Stability Analysis of Rock Slope having Transmission Tower

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ABSTRACT: The need for electricity and communication network connectivity is increasing with the day. The erection of transmission towers in remote hilly areas is a challenging task due to difficult terrain and topology. Therefore, the study of the stability of slope having a foundation on top of it is necessary. In this paper, the maximum deflection in slope is studied by varying joint dip and distance of footing from the edge of the slope by keeping the footing size at 4.5 m x 4.5 m. The maximum footing size for the transmission tower is taken from the standards. The number of joint sets considered is one. The slope taken is a stair-steps slope having a road on one step and bottom step as riverbed and with the slope angle taken as 75 degrees with the horizontal. The analysis is done using ABAQUS, a finite element method based software. It is found that the maximum deflection is observed in the case when the distance of footing from the edge is 4.5 m (d=1) and the joint set angle is 45 degrees with respect to the slope. The maximum deflection observed is 2.66 mm on the far extremafrom the edge of top horizontal extent and deflection just beneath the footing is 1.71 mm.

KEYWORDS:*Slope Stability, Transmission Tower, Footing, ABAQUS, FEM*

1 INTRODUCTION

The rapid increase in population in the recent decades has made the people move to farther places in search of living space. Thereby, increasing the electricity demand, leading to the execution of hydroelectric power projects. The hydropower plants work on the principle of harvesting the potential energy of falling water. This necessitates the construction of the reservoir. The location of reservoir and dam are normally in the mountainous region.Therefore, the transmission of electricity needs erection of thetransmission towers on the hills and slopes. The construction of transmission tower in the hilly region is a challenging task, it needs the excavation of slope and its stability for the successful erection and working of these towers.The stability of slope depends upon its material properties, geological conditions, topology and the structural elements like joints, fault system, folds and shear zones etc. The presence of joints is one of the parameters controlling the stability of slope [1]. In addition to joints, the bedding plane and foliation also affect the stability of rock slope under static or dynamic load [2]. Therefore, the analysis of slope stability is an important task before the proper design of the system. Hence, in this paper, the instability of slope due to discontinuities and foundation of transmission tower has been considered.

Numerical methods like finite element analysis are widely used to analyze the stability of rock slopes [3]. Finite element methods have proved accuracy, robustness and fast computing over the conventional method of limit equilibrium [4]. The assumptions made in limit equilibrium methods can lead to unreliable results for anisotropic rocks [5]. Therefore, the FE methods are becoming a handy tool for practising engineers [4]. The analysis of rock or soil slope can be done using finite element packages like ABAQUS, ANSYS, Phase2, etc[6].This paper presentsa case study of slope from the site at Karcham – Wangtoo in Himachal Pradesh, India. The stability of slope having a foundation of transmission tower is studied in terms of maximum deflection for the varying joint set orientation and the distance of foundation from the tip of the slope. The most unstable combination of these two parameters is found out,though factor of safety is not calculated. The main reason behind this is to focus only on finding the condition which will lead to minimum FOS for slope stability. Another reason to avoid the calculation of FOS is to speed up the computation without compromising the end result.

2 NUMERICAL MODEL

2.1 Geometry

The geometry of the model is based on the actual geological conditions of the slope at Karcham Wangtoo. The slope is having 75-degree dip angle and the width of the road as 15 meters and the width of a neighbouring river as 20 meters. The elevation at which the transmission tower is established from the river bed is 40 meters. The analysis is carried forward for basalt rock mass. The footing of the transmission tower is taken as 4.5m x4.5m. Joint orientation parallel to the slope named as 0 degrees. The orientation is varied from 0degree to 90 degree [7] clockwise of the slope as shown in Fig. 1. The joint set taken is fully persistent and open-ended. Joint spacing is 2 m uniformly throughout the slope, whose stability is being analyzed.

