

Evaluation on Nondestructive Plant Strength for Typhoon and Earthquake Areas in Taiwan

Chun-Pin Chang¹, Ta-Ching Liang^{2,*}

¹Department of Landscape Architecture, Chung Chou University of Science and Technology, Taichung, Taiwan, R.O.C.

²Department of Leisure and Recreation, National Formosa University, Yulin, Taiwan, R.O.C.

Email address:

plus871014@gmail.com (Chun-Pin Chang), taching@nfu.edu.tw (Ta-Ching Liang)

*Corresponding author

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Abstract: In this study need to construct the criteria of landslide area protection for the selected vegetation materials in considering their characteristics and the soil solidities for the root system. Selection three pioneer plants, India-charcoal Trema, Formosan alder and Roxburgh sumac, doing destructive pulling resistance test. By the weight of plant above the ground, weight of root-soil, and get non-destructive resistance models. With the diameter of the tree just above the ground, were derived with multi-variable regression analysis, respectively. The models gave higher statistical regression coefficients when they were compared with the results of relative researches. The significant level factors to influence the plant pulling resistance capacity are climate and soil properties that fitting models of root strength provided the quantitative prediction on slope stability in the landslide areas.

Keywords: Pioneer Plant, Pulling Resistance, Nondestructive Models

1. Introduction

The South and East Taiwan was damaged in large landslides and disaster by Typhoon Morakot with its strong winds and heavy rains. Slope land is quite easily eroded resultant in the nude land surface and the shallow layer fertile soil collapsing, which is adverse circumstances for plants living, is also lost, especially, after the Chi-chi earthquake with the fragile geomorphic condition. Pioneer plants, which can adapt the rigorous situation then germinate and grow up, are important with their roots to restrain the occurrence of shallow landslides for initial stage because of mechanical reinforcing force of roots and friction of roots-soil binding. Pioneer plant species is able to reduce the runoff and soil erosion, thus that served as vegetation material may be the best choice for landslide control.

Vegetation can adjust the soil water and reduce pore pressure from evapotranspiration to stabilize the soil slope. Tree roots also provide reinforce strength of anchoring reaction through tensile reinforce and the mechanical reinforcement from the inter-actions of tree root in soil [2, 13,

22, 25]. Tree roots systems also increase the shear stress resistance to reduce the risk of shallow landslides. Most research showed a relationship between the pulling resistances force and the diameter of bole near ground. [1, 3, 9], or the tensile strength of the root with its diameter [2, 14]. Some researches of pulling resistant force, such as *Pluchea indica* (L.) Less and *Clerodendron inerme* (L.) Gaertn in mudstone area with the diameter of bole near ground, presented the exponential positive correlation [1, 3, 9, 10, 21]. The pulling resistance between *Bambusa stenostachya* Hackel and its breast-height diameter, or the tensile strength of the root with its diameter in mud-stone area was also in the form of exponential positive correlation [13, 14]. Data were so limited that only linear models have been proposed with the coefficient of determination (R^2) the only criterion used to evaluate the linear relationship and to compare the fitting agreement of the models [1, 3]. Factors that influence solidification, such as stem weight, soil texture, slope, tree root distribution, and weather were not considered in these earlier models.

The root-soil pulling resistance also could be transformed

directly into shear resistant force on the land slope stability with vegetation [11, 12, 25]. The fine-root with load-destruction test of *Fagus hayatae* and *Larix gmelini* [19] presented the relationship of axil force and strain in the form of the water contain of root soil with the destructive strain, and the pulling rate with the stress [8]. Nondestructive dry-matter estimation methods have been developed to estimate dry materials of leaves using a regression model. [4, 5, 6, 15, 16, 18, 23]. While for the prediction of the root strength and landsides risk reduction benefits of dominant plants without interfering with plant growth, this model must be developed.

The ecological environment was seriously destroyed after the land surface naked with landslide. For the purpose of environment recovery, soil and water conservation plays important role. Vegetation for environmental protection and slowing down the environmental impact will be the relevant topic for this moment and is also our main purpose of this paper. According to the testing results, the statistical regressive analysis was performed to formulate the relationships between the pullout resistance of root system, the growth characteristics of plant, and the field site

environment in order to establish the pullout resistance models for these three particular plants, India-charcoal Trema (*Trema orientalis* Blume), Formosan alder (*Alnus formosana* Makino) and Roxburgh sumac (*Rhus javonica* L. var. *roxburghiana*) in the site of Central Cross-Island Highway in Taiwan. All the possible factors are regressed to obtain the better ones and then comparing with the results of the Takanshan limestone mining district with discussion of the differences in the plant of *Rhus javonica* L. var. *roxburghiana*. DC.

