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Investigation of soil layer on steep slope using SH-type penetration test

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Abstract

There occur a lot of slope failures caused by heavy rainfall in Japan every year. For the first step of recovery from those disasters, it is necessary to make the urgent works effectively and smoothly. Therefore, it is important to clarify the strength and/or thickness of soil and/or rock layers, slope shape, characteristics of soil and geology in those slopes. Although simple penetration test of a traditional type, which is composed of weight(5kg) and cone, have been carried out very frequently, the intensity of penetration is too strong to grasp the detail of soil structure in this test.

The instrument of SH-type penetration test is composed of weights(2kg+3kg), cone and penetrometer with an automatic recorder. The weight of this instrument is lighter than that of the traditional type, so that it can be carried onto steep slope and/or mountainous area easily. Moreover, this test has sensitivity in estimating the soil strength with the lighter weight. Therefore, detailed structure of soil layer can be obtained more precisely.

In this paper the authors report a result of field tests of SH-type penetration in Odaizawa area(Nagano pref.). In the upper reaches of Odaizawa-river reaches, there occurred a lot of slope failures caused by heavy rainfall in July, 2006.

According to a series of SH-type penetration tests, soil structure of this area is roughly divided into 5-layers as follows.

Ⅰ layer (surface soil, colluvial deposit, talus accumulation Nc<5)

Ⅱ-1 layer (under Ⅰ layer, 5< Nc<10)

Ⅱ-2 layer (under Ⅱ-1 layer, 10< Nc<20)

Ⅲ layer (under Ⅱ layer, 20<Nc<50)

Ⅳ layer (basement rock, Nc＞50)

At the same time, the mechanism of two surface failures in Odaizawa-river reaches is considered as follows.

(1) Slip surface of slope failures is located between Ⅱ-1 layer and Ⅱ-2 layer, or within Ⅱ-1 layer.

(2) In the cross section of slope failures, Ⅱ-1, Ⅱ-2 and Ⅲ layers take concave shape.

Keywords: slope failure, thickness of weathered rock, slope shape, SH-type penetration test, investigation method

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Introduction

There occur a lot of slope failures caused by heavy rainfall in Japan every year. For the first step of recovery from those disasters, it is necessary to make the urgent works effectively and smoothly. Therefore, it is important to clarify the strength and/or thickness of soil and/or rock layers, slope shape, characteristics of soil and geology in those slopes. Although simple penetration test of a traditional type, which is composed of weight(5kg) and cone, have been carried out very frequently, the intensity of penetration is too strong to grasp the detail of soil structure in this test.

The instrument of SH-type penetration test is composed of weights(2kg+3kg), cone and penetrometer with an automatic recorder. The soil strength(it is referred to as the Nc-value) is obtained by dropping the weight from the top of the rod to the knocking head(Fig.1). Nc-value is calculated by the following expression.

$$Nc = \frac{1}{\text{Quantity of penetration by using the weight(2kg+3kg) per a drop(mm)}} \times 100(\text{mm})$$

The weight of this instrument is lighter than that of the traditional type, so that it can be carried onto steep slope and/or mountainous area easily. Moreover, this test has sensitivity in estimating the soil strength with the lighter weight. Therefore, detailed structure of soil layer can be obtained more precisely.

