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Kinematic analysis to assess the stability of slopes in opencast coalmines

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Abstract

A detailed and systematic geological mapping was carried out to pick up the discontinuities in working benches in open cast coal mine of PK OC-II Mine and RG OC-II Mine of the Singareni Collieries Co. Ltd. A total of 172 joint readings were recorded in sandstone benches while 50 readings in metamorphic benches. Besides this, major fault and some minor slips were identified and mapped. Filtered the data during mapping at field level itself, without compromising with the quality. In RG OC-II Mine, besides sedimentary benches, metamorphic benches were also mapped since mine authorities reported that 60cm of sliding was observed in High wall towards SE-NW and was along the major boundary fault (F1) between metamorphic and sedimentary formations. The paper deals with the structural mapping to assess the stability of over burden benches in the opencast coalmines to assess the stability of slopes with kinematic analysis by using the DIPS software.

1. Introduction:

Coal is the most important and abundant fossil fuel in India. It accounts for 55% of the country's energy need. The country's industrial heritage was built upon indigenous coal. Commercial primary energy consumption in India has grown in the last four decades. The current per capita commercial primary energy consumption in India is about 350 kgoe/year, which is well below that of developed countries. Driven by the rising population, expanding economy and a quest for improved quality of life, energy usage in India is expected to rise.

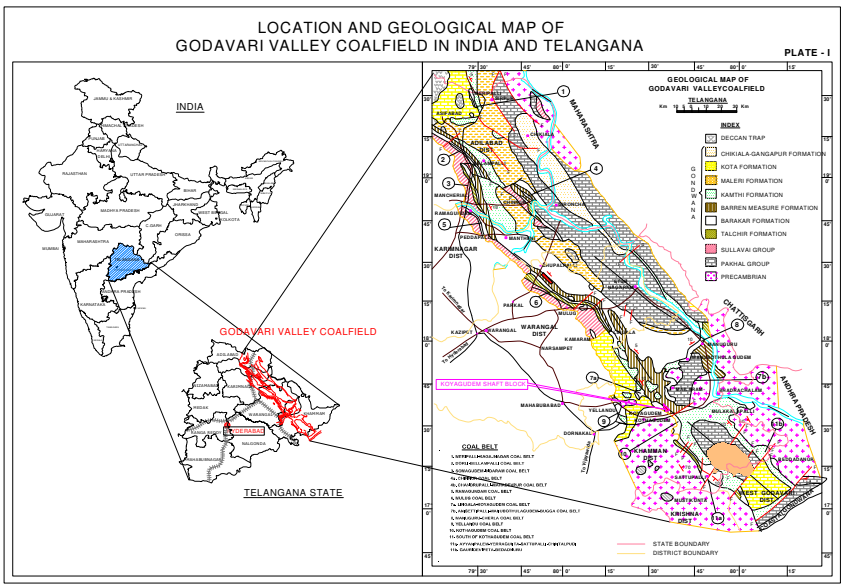


Figure 1 Geological map of Godavari Valley coalfield.

2. Geology of Godavari Valley Coalfield:

Pranhita-Godavari basin, trending north west-south east on a Precambrian platform, is one of the principal Gondwana basins in India and follows the course of Pranhita-Godavari River over a strike length of 470 km. The south eastern sector of about 350 km covering 17000 sq.km located in the state of Telangana is referred to as "Godavari Valley Coalfield" falling in six districts of Telangana (Figure 1). The other sector, further North West, extending in Maharashtra state is designated as Wardha Valley Coalfield. The Godavari Coalfield is bound by North Latitudes 16° 30'-19° 32' and East Longitudes 79^o12' to 81^o39'.

