The effect of high strength geosynthetic to stabilize an embankment on soft ground

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ABSTRACT: Geosynthetics of many types such as nonwoven and geogrids have been used widely as reinforcements for embankments. One of these materials, a geosynthetic based on a high strength web material, was installed to stabilise an embankment until the soft ground could get sufficient strength due to consolidation. It was used in order to reduce the cost of construction of an expressway. The stress-strain behaviour of the material was examined in the laboratory and the behaviour of the reinforcement in the embankment was measured.This paper describes the relationship between the designed value and the observed behaviour of the material in the embankment together with the laboratory results.

1 INTRODUCTION

In road construction, the initial construction cost of an embankment is cheaper than that of a bridge or viaduct, etc. Recently, it was important to use local surplus soil effectively and a huge embankment has been constructed with this soil. In the construction of such a huge embankment it is necessary that the foundation ground can support the embankment without harmful settlement or unacceptable subsidence. Ground is judged as soft when the embankment doesn't become stable, due to lack of inherent strength. In this case, the reinforced embankment method that uses geosynthetic can be used economically. The reinforcement material is used as the tensile material to make up the strength of the soft ground, until the strength of the soft ground increases significantly due to consolidation as presented by Japan Highway Public Co (1998).

The required tensile strength of the reinforcement material can be estimated by slip circle analysis. Sometimes multiple reinforcement layers are required depending on the relationship between the strength characteristics of the soft ground, the embankment loading, and the tensile strength of the reinforcement materials. In the present case, the operation on site was improved by laying the reinforcement material in a single-layer, thus reducing the cost and shortening the time of construction.

This paper describes how a high strength web-shaped geosynthetic was used to stabilise an embankment of 13.2 m height on soft ground. The strength and extension characteristics of the geosynthetic were obtained by laboratory testing. The field observations were carried out to investigate the effectiveness of this web-shaped geosynthetic for stability of the embankment on the soft ground. This paper describes the behaviour of the foundation ground and the reinforced embankment.

2 DESIGN OF EMBANKMENT

2.1 *Abstract of soft ground*

The area was composed partly of highland skirt and flat land to the south of the Butsuzou tectonic line. The highland skirt part has ridge like fingers which project toward the south. The highland skirt is 40-50 m in elevation and is a Shin-Doi layer that is situated in the northern part of the Shimanto-belt and has alternating strata of sandstone and mudstone. The flat land is low ground with a buried valley and is 5-10 m in elevation. This land is alluvium and its bottom base at approximately 15 m deep and has Otochi-pozzuolaus layer at around 10m depth. The embankment of a height of 10 m and more was planned on the soft ground. Fig 1 shows the soil profile of this section.

The huge embankment is shown in detail in the cross section of Figure 2. This section is the STA 152+00 in Figure 1, and the height of the embankment is 13.2m. These layers consist of the clay and peat which have been consolidated by the load of the embankment. The relation between Void ratio (e) and consolidation load (log p) of the clay and the peat are shown in Figure 3. And the relation between coefficient of consolidation (log C_v) and consolidation load (log p) of the clay and the peat are shown in Figure 4. Furthermore, Figure 5 shows the relation between the height of the embankment and settlement of the ground. From Figure 5, the settlement of soft ground is about 60 cm at the completion of the embankment. And at that point, the degree of consolidation of soft ground is 59.1%.

