MODEL EXPERIMENTAL STUDIES ON THE SOIL CONSERVATION BY A STANDING TREE

Hiroshi Omura, Ryoichi Abe

Depart. of Forestry, Fac. of Agriculture, Shizuoka University, Shizuoka, Japan

SUMMARY

When the forest resists as a fence against landslide or rock falling, the forest can stop and catch them by trees stem. Some experiments were carried out to clear the quantitative fence effect of single standing tree by the model slope system. In results, the stocked weight S by a tree increases with that of mass movement M and attains the maximum constant S_{max}, this relation is shown by the Mitcherlich's growth curve. The efficiency ratio of S to M attains 13 % at the maximum state. If the forest effect is estimated by the total of each trees action, 8 trees can stop 100 % of a mass movement. The maximum stocked weight S_{max} is proportional to cubic power of basal diameter D and decrease with exponential of slope angle θ that participates in frictional force and velocity of mass movement. The velocity of mass movement on rough and gentle slope is slow, a tree can catch them more easily than smooth and steep slope case. As a result the stocked weight S is given by the next equation,

$$S = K D^3 \exp^{-\gamma\theta} (1 \quad \exp^{-\lambda M})$$

where K, γ and λ are the coefficient depending on particle size, surface roughness and location of tree from the starting point of mass movement. The value of K on surface of coarse sand paper is as five times as naked smooth veneer. The above equation is useful to estimate the effect of preventive forest.

(Preventive forest, Mass movement)

INTRODUCTION

Recently many disasters by rolling down rocks and landslide have broken out at hilly mountainous district in Japan. If there is the shelter belt of dense forest or thicket at upper slope side along road, forest system of many various trees will be able to resist as preserve fence against above mentioned mass movement to defend some traffic cars in safety from disaster. To plant the suitable preventive forest belt, the fence effect by forest must be investigated quatitatively. Especially the information on relation between trees density, diameter, arrangement in forest and their effect against mass movement is very important. As the first step, some fundamental experiments are carried out to clear the fence effect of a standing tree with model slope apparatus. The purpose of these experiments is to study the relation between weight of stocked material by a tree and its basal diameter in some controled condition of slope and mass movement.

MATERIAL AND EXPERIMENTAL APPARATUS

The artificial model slope system as shown by Fig-1 is constructed up on the assumption that the phenomina on the controled model slope is similar to that on natural complicated slope in forest. This system is composed of the shot box, slope of monotonous plane, a standing log and recover sauce. They are supported by scaffolding pipes. The surface of slope is covered by bare smooth veneer or coarse sand paper having uniform roughness. The inclination of slope is changeable at a arbitrary angle by removing up or down the level of pipe bar supporting this system. In most case, slope angle is fixed at 33 degree that is the critical movable inclination and slightly more than the respose angle of sand. The standing log with bark as a tree is set upright at 2 m distance from the shot box. The box having the door of 25 cm is installed at the top of slope.

