FINITE ELEMENT SLOPE STABILITY ANALYSES OF A SLOPE IN THE HIMALAYAN REGION OF INDIA CONSIDERING SELF-DRILLING ANCHORS

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ABSTRACT

Stability analysis of a slope in the Chamoli District in Uttarakhand state of India was performed because this slope had been facing severe landslides due to major or minor seismic activities in that area as per the records of Geological Survey of India. As per the earthquake zonation map of India, the slope lies in Zone V, corresponding to high seismicity. The study slope is 36.5 m high with the average slope (with horizontal) as 61^0 in lower reaches, 42^0 in middle reach and 50^0 in upper reaches. The analysis were performed under pseudo static conditions using the software $PHASE^2$, Rocscience, 2011. Mohr-Coulomb shear strength criteria is adopted for soil material and self-drilling anchors (SDA) are modelled as bolts with parameters like modulus of elasticity, diameter of anchors and peak pull out resistance of the anchors. The slope was found to be unstable under pseudo static conditions with computed factor of safety of 0.93. But by using SDA, the factor of safety increased to 1.12 in seismic conditions.

KEYWORDS: Pseudo Static, Self-drilling Anchors, Slope Stability, Analysis

INTRODUCTION

This paper describes the stability assessment of a slope where Pipalkoti Hydroelectric Project is being developed, located in Chamoli district of India. The general location of the slope can be seen in Figure 1. The general inclinations of slope with horizontal are illustrated in Figure 2. The region is affected by major or minor seismic activities from time to time. A view of the study slope is shown in Figure 2.

Fig. 1 Location of the Study Slope

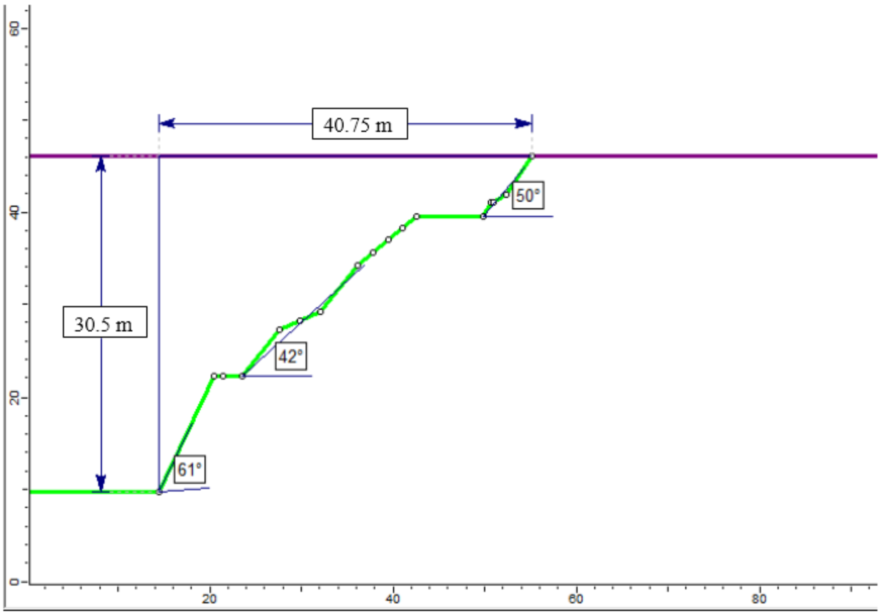

Fig. 2 Geometry and A view of study Slope

In the area of the study slope, a new Pipalkoti Hydro Electric Project (PHEP) is being developed along the river Alakananda by Tehri Hydro Development Corporation Ltd. (THDCL) in Chamoli district of Uttarakhand state in India. Additional to the recurring rainfall landslides, the project is located in a region of high seismicity, especially it is located in Zone V of earthquake zonation map of India. Hence it is essential to perform pseudostatic stability analysis of the slope considering pseudo static technique of analysis. In the present paper, we present the stability assessment of the study slope (Pipalkoti slope). Due to unstable conditions, a stabilization is recommended by using Self drilling anchors. SDAs are soil anchors generally 32 mm shaft dia with spiral surface (or with ribs on its periphery). In this region, mostly fragile mountains exist, hence landslides are very common every now and then. Therefore, for any important project in this region, anchoring of soil is essentially required.

