

## Evaluation of stability of cutslopes in open cast metal mines using numerical modelling and field monitoring

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### **ABSTRACT**

Slope failure is one of the biggest concerns in the opencast mines in the mining industry. Monitoring information about the slopes is used for various aspects such as current mining plan evaluation, designing of future slopes and its safety control. Proper designing of slopes is crucial for its stability but in spite of how well it's designed is, it's susceptible to slope failure because of unidentified geological structures, unexpected weather conditions, or seismic activities, etc. So continuous monitoring of slopes is needed to ensure stability. In this paper Slope, stability monitoring was performed in Mine-A. The entire mine has several cut slopes made to have the passage for the conveyor belts. The field study was done in Nine locations of Mine-A. The monitoring was done with the total station and the data was compared for the two consecutive studies to find any movement. In displacement analysis, it was found that the change in displacement varies from 0-5cm from May 2015 to Feb 2016 for most of the area in the mine except the deep cut areas which have the variation of up to 9 cm in some places. The slopes are stable, but slopes in the deep cut area are moving very slowly. So, periodic monitoring is necessary for the area. The numerical modeling in this study was done with Fast Lagrangian Analysis of Continua (FLAC) Slope and Oasis softwares to find the Factor of Safety (FOS). With FLAC Slope, the value of FOS was in the range of 1.3-1.51 while Oasis slope gave the value of FOS in the range of 1.39 -1.71. The result of the graphical analysis, as well as the numerical modeling, indicates that the slopes are stable since FOS values are well above one.

## 1. INTRODUCTION

Slope stability accidents are leading causes of accidents in open pit operations. Even slopes in the several mines are moving at a very slow rate still many mines continue to work because of slope stability instruments which give timely warnings against deteriorating slope stability condition. The designing of slopes is done in such a way that their factor of safety is always well above one to control any danger of rock falls and slope failure. The important elements for the design of safe and efficient structures of the slope are rock mass characteristics, geological structure and water condition. Surface water, ground water can be controlled to abate their deteriorating effects on stability. Various slope stabilization methods are also used like secondary supports and catchments of rock fall [1-2]. However, different geological structures, seismic activities and bad weather condition can be the cause of failure to even well designed and constructed slope. So to avoid these failures, systematic monitoring, and daily observation is very important to identify slope failure hazards. Slope failure is not a process which occurs instantaneously. It gives a well measurable deformation and also cracks tension development as part of the indication of slope failure. Landslides are the results of the development of cracks over hundreds of years resulting in the form of movement of some meters. Groundwater levels and displacement are the major factors. Displacement of the slope is characterized regarding magnitude and rate, direction and regarding depth plane by the use of regular slope monitoring whereas for determining water

levels, piezometers are used [3-4]. The instruments like tilt meters, extensometers, and inclinometer take care of changes felt in the rate of slope movement and direction and also the areal extent of failure mass when deployed for surveying of fixed surface movement. Cut slopes are the man-made slopes made for the purpose of making roadways, railways; conveyor belts pass through the hilly terrain. Structural geology always concerns the design of rock cut for making highways and roads. In mining and civil projects, the rock cuts have very fewer stresses much less than the rock strength of the rock, so there's a very little chance that a fracturing will occur. So, designing of the slope is mainly concerned with the design in a jointed rock formation.

## 2. DESCRIPTION OF STUDY AREA

Mine-A is one of the largest deposit of bauxite mines in India; everyone knows the importance of scientifically engineered, properly designed and safety of slope [5]. The slope stability problem comes into picture when it endangers the total mining operation in the mine. The mine is a highly mechanized mine having dumpers of capacity 50 and 55 tons, shovels of up to 8.7 m<sup>3</sup> capacity and the trenches are 8 to 10 m high and 50 m wide. The Bauxite is soft in nature, so ripper and dozer also rip it along with drilling and blasting. 1600 mm is the average rainfall annually. The 14.6 km conveyor belt which passes through many cut slope areas to transport the bauxite right from the mine to the alumina plant. Field visits

were conducted in 9 areas of Mine-A for cut slope stability including one mine area and slopes around the cable belt conveyor. The total station was used for monitoring in this study.

### 3. DISPLACEMENT ANALYSIS

Table 1 gives an overview of the data obtained by total station monitoring during field visit; it shows the three maximum displacements at different locations and probable cause along with the remarks based on the analysis using displacement analysis.

