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A case history of the construction of a reinforced high embankment on an extra soft ground

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ABSTRACT: This paper describes a case history of the construction of a geotextile-reinforced high embankment on peat. The estimated safety height of the embankment was 1.8 m against to 6 m in design height. Settlement as large as about 1.7 m was also predicted from the results of the laboratory consolidation tests. The use of ground improvement techniques, however, was not accepted in this construction work because of the existence of a well of cold mineral spring quite nearby the site. Under these conditions, to increase the factor of safety of the design embankment to 1.15 immediately after the construction, the use of five layers of a strong geotextile and a stage construction sequence were adopted. The embankment filling was successfully completed without making any serious errors. From the result of this field case history, it was demonstrated that the construction of a high embankment on peat was possible by reinforcing the embankment bottom rigidly, even if ground improvement techniques were not conducted.

1 INTRODUCTION

A road embankment of 6 m in design height was planed to traverse a small valley where extra soft soil such as peat has been deposited to a depth of about 1.2 m - 11.3 m. The location of the soft soil deposit-firm bottom interface varied considerably both transversely and longitudinally in the valley. The total stress analysis yielded unacceptable factor of safety of 0.46 when assumed that the embankment was constructed to the design height in one stage, showing a safety embankment height of 1.8 m. Moreover, a large construction settlement as large as about 1.7 m was anticipated from the results of the laboratory consolidation tests.

The another biggest problem in this construction was the existence of a well of cold mineral spring quite near by the site. It was strongly demanded not to dry this well by the construction work. So, the ground improvement techniques such as Sand Compaction Pile Method or Dry Jet Mixing Method were not accepted to be used here. Bridging over this valley and the use of lightweight fill material such as Expanded Polystyrene Blocks were also rejected because of the cost. Under these conditions, to increase the factor of safety of the embankment to 1.15 immediately after the construction, the use of five layers of a strong geotextile was considered together with the use of a stage construction sequence. The embankment filling was successfully completed without making any serious errors.

In this paper, the design of the embankment will be described together with the results of the field measurements.

2 SITE DESCRIPTION AND SOIL PROFILE

The ground plan of the execution site is shown in Fig.1. As indicated by the figure, the load was planed to traverse rice fields in a small valley. Unfortunately, there was a well of cold mineral spring quite near by the site as shown in the figure. From old times, the ground water around the site had been pumped up from this well and had been used as a hot spring by heating the water. So, it was strongly demanded not to dry this well by the construction work.

Centerline profile and cross section at station A are shown in Figs.2 and 3, respectively. The thickness of the soft soil deposits varied considerably both transversely and longitudinally from 1.2 m to 11.3 m as illustrated in the figures.

The upper layer of the deposits was fibrous peat with an average natural water content (ω_n) of about 400% and an average unconfined compressive strength (c_u) of about 11 kPa. Below the peat, there was a layer of amorphous peat with ω_n of about 260% and c_u of about 20 kPa. This peat was underlain by clayey silt and sandy silt with ω_n=90%, c_u=28 kPa and ω_n=35%, c_u=127 kPa, respectively. Below these soft deposits, a dense gravel layer was encountered. Ground water table,

