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An Investigation on Stability of Mine Slopes using Two Dimensional Numerical Modelling

*V. Vishal[1] *, S. P. Pradhan[2], T. N. Singh[2]*

[1]Indian Institute of Technology Roorkee, Roorkee, India
[2]Indian Institute of Technology Bombay, Mumbai, India
[*]Email: vik12fes@iitr.ac.in

ABSTRACT

The expansion of open cast mines and accessing deeper reserves of coal have tremendously contributed to meeting the growing energy demands of the country. Working slopes are being made steeper to extract the left over coal and is indeed a threat to men and machinery located in the active slope areas. Steep slopes were encountered in an open cast mine in Jharia coal field that produces good quality of bituminous coal. Two distinct slopes were identified based on lithological variations and joint sets and a detailed investigation was conducted to establish the stability of the slopes. Although, random occurrences of failures were seen on both – working as well as left over slopes, it was important to understand the behaviour of slopes from within. The pertinent geo-mechanical characteristics of the rock specimens were determined in the laboratory. These parameters were used as inputs during simulation. The results were corroborated with the field conditions and a detailed understanding of the mechanics of rock behaviour was established. Slope with highly fractured sandstone showed considerable failure scenario in the numerical model. It was interesting to note that slope with a visibly stable condition turned out to contain possible failure planes within the rock strata. This plane could prove to act as a plane of weakness and cause large scale failure along the slope. Numerical modelling proved extremely useful to visualize the state of slopes and identify the zones of maximum deformation not only on the surface but also at sub surface levels.

Keywords: Stability of slopes; Factor of safety; Finite element method

1. INTRODUCTION

Jharia coal field is one of the largest coal fields located in Jharkhand, India having estimated reserves of 19.4 billion tonne of coal. Jharia coal field consists of 23 large underground and 9 open cast mines. It produces bituminous rank of coal. Slope stability of open cast mines is always a challenging task because of safety and economic considerations. Slope stability problems are very common on the excavated slopes due to imperfect blasting and poor techniques of excavation of the rock mass. Further, the slopes are also affected due to fire at many locations.

The mine slope was studied for Rajapur open cast mine in Kustore area in Jharia. The identified slopes were simulated using state of the art numerical code Phase^2 based on finite element method (FEM).

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2. STUDY AREA

Rajapur open cast mine in Kustore area is under Bharat Coking Coal Limited located in the eastern side of the Jharia coal field. The area falls under the Barakar formation in Lower Gondwana of Permian age. It is about 9 km South-West of Dhanbad railway station and about 2 km from Jharia Township (Fig.1). Rajapur open cast mine is bounded on its four sides by Bastacola in North, Bhuggatihin South-East, Dobari in East, and Ena industry in the West. The longitude and latitude of field sites are 86° 25' E and 23° 45' N respectively. This area experiences a hot humid sub tropical climate and temperature ranges from 14°C to 48°C. Average rainfall is approximately 140 cm (55 inch). Jharia coal field is characterized by gently undulating to a rolling topography with overall slope towards east to south east. The ground elevation varies from 150 m to 250 m. Rajapur open cast mine produces bituminous rank of coal but has many problems like water seepage, fire and slope instability. The active mining site has 4 benches of 12 m in height and 5 m in width. Generally, two sets of joints and at some locations three sets of joints were observed. So, two distinct slopes were seen in terms of slope stability- one was fractured sandstone showing wedge failure and the other was intercalated shale and sandstone having two set of joints which were internally disturbed.

