# 大型原位置一面セン断試験機による土層セン断予備実験について

| | |
|---|---|
| 誌名 | 日本林學會誌 = Journal of the Japanese Forestry Society |
| ISSN | 0021485X |
| 著者 | 阿部, 和時<br>岩元, 賢 |
| 巻/号 | 68巻2号 |
| 掲載ページ | p. 61-65 |
| 発行年月 | 1986年2月 |

日林誌 68(2)'86 61～65

短　　報

# Preliminary Experiment on Shear in Soil Layers with a Large Direct-Shear Apparatus*

Kazutoki ABE** and Masaru IWAMOTO**

## I. Introduction

Forest cutting by both land development and forest management poses serious problems for slope stability. The role of the forest in preventing landslides has been statistically shown as the accumulative effect of shear strength of soil due to tree roots (*1, 2*). Accordingly, the effect of tree roots has to be understood quantitatively to enable the making of a counterplan for forest conservation. However, it is very difficult to measure and evaluate the effect of tree roots using the ordinary types of shear apparatus, for example, the triaxial compression test, the small direct-shear test, the vane test, and so forth, because the scale of these tests are too small to shear soil with tree roots.

The authors have designed a large scale in-situ type of shear apparatus to measure the shear strength of soil in a nursery. The outline of this apparatus, the procedure of the test and some results are presented herein.

## II. Definition and Characteristics of Large-Scale Direct-Shear Test

When discussing forest-slope stability, three factors are considered as resistant forces against landslides. They are shear strength of the soil, root tensile-strength, and soil-holding strength (the compound strength generated by both soil and roots). Although, these strengths can be obtained by their respective tests as shown in Figure 1, actually, there are only a few reports on the shear strength of soil with live tree roots under natural conditions. It is important to measure the shear strength of soil with tree roots in the field so as to quantitatively evaluate the effect of the forest on slope stability. In such situation, our large shear-apparatus can satisfy the above-mentioned requirements, for example, the root tensile-strength, the soil-holding strength, and the shear strength of soil itself can be measured at the same time. Thus, this test is positioned with regarded to a part of the shear test series of soil layers as shown in Figure 1. Similarly, the other tests (the root-tension, root pulling, and uprooting tests) also have to be made and analyzed together with the results of this test.

Figure 2 illustrates the large-scale direct-shear test. In this test, a soil block, 1 m wide×1 m long×0.5 m high with live tree roots, can be sheared in the field. The advantages of this test are as follows: (1) The shearing area is 1.0 $m^2$, and thus a large tree can be selected as the test tree. (2) The displacement process of the soil block can be observed from the block side. (3) Both the acting forms of the roots in the soil and the movement of the soil block can be observed by exposure after the test. (4) The results can be expressed by the Coulomb equation.

The measuring system is shown in Figure 3. The shearing load, normal stress, displacement, pore-water pressure, and the soil strain and slant are measured by strain-gauge type instruments. All of the measured values are easily and automatically memorized at regular intervals of 30 or 10 seconds by a digital strain recorder. These data are transferred immediately to a computer and then analyzed. The displacement processes also are observed by the video tape-recorder (V. T. R.) and the motor-driven camera. Furthermore, both measurements of the root distribution and their cutting forms caused by the soil failure are made in detail when exposured after the test.

## III. Apparatus and Methods

### 1. *Apparatus*

The test apparatus is composed of the following parts:

1) Shear box: Made of steel plates three millimeters thick capable of firmly holding the soil block during the test. The shear box height can be set from 0.3 to 1.0 m.

2) Oil jack and pump: Used to produce the shear load, both their stroke and maximum capacity are 50 cm long and 20 tons, respectively.

3) Load cell: A compression type of load cell (maximum capacity 5 tons) to measure the shearing load.

4) Displacement meter: Both the cylinder type (stroke capacity: 10 cm long) and wheel type