The methodology of anchor design for slope stabilization had been developed by many investigators since long (Hryciw, 1991; Sabatini et al., 1999; Cushing et al., 2003; Zhu et al., 2005, Mittal and Mukherjee, 2014). Hryciw (1991) performed a theoretical study to determine the optimum orientation of anchors for stabilization of slopes by employing the concept of surface loads. Cushing et al. (2003) provided a description of a procedure to evaluate the design of anchored flexible retaining structures, in which the coefficients of variation (c.o.v.) of pullout resistance of anchors in both cohesionless and cohesive soil were proposed. Previous studies on soil anchor have explored methods of design of anchors for various uses (Mittal and Mukherjee, 2014).

DESCRIPTION OF THE UNSTABLE SLOPE

a) Location

The slope is situated in hilly state of Uttarakhand in Chamoli District near river Alakananda where a Dam of 65 m height and 3.63 Million cubic meters storage capacity is proposed to be built. The slope under study is located near Village Helong at Coordinates (E - 79^0 29’ 30” N - 30^0 30’ 50”). There are several tectonic faults, folds and over thrusts in this region which are responsible for the shearing of the soil and the rock mass at greater depths from time to time.

b) Geology and Seismicity

The geology of the region comprises of Himalayan young mountain range. The range consists of rocks like gneisses, limestone, phyllites, quartzite, sericite-biotite schist and slates. Physiographically the areas lie in a region of tectonic or folded and over thrust mountain chain with strata structurally marked by complex folds, reverse faults, over thrusts and nappes of great dimensions (Krishnan, 1982). All these, as well as frequent earthquake of varying intensity give the reason to believe that the region is still unstable.

c) Rainfall

As the elevation of the district ranges from 800 m to 8000 m above sea level, the climate of the district very largely depends on altitude. Rain gauging stations put up at seven locations by Meteorological department of Govt. of India show that most of the rainfall occurs from June to September when 70 to 80 percent of the annual precipitation is accounted for in the southern half of the district and 55 to 65 percent in the northern half.

d) Geometry and Vegetation

The vegetation cover on the slope is average. The historical data reveals that whenever failure occurred, it was wedge failure, with average depth of 8 to 10.5 m. Geometry of the slope is given in Figure 2.

e) Geotechnical Design Parameters

The height of the study slope is about 36.7 m high with general slopes as mentioned in Figure 2. Soil sample was collected from different locations along the slope from different depths for determining its unit weights, moisture contents and shear strength parameters in the laboratory. From Proctor tests of soil sample, the maximum dry density (MDD) was determined as 17 kN/m^3 against an optimum moisture content (OMC) of 7.5%. The direct shear test was conducted to get the shear strength parameters ($c, \emptyset$). On the basis of laboratory tests, it was concluded that the soil mass in the study slope area is almost homogeneous. Following soil parameters were adopted for FEM analysis (Table. 1).

Table 1: Properties of soil present in the slope

Properties	Values
Saturated Unit Weight of the soil (γ_{sat})	20 kN/m^3
Angle of Internal Friction of soil (ϕ)	27^0 (Total)
Cohesion *(c)*	75 kPa (Total)
Young's Modulus of the soil *(E)*	250 MPa
Poisson's Ratio (v)	0.3

METHODOLOGY

Pseudostatic stability analysis of the study slope were conducted by using the FEM based Software PHASE^2 (ROCSCIENCE, 2011). In this study, the analysis were carried out in two parts. In the first part, the slope was modelled considering its existing condition without any reinforcement scheme in the slope. In the second part, the slope is analysed under various possible design considerations using reinforcement with self-drilling anchors (SDA). Static and pseudo static stability analysis is carried out in both parts of study.

NUMERICAL MODELLING

The stability of the slope has been analysed by Finite Element Programme PHASE^2 (ROCSCIENCE, 2011) in which the factor of safety has been computed using the shear strength reduction technique (Mittal and Mukherjee, 2014). Field stress conditions are applied to the slope when it is analysed under Static condition. In pseudo static condition, horizontal seismic coefficient of 0.2 was taken based on IS: 1893, 2012, thereby a horizontal peak acceleration of 0.2 g and a vertical peak acceleration of 0.10 g was applied to the model.