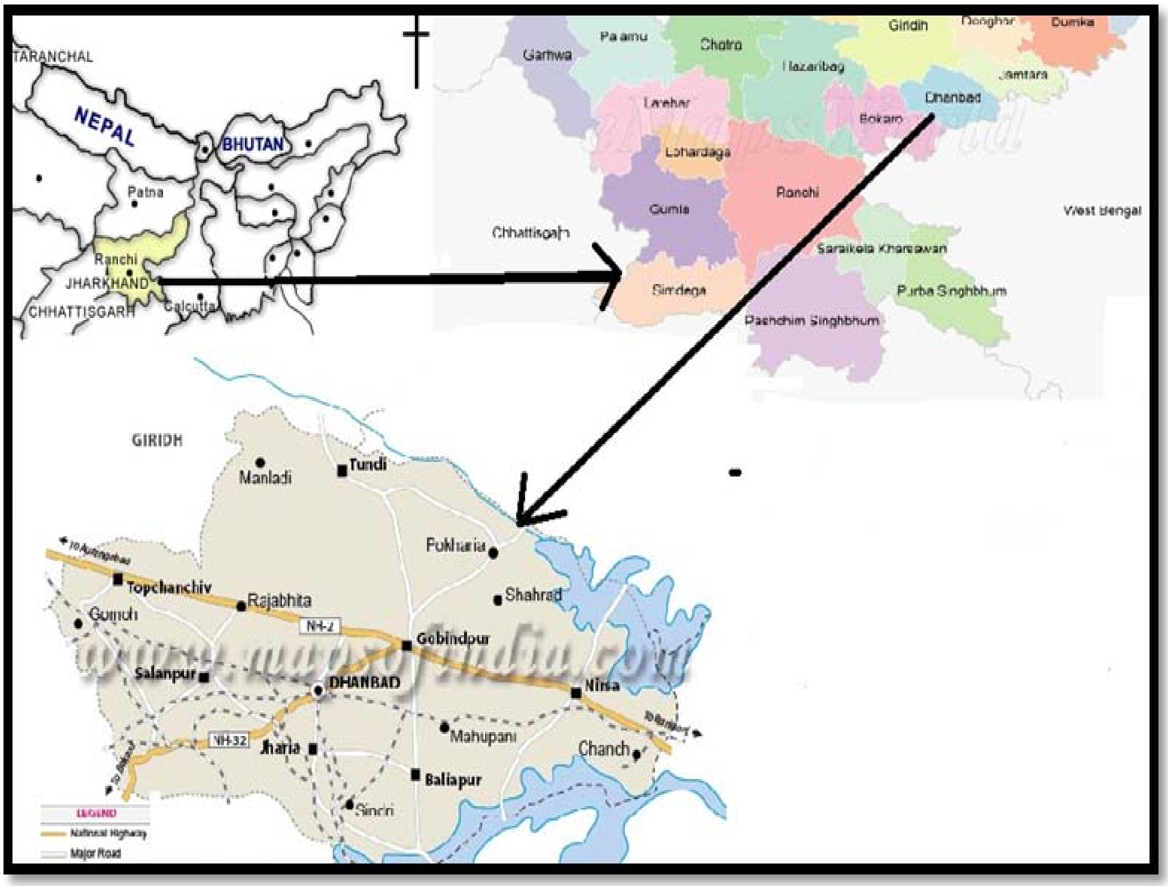

Fig. 1 - Area of investigation shown in a political map

3. NUMERICAL SIMULATION OF SLOPES

Two slopes i.e., slope-1 and slope-2 (Figs. 2 and 5) were studied in the area. These have similar geometry but vary in joint orientation and spacing of the joints. These two slopes were simulated using FEM based Phase^2 simulator. Few earlier studies have also addressed the failure of slopes in mines using different methods such as SMR, kinematic analysis and other numerical tools (Gupte et al., 2013; Pradhan et al., 2011 & 2014; Singh et al., 2013; Trivedi et al., 2012; Vishal et al., 2010).

The FEM divides the mass continuum into discrete units called finite elements. At the nodes and continuum boundaries elements are interconnected. Displacement method of formulation of the FEM is used for geotechnical applications and results are available in the form of displacements, stresses, and strains. There are many two and three dimensional computer programs available based on finite element analysis of slopes and embankments (Desai et al., 1984). Many difficulties are associated in finding a factor of safety (FoS) against failure. Wong (1984) explained the problem associated in evaluating FoS. In any conventional limit equilibrium approach, failure may be described as the condition where the driving forces/moments are more than resisting forces/moments. The failure phenomenon is progressive where all elements do not fail at a time. Therefore, failure is extended to a wider range where yield occurs from the first to the final failure state. In final states, all elements have effectively failed.