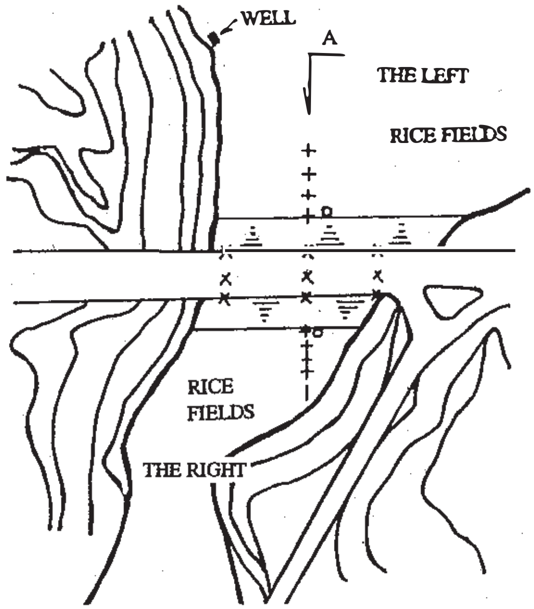

Fig. 1 The ground plan of the execution site

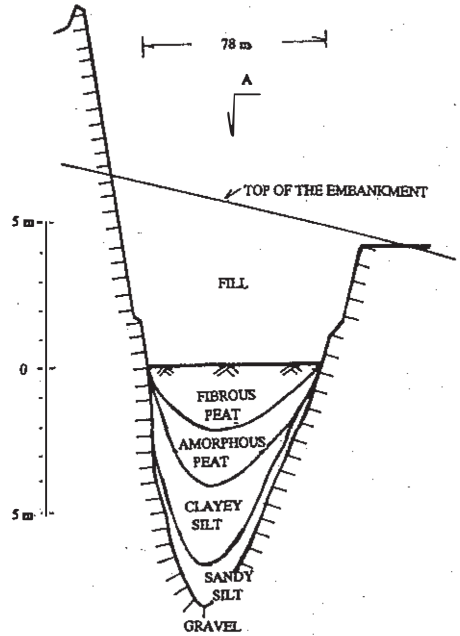

Fig 2 Centerline profile

LEGEND
×, ⊥ : SETTLEMENT PLATE
o, ||: VERTICAL INCLINOMETER
+ : STAKE
o : BOREHOLE

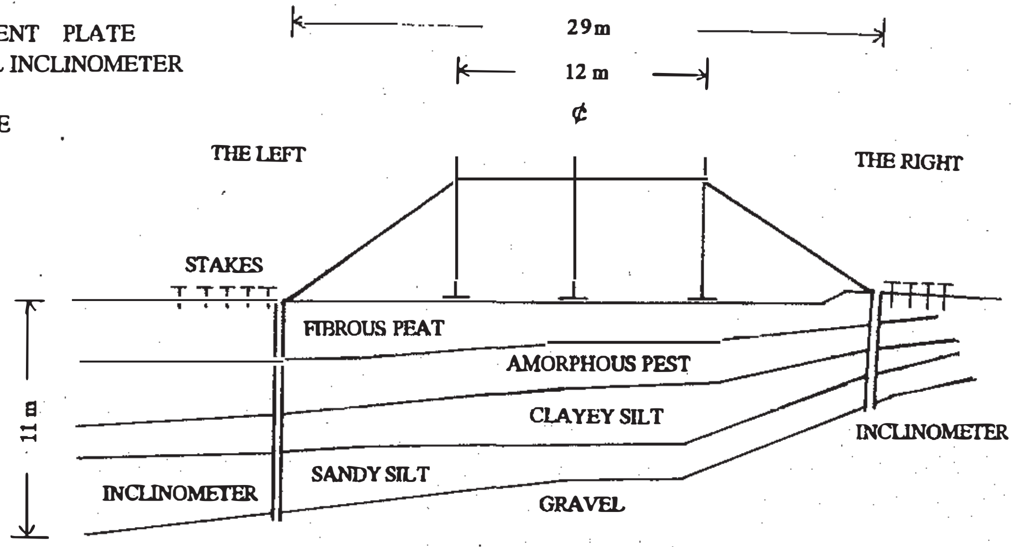

Fig. 3 cross section at station A

though it slightly varied with the season, coincided with the ground surface.

3 SEQUENCE OF CONSTRUCTION

Since the initial shear strength of the deposits was very low, the embankment was constructed in two stages.

The first stage of construction consisted of the lift of embankment materials up to the critical height of 1.8 m. After clearing and leveling the original ground surface, the first layer of geotextile was placed directly on the ground surface. This was not only for reinforcing the subsequent lift of fill but also for avoiding punching failure caused by the construction traffics. Sand working platform was then placed up in the thickness of 1 m and the second layer of geotextile was placed on it. After this, ordinary fill material of soil was carefully placed up to the critical height of 1.8 m. In this process, the third layer of geotextile was installed with an interval of 60 cm from the second layer of geotextile.

The second stage of construction began after ten months later from the end of the fill placing period in stage I. In this stage, fill placing was brought up to the design height of 6 m. Installation of forth and fifth layer of geotextile was included in this stage. Each layers of geotextile, i.e. from second to fifth, had an interval of 60 cm in vertical direction.

Thus, about one third of the embankment bottom was reinforced by the five layers of geotextiles. Geotextiles used here were two types of polymer grid such as shown in Fig.4. SS1 was used as a geotextile at the first layer only. Another four layers were SR110. Those properties are given in Table 1.

