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EFFECTIVENESS OF REINFORCEMENT IN EMBANKMENT GROUND SUBJECTED TO REPEATED SHEAR DEFORMATION

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ABSTRACT: In this research, a comparative study is done on the effectiveness of reinforcement in embankment ground. The restraint effect of ground displacement by reinforcement of sheet pile and the sheet pile combined with the nailing method are investigated by model tests and corresponding finite element analyses. An elastoplastic model and subloading t_{ij} model are used in the analyses. Two loading conditions were applied namely, the simple vertical loading to the footing and cyclic loading associated with repeated shear deformation in the ground for both series of the model tests and the finite element analyses. Soil-water coupling analysis applying an inertial force to real ground embankment is also performed. It is revealed that when the bearing capacity of the ground increases, the lateral and vertical displacements are restrained. The reinforcement by the sheet pile combined with the nailing method is effective compared with that of the sheet pile alone.

Keywords: Embankment, reinforced ground, bearing capacity, finite element analysis

1. INTRODUCTION

It is necessary reinforcing the subsoil beneath the embankment to prevent any damage to the nearby structures or failure of the embankment [2]. In recent years, many designers around the world are specifying base reinforcement as one of the solutions for the short-term instability to make use of the tensile strength of the reinforcement to limit the spreading of the embankment and lateral displacement of the foundation [5], [8]. In this research, effectiveness of reinforcing in embankment ground has been investigated and reinforcing mechanism has been clarified by laboratory model tests and the corresponding numerical simulations. To analyze the behavior of reinforced earth structure on soft ground, it is necessary to consider (i) the elastoplastic behavior of soil, (ii) soil/reinforcement interaction, and (iii) soft ground consolidation systematically and simultaneously [1]. The numerical analyses are carried out with a finite element program called FEMtij-2D, using the elastoplastic subloading t_{ij} model [4]. This model can describe the typical stress, deformation and strength characteristics of soils, such as the influence of the intermediate principal stress, the influence of stress-path dependency of the plastic flow and the influence of the density and/or the confining pressure.

2. OUTLINE OF MODEL TESTS AND ANALYSES

2.1 Model Tests

Fig. 1 shows an apparatus for laboratory model test. The model test was conducted with the aspect ratio of 1:100 between the model tests and prototype scale. The width of the ground is 100cm and having the height of 50cm. A stack of aluminum rods, in which two kinds of round rods having diameters of 1.6mm and 3.0mm are mixed in the weight ratio of 3:2, was used as the model ground. The unit weight of the mass of aluminum rods is 20.8kN/m^3 at model stress level. The width of the loading plate is 12cm with the thickness of 3cm which corresponds to the width of the embankment in real field. The sheet piles are emulated with aluminum boards. The thickness of the aluminum board is obtained considering the same similarity ratio between the model tests and prototype scales.
Fig. 2 shows the footing model and parameters for reinforcement. Here, the thickness (t) of 0.5mm is employed. The distance of the sheet pile from the edge of the loading plate, Hw, is 3cm. In the nailing method, a tracing paper is being spread into the ground with an angle of 30° from the horizontal direction. In the tracing paper, aluminum rods were glued with an interval of 1cm to provide frictional behavior in the nailing. The load is applied on the loading plate with a motor which is attached to the loading device, and the magnitude of the load is measured with a load cell installed at the tip of the device. A slider is attached in the loading device to permit the lateral displacement of the base loading plate. Photographs are then taken during the experiments and they are used later as input data for the determination of ground movements with a program based on the technique of Particle Image Velocimetry (PIV). Several model tests have been conducted varying the length of the sheet pile L=12cm, 24cm, and the length of the nailing L_N=6cm, 9cm, to investigate the effects the length of the sheet piles and nailing in the applied repeated shear into the ground. The test patterns are listed in Table 1.