---

* 阿部和時・岩元　賢：大型原位置一面セン断試験機による土層セン断予備実験について

** 林業試験場 For. and Forest Prod. Res. Inst., Ibaraki 305

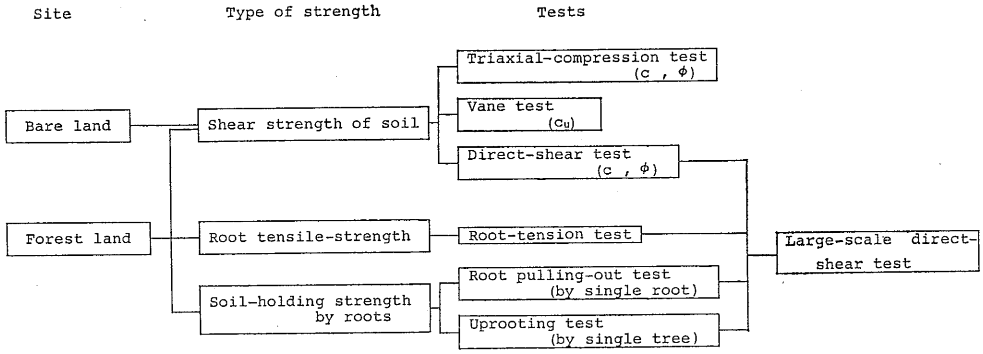


Fig. 1. Position of large-scale direct-shear test

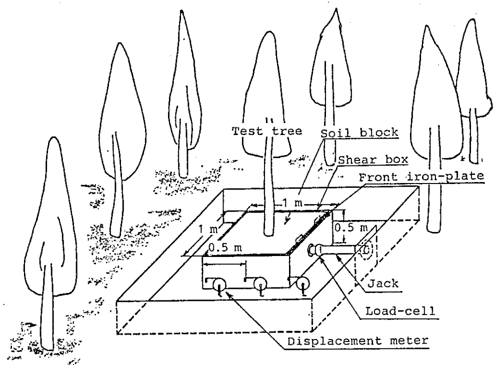


Fig. 2. Large-scale direct-shear test

(stroke capacity 50 cm) of displacement meters are used to measure the displacement of the soil block with a measurement accuracy of 0.02 mm.

5) Digital strain-recorder: With a memory capacity for 32 kilo-bytes, 16 channels are used to memorize all of the data during the test.

6) Steel bar: Used for additional load, it is 50 kg in weight and one meter in length.

In addition, pore-water pressure meters, strain gauges, and slant meters are readily available to obtain data in the soil with a high degree of accuracy.

Figure 4 shows the setting sequence of these parts, namely, (a), a test tree is selected and the stem and crown above the ground surface are cut off. Next, the ground is removed around the test tree to make a test soil-block. In (b), the shear box is set on the test block, and a frontal iron-plate (10 mm thick) is inserted between the inner soil-block and the outer shear-box on the front side. The jack, load cell, and frontal iron-plate are joined together straight to the front of the box at one-third of the box height. Then,

