Numerical Analysis of Instability of Slope near Rudraprayag Area, Uttaranchal, India

T.N.Singh*, V. Bhardwaj**, L. Dhonta** and K. Sarkar*

ABSTRACT

Slope stability analysis provides a quantitative measure of the stability of a slope or part of a slope and is expressed in terms of factor of safety. The analysis techniques chosen depend on both site conditions and potential mode of failure, which depends upon geological and rock mass characteristics. In the present excerise, PLAXIS 2D software has been used for numerical simulation to slope instability. Different models for the same rock are employed for analyzing overall possibilities for estimation of parameters affecting the stability, thus, providing a holistic analogy for slope instability of road cut slope in Rudraprayag, located midway on NH 58, which runs from Rishikesh to Badrinath.The main aim of the paper is to study the influence of slope angle and height on slope stability. Deformation meshes, total strain, total displacement are other parameters obtained from the results computed and analyzed using PLAXIS-2D and results were compared with field data. The close relations of various parameters are compared and the observations are used to calculate the overall stability of the slopes. The Factor of Safety (FOS) varies between 1.54 – 0.37 and 1.40 – 0.98 at various slope angles and heights respectively.

Introduction

Slope failures are complex natural phenomena that constitute a serious natural hazard in many countries. They are responsible for hundreds of millions of dollars of damage to public and private property every year. To prevent the slope failure damage, slope-stability analyses and stabilization require an understanding and evaluation of the processes that govern the behavior of the slopes. The factor of safety (FOS) based on an appropriate geotechnical model as an index of stability, is requisite in order to evaluate slope stability. Many variables are involved in slope stability evaluation and the calculation of the FOS requires geometrical data, physical data on the geologic materials and their shear-strength parameters (cohesion and angle of internal friction), information on pore-water pressures, etc. Thus, making slope failure prediction an intricate non linear system. Conventionally, the researchers tried many approaches such as limit equilibrium methods which are the most commonly adopted method in rock slope engineering. The Bishop's method (Bishop, 1955), Janbu's simplified methods (Janbu, 1954) or the later improved sophisticated methods [3-5] which are based on assumptions regarding the inclination and location of the inter slice forces. The discrete element method (DEM) (Cundall & Strack, 1979) describes the mechanical behavior of assemblies of discs and spheres. Particle Flow Code (PFC) (Wanga et al., 2003) was used to carry out a general study on the stability of heavily jointed rock slope. Stability analysis of jointed rock slopes using the Barton–Bandis (BB) constitutive model was done by using UDEC (Sung et al., 2005). The deformation and stability analysis of a highly discontinuous rock slope, consisting of sub-horizontally bedded and sub-vertically jointed, stiff, dolomite blocks was calculated using a fully dynamic version of discontinuous deformation analysis (DDA) (Hatzora et al., 2004), in which time-dependent acceleration was also used. This was earlier analyzed (Tsesarsky and Hatzor, 2002) by comparing displacements of a single block on

*Department of Earth Sciences, IIT Bombay, Powai – 400 076
**Institute of Technology, Banaras Hindu University, Varanasi 221 005
e-mail: tnsingh@iitb.ac.in

an inclined plane subjected to dynamic loading obtained by DDA and by shaking table experiments. Geographical Information System (GIS) interlinked Universal Distinct Element Code (UDEC) was used for the modeling of rock slope instability phenomena on vertical 2-D cross sections through a GIS-based specification tool (Tamimi et al.,1989).

First, the data from the field is analyzed by finite element method (FEM) using PLAXIS 2D due to its versatility to simulate various complex problems. After that, FOS is calculated for various slope angles keeping height constant and then for different heights for same slope angle to study their respective effects on the stability of the slope.

