New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Case study of Geotextile Method on extremely soft ground

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ABSTRACT: The New Kitakyushu Airport is an off-shore airport constructed on the ground filled up by dredged soils from various port projects. Those dredged soils are classified as very soft clayed soil with over 300% water content immediately after discharged. For airport construction, the settlement acceleration work was necessary to be conducted with a view to secure trafficability and soil stabilization, and also to improve bearing strength of the ground. The Geotextile Method has been adopted for this purpose. As a large-scale rupture of geotextile occurred during construction, some countermeasures have been proposed to achieve safe construction based on those work experiences. Test soil stabilization works were carried out together with laboratory analyses to confirm the trafficability of the ground after sand spreading as a cover. The analyses confirmed that the geotextile rupture occurred due to differential strength distribution of ground, and non-uniform thickness of soil spreading accompanied by load concentration on geotextile.

1 INTRODUCTION

The New Kitakyushu Airport is an off-shore airport constructed about 3km off-shore from Kitakyushu City, Fukuoka Prefecture. The air port ground was filled up by dredged soils disposed from the adjacent construction works of Kanmon Navigation Channel and New Moji Navigation Channel. The disposal site of dredged soils was made up of four separate divisions as shown in Figure 1.

The dredged soil brought over to the disposal site were composed of supersoft clayey soil with water content of 2000% just after dredging and with 300% immediately after discharged into the disposal site. Furthermore, it is a clayey soil that undergoes consolidation settlement over a long period of time.

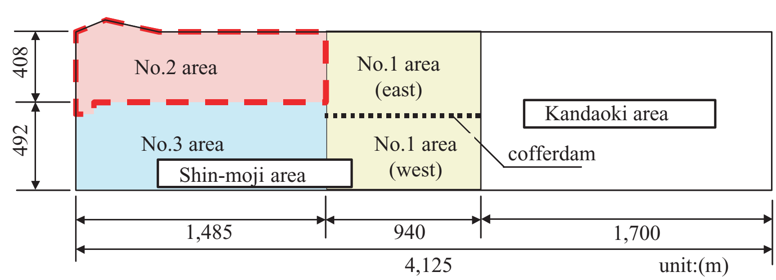

Figure 1. Plan view of New Kita-Kyushu airport construction site.

To construct an airport according to a fixed time schedule on such an extremely soft ground, it is necessary to improve the latter to a degree of hardness with the residual settlement brought down to an allowable limit. With the idea in mind, first the upper soil-layer treatment was conducted to secure trafficability and then the ground was improved to obtain sufficient bearing strength by means of consolidation settlement acceleration method and also to secure hardness gain by means of settlement acceleration method.

In this project geotextile method was adopted as a kind of surface treatment method for Shin-moji No.1 Work Section. However a large-scale geotextile rupture occurred during sand spreading. Hence, following that incident, studies were conducted to find causes of and countermeasures against geotextile rupture in order to safely conduct surface treatment method and settlement acceleration method. Furthermore, conducting loading tests by the use of ground improvement equipment, the trafficability of construction machines on the ground was checked. And then on the basis of the results, the new ground improvement and management system was formulated and applied to the project and the ground improvement works were successfully completed. In this paper, the outline of the case of geotextile rupture that occurred in Shin-moji No.1 Work Section shall be described together with the results from loading tests conducted by using ground improvement equipments.

2 THE OUTLINE OF GROUND AT SHIN-MOJI NO.1 WORK SECTION

Figure 2 shows the composition of ground at Shin-moji No.1 Work Section just after dredged soils were discharged (Egashira 2003). It is a typical presumed cross-sectional view of the ground. From this figure, it is learnt that the dredged clayey soil of thickness about 15 m were discharged onto the soft alluvial clay layer of thickness 3 m ~ 7 m.

Figure 3 shows the distribution with depth of physical characteristics and strengths of dredged clayey soil layer. From this, the shear strength of this ground is $\tau = 0.055 \sim 1.149\,kN/m^2$, water content $w_n = 120 \sim 210\%$ and wet density $\rho_t = 1.25 \sim 1.40\,g/cm^3$. These characteristics reveal that it is a super-soft clayey soil.