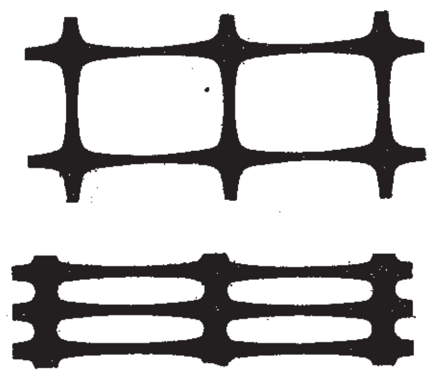

Fig. 4 Two types of polymer grid used here

Table 1 Properties of polymer grid

	SS1	SR110
Polymer	PP	HDPE
Mesh (mm×mm)	28×38	166×22
Direction	two	one
Tensile strength (t/m)	1.8	11

4 INSTRUMENTATION

To monitor the behavior of the foundation subsoil during the construction and then to control the construction procedure, field instruments were installed.

A total of six surface settlement plates was placed on the original ground to measure the vertical movements of the ground surface under the embankment.

Lateral displacement of the foundation subsoil was measured with vertical inclinometers that were installed at both the toes of the embankment.

Vertical and horizontal movements of the outer ground surface were also monitored by four movement stakes that were driven into the outside ground with an interval of 5 m from the toes of the embankment.

Ground water level during construction was also recorded using the open boreholes that were drilled at both the toes of the embankment.

Pore water pressure was not measured. However, a change of electric resistivity of the ground water, i.e. specific resistivity, was measured using the open boreholes to know the horizontal movement of the ground water during construction.

The locations chosen for the instrumentation and the instrumentation layout are shown in Figs. 1-3.

5 FIELD OBSERVATIONS AND DISCUSSION

The measured settlements of the ground surface at three points along the station A, almost the middle in the valley, are shown in Fig.5. One curve was measured below the center line and the other two curves were measured below the shoulders of both sides of the embankment. According to the figure, rapid settlements occurred during the fill placing periods in both the stages. The magnitude of these rapid settlements had amounted to more than 70% of the ultimate settlement that was estimated by the hyperbolic curve fitting method. On the other hand, during the settlement periods, i.e. during the rest of filling, the rate of settlement was not so large compared with that during the fill placing periods.

As mentioned before, the first stage filling was conducted up to the critical height without rest. So, not only a rapid settlement such as shown in Fig.5 but also a local rotational failure of the embankment was feared in the design stage. However, no evidence of rotational failures, tension cracks and extreme large formations of surface waves on both the sides of the embankment was observed. From this matter, it was confirmed that the construction of a high embankment on peat was possible by reinforcing the embankment bottom rigidly, even if a ground improvement technique was not conducted.

In general, a settlement below the center line is larger than those below the shoulders. As can be seen in Fig.5, however, the measured settlements of these points were almost same. This might suggest that the sand working platform of 1 m thick that was sandwiched by the two layers of geotextiles had acted as a rigid plate, resulted in the uniform settlements of the embankment

Fig.6 shows the horizontal displacement of the foundation subsoil measured at both the toes of the embankment. According to the figure, about 2-3 cm of outward displacements had occurred during the fill placing period in stage I at 3 m below the ground surface where was the interface of fibrous-amorphous peat. It is interesting to note that as can be seen in the figure, this amount of outward displacement had hardly changed during the settlement period. This matter might suggest that in the construction of a rigid reinforced embankment, the shear deformation of the foundation subsoil might hardly take place during the settlement periods,