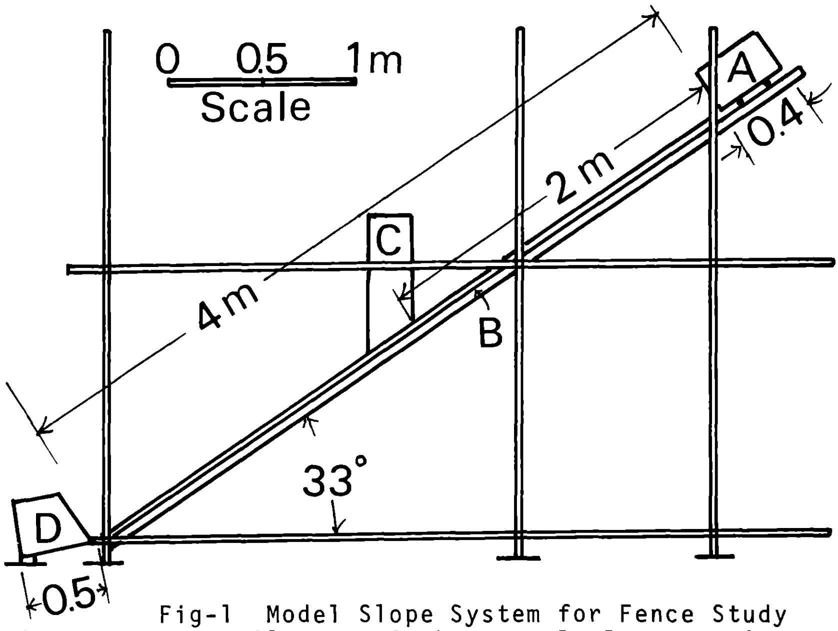

Fig-1 Model Slope System for Fence Study
A: Shot Box, B: Slope, C: Log, D: Recovery Sauce

The weighed material of air dried sand or gravel is put into the shot box. By opening the door, material slides or rolls to speed up like a mass movement on the slope and collides against a standing log. Some portion of material is stopped, piled and stocked at the upper side of log as shown by Photo-1. The other reduces speed down, changes own direction and disperses into the recovery sauce at the foot of slope.

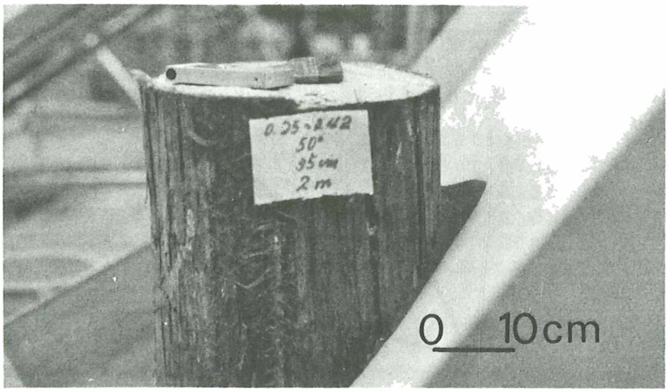

Photo-1 Stocked Material behind a Log

As the fence effect by a tree, the stocked material behind log is weighed by the ballance. The experiment is repeated under the controled condition of some factors that take part in the velocity of mass movement. The combination of factors in these experiments is shown by Table-1 as follows.

Table-1 Controled factors on the fence effect by a tree

	Experiments A	Experiments B
Basal Diameter cm.	10	1.2, 2, 10, 24, 35
Location of Log m.	0.8, 2.0, 3.2	2.0
Input Weight kg.	0.1 — 5.0	3.0
Particle Size mm.	0.11 — 25	0.25 — 0.42
Slope Angle degree	33	33, 40, 50, 60
Slope Surface	Smooth Veneer	Coarse Sand Paper

RESULTS AND DISCUSSION

Fig-2 shows the main results from experiments A at the location of 2 m. In the case of big particle input, stocked material S increases remarkably with input weight M of mass movement at intial stage. But when input is relatively heavy, as there is the limit space where a tree can catch mass movement, stocked weight attains the maximum constant S_{max} The incresing state has analogy with the growth of plant. Then the relation between both weight S and M is approximately given by the Mitcherlich's growth curve,

$$S \quad S_{mx}(\,1 \quad exp^{-\lambda M}\,) \qquad 1$$

where λ is the coefficient of $k.g.^{-1}$ unit and nearly equal 1.0 from results. In the case of fine sandy particle, the tendency is almost similar to above mentioned state. But the stocked weight is approximated by the logistic curve as follows,

$$S \quad \frac{S_{mx}}{1 + \beta\, exp^{-\alpha M}} \qquad 2$$

where α and β are the coefficient of $k.g.^{-1}$ unit and non dimension relatively.