2. Study Methods

The management, restoration strategies, and vegetation succession mechanism in landslide areas are distinct because of their characteristics. Aiming at landslide areas in Taiwan, the primary plant succession and vegetation cluster analysis were preceded to discuss. The real field practice of wired pavement Hydroseeding of vegetation engineering [17] was done with the plant association at landslides area where were caused by 921 Chi-Chi Earthquake in Taiwan. The flow chart of this study is presented in Figure 1.

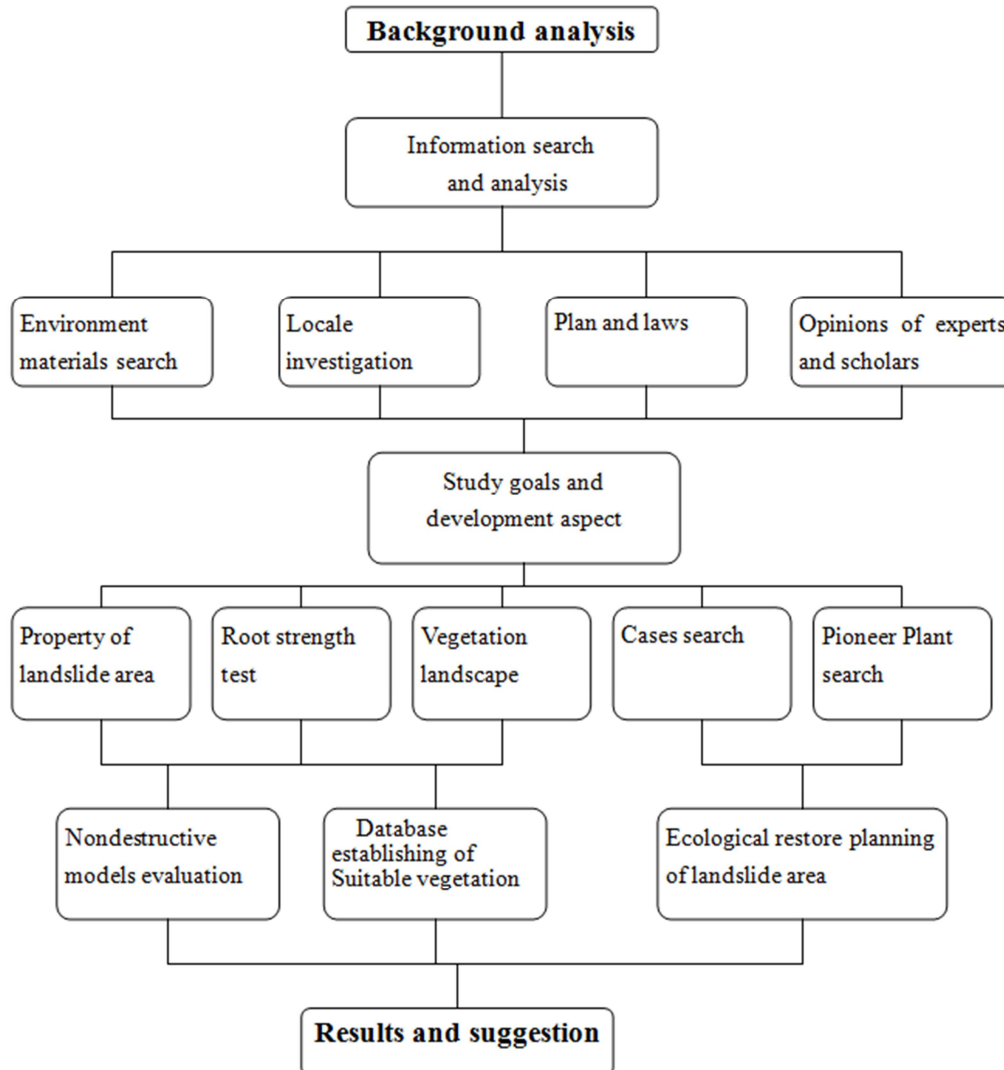


Figure 1. The flow chart of study.

