Slope Stability Analysis of Kattery Watershed in Nilgiris District

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Abstract : The slope stability analysis is always under severe threats in many parts of nilgiris district, causing disruption, loss of human life and economy. The stability of slopes depends on the soil shear strength parameters such as Cohesion, Angle of internal friction, Unit weight of soil and Slope geometry. The stability of a slope is measured by its factor of safety using geometric and shear strength parameter based on infinite slopes. In this research, investigation was carried out at 5 locations in Kattery watershed in nilgiris district. The factor of safety of the slope determined by Mohr Coulomb theory based on shear strength parameter calculated from direct shear test which is a conventional procedure for this study. Artificial.
Neural Network (ANN) Model is used to predict the factor of safety. The input parameters for the (ANN) are chosen as Cohesion, Angle of internal friction, Density and Slope angle and the factor of safety as output. The results obtained in ANN method were compared with that of conventional method and observed a good agreement between these two methods.
Key words : Slope stability analysis, Kattery watershed, Nilgiris district, Factor of safety, ANN Modelling.

Introduction

Slope stability in hill areas are always a major threat in several parts of Nilgiris district causing disruption to traffic, loss of human life and economy. Poor drainage systems in this area are the vital cause which leads to progressive disintegration of the soil mass structure resulting in landslide. Apart from the heavy rainfall, following factors such as population increase, infrastructure development, landuse, Cropping pattern change and Deforestation increases the possibility of landslide many times in this area (Manimaran et al 2012, Ramasamy et al 2006, Kumar &Bhagavanulu 2008). The above said hill has also suffered soil slips, earth slides, rock falls and land subsidence, due to the fact that the area is highly vulnerable because of steeper hill slope which become more unstable against landslides. The landslide activity in any area may be contributed by the geotechnical, mineralogical aspects of the soils and the forces acting on these materials (Yalcin 2007).

Detailed field observations and measurements of the geometric and geotechnical characteristics of the landslide occurred spot is mandatory to evaluate the properties of these landslide prone soils, in order to understand the sliding mechanisms operating within the study area. Slope displacement mechanisms as described by Hutchison 1988 are idealized ways through which slope material might move. Sliding theory depend on geometric, physical and mechanical properties of weathered profile of particle size, pore pressure, cohesion, effective angle of internal friction, soil thickness, slope angle, bulk density, the transient properties of natural water content, degree of saturation and the mineralogical composition of the soils (Ganapathy et al 2010).

The above facts warrant a deep and detailed scientific study on the slope stability of this micro watershed. Hence, the study of slope stability is felt necessary particularly in vulnerable sections (Ajaynaithaniet al 2002, GSI, 2000). Besides the above; there are certain places where the slope angle is so hazardous which paves way for landslides. Since such landslides are frequent mainly during the rainy seasons, this present study aims to find out measures to maintain slope stability which reduces the chance of landslides. There are various analytical methods to compute the slope stability of a soil in a slope, such as limit equilibrium and finite element analysis. In order to overcome the difficulties of conventional methods. Artificial neural network (ANN), a computer technique is used to analyse the slope stability (Ajaynaithani 2002, Gopalaranjan and Rao 2005,Cho 2009, Ganapathy 2010,Abdulla et al 2012).

Artificial Neural Network

Artificial Neural Network (ANN) is a broadly used soft computing tool in the field of engineering research and it simulated artificially such as human brain function. It has the abilities of learning, adaptation, self-organization, decision making, function approximation and large-scale parallel processing. This neural network includes back propagation algorithm, genetic algorithm and ant colony algorithm. The back propagation learning algorithm is composed of forward propagation and Backward Propagation (BP-ANN). The neural network consists of input layer, output layer and one or more hidden layer in which neurons are linked to each other with changeable weight. The forward propagation transmits input signal to output layer through hidden layer. The backward propagation calculates the error between sample output and network output along with the original connection path, in the process of which the weights and thresholds of every layers are adjusted by the gradient descent method (Shahin et al 2008, Jha et al 2000). The output of the network is compared with the value produced by the network to determine the error which is used to evaluate the performance of the network. The back propagation is used to identify slope stability analysis using forward propagation and back ward propagation (BP-ANN) by many researchers (Arora 1988, Cruden, D.M., 1991, Ajaynaithani et al 2002, Cho 2009) (Ajaynaithani 2002, Gopalaranjan and Rao 2005,Cho 2009, Ganapathy et al 2010, Abdulla et al 2012).

Methodology

A survey was conducted in the watershed area, Revealed that in many places the slope are unstable. As a result of this observation, 5 locations were selected within the study area which includes the places of past landslip incidences. The exact latitude and longitude of the sampling locations were observed and are noted in Table 3. The soil samples were collected in each location using core cutter soil sampler to analyze the slope stability based on the physical properties of the soil such as unit weight, cohesion, angle of internal friction and slope angle were measured using geologist's Clino-meter compass. Index property of soil such as plasticity index, which is based on liquid limit and plastic limit has been identified for the soil sample collected in the above 5 locations in order to understand the mass of movement of soil due to soil saturation (Ajaynaithani 2002, Gopalaranjan and Rao 2005,Cho 2009, Ganapathy et al 2010,Abdulla et al 2012).

