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Landslide Susceptibility Analysis Using Numerical and Neural Network, Near Kedarnath, Uttarakhand, India

Vinay Kumar Singh, Tariq Anwar Ansari, Vikram Vishal and T.N. Singh

Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai- 400076, India

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Corresponding Author:
Tariq Anwar Ansari
Department of Earth Sciences,
Indian Institute of Technology
Bombay, Mumbai- 400076,
India
Email: 22tariq@gmail.com

Abstract: The major concern in hilly regions is the stability of those slopes, which have been proclaimed due to unplanned excavation and uneven blasting during road widening and development activity. These slopes again become more vulnerable under dynamic loading and/or various types of human involvement, heavy rainfall and seismic activity. Failure of these slopes leads to loss of property and human being, disruption of traffics and environmental degradation. The Kedarnath area is the most vulnerable hilly terrain due to its inferred locality. To analyze the vulnerability near Kedarnath, the field observation was done to collect the geological and geotechnical details of three vulnerable locations. The present article illustrates the collective analysis of numerical simulation and artificial intelligence (ANN) models for the chosen vulnerable soil slopes. Numerical modeling was done to compute safety factor, stress distribution and maximum displacement using LEM and FEM modules. Further, the machine learning technique, ANN was also functionate to predict the stability based on geotechnical data's and numerical simulation results. The numerical analysis for the homogenous finite slopes shows that slopes are stable, critically stable and also prone to failure during rainy season. The ANN model evaluate that, the FoS by numerical modeling displays 98% validation to predictive neural networking system. The simulation result could be effectively applied to lessen/decrease the effect of regularity for the landslides in the area of particular morphology.

Keywords: LEM, FEM, ANN, Slope Stability, FoS

Introduction

Slope instability has composite natural phenomenon which consists of serious natural hazards in many countries. In India study of slope stability is very crucial, because 15% of land mass in India prone to failure (>0.49 million km^2; Sharda, 2008). Various types of slope failures often occurred in the active terrain of Himalaya i.e. northeastern India and a part of western Ghats of southern India. Himalayan terrain is always witnessed with a major and minor landslide, because of its dynamic nature (i.e., collision of Indian plate and Eurasian plate), diverse lithology, multiple phase of deformation, complex geological environment, urbanization with various development activity along the highway, where shallow landslides increased in the in rainy season (Mathew *et al*., 2007). These shallow landslide, when saturated with water, formed various debris flow, mud flow and earth flow with higher speed and more run out distance than earlier (Brabb and Harrod, 1989; Prochaska *et al*., 2008). The soil stability analysis had always been a major issue due to optimization of critical slip surfaces along which the soil failures commonly happened. Chen *et al*. (1983) had defined that excessive shear stress along the slip surface caused mass failure. Slope failures have always distress effects, leading to loss of lives and harm to natural belongings. In the Himalayan Terrain slope failure is now increased due to large-scale human involvement, which included street broadening, development of bridges, dams and tunnels, along valleys and major roads. All these events surge the susceptibility of slope failures (Sarkar and Singh, 2008; Umrao *et al*., 2011). In the hilly terrain of the Himalaya, communication and transportation with different parts of Uttarakhand totally depends on the roads and street networks. These road networks had been constructed by excavating these sub vertical and vertical slopes without any surveys. Excavation of these slopes without choosing a right geotechnical investigation and explosive design caused more instability of slopes. Numerous large and minor landslides happened nearly every month, which caused roadblock and traffic disruption for hours and sometime many days (Umrao *et al*., 2012; Singh *et al*., 2012). In the Rudraprayag district, the Mandakini river had witnessed several landslides brought by heavy rainfall. In July 2000 the Phata and Byung Gad landslides caused loss of 20 humans and injured many others (Naithani and Prasad, 2002). The another landslide happened on 24 September 2003 in Uttarakashi, caused blockade of the foothill of the hillslope and huge loss (Kanungo *et al*., 2004). In 2005, a landslide happened near Agastmuni alongside seasonal stream driven a heavy loss of buildings and killed four persons (Sarkar *et al*., 2006). The country's worst natural cloudburst tragedy happened in June 2013, which caused several shallow landslides that brought thousand deaths, more than four thousand went missing and scores of thousands remained stuck, holding for airlifted. The Rudraprayag-Kedarnath highway (NH-109) became worse during heavy rainfall because of flooding through the Mandakini River. As a result, the slope stability analysis of the soils slopes in the Himalayan region are very crucial to reduce and design the appropriate protection. There are numerous traditional (i.e., laboratory and field experiments) and numerical simulation methods which are utilized for the slope stability analysis. (Coggan *et al*., 1998; Umrao *et al*., 2012; Singh *et al*., 2012). The conventional methods consist kinematic and empirical methods (Umrao *et al*., 2011; Vishal *et al*., 2017), whereas the numerical techniques can be categorized into 3 parts: Continuum, discontinuum and hybrid modeling. Continuum techniques were widely used to analyze the slopes that consist intact rocks, fractured rocks and also for soil slopes (Jing and Hudson, 2002). In present article the limit equilibrium method and finite element method was adopted to analyze the soil slopes. The FEM model was largely applied to evaluate the stableness of numerous forms of slopes throughout the world (Chang and Huang, 2005). The other method Artificial Neural Networks (ANNs), possibly the most popular intelligent technique, was applied based on the function of nervous system and human brain (Shahin *et al*., 2004). Suman *et al*. (2016) used the Functional Networks (FNs), Multivariate Adaptive Regression Splines (MARS) and Multigene Genetic Programming (MGGP) to predict the factor of safety by collecting the literature data of slope stability and found MARS to have comparatively better prediction accuracy than others. In Manouchehrian *et al*. (2014) discussed the genetic algorithm model to predict the factor of safety of different slopes and showed more efficient than GP model of Yang *et al*. (2004). Lu and Rosenbaum (2003) examined the FOS and the stability of the slope for the Sah *et al*. (1994) and Xu *et al*. (1999) dataset and showed ANN to have a well precision than Hossein Alavi and Gandomi (2011) carried out Gene Expression Programming (GEP), Linear Genetic Programming (LGP) and Multi-Expression Programming (MEP) to evaluate the FOS for the literature data of Wang *et al*. (2005) and exposed that LGP is more accurate than MEP and GEP models.

