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A new countermeasure for soft ground using surface stabilization and geosynthetics

Masuda, H.
Road Bureau, National Highway and Risk Management Division, M.L.I.T., Japan

Yokomine, M.
FUKUOKA National Highway Office, M.L.I.T., Japan

Okochi, Y.
NOM Co. Ltd., Japan

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ABSTRACT: As a new countermeasure for stabilising soft ground during construction of embankment, combination of surface stabilization and high strength web-shaped geosynthetics was adopted. Elasto-plastic FEM analysis was carried out to investigate the effective position of geosynthetics and its consolidation behaviour. Geosynthetics were positioned the bottom part of the stabilized layer to control the occurrence of tensile stress in the stabilised layer. As for the consolidation behaviour, though the drainage condition was regarded as a single drainage and required time for convergence of the settlement was certainly long, computed duration was much shorter than it if the anisotropy of the permeability was considered.

Monitoring mainly settlement was carried out during construction. Embanking procedure was rather irregular because of the restriction of the construction schedule and supplying condition of the banking material. Nevertheless the behaviour of the stabilized ground was stable and the time for the convergence of settlement was much shorter than computed by single drainage. This situation was well explained by the FEM analysis considering anisotropy of the consolidation characteristics. As a consequence, this method is expected as one of the effective and low cost countermeasure for soft ground.

1 INTRODUCTION

Ariake sea coastal road will become a local high standard highway from Omuta-city, Fukuoka prefecture to Kashima-city, Saga prefecture. About half part of this road will be constructed by high embankment on soft ground. The thickness of the soft layer is three to 15 meters and its N-value is zero to one.

In order to reduce the construction cost, proper method for evaluating soil property of soft ground and choosing counter measures are the major subjects to be solved. For this purpose, full-scale test embankments were carried out. Through the observed data of these tests, soil parameters for design could be revised (Masuda et. al. 2005). The overview of test embankments was shown in Photo 1.

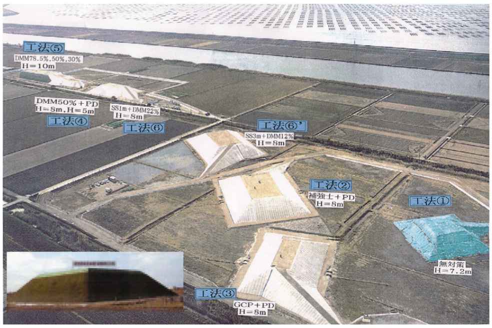

Photo 1. Overview of the test embankments.

Also, utilising high strength web-shaped geosynthetics (Kawahara et. al. 2004) was regarded as effective and lowest cost method for stabilizing the slope. However, it was apprehended the occurrence of significant deformation if the reinforcement was geosynthetics only for the case that computed factor of safety of the slope stability was much lower than 1.0 without any countermeasure. In order to secure more stable behaviour, a new method utilising surface stabilization and high strength web-shaped geosynthetics was adopted.

In order to investigate the behaviour of the embankment during construction, FEM analyses were carried out. Elasto-plastic deformation analysis was aimed to determine the appropriate position of the geosynthetics and the purpose of consolidation analysis was to evaluate the time of convergence of the settlement.

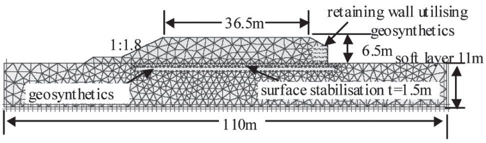

Figure 1. Model mesh of CASE d-B.

2 ANALISES BY FEM

For the purpose of investigating the proper position of the geosynthetics and the behaviour during consolidation, two-dimensional FEM analyses were carried out.

Hardening soil model of PLAXIS (PLAXIS B. V. 2002) was used to consider the nonlinearity of the soft soil. The parameter used in the analyses was listed in Table 1. As these analyses were rather intended parametric study, this parameter was determined by considering the result of test embankment and the data from soil exploration. Although diluvial clayey-sand layer was underlying beneath the soft ground, as the anticipated deformation of this layer was negligibly small, this layer was not modelled in the analyses. Surface stabilised layer was modelled by Mohr-Coulomb.

The finite element mesh used was shown in Fig. 1

For the plane strain elements, six-node triangular was used. Total number of nodes was 2895 and that of elements was 1386. Geogrid element was used for high strength web-shaped geosynthetics. This element is a kind of truss that works only tensile force.

