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Pulling Resistance and Modeling of Dominant Plants in Limestone Mining Spoils

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ABSTRACT
In South Taiwan, staged open-cut mining method was adopted for industry of limestone mining. Such improper cutting method results in a large area of original plantation removal, creates a large volume of spoils, and consequently, causes serious impact on the ecological environment of the entire mining area. The vegetated hill slope always possesses a layer of topsoil for capable protection against soil erosion to stabilize the slope of a certain extent. To mitigate the influence of the improper mining activity, we improve the overall environment by vegetation with dominant plants in the local area. After vegetating treatment and succession, the important woody dominant plants are Dense-flowered False-nettle (*Boehmeria densiflora* Hook. & Arn.), Roxburgh sumac (*Rhus javonica* L. var. *roxburghiana*. DC.) and Pluchea (*Pluchea carolinensis* (Jacq.) G. Don) in South-Taiwan limestone spoil area. The roots of plants could be restraining the occurrence of shallow landslides because of mechanical reinforcing force of roots, and friction of roots-soil binding. These three plants were selected to obtain root-strength model from pulling resistance. The statistical regression analysis was performed to formulate the relationships of pulling resistance of root system (Pr), the growth characteristics of plants and field site environment with the testing results. Good regression relationships were obtained, thus, that served as an economical vegetation material at mining waste dumping area.

***Keywords* -** limestone spoil, pulling resistance, dominant plants, regression analysis

I. INTRODUCTION

Limestone mining（$CaCO_3$）is the main resources of cement and it is an abundant production located in Hsinchu, Chiayi, Tainan, Kaohsiung, Hualien and Taitung of Taiwan and occupying more than 40,000 ha (〔1〕) in 1995 while 3,000 ha only in 2001 (〔2〕) due to the demand reduction, the industrial relocation to mainland China and the statute of limitations from the Government. In fact, we have only 632 ha (〔3〕) up to 2012. The variation of limestone mining annual yield from 1,434,000 Tons to 6,000 Tons is shown in Figure 1. During the mining-cutting process, the plants were cut out, the land surface was naked, the mine area was abandon, the ecological environment was seriously destroyed. The landscape became unsightly. Based on the view point of environment recovery, soil and water conservation plays important role. With vegetation to protect the environment and slow down the environmental impact will be the relevant topic for this moment and is also our main purpose of this paper.

Besides the water contents in the soil, the plant root grows stronger and it contributes some strength for soil land-slope fastening, the root piles anchoring contributes the mechanical force on consolidating the soil structure with reinforce of soil shear resistant strength to avoiding or suppressing the landslide on shallow soil layers (〔4〕,〔5〕,〔6〕). Some researches of pulling resistant force, such as *Pluchea indica* (L.) Less and *Clerodendron inerme* (L.) Gaertn in mud-stone area with the diameter of bole near ground, showed the exponential positive correlation (〔6〕,7〕,〔8〕,〔9〕). 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 (〔1〕,〔9〕). The root-soil pulling resistance also could be transformed directly into shear resistant force on the land slope stability with vegetation (〔10,11〕,〔12〕).

The fine-root load-destruction test of *Fagus hayatae and L. gmelini* (〔1〕,〔13〕) presented the relationship of axil force and strain that the water contain of root soil exceeding 60%, the destructive strain will be more than 16%；The pulling rate of *Fagus hayatae* from 10 mm/min to 400mm/min , the stress will increase 8-20% (〔14〕).

Traditional statistical analysis just evaluates the rations of significant level and form of linear equation with R^2, coefficient of determination, yet, whether the appropriation of model is suitable or not could be no discussion. The influence factors of root-soil resistance include weight of plant above the ground, soil properties, such as hardness, chemical and physical characteristic, root distribution, land slope and climate (〔6〕, 〔15〕). Some researchers also did some regression analysis on the studies of pulling forces models on lands-lope stability (〔16〕, 〔17〕, 〔18〕, 〔19〕, 〔20〕, 〔21〕, 〔22〕). In our paper, the dominant plants of the Takanshan limestone mining district at the south of Taiwan are studied, and the root-soil resistance models with all the possible factors are regressed to obtain the better ones and then comparing with the results of Central Cross-Island Highway with discussion of the differences in the plant of *Rhus javonica* L. var. *roxburghiana*. DC.