The present article is collective analysis of numerical and artificial intelligence (ANN) methods to investigate the soil slopes stability of three susceptible locations near Kedarnath in Indian Himalayan terrain. The geotechnical data and representative samples from different location were firstly collected. The collected soil samples were experimented to find out the input parameters for numerical simulation. Then the input parameters were emphasized to analyze the stability of soil slopes using LEM and FEM methods. Stress- strain distribution, factor of safety and failure mechanism were exhibited using LEM and FEM models. Lastly artificial intelligence (ANN) method were applied to predict and validate the calculated FoS.

Study Area Description

The study area lies in Higher Himalaya region, which had been divided into six lithological groups as Vaikrita Group, Almora Group, Ramgarh Group, Debguru Porphyroid/Ramgarh porphyry, Jaunsar Group and Damta Group by Valdiya (1980). The main geomorphological feature of the area had spatially glaciated zones, narrow deep valley, fluvial terraces, colluvial fan, moraines, reworked moraines, debris flow deposits, modified colluvial deposits, broad river channel and narrow river channel (Sundriyal *et al*., 2015; Poonam *et al*., 2017). In Rudraprayag major tectonic features that traverse from south to north are Ramgarh thrust (near Tilwara), the Masuri thrust (near Kund), the Vaikrita thrust (above Gaurikund), the Pindari thrust (near Rambara) and the Alkananda fault. The Main Central Thrust (MCT) is the major structure, constituting a wide zone between Kund and Rambara (Valdiya, 2014; Singh *et al*., 2014) The slope study was carried out along the NH-109, which runs from Sonprayag to Kedarnath along the Mandakini River. The Sonprayag (30°37′54.68″N; 78°59′55.28″E), Gaurikund (30°39.158′N; 79°01.549′E) and Kedarnath (30°44′04.66″N; 79°04′00.82″E) occurs within topo sheet number 53J/15 and 53N/3 of survey of India. Sonprayag is situated at the confluence of the Mandakini and the Vasukiganga rivers. Sonprayag (5 km away from Gaurikund and 5 km. towards Kedarnath) and Sitapur (3 Kms. towards Rudraprayag) are important places as they are used as a halt by pilgrims and travelers on their way to the world-famous holy shrine of Shri Kedarnath, which attract thousands of visitors (Yatris) every year. As from primary inspection the study area has many slope stability issues, where three different vulnerable soil locations have been chosen for the stability analysis (Fig.

1). From the elevation map of the area it's find out that the area is situated at very high elevation form sea level which can be seen from elevation map in the Fig. 2. Slope map of area were also studied to know the range of variation, which depicts large variation of slope angle with very less horizontal ground (Fig. 3). As the rainfall had increasing trend in Himalayan Region, which is key factor for slope stability. So, the analysis of soil stability is required for the public safety and stability of pathway for the pilgrims.

The identified slope vulnerable location along the pathways with their photographs is given in the Fig. 4. Location 1 (28 m height) has two pathways, with variation of slope angles. Location 2 has 16 m height and location 3 has 20 m height with the varying slope angle. The representative soil sample were collected from different varying layers of each slopes to investigate the geotechnical input parameters for numerical simulation as well as for ANN.

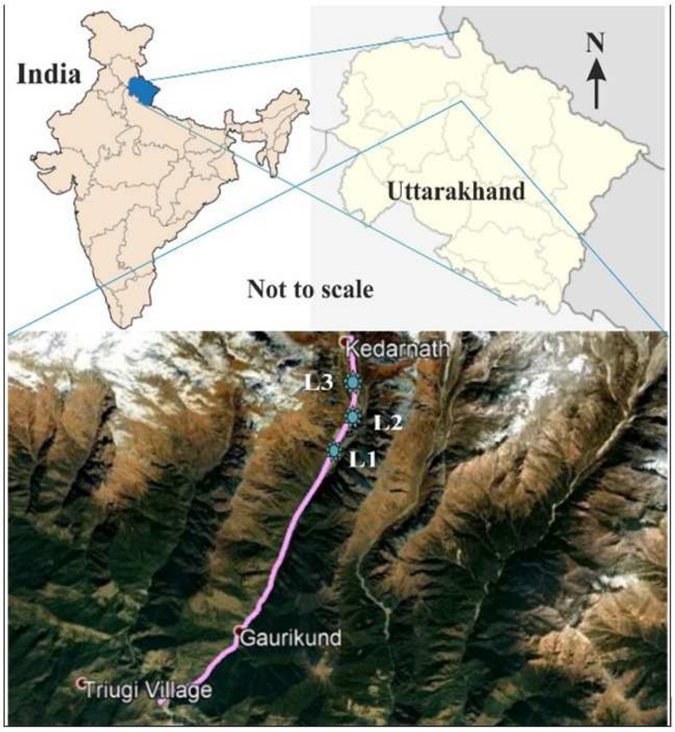

Fig. 1: Soil landslides locations (L1, L2, L3) along the pathway Sonprayag to Kedarnath