2.1. Test Plant

Based on the result of that investigation, the dominant woody plants were *Trema orientalis*, *Buddleja asiatica*, Taiwan Acacia... etc. According to the investigation and analysis, Formosan alder and Roxburgh sumac was the pioneer and dominant trees at slope failure area after treatment in cross-island highway, Taiwan [4, 6]. From the real field exploration with the evolution of natural and man-made plant groups, India-charcoal Trema, Formosan alder and Roxburgh sumac are chose as our choosing plants in this paper. They are the positive pioneer and dominant varieties of native trees grow in the sunny side of the nude landslides ground rightly.

Chemic fertilizers, organic matter, and peat are chosen to increase the effectiveness of soil nutrients as the reference of plant recovery for land slope stable. The landslide of Central Cross-Island Highway in Taichung City, Taiwan is the testing site for soil and water conservation and the land-sliding protection engineering.

2.2. Plant Strength Tests

Randomly choosing the different heights of plants is done based on the concepts of normal distribution and each single plant for pulling test is going on without land slope destruction, influence of other plant root system, and interference of original plant group. Before the pulling resistance tests, the measurements of plant heights (h, cm), the diameter of the tree just above the ground (D, mm), the tree diameter with 10cm above the ground (D_{10} , mm), the soil weight below ground 5~10 cm (Ww), the weight of plant above the ground (Wu), the weight of root-soil (Wd), the age of the plant (Yr), the land slope (dg), and the Yamanaka's hardness (H) are recorded. The pulling resistance (Pr, kgf) for 1-5 year-dominant plants is measured by Back muscle force meter suitable for less than 240 kgf. The pulling direction must be vertical to the face of the land slope and the pulling velocity is 10 cm/min (See Fig. 2). The dry weights of plant above the ground (Wud, g), and the ones of root-soil separately put in oven with 85°C and 105°C for 48 hours, respectively. The water contains of plant above the ground (Uw, %), the one of root-soil (Rw, %), and the other for total soil (Sw, %) are calculated and expressed in Fig. 3 individually.



Figure 2. Pulling resistance test of tested plant.

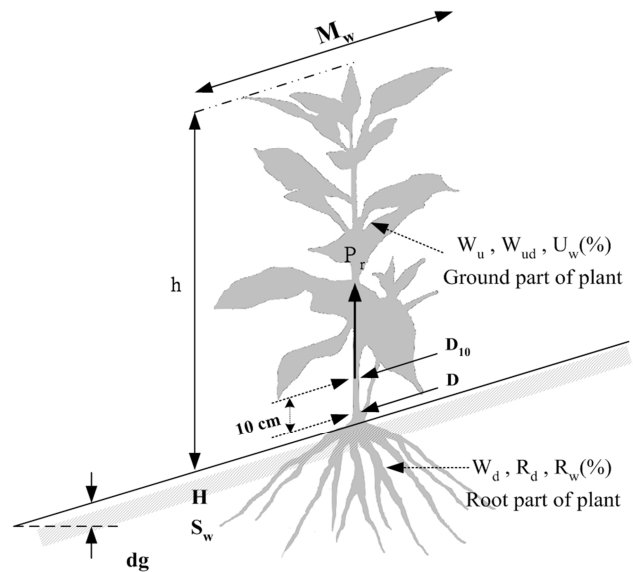


Figure 3. Illustration of model parameters for tested plant.

2.3. Pulling Resistance Models

By stepwise linear regression and col-linearity, the model of pulling resistance with multi-variables can be set up and at the same time the coefficient of each variable will be checked by Variance inflation factors, VIF, and $VIF=1/(1-R_i^2)$ with the R_i^2 of the regression coefficient for certain variable after multi-variable regression. General speaking, if VIF is great than 10, it shows the col-linearity is high [20]. For the purposes of model evaluation, Coefficient of determination, R^2 , Standard error, S, Mallor's Cp Statistic, Prediction sum of square, PRESS, outliers and the standard residual with statistical assumption of normal distribution are used for the proofs for validities and prediction of optimum models.