The critical strength reduction factor (SRF) is equivalent to the conventional limit equilibrium "safety factor" of the slope (ROCSCIENCE, 2011). In the strength reduction technique, the strength parameters of a slope are reduced by a factor (SRF), and the finite element stress analysis is computed. This process is repeated for different values of SRF, until the model becomes unstable becomes unstable (e, g., the analysis results do not converge). This determines the critical strength reduction factor (critical SRF), or safety factor of the slope.

Additional assumptions considered in the analysis are:

(a) Plane strain condition is valid throughout the slope section.

(b) The earthquake load is considered by means of a pseudo static load through horizontal and vertical seismic coefficients.

(c) Homogeneous geotechnical conditions with properties are constant and independent of depth.

(d) The piezometric line exists at 11m from the top of the slope.

The flow diagram of the analysis is shown in Figure 3. The stability of the slope is analysed in two parts i.e. under static and pseudo static conditions.

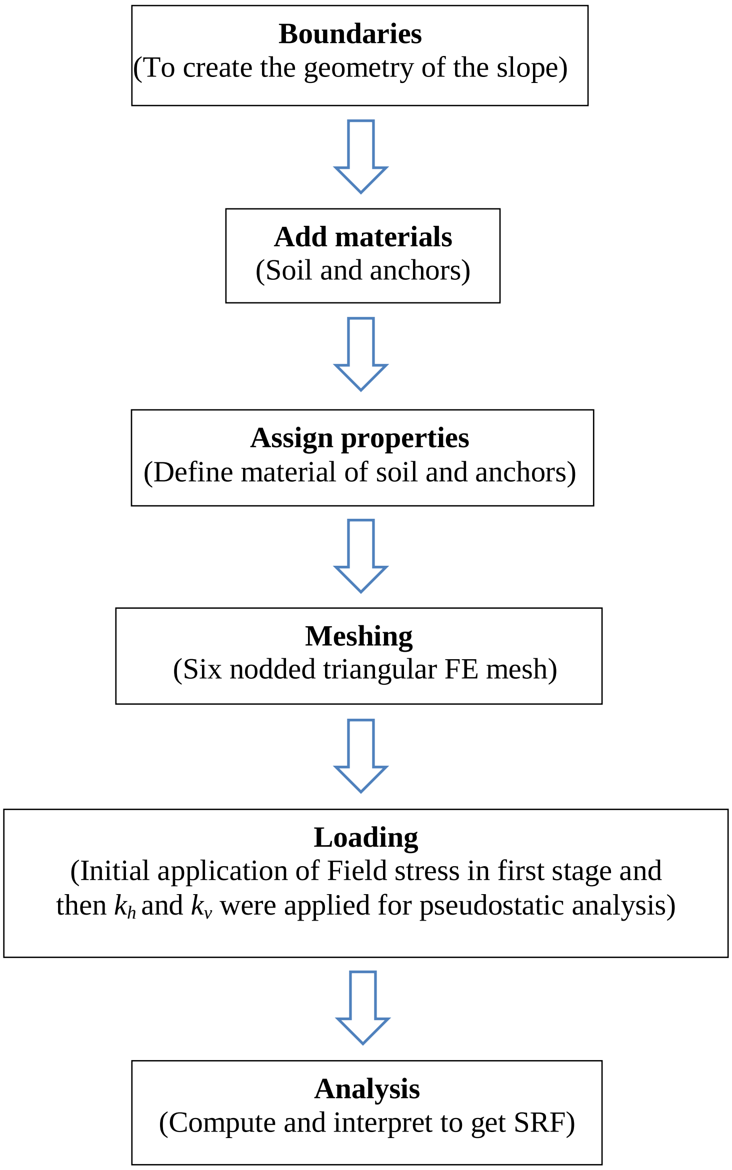

Fig. 3 Flow diagram of FE Analysis

Firstly the geometry of the slope is modelled by external boundary then entire domain of the model is discretized into six nodded triangular finite element mesh. PHASE^2 (ROCSCIENCE, 2011) solves the problem using Gaussian elimination technique using properties defined at each node of mesh. Boundary conditions are then applied to the slope as shown in Figure 4. Roller boundary conditions are applied at vertical sides of the slope (Figure 4) in which the movement is fixed in x - direction and free in y - direction and in the base of the slope. The movement is kept fixed in both x and y directions by applying pinned support at the boundary to simulate actual ground conditions. The details of both the analysis are discussed in subsequent para.

