

Study on Vegetation Root Strength of Pioneer Plants for Forest Areas in Taiwan

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Abstract Forest plant roots may restrain the occurrence of shallow landslides for forest land and pioneer tree species can also reduce runoff and soil erosion; thus they are useful practical ecological materials for landslide control and erosion control. In this study, two important pioneer plant species Fomosan Alder (*Ahus fomosana Makino*) and Roxburgh Sumac (*Rhus chinensis Mill Var roxburghii* (DC.) Rehd.) were selected at landslide areas under vegetation treatments for soil and water conservation. In order to obtain the root strength model for the factors affecting pulling resistance and root tensile strength, experimental materials were tested and the data were analyzed using regression techniques. These models could be used to provide the index of slope stability and to quantify the root strength using non-destructive methods.

Keywords pioneer tree; vegetation root strength; regression analysis

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1 Introduction

With extensive development in Taiwan, landslide can occurs near the road, because of extensive precipitation and fragile geomorphic condition. Recently, serious landslides were occurred as a result of earthquake. According to survey records in 1989, the failure area of mountain landslide in 1989 was 8 100 hm². The September 1999 Chi-chi earthquake produced new slope failures of covering 16 000 hm² in Taiwan. Several factors make it difficult to be vegetated, such as barren, coarse-textures soils, and steep slope. However, the pioneer species Fomosan Alder and Roxburgh Sumac can vegetate at slope failures and are found to be as precursors to succession by dominant plants (Lin and Chang 1995). These two species were selected to investigate the influence of tree roots on slope failures associated with Cross-island Highway.

Tree roots provide important soil reinforcement that improves the stability of hill slopes. One stabilizing function of vegetation comes from evapotranspiration, which can adjust the soil water and reduce pore pressure. Tree roots also provide reinforce strength through tensile reinforce (tree root anchoring reaction) and the mechanical reinforcement from the interactions of tree root in soil (Wu 1976, Waldron 1977, Abe and Iwamoto 1990, Chang and Lin 1995).

Tree roots systems also increase shear stress resistive, reducing the risk of shallow landslides. Most research results show a relationship between the pulling resistances

force and root diameter. Sample data are so limited that only linear models have been proposed. The coefficient of determination (R^2) was the only criterion used to evaluate the linear relationship and to compare the fitting agreement of the model (Wu 1989, Abe and Ziemer 1991, Chang and Lin 1995). Factors that influence solidification, such as the stem weight, soil texture, slope degree, tree root distribution and weather were not considered in these earlier models. These experiments used nondestructive technique. Nondestructive dry-matter estimation methods have been developed to estimate dry materials of leaves using a regression model (Pasian and Lieth 1994, Chen and Lin 1999). In order to predict the root strength and landslides risk reduction benefits of dominant plant without interfering with plant growth, nondestructive estimation model must be developed. In this study, the strength characteristics of Fomosan Alder and Roxburgh Sumac are evaluated using nondestructive measurement to quantify some physical factors.

2 Materials and methods

The experiments were conducted on landslide areas of Taiwan Cross-island Highway using two native plants, Fomosan Alder and Roxburgh Sumac as experimental samples. According to the vegetation survey, they are representative and dominant pioneer plant for this area (Lin and Chang 1995). Pulling resistance force was measured for further regression analysis. The flow chart of this study is presented in Figure 1.

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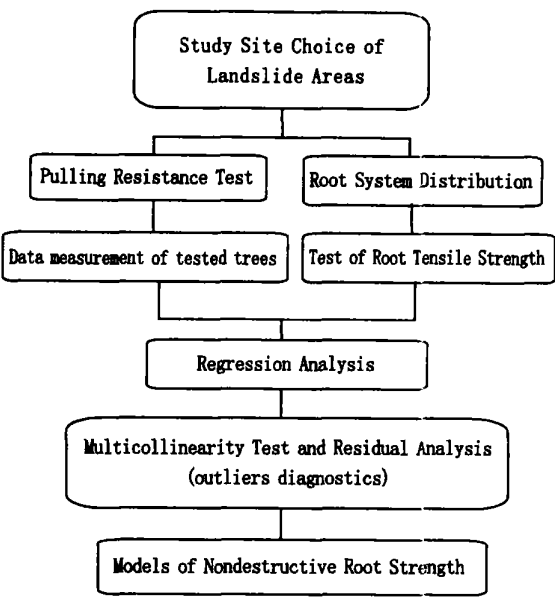


Fig. 1 Flow chart of study

2.1 Experimental material

The experimental area was located at 70 km² landslide area of Taiwan Cross-island Highway after Chi-Chi earthquake. In a 3.5 km² landslide area, the pioneer plants in this area are Fomosan Alder and Roxburgh Sumac. Kikuyu grass used on landslide area at the experimental site and it was applied to slope failures. The vegetation survey 16 months after the Chi-Chi earthquake found that there were 164 of Fomosan Alder and 130 samples of Roxburgh Sumac on this site. A resurvey after 25 months found that the number of Fomosan Alder was 286 and there were 250 Roxburgh Sumac.