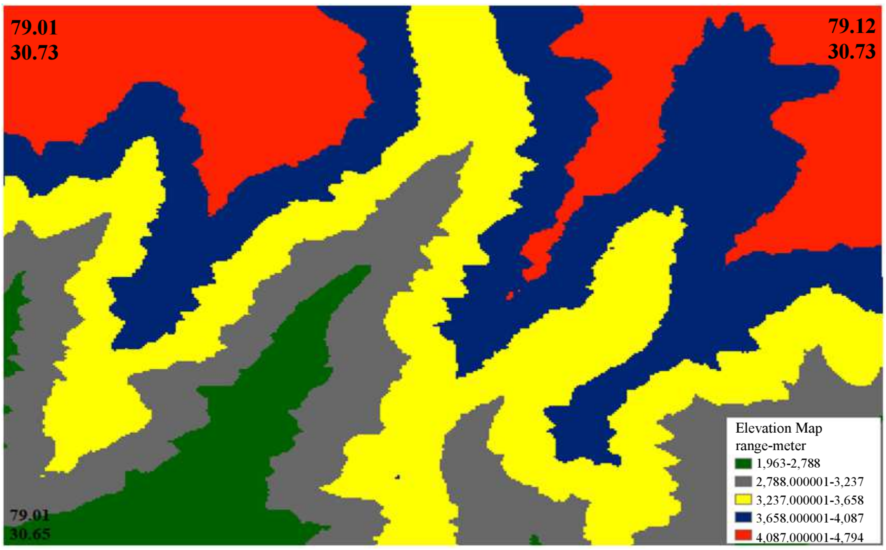

Fig. 2: Elevation map of the area

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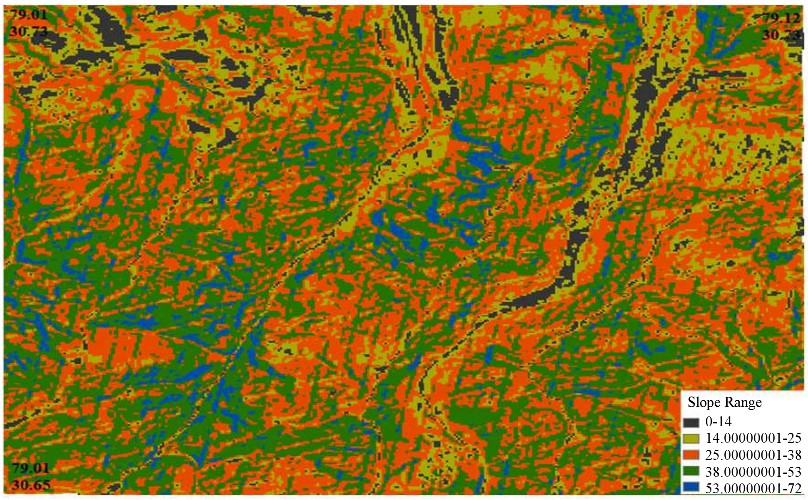

Fig. 3: Slope map of the area

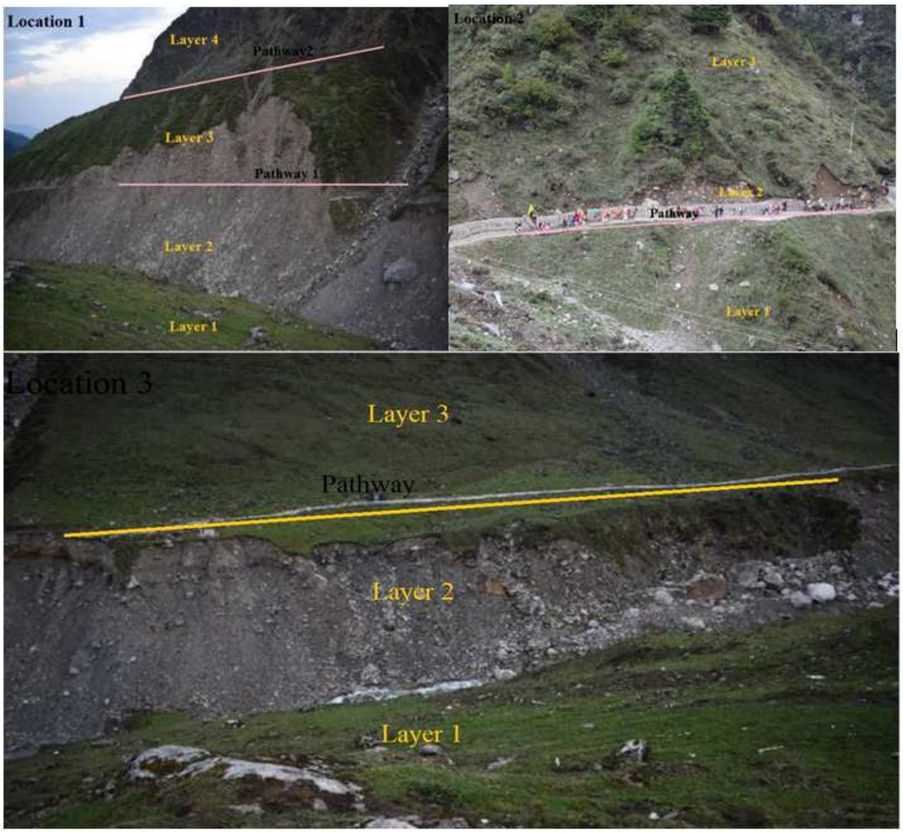

Fig. 4: Soil locations photographs

Rainfall Prediction of Study Region

Effect of rainfall on slope instability is common parameter in tropical and subtropical region, subsiquently the study of hydrological characteristics are required to find the significant trends in particular area. Generally in rainfall season, the infiltration through unsaturaed soil increases the negative pore water pressure that decreases the shear strength of the soil upto potential slip failures.

The required rainfall data were collected from Indian Meteriological department for time period 2013 to 2017. The analogous rainfall data were analysed to ascertain the cumulative and monthly rainfall variant Fig. 5.

