Well Documented Case Study of a Reinforced Soil Wall

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ABSTRACT: A full scale 7.5m high by 15m wide geogrid reinforced soil wall has been constructed of cohesive soil. Non-woven fabrics were used for the drainage of the soil. The purpose of the test wall was to evaluate the applicability using cohesive soil. Full scale field performance during and after construction was monitored by incorporating extensive instrumentation including: deformation plates of the wall, pore water pressure meters and earth pressure cells in the backfill, extensometers, displacement rods and strain gauges on geotextiles.

This paper gives well documented results of the several measurements and reports on the applicability of a reinforced soil wall using cohesive soil.

1 INTRODUCTION

As a construction material, the geogrid developed in England in 1979 has high strength. A great number of reinforced embankments using this material have been constructed. Through this construction method, which originated in Europe and the U.S.A., sandy soil has been used as fill material. However, taking into account the conditions in Japan, where cohesive soils are being used as fill materials and where there is heavy rainfall , the design and the execution of this construction method posed several problems when applied. Therefore, to confirm the applicability to the site of this method using cohesive soils, a 7.5m high and 15m wide geogrid reinforced soil test wall was built at a construction site in a mountain region.

During construction, special care was taken of the drainage in the embankment and on the foundation ground, taking into account the fact that cohesive soil was being used.

To confirm the applicability of cohesive soil for a geogrid reinforced wall, the deformation of the embankment, pore water pressure and earth pressure in the backfill and strain and deformation of the geogrid were measured.

2 DESIGN OF THE WALL

As shown in Fig.1, the height of H = 7.5m of the embankment, the slope gradient of 1: 0.3 and the surcharge of q_s = 27kPa of its wall were taken into consideration. The design conditions were: a unit weight γ = 19.6kN/m^3 and angle of internal friction $\phi = 25^0$ for the fill material, as reinforcement material geogrid Tensar SR2 was used and the design tensile strength was 31.4kN/m.

The test wall was designed with the WAGGLE program by Netron Corporation.

According to the design concept, 11 mats of geogrid with a length of 7m, were laid within the embankment.

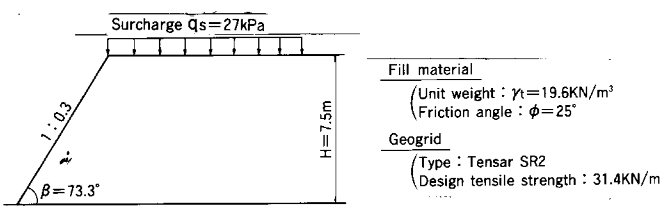


Fig.1 Design parameters

3 SOIL PROPERTIES

The soil properties of fill material are shown in Table 1.

Table 1. Soil properties

Grain size: sand 23.3%, silt 53.3%, clay 23.4%
Natural water content: w_n = 25.0%
Liquid limit: w_L = 54.6%
Plastic limit: w_p = 26.8%
Maximum dry density: ρ_{dmax} = 1.48Mg/m^3
Optimum water content: w_{opt} = 26.4%
Angle of internal friction: $\phi = 20.6^0$
Cohesion: c = 42.2kPa

4 GEOTEXTILE PROPERTIES

Two types of geotextile were used. Geogrid for reinforcement and non-woven fabric (Teijin Corp., Endren filter EF-3) for drainage.

Table 2 shows the properties of geogrid and non-woven fabric. Figure 2 also shows a diagram of the relation between strain and tension of geogrid

Table 2. Geotextile properties

Geogrid	
Opening dimensions:	110 x 22mm
Tension at failure:	78kN/m
Elongation at maximum strength:	17%
Non-woven fabric	
Width and thickness:	300 x 4mm
Mass per unit weight:	300g/m^2
Permeability:	5x10^{-3}m/sec (σ=98kPa)

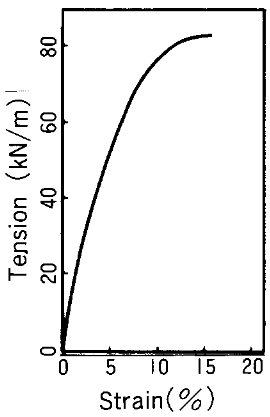


Fig.2 Strain versus tension for geogrid

5 CONSTRUCTION

Prior to filling up the reinforced embankment, 1m of soft soil in foundation ground was removed and replaced with gravel.