Method Used to Determine Physical and Index Properties

Geotechnical analysis was carried out on both the undisturbed and disturbed soil samples collected in the micro watershed. For the slope stability analysis, following engineering properties were determined (Ganapathy et al 2010).

Unit weight of soil

The unit weigh of soil is determined by core cutter method in accordance to the Indian Standard IS 2720-Part 29-1975.

Shear Strength

Figure 1. Shear strength determination

Shear strength of a soil is the maximum resistance to shearing stress at failure on the failure plane. Shear strength is composed of:

(i) Internal friction which is the resistance due to friction between individual particles at their contact points and interlocking of particles. This interlocking strength is indicated through parameter ø.

(ii) Cohesion which is the resistance due to inter-particle force which tend to hold the particles together in a soil mass. The indicative parameter is called cohesion intercept (c).

These shear parameters were determined by direct shear test Figure1. as per IS 2720-Part 13-1986.Direct shear test was performed over the samples with 6 cm X 6 cm X 6 cm size shear box to determine shear strength parameters of cohesion and angle of internal friction of soil. In order to ensure in-situ field condition, the tests were carried out under un-drained condition. The surcharge weight applied over the samples was equal to the amount of overburden existing at the site. The values of these parameters were obtained using Mohr-Coulomb's failure criterion as expressed in equation.

Coulomb has represented the shear strength of soil by the Equation

$$\tau_f = c + \sigma_n \tan \varphi$$

where,　$\tau_f =$ shear strength of soil = shear stress at failure
c = cohesion intercepts.

$\sigma_n =$ Total normal stress on the failure plane.
ø = Angle of internal friction of shearing resistance.

Slope angle

Slope angle in each location was measured with Geologist's Clinometer compass, and lat-long locations of sampling places were simultaneously recorded with the help of tremble Global Positioning Systems (GPS).

Index property- plasticity index

Atterberg's limit such as liquid limit, plastic limit are the standard measure of the consistency of fine-grained soils which depends on its moisture content. These limits are used to determine the plasticity index, which provides knowledge on flow movement or slide of mass movement that would characterize a given area. Normally, very dry soils behave like solids; as the moisture content increases, the behaviour of a soil changes from solid to plastic. This transition point is known as the plastic limit. If the moisture content increases further, a stage is eventually reached where the soil particles behave as suspended in water and the soil exhibits viscous behaviour, starting to flow under its own weight. This transition is referred to as the liquid limit (Summerfield 1991, Jackson et al 1996). These limits are characterised for the soil size less than 420 μ m size fraction. Liquid limit is determined with the aid of a Casagrande'sapparatus.Using LL and PL, plasticity index were calculated and categorized as given in the Table 1(Ganapathy et al 2010).

Table 1. Plasticity characteristics

S.No	Plasticity index	Plasticity
1.	0	Non – plastic
2.	1 to 5	Slight Plastic
3.	5 to 10	Low Plastic
4.	10 to 20	Medium Plastic
5.	20 to 40	High Plastic
6.	>40	Very High Plastic

Determination of Factor of Safety

The soil slope is classified as finite and infinite. In finite slope, the height of slope surface is measurable whereas the height of the slope surface is infinite in the other case. From the observation made in the study area, it is recognized that the profile of the mountain is falling under infinite slope. Therefore considering as infinite slope, the factor of safety of 100 slope locations were determined by Mohr's Coulomb theory for infinite slope as given in Equation (Ganapathy et al 2010). Thus obtained factor of safety (FS) were categorized according to Table 2.

$$FS = (C+\gamma Z[\cos]^2 \beta\tan\theta)/\gamma Z\cos\beta \sin\beta$$

Where

c = Cohesive in g/cm^2
γ= Unit weight of soil in g/cm^3
Z = Depth of soil in cm
θ = Angle of internal friction in degrees
β = Angle of soil slope to the horizontal in degrees

Table 2 Categorization of factor of safety values

Criteria	Stability	Landslide susceptibility	Remarks
FS<1	Unstable	Very high	Stabilization techniques are needed for stability
1-1.25	Quasi stable	High	Minor destabilizing factors lead to instability
1.25-1.5	Moderately stable	Moderate	Moderate destabilizing factors lead to instability
FS>1.5	Stable	Low	Only major destabilizing factors lead to instability

The physical and index properties of soil obtained in the 5 sampling locations has been tabulated in Table 3. From this table, it is evident that out of 5 locations 3 locations were assessed as unstable, 2 locations were identified as moderately stable. This signifies the importance of the present study in terms of slope stability analysis (Ganapathy et al 2010).

