Reinforced Embankment Using Geosynthetic Horizontal Drains

M. Kamon
DPRI, Kyoto University, Japan
T. Akai
Osaka Prefectural Industrial Technology Research Institute, Japan
M. Fukuda
Osaka Soil Testing Laboratory, Japan
O. Yaida
Osaka Geotextile Research Committee, Japan

ABSTRACT: In the present study, newly developed geosynthetic horizontal drains (abbreviated as GHDs) consisting of geosynthetic materials of which transmissivity and core strength are reliably high, were included in reinforced embankments. The basic reinforcing characteristics of GHDs were investigated with a pull-out test and direct shear test. According to the test results, GHDs can be used for the reinforcement of soft clay embankments. The slope deformation and pore water pressure of the reinforced embankment were carefully monitored and the results showed reasonably little deformation. The integrity of the reinforced embankments using GHDs was maintained even throughout the heavy rainy season of 1993.

1 INTRODUCTION

Geosynthetic materials have often been used for the reinforcement of road and railway embankments because of their cost effectiveness. Drainage of embankments during and after heavy rain is of primary importance for slope stability, and reinforcing with geosynthetic materials of high permeability has several advantages over using non-permeable reinforcing inclusions for drainage within the embankment. However, the drainage effects of using these materials have largely been ignored in the design of reinforced embankments because of uncertainty regarding their properties, and to date have only been considered in decisions concerning the configuration of the inclusion.

Prefabricated band-shaped drains (abbreviated as PDs) are often used as vertical drains to accelerate consolidation of soft clay ground. The newly developed geosynthetic horizontal drains (abbreviated as GHDs) are similar to PDs but are both wider and thicker. The design concept and principle behind the development of GHDs is to facilitate the replacement of the sand mat, and are laid on soft clay ground to obtain trafficability and to discharge water from the clay ground. GHDs are composed of geosynthetic composite materials. Their opening patterns of filter are ideal with respect to the fabric parameters concerning permeability and their core materials have reliable strength (Osaka Geotextile Research Committee, 1991). Therefore, GHDs have high tensile strength and can be applied to reinforced embankments.

In the present study, the basic properties of GHDs as reinforcing inclusions were determined, and subsequently they were applied to practical use for reinforcing soft clay embankments.

2 DEVELOPMENT OF GHDS

2.1 Basic properties of GHDs

The basic hydraulic characteristics of geosynthetic composite horizontal drains are initially discussed with regard to suitable discharge capacity, or transmissivity, under large confining pressure. Four different kinds of GHDs have been developed by the textile makers of Osaka Geotextile Research Committee. These are classified as (1) pile-type (pile-state polypropylene on polyester woven base cloth), (2) nonwoven three-dimensional type (mesh-state mono-filament polypropylene in nonwoven sheath), (3) woven three-dimensional type (pile-state yarn on woven base cloth) and (4) straw-type (nonwoven filter and polyolefin resin core) structures. All of these types of GHDs have high in-plate permeability, and thus, their transmissivity is sufficient to discharge the groundwater in clay ground.

Reinforcement of the embankment requires not only good drainage capacity but also high strength in these GHDs. Because the pile- and straw-type GHDs have the highest tensile strength, these two were selected for the reinforced embankment in the present study. The material properties of the GHDs used are summarized in Table 1. In cross-sections, they ranged in width from 30 to 60 cm, and from 10 to 12 mm in thickness as shown in Fig. 1. Nonwoven cloth was also selected as a representative permeable geosynthetic inclusion. The transmissivity of the GHDs was more than a hundred times that of the nonwoven cloth.

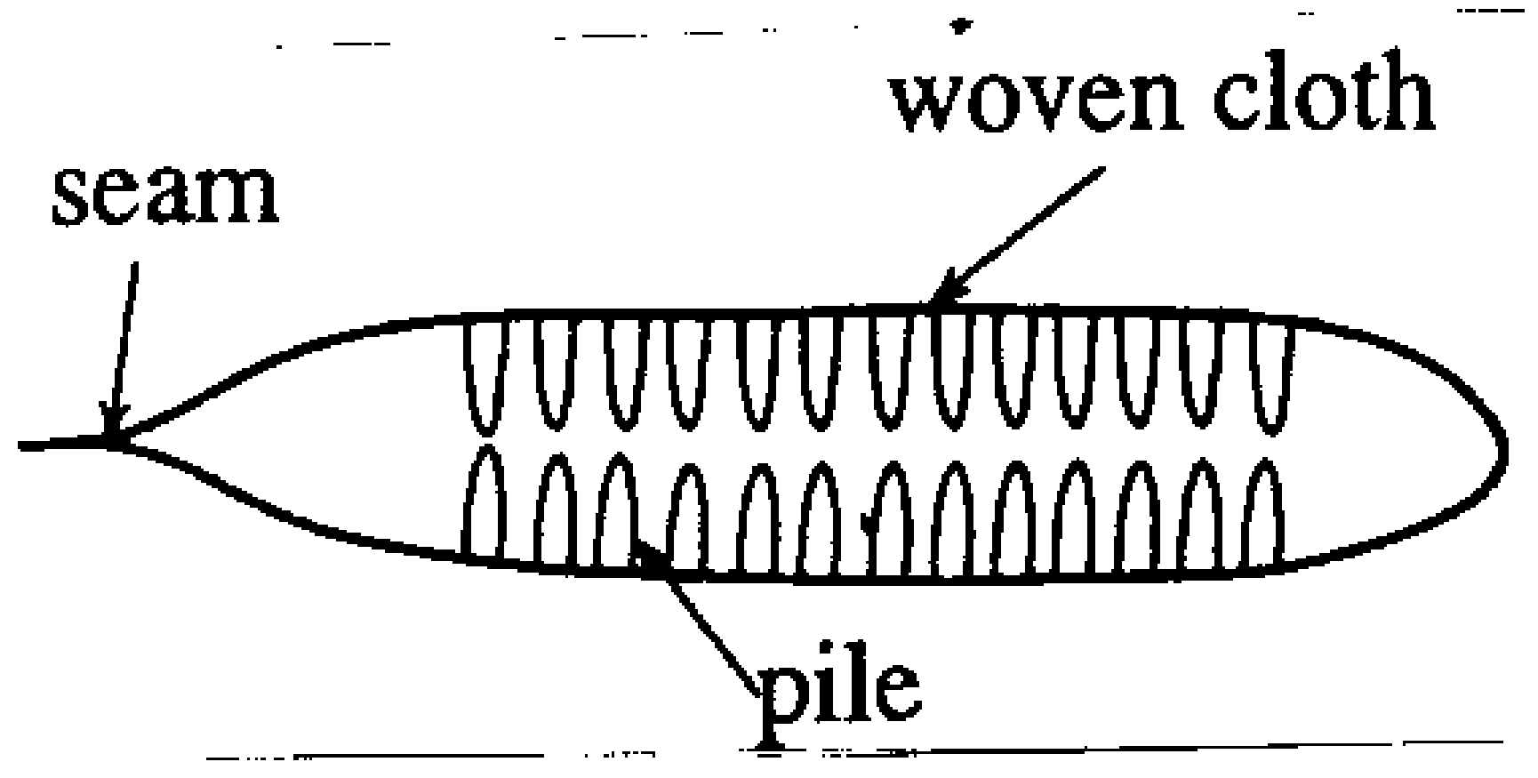
2.2 Pull-out test

A pull-out test was conducted to investigate the reinforcement effects of GHDs. The apparatus used is