3.1 Phase^2 Simulator

Phase^2 is a 2-dimensional elasto-plastic finite element program for calculating stresses and displacements in many engineering discipline and also in mining problems. Hammah et al. (2004) used shear strength reduction technique for FoS. The method calculates stress-strain relation at any point of a defined grid. Mohr-Coulomb criterion of failure is used. For evaluation, six input parameters of the dump material like angle of internal friction, cohesion, Young's modulus of elasticity, Poisson's ratio, dilation angle and unit weight are required. Uniform mesh with six-noded triangular elements, 1500 mesh elements are required to divide the slope geometry in the analysis. Plane strain analysis with Gaussian elimination solver and maximum number of iterations (500) with a tolerance (0.001) are some of the important features. FEM program caters the needs like general geometries, rock property variations including variable water levels and pore water pressures. The program adopts reduced integration in the gravity load generation. Further, it generates the stiffness matrix and the stress redistribution phases (Griffiths, 1990). It is assumed that the material is initially elastic and at all Gauss-points within the mesh, normal and shear stresses are generated. With Mohr-Coulomb failure criterion, the generated stresses are compared. Location is considered to be in elastic state if the stresses at the Gauss point lie within the Mohr-Coulomb failure envelope. Location is considered to be yielding, if the stresses lie on or outside the Mohr-Coulomb failure envelope. Yielding stresses are redistributed throughout the mesh (Zienkiewicz, 1971). Overall shear failure occurs, if sufficient number of Gauss-points has yielded to develop the failure mechanism.

3.2 Slope-1

Slope-1 strikes N50^0 with a slope angle of 75^0. The height of the slope is 60 m. In case of slope-1, there are three sets of joints whose orientation is given in Table 1. The slope is simulated by Phase^2 numerical code to evaluate the stability.

Table 1 - Attitude of joints and slope (slope-1)

Joint	Strike	Dip
J1	N 30°	75° due ESE
J2	N 120°	75° due SSW
J3	N 345°	80° due SW
Slope	N 50°	75° due SE

The critical strength reduction factor (SRF) computed for slope-1 was found to be 2.03, which indicates that the slope is stable in terms of SRF. A zone of concentration of semi-circular shear strain was noticed at the mid of the entire slope and concentration of higher shear strain at the base of the toe. The magnitude of this shear strain was found to be 1.0×10^{-1} (Fig. 3). Maximum displacement at critical SRF was 0.362 m (Fig. 4). Numerous tension points were developed at the topmost bench along the slope face (Fig. 4). These tension points joined to form tension crack which may create instability and this can be corroborated with the field observations (Fig. 2). A proper monitoring of this entire zone is required for stability.