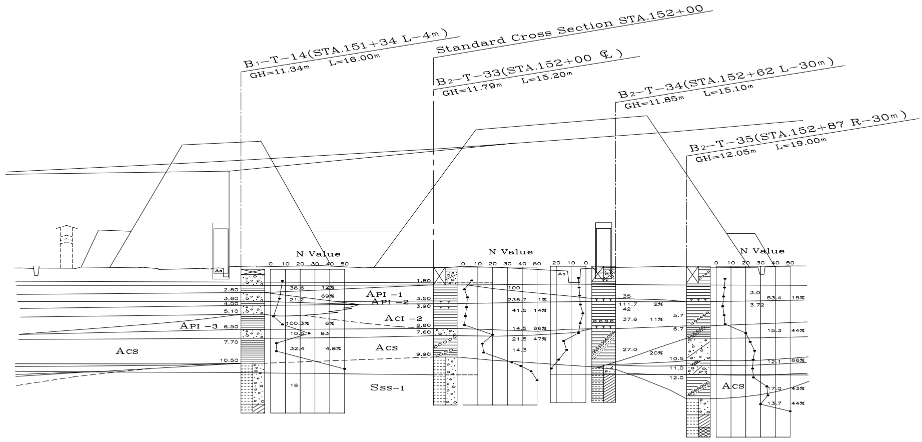


Figure 1. Soil property chart

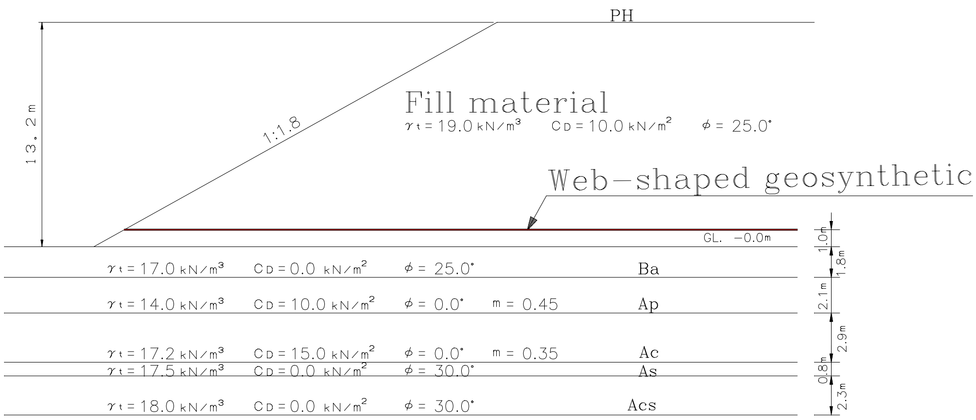


Figure 2. Cross section

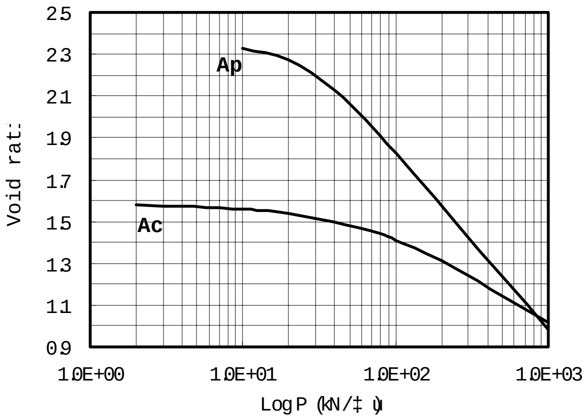


Figure 3. e-logP

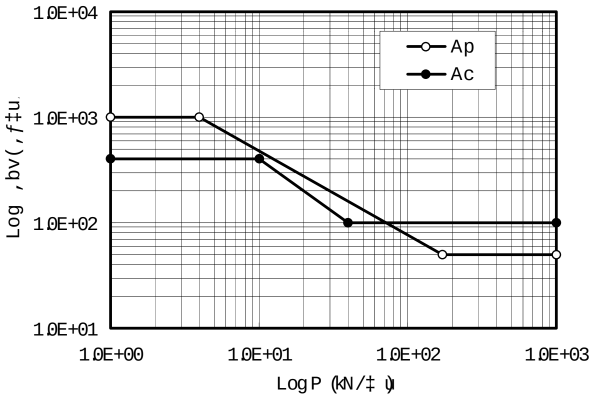


Figure 4. logCv-logP

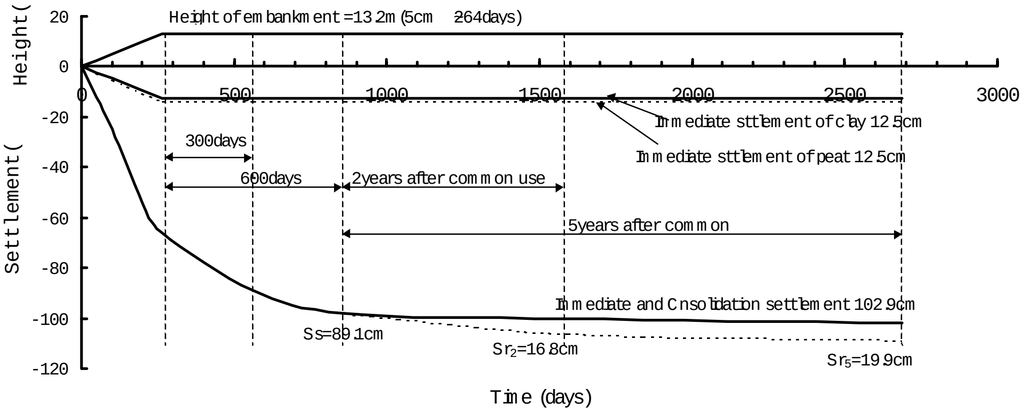


Figure 5. Result from calculation of settlement

2.2 *Stability analysis*

A stability analysis of the embankment on the soft ground was carried out by circular slip method by using an equation (1) based on the total stress.

$$F = \frac{\Sigma(C \cdot l + W \cdot \cos\theta \cdot \tan\phi)}{\Sigma W \cdot \sin\theta} \quad (1)$$

where,

c:cohesion(kN/m2),
l:length to sliced circle (m)
W:weight of sliced soil(kN),
ϕ :internal friction angle

The shear strength of Ac and Ap is estimated by the rate of strength increase, m(=c/p), based on the degree of consolidation of soft ground at the completion of the embankment.

The required value of the safety factor Fs', is more than or equal to 1.10 at the completion of the embankment. The case that Fs' is less than 1.10, the lack of resisting force to sliding was supplemented by the tensile strength of the web-shaped geosynthetic.

The concept of resisting tension by geosynthetic on circular slip surface is illustrated in Figure 6. The value of the tensile strength was calculated by the equation (2).

$$F = \frac{Mr + \alpha \cdot R \cdot T}{Md} \quad (2)$$

where,

R: radius from center of circle (m)
T:design standard tensile strength of web-shaped Geosynthetic (kN/m)
α :reduction coefficient of web-shaped geosynthetic (=0.68)
Mr : resisting moment of unreinforcement (kN・m/m)
Md: driving moment of unreinforcement (kN・m/m)