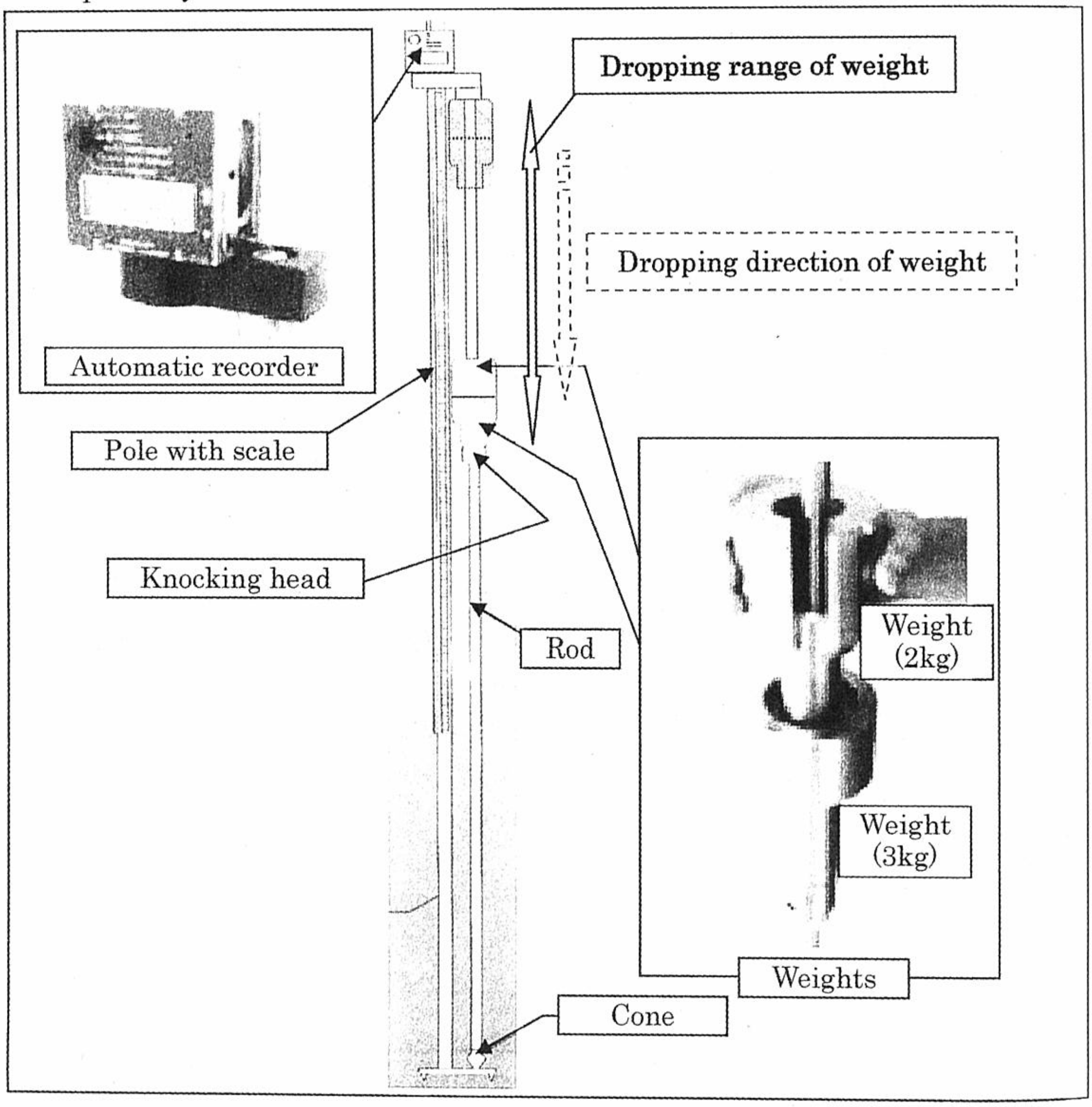

Fig.1 The instrument of SH-type penetration test

In this paper the authors report a result of field tests of SH-type penetration in Odaizawa area, Nagano pref.(Fig.2). In the upper reaches of Odaizawa-river reaches, there occurred a lot of slope failures caused by heavy rainfall in July, 2006.

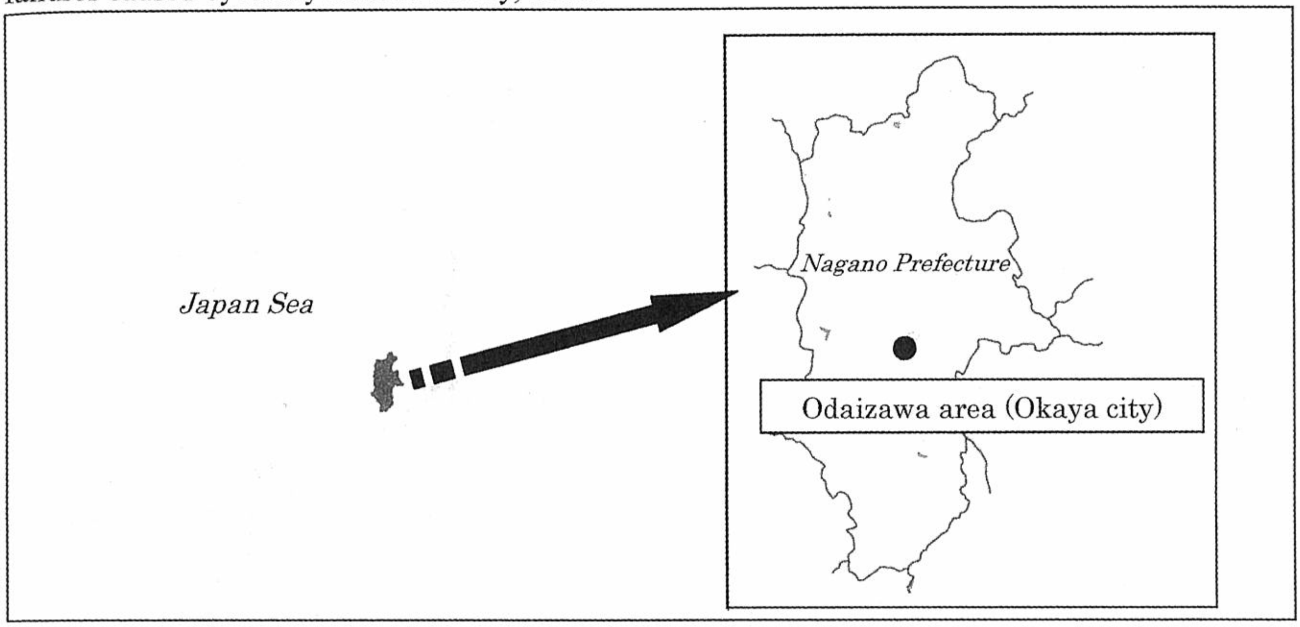

Fig.2 Location of Nagano prefecture

Investigation area

The investigation area is located in the upper reaches of Odaizawa-river(Fig.3), Okaya City(Nagano Pref.) where a lot of slope failures and debris flows occurred due to heavy rainfall in July 15th-24th, 2006. In this area, a lot of slope failures had occurred near the ridge of mountain.

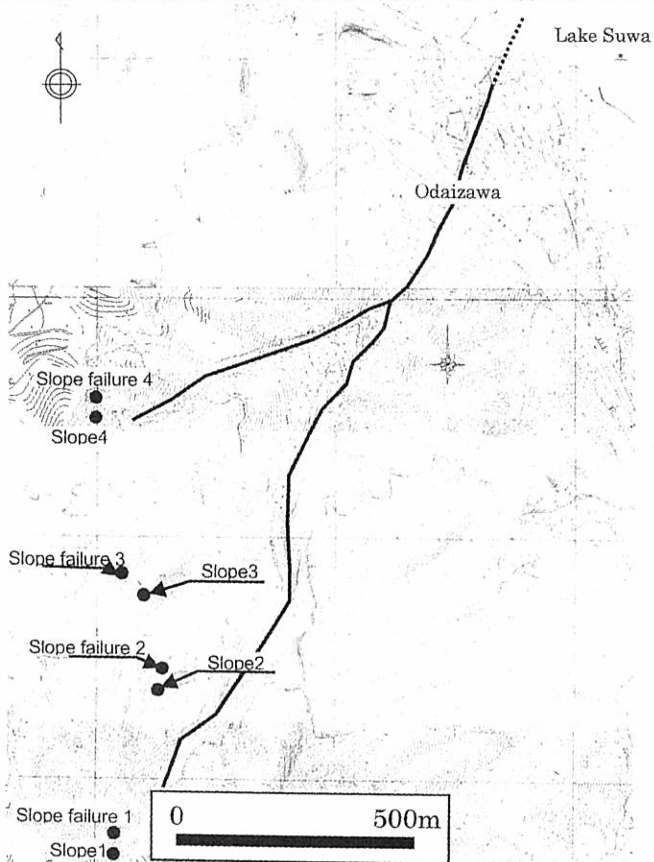

Fig.3 Investigation area

First, the authors selected four slope failures that are in the most upper part of tributary Odaizawa-river reaches, because those slope failures were regarded as a cause of debris flow. For the comparison of the characteristics of soil layer, the authors chose four non-collapsed slopes close to the above four slope failures again.

