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High embankment of clay reinforced by GHD and its utilities

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ABSTRACT: Over ten years, the research on the behavior of three prototype test fills of clay soils reinforced by the geosynthetic horizontal drain (GHD) has been lasted. Some results have been already published. In this paper, fundamental data referred to strength of filled clay, frictional coefficient and durability of filter effect of GHD are focused the checking method of permeability of installed GHD at the site is pointed out for investigating clogging condition of filter. Another efficient role in the clay utility such as the counter measure is proposed analytically for dynamic motion of sandy embankment.

1 INTRODUCTION

The volume of surplus clays delivered from construction sites is increasing year by year. However, their properties are so complicated that they have become difficult to use as fill materials. This is because they have properties such as high water content, fine grain size distribution, weak structural characteristics and so on that scatter across a broad range. However, with the exception of weak structural characteristics and low bearing capacity, clay has beneficial properties with regard to engineering characteristics. It has especially been shown to have high durability against erosion, high strength for liquefaction and strict water proofing characteristics. These specific properties could be valuable, if combined in fills with other materials. Even though it has weak structural characteristics, there are many examples of reclaimed island using clay of high water content developed as foundation material for lower building facilities. It proves that the reclaimed clays can be changed to have many functions, if its water content is reduced by vertical drain method based on the consolidation theory.

To broaden the utilization field for the surplus clay, it is especially important to show whether high, steep and stable embankment can be constructed even though using clay of various water contents. On this purpose, the prototype embankment tests were performed using soft clay, but reinforced by GHD. Emphasis is placed on the following issues in this research.

1) Increased strength of filled soft clay taken through prototype fill test is shown.
2) How to research durability of filter effect of installed GHD at a site is proposed.
3) Role of clay materials partially installed at a foot of fill is stressed on seismic stability of embankment.

2 FILLING OF CLAY REINFORCED BY GHDs

Based upon the measured data, the behavior of embankment during and after completion relating to the strength, water content and flowing properties was described. These data obtained by the large scale of embankment test can prove that surplus clay has many functions to make an embankment being stabilized (Kamon et al. 1994, Kamon et al. 1996).

Figure 1 shows the scale of fills, types of arranged GHDs, and material properties relating to the tensile strength and elongation. Every test used the clay of water contents ranging from 40% to 100%. The heights of fills are 3m to 10m with the slants of 1:0.6 to 1:1.5.

Figure 2 describes the representative GHD materials, plastic core with nonwoven fabric type, reinforced nonwoven fabric type and tufted pile fabric type. Their tensile strengths range from 17 kN/m to 82.8 kN/m and their elongations from 11% to 90%. In fact, it is evident that they have lower strength and higher extensibility compared to the characteristics of geogrids. Among three cases, the case 2 was forced to collapse by the surcharge acting on the head surface of the fill after reaching the height of 3 m. The two other embankments remained stable after the passage of 5 or 7 years, even though the height of 10 m test embankment has the steep slope of 1:0.6. According to the site observation, there was no sign of the development of a failure or erosion in the future.

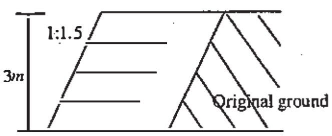
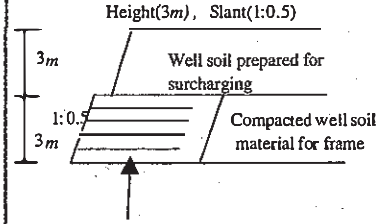
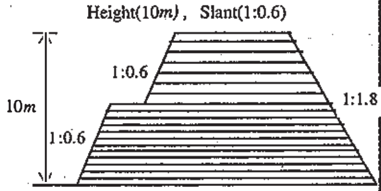
Case of tests	Scale of filling	Material properties			
		Filled soil	GHD		
			Material	Tensile strength (kN/m)	Elongation (%)
Case 1 Low hight of filling	Height(3m), Slant(1:1.5) 	Sandy clay	1)Plastic core 2)Tufted pile fabric 3)Nonwoven fabric	49.6 74.5 17.2	22.0 56.3 90.8
Case 2 Compulsory failure test with clay of high water content	Height(3m), Slant(1:0.5) 	Clay (W= 85%)	1)Nonwoven fabric 2)Reinforced nonwoven fabric 3)3-dimensional knitted fabric 4)Plastic core	41.0 72.9 79.9 82.8	82.5 11.4 18.1 32.1
Case 3 High filling test with clay	Height(10m), Slant(1:0.6) 	Clay (w=40-50%)	1)Plastic core 2)Reinforced nonwoven fabric	82.8 72.9	32.1 11.4

Figure 1. Reinforced clay filling tests by GHD.