STABILITY ANALYSIS RESULTS

a) Pseudostatic Condition on Unreinforced Slope

This subsection presents stability assessment of study slope without reinforcement and under seismic solicitation using pseudostatic approach. The slope was then analysed to get the critical factor of safety. For pseudo static case the FOS is 0.93 which indicates that the slope is highly unstable under seismic condition. The pattern of failure can be observed in the strain plot as shown in Figure 4, also from Figure 5, it is further clear that the soil mass at the slope face becomes unstable and tends to come out. Therefore its stability was tested by reinforcing it with Self Drilling Anchors.

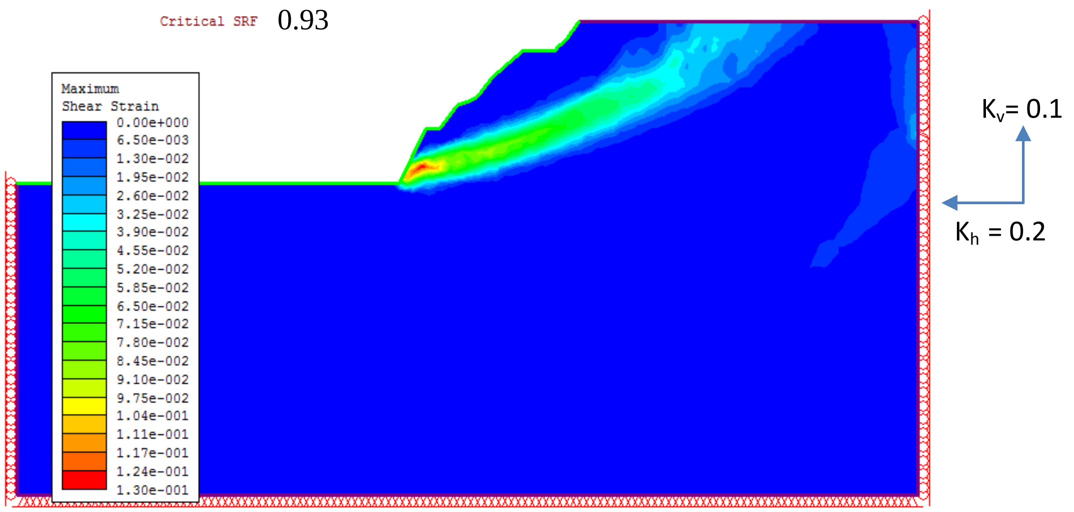

Fig. 4 Strain contours of the Un-reinforced slope under pseudo static condition

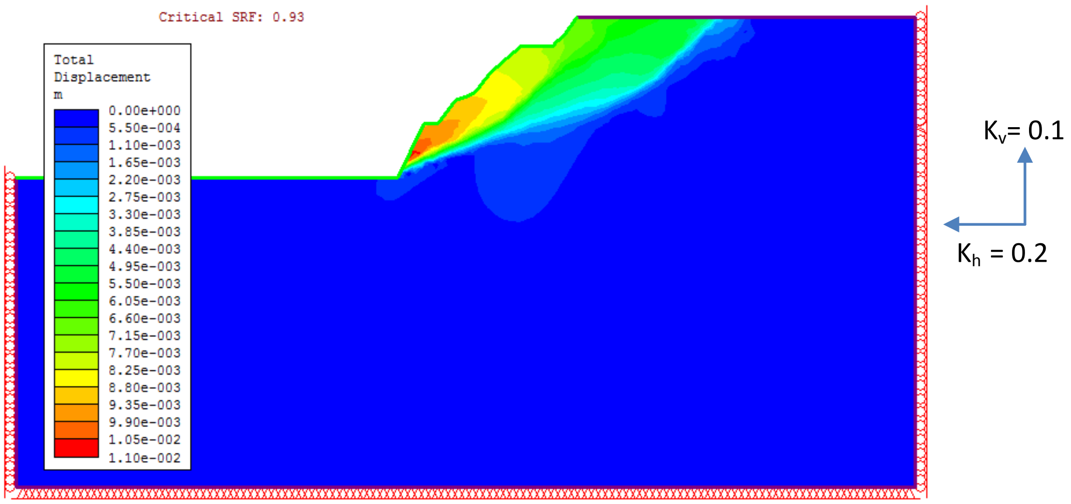

Fig. 5 Displacement contours of Un-reinforced the slope under pseudo static condition

STABILISATION OF SLOPE USING SDA

As the slope is found to be unstable under seismic condition, its stability was analysed with use of self-drilling anchors. For this analysis, the SDA was modelled as bolt in PHASE^2 (ROCSCIENCE, 2011) for which required input parameters are shown below in Table 2.