The Study Area

The present field area lies within 3 km east to 4 km west of Rudraprayag town, Uttaranchal. Rudraprayag is located midway on NH 58, which runs from Rishikesh to Badrinath. The important towns around this locality are Dehradun (Lat: 30° 19' N, Long: 78° 04' E) and Rishikesh (Lat: 30° 7' N, Long: 78° 42' E) to the west.

Most of the rainfall occurs during the period from June to September. The highest summer temperature is around 34°C and in winter the temperature drops as low as 0°C, with January being the coldest month.

Geology of the area

The rock samples collected from the exposed slope of Rudraprayag, Uttaranchal. The rocks in central Uttaranchal, from Srinagar (34 km west of Rudraprayag) in the west, to Nandprayag (23 km east of Rudraprayag) in the east, have been classified into the Central Crystalline, Garhwal and Dudatoli Groups, which form the northern, central, and southern parts of the area, respectively. The Main Central Thrust separates the Central Crystalline Group from the Garhwal Group, which comprise the rocks in the study area, whereas the North Almora 'Thrust' marks the boundary between the Garhwal Group and the Dudatoli Group (Agarwal and Kumar).

Laboratory Investigations

The slope analysis is done taking the strata to be an anisotropic Quartzite, which is exposed all along the slope. The rock samples were collected from the field and the various physio-mechanical properties of Quartzite were determined in the laboratory (Table.1). The non destructive and destructive tests were performed as per specification of International Society of Rock Mechanics [13]. The other statistical parameters were determined like uniaxial compressive strength (UCS), tensile strength (TS), Young's modulus (E), strength of cohesion(C), angle of internal friction (Ô) are were used as an input parameter. The 40 rock samples were prepared to test the rock to determine the various set of input and output parameters.

Table.1: Physico-mechanical properties of Quartzite

Properties	Value
Density	2.8 g /cm ^{3}
Permeability	3.54 x 10 $^{-8}$ m / day
Young's modulus	72 GPA
Poisson's ratio	0.2686
Friction angle	51 ^{0}
Cohesion	4MPa
porosity	3.028 %
Dilatancy angle	51 ^{0}

Finite Element Method (FEM)

FEM consists of a computer model of a material or design that is loaded and analyzed for specific results. Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of geometrical shape. The elements are joined to one another at a finite number of nodal points. The fundamental assumption is that displacements within the element may be interpolated with adequate accuracy from the displacements of the element's nodal points (Walter Wittke, 1990). Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of equilibrium are assembled in a matrix form that can be easily be programmed and solved on a computer. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated. Within each of these modeling schemes, numerous algorithms (functions) can be inserted which make the system may behave linearly or non-linearly. Linear systems are far less complex and generally ignore many subtleties of model loading and behavior. Non-linear systems accounts for more realistic behavior such as plastic deformation, changing loads etc. and is capable of testing a component all the way to failure.

Slope Modeling

To carry out a finite element analysis, a two dimensional finite element model was created using PLAXIS 2D. A plane strain model is used for geometries with uniform cross section and corresponding stress state and loading scheme over a certain length perpendicular to the cross section (z-direction).Displacements and strains in z-direction are assumed zero. However, normal stresses in z-direction are fully taken into account.

A Jointed rock model is used for simulating the behavior of stratified or jointed rock. In this model, it is assumed that there is intact rock with an eventual stratification direction and major joint directions.

To solve any geotechnical problem using Plaxis 2D, three components of a problem certify three conditions i.e. generation of mesh, constitutive behavior and material properties, and initial and boundary conditions.

The grid (mesh) defines the geometry of the problem under consideration as shown in Fig. 2. The size of mesh has great influence on the computational results. Generally, the finer mesh size, yield higher accuracy. However, at the same time too fine mesh will consume more computer memory and computation time, and too rough mesh will decrease the computational accuracy. The basic type of mesh is the 15-node triangular element or the 6-node triangular element meshes. The constitutive behavior and associated material properties dictate the type of response of the model that display disturbance while loading. Boundary and initial conditions such as ground water head or pore water pressure, external water pressure and closed flow boundary etc., defines the state of model being simulated. Mohr-Coulomb (elasto-plastic) type of material behavior is normally expected for the analysis of slope.