In each test sites the authors set traverse lines in order to grasp the structures of soil layers, and tried to analyze not only vertical sections but also cross sections of collapsed and non-collapsed slopes.

At this stage it is desirable to implement SH-type penetration tests as many points as possible in order to grasp more detailed structures of soil layers, but practically it is almost impossible due to many conditions. Therefore, it is necessary to set the minimum test points for analysis efficiently on the vertical and cross sections.

In the case of deep-seated landslide, at least 4 points are usually set on a measurement line(Fig.4). Similarly, even in the case of slope failure, the authors considered that at least 4 points were necessary to obtain accurate shapes of layers. In addition, we tried to set at least 3 test points on the cross sections(Fig.5).

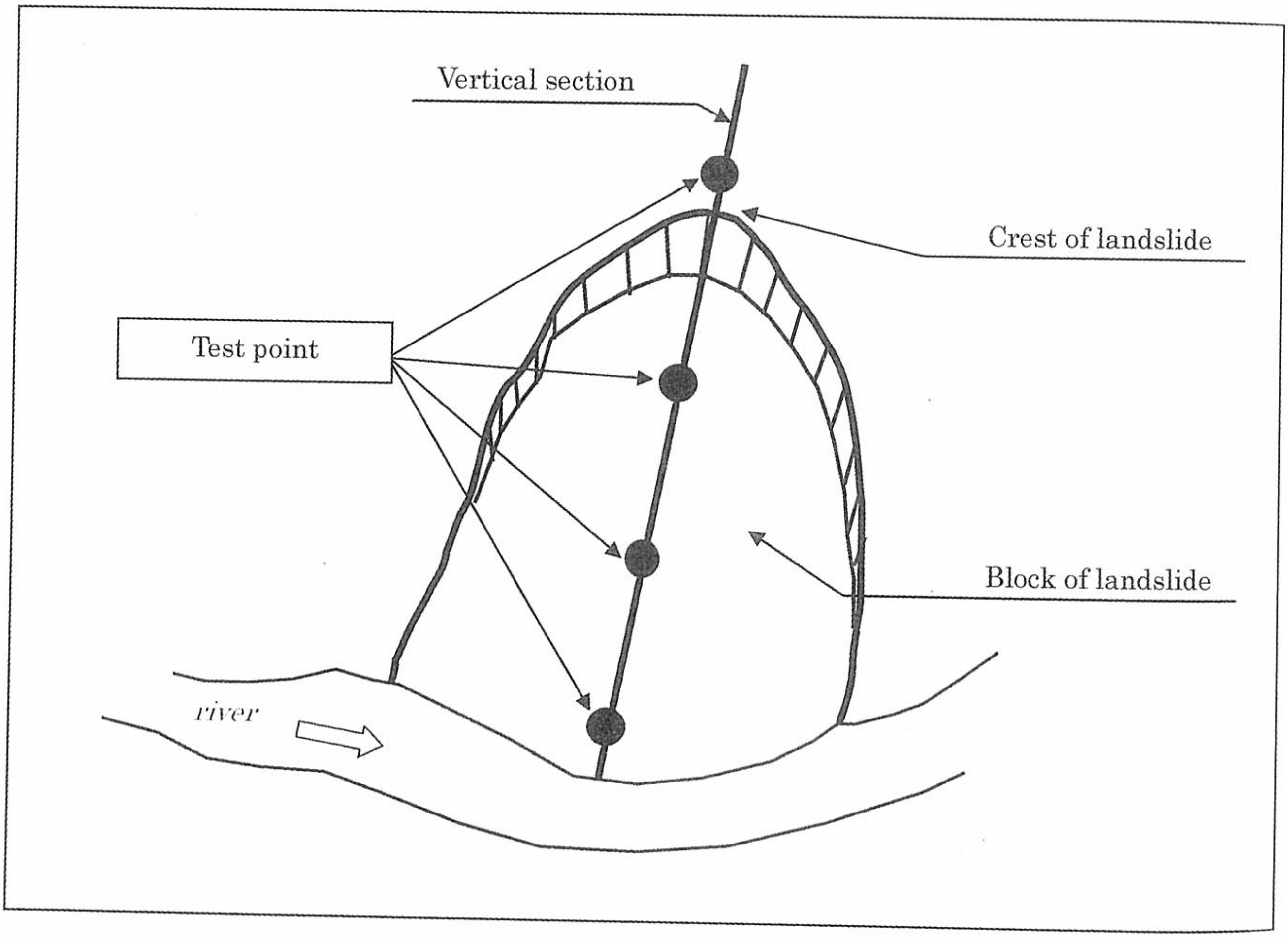

Fig.4 Example of the arrangement of boring points for deep-seated landslide

Basically, the authors implemented SH-type penetration tests at least 8 points(on the intersections of vertical, and cross sections) in every test site(Fig.5). From series of these tests, it became possible to grasp the shapes of soil structure of those slopes.