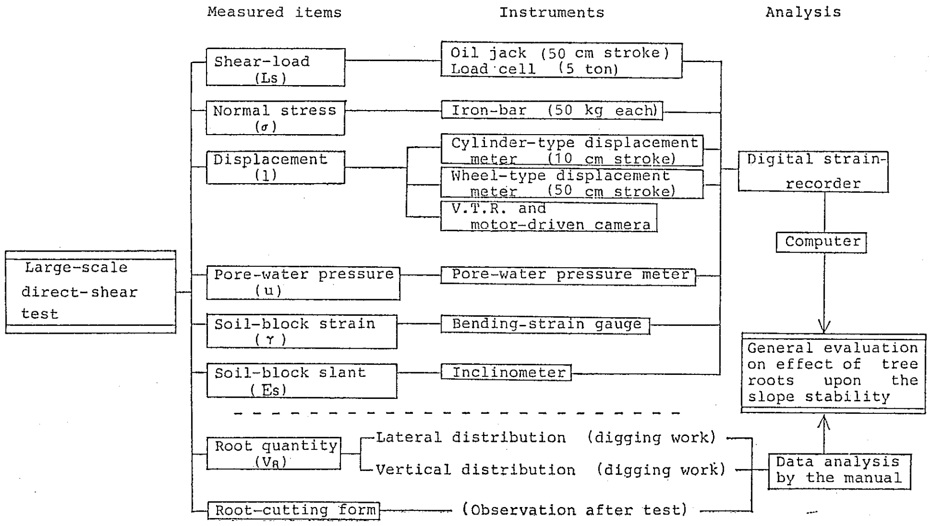


Fig. 3. Measuring system

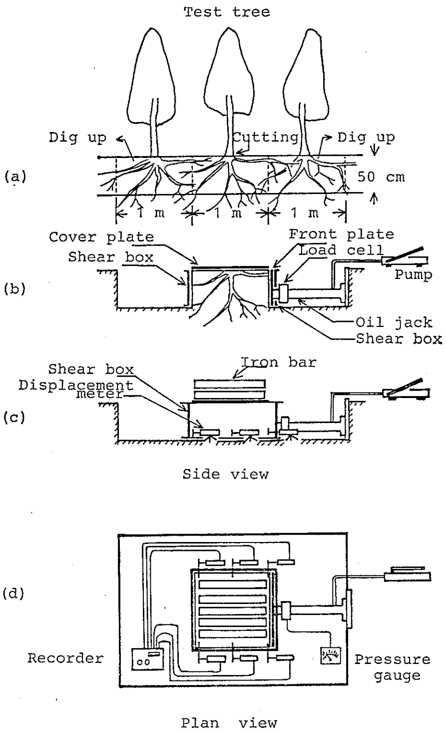


Fig. 4. Setting sequence

Table 1. Test conditions

| | Shear depth $Z$ (cm) | Soil-block weight (kg·f/m$^2$) | Additional load (kg·f/m$^2$) | Normal stress (kg·f/m$^2$) |
|---|---|---|---|---|
| Planted plot | 50 | 900 | 0 | 900 |
| | | 900 | 500 | 1,400 |
| | | 900 | 1,000 | 1,900 |
| Bare plot | 50 | 900 | 0 | 900 |
| | | 900 | 500 | 1,400 |
| | | 900 | 1,000 | 1,900 |

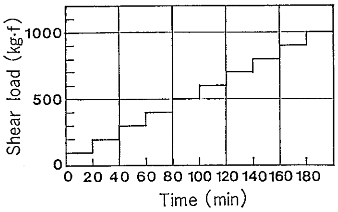


Fig. 5 Application of the shear load

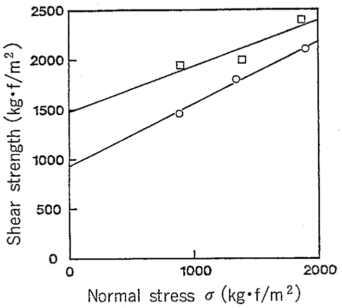


Fig. 6. Shear strength of the bare plot and the planted plot

○ Bare plot, □ Planted plot

the shear load is applied uniformly to the frontal face of the soil-block through the frontal iron-plate. In (c), an iron-plate cover (5 mm thick) is set on the soil block, and several iron bars are placed on it for a normal compression-load. Next, with two slit openings low on both sides of the shear box, displacement meters are set on them. The meters are set 0, 0.5, and 0.9 m from the front face, and the digital strain-recorder also is set near them.

2. *Experimental method*

A series of large-scale direct-shear tests have been made in the nursery at Chiyoda Experimental Branch Station of the Forestry and Forest Products Research Institute in Ibaraki Prefecture. The soil conditions are uniform at the test site because the soil was developed by soil dressing. The soil type is loamy sand (Kanto loam) and it is hardly compacted (about 350 kg·f·cm by Vane tests). For the test tree, a *Cryptomeria japonica* D. DON (sugi) six years old (about 4.5 m in height and 7.0 cm in diameter), was selected. When evaluating other species, it is reasonable to standardize the effects on sugi first because it is the mostly widely planted tree in Japan.

Six tests were made in this preliminary test series. Test conditions are shown in Table 1. Three degrees of additional load were prepared, 0, 500, 1,000 kg·f/m$^2$. Soil moisture was natural. The shear method is stress controlled. As shown in Figure 5, the shear load is increased in steps of 100 kg·f every 20 minutes to measure the characteristics of soil creep. Therefore, the shear load must be kept constantly at a certain value every 20 minutes using the oil pump and jack. Tests on the bare plot were first made to obtain original basic data (the shear strength of the soil alone) to determine the effect of tree roots on the planted plot. Next, tests on the planted plot were made in the same way.

## IV. Results and Discussion

1. *Reinforced shear strength by roots*

The relationship between the shear strength and the normal stress on both the planted plot and the bare plot are shown in Figure 6. For the bare plot, three measured values fitted on the line of the Coulomb equation. From the equation, the cohesion was 930 kg·f/m², the internal friction angle was 32°, and their correlation coefficient was 0.996. For the planted plot, all of the values were larger than the respective values on the bare plot because of the existence of tree roots, although there was a little dispersion among the values.