Table 1. Result of the design

Items	Values
Height of the embankment (m)	13.2
Fs'	0.852
Mr(kN・m/m)	34565
Md(kN・m/m)	40576
R(m)	22.35
Tr(kN/m)	451
T(kN/m)	700
Fs	1.114

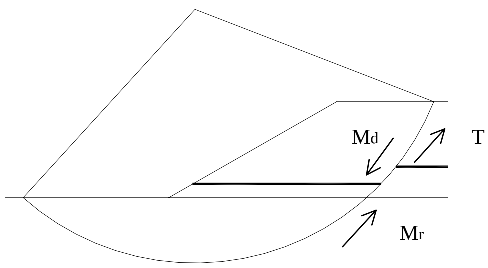


Figure 6. Schematic tensile force of geosynthetic

The shear strength of the soft ground 300 days after completion of the embankment is regarded as sufficient to support the embankment. Approximately 2 years durability was required after installation of the web-shaped geosynthetic. The reduction coefficient that corresponds to 2 years durability of the web-shaped geosynthetic is α : = 0.68 times the design standard tensile strength T. The result of calculation according to equation (2) at the completion of the embankment is shown in Table 1. The design standard tensile strength of the web-shaped geosynthetic, T, is 662 kN/m ≒ 700 kN/m at this time.

The basic properties of the web-shaped geosynthetic are the same as those required for the reinforcement material for the reinforced soil (PWRC,1996; Konami et al, 1996).

3 PROPERTY OF GEOSYNTHETIC

3.1 *Design and characteristics of the Web of the geosynthetic*

One web of the geosynthetic reinforcement is 91 mm in width. One sheet of this reinforcement material is made from 25 pieces of this web. The separation of webs is 18 cm and total width of one sheet is 4.5 m. The web is covered with polyethylene. The polyethylene is resistant to corrosion, chemicals and impact load. From the result calculated by equation (2), the design standard tensile strength of the reinforcement material is estimated at 700 kN/m and the tensile strength of one web is 126 kN (700 kN/m x 4.5/25).