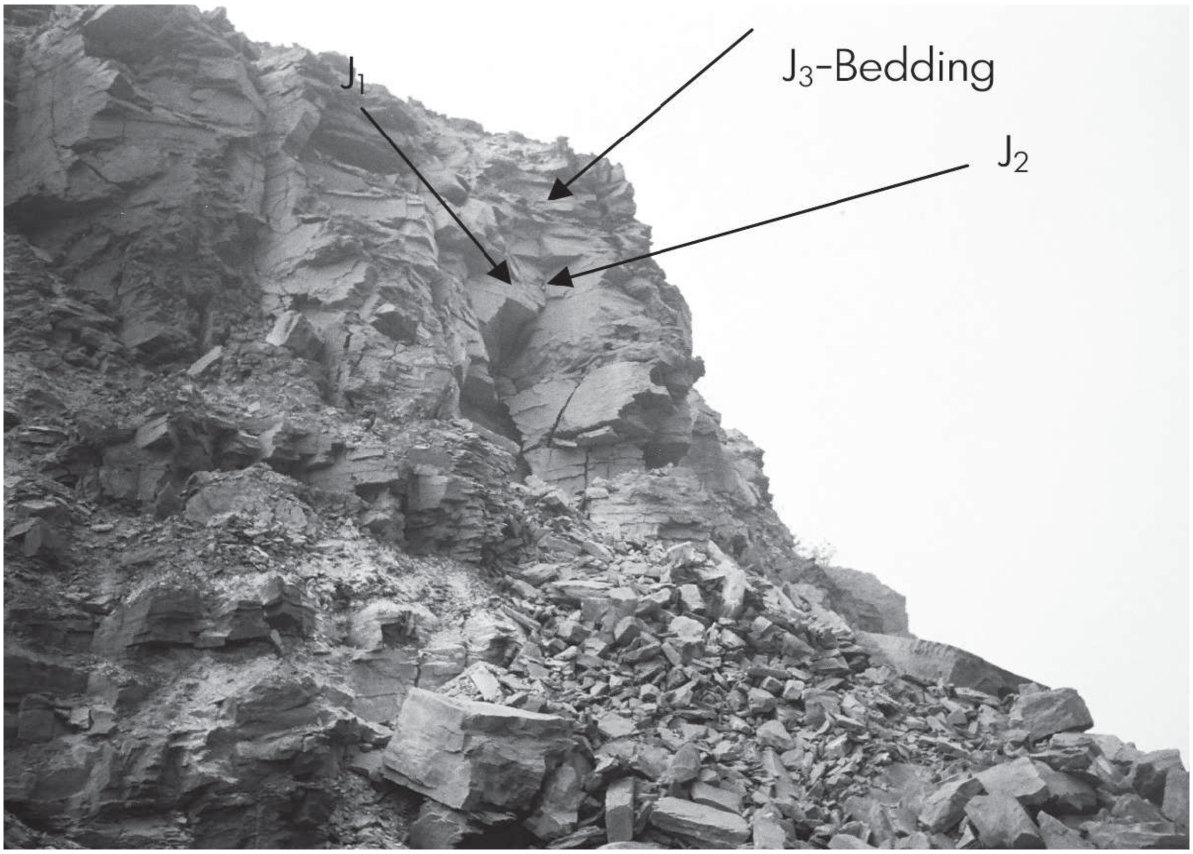

Fig. 2 - Condition of slope-1

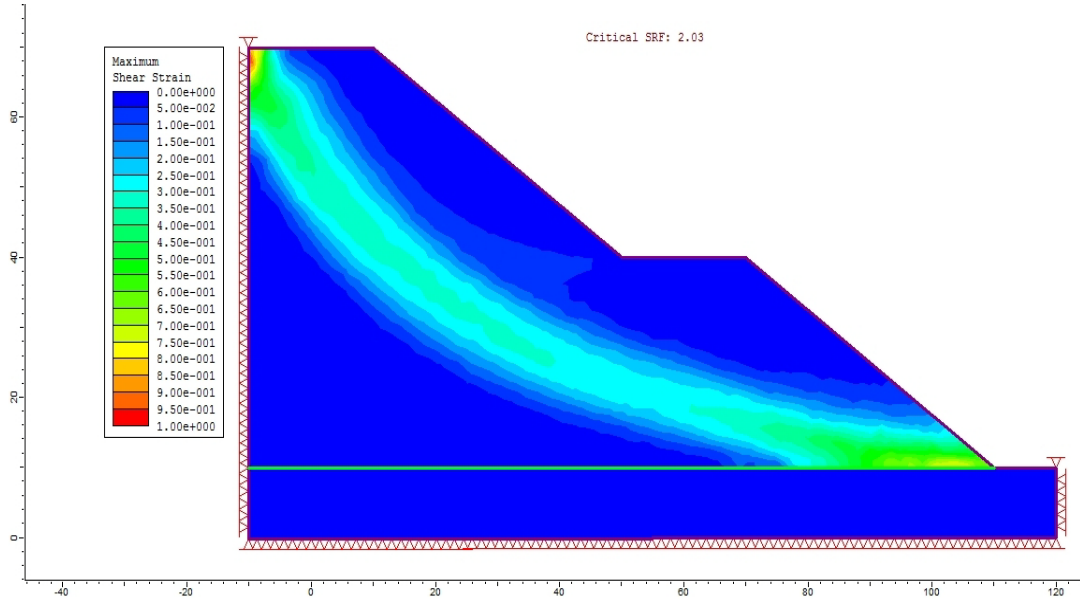

Fig. 3 - FEM model showing strength reduction factor (SRF) and maximum shear strain in slope-1

3.3 Slope-2

The slope-2 strikes N 355^0 with bench slope angle of 70^0. The height of the slope is 60 m benched into two benches of 30 m each (Fig. 5). There are two sets of joints present whose orientation is given in Table 2. The slope is simulated to evaluate its stability.

In this case, the estimated SRF was found to be 2.99 (Fig. 6). The maximum value of shear strain was found to be 1.0. It was higher as compared to slope-1, but the pattern of shear strain was almost similar to slope-1. The zone of shear stress is discontinuous as compared to earlier one. The maximum displacement was observed to be 0.355 m (Fig.7).