3. Result and Discussion

3.1. Plant Strength Models

For the pulling resistance tests, 25 sampling plants of *T. orientalis*, 51 of *A. formosana* and 43 of *R. javonica* var. *roxburghiana* DC. are chosen from Typhoon and Earthquake's landslide areas. Have the following optimum regression equation for each sample group with multi-variable regression analysis:

(A) *Trema orientalis*

$$\text{with } R^2=0.91 \text{ Pr}=0.47W_u \quad (1)$$

(B) *Alnus formosana*

$$\text{with } R^2=0.93 \text{ Pr}=2.96D+0.02W_d \quad (2)$$

(C) *Rhus javonica* var. *roxburghiana*. DC

$$\text{with } R^2=0.94 \text{ Pr}=1.018D+0.080W_u \quad (3)$$

Checking the VIF in Eqs.(1), (2) and (3), the values are all less than 10 which means the col-linearity is low with

independence. By checking of model rationality and the characteristics of normal distribution, the figure of outliers and the square of the residual errors are shown in Fig. 4 for *Alnus formosana*. The standard residual of Eq. (2) is between -1.98 to 2.42 with the mean close to 0 that no significance, divergence, and irregularity. This information gives us that the regression model has good prediction ability for the given ranges of chosen variables.

The different models of pulling resistance are due to the different roots' types of these pioneer plants. Roxburgh Sumac has dense root system in upper-layer soil, there the horizontal roots stretch outward as a new individual, that could be grows gathering in stone area [13, 26]. *Trema orientalis* Bl. belonged to the parallel type (P-type) root system, and the roots gather up on upper layer of soil [5, 7]. *Alnus formosana* had vertical and horizontal roots stretch, the roots system were well-developed [7, 24].

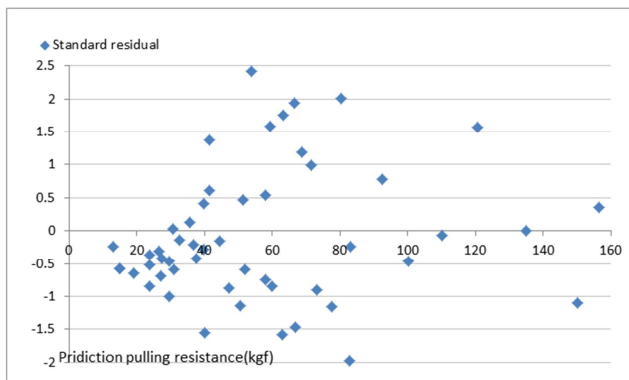


Figure 4. Standard residual of pulling resistance model for *Alnus formosana*.

3.2. Non-destructive Models

Selecting D, h, Mw, H and dg as the parameters of non-destructive views for pulling resistance, that have:

(D) *Trema orientalis*

$$R^2=0.77, Pr=2.88D \quad (4)$$

(E) *Alnus formosana*

$$R^2=0.92, Pr=3.15D \quad (5)$$

(F) *Rhus javonica var. roxburghiana* DC.

$$R^2=0.93, Pr=2.2433D \quad (6)$$

Eq. (4), (5), (6) could be used for these three pioneer plants with real field application. For the checking of model rationality and the characteristics of normal distribution, the figure of outliers and the square of the residual errors are done in Fig. 5 for *Rhus javonica var. roxburghiana*. DC. The standard residual of Eq. (6) shows between -1.7 to 2.39 with the mean close to 0 which means no significance, divergence, and irregularity. This regression model presents good prediction ability for the given ranges of chosen variables. These models are also gives us the information in good trends for statistical theories and high applicability for field testing. Because of these pulling resistances (Pr) models are correlative with the diameter of bole near ground (D), while the same 'D', compare with the 'Pr' as follows: *Alnus formosana* > *Trema orientalis* > *Rhus javonica var. roxburghiana*.

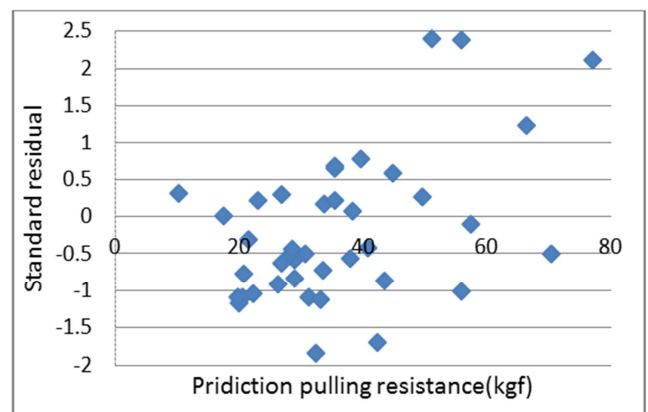


Figure 5. Standard residual of pulling resistance model for *Rhus javonica L. var. roxburghiana*. DC.