Table 2: Input parameters for SDA

Property	Value
Young's Modulus (E)	470 MPa
Diameter (d)	32 mm
Length (L)	9 m to 35 m
Tensile capacity	250 kN

From Figure 4 and Figure 5 it is clear that the strain and displacements are higher in area near the toe of the slope, therefore the SDA were placed at the face of the slope near the toe region in which the higher strain and displacement values create the instability in the slope. These anchors were assigned properties as given in Table 2 and the length of different anchors are decided according to failure envelope of the slope (Figure 4). Thereby the length of the anchors were varied from 8 m to 10.5 m, according to the requirement at various positions. Also the anchors are modelled as fully bonded anchors to accommodate the effect of grout, as the SDA behaves as a grouted nail. The out of plane spacing of the anchors is taken as 1.5 m. Gosavi et al. (2009) and Mittal (2014) have proved that the optimized angle of inclination for reinforcing the slope with nails give best results at nail slope of 10^0 with the horizontal, therefore the anchors in the present analysis have also been considered by adopting angle of inclination as 10^0 with horizontal. The layout of anchors is illustrated in Figure 6. The details of layout of anchors is given in Table 3. Figure 7 shows the strain plot of the SDA reinforced slope which gives FOS as 1.12 under pseudo static condition.

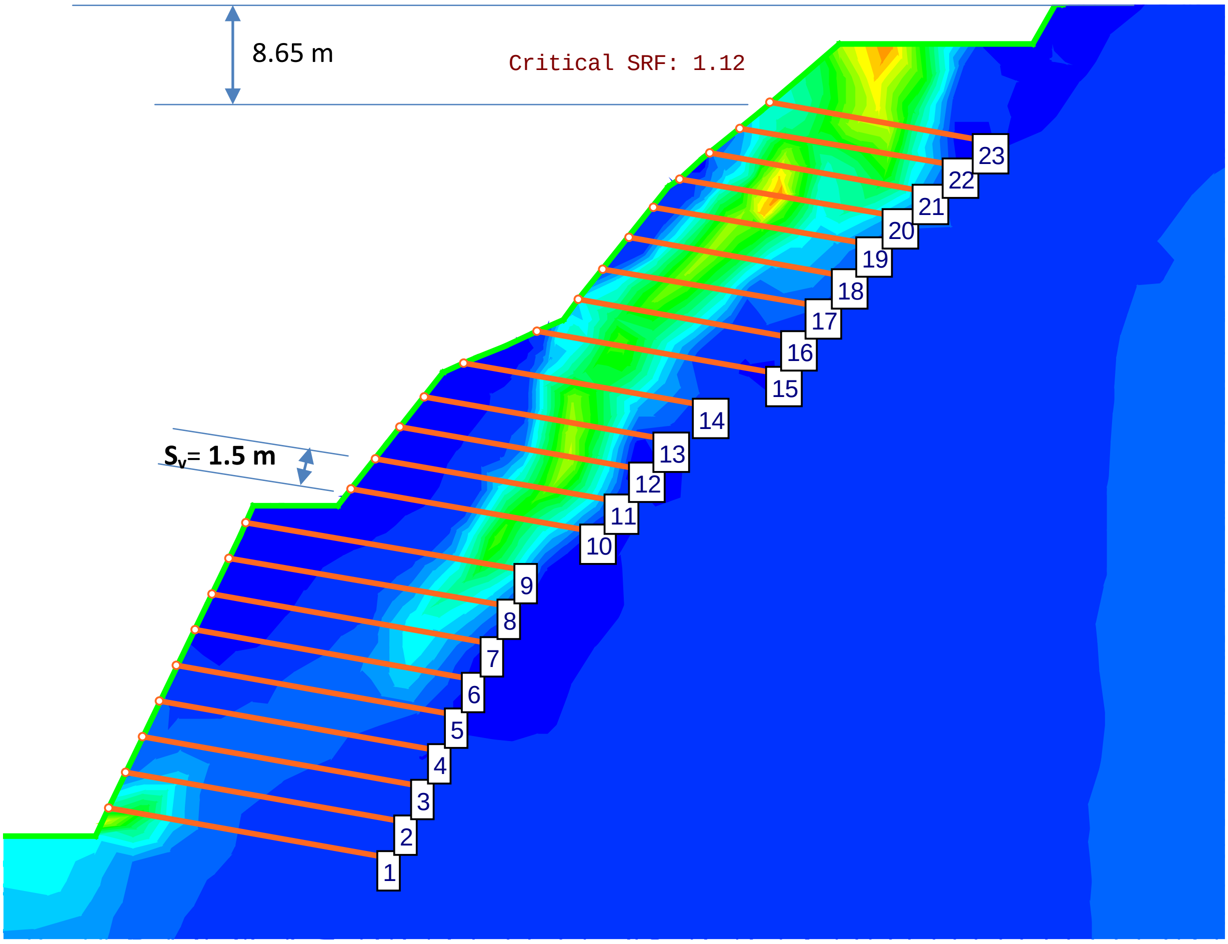

Fig. 6 Layout of Anchors

Table 3: Layout of Anchors

Anchor No.	Depth from Top (m)	Length of Anchor (m)	Remarks
23	8.65	8	**THE HORIZONTAL SPACING OF ALL ANCHORS ARE 1.5 M C/C. (S_H = 1.5)** The vertical spacing, S_v = 1.5 m c/c for anchor Angle of inclination of anchors = 10^0 from horizontal
22	9.65	8	
21	10.65	8	
20	11.65	8	
19	12.7	8	
18	13.90	8	
17	15.75	8	
16	16.23	8	
15	17.55	9	
14	18.7	9	
13	19.85	9	
12	21.00	9	
11	22.15	9	

10	23.35	9	
9	24.30	10.5	
8	25.65	10.5	
7	27.10	10.5	
6	28.80	10.5	
5	30.20	10.5	
4	31.80	10.5	
3	33.10	10.5	
2	34.30	10.5	
1	35.45	10.5	