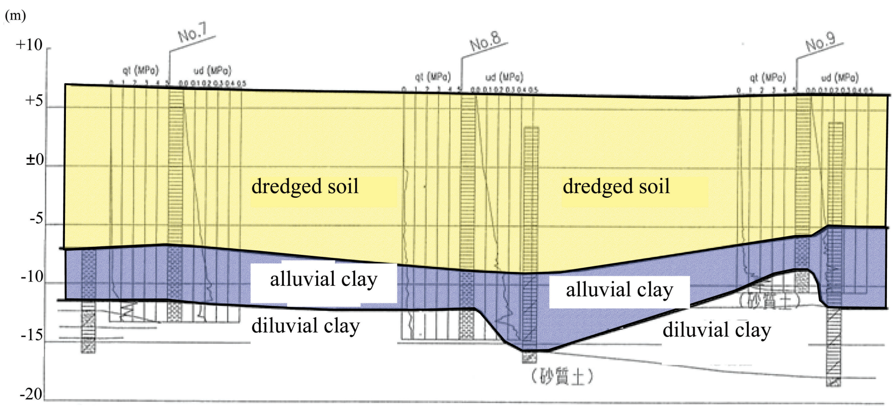

Figure 2. Presumed cross-sectional view of ground (Shin-moji NO.1 work section).

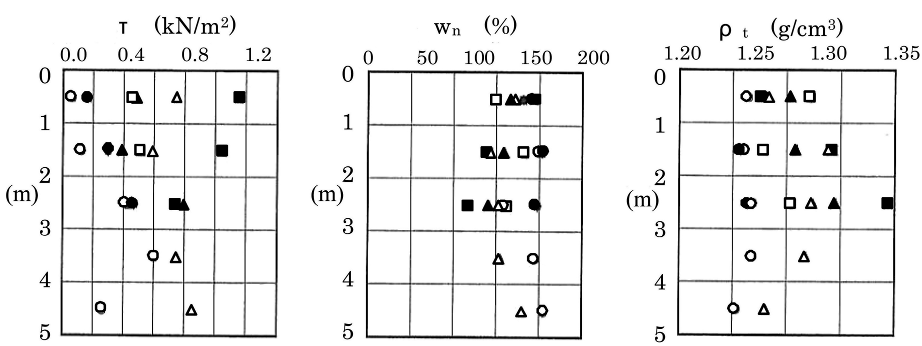

Figure 3. Strength and physical characteristics of dredged clayey soil layer (Shin-moji No.1 work section).

3 SUMMARY OF CONSTRUCTION WORKS AT SHIN-MOJI NO.1 WORK SECTION

As stated above, the dredged clayey soil has an extremelty low strength and in such a condition, it cannot be developed or improved to become a ground for construction works. Hence surface-layer treatment method was employed, in which sand spreading was done by hydraulic conveyor method after geotextiles were laid on the soil. The tensile strength of geotextile was determined by equation 1 and Figure 4, T was taken 80 kN/m

$$q_d = \alpha c N_c + T\left(\frac{2\sin\theta}{B} + \frac{N_q}{r^2}\right) + \gamma_t D_f N_q \quad (1)$$

q_d = ultimate bearing strength
c = cohesion of clayey ground
N_c, N_q = Terzaghi's coefficients of Bearing Strength
γ_t = unit weight of soil
α = shape factor
T = Tensile strength of geotextile
D_f = Length of geotextile Settlement
r = The radius of ground when its displaced shape around loading domain is assumed appropriately as a circle
θ = Angle of inclination with geotextile

Geotextile were laid using a special reserved boat. After laying geotextiles, sand spreading was carried out. In sand spreading, first 0.9 m thick sand layer was spread using a hydraulic conveyor technique in which a micro-pump boat was employed. And then 0.6 m thick sand was spread by means of on-land conveying method in which on-land construction equipments such as bulldozer and dump truck were used. It is planned in on-land conveying method to make use of granulated slag instead of sand for weight reduction ($\gamma_t = 15$kN/m^3).

