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SLOPE STABILITY PREDICTION USING STATISTICAL METHOD

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ABSTRACT

The stability of slopes is a major challenge for the geotechnical engineers. Predicting the slope stability is an everyday task for geotechnical engineers. The basic purpose of the slope stability analysis is to determine the factor of safety (FOS) against failure. If the FOS is determined to be large enough, then the slope is judged to be stable (safe). But if the FOS is equal to 1.0 or less than that, it is considered to be unsafe. In this paper, a prediction model has been developed to predict the FOS using regression analysis. A total of 110 cases with different geometric and soil parameters were analyzed using the well-known Bishop's Simplified Method. Out of these, 100 cases were used to train up the prediction model and the correlation coefficient is found out to be 94.9% thereby, bearing a close relationship between the predictor variables. The prediction model is validated by comparing the results with the remaining 10 cases.

Keywords: Geotechnical engineering, Slope stability, Regression analysis, Factor of safety.

INTRODUCTION

The problems of stability of slopes have been faced throughout history when men and nature disrupted the balance of natural slopes and hence the slope failure has become a common natural disaster all over the world. The problem of slope stability is often the most critical safety issue for dams, embankments, bridge abutments and even the residential buildings constructed in the hilly areas. Slide may occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation (*Karl et al., 1996*). Prediction of stability of slopes is a major challenge for the geotechnical engineers because the stability of the slopes generally exists as the combined effects of geology, hydrology and soil parameters. The analysis must be made by considering the site subsurface conditions, ground behavior, and applied loads. Because of its practical importance, slope stability analysis has drawn the attention of many investigators. Judgments regarding acceptable risk or safety factor must be made to assess the results of analyses. Therefore, slope investigation and classification are important for the community (*Lee et al. 2002; Choobbasti et al. 2009; Ping et al. 2009; Vector 2008*). The prediction of slope stability has developed its existence to a great extent in the last two decades. Many researchers in the field of Geotechnical engineering are constantly working to find new prediction models for predicting the stability of slopes. *Sakellariou and Ferentinou (2005)* used artificial neural network (ANN) to predict the stability of slopes for circular failure and wedge failure mechanism and found that the networks have successfully captured the relationship between the input and output parameters. A similar work is done by *Farrokhzad et al. (2008)* to predict the stability of slopes and the prediction model showed that the correlation of the ANN model and Bishop's model in all cases agrees over 92% and in most cases over 95%. *Davis and Keller (2010)* studied on modeling uncertainty in natural resources and developed a slope stability prediction model based on fuzzy sets and Monte Carlo simulation. *Ahangar-Asr et al. (2010)* developed a new method for predicting the stability of soil and rock slopes. They used evolutionary polynomial regression (EPR) for analysis of stability of soil and rock slopes. The finally concluded that the proposed approach is very effective and robust in modeling the behaviour of slopes and provides a unified approach to analysis of slope stability problems. *Mohammad et al. (2012)* used fuzzy logic system for developing a prediction model for predicting the stability of slopes and found that the prediction results of fuzzy logic have higher degree of accuracy. *Chae at al. (2015)* presents a modified equation of infinite slope stability analysis based on the concept of the saturation depth ratio to analyze the slope stability change associated with the rainfall on a slope. The results of the proposed approach were compared with the landslide inventory using a ROC (receiver operating characteristics) graph. In addition, the results of the proposed approach were compared with the previous approach used: a steady-state hydrological model and found that the proposed approach displayed satisfactory performance in classifying landslide susceptibility and showed better performance than the steady-state approach.

METHODOLOGY

In this research, 110 cases having different soil slope parameters were taken from Guwahati and its adjoining areas. Soil samples were collected from all these sites and laboratory tests were performed to find the various soil parameters. These soil parameters were used to analyze the various slopes using Bishop's Simplified Method to find the FOS. Out of these, 100 cases were used to train up the prediction model of regression analysis.

Regression analysis is a statistical process of predicting the relationships among different variables. In the case of simple linear regression, a target value is obtained from one predictor variable, whereas in multiple regression analysis, two or more predictor variables are used to obtain a single target value.

