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Fuzzy Logic System for Slope Stability Prediction

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***Abstract*— The main goal of this research is to predict the stability of slopes using fuzzy logic system. GeoStudio, a commercially available software was used to compute safety factors for various designs of slope. The general formulation of the software could analyze slope stability using various methods of analysis i.e. Morgenstern-Price, Janbu, Bishop and Ordinary to calculate the safety factors. After analyzing, fuzzy logic was used to predict the slope stability. Fuzzy logic is based on natural language and conceptually easy to understand, flexible, tolerant of imprecise data and able to model nonlinear functions of arbitrary complexity. Several important parameters such as height of slope, unit weight of slope material, angle of slope, coefficient of cohesion and internal angle of friction were used as the input parameters, while the factor of safety was the output parameter. A model to test the stability of the slope was generated from the calculated data. This model presented a relationship between input parameters and stability of the slopes. Results showed that the prediction using fuzzy logic was accurate and close to the target data.**

***Keywords*— Limit equilibrium methods; fuzzy logic; factor of safety.**

I. INTRODUCTION

The evolution of slope stability analyses in geotechnical engineering has followed closely the developments in soil. Slopes either occur naturally or engineered by humans. Slope stability problems have been faced throughout history when men or nature has disrupted the delicate balance of natural soil slopes [1]. Slope stability is often the most critical safety issue or feasibility component for dams and hydroelectric facilities, canyon landfills, quarries and borrow pits, water storage tanks, bridge abutments, and residential developments in hill slope environments [2]. Slide may occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation [3].

In any stability analysis some measure of the degree of safety has to be provided. Such a measure of safety may be a factor like a limiting stress or strain or a comparative ratio of resistance. Working stresses in any earth structure are much less than the shear strength of the soil so as to ensure the safety of the structure. The working stress is actual stress at a point or along a continuous surface and may be defined as *developed* or *mobilized strength*. In slope stability problems, shear strength is the governing factor for stability; hence the mobilized or developed shear strength (τ) is also important. If this mobilized strength is less than the available strength (τ_f) of the soil, then the slopes said to be stable. Thus, the factor of safety may be defined in a form most convenient and acceptable to practical engineers as the ratio of the shearing resistance available along a slip surface to the total mobilized shearing resistance that is [4]

$$F = \frac{\tau_f}{\tau} \quad (1)$$

Slope stability is usually analyzed by methods of limit equilibrium. Historically, these methods were developed before the advent of computers; computationally more complex methods followed later. These methods require information about the strength parameters and the geometrical parameters of the soil or rock mass. In limit equilibrium techniques, slope stability is analyzed by first computing the factor of safety. The values must be determined for the surface that is more likely to fail, the critical slip surface. These computational methods have varying degrees of accuracy, depending on the suitability of the simplifying assumptions for the situation being analyzed.

The factor of safety (FoS) is defined as the ratio of reaction over action, expressed in terms of moments or forces, and eventually in terms of stresses, depending on the geometry of the assumed slip surface. In circular mechanisms of failure, FoS is defined in terms of moments about the centre of the failure arc, as the ratio of the moment of shear strength along the failure arc over the moment of weight of the failure mass [5]. In this research four limit equilibrium methods were used to calculate factor of safety i.e. Morgenstern-Price, Janbu, Bishop and Ordinary.

Using a given input/output data set, the *adaptive neuro-fuzzy inference system* (ANFIS) function constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method. This adjustment allows fuzzy systems to learn from the data they are modeling. Depending on the types of fuzzy reasoning and fuzzy if-then rules employed, most fuzzy inference systems can be classified into three types: (i) the overall output is the weighted average of each rule's crisp output induced by the rule's firing strength and output membership function (MF), (ii) the overall fuzzy output is derived by applying "max" operation to the qualified fuzzy outputs, (iii) Takagi and Sugeno's fuzzy if-then rules. [6,7,8,9,10,11]

The main goals of this research are calculate safety factors for 126 different slopes designed by commercial software using LEM, predict the result using fuzzy logic, Adaptive Neuro-Fuzzy Inference System, and generate a model to check the stability of slopes.

II. Methodology

In this research, 126 different designs of slope were created by using a commercially available software, GeoStudio that applied limit equilibrium methods (LEM). The input parameters for those designs consisted of height of slope, H (1 – 4 m), unit weight of slope material, γ (15 - 22 kN/m^3), angle of slope, θ (11.3° - 78.7°), coefficient of cohesion, c (0 - 50 kN/m^2) and internal angle of friction, ϕ (20° - 40°) and the output parameter was an overall factor 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 FoS [12]. After designing the slopes, fuzzy logic (ANFIS) was used to predict the result for overall factors of safety. From the calculated data, a model was generated to test the slope stability.