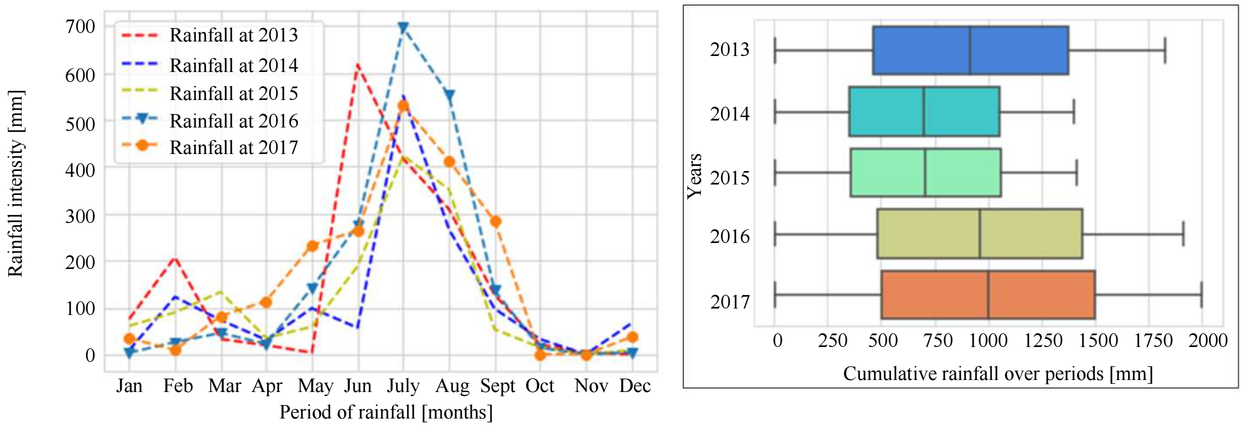

Fig. 5: Monthly and yearly rainfall analysis for the years 2013 to 2017

The monthly cumulative data analysis illustrate that most of rainfall was occurred from June to September in the study region, where the maximum rainfall data gained in July 2016 (700 mm). The yearly cumulative data analysis show that maximum rainfall was gained in year 2017 (1500 mm) than any others. The general role of rainfall in slope instability is well established, so to understand the intensity and time span of rainfall for particular area is an important consideration.

Methodology

The rigorous field study had been carried out to quantify the input parameters for the numerical and ANN analysis of soil slopes. Typical soil samples were collected from different parts of each location to estimate the input parameters. The collected representative samples were tested in the laboratory as per Standards (ASTM D2166, 2013; ASTM D698, 2012; ASTM D4767, 2011; ASTM D4318, 2010; ASTM, 2008) for further evaluation of input parameters. These estimated input parameters and slope geometries had been employed to run the numerical and ANN models. The LEM method was accomplished using Slide v6.0 software, whereas FEM was performed using Phase 2 software. Generally numerical modeling is computer generated programs where a problem of domain is discretized and then solved with different models like LEM, FEM and FDM etc.

The ANN structure of multilayer domain had been used for the soil stability analysis and for the validation of numerical modeling result, which is a sophisticated technique capable of modeling the complex function in nonlinear way.

LEM and FEM

The limit equilibrium method is more popular and widely used method for soil slope stability, where loose geo-materials above the failure surface is divided into numerous vertical slices. The thickness of individual slice should need not be similar; it is a subject of the slope geometry and profile of geo-materials. In the slice method of limit equilibrium (Bishop, 1955) each slice should be satisfied by equilibrium of force or moment or both of them (Fig. 6). To calculate the factor of safety the Mohr-Coulomb criterion is used as the failure criteria. The equilibrium forces on each typical slice appearing within the vertical direction are:

$$N_r \cos\alpha_n = W_n + \left(T_n - T_{n+1}\right) - U\cos\alpha_n - T_r \sin\alpha_n \quad (1)$$

where, $T_r = \frac{C\Delta L_n}{F_s} + N_r \frac{\tan\phi}{F_s}$:

$$N_r = \frac{W_n + \Delta T - U\cos\alpha_n + \frac{C\Delta L_n}{F_s}\sin\alpha_n}{\cos\alpha_n + \frac{\tan\phi\sin\alpha_n}{F_s}} \quad (2)$$

where, $\Delta T = T_n - T_{n+1}$, By putting the value $\Delta T = T_n - T_{n+1}$ and solving:

$$F_s = \frac{\sum_{n=1}^{n=p}\left[C\Delta L_n \cos\alpha_n + \left(\left(W_n - U\cos\alpha_n\right) + \Delta T\right)\tan\phi\right]\frac{1}{m_\alpha}}{\sum_{n=1}^{n=p} W_n \sin\alpha_n} \quad (3)$$

where, $m_\alpha = \cos\alpha_n + \frac{\tan\phi\sin\alpha_n}{F_s}$

The mathematical expression of the forces acting on the slice are:

W_n is the weight of the slice, N_r and T_r are the normal and tangential component, the P_n and P_{n+1} = normal force act on the side of the slice, T_n and T_{n+1} = shearing force act on the side of the slice and F_s is the (FoS) along the slip surface.

The factor of safety was calculated by Simplified Bishop Method (Bishop, 1955), which is based on the method of slices (Fig. 6) with restriction as circular type of failure. Present method is very much useful for the failure assessment of loose type geomaterials viz. soil and derbies. The alternative method FEM was also utilized for soil stability to reduce the limitation of LEM method. The FEM model is intended with Mohr coulomb failure criterion and 6 nodes triangular mesh. (Singh *et al*., 2013; Zienkiewicz *et al*., 1977). In FEM model the soil failure takes place, when the shear strength of the soil is not able to resist the shear stress along the slipping surfaces:

$$F_s = \frac{\tau}{\tau_f} \tag{4}$$

where, τ is the shear strength of the slope material and τ_f is the shear stress on the sliding surface. The shear strength of the slope material τ calculated though Mohr-Coulomb criteria:

$$\tau = C + \sigma_n \tan\phi \tag{5}$$

The τ_f shear stress on the sliding surface is:

$$\tau_f = C_f + \sigma_n \tan\phi_f \tag{6}$$

Hear, C_f and ϕ_f are related to shear strength parameters of slope by a factor called as strength reduction factor. The value of C_f is calculated as:

$$C_f = \frac{C}{SRF} \tag{7}$$

$$\varphi_f = \tan^{-}\left(\frac{\tan\phi}{SRF}\right) \tag{8}$$

where, *SRF* strength reduction parameter (Matsui and San 1992; Kainthola *et al*., 2013).

Artificial Neural Networks (ANNs)

An ANN based predictive model is consist of simple highly connected processing elements called neurons, which is typically arranged in the form of layers. Generally, an ANN model architecture had numerous layers (three or more layers), which contain an input layer, one or more hidden layers and an output layer. The neurons of the input layer accept input from the external sources. This layer do not perform any computations at input, where hidden layer receive information inputs from the input layer and perform computation and delivered the outputs to output layer (Choobbbasti *et al*., 2009). Each neuron in a given input layer was linked to all neurons in the next layer by means of weighted connections. Basically, ANN architecture defined interconnected feed-forward Multi-Layer Perceptions (MLP) predictive model (Göktepe *et al*., 2005). The performance of the overall ANN model could be assessed by several criteria. A typical ANN architecture for landslides monitoring is shown in Fig. 7.