The general equation for multiple regression is

$$\mathbf{Y = a + b_1 * x_1 + b_2 * x_2 + b_3 * x_3 + \ldots + b_n * x_n}$$

Where Y = Dependent Variable

$x_1, x_2, x_3, \ldots, x_n$ = Independent Variable

$b_1, b_2, b_3, \ldots, b_n$ = Regression co-efficient

a = Constant

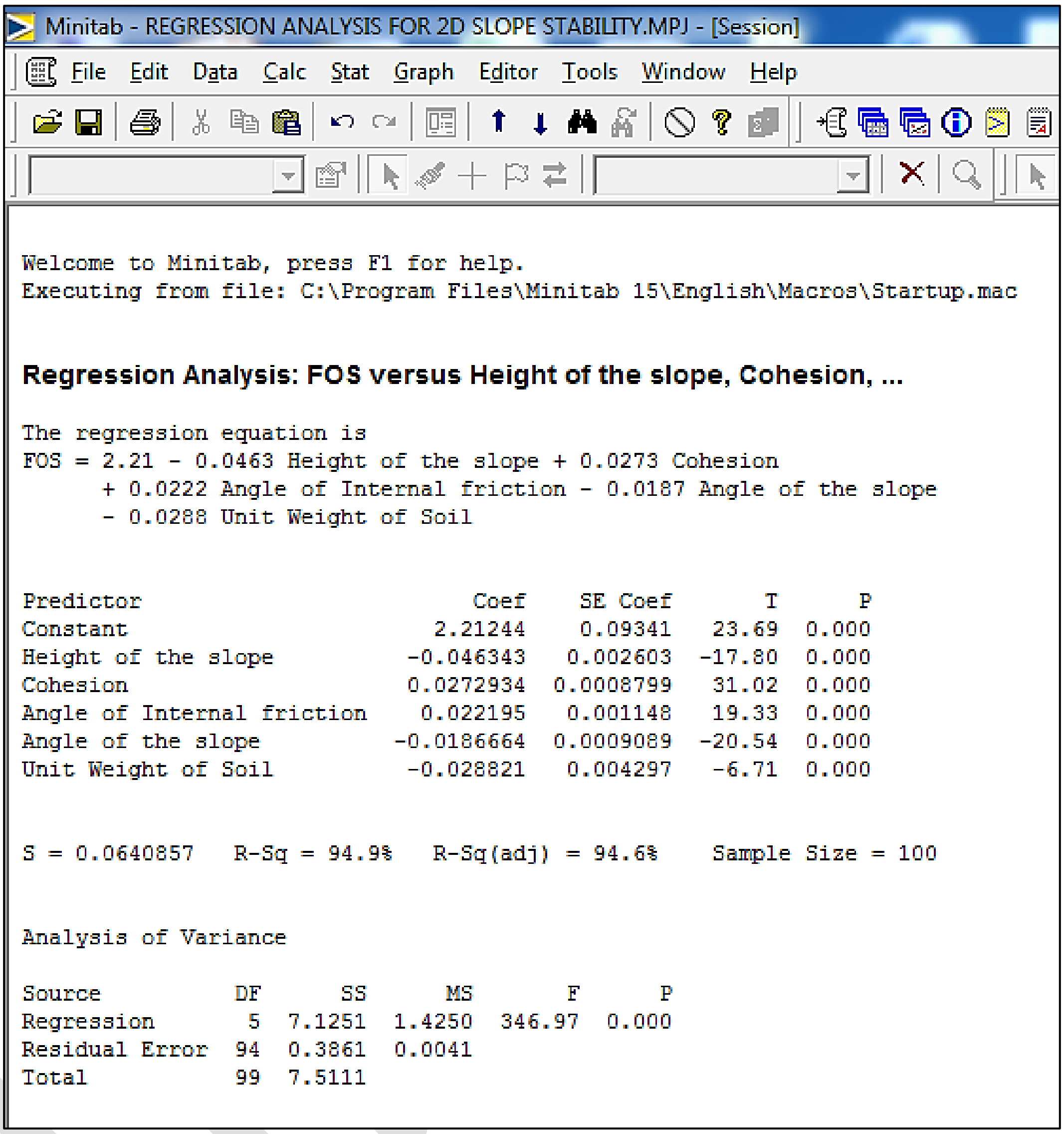
Here, the regression coefficients represent the independent contributions of each independent variable to the prediction of the dependent variable. The regression line expresses the best prediction of the dependent variable (*Y*), given the independent variables (*X*). However, the nature is rarely perfectly predictable, and hence there is always a substantial variation of the observed points around the fitted regression line. The deviation of a particular point from the regression line is called the residual value. When the variability of the residual values around the regression line is small, the predictions from the regression equation are good.