The fill material is a cohesive soil of weathered mudstone. Because the fill material is a cohesive soil, 6 mats of non-woven fabric were laid to ensure the drainage within the embankment.

The reinforced embankment is constructed with 11 mats of geogrid and vegetation blocks (sand bags) were used for the surface. Figure 3 shows a cross-section of the reinforced embankment.

The embankment is at 25cm of lift, which is rolled and compacted 4 to 8 passes with a vibrating roller (weight 70kN). However, because the working space is limited up to 2m high from the foundation ground and because it was feared that up to 1m from the wall, deformation of the wall could occur, the embankment was being compacted with a plate-compactor.

The reinforced embankment was completed at a height of 7.5m, whereupon a surcharge of 1m was implemented on the backfill.

For the compaction control a radioisotope was used to measure water content and density. The water content ranged 22 to 28% and the unit weight was in the range of 15.7 ~ 17.2kN/m^3.

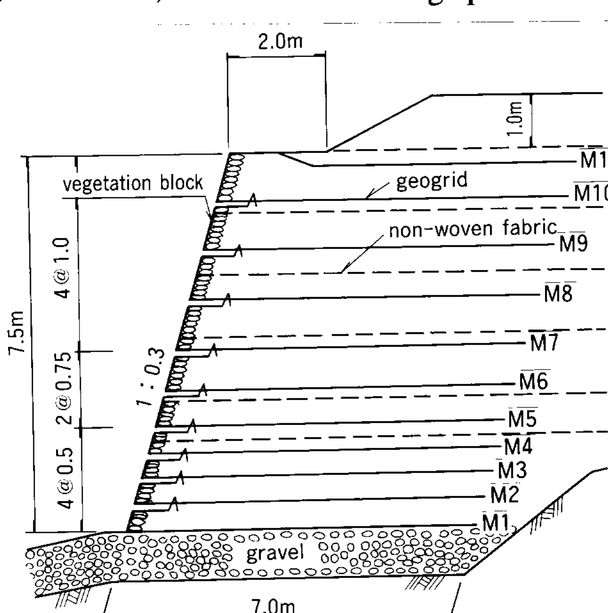


Fig.3 Cross section of the embankment

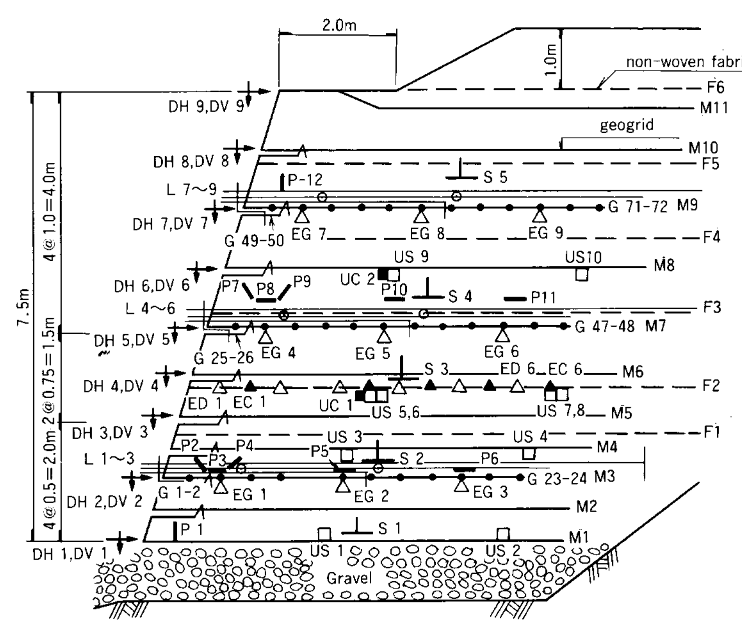
6 INSTRUMENTATION

To confirm the applicability of a reinforced embankment using cohesive soil, a great number of instruments were incorporated to monitor the behavior of embankment and geotextile.

Figure 4 shows the types of instruments used for measuring an the location where they were incorporated.

