Prediction of Slope Stability Using Statistical Method and Fuzzy Logic

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Abstract: The main goal of this research is to predict the stability of slope using fuzzy logic, Adaptive Neuro Fuzzy Inference System (ANFIS), and statistical method, Multiple Linear Regression (MLR). Four limit equilibrium methods (LEM) i.e. Morgenstern-Price, Janbu, Bishop and Ordinary were used to calculate the safety factors for various designs of slope. For prediction, five parameters were used as the inputs i.e. height of slope, unit weight of slope material, angle of slope, coefficient of cohesion, and internal angle of friction, while the output parameters are factors of safety. MLR obtained regression square (R^2) of 0.470 for Bishop, 0.459 for Janbu, 0.470 for Morgenstern-Price, and 0.468 for Ordinary Method, while ANFIS obtained regression square (R^2) of 0.9996 for Bishop, 0.9994 for Janbu, 0.9995 for Morgenstern-Price, and 0.9997 for Ordinary Method. The result showed that ANFIS could predict the safety factors with high accuracy compare with MLR.

Key words: Fuzzy logic, Slope stability

Introduction

Slopes either occur naturally or engineered by humans. Slope stability problems have been faced throughout history when men and women or nature has disrupted the delicate balance of natural soil slopes, so the slope failure become a common natural disaster which takes place around the world. In addition, the increasing demand for engineering cut and fill slopes on construction has only increase the need to understand analytical methods, investigative tools, and stabilization methods to solve slope stability problems. Slope stabilization methods involve specialty construction techniques that must be understood and modeled in realistic ways. An understanding of geology, hydrology, and soil properties is central to applying slope stability principles properly. Investigations of failures of soil masses are subjects touching both geology and engineering. These investigations call the joint efforts of engineering geologists and geotechnical engineers. Slope stability problem has been an important issue in geotechnical engineering. The evolution of slope stability analyses in geotechnical engineering has followed closely the developments in soil. Geotechnical engineers have to pay particular attention to geology, ground water, and shear strength of soils in assessing slope stability. Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied loads. 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 limit equilibrium methods (LEMs) (i.e. linear methods: infinite slope analysis, wedge analysis, circular arc methods; non-linear methods: Bishop's routine method, Janbu's simplified method, Spencer's method, Morgenstern and Price's method, Janbu's rigorous analysis) are widely used for the analysis of slopes (Nash 1987). Historically, these methods were developed before the advent of computers; computationally more complex methods followed later. These computational methods have varying degrees of accuracy, depending on the suitability of the simplifying assumptions for the situation being analyzed. A useful concept in the application of limit equilibrium methods for slope stability analysis and design is the idea of mobilized shear strengths and mobilized shear strength parameters (Bromhead 1999; Sakellariou & Ferentinou 2005).

The power of Artificial Intelligent (AI) becomes more authoritative when the system is programmed to cater the need of complex applications. Adaptive Neuro-fuzzy Inference System (ANFIS) Model using neuro adaptive learning techniques which are similar to those of neural networks was originally presented by Jang. Given an input/output data sets, ANFIS constructs fuzzy Inference System (FIS) whose membership function (MF) parameters are adjusted using back propagation algorithm or other similar optimization techniques. Hence, the advantages of a fuzzy system can be combined with a learning algorithm (Sivarao et al. 2009; Merikoski et al. 2001; Jang 1996; MathWorks 2009 and Sakellariou & Ferentinou 2005).

Regression is most often used by scientists and engineers to visualize and plot the curve that best describes the shape and behavior of their data. As with most statistical analyses, the goal of regression is to summarize observed data as simply, usefully, and elegantly as possible. Researchers are often interested in the relationships between one variable and several other variables. Regression procedures find an association between independent and dependent variables that, when graphed on a Cartesian coordinate system, produces a straight line, plane or curve. The general purpose of Multiple Linear Regression (MLR) is to seek for the linear relationship between a dependent variable and several independent variables. (SigmaPlot 9 2004; SigmaPlot 11 2008; Sanford 2005; Xin & Xiaogang 2009).