Following two cases were analysed to investigate the difference of the effect of position of geosynthetics.

(1) CASE d-A
Geosynthetics was laid on the surface stabilisation.

(2) CASE d-B
Geosynthetics was laid under the surface stabilisation.

In general, CASE d-A is easier method for construction. However, as a tensile reinforcement should be located tensile side, in these cases, CASE d-B was regarded better method than d-A. The purpose of the simulation was to evaluate the difference.

For the consolidation analysis, diluvial clayey sand layer of 7.5 m thick was added at the bottom as drainage and width of the model was widened to 300 m.

Following two cases were analysed to investigate the behaviour of consolidation. The speed of embanking was 10 cm/day.

(1) CASE c-A
The permeability coefficient was isotropic i.e. k_h equals to k_v.

(2) CASE c-B
The permeability coefficient was anisotropic and k_h equals to $5 \times k_v$.

From the oedometer test, c_v was around 1000 cm^2/day and k_v was around 1×10^{-6}cm/s.

For the embanking material and diluvial layer, almost full drainage was assumed and input parameter for permeability was three order higher than sandy-silt. As the surface stabilisation was assumed as impermeable and adopted value was four order lower than sandy silt.

3 ANALYSYS RESULTS

Settlement at the centre of the embankment was compared in Table 2.

Table 2. Settlement at the center of embankment.

CASE	Settlement (m)
d-A	1.06
d-B	1.00

Settlement was almost the same in both cases. However, as shown in Fig. 2, the occurrence of tension cut-off points was certainly different.

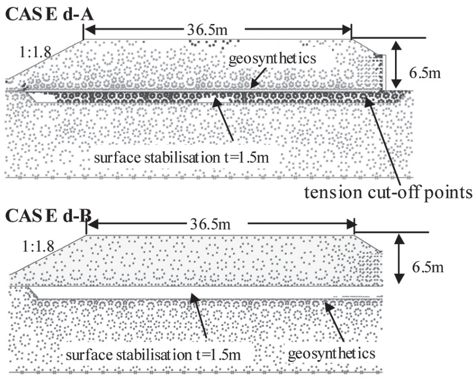

Figure 2. Comparison of tension cutoff points.

Table 1. Soil parameters for hardening soil model.

Soil	Thickness m	N: SPT	γ_t kN/m^3	E_{50} kN/m^2	E_{oed} kN/m^2	C kN/m^2	$\phi°$	ν
Sandy-silt	11	0-1	16	1000	1074	7.6	10	0.42
Embankment	6.5	10	19	9000	9803	0	30	0.33
Surface stabilised layer	1.5	50	15	60000*	–	200	0	0.2

Note:*1: Empirical equation from unconfined compression test.

This meant that CASE d-B showed less possibility of progressive failure due to tensile stress in surface stabilised layer.

Regarding consolidation characteristics, as the surface stabilised layer by using cement was regarded as impermeable in general, consolidation behaviour was usually considered as single drainage. If the one-dimensional consolidation was supposed, it was evaluated that more than two years to achieve U_{90}. However, actual behaviour of the consolidation is multidimensional. So, analytical investigation by using two-dimensional FEM was carried out.

Comparison between the results of above three methods was illustrated in Fig. 3. From these results, computed time of convergence by one-dimensional consolidation is certainly longer than two-dimensional FEM. Even in the case c-A, necessary time to U_{90} was less than 80%. In the case c-B, it was less than 1/7.

In general, it is said that k_h is three to five times greater than k_v. If this situation was considered, convergence time for the consolidation had to be certainly shorter than one-dimensional consolidation.

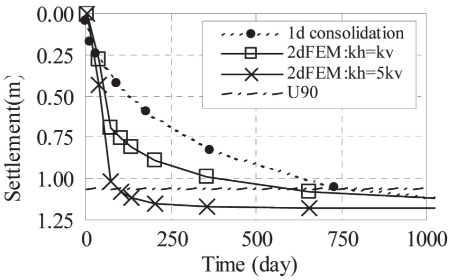

Figure 3. Comparison of computed results.

4 CONSTRUCTION METHOD AND OBSERVED SETTLEMENT

From above mentioned analytical results, placing the high strength web-shaped geosynthetics under the soil stabilisation was conducted by following procedure.