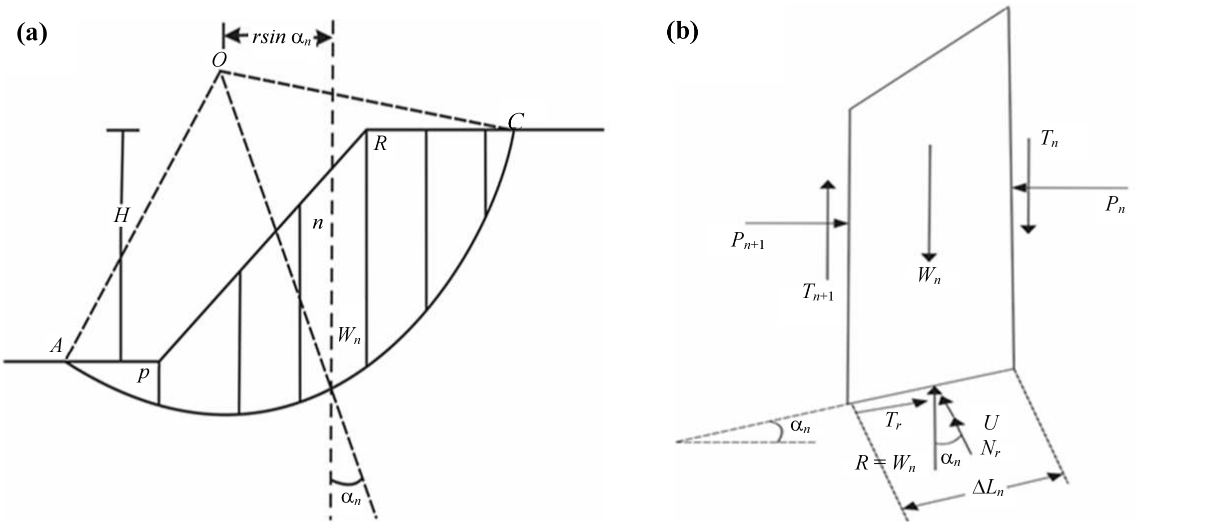

Fig. 6: (a) The simplified Bishop's method a slice of the soil above failure plane; (b) Effect of the forces on the side of a particular slide (Bishop, 1955). After substituting the value of T_r in Equation (1):

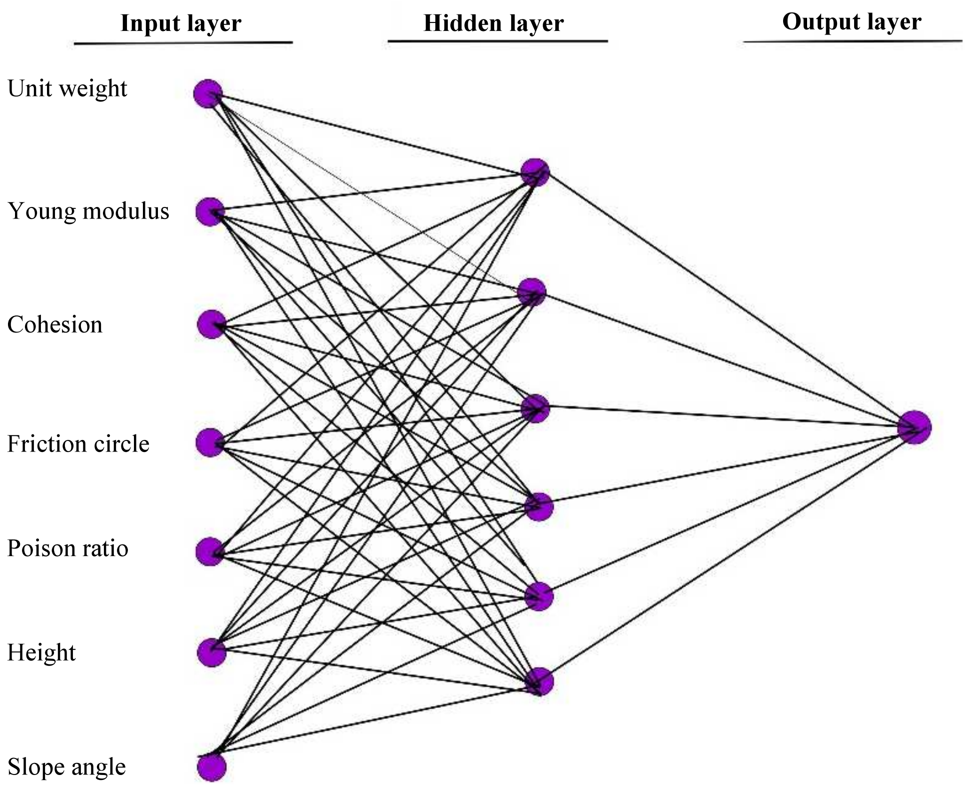

Fig. 7: A typical ANN architecture for landslides monitoring

Back-Propagation (BP) Neural Networks

Mostly, Back propagation neural network is one of most popular machine learning technique among the different available prediction models, in slope stability monitoring projects for its nonlinear mapping nature, easy realization and robustness, which was used to enhanced the connection weights for different layers from the previous layer to the next layer using the difference of real output and predicted output:

$$Net_j = \sum_i W_{ij}.O_i \quad (9)$$

where, W_{ij} shows The Weights between Nodes *I* and *J* and O_i is the Output from Node *J*, Given By:

$$O_i = f\left(net_j\right) \quad (10)$$

The *f* is mainly a non-linearity based activation function (sigmoid function), which is used to the weighted sum of inputs before, it propagates to the next layer of the neural network. One major advantage of this non linear activation function is its derivative which can be derived in forms of the function:

$$f'\left(net_j\right) = f\left(net_j\right)\left(1 - f\left(net_j\right)\right) \quad (11)$$

A program with a user interface was developed in the Matlab program to estimate the Factor of Safety (FoS) for the homogeneous finite slopes subjected to different forces (Cetin, 2010).