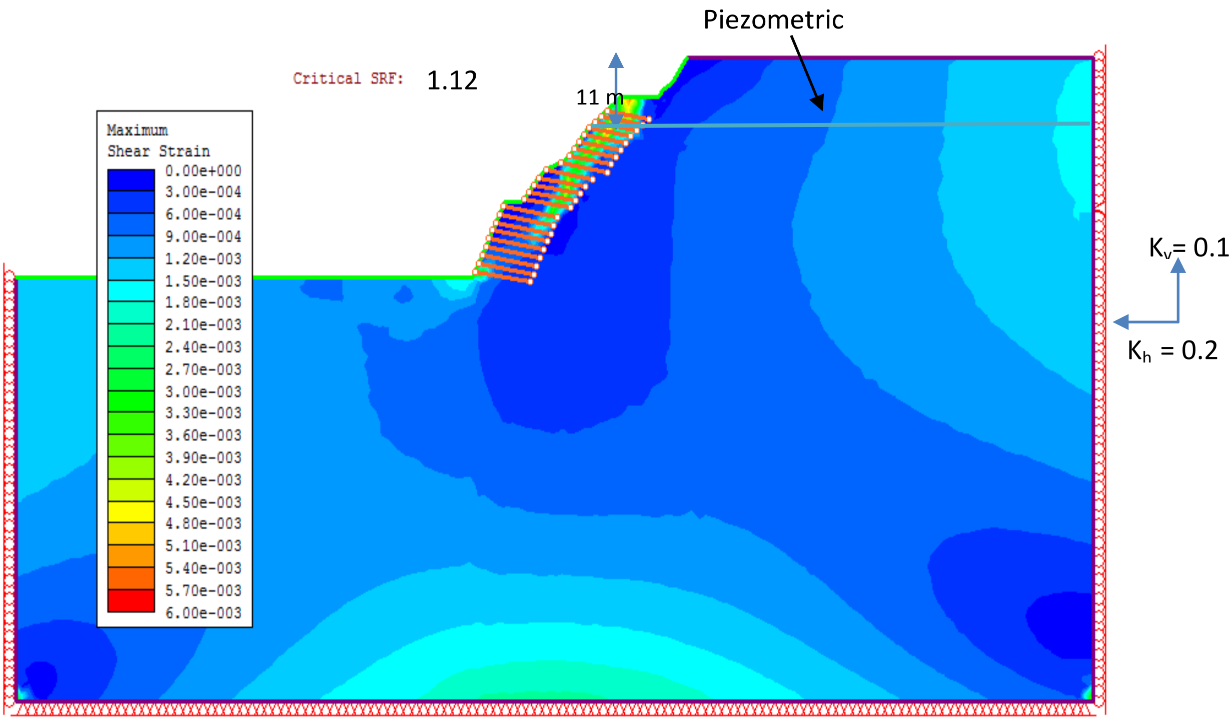

Fig. 7 Strain Contours of Reinforced Slope under Pseudo Static Condition

BACKGROUND ON SDA

Soil anchoring is a method of reinforcing the soil with tor steel bars or self-drilling anchors. The purpose of inserting anchors/nails is to increase the tensile and shear strength of the soil and restrain its displacements. The self-drilling anchors are used for reinforcing the soil and these are directly driven into the soil with the help of bit on its front. After inserting anchor to design depth, the slurry is injected through the anchor body which comes out from 2-4 holes provided in bit. The slurry thus coming out from bit makes anchor monolithic with soil. Self-Drilling Anchors (SDA) considered