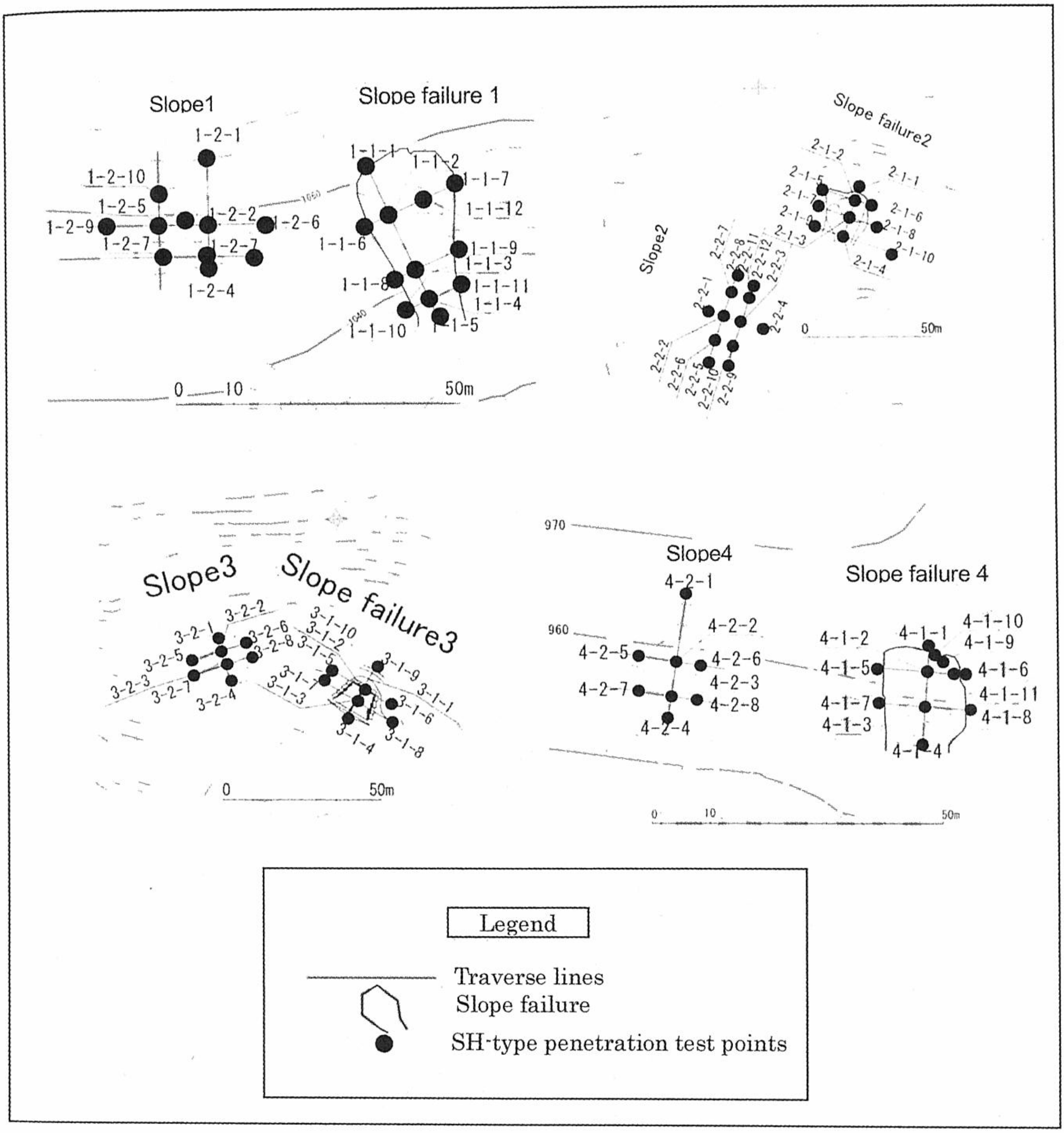

Fig.5 SH-type penetration test sites and traverse lines

Results of SH-type penetration test

As for the SH type penetration test, the strength of ground is expressed by Nc-values(results of measured value by 3 kg weight) and Nc'-values(results of measured value by 5 kg weight). Regarding these values, it has been reported that Nc' -values are 1.96 times larger than Nc-values (Yoshimatsu et al). In this paper, therefore, the authors use the Nc-values for evaluating the strength of earth layer as this value is considered to express the condition of the layer more sensitively.

There have been a lot of investigations and researches used by SH-type penetration tests. For example, Uchida et al. classified the earth layers of slopes into four layer(Table1), and reported that the slip surfaces of slope failures were formed in the I layer or the upper part of II layer.

Table.1 Instance of soil classification(Uchida et al, 2004)

layers	characters
Ⅰ layer	Surface soil, Nc＜10, Nc-values varying narrowly
Ⅱ layer	Under the Ⅰ layer, 5＜Nc-values＜20
Ⅲ layer	Under the Ⅱ layer, 20＜Nc-values＜50
Ⅳ layer	Nc-values＞50, impossible to measure by SH-type penetration test

Through series of these tests the authors observed that Ⅱ layer is divided into two layers in this area: the upper layer in which Nc-values indicate from 5 to 10 and the lower layer with Nc-values from 10 to 20(Fig.6).