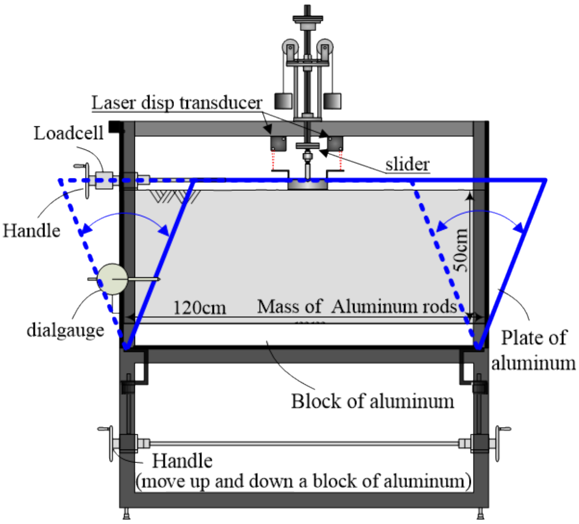


Fig. 1 Layout of the apparatus for model tests

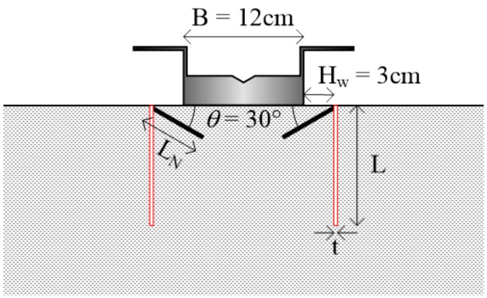


Fig. 2 Dimensions of reinforcement

Table 1. Test patterns

		sheet pile	length of nailing L_N	
			L_N=6cm	L_N=9cm
lenngth of sheet pile	L=12cm	t=0.5mm	t=0.5mm	t=0.5mm
	L=24cm			t=0.5mm

2.2 Numerical Simulations

An elastoplastic constitutive model for soils, called the subloading t_{ij}-model [4], was used in finite element analyses. Model parameters for the aluminum rod mass are shown in Table 2. The parameters are fundamentally the same as those of the Cam clay model [6] except for the parameter *a*, which is responsible for the influence of density and confining pressure. Where, λ and κ are the slope of loading and unloading curve of *e-lnp* graphs at the loosest state. *N* is the void ratio at mean principal stresses (p) 98kPa in the above mentioned loading curve and ν_e is the Poisson's ratio. The parameter β controls the shape of yield surface. Fig. 4 shows the results of biaxial tests for the mass of aluminum rods used in the model tests. The figure shows the positive and negative dilatancy of aluminum rod mass; and it is clear that the strength and deformation behavior are very similar to those of medium to dense sand.

Fig. 3 shows the mesh used in the finite element analyses for the analyses of the model tests. Isoparametric 4-noded elements are used to represent the soil. The mesh is well refined with elements of finer mesh in most regions. The sheet piles and soil nailing method are modelled using elastic beam elements. The frictional behavior (friction angle δ=18^o) between the reinforcements and the ground is simulated using elastoplastic joint elements [3]. The frictional angle, δ=18^o, was obtained from a laboratory model test. Both vertical sides of the mesh are free in the vertical direction, and the bottom face is kept fixed. The analyses were carried out under plane strain conditions, since the aluminium rods do not deform in the out of plane direction. The analyses are carried out with the same conditions of the model tests. The initial stresses of the ground are calculated by applying the body forces due to self-weight (γ=20.4kN/m^3), starting from a negligible confining pressure (p_0=9.8×10^{-6}kPa) and an initial void ratio e=0.35. After self-weight consolidation the void ratio of the ground was 0.28 at the bottom and 0.30 at the top.

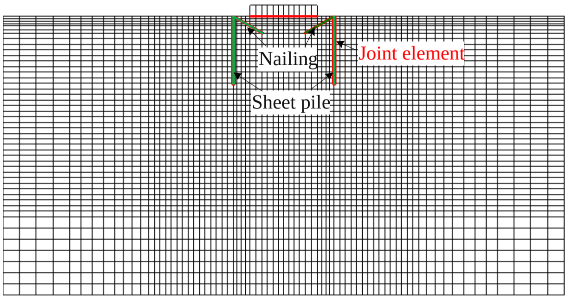


Fig.3 Mesh for Finite Element Analyses

Table 2 Material parameters for aluminum rods

λ	0.008	Same parameters as Cam- clay model
κ	0.004	
N (e_{NC} at p=98kPa & q=0kPa)	0.3	
R_{CS}=$(\sigma_1/\sigma_3)_{CS(comp.)}$	1.80	
ν_e	0.20	
β	1.20	Shape of yield surface (same as original Cam-clay at β=1)
a	1300	Influence of density and confining pressure