In this research, multiple regression analysis is used to find the FOS from different independent variables. The height of the slope (H), cohesion (c), angle of internal friction (φ), slope angle (β) and unit weight of soil (γ) are used as predictor variables.

To validate the prediction model, the FOS values for the remaining 10 cases were compared with the values obtained from the regression analysis. The results of the regression analysis are summarized as below.

RESULTS AND DISCUSSION

The summary of the regression analysis is shown in the figure 1 below.



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Regression Analysis: FOS versus Height of the slope, Cohesion, ...

The regression equation is
FOS = 2.21 - 0.0463 Height of the slope + 0.0273 Cohesion
+ 0.0222 Angle of Internal friction - 0.0187 Angle of the slope
- 0.0288 Unit Weight of Soil

Predictor	Coef	SE Coef	T	P
Constant	2.21244	0.09341	23.69	0.000
Height of the slope	-0.046343	0.002603	-17.80	0.000
Cohesion	0.0272934	0.0008799	31.02	0.000
Angle of Internal friction	0.022195	0.001148	19.33	0.000
Angle of the slope	-0.0186664	0.0009089	-20.54	0.000
Unit Weight of Soil	-0.028821	0.004297	-6.71	0.000

S = 0.0640857 R-Sq = 94.9% R-Sq(adj) = 94.6% Sample Size = 100

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	7.1251	1.4250	346.97	0.000
Residual Error	94	0.3861	0.0041		
Total	99	7.5111			

Figure 1. Results of Regression Analysis

From figure 1, it has been found that the regression analysis is having a correlation coefficient (R-square) of 94.9 % which shows that there is strong relationship between the variables. The final regression equation is given by:

FOS = 2.21 - 0.0463 Height of the slope + 0.0273 Cohesion + 0.0222 Angle of Internal friction – 0.0187 Angle of the slope – 0.0288 Unit Weight of Soil

The final scatter plot matrix is show in figure 2 bearing the relationship between the different predictor variables and the criterion variable. The normal distribution histogram between frequency and residual value is shown in figure 3 which shows that the maximum residual values are in the range of -0.05 to +0.05 bearing a strong relationship between the variables.