in analysis are 32 mm dia with spiral surface (or with ribs on its periphery). Normally an anchor is 1.5 to 5 m long (Figure 8a) and it is driven through a special machine (Figure 8b).

Fig. 8 (a): A view of self drilling anchor

Fig. 8 (b): Special machine for driving Self drilling anchor

These anchors (Figures 9a and 9b) are driven cum-grouted anchors and can be installed in all types of soils including boulder- gravel soils. These anchors are superior to soil nails in many respects as these are essentially like grouted nails and are easily driven into bouldery soils. The anchors are joined with each other through coupler(s).

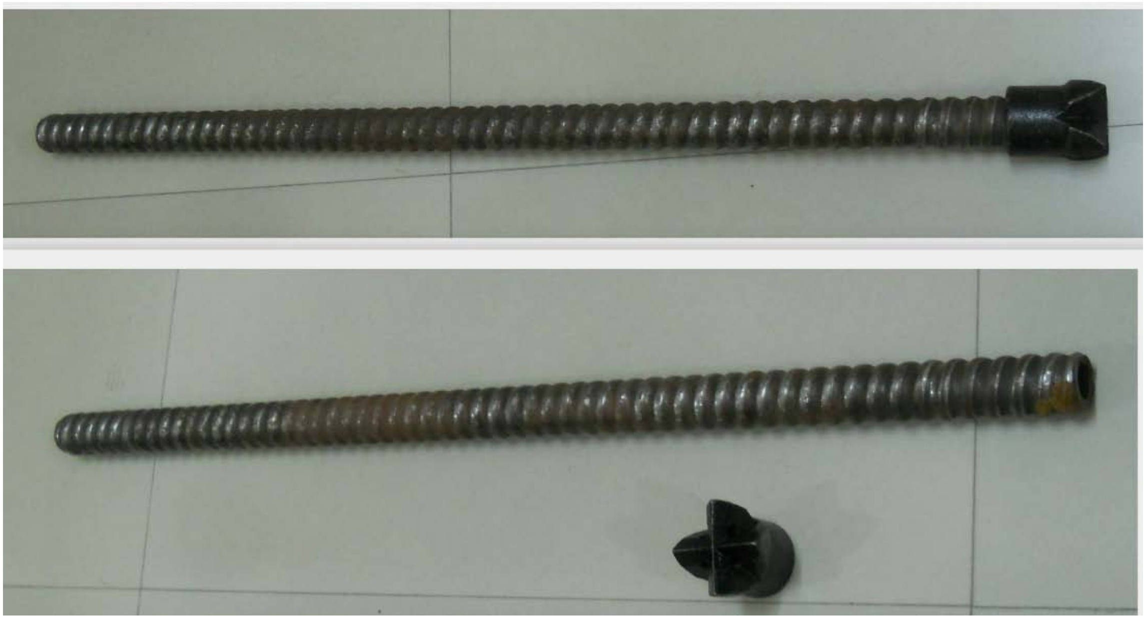

Fig. 9 (a) Self drilling anchor (Rod and cutting bit)

