Effect of Tree Roots upon the Shear Strength of Soil

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As to the effect of forest vegetation on the slope stability, the following four ways were recognized by Gray[1]; firstly the root system of forest trees reinforces mechanical strength of the soil; secondly trees grown on the ground acts like a additional load; thirdly wind in the trees causes ground surface shears and moments; fourthly soil moisture content and water level in the soil layer are modified by vegetation changes.

Among these four ways, in this report is dealt with the effect of root system on mechanical strength of the soil as this factor is considered to be related with outbreaks of landslide on rather steeper slopes after logging.

There are two schools of study concerning the preventive mechanism of tree roots against landslide. The one is the studies which adopt statistical analysis involving important relating factors such as amount and intensity of rainfall, some components of geographical features, geology, kinds and cover degree of forest vegetations and so on. This method has already been tried by many researchers in many places.

The other method is based on soil mechanics[2,5]. It is needless to say that preventive function of trees against landslides depends not on the upper parts of tree above the ground, but on the action of root system stretched widely in the soil layer.

Therefore, in the latter method the point to which special attention should be paid is to clarify how and to what extent the mechanical strength of soil can be increased by the existence of root system of trees.

Keeping this in mind a series of experimental study I and II on the effect of the root system upon the shear strength of the soil was made and some of the results were reported already in 1968[3] and 1979[4].

No other report along this line have appeared up to the present. Therefore, experimental procedures and results obtained mainly from the study II will be presented in this paper.

Experimental method

large number of plots each of which had an area of 50 cm × 50 cm were prepared for this experiment in a corner of the nursery after cultivated as deeply and uniformly as possible. Then, planted plots and no-planted plots were arranged at random on the whole area, and 1–2 seedlings at 1 year of age were planted on each planted plot.

Two kinds of tree species, *Betula japonica* Sieb. and *Alnus japonica* Steud., were selected for use, because of their rapid growth in the young stage. In the autumn after the two growing seasons had passed, the measurements on shear strength of the soil were made at each plot.

In the measurements, depths of 25 cm and 30 cm were employed as the depth from ground surface to a shear plane in the soil. To show the outline of the experimental procedure and apparatus used, a schematic illustration is given in Fig. 1.

As shown in Fig. 1, the shearing apparatus used were composed of such instruments as a shearing case, a outer frame, a wooden load stand, concreate sticks served as a additional

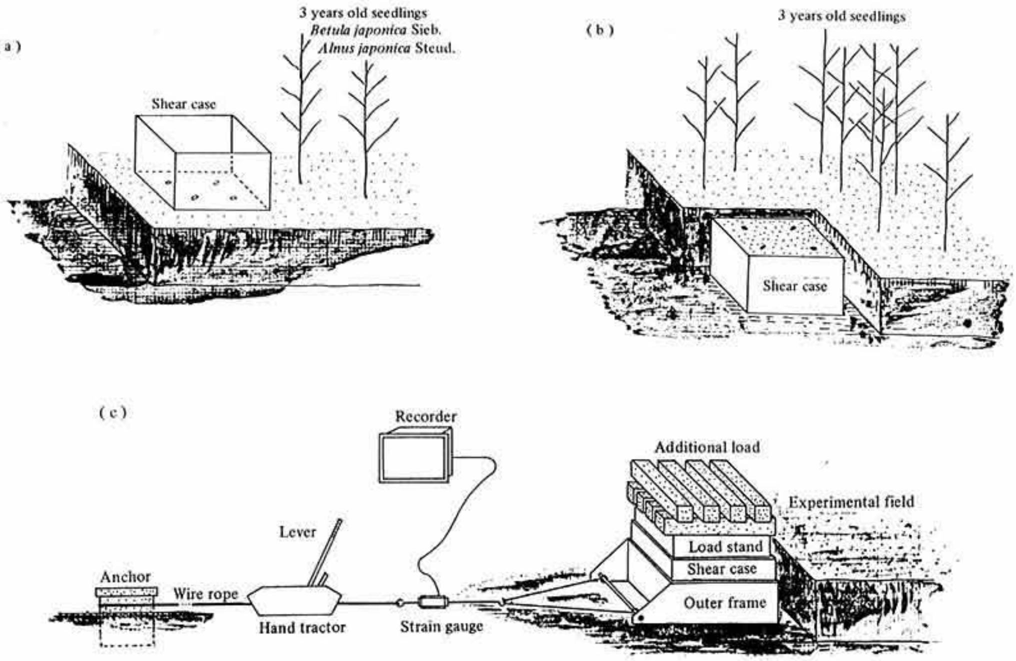

Fig. 1. (a, b & c) Schematic illustration of the experimental procedure and apparatus

load, a hand tractor of 2.5 tons capacity, two wire ropes with 10 mm of diameter and a set of strain gauge and recorder.

The shearing case made of iron plate of 3 mm thick serves as a kind of protector to keep tightly the soil column under shearing. On the other hand, the outer frame hold the case in its inside and acts as a carrier of the case containing the soil column.