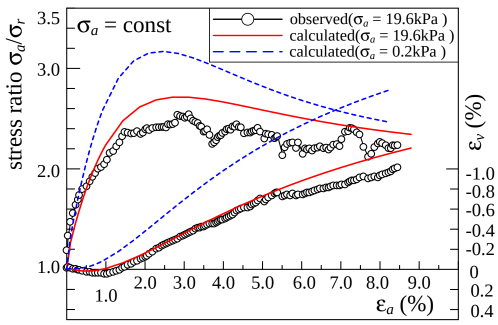
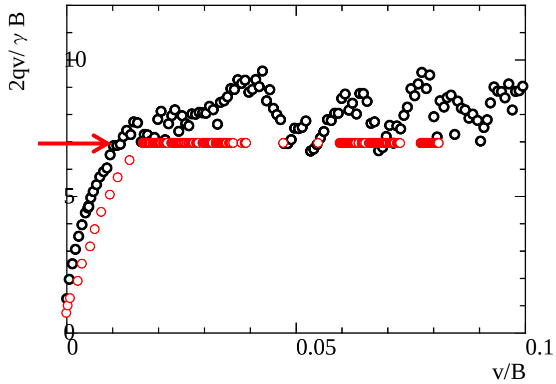


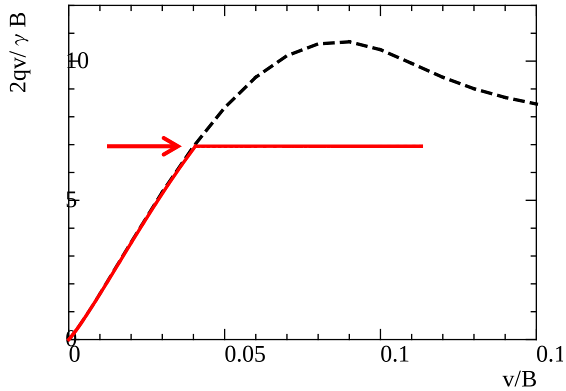
Fig. 4 Stress-strain-dilatancy relation for the mass of aluminum rods

2.3 Loading conditions

Fig. 5 shows the results of model test (illustrated in black open circle) and numerical analyses (illustrated in black dashed line) of the load bearing capacity in unreinforced ground. In the repetitive shear tests, as shown in both figures (red open circle and red solid line), the dead load of around 70% of the ultimate load was applied to the ground, and the repetitive shear deformation corresponding to the horizontal seismic coefficient of k_H=0.4 was employed on the ground under the loading condition shown in Fig. 6. From the results of vertical load test [7], test patterns (Table 1) are chosen for which the significant effects were achieved.