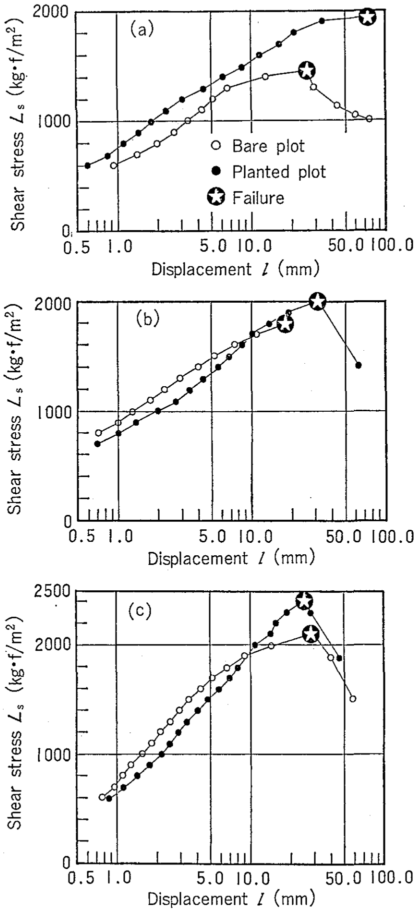


Fig. 7. Relationships between shear stress and displacement

(a) Normal stress: 900 kg·f/m²; (b) Normal stress: 1,400 kg·f/m²; (c) Normal stress: 1,900 kg·f/m²

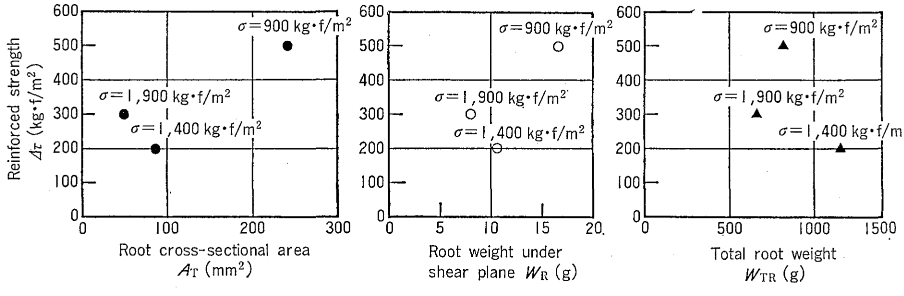
Comparing the shearing strengths of the two plots, it is concluded that the shearing strength values on the planted plot were 11∼34 percent larger than those on the bare plot.

*2. Displacement process*

Figure 7 shows the displacement process at the frontal face of the soil-block. In the figure, the planted plot process and that of the bare plot are compared for each normal stress ($\sigma$). The displacement ($l$) almost increased by constant ratios until near failure in all tests, but increased much more just before failure. According to these comparisons, the displacement of soil-blocks of the planted plot tended to be greater than those of the bare plot. This means that the existence of tree roots in the soil increases the shearing strength, extremely so in the final range of displacements over 10 mm. For example, in cases of $\sigma=1,400$ kg·f/m² and 1,900 kg·f/m², the shear strength of the planted plot obviously were larger than those of the bare plot in the final stage of the displacement distance ($l>10$ mm). Furthermore, in the case of $\sigma=900$ kg·f/m², the effect of roots appeared throughout the entire displacement process.

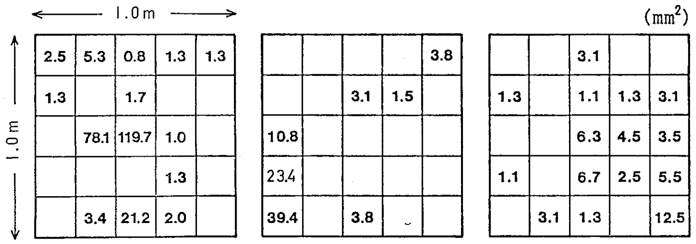
*3. Relationships between reinforced strength and root quantity*

The dispersion among the values of shearing strength on the planted plot seemed to be caused by the difference of tree-root quantity in the soil-block. The total root cross-sectional area on the shear plane, the root weight in the soil ten centimeters under the shear plane, and the total root-weight in the block were measured after the test. Figure 8 shows the relationships between the re-



(a) (b) (c)

Fig. 8. Relationships between reinforced strength and total root cross-sectional area on the shear plane (a), root weight under the shear plane (b), and root weight in the siol-block (c)



(a)

| | | | | |
|---|---|---|---|---|
| 2.5 | 5.3 | 0.8 | 1.3 | 1.3 |
| 1.3 | | 1.7 | | |
| | 78.1 | 119.7 | 1.0 | |
| | | | 1.3 | |
| | 3.4 | 21.2 | 2.0 | |