**Table 1.** Maximum displacement at different stations

Location(Station)	No. of monitoring stations	Maximum Displacements (cm)	Possible cause	Observation/Remarks
Eastern side of part-II mining area.(N18°51.022', E83° 00.757')	27	6.7, 4.9, 4.7 at station 8, 15 and 18 respectively	No	The strain due to movement is well within safe limits. No major concern.
Southwestern side of part-II mining area.(N18°51.201', E83° 00.593')	17	2.1, 1.9 and 1.6 at station 44, 34 and 37 respectively	No	
The Western side of Drive House Area. (N18°50.761', E83° 01.317')	12	4.3, 4.0, and 2.9 at station 29, 23, and 33 respectively	Local displacement	The strain due to movement is well within safe limits. No major concern.
Western Hill of cable belt corridor adjacent to the southern side of Drive house. (N18°50.691', E83° 01.226')	14	4.3,4.2 and 3.1 at station 10,2 and nine respectively	Local displacement	Some crack developing on the lower side of the slope, so some reinforcement needed.
Eastern hill of cable belt corridor adjacent to the southern side of Drive House. (N18°50.665', E83° 01.248')	27	5.2, 4.8 and 4.3 at station 37,31 and 23 respectively	No	The strain due to movement is well within safe limits. No major concern.
Eastern side of deep cut area. (N18°47.591', E82° 58.292')	9	9.4, 9 and 6.3 at station 6, 3 and nine respectively	Local displacement	Readings show that there is considerable movement in the area, but visual observation suggests it's safe. The wrong readings can be attributed to many broken or missing stations.
The Western side of the deep cut area. (N18°47'35.25", E82° 58'15.37")	7	9.3, 8.1 and 8.1 at station 37, 38 and 35 respectively.	Local displacement	
The Eastern side of conveyor belt line between bridge nos. 3 & 4. (N18°47.250', E82° 57.630')	10	5.3,4.6 and 4.1 at station 18,24 and 21 respectively	Most of the stations are damaged or inaccessible due to soil erosion	The strain due to movement is well within safe limits. No major concern.
The Western side of conveyor belt line between bridge nos. 3 & 4. (N18°47.260', E82°57.597')	9	2.8, 2.2 and 0.8 at station 1 ,2 and 5 respectively	Most of the stations are damaged or inaccessible due to soil erosion	The strain due to movement is well within safe limits. No major concern.

### 4. LABORATORY ANALYSIS

Direct Shear test was used to find out the shearing strength of the soil using the direct shear apparatus. This test also gives the value of Cohesion (c) and Frictional angle (Ø) which are utilized for the numerical modeling analysis for determining the stability of the slope [6]. The soil sample was collected from the selected mine from two locations having the highest and lowest displacements were taken and tested in the lab for “c” and “Ø” using direct shear test. The cohesion and Frictional angle values for Deep cut area are 83Kpa and 33di and for part-II mining area are 87Kpa and 38di.

### 5. NUMERICAL MODELLING OF SLOPES

Numerical modeling was done using the Oasys and FLAC SLOPE softwares [7-8]. Analyzing the slope stability is the primary function of the Oasys software. Soil reinforcement

and earth pressure can be taken into account while modeling both soil and rock slopes which allows circular as well as non-circular failure. Oasys works on the principle of limit equilibrium method. Bishop method is the preferred method for calculating FOS in Oasys in which Bishop's variably inclined inter-slice forces method is used as the best method in Bishop's Oasys slope to calculate FOS. The rock materials constituting a pit incline decides the rock mass FLAC/Slope is a smaller than normal form of FLAC that is organized specially to do the component of safety means slope strength examination. This adaptation is executed just from FLAC's graphical interface which helps for a quick beginning of models for rock slope/or soils and portrayal of their circumstances related to strength. Here the modeling of cut slopes different location of Mine-A was done by taking the required data like cohesion friction angle slope height obtained from the direct shear test performed in the laboratory. Figure.1 to Figure.4 shows the Oasys and FLAC modeling of the cut slope of part II mine area, drive house area and Deep cut area.

Table.2 shows the Comparison of FOS values using FLAC and Oasys modeling.