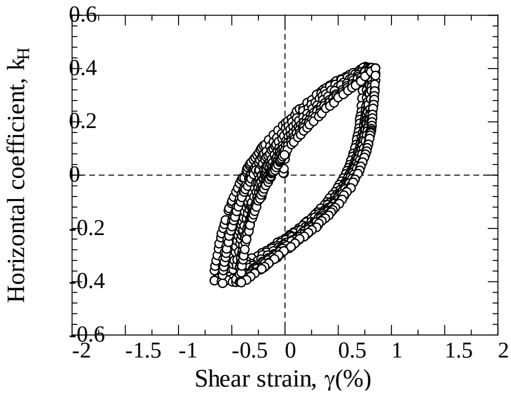


5(a) Observed

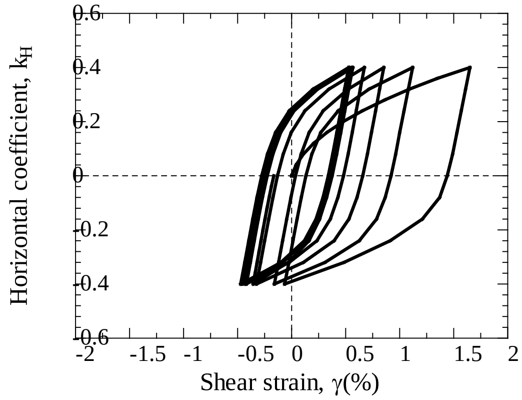


5(b) Computed

Fig. 5 Initial vertical loading condition



6(a) Observed

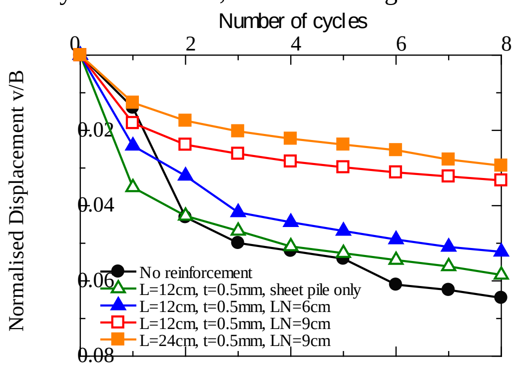


6(b) Computed

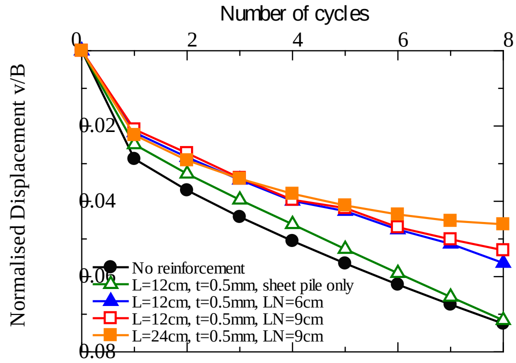
Fig. 6 Loading conditions for repeated shear

3. RESULTS AND DISCUSSIONS

Fig.7 shows the observed and computed normalized displacement with respect to the increments of the footing subsidence caused by the increase of loading cycle. Here, the vertical displacement (v) is normalized by dividing with the width of the footing (B). It is revealed from the model tests that there is a little effect of sheet pile alone in restricting the subsidence of the foundation. In contrast, the subsidence of the foundation is controlled significantly when the nailing is combined with the sheet pile. However, the degree of the reinforcing effect is small for L_N=6cm in the model test though the sufficient effect can be seen in the analysis. Moreover, even if the length of sheet



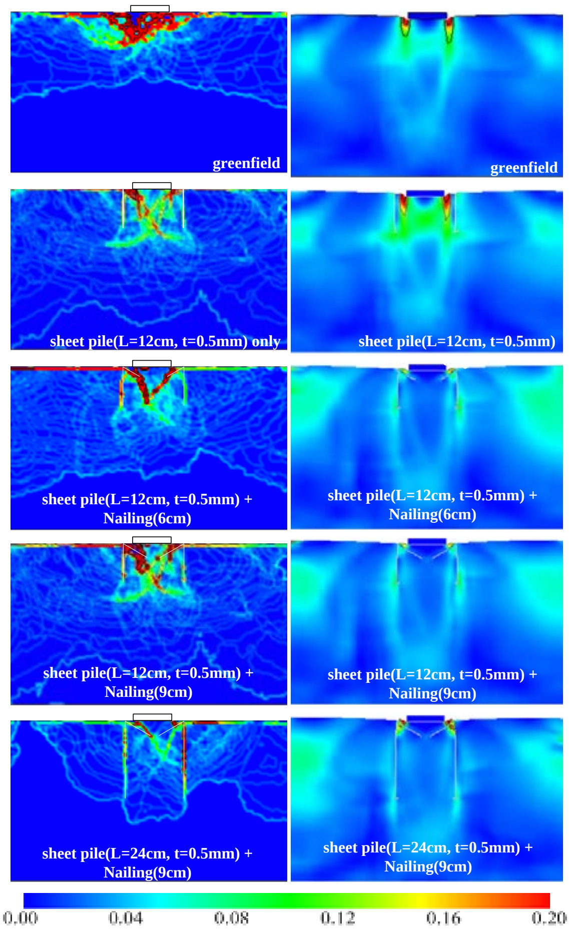
7(a) Observed



7(b) Computed

Fig. 7 Normalized displacement in cyclic loading pile does not show significant change, which agrees well the results of the static vertical loading [7].