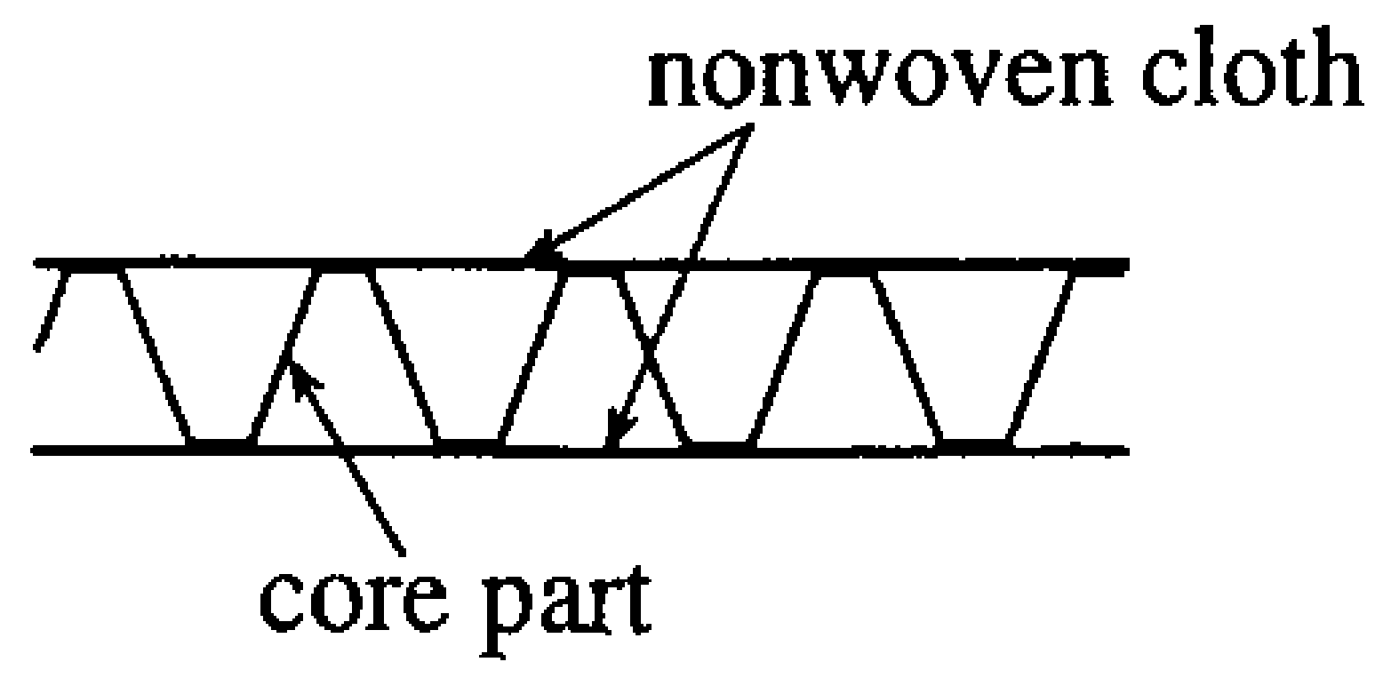
Table 1 Material Properties of GHDs

Materials	Thickness (mm)	Unit density (g/m²)	In-plate permeability(cm/s) Normal stress at 98.0kPa	In-plate permeability(cm/s) Normal stress at 294.0kPa	Tensile strength (kN/m)	Transmissivity (cm³/s) at 98.0kPa
Nonwoven cloth	3	436	$1.8\text{x}10^{-1}$	$1.3\text{x}10^{-1}$	15.7	0.14
Pile-type GHD	12	1763	$1.1\text{x}10^{1}$	$4.8\text{x}10^{0}$	74.5	33.0
Straw-type GHD	10	1981	$2.3\text{x}10^{1}$	$2.2\text{x}10^{1}$	49.6	23.0

Note: Transmissivity was calculated for a 30 cm wide sample.