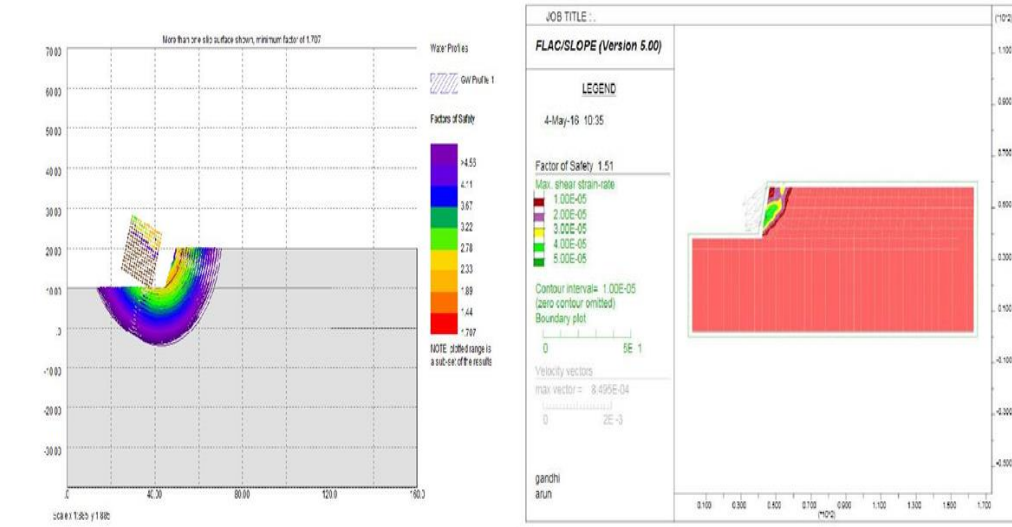


Figure 1. Oasys and FLAC modeling of cut slope of part II mine area having slope height 35m, and slope angle 60°

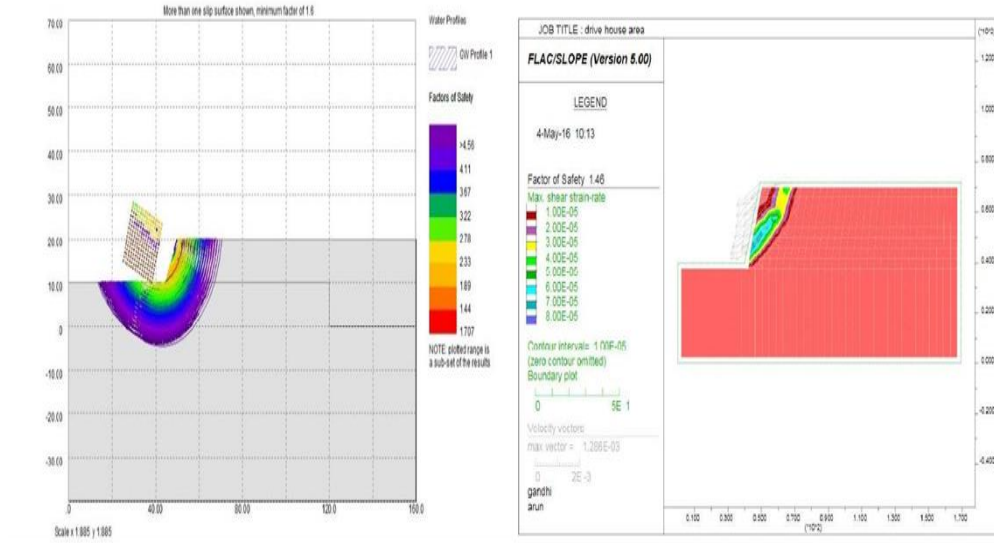


Figure 2. Oasys and FLAC Modeling of cut slope of drive house area having slope height 32m, and slope angle 74°