(b)

| | | | | |
|---|---|---|---|---|
| | | | | 3.8 |
| | | 3.1 | 1.5 | |
| 10.8 | | | | |
| 23.4 | | | | |
| 39.4 | | 3.8 | | |

(c)

| | | | | |
|---|---|---|---|---|
| | | 3.1 | | |
| 1.3 | | 1.1 | 1.3 | 3.1 |
| | | 6.3 | 4.5 | 3.5 |
| 1.1 | | 6.7 | 2.5 | 5.5 |
| | 3.1 | 1.3 | | 12.5 |

Fig. 9. Distribution of root cross-sectional area on the shear plane
(a) $\sigma=900$ kg: $A_T=240.9\,\mathrm{mm}^2$, $\bar{A}=10.0\,\mathrm{mm}^2$, $A_{max}=67.9\,\mathrm{mm}^2$
(b) $\sigma=1,400$ kg: $A_T=85.8\,\mathrm{mm}^2$, $\bar{A}=8.6\,\mathrm{mm}^2$, $A_{max}=36.3\,\mathrm{mm}^2$
(c) $\sigma=1,900$ kg: $A_T=57.1\,\mathrm{mm}^2$, $\bar{A}=2.0\,\mathrm{mm}^2$, $A_{max}=4.5\,\mathrm{mm}^2$
$A_T$, total amount of root cross-sectional area on a shear plane; $\bar{A}$, mean root cross-sectional area ($A_T$/number of roots); $A_{max}$, cross-sectional area of the largest root

inforced strength and the above root values measured. In the figure, however, obvious tendencies cannot be pointed out from these data. It should be explained that the reinforced strength of both the total root cross-sectional area on the shear plane (Fig. 8(a)) and the root weight under the shear plane (Fig. 8(b)) are in some degree better than that of the total root weight in the soil-block (Fig. 8(c)).

The shearing strength is influenced also by both the number of roots and the root distribution. Then the distribution of the root cross-sectional area on the shear plane was measured by exposure of the soil-block and the results are shown in Figure 9. In the figure, the root distribution varied for each block. For that of $\sigma=1,400\,\mathrm{kg\cdot f/m^2}$, the reinforced strength was $200\,\mathrm{kg\cdot f/m^2}$ compared with that of the bare plot under the same conditions. This means that many roots were concentrated at the edge of the shear plane, and thus the shearing strength was increased by them. For that of $\sigma=900\,\mathrm{kg\cdot f/m^2}$, the reinforced strength was $450\,\mathrm{kg\cdot f/m^2}$, and this larger value was caused by the existence of many roots at the middle of the shear plane. For that of $\sigma=1,900\,\mathrm{kg\cdot f/m^2}$, the reinforced strength was $300\,\mathrm{kg\cdot f/m^2}$ because the amount of root cross-sectional area was smaller than that of $\sigma=900\,\mathrm{kg\cdot f/m^2}$ but larger than that of $\sigma=1,900\,\mathrm{kg\cdot f/m^2}$.

## V. Conclusions

From the experimental results, this large-scale direct-shear apparatus has advantages over the conventioned shear apparatus, and some significant facts are as follows:

1) A sample depth on any selected plot can be set up with a combination of plate heights, for example, depths of 20, 60, 100 cm and so forth.

2) When a large tree root is present in the soil block, the oil jack can easily shear the block with a uniform pressure.

3) Many kinds of measuring data can be recorded automatically during the test, even at any time interval, for a long period of time. Furthermore, the data can be analyzed soon by the computer.

4) The existence of tree roots in the soil seems to increase the shearing strength by at least ten percent compared with that of a soil block without roots.

5) Furthermore, the thickness, length, and distribution type of tree roots also seem to influence the reinforced strength, and so their function forms should be observed in detail under the many kinds of test conditions, for example, the root-tension test, the root pulling-out test, and so forth.

## Literature cited

(1) Endo, T. and Tsuruta, T.: The effect of the tree's roots upon the shear strength of soil. 1986 Annu. Rep. Hokkaido Br., For. and Forest Prod. Res. Inst. **18**: 167~182, 1968*

(2) Kitamura, Y. and Namba, S.: The function of tree roots upon landslide prevention presumed through the uprooting test. Bull. For. and Forest Prod. Res. Inst. **313**: 175~208, 1981*

* In Japanese with English summary

(Received February 4, 1985)