Fig.8 represents the deviator strain distribution of the ground tests and numerical analyses generated when the shear deformation is repeatedly imposed to the ground up to eight cycles. From the figures, even if the shear deformation is repeatedly applied, the generation of the deviator strain is hardly seen right under the foundation when nailing is attached with the sheet pile. On the other hand, the area with the large deviator strain develops right under the foundation due to the repeated shear imposed into the ground when sheet pile alone or no reinforcements are used in the ground. Therefore, it can be said that the subsidence is controlled by the embedment effect of the combination of sheet pile and the nailing, the same as the case of static vertical loading [7].



8(a) Observed 8(b) Computed

Fig.8 Distribution of deviatoric strain

4. SIMULATIONS ON THE EFFECT OF REPEATED SHEAR IN FIELD

In the previous section it was seen that the numerical analysis can well reproduce the results of the model tests in all cases of test patterns. In this section, the results of the soil-water coupling analysis for the effect of inertial force to real ground having embankment will be discussed. The results of the consolidation have already been reported in the reference [7]. Fig. 9 illustrates the ground types with the dimensions of the embankment to be analyzed in this section. The levee crown width is 5m, the bottom width is 25m, and the height is 5m of the embankment with an inclination of 1:2. Fig. 10 shows the mesh for the finite element analyses. The width of the ground is 125.0m having 60m in depth. The bottom face is assumed as fixed boundary condition. The vertical faces are kept free in both directions during applying the repeated shear along with both boundaries of the ground. The analyses are carried out considering soil-water coupled and plane strain conditions. The top surface of the ground is allowed to drain, and all other faces are assumed as impermeable boundaries. The water table is assumed at the top of the ground. To consider the soft soil, parameters of Fujinomori clay (bulk unit weight, γ_t=18.52kN/m³) is used as the base ground, and Toyoura sand (bulk unit weight, γ_t=15.48kN/m³) is used as the material of soil fill. The material parameters are shown in Table 3. The coefficient of permeability for the ground is assumed as 10^{-7}m/min. The ground, normally consolidated clay (OCR=1.0), is used to investigate the dependency of ground stiffness.

Fig. 11 shows the stress-strain-dilatancy relation at triaxial condition for (a) Fujinomori clay with normally consolidated condition and (b) Toyoura sand with relative density Dr=75% under constant cell pressure.

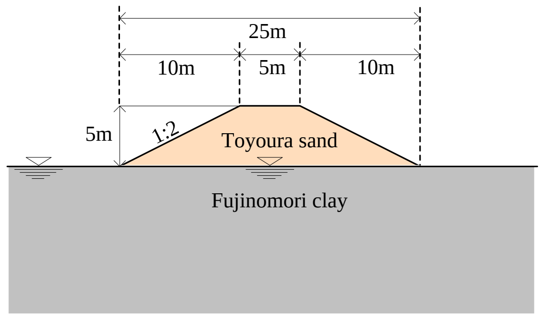


Fig. 9 Dimensions and ground types of embankment

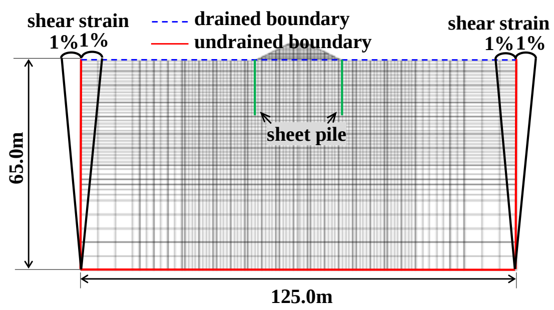


Fig. 10 Mesh for FEA- real ground

Table 3. Parameters for Fujinomori Clay and Toyoura Sand

Parameters	Fujinomori Clay	Toyoura Sand
λ	0.10390	0.070
κ	0.00990	0.0045
N (e_{NC} at p=98kPa & q=0kPa)	0.9220	1.10
$R_{CS}=(\sigma_1/\sigma_3)_{CS(comp.)}$	3.20	3.20
ν_e	0.20	0.20
β	1.50	2.00
a	500	$a_{(AF)}$=30 $a_{(IC)}$=500