Strength Reduction Technique

The basic principle of elasto-plastic FEM strength reduction method is to reduce the strength parameters (i.e. angle of internal friction, cohesive force) of rock mass during the computation process to make slope reach the limit equilibrium condition. When the finite element static computation is not converged, the reduction coefficient of rock mass parameters is regarded as safety factor. In this analysis, cohesive force of rock is reduced during computation process to make slope reach the failure condition.

Results and Discussion

PLAXIS-2D is used to analyze the existing slope and to study the failure response

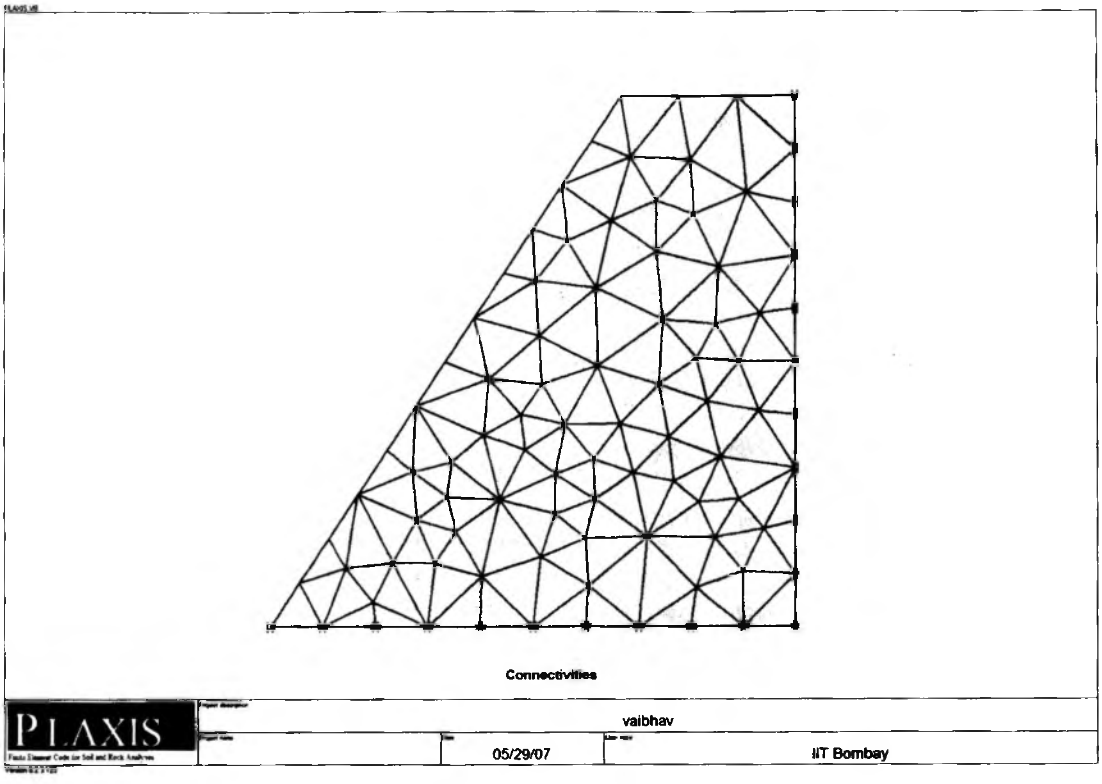

Fig. 1: 15-NodeMesh Generation

behavior. The contribution in the overall probability of failure depends, mainly on the specific geometry of the slope (slope angle), water level conditions, and on the distribution of forces acting on the rock. The ability to compute such contribution is a valuable feature of this methodology, since it provides quantitative information of interest in the design process. A safety analysis in PLAXIS 2D is executed by reducing the strength parameters of the rock. This process is termed as Phi-C reduction, and is selected when it is desired to calculate global factor of safety for a given situation. Therefore, Phi-C reduction process is adopted for calculating the factor of safety (FOS). The critical slope angle is the key factor in the slope failure analysis.