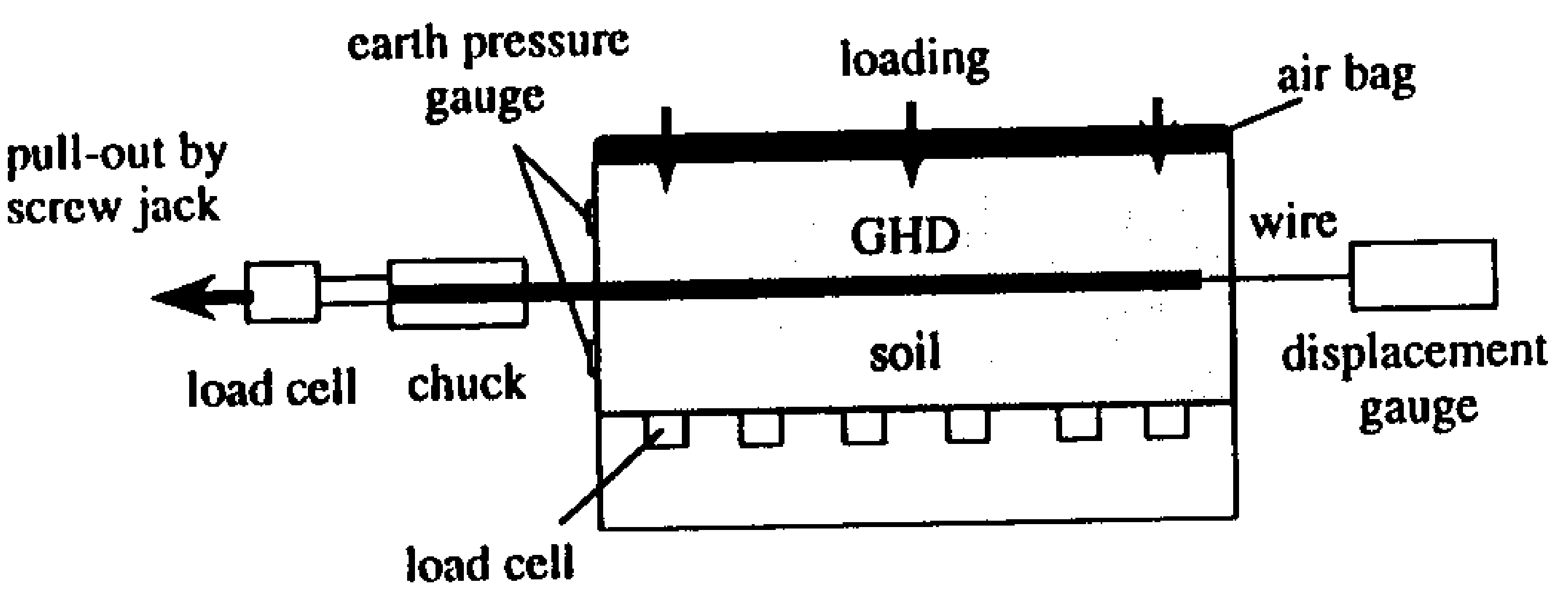
(a) Pile-type GHD



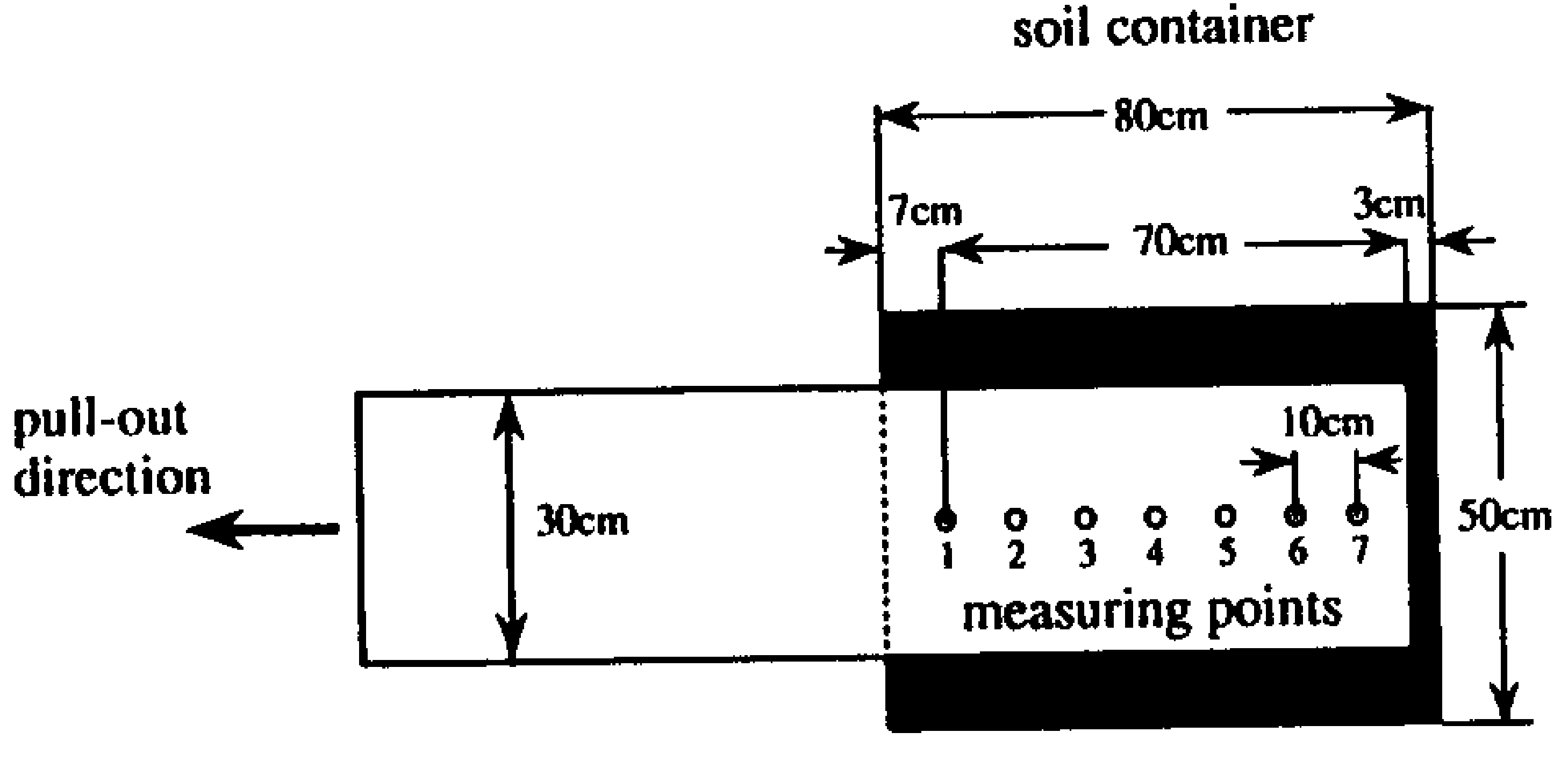
(b) Straw-type GHD

Fig. 1 Cross-Section of Two GHDs

illustrated schematically in Fig. 2 (Kamon et al., 1993; Farrag et al., 1993). The cross-sectional size of the soil container was 50x80 cm, and the thickness of soil above and below the reinforcing inclusion was 10 cm. Elongation of the GHD sample during the pull-out test was measured by the seven points at which wires were fixed, and the other sides of wires were connected to potentiometers used as displacement gauges. The pull-out rate used was 1.0 mm/min. An example of a pull-out test result is shown in Fig 3. This figure shows pull-out force as measured by a load cell, and displacement of each point of the GHD in the soil container. Because the maximum displacement occurs at the point nearest to the pulling side, the strain between points 1 and 2 was selected to determine the tensile strength of the GHDs used. The pull-out strength at 5% strain, T_5, is shown in Fig. 4, and at normal stresses the straw-type GHD showed the greatest strength.



(a) Schematic representation of apparatus used



(b) Sample dimensions tested (Numbers indicate points for displacement gauges)

Fig. 2 Pull-out Test Apparatus Used

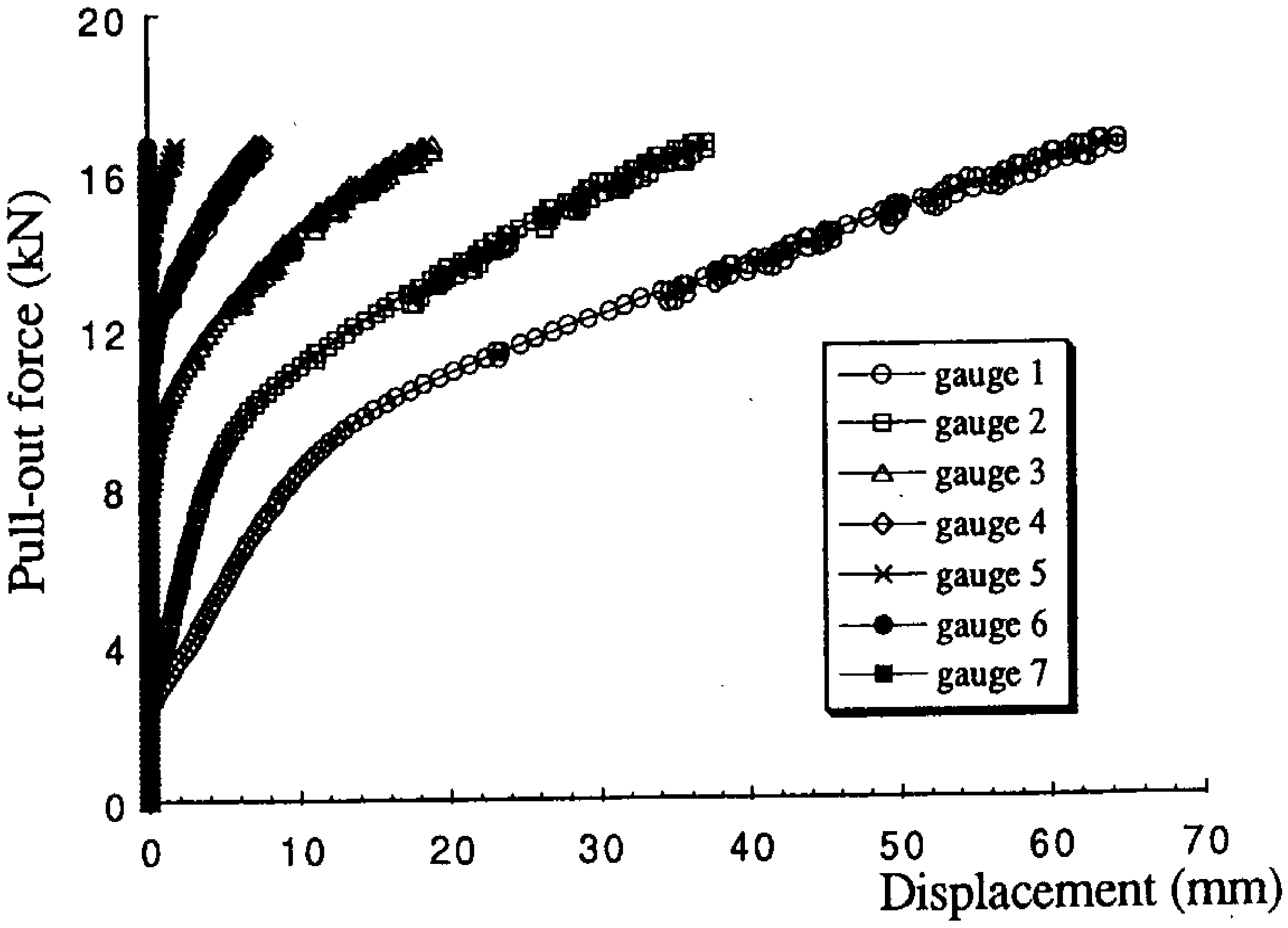


Fig. 3 Displacement of Pile-Type GHD (Normal stress: 98.0kPa)

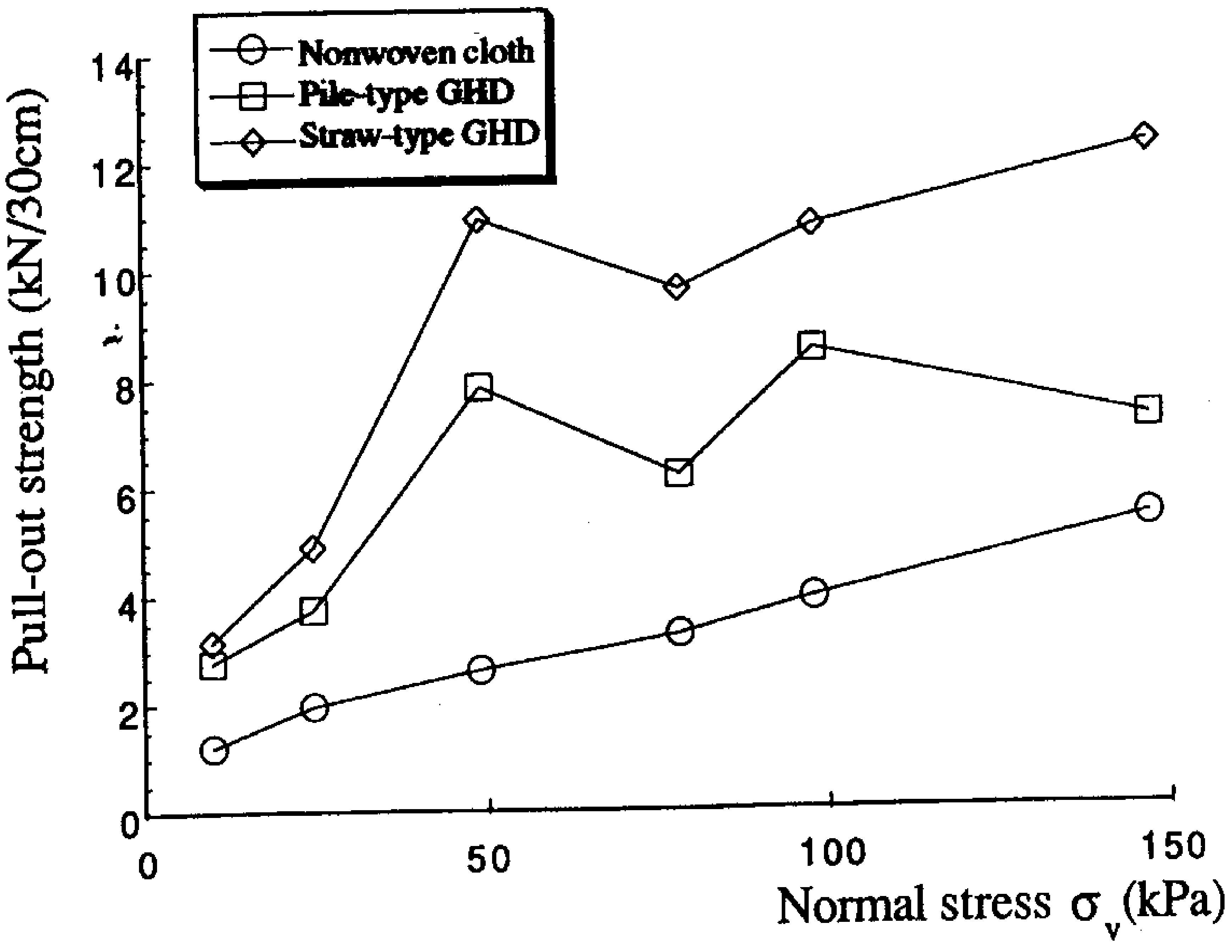


Fig. 4 Pull-out Strength of GHDs (at 5 % strain)

2.3 Shear box test

The coefficients of friction between GHD and clay soils were measured by a shear box test, as summarized in Table 2. The clay samples used were remolded and consolidated in the shear box and arranged under high and low water

Table 2 Coefficient of Surface Friction of GHDs

Materials	Coefficient of surface friction
Nonwoven cloth	0.71 - 0.81
Pile-type GHD	0.51 - 0.86
Straw-type GHD	0.69 - 0.89

content conditions. The test results were scattered from 0.51 to 0.89. The lowest values of the surface friction coefficient were obtained under high water content soil conditions. Therefore, we must use the lowest value for designing the reinforced clay soil embankment.