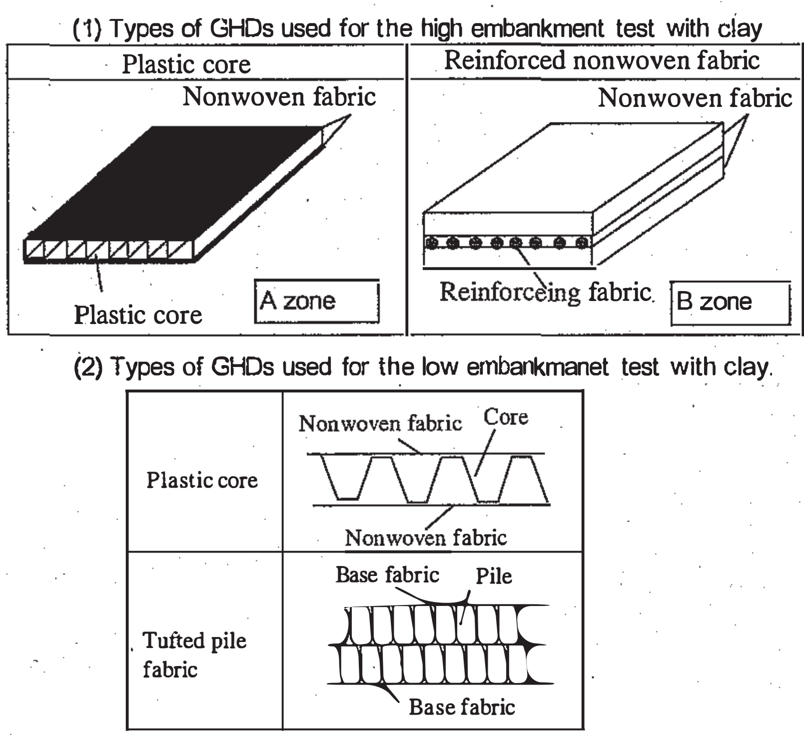


Figure 2. Sections of GHDs used in the project.

3 INCREASED STRENGTH OF CLAY

Figures 3 and 4 reveal the profile of water content and cohesive strength (c_u) that obtained at the site of case 2 during filling and after the compulsory failure. The solid lines are the data during filling and the dotted lines correspond the relationship after the failure. Both figures make it clear that the clay soil has high water content ranging from 80% to 90% and low strength less than about 60kPa. It was impossible to fill over 3m if not be reinforced by GHD.

Each zone was successfully filled to the height of 3m with a steep slope of 1:0.5 and collapsed by the intensity of the surcharge estimated. Data of water content proved that their values have a tendency to decrease with depth, and the strength of clay increases with depth. These phenomena were caused by the consolidation so that the facility of GHD was clearly confirmed.

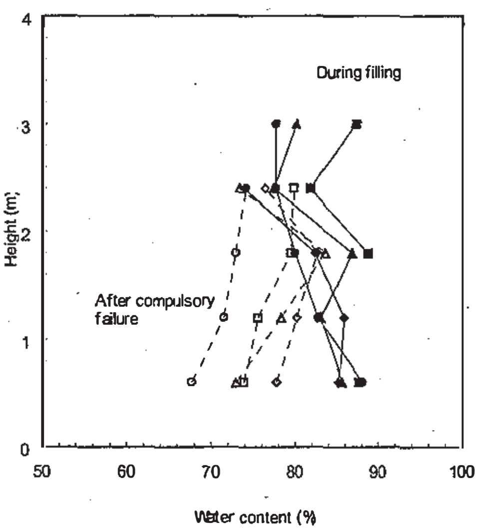


Figure 3. Profile of water content at the site of case2.