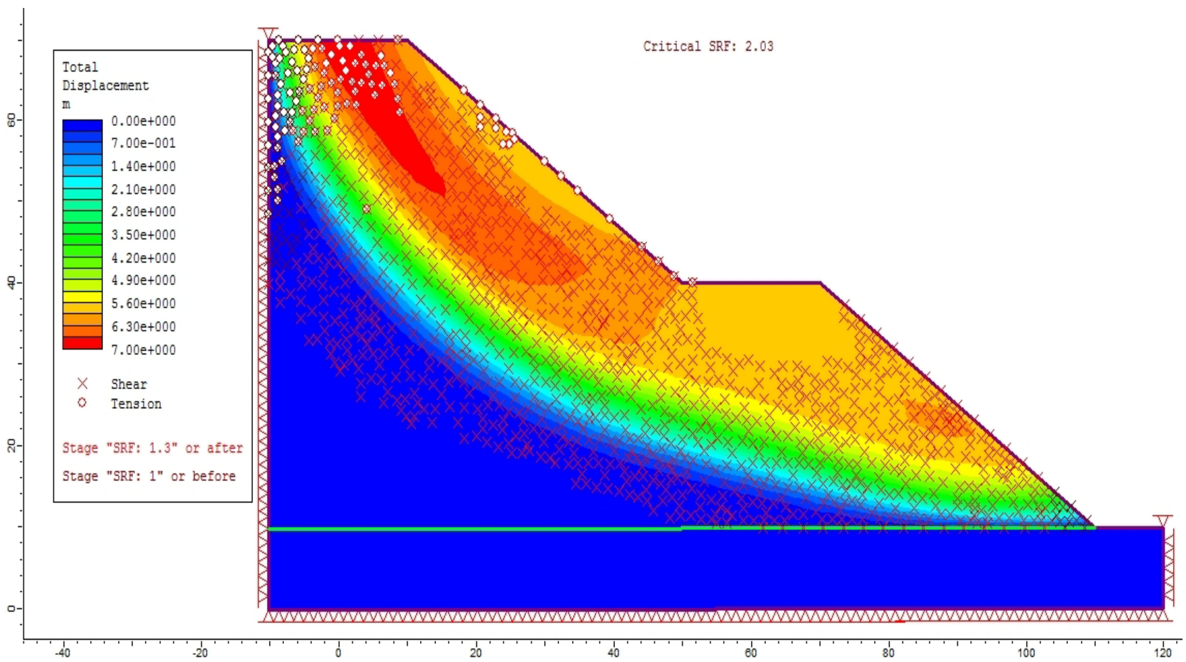

Fig. 4 - FEM model showing total displacement and plastic points in slope-1

Fig. 5 - Condition of slope-2

Table 2 - Attitude of joints and slope (slope 2)