3 APPLICATION TO REINFORCED EMBANKMENT

3.1 Site condition and design procedure

The southern part of Osaka Prefecture is comprised of a typical Tertiary-type landslide area, and many slope failures of embankments in this area take place during the heavy rainy season every year. This hilly area is used for rice farming and embankments are usually about 3 m high. GHDs were applied to the reinforced soft clay embankments in this area for the rehabilitation of two embankments which had broken with the heavy rain in autumn, 1992. Figure 5 shows a model cross-section of a reinforced embankment. The soil conditions and inclusions used are listed in this figure.

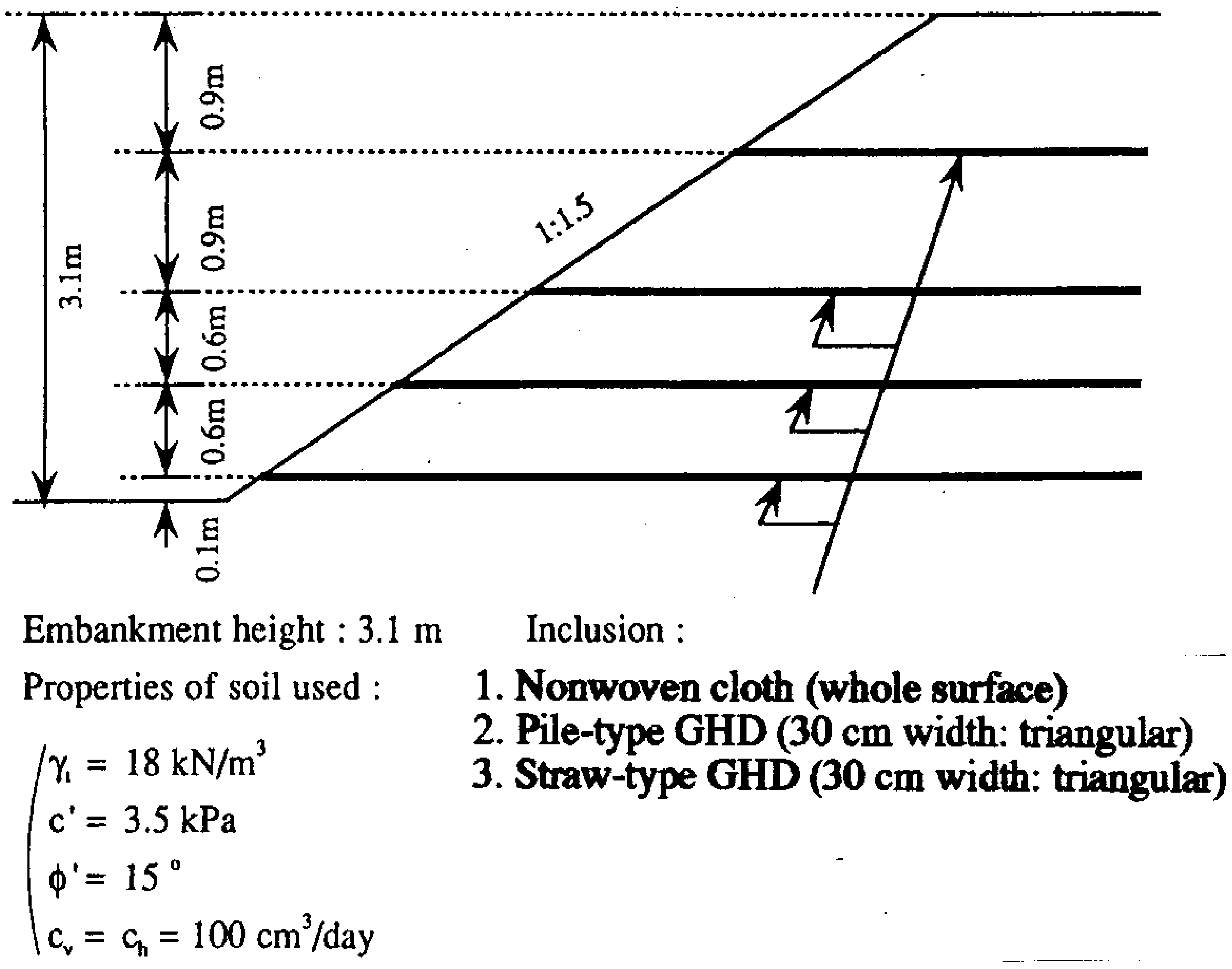
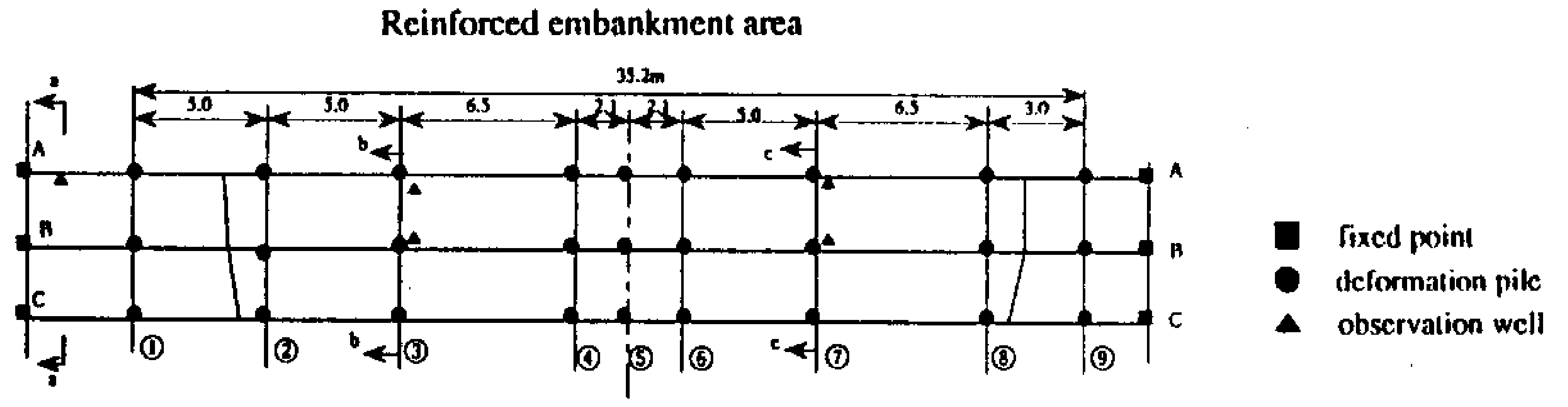


Fig. 5 Model Cross-Section of Reinforced Embankment

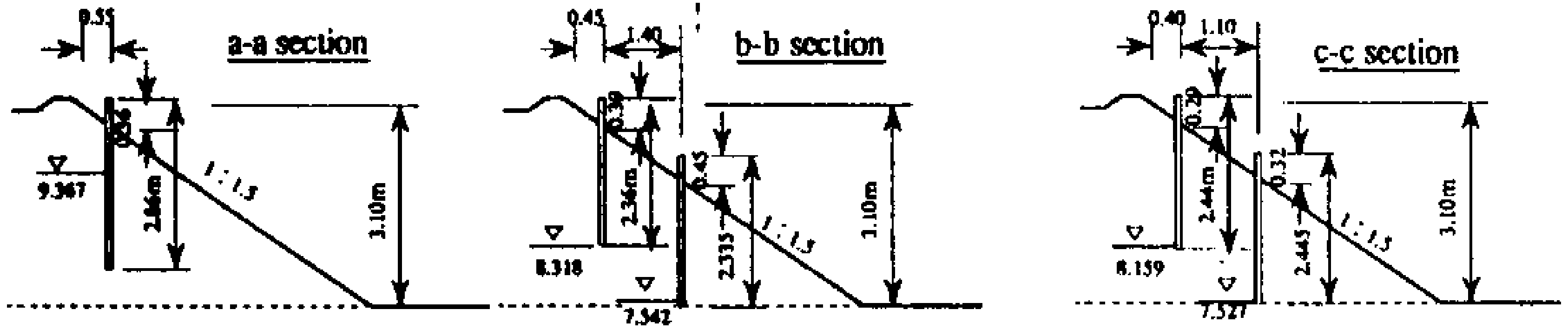
The design procedure of the reinforcement is discussed on the basis of the material properties and the in situ condition of the embankments. As the basic design concepts of reinforcement by GHDs, the design procedure established by Ministry of Construction (Public Work Research Institute, 1992) was used in the present study. As shown in Fig. 5, each 30 cm wide GHD was laid on every 60 cm soil layer at 1.3 m intervals with a triangular configuration. The nonwoven cloth reinforcement was laid on every 60 cm soil layer for the whole surface.