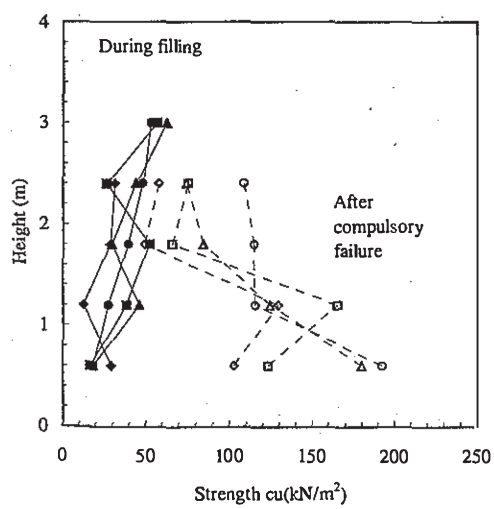


Figure 4. Comparison of strength between during filling and after failure.

4 ENGINEERING PROPERTIES OF GHD

To improve the design method of fill reinforced by GHD, the knowledge of the coefficient of friction between a filled soil and GHD, its creep properties and its permeability are required. Figure 5 shows the frictional characteristics of GHD against the clay and fine sand. The brackish marks show the maximum frictional relationship between GHD and clay. On the other hand, the white marks reveal the maximum frictional pressure between GHD and sand. And the dotted lines are the inner frictional characteristics of the find sand itself.

The coefficient of friction ranges from 0.3 to 0.4, and are grouped together in spite of the difference of GHD. On the contrary, the characteristic of friction is predicted to depend on the soil classification from Figure 5. Because the trends of increasing friction are similar with each type of GHD, the difference among characteristics of soils appear more influential than the difference in materials.

Figure 6 shows the creep characteristic of GHD. The creep strength will take a more important role than the tensile strength, because the influence of the

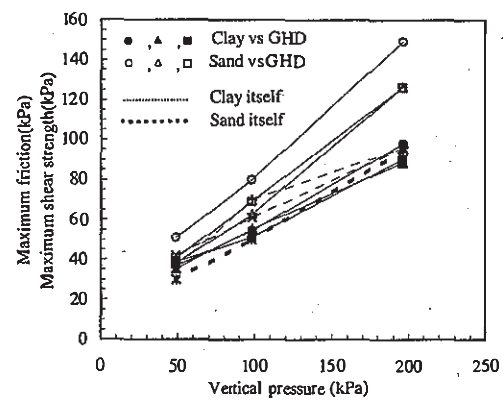


Figure 5. Frictional properties between GHD and surrounding soil.

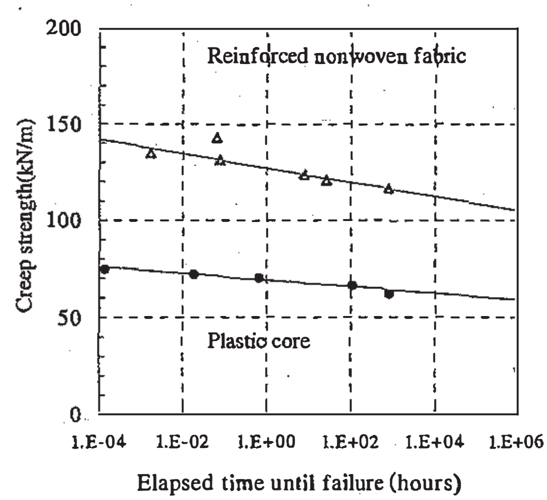


Figure 6. Creep properties of GHD.

maximum strength characteristic will emerge well beyond large strain, on the contrary, the creep effect shows up even under small load intensity.

5 PERMEABILITY EFFECT OF GHD

Water pouring tests were carried out through poly vinyl chloride pipe at the sites. This test was performed to investigate the permeability characteristic of GHD installed horizontally. As shown in Figures 7 and 8, the corresponding hole was dug out to insert a pipe for pouring water. The pipe must be in contact with the surface of GHD at the end. Poured water flows along the plane of the GHD as shown in Figure 8. This relationship between height of water level in a pipe and elapsed time is derived as the Equation (1) on the assumption of the simple flow like Figure 8.

$$\frac{h}{h_0} - \ln\left(\frac{h}{h_0}\right) = 1 + \frac{4ka^2 t}{h_0 A^2} \quad (1)$$

where h = water head at elapsed time t, h_0 = an initial value of the water head h, k = a hydraulic conductivity of GHD in plane, a = the horizontal area of GHD for water flowing, and A = the sectional area of a pipe.