6.1 Fill instrumentation

The items to be measured were: pore water pressure,



LEGEND

Instrumentation			Numbers of instrumentation
G	● ○	Strain gauge	12×2×3=72 2×3=6 (geogrid)
EG ED	△	Extensometer (1)	3×3=9(Geogrid) 6(non-woven fabrics)
EC	▲	Extensometer (2)	6(non-woven fabrics)
UC	■	Pore water pressure meter (1) (potentiometer type)	2
US	□	Pore water pressure meter (2) (differential transformer type)	10
P		Earth pressure cell (differential transformer type)	12
S	⊥	Settlement plate	5
L		Displacement rod	3×3×3=9 (geogrid)
DH DV		Deformation plate of the wall	9

Fig.4 Instrumentation layout

earth pressure, displacement of the wall surface and settlement.

Pore water pressure was measured by pressure meters of the potentiometer and differential transformer types.

As for the earth pressure, horizontal and vertical pressure was measured by pressure cells of the differential transformer type. The earth pressure cells to measure the shear strength, were located at two places.

As for the displacement of the wall surface, to measure the vertical and horizontal displacement by level and transit, steel plates were embedded in the wall surface at nine places.

The settlement in the backfill was measured by level, with a settlement plate located at five places in a section 3.5m from the surface of the wall.

6.2 Geotextile instrumentation

The strain of geogrid was measured by placing strain gauges in the geogrid of the 3th, 7th and 9th mat.

The geogrid displacement was measured with extensometers and displacement rods. As for the displacement rod, a steel rod with a diameter of 5mm is directly placed to the geogrid, to obtain the displacement of geogrid, by measuring the displacement of the rod at the surface of the wall. The displacement of non-woven fabric is measured by placing extensometers in the second mat of fabric.

7. RESULTS OF MEASUREMENT

The results of the measurement are given below. However, for the displacement of the non-woven fabric, there were several measurement instruments that could not be read and therefore the results cannot be examined. Therefore, the measured results of: strain and displacement of geogrid, pore water pressure and earth pressure within the embankment, settlement within the embankment and the displacement of the wall surface are described below.

7.1 Strain and displacement of geogrid

The time-based change, after the completion of construction, of the strain distribution in the mats M3, M7, M8, where strain gauges were applied, is shown in Fig.5. For places not measurable by strain gauges, the values of strain were obtained after a correction by the displacement of the rod. Figure 5 also shows the time based change of the embankment and the rainfall. As shown in this figure, the strain increases gradually from immediately after the construction. When the strain with a maximum value of 3.1% in M7 is calculated, it amounts to 40kN in tension. This is higher than the design strength (31.4kN), but as it is lower than the tension of failure (78kN), no problems occurred. Figure 6 shows the horizontal displacement of the geogrid and the horizontal displacement at the surface of the wall, five months after the end of construction.

As for the displacement of geogrid, displacement of maximum 154mm occurred up to 6m away from the wall surface. As a result, concerning displacement in the backfill, it is estimated that displacement occurs even further than 7m away from the wall surface, where no geogrid is laid. This means that displacement successively occurs far passed the assumed slip surface used in the design.