3.2 Monitoring results

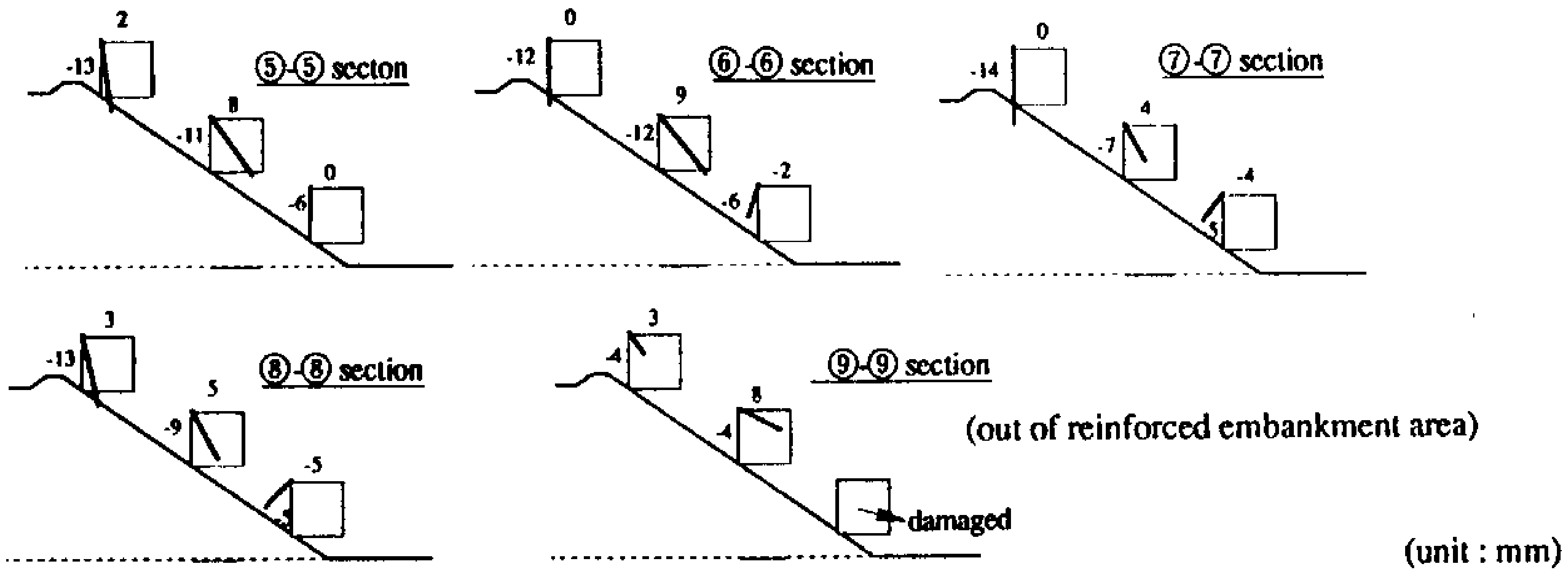
Deformation piles and polyvinyl chlorite pipes (ϕ: 5 cm) with strainers to act as observational wells were installed. The elongation and stress induced in reinforcing GHDs were measured by strain gauges fixed on their surfaces. Figure 6 shows the instrumentation of the reinforced embankment using the pile-type GHD (2, 3 and 4 sections) and straw-type GHD (6, 7 and 8 sections). Monitoring results at around one year after completion of the earth work are also shown in Fig. 6. Very low groundwater levels were observed in b-b section (pile-type GHD) and c-c section (straw-type GHD) in contrast to the high groundwater level observed in a-a section (non-reinforced area). Relatively large surface slope deformations (total values of about 10-13 mm) were observed at the top and middle parts of the slope, but these values were not



(a) Instrumentation points



(b) Groundwater level in embankment



(c) Deformation of embankment

Fig. 6 Instrumentation and Monitoring Results of Groundwater Level and Deformation

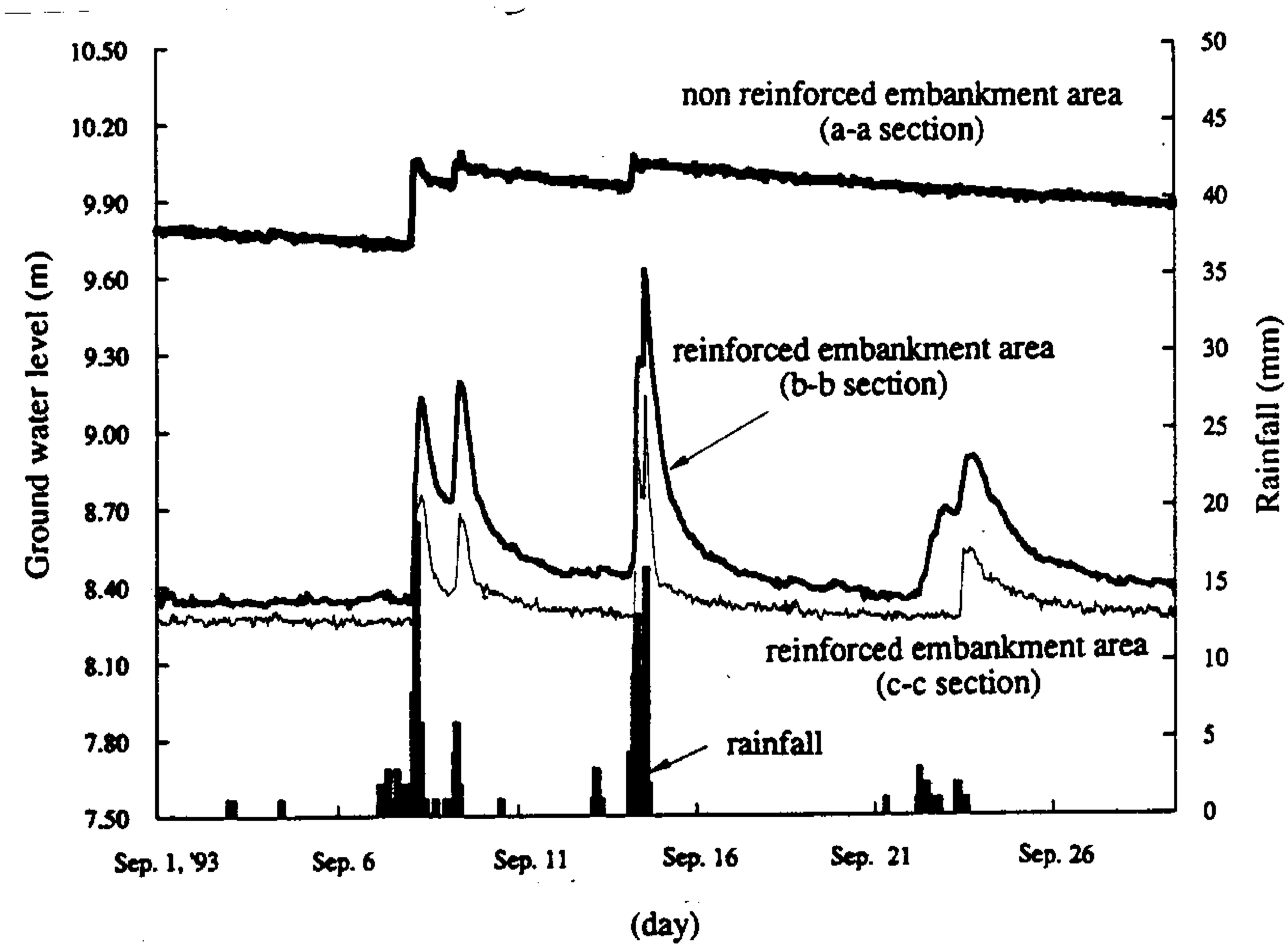


Fig. 7 Fluctuation of Groundwater Level

significant. On the other hand, large vertical and lateral deformation (about 10-17 mm) was observed for only two months in the reinforced embankment using nonwoven cloth. The total values of deformation in the embankment using nonwoven cloth were around 27-35 mm for one year, and it was considered that lateral movement as well as consolidation settlement to had occurred in the embankment. These deformations will be settled in the near future. The observed strains in the GHDs were very small and the values of surface slope deformation were approximately half of those using nonwoven cloth inclusions.