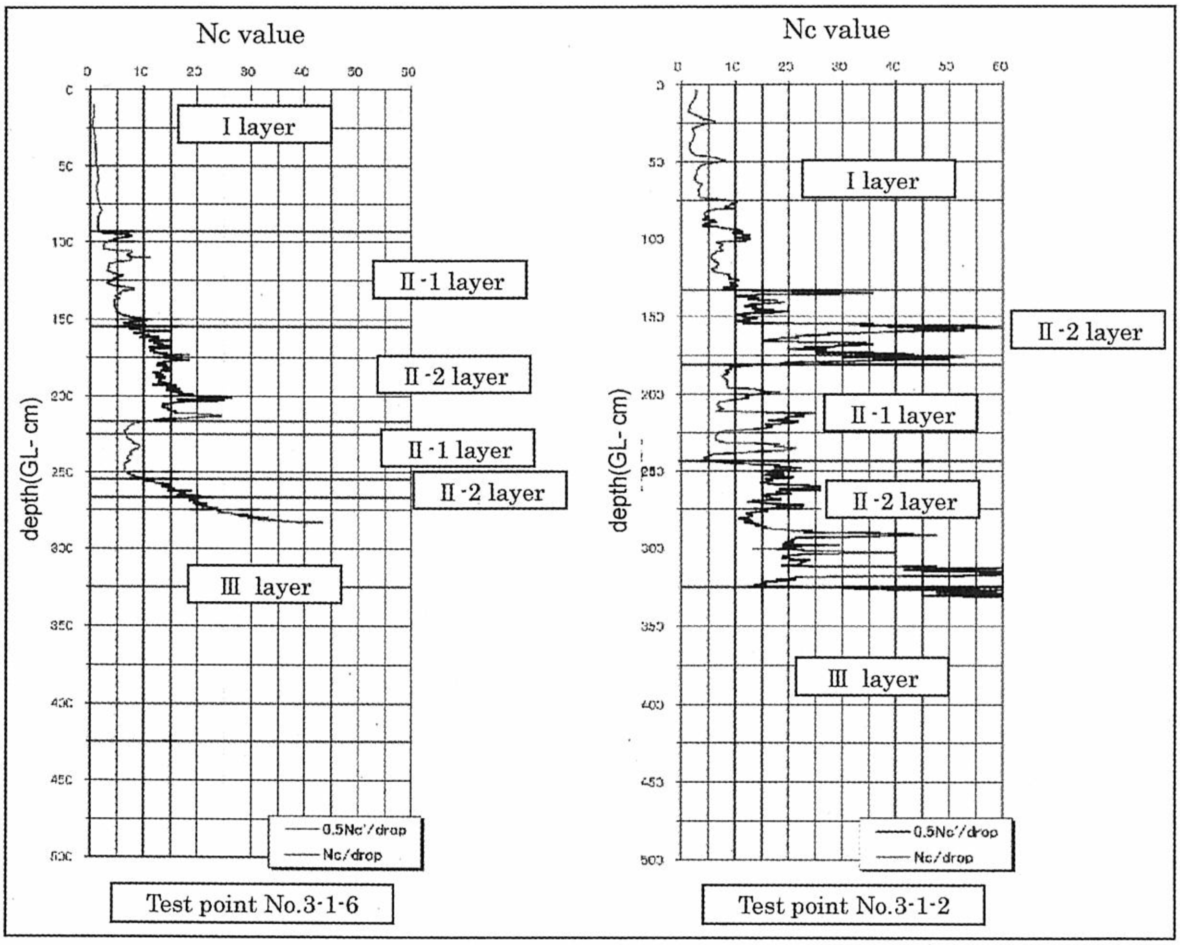

Fig.6 Example of SH-type penetration test(point No.3-1-6 and 3-1-2)

Therefore, the authors divide II layer into II-1 layer and II-2 layer to evaluate details of the soil property in this area(Table2) more appropriately. Hereinafter, structure and characteristics of 4 collapsed and 4 non-collapsed slopes are described.

Table2 Soil classification in this report

layers	Soil/rock	Symbols	Characters
Ⅰ layer	Surface soil	OV	Nc<5
	Colluvial deposit	M	Nc<1
	Talus accumulation	Dt	Nc<5
Ⅱ-1 layer	Weathered accumulation	Anw1	Under the Ⅰ layer 5<Nc-values<10
Ⅱ-2 layer	Heavily weathered andesite Heavily weathered tuff breccia	Anw2 Tbw2	Under the Ⅱ-1 layer 10<Nc-values<20
Ⅲ layer	Weathered andesite Weathered tuff breccia	Anw Tbw	Under the Ⅱ-2 layer 20<Nc-values<50
Ⅳ layer	-	-	Nc-values>50, impossible to measure by SH-type penetration test

Slope failure 1 (Fig.7)

The proportions of the slope failure 1 are as follows.

Length: 20m

Width: 16m

Depth: 3m~4m(estimated from the height of scarp)

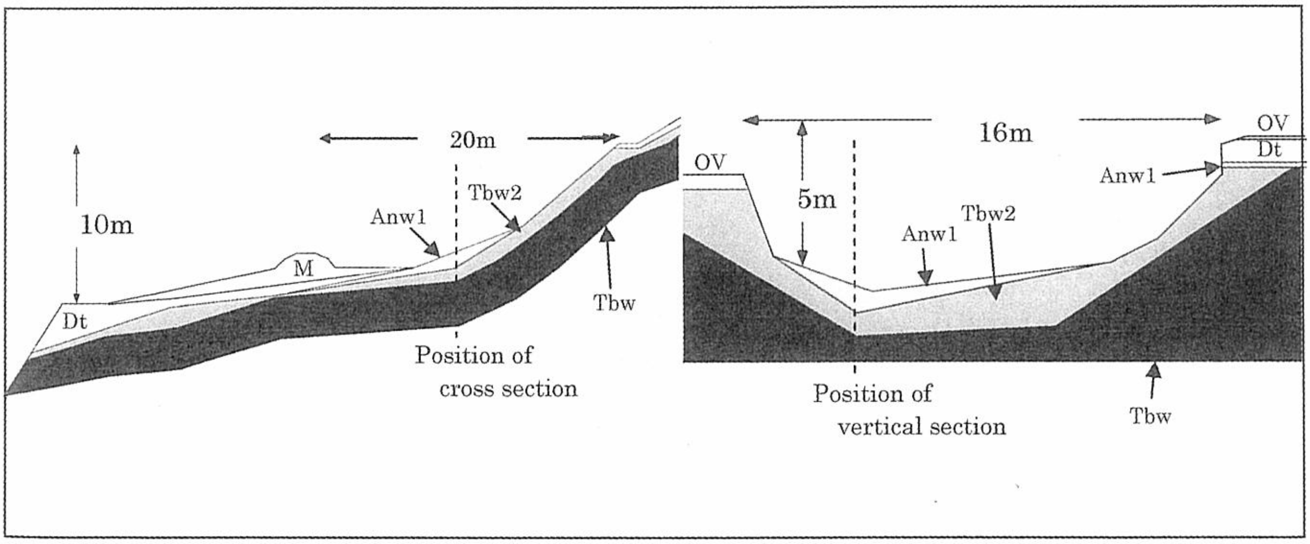

Fig.7 Vertical section(left) and cross section(right) of the slope failure 1

Slip surface of the slope failure 1 is located between Ⅱ-1 layer and Ⅱ-2 layer, or within Ⅱ-1 layer. In the cross section of slope failure 1, Ⅱ-1, Ⅱ-2 and Ⅲ layers form concave shape.

Slope failure 2(Fig.8)

The proportions of the slope failure 2 are as follows.

Length: 13m

Width: 17m

Depth: 2m~3m(estimated from the height of scarp)