The deformation of the mesh is shown in Fig.2 and it is maximum at the toe, since the toe is under heavy strain as shown in Fig. 5.The toe of the slope displaces leading to the formation of a failure zone as shown in Fig. 3.

Fig. 3 shows the total displacement of the slope. The failure of the slope is circular as seen in Fig.3. Since the toe is made of stiff material therefore; the displacement at the bottom of the slope is in upward direction. The total displacement as calculated by PLAXIS 2D is 45.74mm.

Fig. 4 shows the concentration of total stress in the slope. The stresses are concentrated towards the base of the slope because of the large weight of overlying strata.

Fig.5 shows the total shear strain. The strain are concentrated more at the toe and forms a circular zone of failure. This is because of the stress concentration and load distribution.

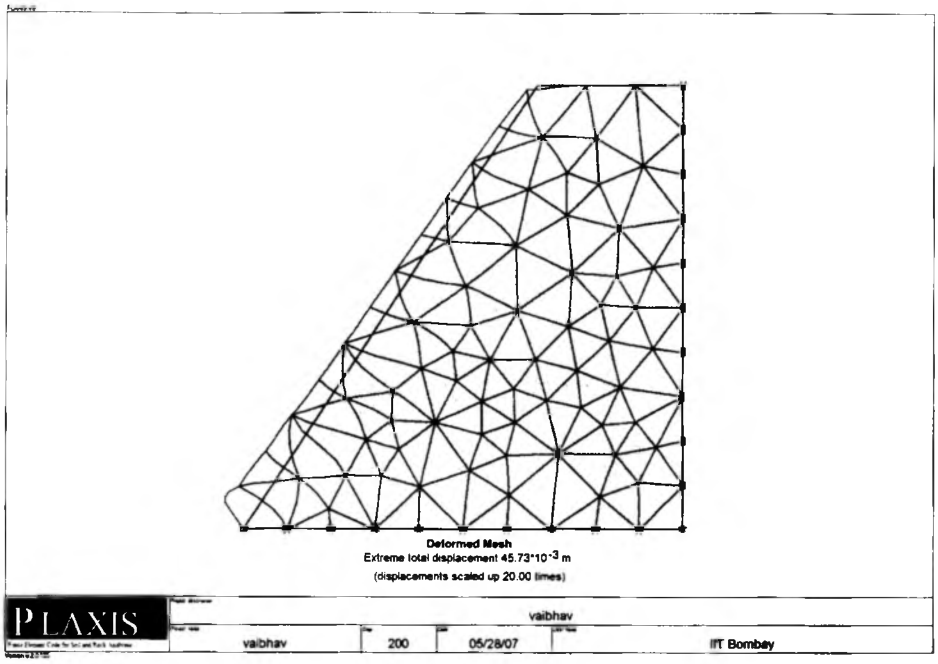

Fig. 2: Deformed mesh

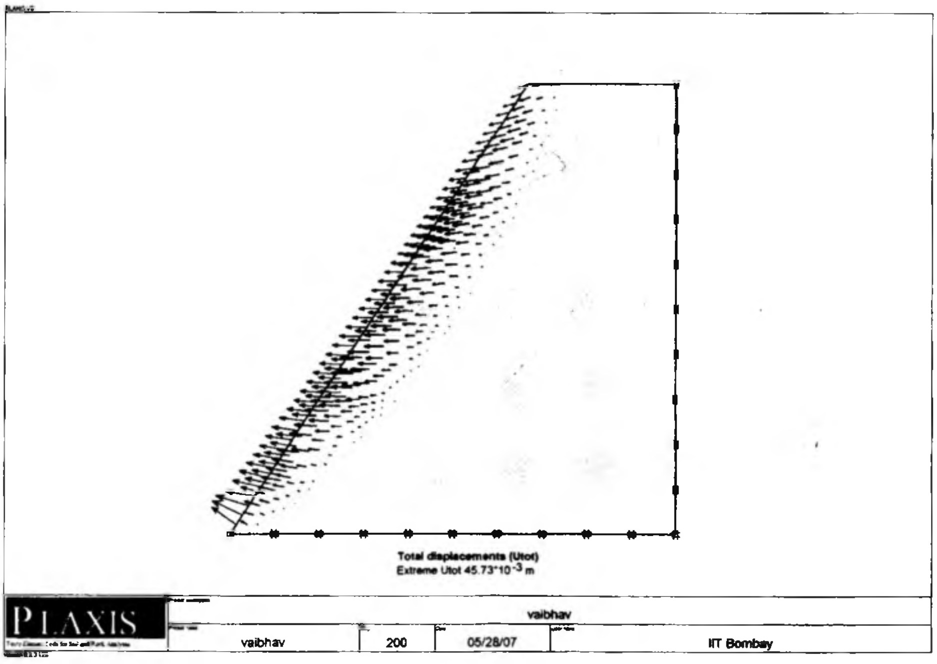

Fig. 3: Total Displacement

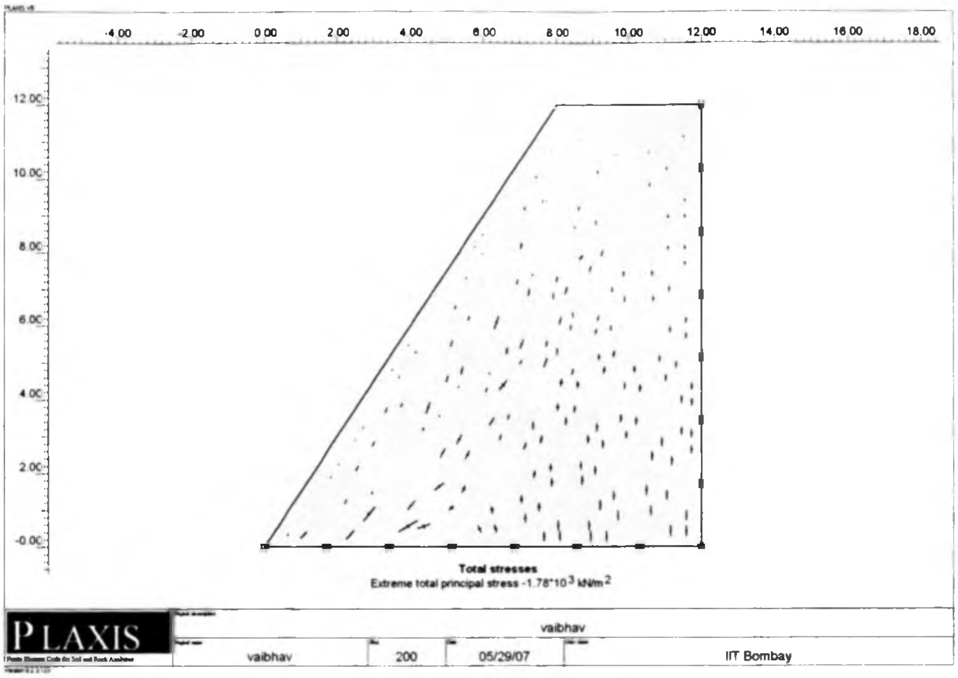

Fig. 4: Total Stresses

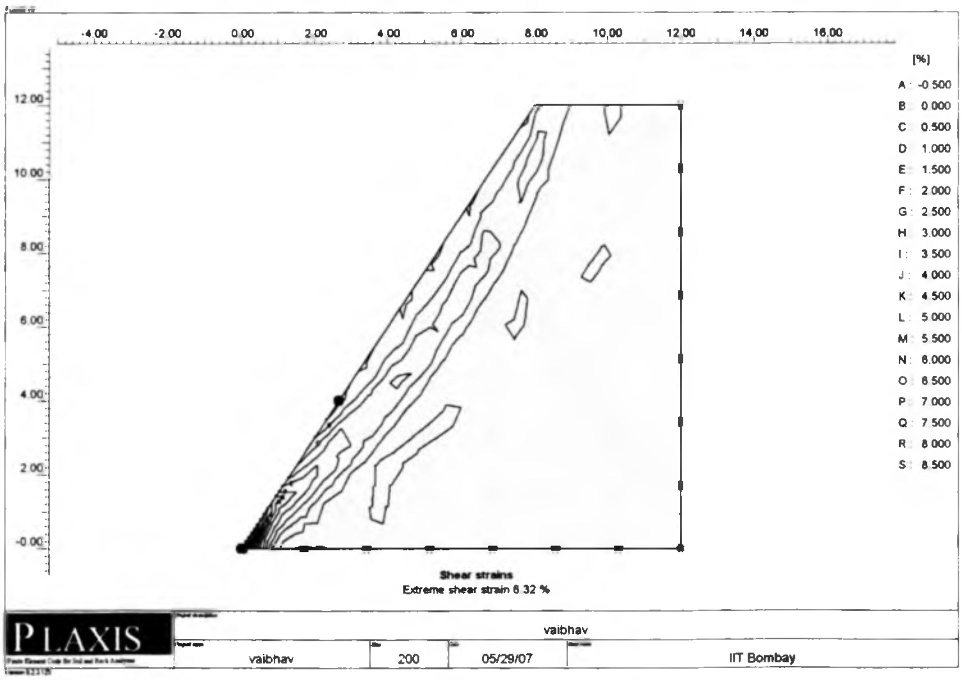

Fig .5: Total Shear strain

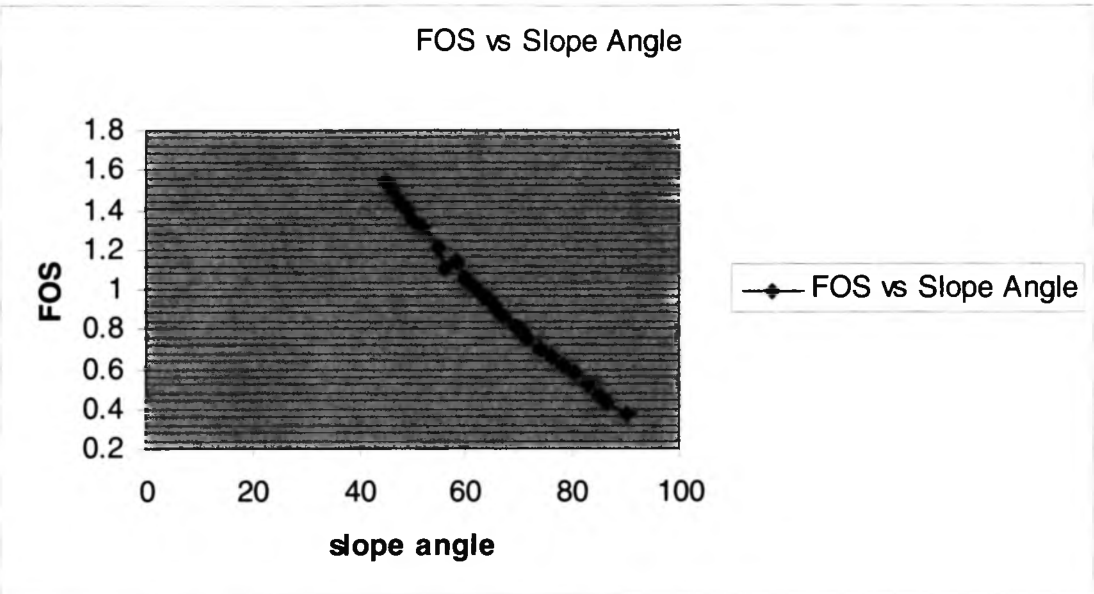

Fig.6: Plot of FOS vs. Slope angle (in degree)