(1) Excavate the ground to specified depth with slope so that heavy machine could go down.
(2) Place the high strength web-shaped geosynthetics. Then, trafficability was assured.
(3) Improve the soil on the ground. A self-propelled soil improving machine was used in this case. Then, refill the improved soil and compact.
(4) Embank up to design height by specified speed.

The method was illustrated in Fig. 4. In Japan, the cost of this method is lower than in-situ mixing method in general.

The situation during construction was shown in Photo 2. Though the excavated bottom was wet and soft, due to the high strength web-shaped

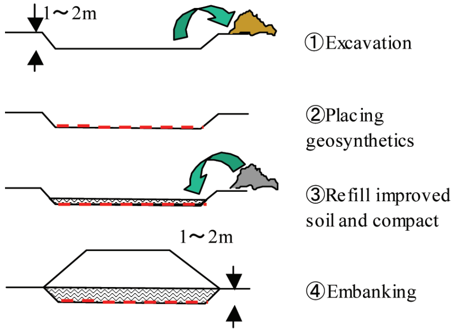

Figure 4. Construction procedure.

Photo 2 Placing geosynthetics and improved soil.

geosynthetics, improved soil could be placed and compacted on it.

The embanking procedure was irregular because of the restriction of the construction schedule and supplying condition of the banking material. Four steps of embanking was carried out as shown in Fig. 5. Though the shape of the embankment was not exactly the same as analyses, the tendency of the behaviour of embankment could be evaluated. The observed points of this section were also illustrated in Fig. 5.

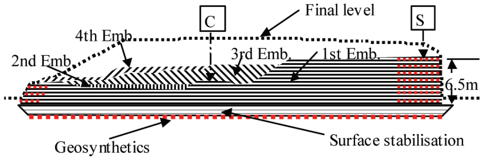

Figure 5. Embanking procedure and mesured points.

Comparison between observed data at C and results of analysis was plotted in Fig. 6. Embanking at C was about one year delayed than first embanking and the height is still 4.8 m. So, it was not appropriate to compare the data directly. However, it could be understood that the time for convergence was much shorter than one dimensional consolidation.

The observed data at S was much simpler because first embanking was carried out almost continuously up to 6.5 m which was the same height as the analysis.

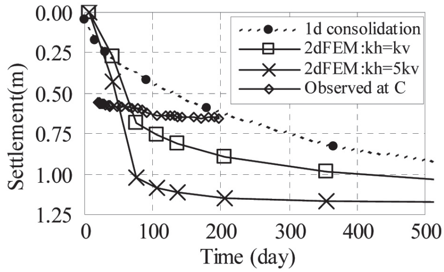

Figure 6. Comparison of computed results and observed data.

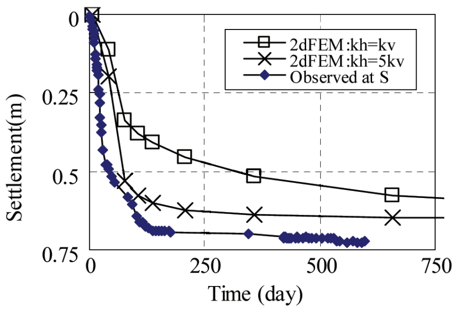

Figure 7. Comparison of computed results and observed data near the vertical wall.

The results were shown in Fig. 7. The case c-B showed good agreement with the observed data. It was suggested that even though the width of the embankment was around 50 m, two dimensional consolidation had to be considered. In addition, anisotropy of the permeability had to be taken into account. If one dimensional consolidation was applied for the design, the time until convergence might be overestimated.

5 CONCLUSIONS

As a new countermeasure for stabilising soft ground during construction of embankment, combination of surface stabilization and high strength web-shaped geosynthetics was adopted. Elasto-plastic FEM analysis was carried out to investigate the effective position of geosynthetics and its consolidation behaviour. After a part of embanking, observed settlement was compared to the analysis results. From this investigation, following conclusions were obtained.

(1) The case that geosynthetics were placed at the bottom of surface stabilisation showed much less tension cut-off points in the layer than the case it placed on the layer.
(2) The time for convergence of consolidation was much shorter in two dimensional FEM than one dimensional consolidation with single drainage.
(3) The field observed data showed good agreement with the analysis of two dimensional FEM considering anisotropy of permeability.

As this new countermeasure for soft ground showed stable behaviour during construction and acceptable convergence time of consolidation, this method can be expected as one of the effective and low cost countermeasure for soft ground.

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