Slope Stability Analysis by ANN

In order to simplify the analysis of slope stability and to predict the factor of safety model for the entire study area, ANN model has been developed and trained using the properties obtained. For analysing slope stability, the soil parameters such as density, angle of internal friction, Cohesion and Slope angle obtained from the conventional method were trained in Neural Network (BP-ANN) using MATLAB version 2010a. The training was performed with 70% of sample and remaining 30% used as testing data for the prediction of factor of safety. Initially the dataset was normalized with Z score normalization. Density, angle of internal friction, cohesion and slope angle were the input parameters; factor of safety was output and minimum error was achieved by trial and error. To optimize the number of neurons in the hidden layer, it was trained different number of neurons. The activation function used in the first layer was "tansig" the second layer was "purelin". The Back Propagation Artificial Neural Network (BP-ANN) technique as presented in Figure 2 was adopted with training function as Levenberg Marquardt along with the performance function of mean square error which was a statistical index. The testing output of the network results are compared with conventional method of field observation (Ajaynaithani 2002, Gopalaranjan and Rao 2005,Cho 2009, Ganapathy et al 2010,Abdulla et al 2012) .
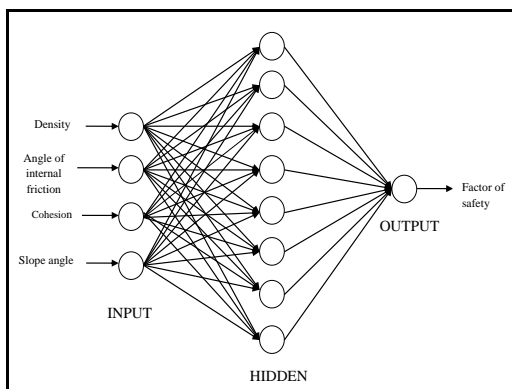

Figure 2.BP-ANN Architecture

Table 1 Physical and Index Properties of Soil Sample

S.No	Latitude	Longitude	Angle of Internal Friction in degrees	Slope angle %	PI%	Plasticity characteristics	Factor of safety	Stable/ Unstable
1	$11^0 23'3''$	76^0 44'	31^0	57	24	LP	0.92	US
2	11^0	76^0	27^0	59	22	LP	0.87	US
3	$11^0 23'63'$	76^0	25^0	49	27	LP	1.27	MS
4	$11^0 22'55'$	76^0	23^0	45	29	LP	1.31	MS
5	$11^0 22'59'$	76^0	30^0	60	20	LP	0.91	US

Identification of Slope Stability by ANN

In the Back Propagation Neural Network Analysis (BP-ANN) using Levenberg Marquardt (Jha et al 2000) training algorithm and mean squared error performance algorithm, results of first 70 sample locations were used for training set and results of remaining 30 sample locations were used for validation. The BP- ANN training performance has been presented as screen shot in Figure 3. The mean squared error Vs epoch curve revealed that the Mean Square Error (MSE) stabilized at 0.0234 after 37 epochs (Ganapathy et al 2010).

Figure 3 BP-ANN Performance Chart

Figure.3 shows the regression plot between target values and predicted values of factor of safety with coefficient of determination, R = 0.99986, which indicates the very high level of accuracy prediction. Since the ANN model prediction is having higher degree of accuracy, it is extended to the entire study area for modeling the factor of safety of the hill slopes (Ganapathy et al 2010).

Validation of ANN - GIS Model

Validation of ANN-GIS based vulnerability map has been done by superimposing the past landslide occurred locations over it and presented in the Figure 4 locations were fitted in the unstable and 2 in moderately stable where the maximum factor of safety is 1.25. Therefore the landslides occurred in the past lies in the unstable and validated the ANN-GIS model (Figure 4).
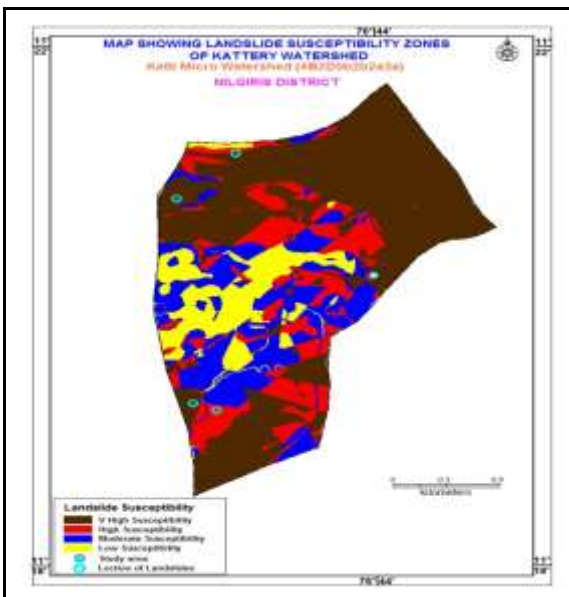

Figure 4 ANN-GIS Based Vulnerability Map

Conclusion

Slope stability analysis was done at five site specific slide prone areas in ketti micro watershed. The slope was measured by abney's level and clinometer. The locations were recorded by GPS gadgets. Necessary soil samples were collected to analyse various engineering properties of the soil. The slope stability analysis was done by a computer based ANN methodology. The results revealed that the spots analyzed were unsafe.

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