Fluctuations in groundwater level in the observational well during a heavy rainy season are illustrated in Fig. 7. In the non-reinforced area, groundwater level was very high and took a very long time for dissipation. On the other hand, GHDs showed high level drainage effects, and thus, pore water pressure in the embankment was quickly dissipated.

4 DISCUSSION

Based on the above monitoring results, the GHDs showed very high drainage effect for more than one year. Because the pore water pressure in the embankment directly affects slope stability, high level drainage characteristics are very useful for increasing the safety factor of the slope. Therefore, we can consider in the design of the slope that GHDs not only have a reinforcing effect but also a dissipation effect on pore water pressure. Miki (1993) proposed a design procedure to reinforce soft clay embankments using horizontal drain inclusions. The drainage effects of inclusions used in the present study were calculated by Giroud's equation (1983). Figures 8 and 9 show the calculated results of the safety factors of the slopes, which are considered to represent consolidation of the soft clay soil due to dissipation of pore water pressure by the inclusions. The transmissivity of inclusions affects the safety factors of the slope by three days after completion of the earth work. It can be clearly seen that the safety of the soft clay embankment is lowest in the early stages of execution, and that the high transmissivity of GHDs confers a high level of safety on the slope.

There was extremely heavy rainfall in the summer and autumn of 1993, as a result of which many slope failures occurred in this area. Nevertheless, there were no problems in these two reinforced embankments. Thus, a high level of safety of the embankment was achieved by reinforcing with GHDs.

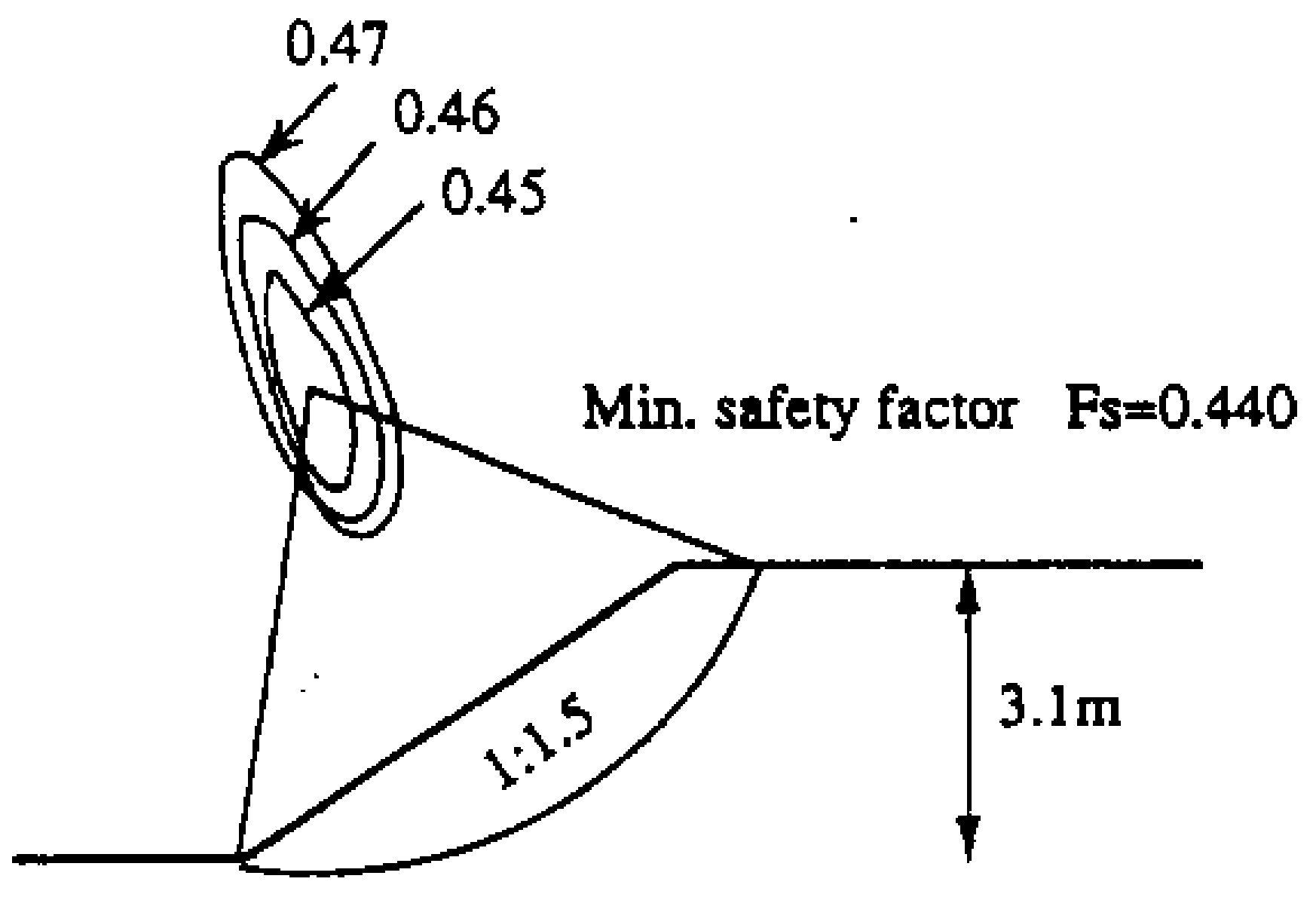
5 CONCLUSIONS

We applied the newly developed geosynthetic horizontal drain materials to reinforced embankments and investigated the resultant slope stability. The following conclusions were obtained for the newly developed GHDs and their practical application to reinforced embankments:

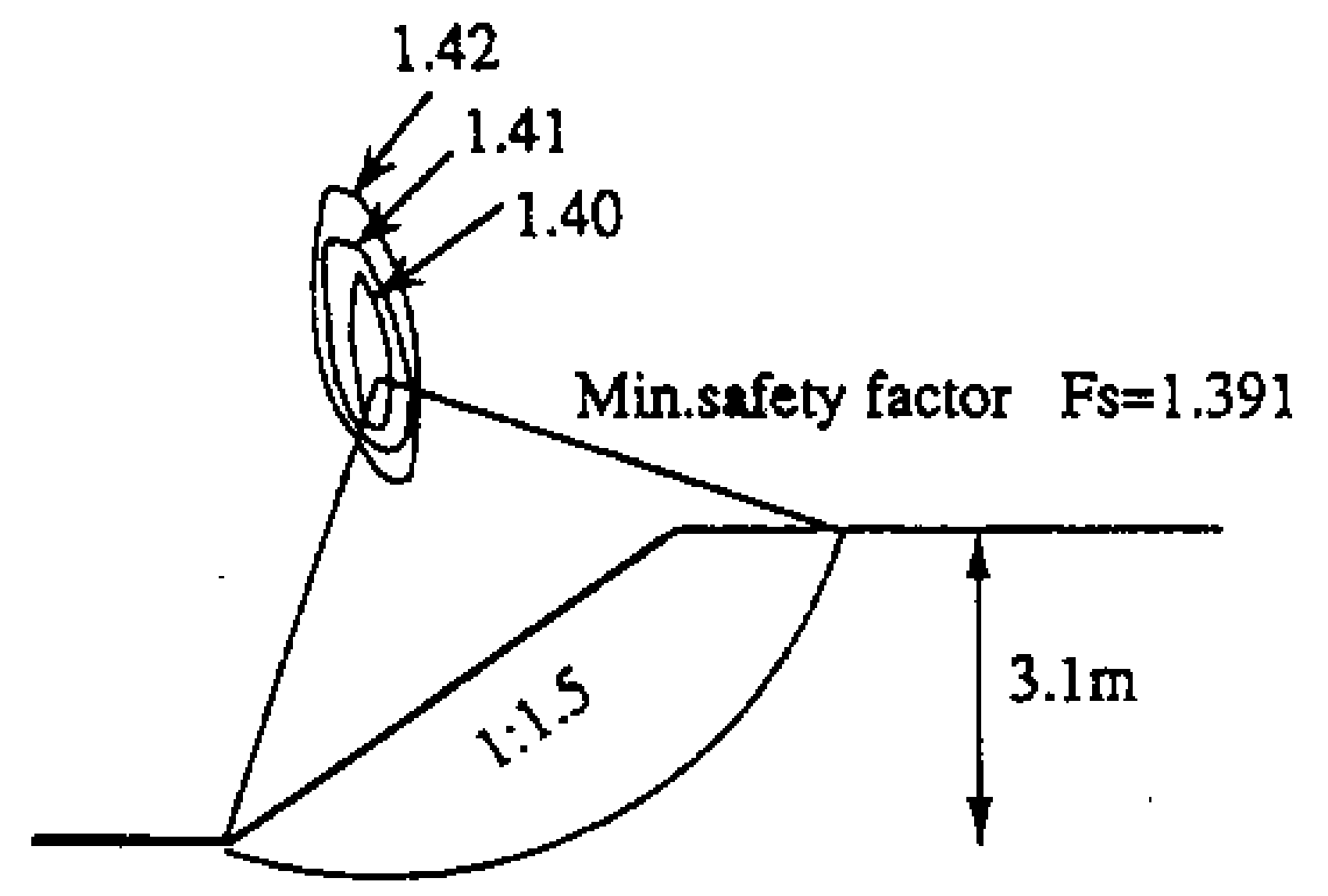
(1) Newly developed GHDs have high tensile strength and high transmissivity.