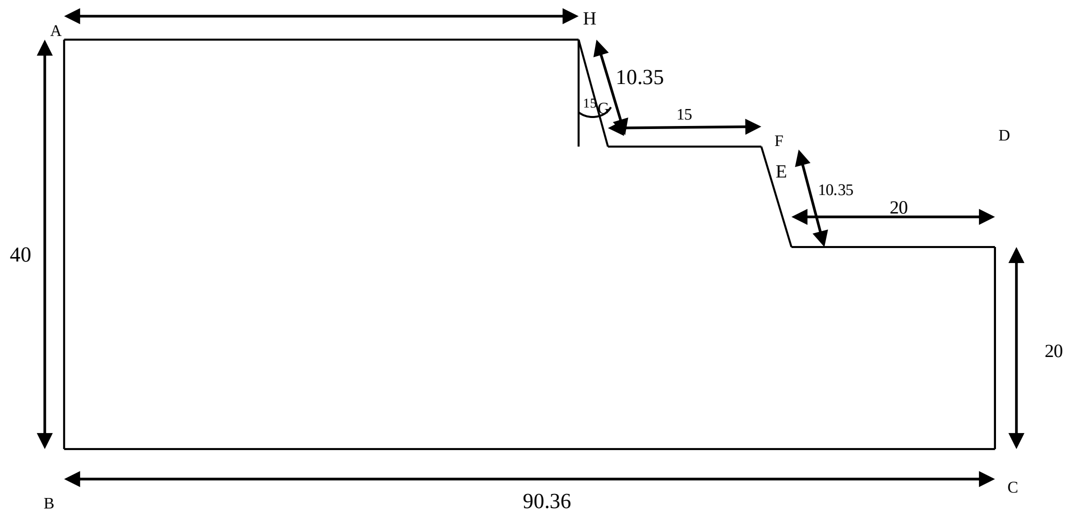

Fig1: Geometry of the Karcham Wangtoo slope. (dimensions in m)

2.2 Property

The Mohr-Coulomb failure theory is considered for the elasto-plastic analysis of the slope stability which has transmission tower constructed on it[8]. The elastic model is considered for the transmission tower footing as the failure behaviour of the footing is of less importance when compared to the stability of slope due to heavy load of footing. The material properties of rock and concrete are as follows [9]:

Table 1. Properties of the Rockmass considered

	Property	**Values**
Basalt	Mass Density	2910 kg/m^3
	Young's Modulus	46.5GPa
	Poisson Ratio	0.186
	Friction Angle	63.38
	Cohesion	26.25Mpa
Concrete	Mass Density	2400 kg/m^3
	Young's Modulus	25GPa
	Poisson Ratio	0.15

2.3 Loads and Boundary Conditions

The analysis is followed by applying loads and boundary conditions to the model. In this step, first of all, the load is applied and then boundary conditions are applied. The footing of the transmission tower used as a sub-structure to transfer the load of the upper steel structure and capacitors. The gravity load for the whole model is applied. The value of acceleration due to gravity has the value of 9.81N/m^2. The left side of the slope has y-component of boundary allowed to deform vertically. The right side of the slope was considered similar to left side. The base of the model has fixed boundary condition as the rockmass extends to a larger depth and the top is free for any movement.

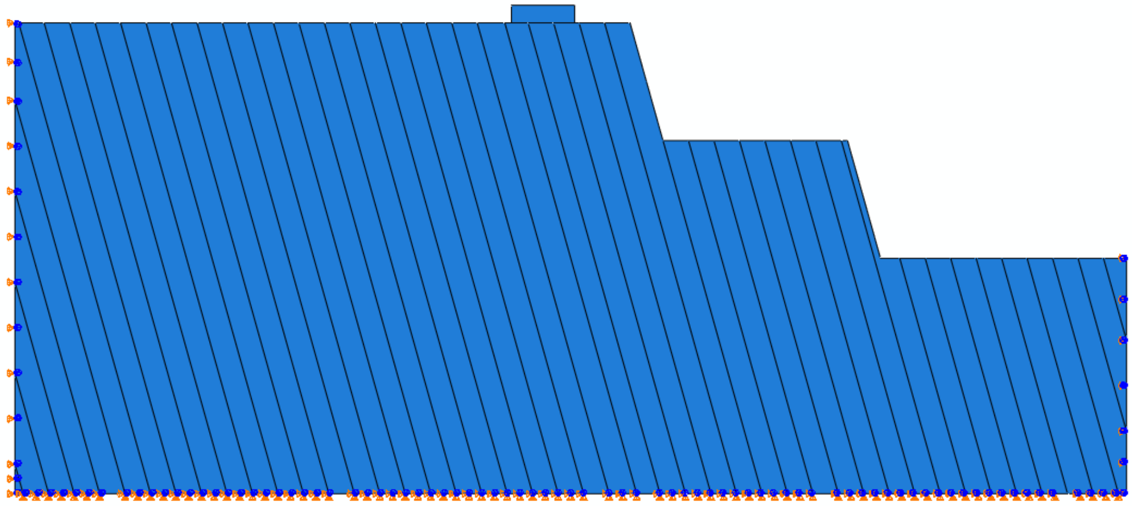

Fig2: Rock Slope Assembly and Boundary Conditions

2.4 Meshing

The meshing of model governs the size of the element in the meshing of the model of rockmass slope and footing have been taken as CPE4R – Ten node linear quadrilateral plane-strain reduced integration and hourglass element type. The non-biased approximate element size of local seed is 0.8 and maximum deviation factor for curvature control taken is 0.1. The maximum global size is considered as 0.8. The slope model has element shapeof a freetriangle.