2.2 Pulling experiment

In this experiment, a pulling resistance meter (SHM PO, FGC-25H, Japan) was used to measure the peak force (pulling resistance) for these plants. The meter can be connected to a computer to record the change of pulling force. The measurements that range from 0 to 250 kgf and its accuracy is 0.2%. The pulling resistance force was measured using the pulling meter for Fomosan Alder and Roxburgh Sumac as less than 5 years old. The pulling resistance force was measured vertical to slope and its operating velocity was 20 cm/min, then the basal diameter and height of plant were recorded. The plants were then cut near underground position. The stem weight was measured after cleaning.

2.3 Tension experiment of variable tree root diameter

The tree root systems of Fomosan Alder and Roxburgh Sumac below 5 years were extracted and packed into a bag and then kept in a cooler. Laboratory tree root pulling experiments were completed within 3 days of root extracted. The pulling mechanism was adopted to examine the pulling resistance force with a universal testing machine (HUNGTA, HT-8338, Taiwan). Its measurement range was ranged from 0 to 1000 kgf with an accuracy of 1%. In order to avoid the destruction of the root, a special elastic

grip was designed by authors. The pulling velocity was 50 mm/min. The distance between the grips was 10 cm before starting the experiment. The tension and tree root diameter would be recorded as the tree root was broken in the middle part.

2.4 Data analysis

Tree root strength models were developed using the regression techniques classified as fitted model and predictable model. Performance were evaluated using the coefficient of regression determinant (R^2), standard error of deviation (s), and prediction sum of square residual ($PRESS$). The lower s and $PRESS$, the better selected model. Residual plots were also used to evaluate the model and justified outliers. The ideal residual plot is the distribution on horizontal axial with a zero value. The collinearity of the regression parameters was checked. The assumptions of regression are normal distribution, non-collinearity, variance constant and the parameter relative with physics and mathematics variance inflation factor (VIF) which can be described (Myers, 1986) as follows:

$$VIF = \frac{1}{1 - R_i^2}$$

(1)

where R_i^2 is the coefficient of determinant of multiple regression analysis. If R_i^2 is high, VIF will be significantly high. The predicted value of coefficient would be worse and represented the collinearity.

3 Results and discussion

3.1 Pulling resistance force

Some experimental errors were detected due to stripped bark and broken stems and some samples could not be completely evaluated. Collected data sets included pulling resistance force (P_r , kgf), stem basal diameter (D , mm), stem height (h , mm), underground weight of the plant (W_d , g), upper part weight of the plant (W_u , g), ratio of upper with underground part (TR), planted year (Yr), and degree of slope (dg). There were 52 samples of Fomosan Alder and 43 samples of Roxburgh Sumac. Some typical relationship between resistance force and diameter, upper part weight and underground part weight are presented. By regression analysis, the tree root models are listed as follows:

3.1.1 Fomosan Alder

$$P_r = -3.90 - 1.44h + 3.89D + 0.11W_d - 0.08W_d - 0.84TR - 0.02dg, R^2 = 0.85$$

or $P_r = -4.35 - 1.43h + 3.89D + 0.11W_u - 0.11W_d - 0.91TR, R^2 = 0.85$

(3)

Slope was not an important factor for equation (2) by t-test, so only equation (3) was checked for its collinearity.

3.1.2 Roxburgh Sumac

$$P_r = -26.94 - 0.14h + 3.07D + 0.03W_u - 0.35W_d - 0.64TR + 6.36Yr, R^2 = 0.89$$

If VIF is larger than 20, this parameter was collinearity with other parameters (Myers, 1986). The results of collinearity check are listed in Table 1. Stem weight and underground part weight all have high collinearity.

Therefore these parameters were deleted from experimental data and other parameters were rechecked. New models are shown in the following.

Table 1 The diagnosis of multicollinearity for parameters in tree root strength models

Tree species	Statistics	<i>H</i>	<i>D</i>	<i>Wu</i>	<i>Wd</i>	<i>Tr</i>	<i>Yr</i>
Fomosan	R_i^2	0.8257	0.7820	0.9742	0.9729	0.3658	0.6771
Alder	<i>VIF</i>	5.7372	4.5873	38.760	36.901	1.5768	3.1102
Roxburgh	R_i^2	0.6505	0.9309	0.9816	0.9748	0.6764	0.5971
Sumac	<i>VIF</i>	2.8612	14.472	54.348	39.682	3.0902	2.4820

3.1.3 Fomosan Alder

The modified model was established after outlier check and deleted.

$$Pr = 1.66D + 1.06Wu, R^2 = 0.90$$
$$PRESS = 3998.5, s = 12.0 \tag{5}$$

$$Pr = 3.504e^{0.24D}, R^2 = 0.82$$
$$PRESS = 5.83, s = 0.45 \tag{6}$$

3.1.4 Roxburgh Sumac

After outlier check and deletion, new modified models are listed as follows.