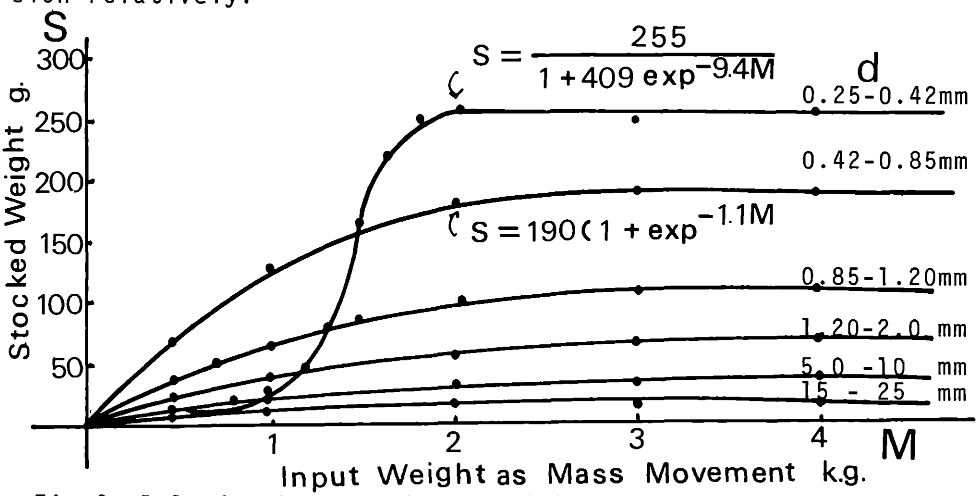

Fig-2 Relation between input weight and stocked weight by a tree d particle diameter

To estimate the maximum stocked weight S_{mx}, two significant non dimensional quantity are deduced from dimension analysis as follows.

$$U \quad \frac{S_{mx}}{\frac{4}{3}\pi\left(\frac{d}{2}\right)^3 \rho} \qquad Z \quad \frac{D}{d} \qquad 3$$

ρ and d are density 2.65 g/cm^3 and diameter of particle. D is tree's basal diameter,10 cm in experiments A. U means the number of caught particle and Z is the chance that a standing log can catch sliding particle at the circumference of foot. Both quantities are combined by the next equation,

$$U \quad a\, Z^b \qquad --- 4$$

where a and b are the coefficient depending on the condition of slope. From experimental results, a is 0.0037 and b is 3.66. By substitution these values and equation 3 into 4, S_{mx} is given by the next equation.

$$S_{mx} = 5.13 \times 10^{-3}\, D^{3.66}\, d^{-0.66} \qquad --- 5$$

In equation 5, the sum of exponent on D and d is always constant 3. The experimental mass movement of fine sandy particle slides slowly in laminar state, tree can resist and conserve them more easily than coarse sand or gravel that rolls or jumps down in high speed. It is difficult to analyse the contribution of particle diameter depending on the slope condition. Then we consider the exponent on d as zero, as a result, S_{mx} is proportional to the cubic power of basal diameter.

$$S_{mx} = k\ D^3 \qquad \text{--- 6}$$

In addition to above factors, coefficient k is depended with the distance of log from the shot box. The value of k in the case of 0.8 m distance is more 50 % extra than 3.2 m case.

The ratio R of stocked weight S to input M means the efficiency of trapping by single tree, it is about 13 % at the maximum.

$$R = S\ /\ M \qquad \text{--- 7}$$

The maximum efficiency is obtained at $M \fallingdotseq 3/\lambda$ by substitution of equation 1 or 2 into 7 and differentiation with respect to M. If forest fence effect is estimated by sum of each tree's effect independently, from above result, 100 % of a sliding material like mass movement can be stocked by 8 trees effectively planted.

Fig-3 illustrates the results from experiments B on the relation between basal diameter D and the maximum stocked weight S_{mx} at various slope angle.