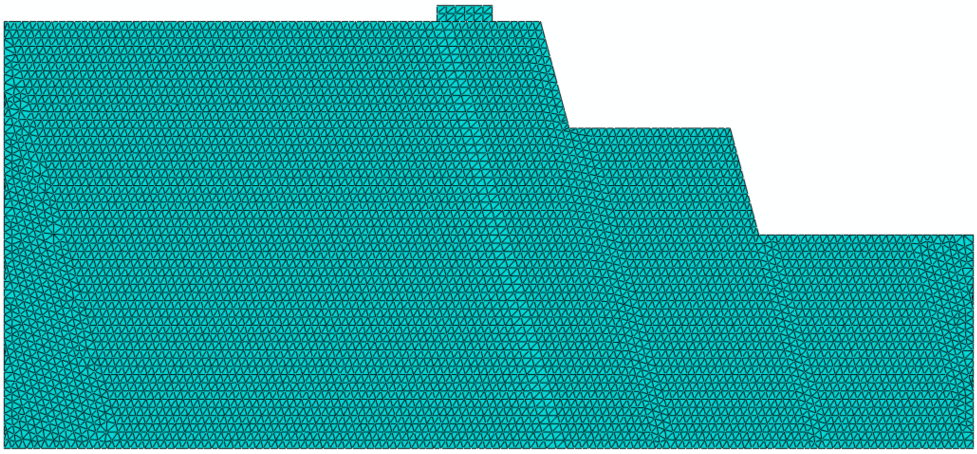

Fig 3: Mesh ofRock Slope Model and Footing of Transmission Tower.

2.5 Analysis

In this paper, the analysis of the rock mass model is carried out in Abaqus/CAE 6.13. The paper considers the analysis of the effect of joint orientation and location of the footing of transmission tower on the stability of the slope. The present study is based on static analysis. The analysis can be divided into three stages:

Stage I – Drawing the geometry of the slope and creating joints with the spacing of 2 meters. The footing is also created in this stage. Then properties were assigned to the created model and assemblage of footing on the slope was done at the required location.

Stage II – The Static general step for 1 second considered for the static analysis in Abaqus/Standard. Then, the interaction of 0.85[10] as a coefficient of friction for the joint surface is applied. Then the load is applied on the footing and the boundary conditions are applied. This load is calculated based on the weight of steel tower, capacitors, and footing.

Stage III – The last stage has meshing of the model, analysis of job and extracting the output results.

3 RESULTS AND DISCUSSION

Two-dimensional finite element analyses were carried out using Abaqus/Standard. The deformation observations are compared for different joint orientation by varying the angle of inclination of the joint from 0 degrees to 90 degrees clockwise and with respect to the slope and varying footing location from the edge of the slope. The slope is having a 75-degree angle of dip. The deflections are observed below the footing and at the edge of the slope, but only the maximum values from both points are reported here. Firstly, the joint dip is set parallel to the slope, and the location of the footing is varied until the maximum deflection condition is obtained as shown in Fig. 4. At distance of d=1 ("d" is width of footing = 4.5 m), maximum deflection was obtained. Then, by fixing the location of footing at d=1, the joint orientation is varied until the worst condition having maximum deflection was obtained as shown in Fig. 5.Table 2 reports vertical deformation for varying angle of orientation for d=1 to a d=5 distance of footing. The Table 2, Fig. 4 and Fig. 5 clearly shows that at d = 1 and having a joint orientation of 30 degrees with respect to slope, maximum displacement was observed.