$$Pr = 1.79D + 0.028Wu, R^2 = 0.78$$
$$PRESS = 2699.1, s = 11.0 \tag{7}$$

$$Pr = 0.89H + 0.57D + 0.04D^2, R^2 = 0.85,$$
$$PRESS = 243.86, s = 9.56 \tag{8}$$

From equations (7) to (8), basal diameter of tree root system, upper part weight and height are the adequate parameters of tree root models for Fomosan Alder and Roxburgh Sumac. The objective of this study was to develop the tree root models by the non-destructive technique. Height and tree root diameter could serve as the adequate parameters of tree root model, so equation (6) and equation (8) can serve as adequate models for Fomosan Alder and Roxburgh Sumac.

3.2 Tension of tree root pulling resistance force

Significant data scattering can be found in the figure. After transforming with logarithmic function of tension, the diversion of data scattering was improved. The same results were found for Roxburgh Sumac. Tree root diameter of Fomosan Alder ranged from 0.8 to 8.7 mm and that of Roxburgh Sumac ranged from 0.5 to 10.5 mm. The samples were younger than 5 years. By different tree root diameter experiments, Fomosan Alder had 105 sets of data and Roxburgh Sumac had 148 sets of data. After primary analysis, tree root models were proposed to describe the relations as equations (3) and (4). After conducting statistical analysis such as outlier detecting and residual plots checking, the tree root models of tension were modified and are listed as follows.

3.2.1 Fomosan Alder

$$\ln(Ti) = -2.63 - 0.54D + 3.73D^{1/2}, R^2 = 0.80$$
$$PRESS = 24.5, s = 0.48 \tag{9}$$

3.2.2 Roxburgh Sumac

$$\ln(Ti) = -2.57 - 0.08D + 2.57D^{1/2}, R^2 = 0.90$$
$$PRESS = 21.6, s = 0.38 \tag{10}$$

3.3 Effect of shear for tree root system

These useful data sets for pulling resistance force of

Fomosan Alder and Roxburgh Sumac can be used for the tree root tensile strength prediction curves. Information about pulling resistance force and tension of dominant tree root system is very useful in area prone of slope failures. The interaction of tree root system and soil shear resistance can prevent soil failure. According to Abe's theory, pulling resistance force and reinforce resistance of tree root soil (ΔS) could be described as (Abe, 1991).

$$\Delta S = (Pr/2)(\cos U \tan b + \sin U) + E Ib^3 B \tag{11}$$

Where U is the frictional angle of soil, b is the coefficient of strain of the tree root system, E is the Young's modulus and I is the modulus of the section.

Tensions of tree root varied with the diameter of tree root system. Tension is the sum of section area and the number of tree root of tension. According to the study of Abe and Iwamoto (1991) and Chang and Lin (1995), tension of different tree root diameters could be used to evaluate the increment of soil shear. The relationship could combine equation (10) and equation (11), and can be used to evaluate the stability of slope. The root reinforce soil by Wu (1976) and Walton (1977) is

$$\Delta S = \sum T_i n_i T_i A_s (\cos U \tan b + \sin U) \tag{12}$$

Where T_i is the tensile stress of root, n_i is the number of roots, A_i is the cross-sectional area of roots and A_s is the sectional area of soil.

The parameter of T_i in equation (12) then can be calculated by equation (9) and equation (10) developed in this study.

3.4 Influence factors of model prediction

Since the errors are resulted from broken stem and strip bark, it is very important to improve the measured technology for some factors such as soil texture, soil moisture aspect and weather were not considered in this study. Since these factors may influence the tree root models, further study needs to be executed.

4 Conclusion

From the non-destructive method, pulling resistance force model of Fomosan Alder was $Pr = 3.504e^{0.24D}$, and that model of Roxburgh Sumac was $Pr = 0.89H + 0.57D + 0.04D^2$. It is necessary to make tree root force model to predict the stability of slope for dominant or preceding plant in slope failures. Therefore, it is possible to describe and to quantify its effect by these tree root force model. To estimate the shear of tree root on plant ecosystem's succession or stability, the pulling resistance force experiment used 52 samples of Fomosan Alder and 43 samples of Roxburgh Sumac in this study. As the numbers of samples are increased, the regression model would be more precise. More data were required to be collected to improve the predictive ability of the model.

The vegetation root models of these plants considered only their tree root system and physical quantity. More factors could be considered in a further experiment such as

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vital factor of plants net photosynthesis rate stomatal conductance, root distribution, solar radiation, wind velocity, rainfall, geographical factor, aspect, soil moisture, slope, soil temperature and heap zone

vegetation root models of pioneer plants in forest These models could be applied to some special landslides area in forest, these models can be incorporated with other factors, such as landslide, slope failures, and stability of slope

The purpose of this study was to establish the

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