FOS for various slope angles for the same rock quartzite is calculated using PLAXIS 2D and is given in Table 2. The FOS of the slope is maximum at 45 ^{0} and decreases with increase in slope angle. From the graph, it can be conclude that with increase in slope angle, the stability of the slope decreases. The trend of decrease in FOS is almost linear. The slope becomes unstable if the slope angle is greater than the angle of repose of the rock material and slope failure occurs in such a way as to reduce the slope angle to angle of repose.

FOS for various heights keeping slope angle constant for the same rock quartzite is calculated using PLAXIS 2D and is given in Table. 3.

Fig.7 shows the variation of FOS with height. With increase in height initially, the stability of the slope decreases sharply as the slope is critically stable. Therefore, slight variation in height leads to sharp decrease in FOS. After that, the decrease in FOS with height is nominal and with further increase in height, it is almost constant.

Table. 2: FOS at various slope angles for Quartzite

Slope angle (0) (degrees)	FOS	Slope angle (0)	FOS
45.00	1.54	65.37	0.92
46.22	1.50	66.00	0.89
47.50	1.44	67.30	0.86
48.81	1.41	69.44	0.81
50.00	1.35	70.00	0.80
51.63	1.31	71.56	0.76
54.69	1.21	73.74	0.70
56.00	1.10	76.00	0.66
57.99	1.14	78.23	0.62
59.70	1.06	80.53	0.58
60.00	1.05	82.87	0.52
61.55	1.01	85.23	0.47
63.40	0.97	86.00	0.44
64.00	0.95	86.40	0.43
		90.00	0.37