The BP based ANN model used in present project mainly consist of input, hidden and output layers (three layers). The first layer is an input layer, wherever the nodes were part of feature. The next layer is the hidden layer. The third and last layer is the output layer, which shows the predicted output data (Atkinson *et al*., 1997). The introduce error, *E*, for an input layer is training pattern, *t*, which is a function of the predicted output:

$$E = \frac{1}{2}\sum_k \left(d_k - o_k\right) \quad (12)$$

The introduced error (E) is propagated back to the ANN and was minimized by correcting the weights of layers. The Simplified Bishop method (1955) was chosen due to its simplicity which makes it easier for this application. In the Simplified Bishop method (1955), it was assumed that the failure surface is represented by a circular arch, which has a center represented by *O* and a radius represented by *R* (Zhu *et al*., 2003). The same slope stability parameters as used in the numerical simulation cohesion, friction angle, unit weight, young modulus and poison ratio has been used for ANN model and validated with numerical model analyzed factor of safety.

Results and Discussion

The susceptible soil slopes namely Location1, Location 2 and Location 3, followed by collection of typical samples for laboratory tests were analyzed by using their input parameters. The geo-technical input parameters have been collected by standard laboratory tests for dry as well as saturated condition (Table 1 and 2). The slopes were analyzed with single slope geometry for LEM and FEM modules (Fig. 8) for dry and saturated condition (Fig. 9). LEM analysis was done by Simplified Bishop method (Using Slide V6 software)to know the FoS. The evaluation of numerical analysis shows color contrast along the slip surfaces, which indicates the change in safety factor. The LEM result depicts that all the location is in stable for dry condition, but in saturated condition location 1 shows instability (Table 3). The LEM has advantage over FEM in sense that it shows the slipping surface along the failure slope, as soil commonly fails along the slipping surfaces.

In FEM model, the Mohr coulomb failure criterion was used with discretization of the slope by 6 nodes triangular mesh under gravitational loading. The determination of the total displacement, displacement vector along the slope and their respective developed maximum shear strain variation were computed by FEM based Phase2 software (Fig. 9). FEM analysis shows the critical condition for slope 1 and 3 in dry situation and stability for slope 2, but in saturated condition slope 1 and 3 goes to unstable (Table 3). Slopes stability analysis of location L1, L2 and L3 shows maximum shear strain accumulated mostly at the top of the slope. The displacement vectors indicate that the slope may fail toward the toe of slope. A comparative knowledge from both the computational process shows that FEM has less factor of safety than LEM methods, which shows positive indication for the advance and accurate stability analysis.

Table 1: Input parameters for dry condition

Location no		Unit weight (Kn/m^2)	Cohesion (KPa)	Friction angle	Young modulus KPa	Poison ratio
Location1	Layer1	20	75	28	42000	0.33
	Layer2	19	38	25	31000	0.33
	Layer3	19	35	22	33000	0.34
	Layer4	19	34	22	34000	0.34
Location2	Layer1	21	38	25	37000	0.33
	Layer2	19	32	23	26000	0.31
	Layer3	19	28	22	31200	0.3
	Layer1	18	44	24	35600	0.32
Location3	Layer2	18	30	23	32800	0.32
	Layer3	19	28	23	33100	0.30

Table 2: Input parameters for saturated condition

Location no		Unit weight (Kn/m^2)	Cohesion (KPa)	Friction angle	Young modulus (KPa)	Poison ratio
Location1	Layer1	22	70	25	40000	0.33
	Layer2	20	35	23	29000	0.33
	Layer3	20	32	21	32000	0.34
	Layer4	20	31	20	32000	0.34
Location2	Layer1	22	35	22	35000	0.33
	Layer2	21	29	21	24000	0.31
	Layer3	22	25	20	23800	0.3
Location3	Layer1	19	41	22	33680	0.32
	Layer2	18	28	21	31500	0.32
	Layer3	22	25	21	31250	0.3

Table 3: Results of LEM and FEM analysis (Dry and saturated condition)

Location no	Slope height	Factor of safety LEM (dry)	Factor of safety FEM (dry)	Diff. between LEM&FEM (dry%)	Factor of safety LEM (saturated)	Factor of safety FEM (saturated)
1	28	1.14	0.99	13	0.94	0.86
2	16	1.62	1.48	9	1.48	1.15
3	20	1.27	1.15	9	1.1	0.91