(2) GHDs can be applied to reinforcement of soft clay embankments in the triangular configuration with good results.

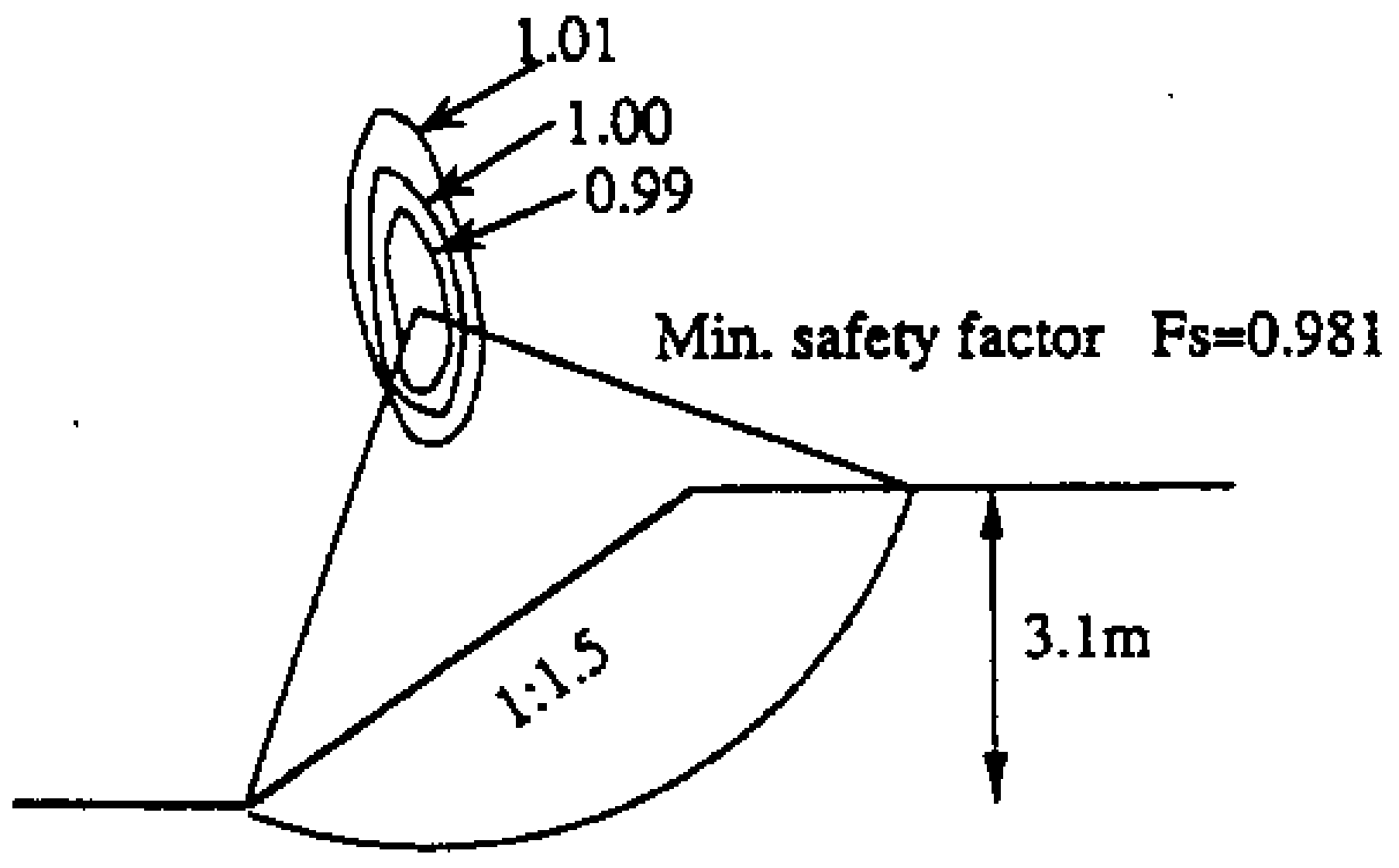
(3)Both reinforcement and drainage effects of GHDs can be considered for stabilization of soft clay embankments.