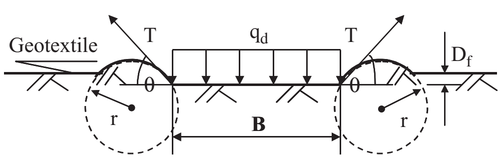

Figure 4. Transformation model concept chart of geotextile.

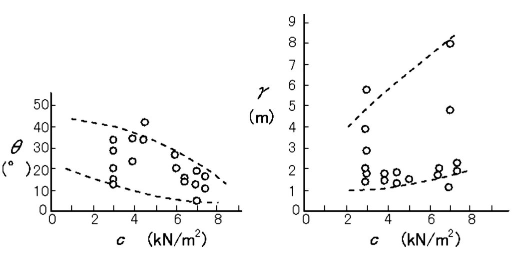

Figure 5. The relationship between c and r, θ (Nishibayashi 1980).

4 GEOTEXTILE RUPTURE

While around 50% of on-land conveying work that made use of granulated slag was in progress after the end of sand spreading by hydraulic conveyor technique, geotextile rupture suddenly occurred with the blow-out of dredged clayey soil extending to a wider area. First geotextile rupture occurred one point and got enlarged along revetment and inner separation embankment. In Figure 6, the scope of dredged soil blow-out and in Figure 7 the cross-sectional view is shown. From this it is found that the final dredged soil blow-out area is 440 m × 330 m; it is around 100,000 m^2 and the ground surface just before blow-out settled down more than 7 m with the pile-up of dredged soil on the upper layer.

5 ESTIMATION OF CAUSES OF GEOTEXTILE RUPTURE

The estimated causes of geotextile rupture are as follows.

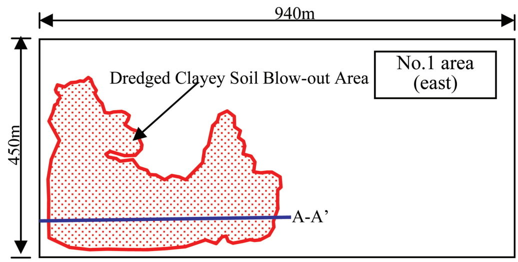

Figure 6. The scope of dredged clayey soil blow-out.

Photo 1. View of dredged clayey soil blow-out.

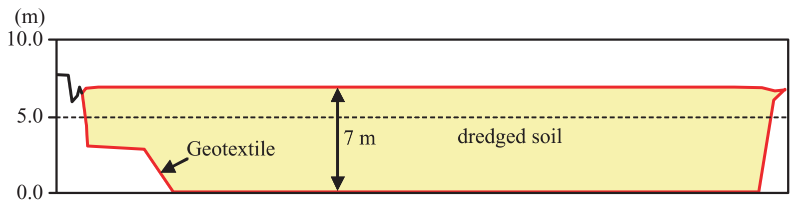

Figure 7. Cross sectional view (A-A′ Section).

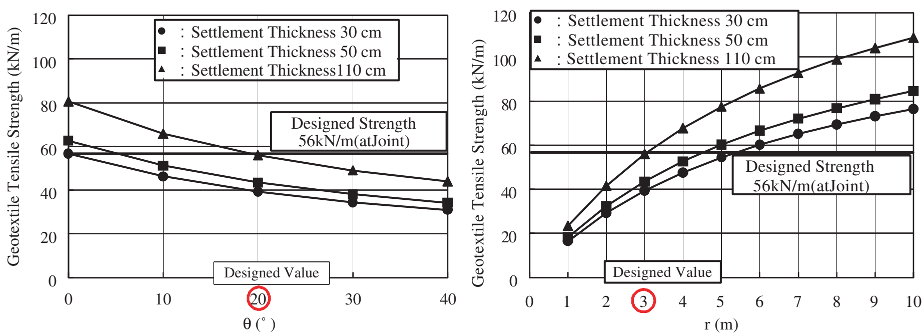

Figure 8. The relationship between r, θ and geotextile strength.

