison with one layer of geogrids in all analytical cases. Therefore, it is considered that two layers of geogrids and soils between geogrids contribute to obtain good effects.

4) The longer the pile interval is, the larger is the strain of upper geogrids near the top of pile. Consequently, the reinforcing effects become appear to be large if the number of geogrid layers increase.

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