(a) Nonwoven cloth

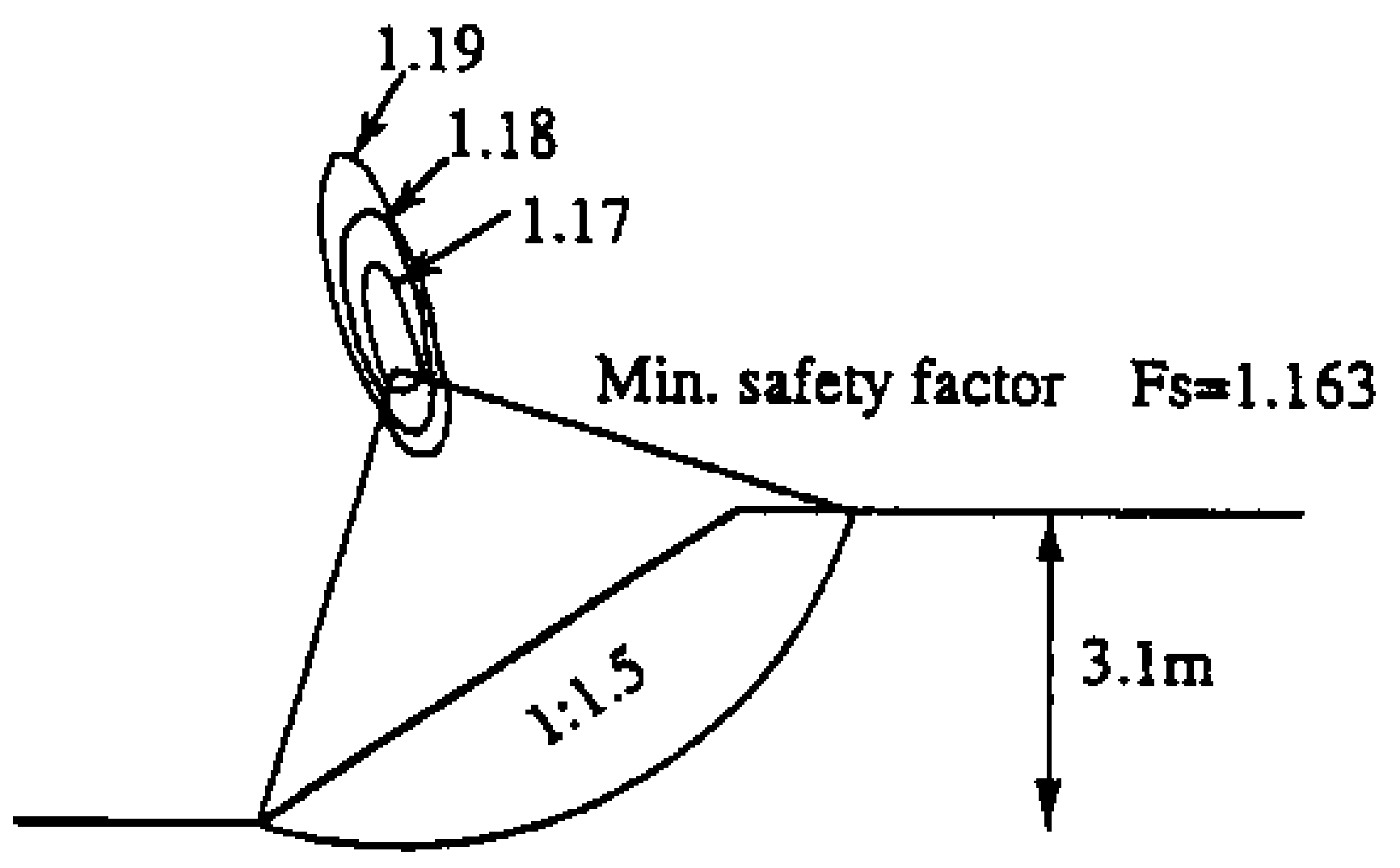


(b) Pile-type GHD

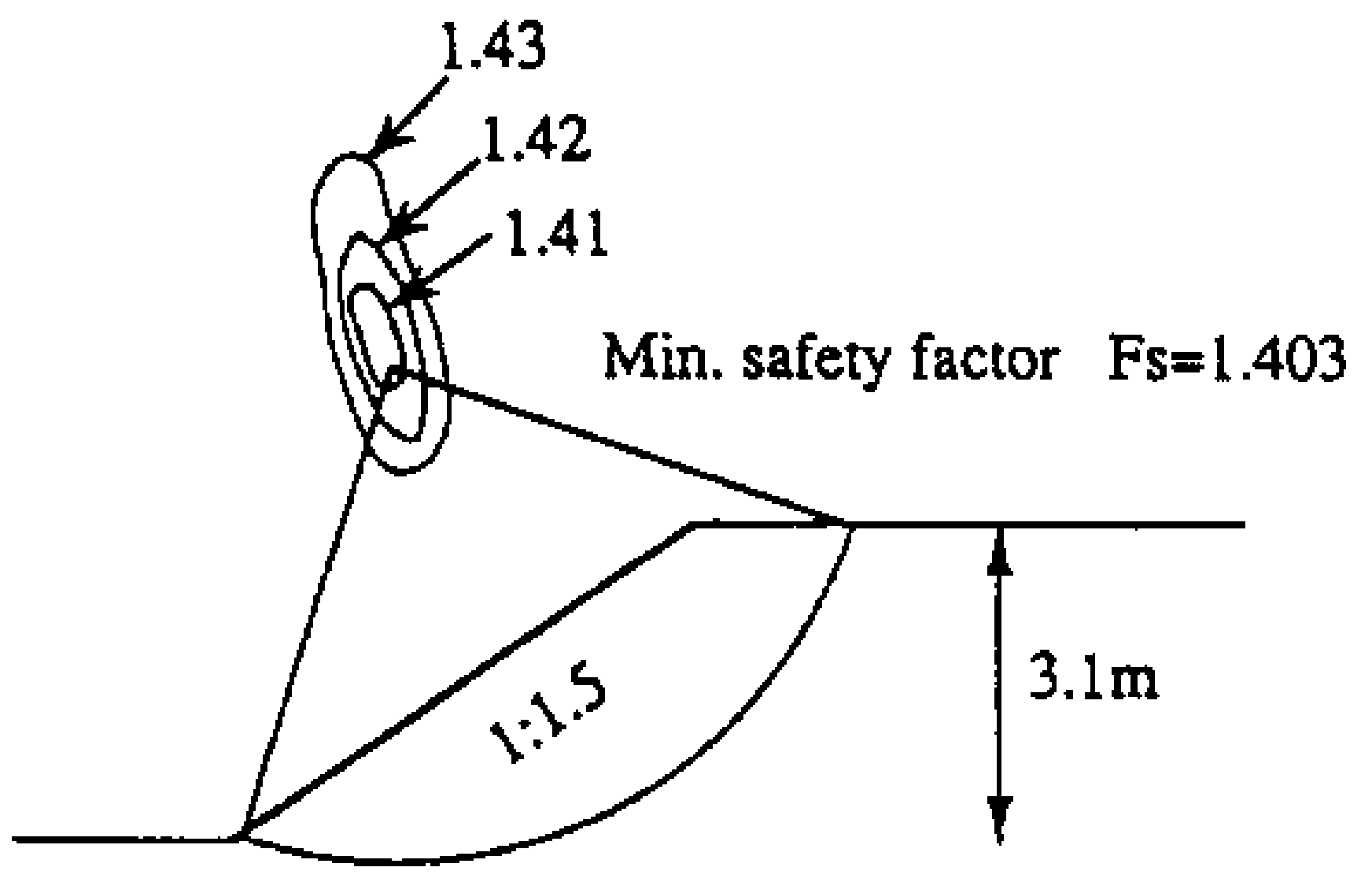


(c) Straw-type GHD

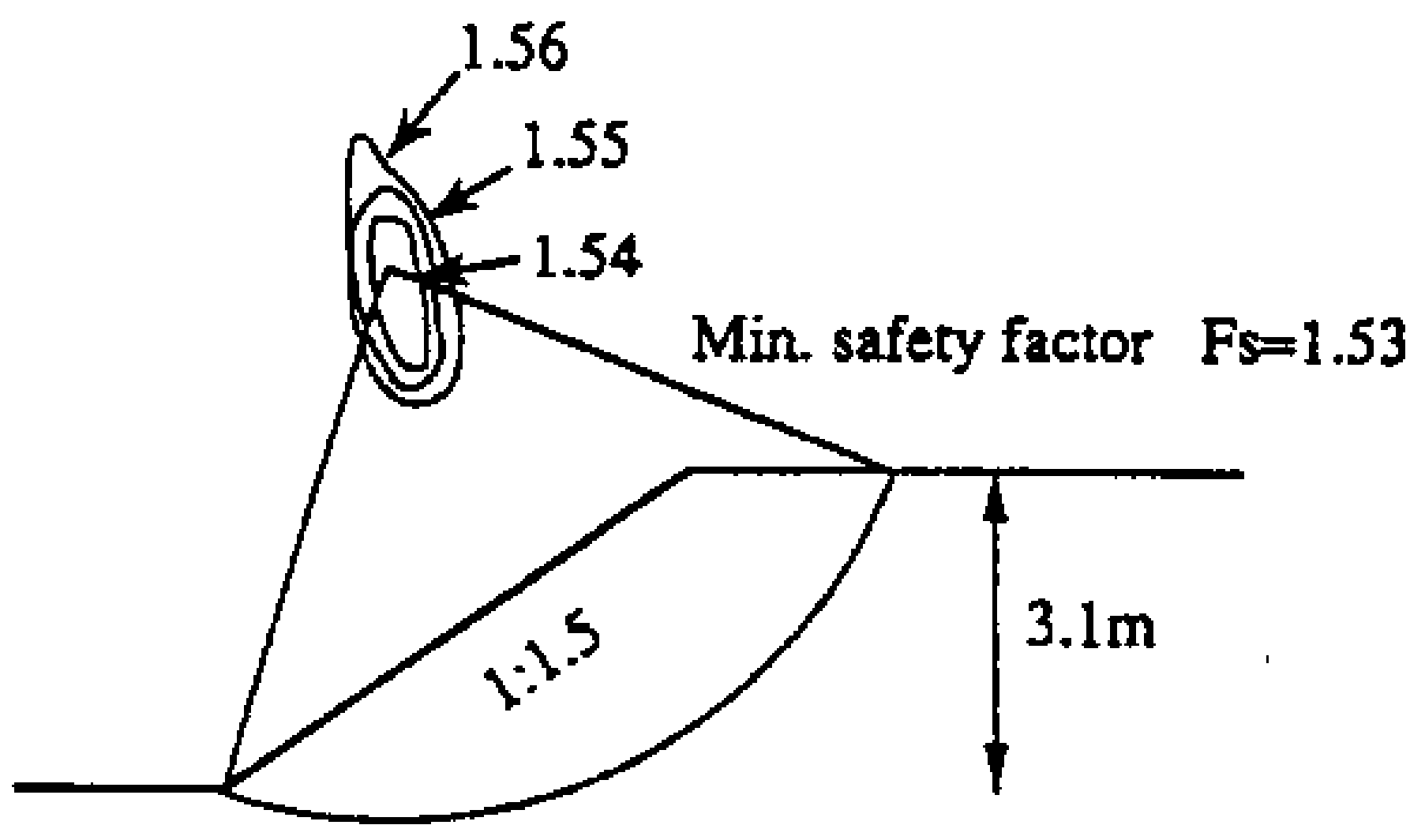
Fig. 8 Distribution of Safety Factors (at three days after completion of earth work)



(a) Nonwoven cloth



(b) Pile-type GHD



(c) Straw-type GHD

Fig. 9 Distribution of Safety Factors (after the full dissipation of pore water pressure)

(4) The groundwater level of reinforced embankments is quickly reduced as a result of the high discharge capacity of GHDs.

(5) The transmissivity of GHDs is very important for the early stage stability of embankments.

The results presented in this study demonstrate significant desirable effects of GHDs for reinforced embankments. It is necessary to further determine quantitatively the influence of the actual pore water pressure in reinforced embankments using GHDs.

REFERENCES

Kamon, M., Nagai, H. and Wada, H. (1993) Pull-out resistance of geosynthetic horizontal drains , *Proc. 43rd Annual Meeting on JSCE*, Sendai, 3:1154-1155.

Farrag, K., Acar, Y.B. and Juran, I. (1993) Pull-out resistance of geogrid reinforcements, *Geotextiles and Geomembrances*, 12:133-159.

Giroud, J.P. (1983) Geotextile drainage layers for soil consolidation, *Civil Engineering for Practicing and Design Engineering*, 2:275-295.

Miki, H. (1993) Reinforced embankment method by geotextile, Jour. of Soil Mech. & Found. Eng., JSSMFE, Vol. 41, No. 9, pp. 69-76.

Osaka Geotextile Research Committee (1991) Filter properties for geotextile, *Annual Report on Applicability of Geosynthetic Horizontal Drains*, 4-66.

Public Work Research Institute (1992) Reinforced embankment method, In: *Design Manual for Reinforced Earth by Geotextile*, 97-135.