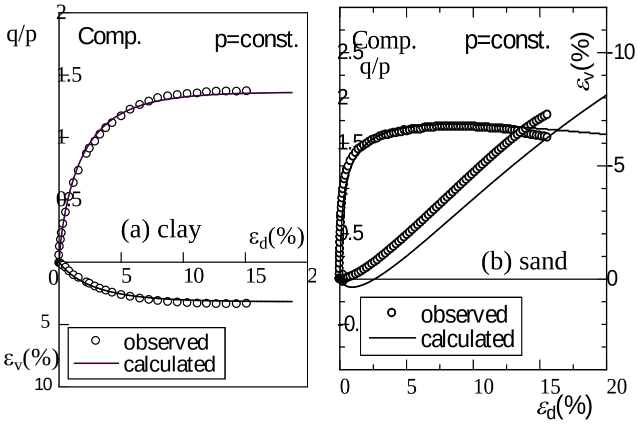


Fig. 11 Stress-strain relation of clay and sand

Table 4. Computed patterns

Case	Reinforcement patterns
1	no reinforcement
2	sheet pile (flexible)
3	sheet pile (stiff)
4	sheet pile (flexible) with nailing
5	sheet pile (stiff) with nailing
6	sheet pile (flexible) with tie rod
7	sheet pile (stiff) with tie rod

In the simulations of the repeated shear in real field, seven cases of numerical simulations have been carried out as shown in Table 4. Here, two types of rigidities of the sheet pile – flexible and stiff with the thickness (t) of 30mm and 50mm, respectively, are employed. In the reinforcement of sheet pile combining with tie rod, the tie rod is modelled with truss element where bending stiffness is not considered. The sheet pile and the nailing are modelled with the beam element the same as the analyses of the model tests.

Fig. 12 shows displacement vector in the ground. Deformations of ground after 8 cycle of loading are shown for all of the cases. The ground substantially deformed in the case of no reinforcement, and the similar tendency is seen when only sheet pile is used as reinforcement. The reinforcement with sheet pile (both flexible and stiff) is not effective for restraining settlement of embankment. The results are similar to the results of 1g condition which are described in the previous section. Restraining ettlement of the embankment is seen when the ground is reinforced by sheet pile with nailing for both stiff and flexible sheet piles, and, the sheet pile with tie rod as well. It may be said that, the ground reinforcing by the sheet pile attached with nailing or tie rod let the embankment hard to be deformed and settled.

Fig.13 shows the surface settlement along the embankment for different methods of reinforcement. The abscissa represents the horizontal distance starting from the toe of the embankment. The distance bounded by two vertical dotted lines represents the surface of the levee crown from the left to the right direction. The data represents the results after applying 8 cycle of shear deformation into the ground. The figure confirms the effectiveness of the sheet pile with nailing and tie rod in restraining the settlement of the embankment.