Before the shearing test, the trees on the plot to be used for it were cut off at a little lower level than ground surface. Then, the shearing case was put on the plot area rightly and was sunk into the soil so as its lower end comes to a prescribed depth by using flat shovels with a sharp edge.

After that, the outer frame was set to enclose the case, and a wooden load stand was placed on the top of soil inside of the shearing case. Then, the certain number of concrete sticks were placed evenly on it as a additional load. Two kind of concrete sticks were used, one was about 18 kg in weight and 60 cm long × 12 cm wide × 12 cm, thick, and other was about 12 kg and 60 cm long × 10 cm wide × 10 cm thick. These sticks were available on the market, not made to order.

Next work to do was to catch a handle of the outer frame with a hook at one end of a wire rope, which was connected with a hand tractor of 2.5 ton capaicty. The tractor was also connected tightly with a concreate anchor settled nearby through other wire rope.

After making all the preparation mentioned above, the tractor was driven forward slowly and smoothly by operating the lever on both sides alternately. The pulling force generated was measured and recorded continuously by using a set of strain gauge and recorder.

In each test, the pulling force expressed on the recording paper showed a distinct tendency to increase gradually up to a certain maximum value and then to decrease. Therefore, every shearing test was brought to an end after it was confirmed that the pulling force passed over its maximum value.

Then, the concrete sticks, the load stand and the outer frame were removed from shearing case one after another.

Finally, the shearing case was slowly tumbled down so that the shear plane came to be exposed. All the roots appeared on the shear plane were collected and their diameter at the cut end was measured by a micrometer.

Experimental results

Results obtained from 37 plots are summarized in Table 1. Using the data shown in the table, multiple regression analysis of shear strength as related to the total cross-sectional area of the roots and effective normal compression stress was made, and the following regression equation (1) was obtained.

$$S=0.765\sigma+41.5D+38.0 \quad (1)$$

where, S=shear strength in kg per $0.25m^2$; σ=effective normal compression stress in kg per $0.25\,m^2$; D=total cross-sectional area of roots in cm^2 per $0.25\,m^2$.

The multiple regression coefficient is 0.9275.

In the study I[3], tree roots in the soil was evaluated in terms of root weight per unit volume of the soil and the effect of tree roots on the shear strength of soil was found to be associated only with an increase in soil cohesion, giving no change in the angle of internal friction of the soil.

Though the result obtained from the study II[2] is almost similar to that of the study I, it pointed out that the effect of tree roots on the shear strength of soil is related to cohesion only, and the cohesion of soil increases linearly with the increase in total cross-sectional area of the roots at a shear plane of soil.

Table 1. The summarized table of experimental results

Plot No.	Effective normal compression stress σ kg : $0.25m^2$	Total cross-sectional area of roots D cm^2 : $0.25m^2$	Shear strength S kg : $0.25m^2$
1	155	0.0732	147
2	155	1.0443	199
3	225	0.2396	199
4	225	0.9150	265
5	225	3.4251	294
6	225	0.2180	210
7	155	0.1991	172
8	155	0.4083	172
9	155	0.6817	192
10	155	0.5726	170
11	288	0.1760	246
12	407	0.3094	349
13	394	0.9647	385
14	394	1.1726	457
15	394	1.2469	342
16	394	3.5716	456
17	272	1.5838	338
18	272	1.5277	327
19	272	0.5157	278
20	272	0.7664	243
21	272	2.7322	352
22	209	1.9225	322
23	209	0.9356	201
24	209	1.2416	266
25	209	0.5472	187
26	209	0·2971	206
27	209	0.7074	237
28	209	1.1213	277
29	209	0.1299	189
30	209	2.3038	370
31	209	2.1307	230
32	209	0.7002	215
33	209	0.3989	213
34	209	4.4298	393
35	272	0.5042	289
36	272	1.5452	332
37	272	0.8375	322

Conclusion

Based on the results of study I and II, it can be concluded that the shear strength of soil with tree root system can be expressed by the same forms as Coulomb law, as in the case of soil without tree root system. In this case, Coulomb law may be written as follows.

$$S=C+\sigma\tan\phi \quad (2)$$

where, S=shear strength; σ=effective normal compression stress on a shear plane; C=cohesion capacity; ϕ=angle of internal friction.

Then, the value of C can be expressed as the sum of the cohesion capacity of soil itself and the effect of tree root system on the cohesion of the soil. The experimental results presented in this report showed that the value of C can be formulated as follows.

$$C = c + b\,R \tag{3}$$

where, R = root weight per unit soil volume; c = cohesion capacity of soil itself; b = experimental constant

or,

$$C = c + b'D \tag{4}$$

where, D = total amount of cross-sectional area of roots at a shear plane; b' = experimental constant.

According to the equation (1), for the soil tested, tan ϕ is 0.765, therefore, ϕ comes to 37°, c equals 38.0 kg per 0.25 m^2 and b' is 41.5 kg per unit cm^2.

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