The main objectives of this research are; calculate safety factors of various slopes using limit equilibrium methods (LEM), predict the result using Adaptive Neuro-fuzzy Inference System model and Multiple Linear Regression and develop a computer program to present the stability of slopes using Graphical User Interface (GUI).

Method

In this research 210 different designs of slope which created by software that applied limit equilibrium methods were used. The range for the input parameters for those designs are: height of slope, H (1–6 m), unit weight of slope material, γ (15-22 kN/m^3), angle of slope, θ (11.31°-78.69°), coefficient of cohesion, c (0-50 kN/m^2) and internal angle of friction, ϕ (20°-40°) and the output is factors of safety. The comprehensive formulation of the software made it possible to easily analyze both simple and complex slope stability problems using a variety of methods to calculate the safety factors (Geo-Slope 2004). After carrying out the stability analyses, ANFIS model were used to predict the result for over all safety factors for all LEMs. The prediction constructed the rule statements based on the descriptions of the input and output variables defined with the fuzzy inference system. Another prediction method using Multiple Linear Regression applied for the same over all safety factors for all LEMs. From predicted data, Graphical User Interface program was generated to present the stability of slopes for all LEMs.

Results and discussion

Five inputs, height of slope, unit weight of slope material, angle of slope, coefficient of cohesion, and internal angle of friction, and one output, factor of safety, were used as membership functions to build the fuzzy inference system with 243 rules and three epochs. On the other hand, the five input parameters and the over all output safety factors were used also for Multiple Linear Regression prediction.

The regression square (R^2) which obtained by Adaptive Neuro-fuzzy Inference System prediction are 0.9996 for Bishop, 0.9994 for Janbu, 0.9995 for Morgenstern-Price, and 0.9997 for Ordinary Method, while the regression square (R^2) which obtained by Multiple Linear Regression prediction are 0.470 for Bishop, 0.459 for Janbu, 0.470 for Morgenstern-Price, and 0.468 for Ordinary Method. Figure 1 until 4 for Bishop, Janbu, Morgenstern-Price, and Ordinary, respectively, showed the calculated values using SLOPE/W and the predicted values using Adaptive Neuro Fuzzy Inference System. The result showed that Adaptive Neuro Fuzzy Inference System could predict the safety factor with high accuracy and close to the target data. In addition, figure 5 until 8 for all LEMs, showed the calculated values using SLOPE/W and the predicted values using Multiple Linear Regression. The result showed that Multiple Linear Regression could predict the safety factor with low accuracy compared with Adaptive Neuro Fuzzy Inference System. Figure 9 until 12 showed the comparison between ANFIS and MLR prediction and the calculated data for all LEMs.

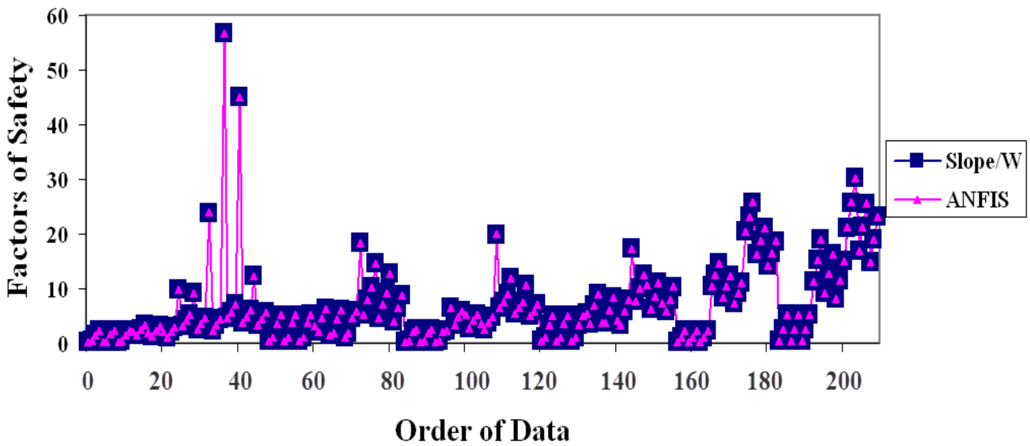

Figure 1 Comparison of calculated factor of safety using Bishop and predicted using ANFIS