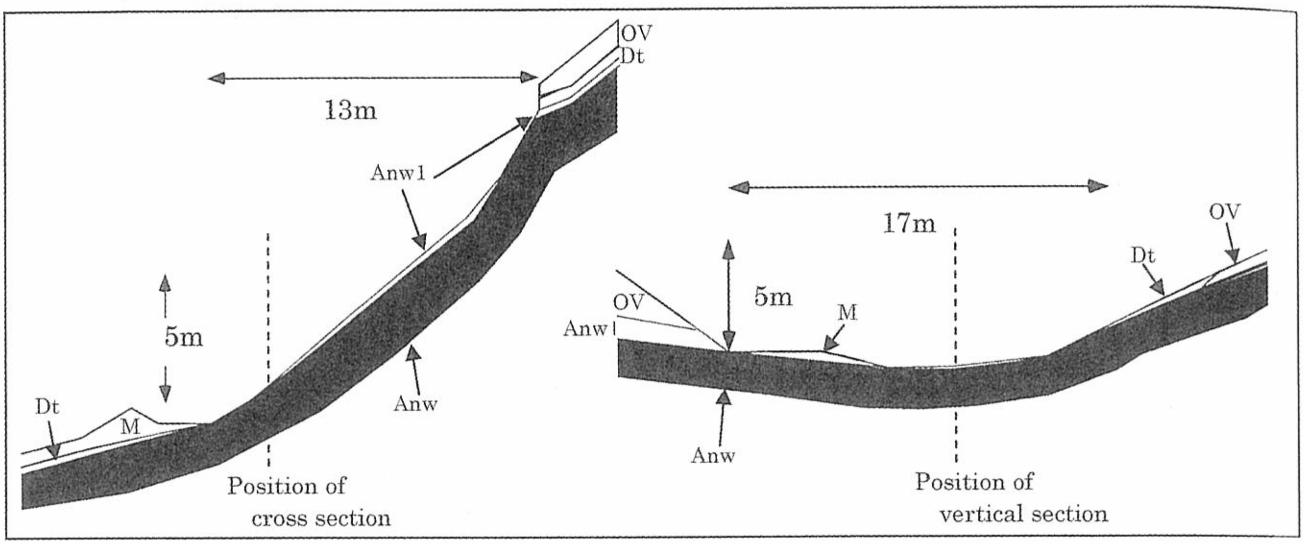

Fig.8 Vertical section(left) and cross section(right) of the slope failure 2

Slip surface of the slope failure 2 is located within Ⅱ-1 layer. In the cross section of the slope failure 2, Ⅲ layer forms concave shape.

Slope failure 3(Fig.9)

The proportions of the slope failure 3 are as follows.

Length: 14m

Width: 14m

Depth: 1m~2m(estimated from the height of scarp)

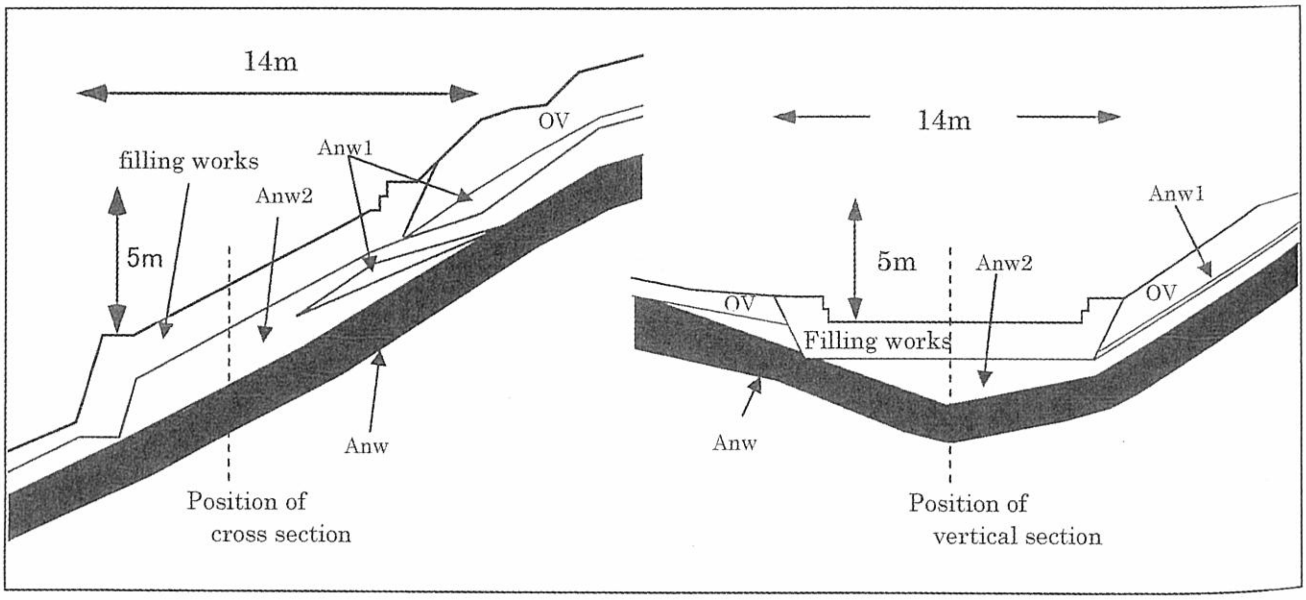

Fig.9 Vertical section(left) and cross section(right) of the slope failure 3

Slip surface of the slope failure 3 is located between Ⅱ-1 layer and Ⅱ-2 layer, or within Ⅱ-1 layer. In the cross section of the slope failure 3, Ⅱ-2 and Ⅲ layers take concave shape.

Slope failure 4(Fig.10)

The proportions of the slope failure 4 are as follows.

Length: 17m

Width: 13m

Depth: 2~3m(estimated from the height of scarp)

Slip surface of the slope failure 4 is located between Ⅱ-1 layer and Ⅱ-2 layer, or within Ⅱ-1 layer. In the cross section of the slope failure 4, Ⅱ-2 layer forms concave shape