Figures 9 and 10 give the test results performed at the case 1 site and case 3 sites. Figure 9 contains the test results obtained at the non-reinforced zone that is shown by the mark (▲). The other thin solid lines with the mark (□,◆) are the data at the site reinforced by the GHD. The set of thick lines are the relationship relating to the hydraulic conductivity of various orders of GHD predicted by Equation (1). According to the trend appearing in Figure 9, the coefficient of permeability is estimated at 0.01 cm/s, on the other hand, the properties of GHD are predicted to have the value around 0.5 cm/s.

Figure 10 shows the test results obtained at the case 3. The solid lines with the brackish marks are the relationship obtained at the site in the case 3 reinforced by GHD of plastic core type shown in Figure 2, and the dotted lines with the white marks are the data at the site in the case 3 reinforced by GHD of the reinforced nonwoven fabric type in Figure 2. Two thick lines without mark are the predicted rela-

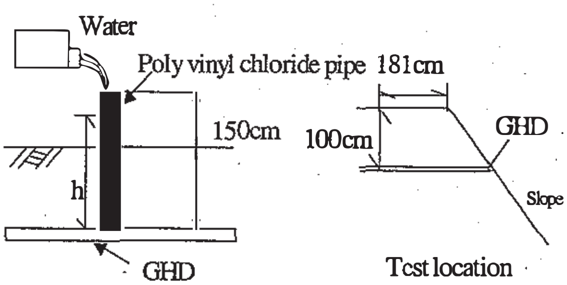


Figure 7. Schematic of pouring water test.

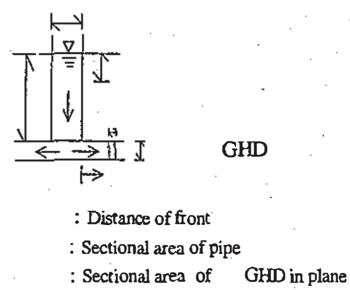


Figure 8. Direction of water flowing.

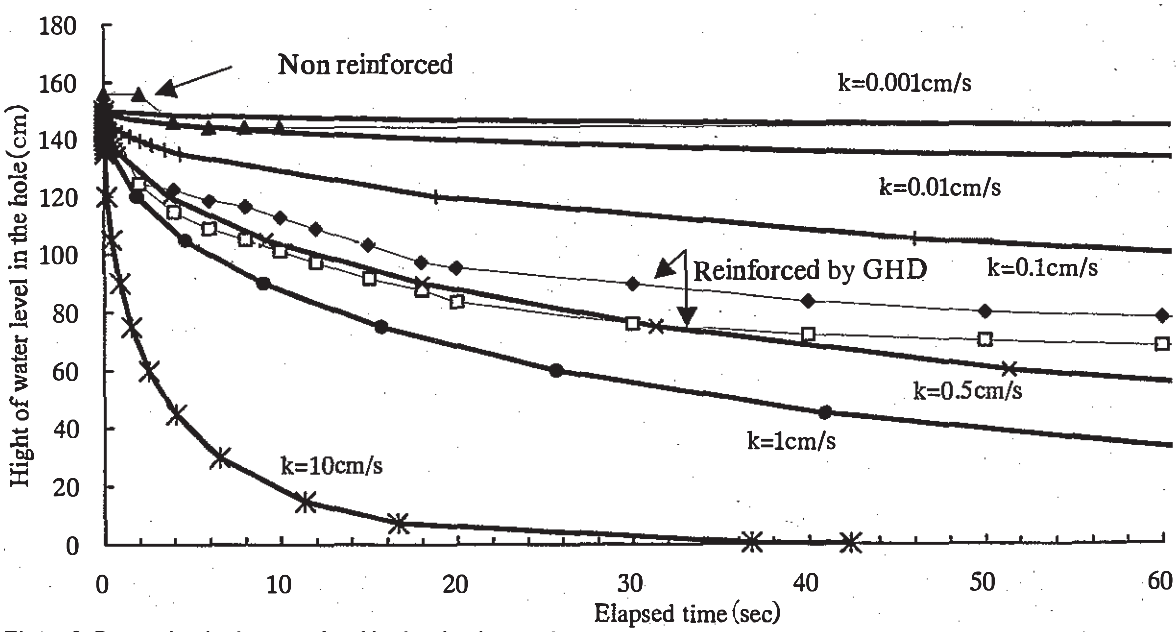


Figure 9. Decreasing in the water level in the pipe in case 1.