Table 2. Maximum Vertical Deformation with Varying Orientation of Joints and Different Locations of Footing (in m)

d angle	0	1	2	3	4	5
0deg	5.33e-04	5.35e-04	5.28e-04	5.12e-04	5.17e-04	5.05e-04
15deg	4.79e-04	4.86e-04	4.87e-04	4.91e-04	4.86e-04	4.85e-04
30deg	2.41e-03	2.66e-03	2.04e-03	1.91e-03	1.71e-03	1.59e-03
45deg	8.48e-04	1.10e-03	8.26e-04	8.20e-04	8.23e-04	8.10e-04
60deg	7.25e-04	6.82e-04	6.76e-04	6.66e-04	6.70e-04	6.67e-04
75deg	5.24e-04	5.32e-04	5.35e-04	5.27e-04	5.24e-04	5.16e-04
90deg	4.82e-04	4.93e-04	4.97e-04	4.97e-04	4.95e-04	4.94e-04

The Fig. 4 shows contour for 0-degree angle of inclination of joints with slope for varying position of footing from d=0 to d=5. This shows the deformation is maximum for d=1 distance of footing from the edge of slope.

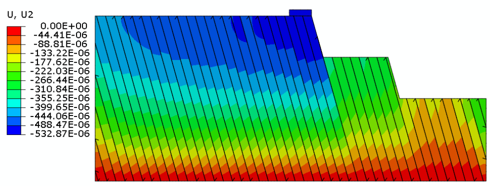

Fig 4.1: Deformation Contour with d=0 and 0-degree Joint Orientation with Slope

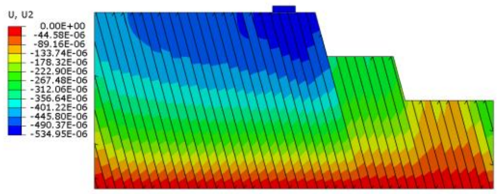

Fig4.2: Deformation Contour with d=1 and 0-degree Joint Orientation with Slope

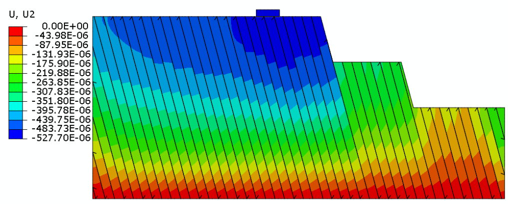

Fig4.3: Deformation Contour with d=2 and 0-degree Joint Orientation with Slope

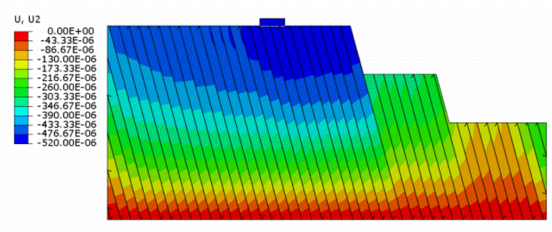

Fig4.4: Deformation Contour with d=3 and 0-degree Joint Orientation with Slope

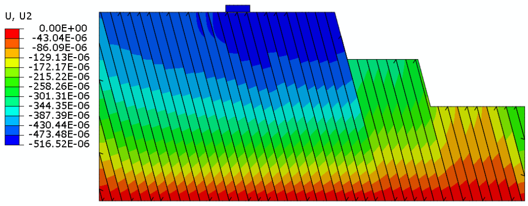

Fig4.5: Deformation Contour with d=4 and 0-degree Joint Orientation with Slope

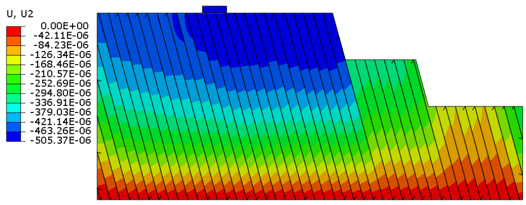

Fig4.6: Deformation Contour with d=5 and 0-degree Joint Orientation with Slope

Fig. 4: Contours of Deformation for Varying Position of Footing from the Edge of Slope and for Joint Orientation of 0 Degrees.

Fig. 5 shows contours for a d=1 distance of footingand varying angle of joint orientation. This shows that displacement is maximum for 30-degrees of joint orientation.