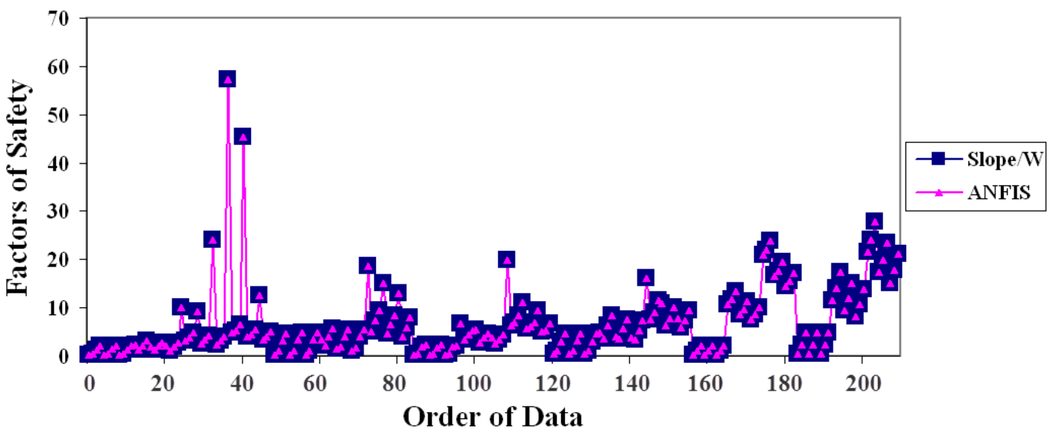

Figure 2 Comparison of calculated factor of safety using Janbu and predicted using ANFIS

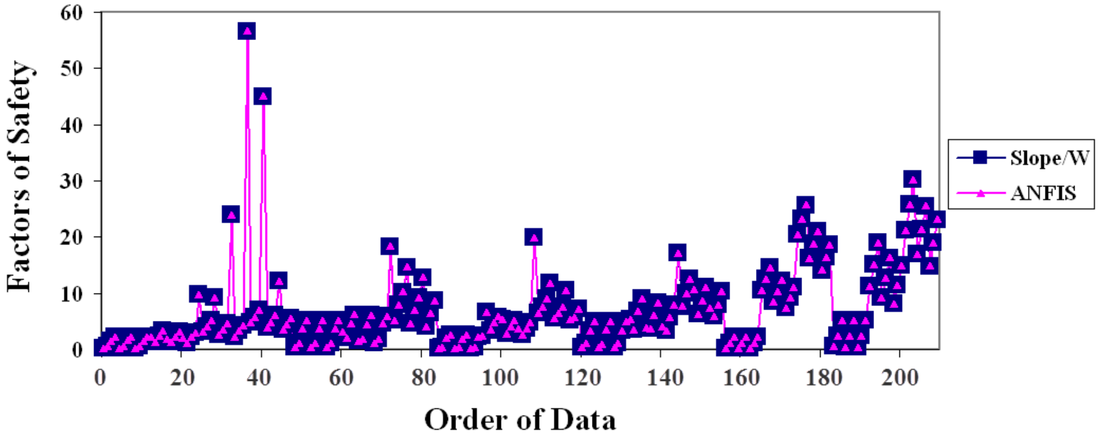

Figure 3 Comparison of calculated factor of safety using Morgenstern-Price and predicted using ANFIS