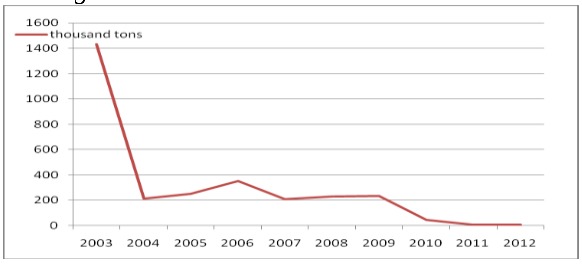

Fig.1 The production volume of limestone products from 2003 to 2012(〔3〕)

II. RESEARCH METHODS

2.1 Plants Characteristics

The dominant plants of Takanshan limestone mining district are woody plants: *Boehmeria densiflora* Hook. & Arn. and herbaceous plants: *Miscanthus floridulus* (Labill.) Warb. ex K. Schum. & Lauterb. Even *Rhus javonica* L. var. *roxburghiana*. DC, is not such a dominant one but it has wide spread area (〔1〕). Based on the real field exploration, after the evolution of natural and man-made plant groups, the dominant introduced plant is *Pluchea carolinensis* (Jacq.) G. Don with more than 3m high (general 1-2.5m). *Boehmeria densiflora* Hook. & Arn, *Rhus javonica* L. var. *roxburghiana*. DC, and *Pluchea carolinensis* are chose as the studied plants in this paper.

2.2 Properties of Testing Site

Limestone mining of Takanshan is the testing site with coral layer of weak alkaline and high calcium which has low permeability (〔1〕) Due to the high pH-value in the limestone mining, the nutrients are locked as non-exchangeable situation and they cannot be utilized by plants. Therefore, chemical fertilizers, organic matter, and peat are chosen to reduce pH-value for increasing the effectiveness of soil nutrients as the reference of plant recovery.

2.3 Pulling Resistance Tests

With the concepts of normal distribution, the random choices of different heights of plants has done and each single plant for pulling test is going on without land slope destruction, influence to other plant root system and interference of original plant group. Before the pulling resistance tests, the measurements of plant heights (h.cm), the width of the tree covers (Mw, 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). 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 with 10 cm/min pulling velocity (See Fig. 2). The dry weights of plant above the ground (Wud, g), and the ones of root-soil separately in oven with 85℃ and 105℃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.

2.4 Constructions of 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-Ri^2) with the Ri^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 (〔23〕).

For the purposes of model evaluation, Coefficient of determination, R^2 , Standard error, S, Mallow'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.

Fig. 2 Pulling resistance of dominant plant

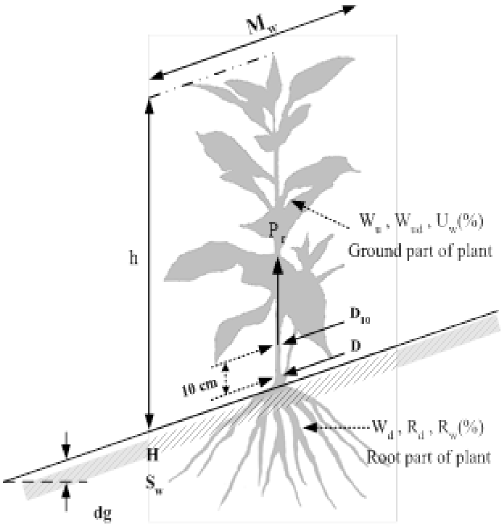

Fig. 3 Illustration of model parameters for pulling test

III. Results of this Study

3.1 Plant Pulling Resistance

For the pulling resistance tests, 25 *Boehmeria densiflora* Hook. & Arn, 17 *Rhus javonica* L. var. *roxburghiana*. DC, and 46 *Pluchea carolinensis* are chosen as the test samples. By multi-variable regression analysis, we have the following optimum regression equation for each sample group:

(1) *Boehmeria densiflora* Hook. & Arn:
$Pr=0.5611D+0.1134h+0.149Wu$,
$R^2=0.788$, PRESS=20414, Cp=2.32, ---- (1)
D: measured with plant age 1 to 4 years,
$37.0g \leqq Wu \leqq 900.0g$

(2) *Rhus javonica* L. var. *roxburghiana*. DC:
$Pr=11.314Yr+0.166Wd$,
$R^2=0.7283$, PRESS=9254.35, Cp=1.976, --- (2)
D: measured with plant age 1 to 4 years,
$15.0g \leqq Wu \leqq 620.0g$

(3) *Pluchea carolinensis*
$Pr=1.397D10+2.280Rd$,
$R^2=0.957$, PRESS=6630 , Cp=5.968 -----(3)
$4.32mm \leqq D10 \leqq 23.58mm$
$0.3g \leqq Wu \leqq 50.66g$

Checking the VIF (See Table 1) of Eqs. (1), (2) and (3), the values are all less than 10, it means the col-linearity is low which gives us they are independent. 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 such as Fig. 4 for *Pluchea carolinensis*. The standard residual show between 2.1 to 3.2 with the mean is close to 0, it means there is no significance, divergence, and irregularity. This information gives us that the regression model will have good prediction ability for the given ranges of chosen variables.

The different models of pulling resistance because of Roxburgh Sumac has dense root system in upper-layer soil, due to the horizontal roots stretch outward to be a new individual, that could be grows gathering in stony area. Dense-flowered False-nettle has a well–developed main root and denser fibril comparatively. (〔1〕)

Table1 The diagnosis of collinearity for parameters in root- strength model

plants	parameters	Ri^2	VIF
Boehmeria densiflora	D	0.3633	1.5706
	h	0.4475	1.8100
	Wu	0.7210	3.5842
Rhus javonica	Yr	0.6354	2.7427
	Wd	0.7084	3.4294
Pluchea carolinensis	D_{10}	0.87	4.1
	Rd	0.68	1.86

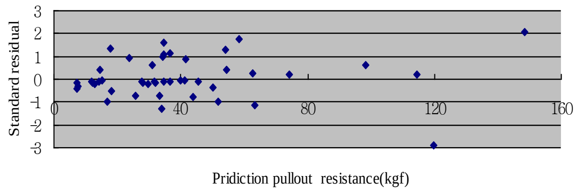

Fig.4 Standard residual of pulling resistance model of *Pluchea carolinensis*

3.2 Checking models with Non-destructive Views

Selecting D、 D_{10},、h、Mw、Sw、H and dg as the parameters of non-destructive views for pulling resistance. Analyzing the factors of models with not sufficiently good regressive results, situation of lime-stone mining district, nutrient of soil, conditions of geography and geology, soil water contains, soil porosity and numbers of test samples are all possible reasons.

(4) *Boehmeria densiflora* Hook. & Arn:
$Pr=2.024D+0.375h$ -------- (4)
$R^2=0.51$, PRESS=39675, S=36.21
$7.0mm \leqq D \leqq 43.0mm$

(5) *Rhus javonica* L. var. *roxburghiana*. DC:
$Pr=0.622D$ -------- (5)
$R^2=0.622$, PRESS=11623.5, S=25.43
$7.0mm \leqq D \leqq 43.0mm$

Eq. (5) could be used for *Pluchea carolinensis* with real field application because of the standard residual shows between 2.44 to 2.59 with the mean is close to 0. It means there is no significance, divergence, and irregularity. This information gives us that the regression model will have good prediction ability for the given ranges of chosen variables. And by testing the soil above the ground 10 cm, Yamanaka's hardness measurement gives H 13.8~24.2 and VIF 6.693 which is also gives us the information that good suitable for statistical theories and high applicability for field testing.