5.1 *The strength of dredged clayey soil is unevenly distributed*

When checking the procedure of land reclamation by dredged soil the site where geotextile was first ruptured n has been used as a spillway during filling of dredged soil. Generally the dredged soil was pumped in pointing toward the outer perimeter. Hence the coarse materials are prone to collect at the outer section and it is presumed that fine particles with high water content settled down at the spillway area. Thus this area had a rather low bearing capacity. And around this area some heavy equipments were passing when geotextile rupture occurred. Hence the repeated travel of heavy equipments possibly weakened the area leading to geotextile rupture.

5.2 *Sand spreading thickness is not uniform*

As stated in 5.1, that spillway area had a rather low bearing strength compared to others. Hence the settlement at this area was great leading to greater settlement by increased sand filling to compensate for the loss. Thus the non-uniform thickness of sand spreading was speculated.

5.3 *Tensile stress higher than the designed value was working on geotextile*

By equation 1, the required tensile strength of geotextile was determined assuming r and θ from ground's estimated bearing strengths.

Figure 8 shows the changes of geotextile's required tensile strengths with the changes of r and θ. From this, when r is greater than the designed value, it is possibly estimated that a great tensile stress higher than the designed value was exerting on the geotextile.

5.4 *High tensile stress was working on edge section of geotextile*

Since the ruptured geotextiles had their edges fixed to the inner separation embankment, there occurred sliding of geotextiles around that embankment as a result of ground settlement or ground bogged down and concentrated tensile stresses were exerting on a part of geotextile possibly leading to rupture.

As stated above, it is considered that various factors were involved in the rupture of geotextiles. The rupture occurred not for a single factor but for various reasons. A single rupture triggered other ruptures at other places covering a wider area.

6 COUNTERMEASURES AFTER RUPTURE

To rehabilitee the geotextile ruptures, the following countermeasures were made up on the basis of the above stated causes and improvement were made as described in Table 1.

- Increase the strength of geotextiles
- Enforce strict construction management to control sand pile-up as much as possible
- Manage Strictly the thickness of sand spreading

Table 1. Comparison of surface layer treatments before and after countermeasures.

Type of work		Before	After
Geotextile laying	Tensile strength	80 kN/m	100 kN/m
	Construction method	By boat	By boat
Sand spreading (sand)	Layer thickness	30 cm/layer × 3	15 cm/layer × 2 + 30 cm/layer × 2
	Construction method	Hydraulic conveyor	Hydraulic conveyor
	Confirmation method	From boat	By driver
Sand spreading (Granulated slug)	Layer thickness	30 cm/layer × 2	30 cm/layer × 2
	Construction method	On-Land conveyor	Dry hydraulic conveyor
	Dump load	15 kN/m^2	4 kN/m^2
Drains installation	Water level	Drain by pump up	High water level as much as possible

Table 2. Results from FEM analysis and physical parameters.

	Slag			Sand			Dredged soil				
Case of analysis	E (kN/m^2)	γt (kN/m^2)	ν	E (kN/m^2)	γt (kN/m^3)	ν	Surface Cu (kN/m^2)	Surface E (kN/m^3)	γt (kN/m^3)	ν	Geotextile EA (kN/m)
Case 1	18660 ($\phi = 35°$)						0.15	E = 210 c_u =31.5			
Case 2	E = 105 qu =21000	13.0	0.35	10500 ($\phi = 30°$)	18.0	0.35			13.5	0.4	49000
Case 3	qu = 2000 kN/m^2						0.80	E = 210 c_u = 168			

- Decrease the surcharge; the transport of granulated slug should be changed to dry hydraulic conveyor method and keep water at high level as much as possible
- Conduct thorough crisis management such as dynamic observation of the ground behavior.

7 LOADING TESTS

In the present work section, there occurred rupture of geotextile during sand spreading. Hence Loading tests were conducted using ground improvement machine (PD driving machine) with a view to checking the stability of passage of construction machine before settlement acceleration works. The stability of passage of construction machine was confirmed by comparing the test results with those of FEM analysis. Furthermore, contemplating the construction of surcharge embankment after ground improvement, the stability was checked with regard to loading by dump truck.