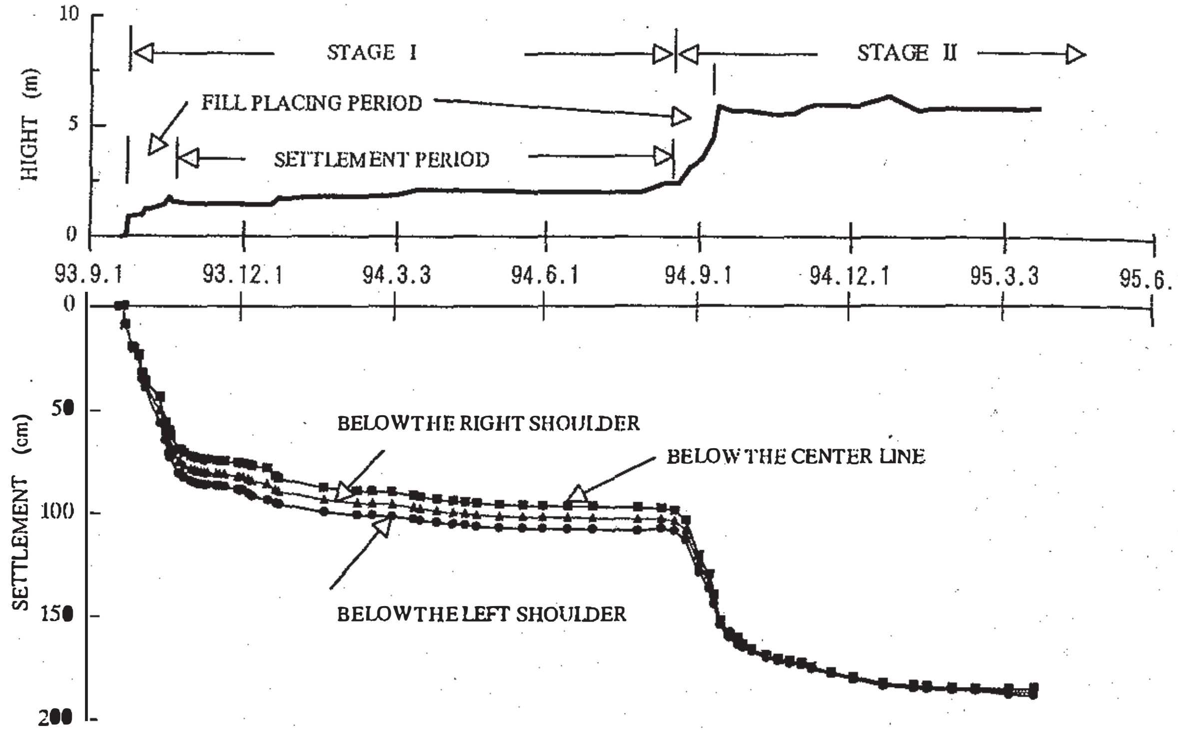

Fig. 5 Settlements at station A

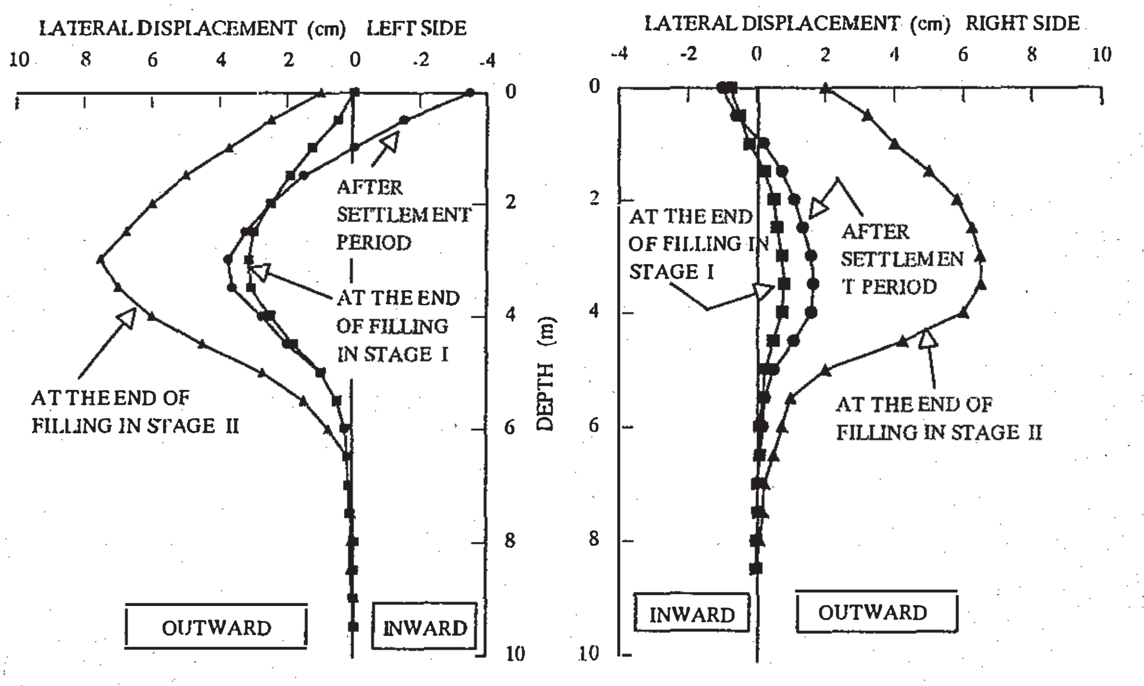

Fig. 6 Lateral displacements of the foundation subsoil

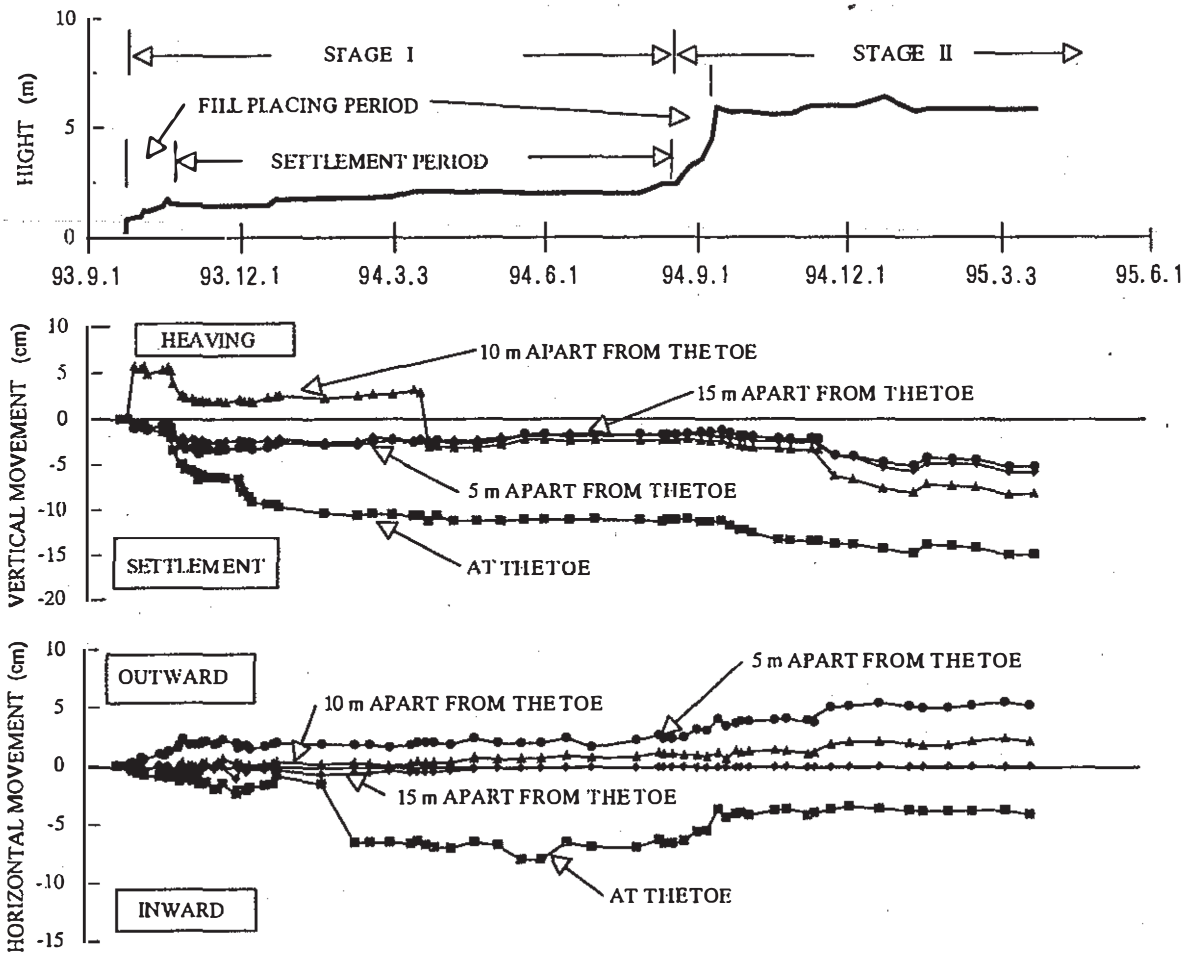

Fig. 7 Vertical and horizontal movements of the outer ground surface

and therefore the increase in strength of the foundation subsoil might be expected during this period. It is also interesting to note that as indicated by the figure, the direction of movement of the ground surface was toward the embankment during the settlement period. What dose this phenomenon mean. The interpretation of this phenomenon requires further investigations.

Subsequent large lateral displacements of the foundation subsoil had occurred only when the filling in stage II had started. From these matters, it may be said that the rapid settlements during fill placing periods were due mainly to the shear deformation of the foundation subsoil.