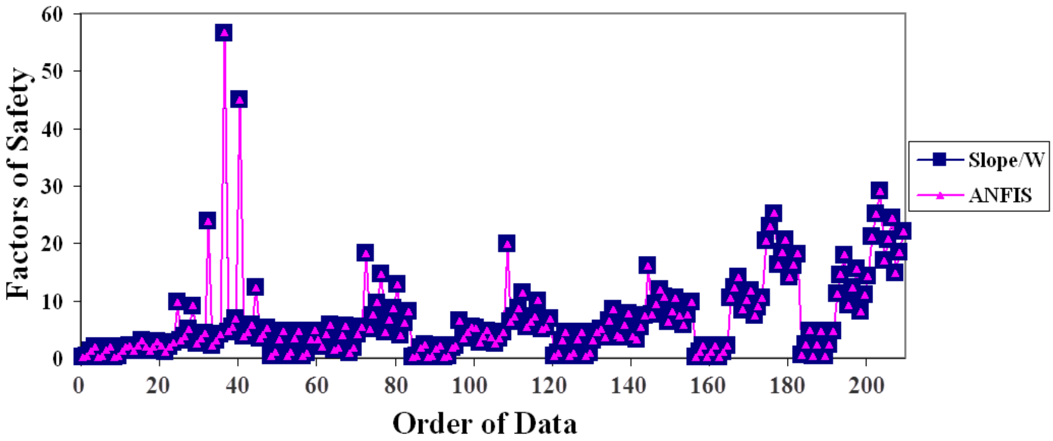

Figure 4 Comparison of calculated factor of safety using Ordinary and predicted using ANFIS

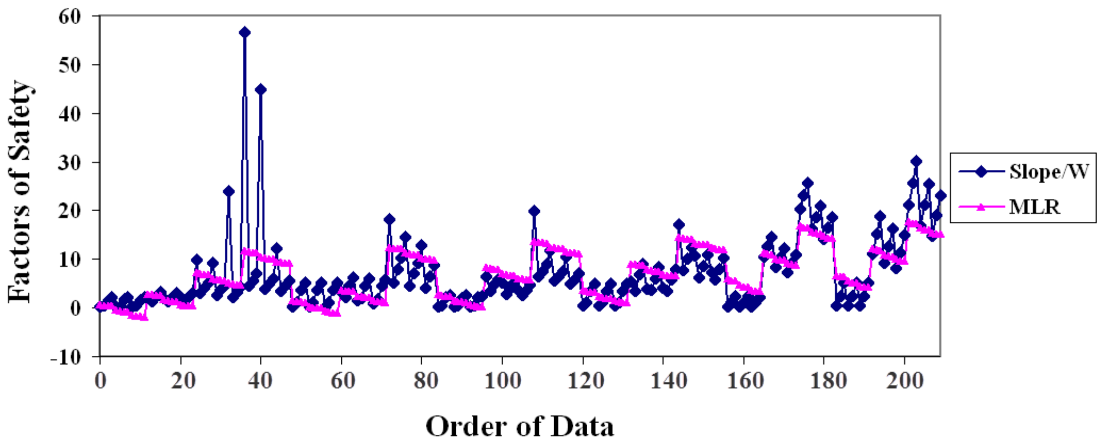

Figure 5 Comparison of calculated factor of safety using Bishop and predicted using MLR