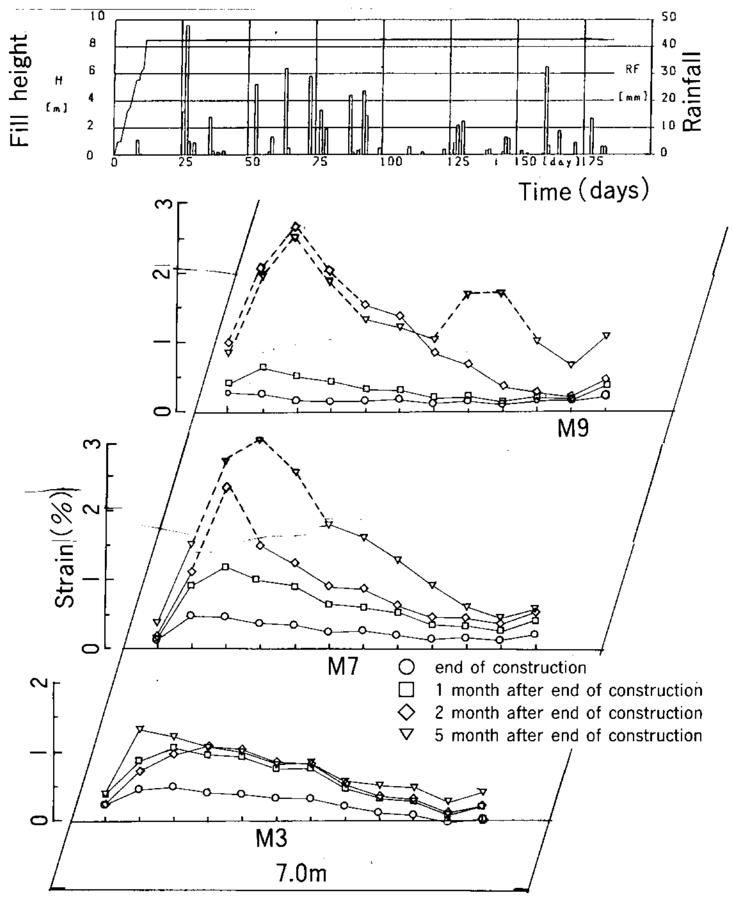


Fig.5 Strain distribution on geogrids

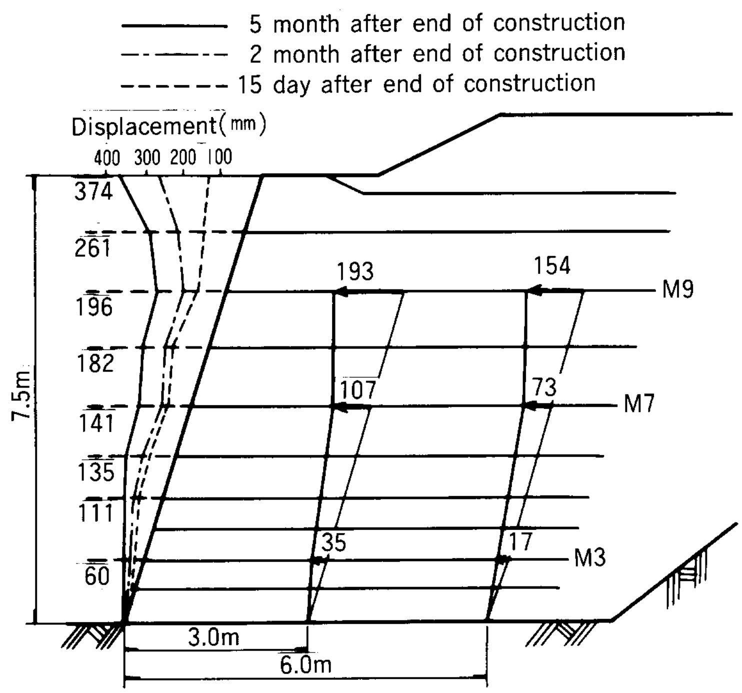


Fig.6 Horizontal displacement at the surface of the wall and in the backfill

7.2 Pore water pressure in the backfill

The distribution of pore water pressure is shown in Fig.7. Immediately after the construction, all pore water pressure was negative. After the end of construction, except for the foundation ground, the pore water pressure showed a tendency to rise due to heavy rainfall (69mm/day 15 days after the end of construction). At the end of construction, the pore water pressure of the foundation ground was negative, but became virtually zero thereafter. This is because the gravel layer at the foundation could be contributing to the effective drainage. Figure 8 shows the contour lines of the pore water pressure in the backfill, five months after the end of construction. Non-woven fabric was laid for drainage, but some pore water pressure in the backfill remains.

7.3 Earth pressure in the backfill

From the end of construction to 5 months after the construction, the vertical earth pressure increased with the construction of the embankment. And the vertical earth pressure changed considerably under the influence of rainfall . The change in the properties of the soil around the earth pressure cells is considered to be the cause thereof.