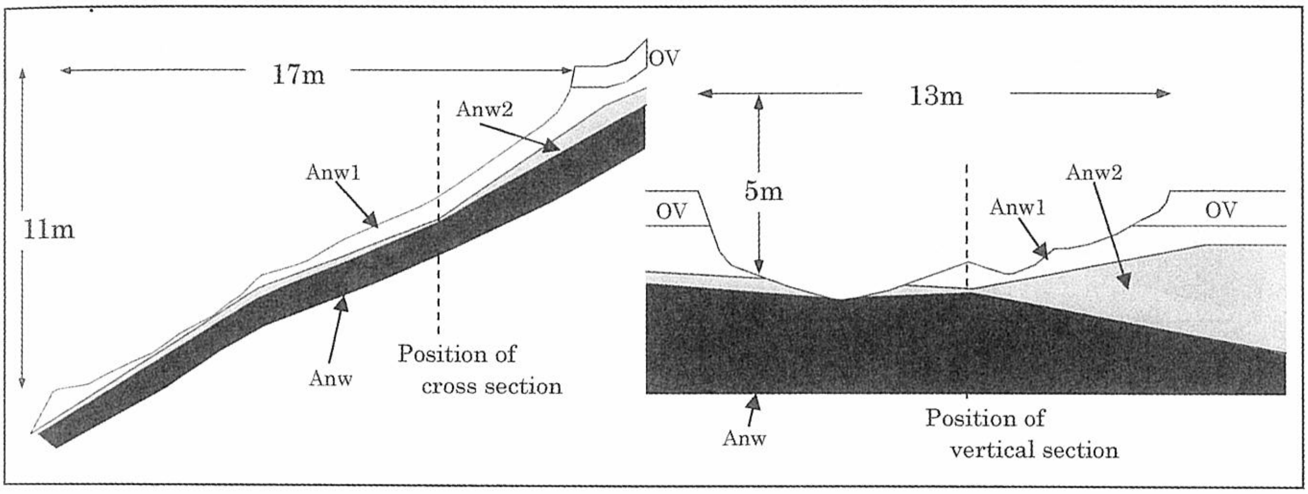

Fig.10 Vertical section(left) and cross section(right) of slope failure 4

Slope 1(Fig.11)

The proportions of the slope 1 are as follows.

Length: 21m

Width: 33m

Average thickness of surface soil(Ⅰ-layer): 3m

In the cross section of the slope 1, Ⅱ-2 and Ⅲ layers take flat shape.

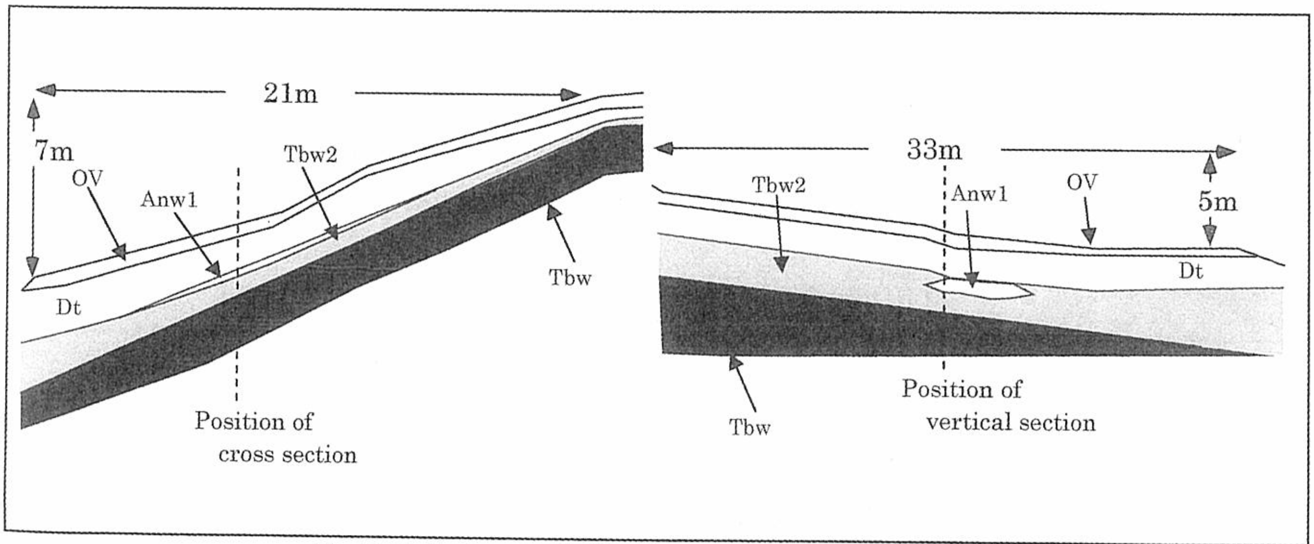

Fig.11 Vertical section(left) and cross section(right) of slope 1

Slope 2(Fig.12)

The proportions of the slope 2 are as follows.

Length: 24m

Width: 37m

Average thickness of surface soil(I -layer): 2~3m

In the cross section of the slope 2, II-1, II-2 and III layers take flat shape.

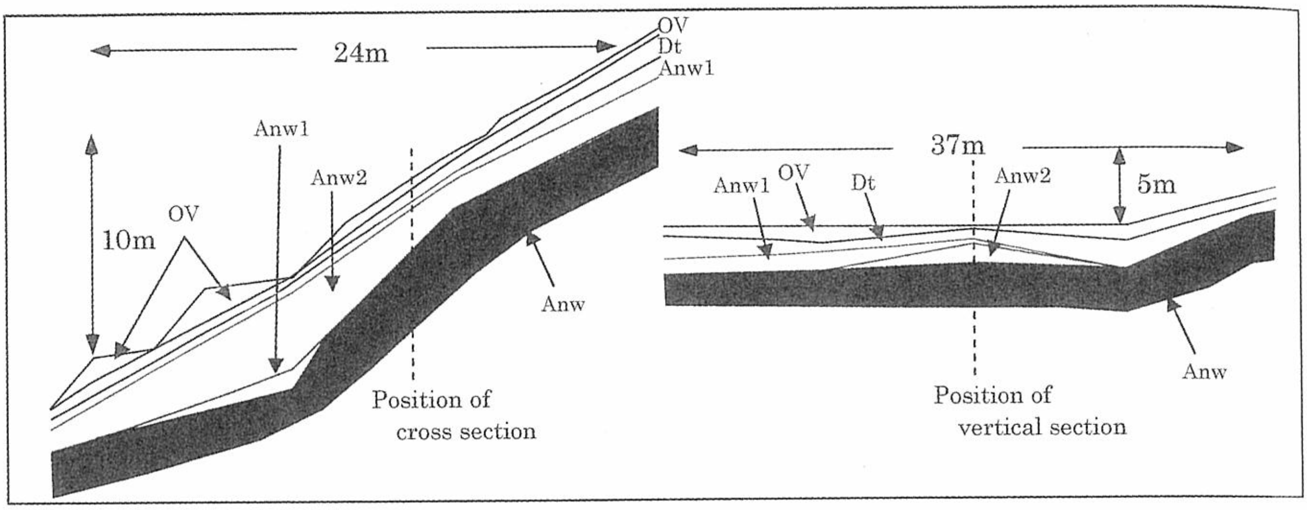

Fig.12 Vertical section(left) and cross section(right) of slope 2

Slope 3(Fig.13)

The proportions of the slope 3 are as follows.

Length: 13m

Width: 20m

Average thickness of surface soil(I -layer): 2~3m

In the cross section of the slope 3, II-2 and III layers form flat shape.