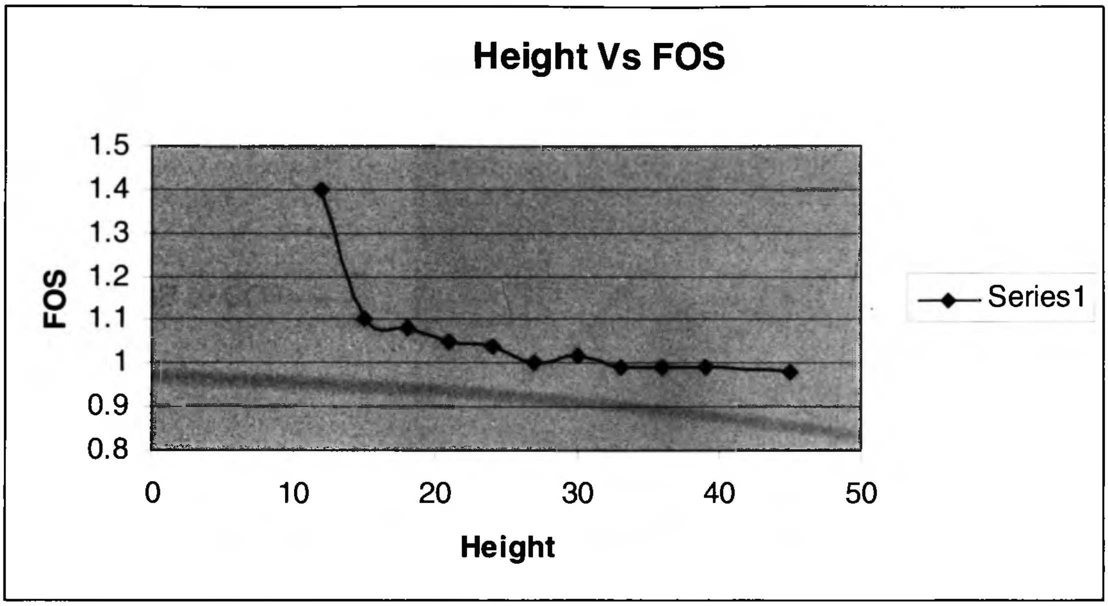

Fig. 7: Height (in m) Vs FOS

Table.3: FOS for Different Height

Height (m)	FOS
12	1.40
15	1.10
18	1.08
21	1.05
24	1.04
27	1.03
30	1.02
33	0.99
36	0.99
39	0.99
45	0.98

Conclusion

The stability of slope is analyzed and factor of safety is calculated using PLAXIS 2D, numerical software tool. It was observed that the factor of safety decreases linearly with increase in slope angle however, slight change in FOS with change in height is observed. Therefore, from the above findings it can be concluded that the slope stability depends more on slope angle as compared as compared to height. The FOS is highest at 45 ^{0}(1.54) while it is as low as at 0.37 at 90^{0} .While with variation in height, maximum FOS is observed at 12 m high slope (1.4) and minimum at 45m (0.98) high slope. The findings can be utilized for safety analysis and the proper selection of rock slope stabilization method, which will be stable and economical too.

Refrences

Bishop A.W. (1955): The use of the slip circle in the stability analysis of slopes. Geotechnique. 1: 7–17.

Janbu N. (1954): Application of composite slip surfaces for stability analysis. Eur. Conf. Stabil. Earth Slopes. 3: 43–49.

Morgenstern N.R. & Price V.E. The analysis of the stability of general slip surfaces. Geotechnique. 15(1):79–93.

Janbu N. (1957) : Earth pressure and bearing capacity by generalized procedure of slices. Proceedings of the Fourth International Conference on Soil Mechanics. 2:207–12.

Spencer E. (1967) : A method of analysis of the stability of embankments assuming parallel interslice forces. Geotechnique.17(1): 11–26.

Cundall P.A and Strack O.D.L. (1979) : A discrete numerical model for granular assemblies. Geotechnique.29:47–65.

Wanga C., Tannanta D.D. and Lillyb P.A. (2003) : Numerical analysis of the stability of heavily jointed rock slopes using PFC2D. International Journal of Rock Mechanics & Mining Sciences, Elsevier publishers. 40:415 - 424.

Sung O. Choi, and So Keul Chung. (2005): Stability analysis of jointed rock slopes using the Barton–Bandis constitutive model in UDEC. International Journal of Rock Mechanics & Mining Sciences, Elsevier publications. 41: 469.

Y.H. Hatzora, A.A. Arzib, Y. and Zaslavskyc, A. (2004): Shapira Dynamic stability analysis of jointed rock slopes using the DDA method: King Herod's Palace, Masada, Israel. International Journal of Rock Mechanics & Mining Sciences, Elsevier publishers. 40:813 – 832.

Tsesarsky and Y.H. Hatzor (Ed.). (2002) : Stability of Rock Structures. Proceedings of the Fifth International Conference of Analysis of Discontinuous Deformation, Balkema Publishers, Lisse. 195 – 203.

Tamimi S., Amadei B., Frangopol D.M. Monte Carlo.(1989): Simulation of rock slope stability. Computational Structures. 33(6): 1495–505.

Agarwal, N.C. and kumar, Geology of the Srinagar-Nandprayag Area (Alaknanda Valley), Chamoli, Garhwal and Tehri Garhwal Districts, Kumaun Himalaya, Uttar Pradesh. Himalayan Geology, v.5, pp.29-57.

ISRM (1980) : Suggested methods for determination of compressive strength. Int. Soc. Rock Mech. Comm. Lab. Tests.

Walter Wittke, (1990) : Rock Mechanics-Theory and Applications with case Histories. Springer-Verlag Berlin Heidelberg. 251.