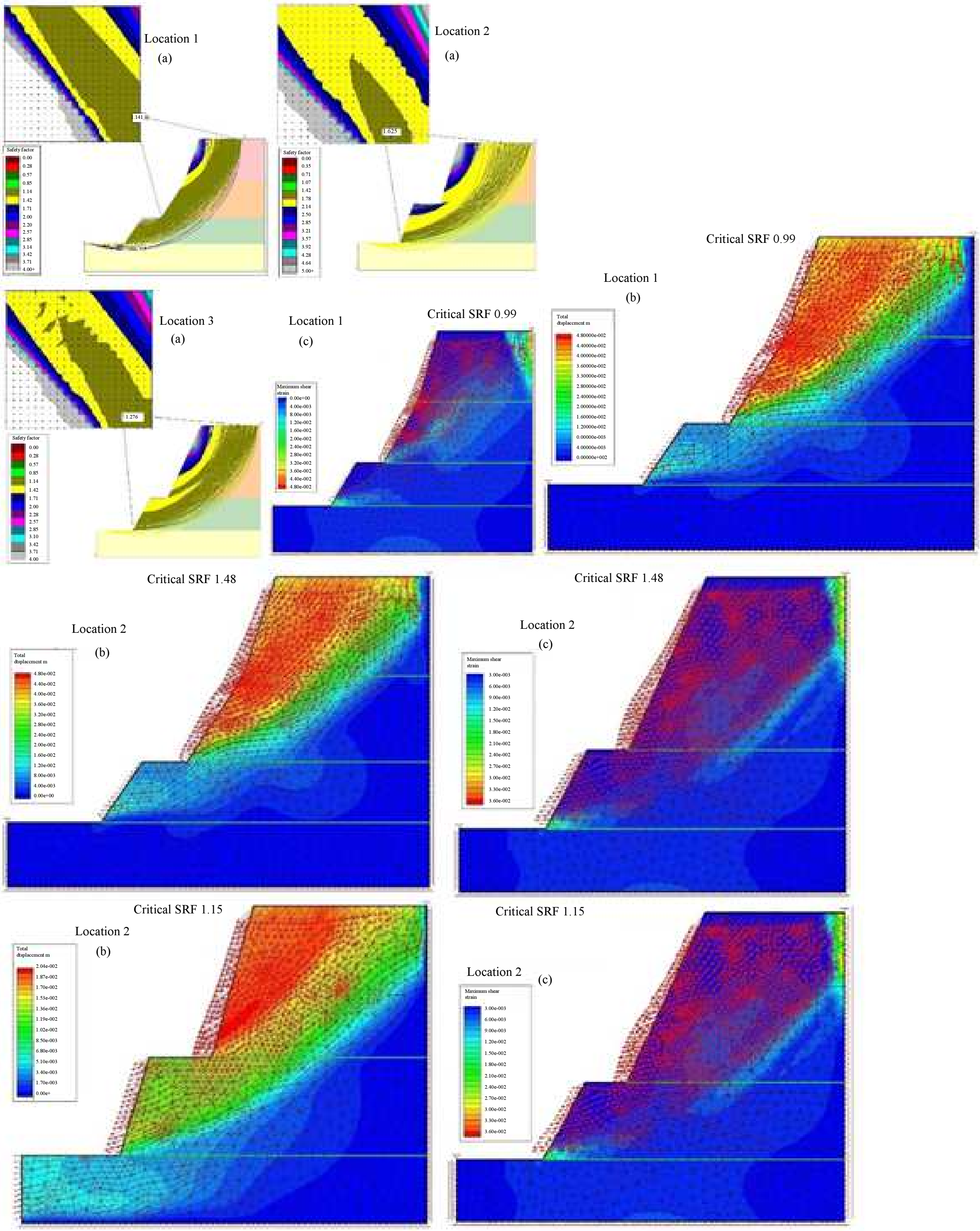

Fig. 8: Dry condition; (a) Analyzed soil slope Kedarnath by LEM (Location 1, 2 and 3); (b) FEM analysis -Total displacement for location (Location 1, 2 and 3); (c) FEM analysis Maximum shear strain for location (Location 1, 2 and 3)

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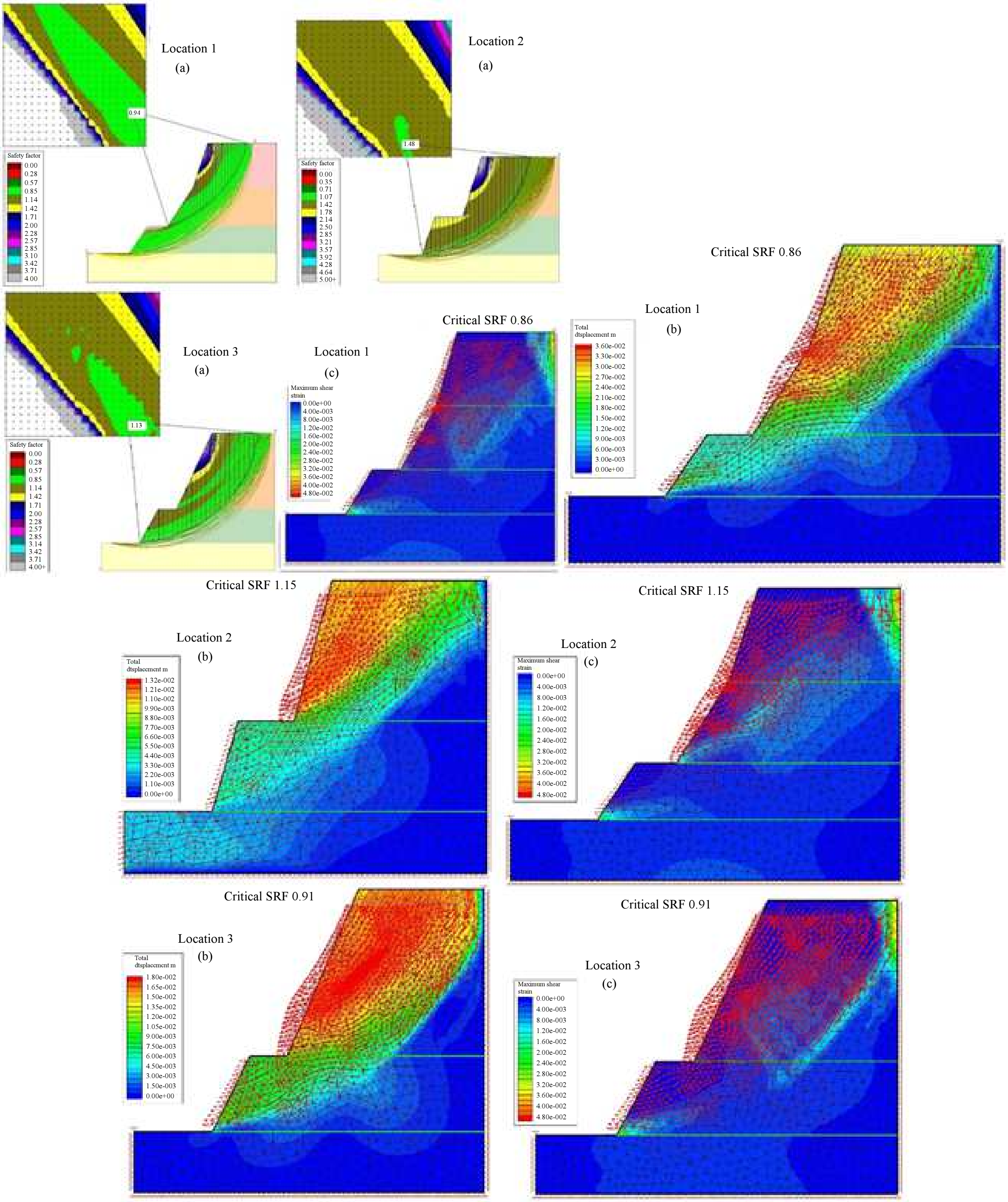

Fig. 9: Saturated Condition; (a) Analyzed soil slope Kedarnath by LEM, simplified method (Location 1, 2 and 3); (b) FEM analysis -Total displacement for location (Location 1, 2 and 3); (c) FEM analysis - Maximum shear strain for location (Location 1, 2 and 3)

The *Fs* values computed from the Simplified Bishop method and finite element method were compared with the *Fs* values predicted with the artificial neural network analysis as depicted in Fig. 10, which shows training, validation and testing of samples, respectively. A typical choice of momentum is between 0.5 to 0.9.