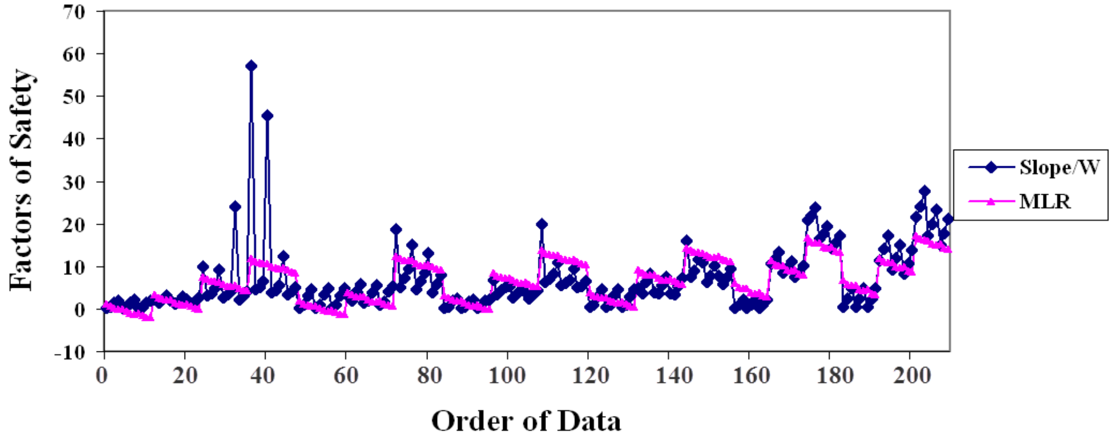

Figure 6 Comparison of calculated factor of safety using Janbu and predicted using MLR

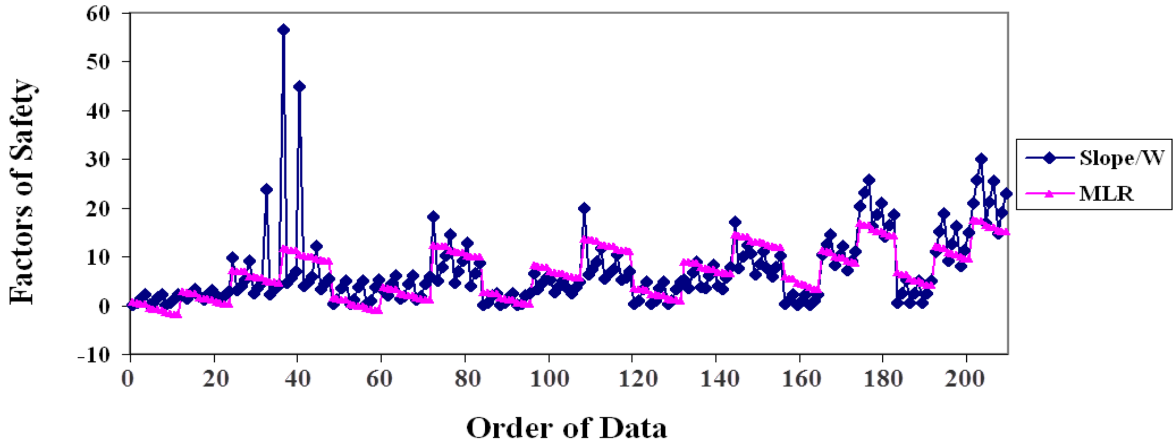

Figure 7 Comparison of calculated factor of safety using Morgenstern-Price and predicted using MLR

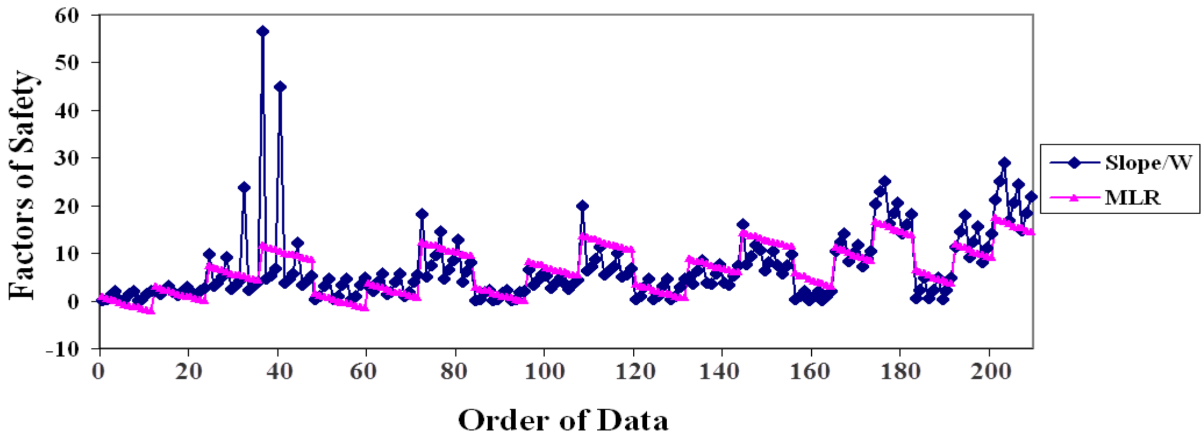

Figure 8 Comparison of calculated factor of safety using Ordinary and predicted using MLR