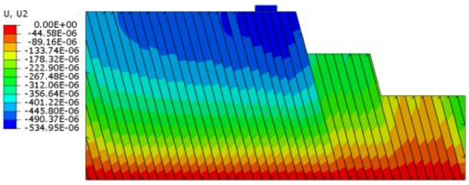

Fig5.1: Deformation Contour with d=1 and 0-degree Joint Orientation with Slope

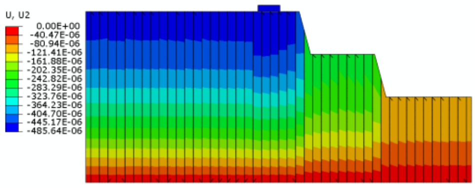

Fig5.2: Deformation Contour with d=1 and 15-degree Joint Orientation with Slope

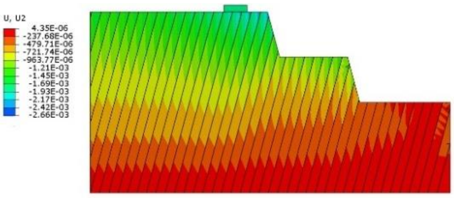

Fig5.3: Deformation Contour with d=1 and 30-degree Joint Orientation with Slope

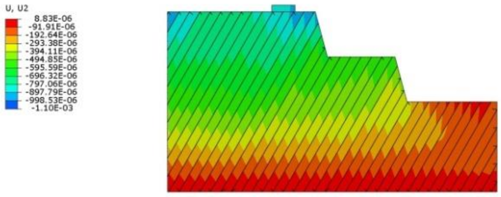

Fig5.4: Deformation Contour with d=1 and 45-degree JointOrientation with the Slope

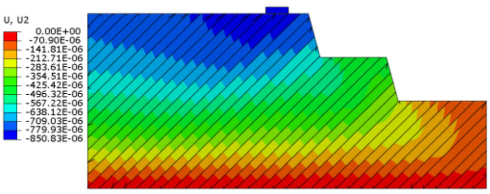

Fig5.5: Deformation Contour with d=1 and 60-degree Joint Orientation with Slope

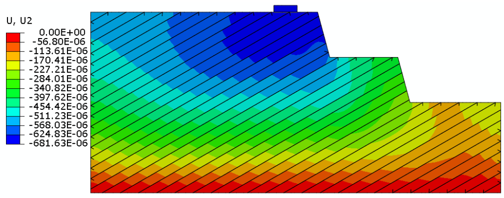

Fig5.6: Deformation Contour with d=1 and 75-degree JointOrientation with Slope

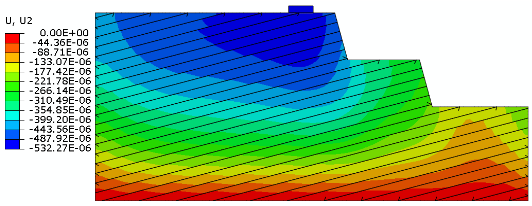

Fig5.7: Deformation Contour with d=1 and 90-degree Joint Orientation with Slope

Fig 5: Contours of Deformation for a Varying Angle of Joint Orientation for a d=1 distance of footing

From the above results it can be said that if the slope is having 75 angles of dip and the joint orientation from the slope is 30-degrees and the footing of the transmission tower at d=1distance from the edge then this leads to the most unstable condition having minimum factor of safetywhich may lead failure of slope and footing. The strength of rock depends upon the anisotropy. For joint orientation of 30-degrees with vertical plane leadsto minimum compressive strength of rock-mass [11]. Although, this analysis shows the maximum deformation at a joint orientation of 15-degrees with vertical(30-degrees with respect to slope). This ambiguity may have been arising due to the particular location of footing. So, it can be inferred that the stability of slope depends upon the joint orientation, location and weight of footing, rock strength, state of weathering, number of joint sets, joint roughness, the spacing of joint, seepage conditions, etc.

4 CONCLUSION

The analysis is carried by the authors of a slope having 75 degrees dip at Karcham wangtoo region by varying the joint orientation and the position of the footing. The finite element software ABAQUS/CAE 6.13 is used [12]. The following points are concluded:

- Transmission tower footing must be placed at a distance greater than d=1from the edge to avoid failure of the slope.
- Joint orientation with respect to slope dip must be less than or greater than 30-degrees for the favourable conditions of the design of slope and footing.
- Finite element analysis proved to be a fast and accurate method to analyse the stability of slopes over the conventional limit equilibrium method.
- The calculation of maximum deformation instead of the factor of safety has proved to be a fast method to analyze the least stable condition. This approach shows a fast method only for the qualitative analysis as it does not quantify the actual factor of safety.
- This method can be applied to any slope having any geological condition and foundation above it.
- The calculation of maximum deformation can be proved to be very useful in the final design of the slope, tower and footing
- The future scope of this study can include the horizontal forces due to wind and earthquake. The number of joint sets can also be increased as per the actual conditions.

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