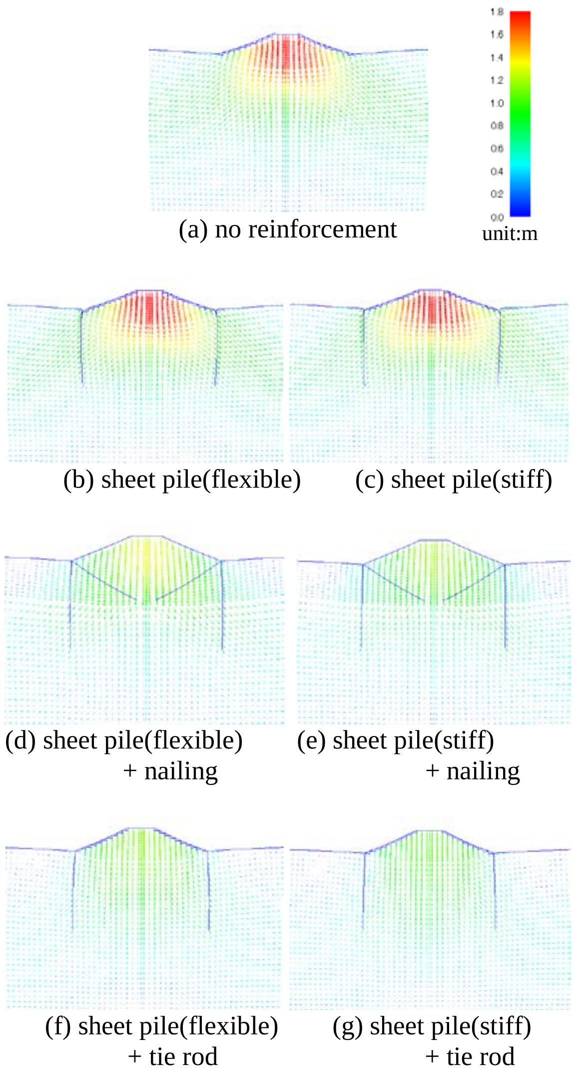


Fig. 12 Displacement vector in the ground

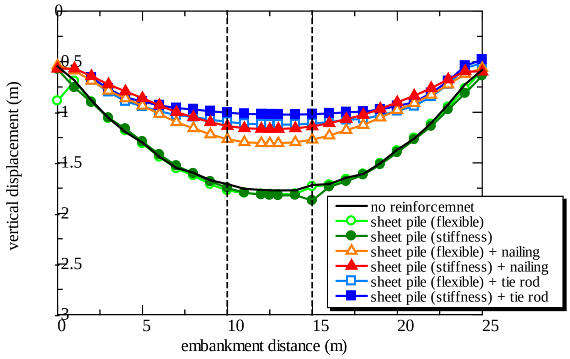


Fig. 13 Surface settlement along the embankment

Fig 14 shows the lateral displacement of the sheet pile (left side) which is located at 3m away from the toe of the embankment. The data represents the results after applying 8 cycle of shear deformation into the ground as same as Fig 13. The results of the ground without reinforcement along the depths at the same place of the sheet pile located are also included in the figure. It is found that sheet pile with nailing or with tie rod reduces the lateral movement of the ground significantly.

Therfore, from the above discussions the reinforced case by sheet pile with nailing and tie rod is equally effective for restraining displacement.

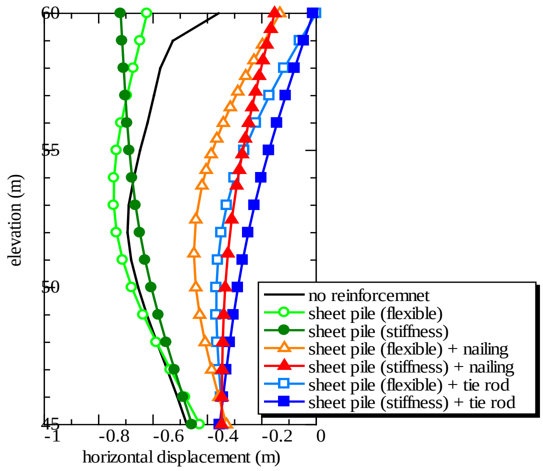


Fig. 14 Lateral displacement of the left sheet pile

5. CONCLUSIONS

In this research, effectiveness of reinforcement method on embankment ground has been investigated with laboratory model tests and numerical simulations study. It is found that in the case of the reinforcing with the sheet pile alone, no significant reinforcing effect is observed for repeated cyclic loading. In contrast, in the case of the composite reinforcing method (sheet pile with nailing), a significant reinforcing effect is seen as the lateral displacement of upper part of the sheet pile is impeded due to the inclusion of the nailing. Even the shorter length of the sheet pile produces almost the same effects as those of the longer sheet pile when nailing is appended along in the reinforcing method. The finite element program FEMtij-2D properly predicts the results of the model tests on the reinforced ground. The subsidence of the embankment and the lateral displacement of the ground can be reduced by introducing reinforcement in a real ground. The composite reinforcement where soil nailing method is combined with the sheet pile caused a significant reinforcing effect on a soft ground. The finite element analyses can give a guideline for the prediction of deformation pattern and for the optimum dimensions of the reinforcement in the soft ground.

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