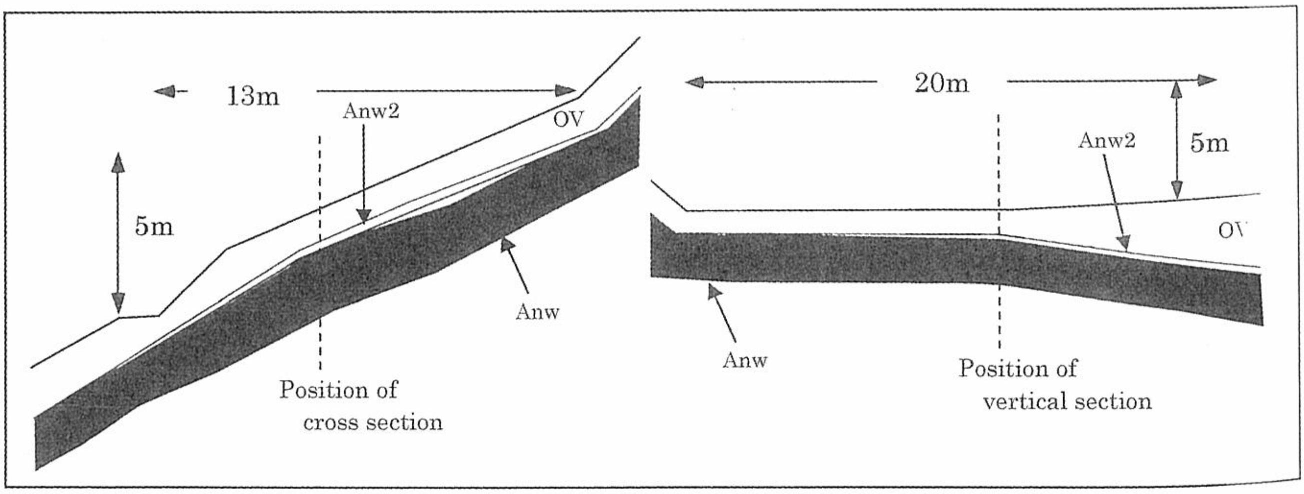

Fig.13 Vertical section(left) and cross section(right) of slope 3

Slope 4(Fig.14)

The proportions of the slope 4 are as follows.

Length: 22m

Width: 21m

Average thickness of surface soil(I -layer) : 2~3m

In the cross section of the slope 4, II -1, II -2 and III layers take flat shape.

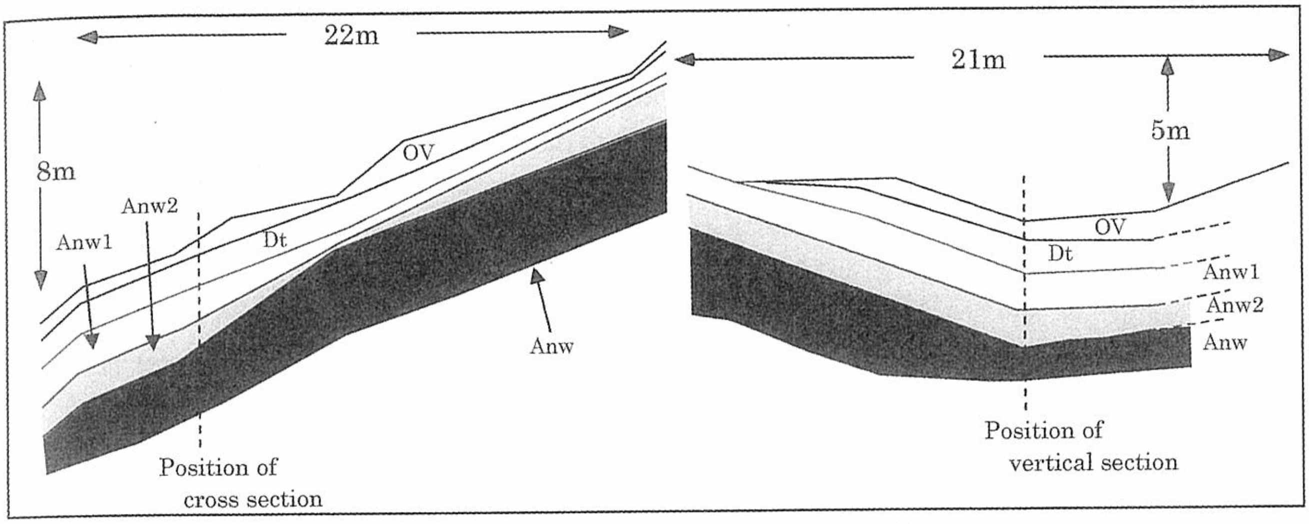

Fig.14 Vertical section(left) and cross section(right) of slope 4

Conclusions

The conclusions obtained from SH-type penetration tests are as follows.

①SH-type penetration test has sensitivity in estimating the soil strength with the lighter weight. Therefore, the authors could obtain the detailed structures of soil layers precisely.

②The authors would kike to recommend that at least 4 points should be set on the vertical sections, and set at least 3 points on the cross sections. Through this way, we could get the profiles of vertical and cross sections efficiently. However, if the scales of slope failures are bigger than those of Odaizawa area, it is necessary to control the numbers of test points.

③According to the results from a series of SH-type penetration tests, soil structure of this area is estimated to be roughly divided into 5-layers as follows.

I layer (surface soil, colluvial deposit, talus accumulation with Nc<5)

II -1 layer (under I layer with 5< Nc<10)

II -2 layer (under II -1 layer with 10< Nc<20)

III layer (under II layer with 20<Nc<50)

IV layer (basement rock with Nc > 50)

④Increasing the depth from I layer to III layer, the rocks become fresh, and the permeability of soil layers becomes low.

⑤Slip surface of slope failures is located between II -1 layer and II -2 layer, or within II -1 layer.

⑥From the facts described in ④ and ⑤, the authors interpret that the groundwater flow exists on III layer, especially between II -1 layer and II -2 layer, or within II -1 layer.

⑦In the cross section of slope failures, II -1, II -2 and III layers take concave shape, which makes the groundwater converge in the area.

⑧It is considered that such factors described in ⑥, ⑦ are main causes of slope failures in this area.

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