3.2 *Tension measurement*

The laboratory tensile test was carried out to investigate the relationship between the tensile strength and the strain of the web-shaped geosynthetic. Two devices were used to measure strain. One way was to measure between lines which were marked on the surface of the geosynthetic. The second way was to measure the strain directly by using the strain gauge which is shown in Figure 7. It is necessary to note that the maximum limit of this strain gauge is approximately 7%.The actual results which were measured by these different methods are shown in Figure 8.

Thus it was confirmed that these devices were able to measure the elongation and the strain. In other words, it was recognised that the strain gauge could measure the strain of geosynthetic when in the soil. And it was proved that the tensile strength at nearly 10% strain of the web is enough to meet the design standard strength (126 kN).

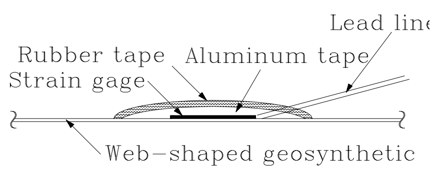


Figure 7. Schematic tensile force of geosynthetic

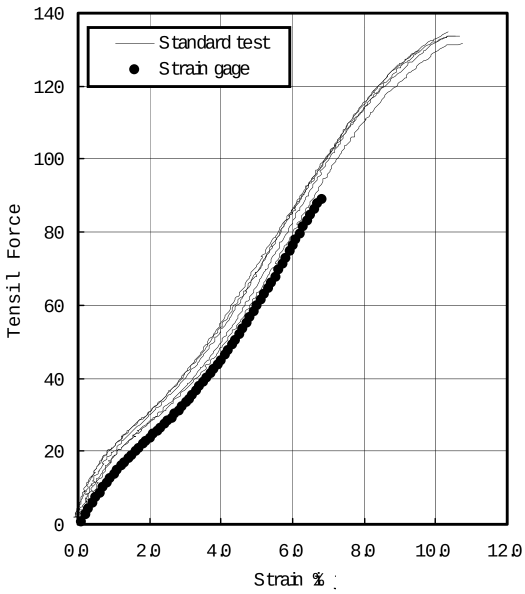


Figure 8. Schematic tensile force of geosynthetic

4 RESULTS OF OBSERVATION

4.1 *Stability of the embankment*

The installation is important during construction of the embankment on soft ground. Figure 9 shows the behaviour of the reinforced embankment that included the soft ground. The settlement at the bottom of the embankment increased due to the height of the fill. The settlement around the centre of the embankment which strengthened the soft ground is approximately 75 cm. However, the settlement at the toe of the slope was minimal. The horizontal displacement at the toe of both slopes was measured along the depth . The maximum horizontal displacement at the toe of right and left appears at the surface and 4 m depth each. It could be said that this embankment on the soft ground has been stable during construction because the horizontal displacement is insignificant in comparison with the settlement.

4.2 *Tension of web-shaped geosynthetic*

The tensile load of the geosynthetic that was buried in the fill can be calculated from the strain by using the relationship of Figure 8.

Figure 10 presents the distribution of the tensile load of the geosynthetic. The maximum tensile load, 60.3 kN/m, appeared around the shoulder of the embankment. These tensile loads increased with the height of the embankment.

Two circular slips in Figure 10 correspond to 13.2 m of height and 10.0 m of height each. The required tensile loads of geosynthetic based on the circular slip surface are 451 kN/m and 244 kN/m each. In the comparison, it is clear that the required tensile load of geosynthetic according to the calculation is larger than the actual measured value. One of these causes might be slower actual filling speed than 5 cm/day. Alternatively high strength web-shaped geosynthetic might be sufficient to reinforce the embankment. It could suggest that geosynthetic confines the fill material on the same basis as the diamond wire net reinforcement (Tonogaito et al., 1996).