7.1 *Summary of loading test and test results*

The ground improvement machines used for loading tests were of two types having dead weight 184 ∼ 342 kN (loading 20 ∼ 25 kN/m^2). Tensile stresses on geotextile and settlements of geotextile were recorded while ground improvement machine was passing in the vicinity of geotextile. From the results of tests the geotextile settled down 170mm at maximum and it became approximately zero when the machine got out of the test area. And the tensile stress exerting on geotextile was around 35kN/m at maximum; that was far below the allowable tensile strength of geotextile : (80kN/m).

7.2 *Checking by finite elements model (FEM) analysis*

The results from loading tests were verified by FEM analysis. FEM method utilized in this project was two dimensional soil and ground water coupling method. Cases of analysis and physical parameters used in the analyses were shown in Table 2.

Furthermore, the results from FEM analyses were shown in Figure 9. From this it is judged that CASE 3 reproduced the results obtained from loading tests.

In this FEM model, it is assumed that soil foundation and the geotextile material are linear elastic bodies and the geotextile material has no strength against the compression stress. In terms of drainage condition of this model, sand layer spread on the dredged soil is assumed to be impervious by taking rapid loading into consideration and be pervious layer of granulated blast furnace slag is assumed as pervious.

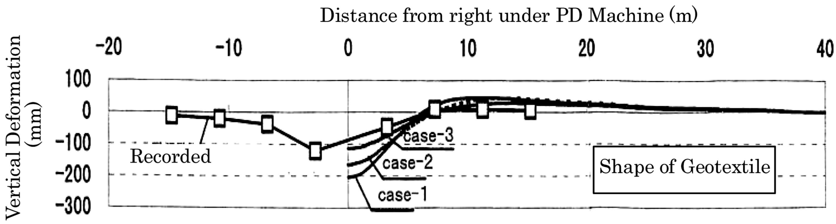

Figure 9. Results from FEM analysis.

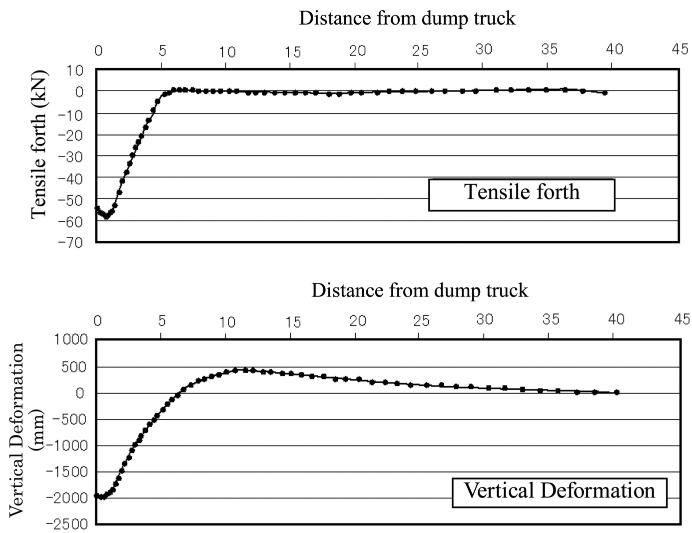

Figure 10. Results from FEM analysis.

7.3 *Analysis during loading by dump truck*

Analysis was conducted on the behavior of geotextile in case the dump truck that shall be used for construction of the after-improvement loading embankment was passing nearly. The FEM analysis (7.2) that could reproduce the loading test results was employed for this purpose.

The results from the analysis were shown in Figure 10. From this, the maximum tensile stress exerting on geotextile was 58 kN/m and geotextile settlement was 1.95 m.

Thus the maximum exerting tensile stress was far below the allowable tensile strength (80 kN/m) of the geotextile used in the project. Hence it was judged that the dump truck could safely be employed for the loading embankment construction.

8 CONCLUSION

With the objective of constructing an airport on the disposal site of dredged soils produced from port development projects, the site had been subjected to surface treatment (geotextile Laying + Sand Spreading). However a large scale geotextile rupture occurred during work execution. Countermeasures were envisaged to execute works safely estimating the causes of rupture and trafficability of construction equipment was checked by loading tests. As a result, sand spreading and settlement acceleration works were safely conducted leading to successful completion of the project.

The results were employed to neighboring disposal sites.

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