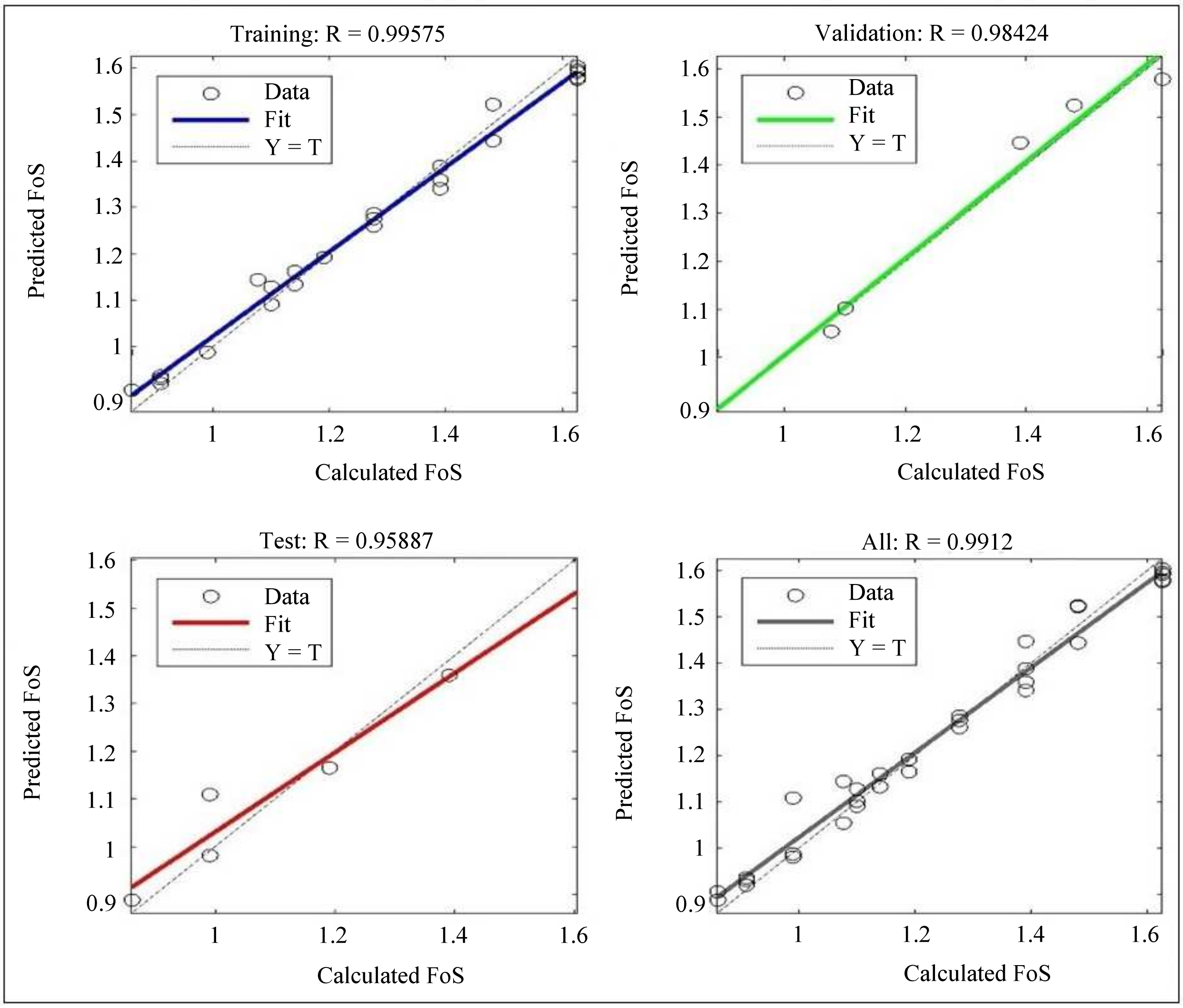

Fig. 10: The comparison of the calculated Fs values with the predicted Fs values from the ANN model for training samples

The proposed ANN model shows, the unit weight, friction angle, young modulus, cohesion and poison ratio considered as input parameters, where as Factor of safety was considered as the target output. The ANN model have been programmed in the Matlab 2011.The find out of regression plot has been shown in the Fig.10. From the plot R was found 0.99, which is close to one for the predicted result, where the value of correlation coefficient for the validation purpose is found as 0.98, which is very close to actual result. Therefore, the critical Fs value for the homogeneous finite material can be evaluated from ANN model to analysis the slope stability.

Conclusion

The numerical simulation using LEM and FEM techniques were used to analyze the soil slope stability and then the same data and simulation result were also used for ANN modelling. The numerical simulation result shows that all the three locations are stable, while location 1 is critically stable only in FEM analysis for the dry state. In the sutured condition of geo-materials, the numerical model evaluate that location 1 and 3 are unstable, while location 2 shows stability. The changes in FoS for LEM and FEM method can be observe 9 to 13%. The maximum shear strains are mostly accumulated at top corner of the slopes and the maximum displacement shows movement from top portion to toe portion as from FEM analysis. The ANN technique is used as a prediction tool to evaluate the FoS for the intended results of LEM and FEM methods. The seventy percent data are used for training, while thirty percent data are used for testing purpose. The numerical simulation result and predicted modelling (ANN) result displays a well correlation of 98%, which demonstrate that ANN technique can be efficiently utilized for the soil slope stability analysis for the particular soil type.

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Author's Contribution

Vinay Kumar Singh: Theory part, ANN and experimental work.

Tariq Anwar Ansari: Numerical Simulation.

Vikram Vishal: Examine the whole manuscript.

T.N Singh: Contributed to the key work plan.

Ethics

This article is original and contains unpublished material. All experimental procedures were conducted in accordance with the Guide for the Care.

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