Joint	Strike	Dip
J1	N 45°	90°
J2	N 345°	80°
Slope	N 355°	70° due SE

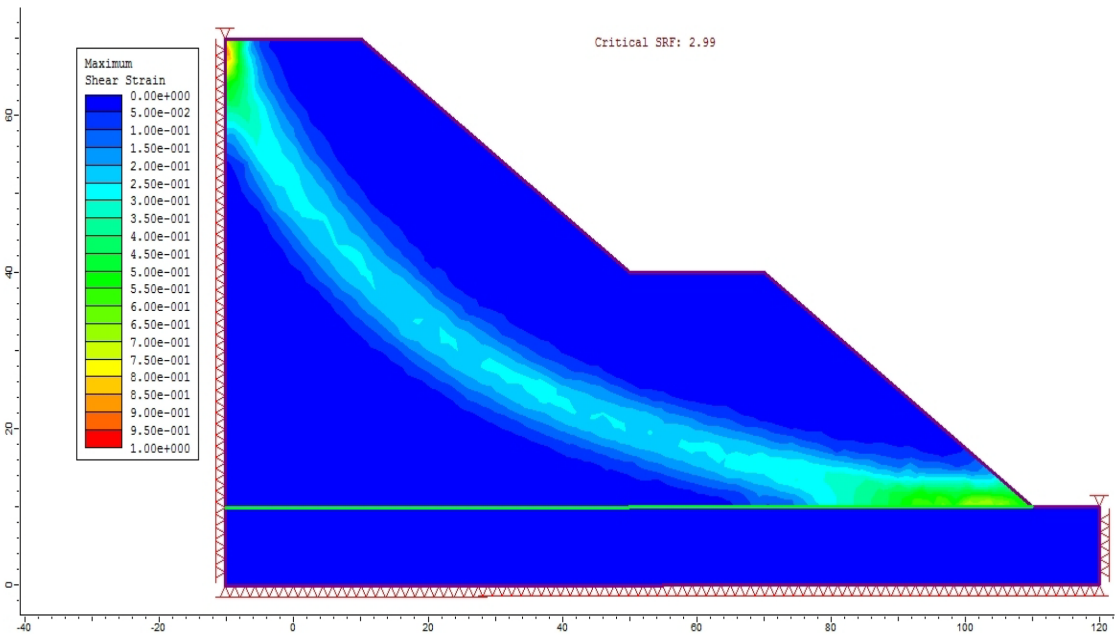

Fig. 6 - FEM model showing SRF and maximum shear strain in slope-2

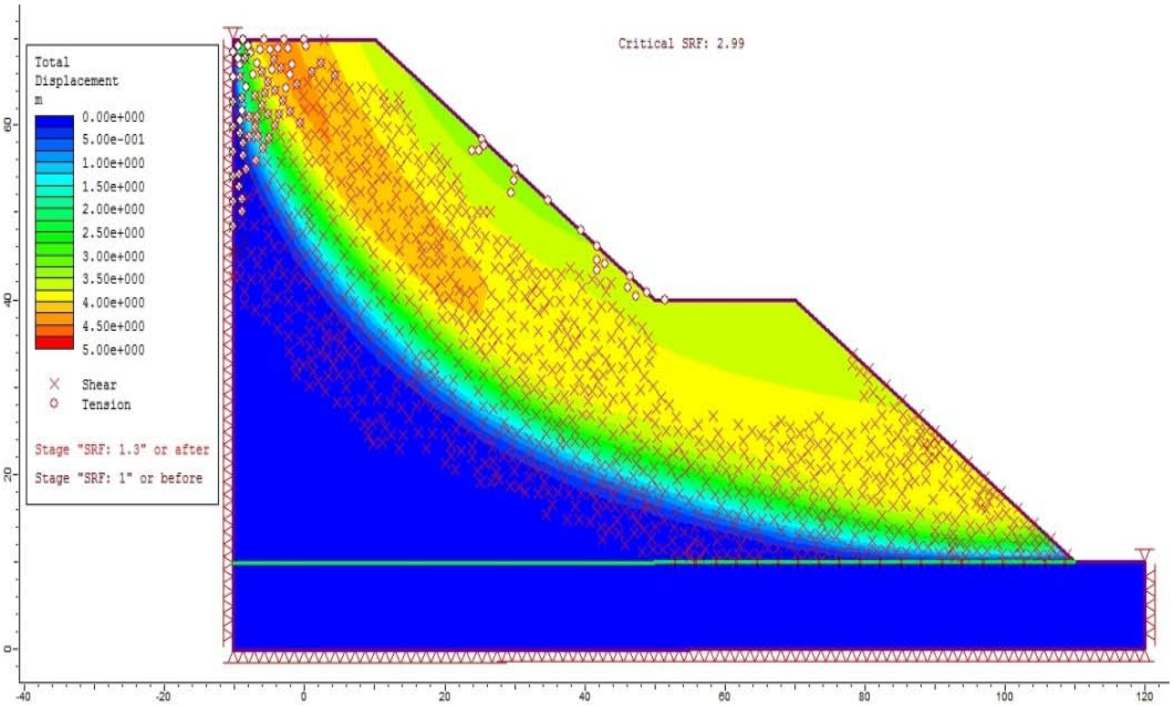

Fig. 7 - FEM model showing total displacement and plastic points in slope-2

While comparing the results of slope-1 and slope-2, it is observed that in case of slope-1 the SRF is less as compared to slope-2. This is because the number of joint sets is more in case of slope-1. More the number of joint sets, weaker is the slope mass and hence the reduction in SRF leading to development of large number of cracks in slope-1. These tension cracks coalesce and trigger slope failure which needs proper attention. In case of slope-2, there are only two sets of joint making the rock mass relatively stronger than that of slope-1. This makes the shear zone discontinuous (Fig. 6) and make the slope more stable. In both slope-1 and slope-2, the yield points due shear are concentrated more in a circular plane. The tension points are more localized at the top and rear end of the slope. Toe section and top of the bench demonstrates chances of planar failure.

4. CONCLUSIONS

In this study, slopes were studied in an open cast coal mine in Jharia. A detailed investigation was carried out to understand the stability of two types of slopes in the area. The results were corroborated with the field conditions. It may be noted that the slope with more number of joints has a weaker rock mass and experiences more events of failures on the surface than the other slope type. A circular plane of weakness was observed in both types of slopes and a large scale failure may occur in future. One of the slopes shows prominent displacement along the circular planes especially in the top rear part of the slope. Attention must be paid to these slopes and proper remedial measures be taken to protect the slopes from failure.

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