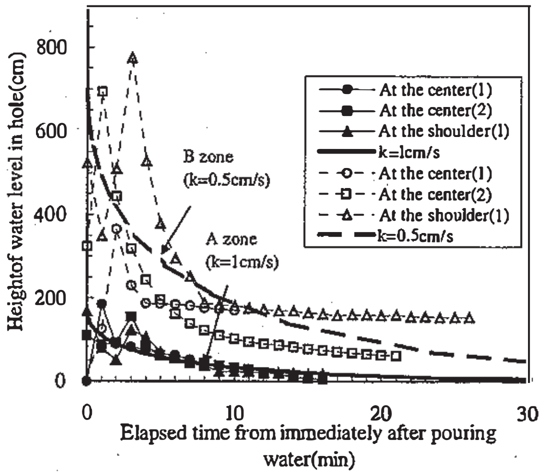


Figure 10. Decreasing of height of water level in the pipe at case 3 test site.

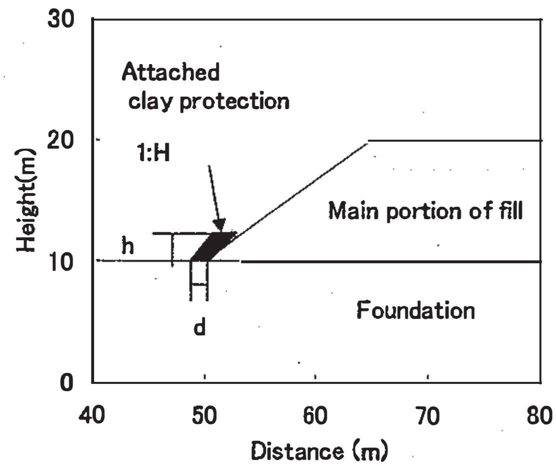


Figure 11. Shape of slope attached by clay block.

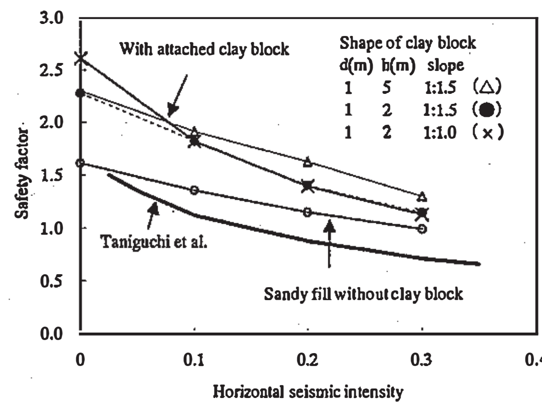


Figure 12. Role of clay block placed at the foot of slope against earthquake.

tionship by Equation (1) on the assumption of the hydraulic coefficient of 0.5 and 1 cm/s. On the basis of this trend, the coefficients of permeability of two GHDs are estimated to range from 0.5 cm/s to lcm/s. These values clearly maintain the initial permeability, even though these tests were conducted a few years after completion of filling.

6 COMPOUND SLOPE WITH CLAY BLOCK ATTACHED AGAINST EARTHQUAKE

To overcome the problem of increasing surplus clay, it is necessary to study the structure of slope that will be resistant against liquefaction if facilitating the strength of clay. Figure 11 shows the corresponding slope for analysis. Figure 12 is the result of the analysis. Figure 12 includes the results given by Taniguchi et al. (1985) applied for the 1984 Nagano west side earthquake. Their corresponding slope has the length of about 200m and the thickness of sliding block of about 20m. Comparing to the simple slope shown in Figure 11, it is much larger. However, the tendency of their research shown in Figure 12 is similar to the results from the simple slope. Based upon the results of the analysis, the clay block can enhance the level of the slope stability, even though the small block is only placed at the foot of a slope.

7 CONCLUSIONS

In this paper, the engineering properties of the full scale clay fill reinforced by GHD were examined analytically. Conclusions can be summarized as follows.

1) Through the results of three prototype filling model tests, it was found that the slopes filled by clay remain stable and have durability.
2) A way was proposed to research permeability characteristics of GHD installation and it was confirmed that the properties of GHD change little from the initial conditions after installation.
3) A clay block installed at the toe of a slope can be effective in preserving a slope of road against earthquake.

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