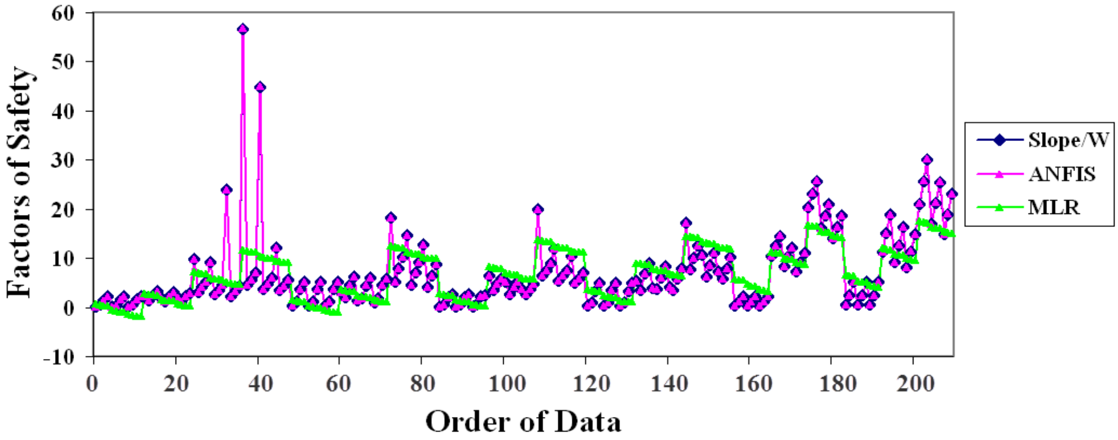

Figure 9 Comparison of ANFIS and MLR for Bishop

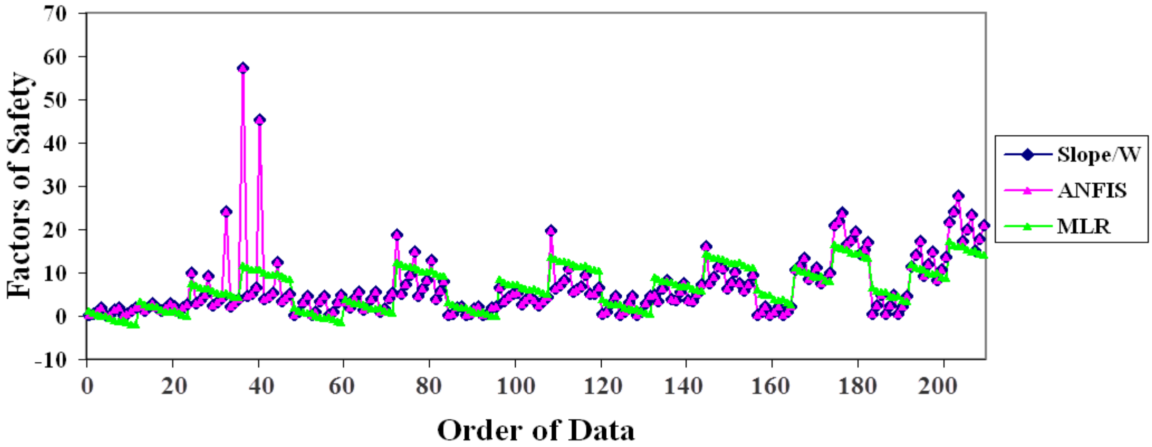

Figure 10 Comparison of ANFIS and MLR for Janbu

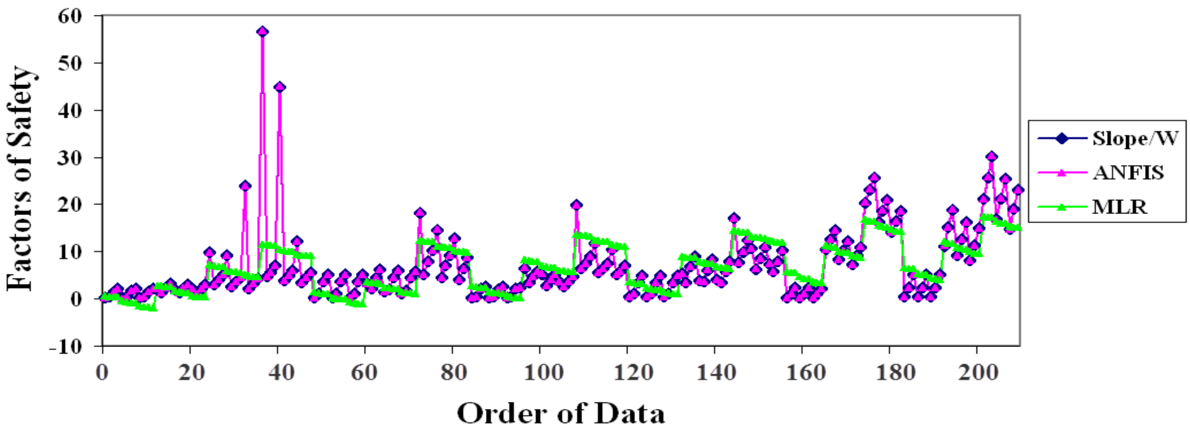

Figure 11 Comparison of ANFIS and MLR for Morgenstern-Price

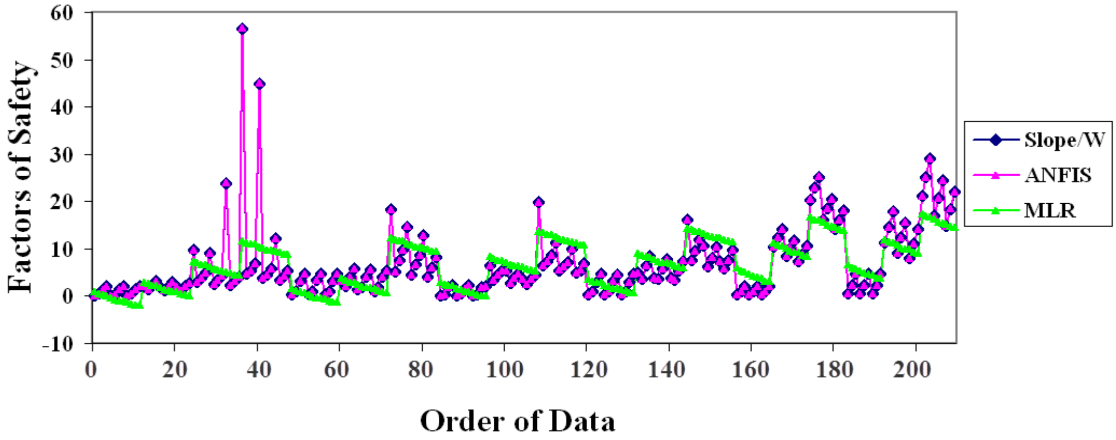

Figure 12 Comparison of ANFIS and MLR for Ordinary

Conclusion

Limit equilibrium methods were used to calculate safety factors for 210 different designs with five input parameters: height of slope, unit weight of slope material, angle of slope, coefficient of cohesion, and internal angle of friction. Adaptive Neuro Fuzzy Inference System model and Multiple Linear Regression were used to predict the five input parameters and the overall output safety factors. From predicted data, Graphical User Interface program was generated to present the stability of slopes. The result seemed that Adaptive Neuro Fuzzy Inference System model could predict the safety factors with high accuracy compared with Multiple Linear Regression model.

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