Additionally we consider D_{10}, which is shown in Eq. (3), the other form for *Pluchea carolinensis* is presented in Eq. (6), and it can be used as the research reference for the future study.

$Pr=6.182D_{10}-1.459H$, $Cp=1.066$, $R^2=0.894$, ---（6）

3.3 Weight of *Pluchea carolinensis* with the soil water contains

The water contains for the *Pluchea carolinensis* is given in Table 2. The values are between 88.07 % and 63.81%, and the mean value is 78.10%. While the root-soil water contains are from80% to 50% with mean-value 69.06%. This result presents that the water contain of the *Pluchea carolinensis* is higher than the one of the root system.

By checking the significance of these two water contains, Pearson two-way is used, and we obtain correlation 0.73, significant level 0.01 and relevance Eta 0.993. The utilization of paired samples test with t=15.64（df=45）, the same results are obtained except the water contain（%） between these two parts with non-significance.

The water contains for the plant and the root system can be regressed in form of land slope, hardness, and soil-water contains. Positive linear correlations are obtained with hardness, and soil-water contains, while we check the col-linearity, the VIF=10.837 is higher than 10. Finally we modify them as the following two equations, Eqs.（7）and（8）, formed only as hardness with highest regression coefficients.

$Uw=3.763H$, $Cp=55.532$, $R^2=0.975$, ---------（7）

$Rw=3.324H$, $Cp=34.743$, $R^2=0.969$, ---------（8）

Table2 Descriptive statistic of plant body and moister water content of soil

Water conte (%)	Max.	Min.	Mean value(%)	Standard error(%)
Plant above ground	88.07	63.81	78.10	4.44
Roots	80	50	69.06	5.79
Soil	23.48	8.93	16.67	3.85

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

$Wu=25.067+4.107Wud$, $R^2=0.966^{**}$ ----------(9)

for $2.3 \leqq Wud \leqq 286.1$; and

$Wd=2.610+2.906Rd$, $R^2=0.972^{**}$ ----------(10)

for $0.3 \leqq Rd \leqq 50.66$

Wu, Wd, and Tw (the total dry weight) are estimated by Eqs. (11), (12) and (13) formed as Mw and H. These results are useful for non-destructive analysis and future study.

$Wu=7.897Mw–10.111H$, $R^2=0.897$ ----- (11)

$Wd=1.038Mw-1.367H$, $R^2=0.883$ ------- (12)

$Tw=2.173Mw-2.908H$, $R^2=0.892$ --------(13)

with $18 \leqq Mw \leqq 135$;

3.4 Pulling Resistance Model Comparisons of *Rhus javonica* L. var. *roxburghiana*. DC. in Different Sites

Comparing the Rhus javonica L. var. roxburghiana. DC pulling resistance models between Central Cross-Island Highway and Takanshan limestone mining, the pulling resistance model of Central Cross-Island Highway is: $Pr=1.7933D+0.0277Wu$, $R^2=0.7797$, PRESS=2699.110, S=11.036 (〔21〕)，while the one of this study is $Pr=11.314Yr+0.166Wd$, $R^2=0.7283$, PRESS=9254.35, S=22.09. The different the sites, the varied regression models are. Here, the F-test is unnecessary because the significance exits already. The significant level may be due to climate or soil factors which will affect the plant root growth and its corresponding pulling resistance capacity.

IV. CONCULUSIONS

With the pulling resistance of *Boehmeria densiflora* Hook. & Arn, *Rhus javonica* L. var. *roxburghiana*. DC and *Pluchea carolinensis*, we found that the different plant has varied dominant regressive parameters because of the reflection of environmental resilience of the given plant. The comparisons between Central Cross-Island Highway and Takanshan limestone mining also gives the influences with geology, geography, thickness of soil layers, and soil nutrient. Even the testing samples are limited; we construct the model of destructive test and effectively to estimate the results of non-destructive models for *Boehmeria densiflora* Hook. & Arn, *Rhus javonica* L. var. *roxburghiana*. DC and *Pluchea carolinensis* with real measurements of some physical quantities in high reliability for real-field application..

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