Vertical and horizontal movements of the outer ground surface are presented in Fig.7 that were measured at the left side of station A. These movements were monitored by the four stakes that were installed transversely to the embankment with an interval of 5 m from the toe. In these figures, the upper one indicates the vertical movements and the lower one indicates the horizontal movements. It is well known that in the construction of a high embankment on peat, a large magnitude of heavings generally occurs outside the embankment. According to the figure, however, only 5 cm of heaving was observed during the fill placing period in stage I at the point 10 m apart from the toe. Moreover, this heaving had disappeared during settlement period and never occurred after. Why was the heaving so small. The interpretation of this phenomenon also requires further investigations.

By the way, according to Fig.7, horizontal movement at the toe was toward the embankment, while the other points moved outward. This matter night suggest a occurrence of tension cracks parallel to the toe line of the embankment. However, the distinct tension cracks were not observed.

Inward movement of the ground surface at the toe of the embankment implied that the first layer of geotextile that was directly placed on the ground surface might be subjected to compression force. Unfortunately, the development of loads on the geotextile was not monitored in this construction work.

Fig.8 shows the changes in specific resistivities of the ground water with depth that were measured before, during and after construction at the left toe of the embankment. As indicated by the figure, the specific resistivities of the ground water before construction could be recognized in the soil layers about 5 m below the ground surface. This suggested the existence of the steady lateral flow of the ground water in the layers. This ground water might has been pumped up from the well and might has been used as a cold mineral spring. Within the upper soil layers, the distinct steady lateral flow of the ground water can not be recognized.

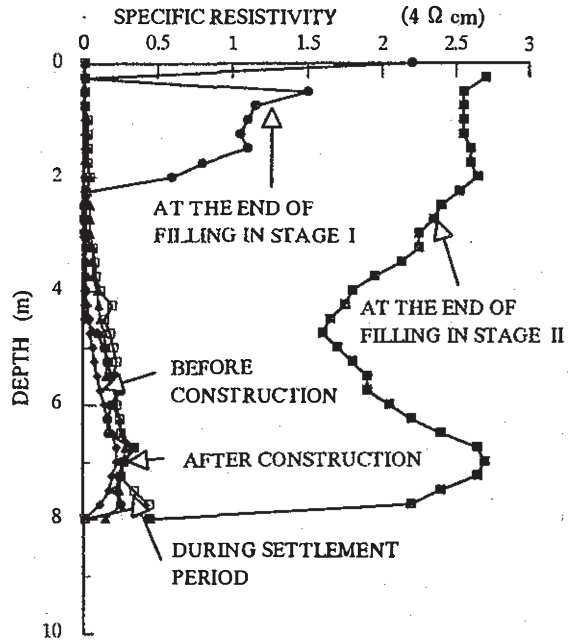

Fig.8 Changes in specific resistivities of the ground water with depth

By the way, as can be seen in Fig.8, the rapid large increase in specific resistivities can be seen during fill placing periods in both the stages of construction, while during the settlement periods, those were almost same with that before construction. This matter strongly suggested that the ground water during the fill placing period had moved not only vertically but also horizontally, although it was mainly vertical during settlement periods. This behavior of the lateral movement of the ground water might affect the lateral movements of the foundation subsoil.

6 CONCLUSIONS

A geotextile-reinforced high embankment was constructed on peat. Ground improvement techniques were not used, but about one third of the lower part of the embankment was reinforced by five layers of polymer grids. The embankment filling was successfully completed without making any serious errors. From the result of this field case history, followings were concluded.

(1) The first layer of geotextile was placed directly on the ground surface and sand working platform of 1 m thick was sandwiched with the second layer of geotextile, resulted in the uniform settlement of the embankment.

(2) In the first stage of construction, the embankment was brought up to its critical height without rest. However, no evidence of rotational failures, tension cracks and extreme large formations of surface waves around the embankment was observed. It was demonstrated from these matters that the construction of a high embankment on peat was possible by reinforcing the embankment bottom rigidly, even if a ground improvement technique was not conducted,.

(3) It was also confirmed that by making the embankment bottom rigidly, the shear deformation of the foundation subsoil would hardly take place during the rest of fill placing period and therefore the increase in strength of the foundation subsoil would be expected during this period.

(4) From the measurements of the specific resistivities of the ground water, it was confirmed that the ground water during the fill placing periods moved not only vertically but also horizontally, though it was mainly vertical during settlement periods.