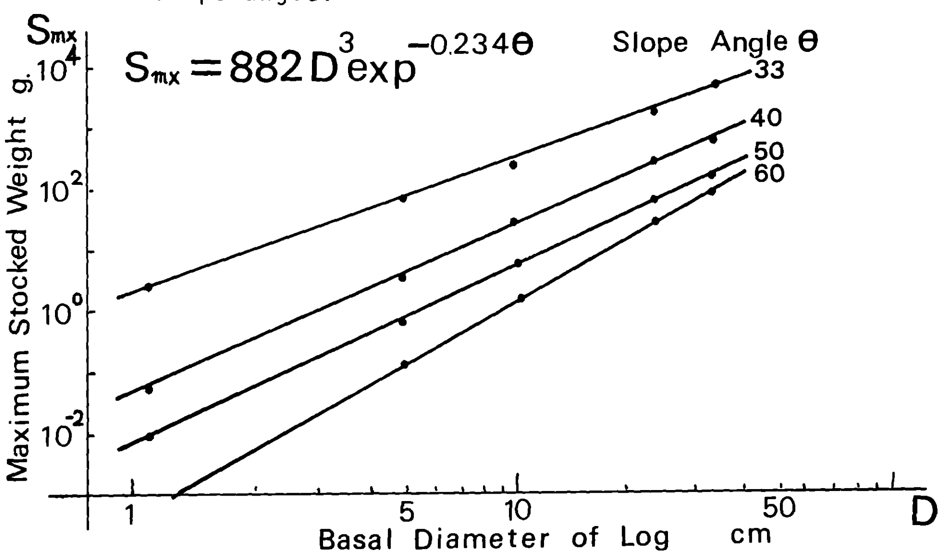

Fig-3 Relation between basal diameter and the maximum stocked weight by a standing tree

From the same analysis as equation 3, next non dimensional quantity is deduced as follows,

$$Y \quad \frac{S_{mx}}{D^3\ \rho'} \qquad W \quad F(\theta) \qquad 8$$

where Y means the efficiency to the capacity that single tree can catch and stock mass movement. W is the function of slope angle θ and ρ' is the apparent density of piled and stocked material. Both quantities are combined as next equation.

$$Y \quad F(\theta) \qquad \text{--- 9}$$

The shape of material that a standing log catches at the maximum is like the trianglar pyramid shown by Photo-1 and always geometrically similar to that in any basal diameter case. The each edge of pyramid is proportional to the basal diameter of log. Accordinly the volume of pyramid is proportional to the cubic power of basal diameter.

The slope angle is the factor that controls the balance of driving force to frictional and the velocity of sliding particle on slope. The velocity of mass movement on smooth surface of steep slope is faster than rough and gentle slope, because the slope component of gravitational force that drives particle down is relatively stronger against frictional force in former case. From results, next equation is adapted as function $F(\theta)$.

$$F(\theta) = k \exp^{-\gamma\theta} \qquad 10$$

By substitution equation 10 and 8 into 9, the maximum stocked weight S_{mx} is reformed as follows

$$S_{mx} \quad k\rho' D^3 \exp^{-\gamma\theta} \qquad \text{---}\ 11$$

where the coefficient γ is about 0.234 of non dimension.

In consequently, the weight of caught and stocked material by a standing tree is given by the next equation with taking account for 1,

$$S \quad KD^3 \exp^{-\gamma\theta}(\ 1 - \exp^{-\lambda M}\ ) \qquad \text{---}\ 12$$

where the coefficient K depends upon density and shape of particle, slope roughness and location of tree from starting point of mass movement. Equation 11 coincides with equation 6 in the estimation of effect of tree's basal diameter. Equation 12 is useful to plant the preventive forest based on the estimation of catchable weight gainst mass movement like landslide and rock falling.

CONCLUSIONS

When the forest in mountainous district resists as preserve fence against landslide or rock falling, even a tree can catch much portion of moving down material to save traffic at road. The stocked weight by a tree is shown by the Mitcherlichs growth curve in general. The maximum stocked weight in this curve is proportional to the cubic power of trees basal diameter and decreases with the exponential of slope angle that participates in velosity of mass movement. The velosity of fine particle on gentle and rough slope is relatively slower, tree can catch mass movement more easily than big particle on steep and smooth case. The stock mechanism in various condition and quantitative estimation of coefficient must be the subjects of future research on fence effect of single tree.

April 14, 1981