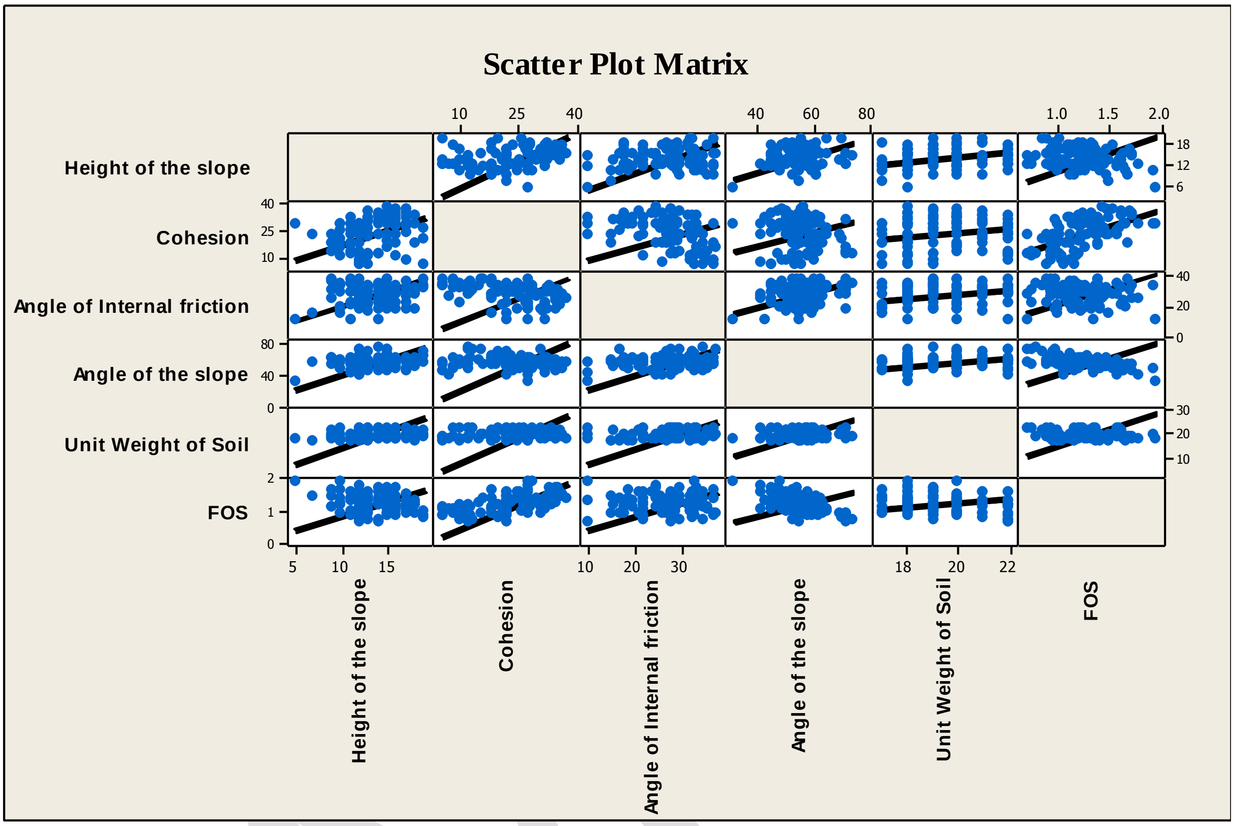

Figure 2. Scatter Plot Matrix

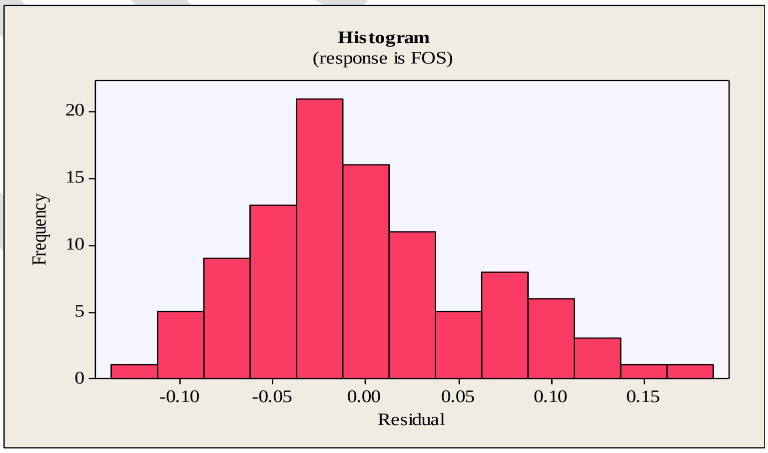

Figure 3. Normal distribution histogram between

frequency and residual value

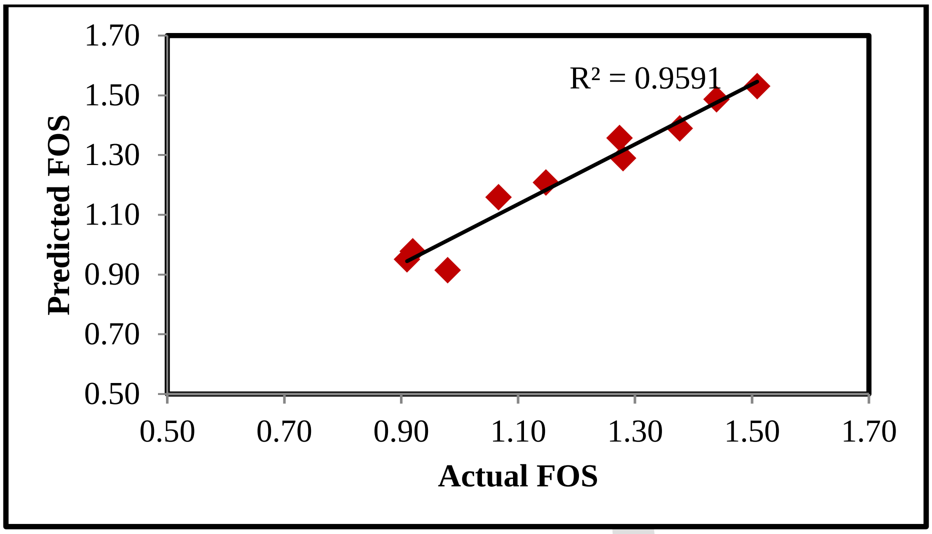

Figure 4. Comparison graph between actual FOS and Predicted FOS

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