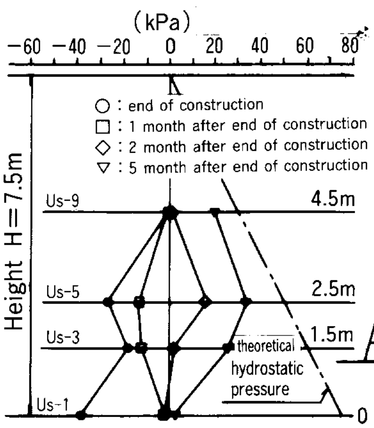


Fig.7 Pore water pressure in the backfill

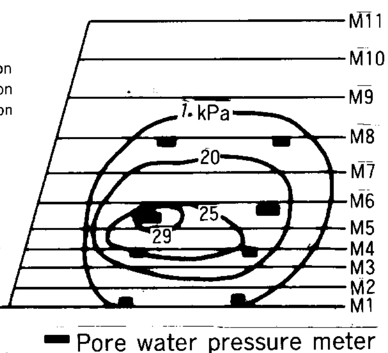


Fig.8 Contour lines of pore water pressure

7.4 Deformation of the wall

The time-based change of the vertical and horizontal displacement of each point of the wall surface is shown in Fig.9. Because the compaction of the vegetation blocks was insufficient and because it took time for the geogrid entraining the vegetation blocks, to restrain the lateral displacement, both the vertical and horizontal displacement show a rather high value. The horizontal and vertical displacement of every measured point on the wall surface is shown in a vector diagram in Fig.9.

7.5 Settlement in the backfill

Figure 9 shows the settlement in the backfill. It is clear that, five months after the end of construction, the settlement is smaller than the vertical displacement of the wall.

The settlement in the backfill was measured with each settlement plate. Five months after the end of construction, the settlement in the backfill was 58cm at 3.5m from the wall surface, and therefore smaller than the settlement at the wall surface (88cm).

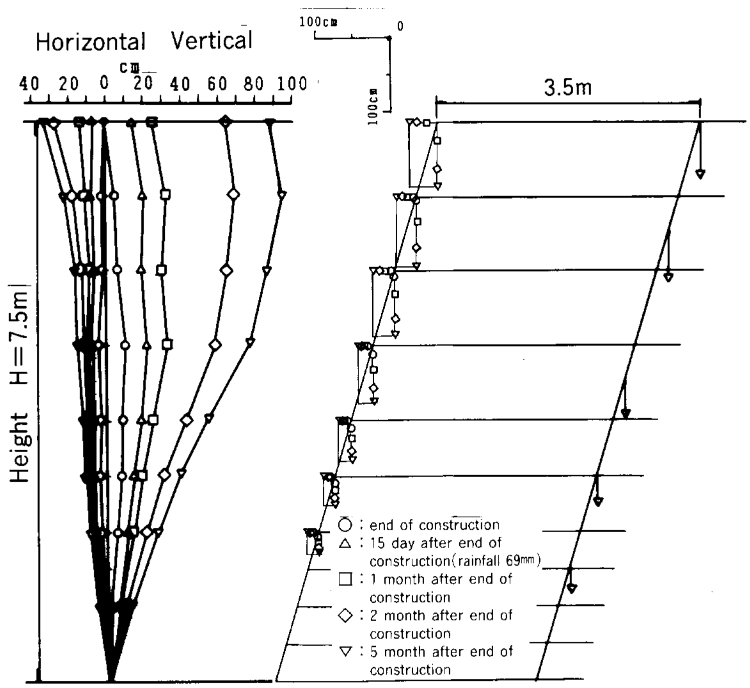


Fig.9 Deformation at the surface of the wall

8 CONCLUSIONS

It was proved that a reinforced soil wall was constructed safely using a cohesive soil under the percolation of rainfall, though the deformation of the embankment was greater than expected, due to the use of cohesive soil and the percolation of rainwater. A considerable change in the modulus of linear deformation and Poisson's ratio of the soil due to percolation of rainwater might be the cause thereof.

It was understood that the displacement in the backfill stretches far passed the assumed slip surface and that there is a considerable gap between the displacement of the wall surface and the displacement in the backfill. Because the deformation of a reinforced embankment is so complex, it is important to consider not only the displacement of the surface but also the displacement of the whole embankment, when implementing an FEM analysis.

The design of this reinforced embankment considers the stability of the embankment and not its deformation. For the design and construction of a reinforced embankment with deformation problems, it will be indispensable to give deformation serious consideration.

Room for improvement remains in the measurement method and the analysis method implemented this time. However, we hope to make this kind of measurements again in the future.