Compare with the pioneer plants of model with pulling resistance for the same 'D' in Table 1.

Table 1. Pulling resistance for the same 'D' (To: *Trema orientalis*; Af: *Alnus formosana*).

| Plant | Estimated models | D1 (mm) | Pr1 (kgf) | D2 (mm) | Pr2 (kgf) |
|-------|------------------|---------|-----------|---------|-----------|
| To | Pr=2.88D | 5 | 14.41 | 10 | 28.82 |
| Af | Pr=3.15D | 5 | 15.77 | 10 | 31.55 |

3.3. Weights and Contains of Pioneering Plants

The water contains for the pioneering plants are given in Table 2. The mean values ('Uw') of *Trema orientalis*, *Alnus formosana*, *Rhus javonica var. roxburghiana* are 72.62%, 63.01%, 70.11% respectively. While mean values of the root system water contains ('Rw') are 76%, 58.83%, 66.44%.

These results present that the water contains of the *Alnus formosana* and *Rhus javonica var. roxburghiana* are higher than the root system with the one of *Trema orientalis* lower than the root system. Comparing with the 'Uw' and 'Rw' values of these three plants, that obtain: *Trema orientalis* Bl > *Rhus javonica var. roxburghiana* > *Alnus formosana*.

Table 2. Plant body and roots water content (To: *Trema orientalis*; Af: *Alnus formosana*; Rj: *Rhus javonica* var. *roxburghiana*).

| Plant | Water content | Max. | Min. | Mean | Standard error |
|-------|---------------|-------|-------|-------|----------------|
| To | Uw(%) | 79.09 | 63.16 | 72.62 | 4.48 |
| | Rw(%) | 88.00 | 60.00 | 76.00 | 6.99 |
| Rj | Uw(%) | 71.10 | 53.72 | 63.01 | 5.06 |
| | Rw(%) | 76.25 | 49.00 | 58.83 | 7.23 |
| Af | Uw(%) | 76.90 | 60.00 | 70.11 | 3.63 |
| | Rw(%) | 76.00 | 50.00 | 66.44 | 7.48 |
| Rj | Pr=2.24D | 5.00 | 11.22 | 10.00 | 22.43 |

The other useful models between wet-dry weight both of plant and root system for *Rhus javonica* respectively, are as following:

$$R^2=0.99, Wu=3.15Wud \quad (7)$$

$$R^2=0.99, Wd=2.56Rd \quad (8)$$

3.4. Model Comparisons

Comparing the pulling resistance models for *Trema orientalis* and *Rhus javonica* var. *roxburghiana* in different sites, the pulling resistance model of *Trema orientalis* in landslides scars of Shi-Men reservoir watershed [9] is, $Pr=8.52D^{1.18}$, $R^2=0.81$ ($2.5cm \leq D \leq 13.5cm$), while the one of this study is $Pr=0.469Wu$, $R^2=0.912$ ($10g \leq Wu \leq 146g$), and the pulling resistance model of *Rhus javonica* var. *roxburghiana* in Takanshan limestone mining is, $Pr=11.314Yr+0.166Wd$, $R^2=0.7283$ [7] while the one of this study is $Pr=1.0184D+0.0802Wu$, $R^2=0.939$. The different the sites, the varied regression models are. Here, the F-test is unnecessary because the significance exits already. The significant level factors to influence the plant pulling resistance capacity are climate and soil properties.

4. Conclusion

Climate and soil properties can influence plant growth and strength for pulling resistance. For the different plant, the pulling resistance was varied with different pioneer dominant regressive parameters. The following conclusions were made:

- Comparing the pulling resistance models of *Rhus javonica* var. *roxburghiana* between Central Cross-Island Highway and Takanshan limestone mining, show that the models were functioned in geology, geography, thickness of soil layers, and soil nutrient.
- The models of destructive test with real measurements of some physical quantities for *Trema orientalis*, *Rhus javonica* var. *roxburghiana*. DC. and *Alnus formosana* Makino gave high reliability for real field application.
- The fitting models of root strength provided the quantitative prediction on slope stability in the landslide areas.
- Non-destructive technology in this study directly presented that dominant plant species served as vegetation materials to reduce the runoff and soil

erosion in slopeland.

- Besides the adaptation of plants, the establishment of diverse vegetative base, the lead-in, management and maintenance of vegetation, the establishment of vegetation zone, and the relative specification of techniques are the most important research and development issues for the application of vegetation for plant root strength in the future.

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