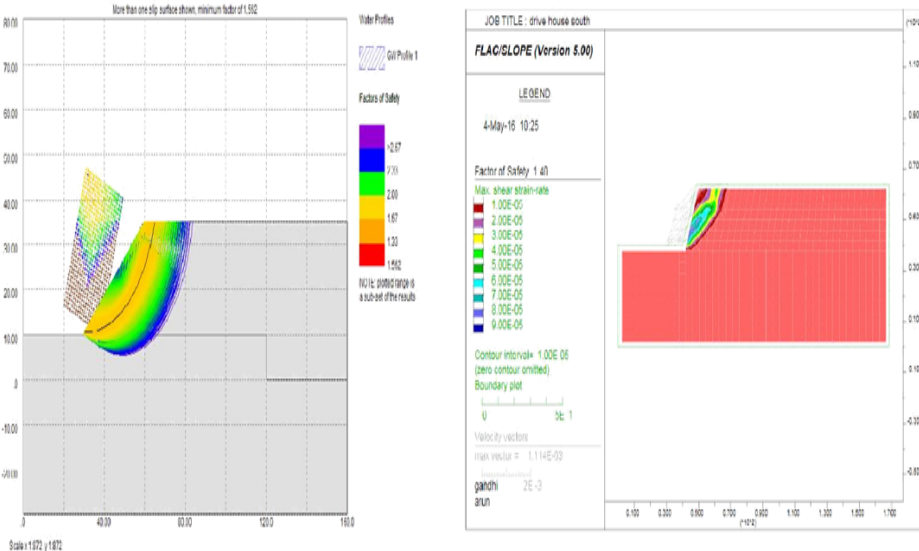
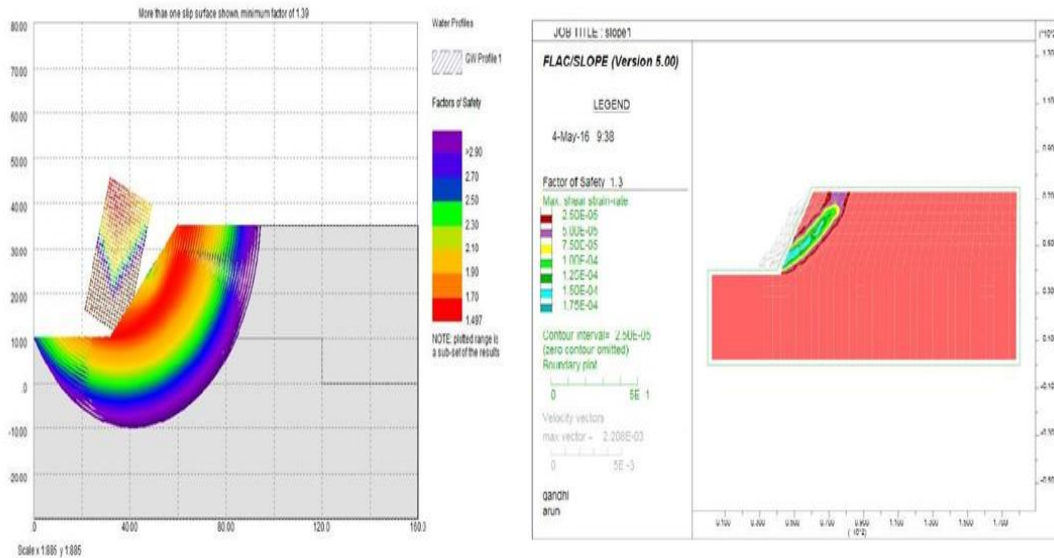


Figure 3. Oasys and FLAC modeling of cut slope of drive house area having slope height 24m and slope angle 70°



**Figure 4.** Oasys and FLAC modeling of deep cut area

**Table 2.** Comparison of FLAC and OASYS value for different sites

Location	Factor of Safety FLAC	Factor of Safety OASYS
Deep cut area	1.3	1.39
Drive house area (24m slope height)	1.4	1.56
Drive house area (32m slope height)	1.46	1.60
Part II mine area	1.51	1.70

## 6. CONCLUSION

Based on the data obtained from mine using Total Station, Numerical modelling using FLAC and OASYS softwares and from the displacement analysis it was concluded that most of the changes in displacement are in the range of 0-5cm for a period between May 2015 and Feb 2016, which indicates that the slope movement is very low in that period. The factor of safety is found out to be in the range of 1.3-1.51 at different locations when modeled using FLAC SLOPE while it is found out to be in the range of 1.39-1.7 when modeled using Oasys Slope. Since the Factor of safety is above well above one, the slopes are stable. Wireless Network system along with Time

Domain Reflectometry (TDR) is also recommended for real-time monitoring of stability of the slope in near future.

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