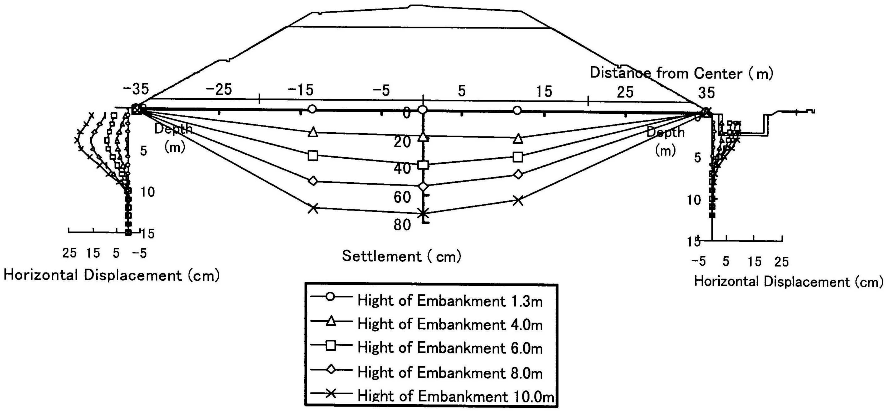


Figure 9. Behavior of soft ground

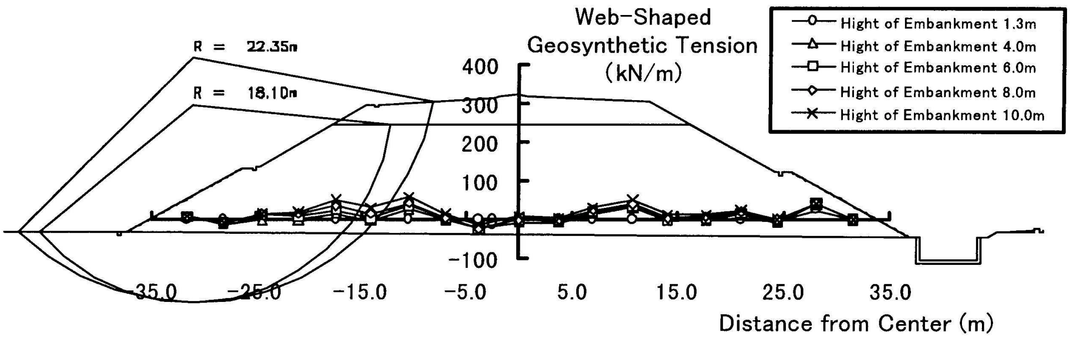
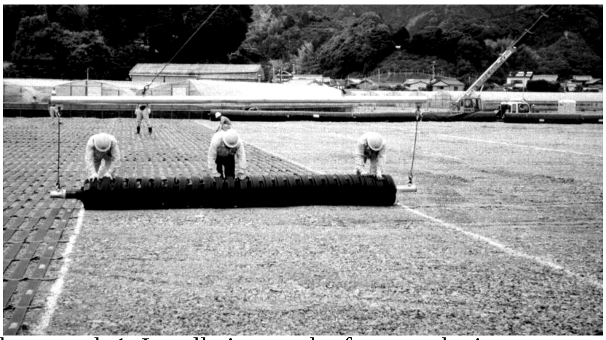
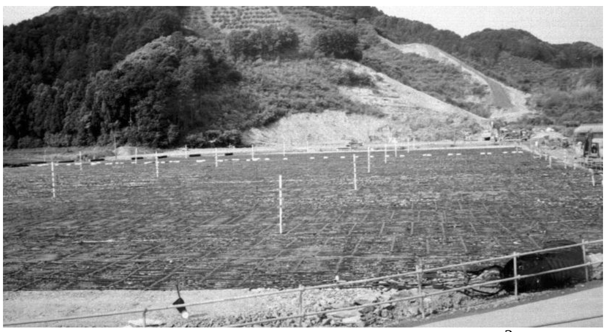


Figure 10. Distribution of tensile force along the geosynthetic


Photograph 1. Installation work of geosynthetic


Photograph 2. IInstalled situation(approx.9000m^2)

5 CONCLUSIONS

High strength web-shaped geosynthetic used as reinforcement of an embankment on soft ground was installed by just rolling out the material. The total geosynthetic of 9000 sq metres was installed completely over 4 days.

According to the observations, the embankment on the soft ground was stable during construction. The observed tension of the geosynthetic was less than the calculated value that was based on the circular slip method. Therefore this behaviour might be explained by the additional effect of the geosynthetic.

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