III. Results and Discussion

The inputs parameters; height of slope, unit weight of slope material, angle of slope, coefficient of cohesion, internal angle of friction, and the output parameter; factor of safety, were used as membership functions to build the fuzzy inference system with 243 rules and 3 epochs. Fig. 1 showed fuzzy inference system structure for slope stability prediction used in this research while Fig. 2 until 5 showed the membership functions for unit weight of slope material, angle of slope, coefficient of cohesion and internal angle of friction, respectively.

The errors obtained by ANFIS prediction were 0.003 for Ordinary, 0.002 for Morgenstern-Price, 0.015 for Janbu and 0.003 for Bishop. Fig. 6 until 9 showed the calculated values using LEM and the predicted values using ANFIS for Ordinary, Morgenstern-Price, Janbu and Bishop, respectively. The result showed that ANFIS could predict the safety factors with high accuracy and close to the target data.

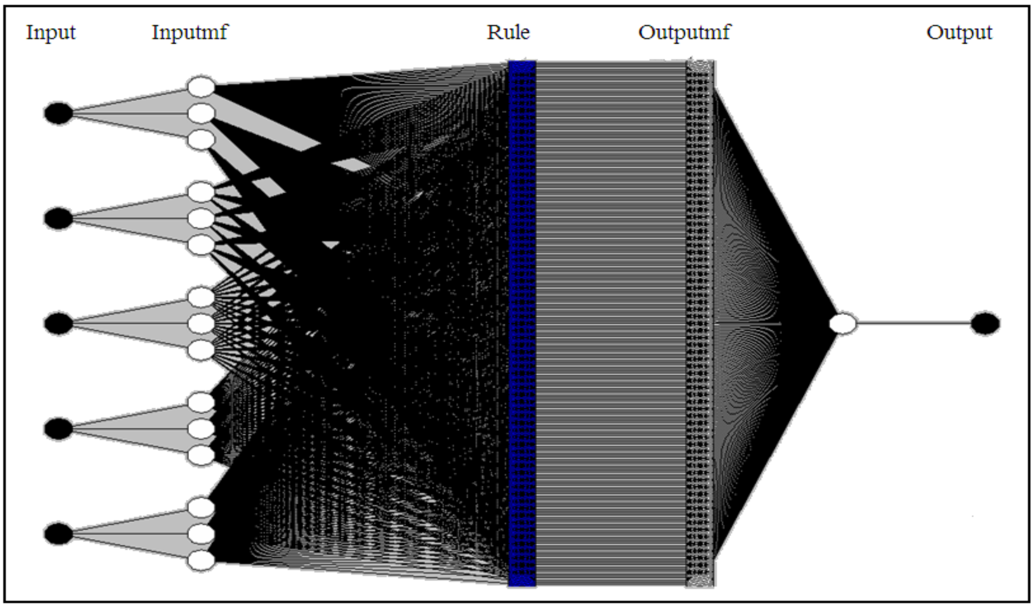

Fig. 1 FIS structure for slope stability prediction

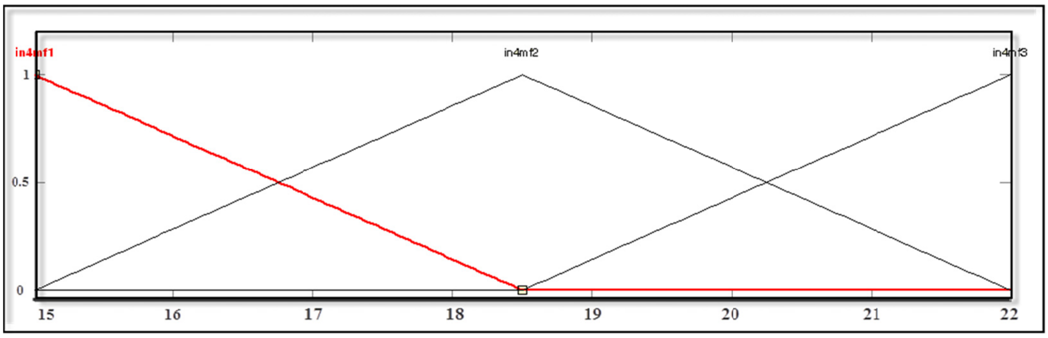

Fig. 2 Membership functions for unit weight of slope material

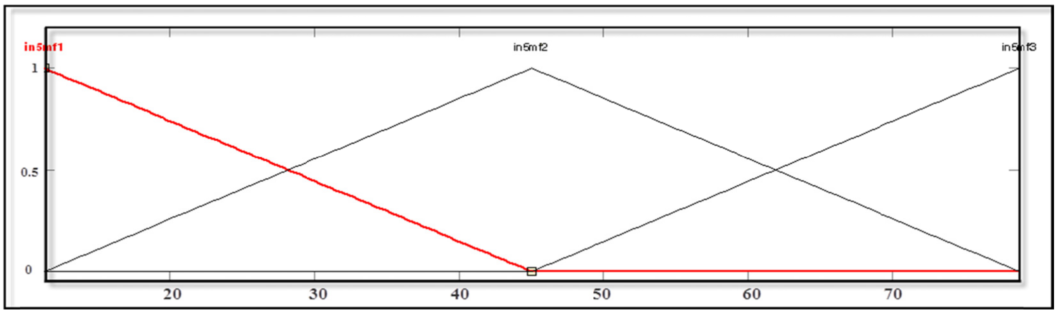

Fig. 3 Membership functions for slope angle

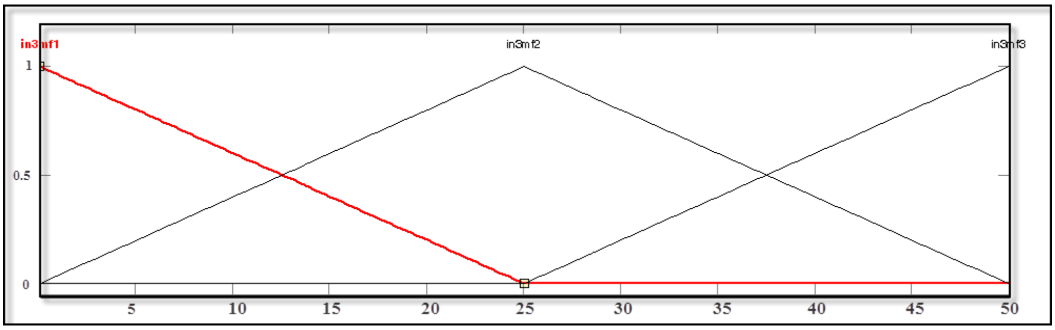

Fig. 4 Membership functions for coefficient of cohesion

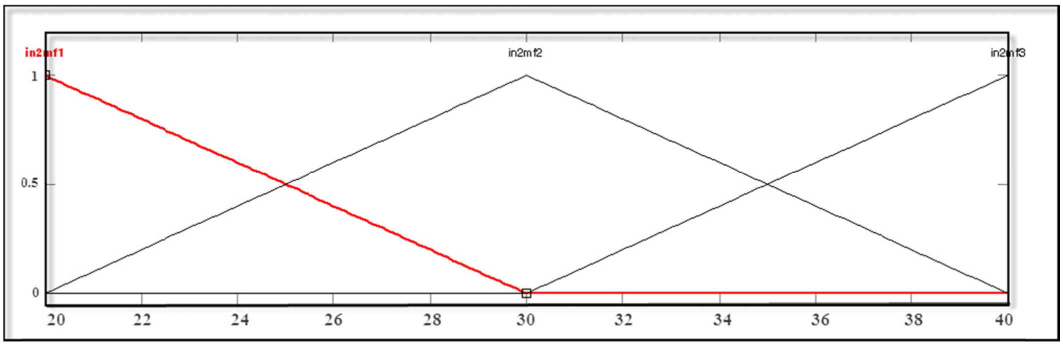

Fig. 5 Membership functions for internal angle of friction

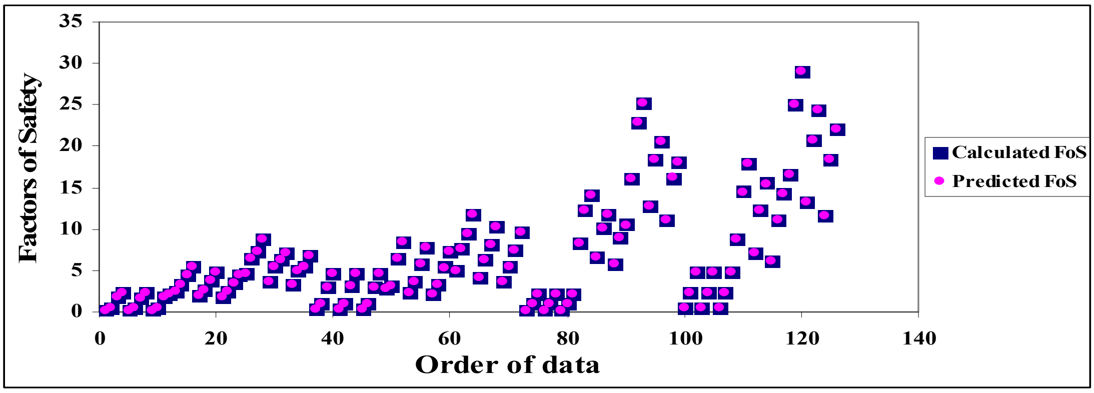

Fig. 6 Factor of safety predicted using ANFIS and calculated using Ordinary method