Fig. 9 (b) Closed view of cutting bit of Self drilling anchor

The special driving machine (Figure 8b) can install these anchors at any inclination as per the design. The special pump assembly attached with the machine can pump the cement slurry into anchor at any desired ambient pressure. This cement slurry (1:6 to 1:10, cement: water ratio) comes out of the cutting bit, when subjected to high pressure to the order of 1 to 10 kg/cm^2 through compressor. The same slurry travels back within the annular space of bore hole thus created by this anchor (Figure 9c). Installation of these anchors is very fast. In one day, easily 4 - 15 anchors can be driven successfully even in boulder - gravel deposits for a length upto 15 m each.

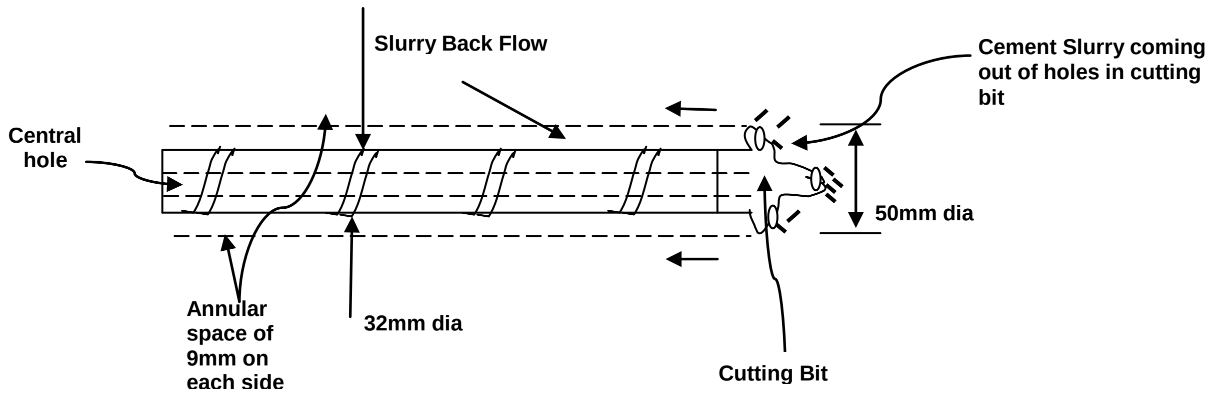

Fig. 9 (c): General configuration of Self Drilling Anchor

The stability of the study slope was analysed in 2D FEM software PHASE^2 (ROCSCIENCE, 2011) under pseudo static conditions and found unstable in its natural state. But, analysis shows that the slope becomes stable when reinforced with Self Drilling Anchors (Table-3). The SDA are modelled as bolts with input properties as dia., length and tensile strength of the anchor.

RESULTS AND DISCUSSIONS

On the basis of pseudostatic analysis of the slope, it is found that the slope is found unstable under pseudostatic condition with FOS as 0.93. The strains are maximum near the toe of the slope and the possible failure surface is circular as seen from the displacements and strain plots. Both maximum strains and displacements are found near the toe of the slope and the slope material tends to come out by showing circular failure pattern. The slope stabilised with Self Drilling Anchors shows FOS as 1.12 under pseudo static condition. SDA are provided on the face of the slope and the lengths of SDA varies from 8 m to 10.5 m according to the position of the failure surface, with higher lengths near the toe, to arrest displacement and strains occurred in the slope.

CONCLUSIONS

In the present study, an existing slope located in the Himalayan Region of India where weathered rock is present has been analysed using the 2D FEM software PHASE^2 (ROCSCIENCE, 2011). The paper evaluates the static and seismic stability with and without stabilization anchors. For the seismic stability the pseudo static approach was used where the earthquake force is considered as equivalent static force using an inertial coefficient. The slope was stabilised with Self-Drilling Anchors (SDA) which were modelled as fully bonded bolts resulting in a seismic FOS of 1.12. From the practical point of view, the SDA anchors were found to be quite easy to install in the field.

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