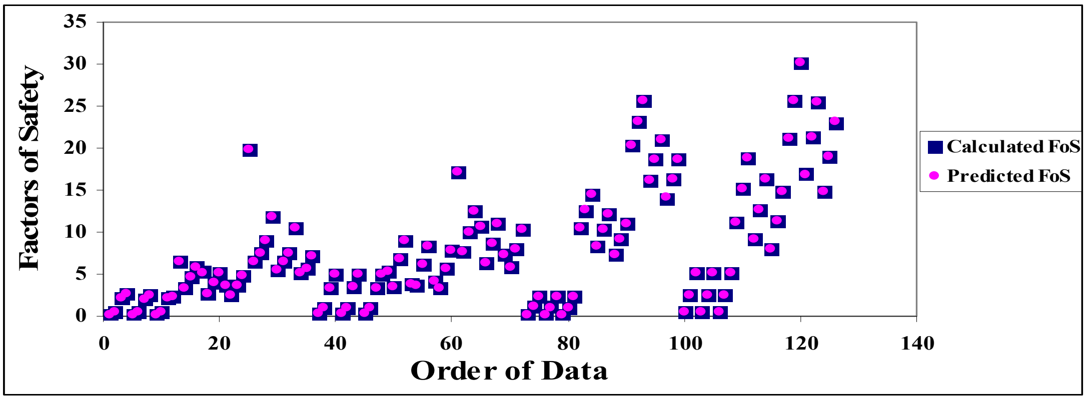

Fig. 7 Factor of safety predicted using ANFIS and calculated using Morgenstern-Price method

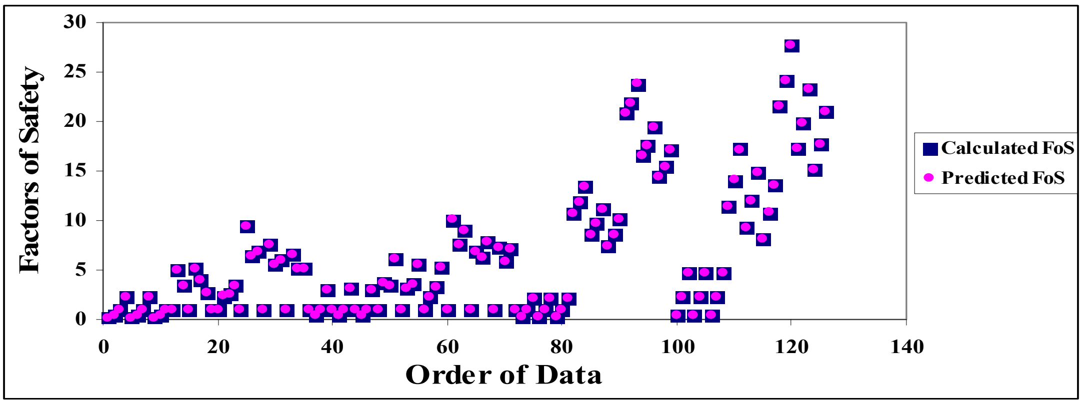

Fig. 8 Factor of safety predicted using ANFIS and calculated using Janbu method

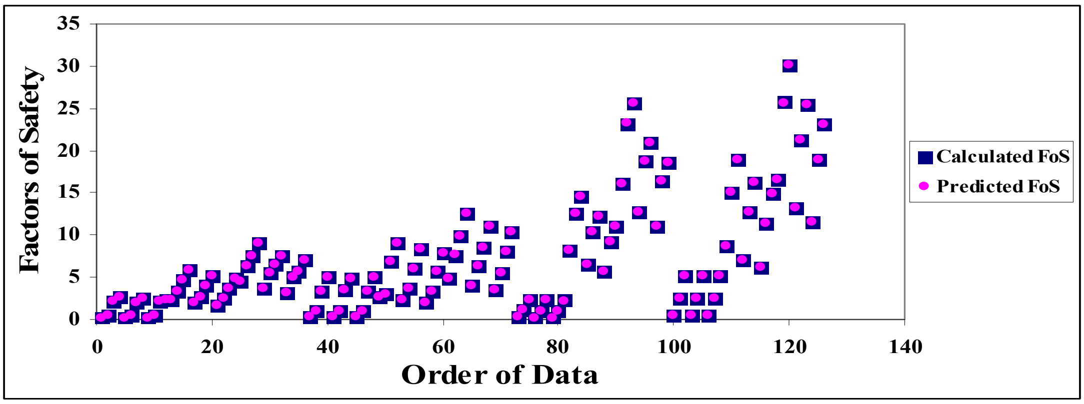

Fig. 9 Factor of safety predicted using ANFIS and calculated using Bishop method

IV. Conclusion

Limit Equilibrium Methods were used to calculate overall factors of safety for 126 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. Fuzzy logic system was used to predict the overall factors of safety. The results showed that it could predict the safety factors with high accuracy.

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