3. Application of Geo-Engineering studies:

The application of Geological sciences to engineering practice for the purpose of assuring that the geological factors affecting the location, design, construction, operation and maintenance of engineering works are recognized and adequately provided for.
It plays a vital role at several stages of mining like-

1. Tunneling
2. Sinking of shafts
3. Designing and preparation of Long wall panels
4. Determination of power support
5. Caving behavior of roof strata
6. RMR studies for Bord and pillar mining
7. Failure of slopes in Open cast Mines
8. Determination of stress field and
9. Rock-testing as per ISRM standards and other Geo-mining problems

In the present paper, case studies of two Opencast Coalmines are considered and details are discussed hereunder:

4. Case studies:

i. PK OC-II Mine

Manuguru coal belt lies in the eastern margin on the southern part of the Godavari Valley Coalfield. The field site is located on the south-western part of the Manuguru coal belt, Godavari Valley Coalfield. Up to sixteen regionally correlatable coal seams contained within the Lower Permian-Upper Barakar Formation are the target of coal exploration and mining. However, only twelve coal seams are minable. The general trend of the coal seams/coal measures varies from NE-SW in the eastern and northeastern part to east-west in the western part of the coal belt, with varying gradient of 1 in 6.05 to 6.97. The swing in the strike rather reflects a broad asymmetrical plunging antiform and synform. The floor contour plan of Thick seam reveals gentle folding of the seam into an asymmetrical plunging synform (syncline) in the eastern part of the area. The coal seams folded into an asymmetrical plunging antiform in the area between PK OC-II Mine and OC-IV, the axis of which is trending towards NNE-SSW. This block is intersected by several faults with varying throw amount.

a. Mapping in the overburden benches:

A detailed and systematic mapping was carried out to pick up trends of Joint system along the Sedimentary working benches in the PK OC-II MINE, Manuguru (Sharma, D.N., Gopal, O. and Srinivas, D., 2015). A total of 127 joint readings are recorded in sandstone OB benches. Locations of all these joints are surveyed with the help of total station. At each location, the details of joints are taken viz. trend, dip direction, dip amount, persistence, spacing, joint filling, joint aperture and joint surface. The F16 fault could be traced at two locations. Besides this, six minor slips are identified and mapped.

b. Joint pattern:

Rose diagrams for joints are drawn for respective benches and shown in Figure 2. It is inferred that in sandstone benches, three most prominent major sets of joints developed in the study area. Mean trend of most prominent joint set J1 is N75°W; correspondingly second prominent joint set J2 trends in N5°E and the third least prominent joint set is J3 trends in N25°E.

An attempt is made to find the influence of fault on trend of joints falling in and around Fault F16. Accordingly, Rose diagrams are drawn only for 24 joints in the vicinity of fault F16 and a separate Rose diagram for rest of the Joints. It indicates that the trends of joints are not controlled by the fault F16.

Further, Stereographic projection of joint poles on lower hemisphere is drawn using Open stereo software, the poles of the joint planes and the contours for the poles have been plotted. This contour diagram is used to identify the clustering of the joint poles, which is further used to identify the different sets of joints and their mean orientations. The data thus processed is depicted in Figure 2.

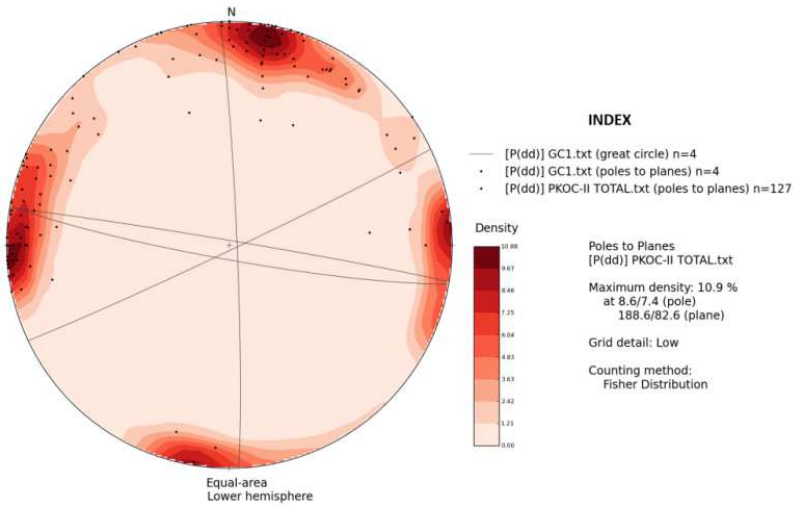


Figure 2 Stereographic projection of joint poles of overburden benches of PK OC-II MINE

c. Faults:

F16 is a lone fault located within the study area. Trend of this fault is NE-SW with down throw towards SE and throw is about 10m. This fault could be traced and taken readings only at two places as in other locations; it is either inaccessible or disturbed along the fault. Along the fault F16, benches are found to be highly disturbed. Besides fault F16, few minor slips are also mapped. Total 8 readings of faults/slips could be taken. Since few readings are available, no meaningful inference could be drawn. However, available data indicates that most of the faults are trending in NW and gives no clue of having any relation with the major joint sets.

ii. RG OC-II Mine:

The field site is located within the Ramagundam Coal belt along the western margin of the Godavari Basin. Up to seven regionally correlatable coal seams contained within the Lower Permian-Upper Barakar Formation are the target of coal exploration and mining. Within the block, to a large extent, III & IV seams are merged and formed a combined seam. Trend of coal seams/ coal measures varies from NW-SE to NNE-SSW with varying gradient of 1 in 4.40 to 7.30. On the southern side, major fault F1 forms the limit of the block. Along this fault, older formations viz. Pakhal Fm, Sullavai Fm and Talchir Fm, were faulted and the Basement rocks of Archaean group came in contact directly with basal Barakar Fm. It is presumed that throw of the fault could be +300m? As natural sequence of formations are missing along with part of Archaean Fm (?). Apart the major fault, the block is intersected by several faults with varying throw amount.

a. Mapping in the Metamorphic and Sedimentary benches:

A detailed and systematic mapping was planned to pick up trends of Joint system of both Metamorphic and Sedimentary benches along the major boundary fault (F1) to find the reasons that are leading to the wide cracks and thereby resulting into failure of benches (Sharma, D.N., Vinay Kumar, R. and Rajendar,G.,2015), In the study area, mapping of major fault couldn't be taken up due to various reasons viz. exact fault plane couldn't be located on the ground since it is disturbed during de-coal, inaccessible etc. The fault was mapped and the details are discussed. Exact location of major fault was surveyed and was taken into consideration.

b. Joint pattern:

Total 45 joints are traced in sandstone benches and 55 joint readings are taken in metamorphic benches and all put together, a total of 100 readings are recorded. Locations of these joints are surveyed with the help of total station. At each location, the details of joints are taken viz. trend, dip direction, dip amount, persistence, spacing, joint filling, joint aperture and joint surface. Rose diagrams are drawn for respective metamorphic and Sedimentary benches. From the Rose diagrams, it is inferred that in metamorphic benches, mean trend of most prominent joint set J1 is in N35^{o}E, whereas in sandstone benches, mean trend of most prominent joint set J1 is in N75^{o}W. Correspondingly least

prominent joint set is J2 trends in N5°W in metamorphic benches and J3 in N35°W of sedimentary benches. It is observed that in metamorphic rocks, only two most prominent major sets of Joints developed and the third set is not significant. Further, the metamorphic rocks are more prone to the major fault F1 and weathering.

Further, stereographic projection of joint poles on lower hemisphere are drawn using Openstereo software, the poles of the joint planes and the contours for the poles have been plotted This contour diagram is used to identify the clustering of the joint poles which is further used to identify the different sets of joints and their mean orientations. The data thus processed is depicted in Figures 2 & 3.

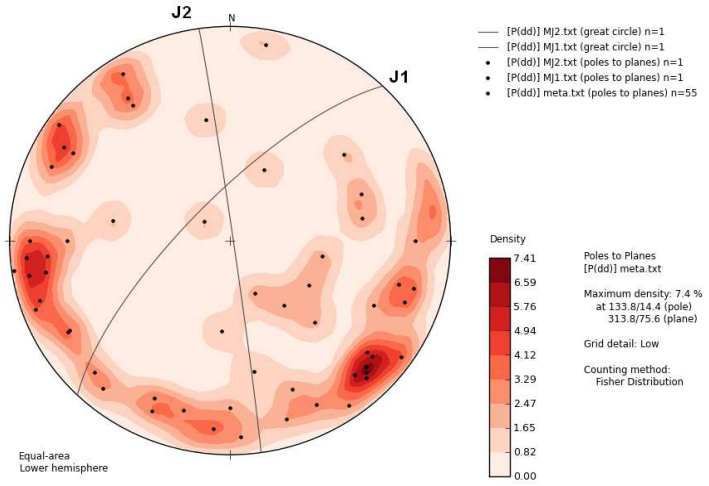


Figure 3 Stereographic projections of joint poles of metamorphic benches

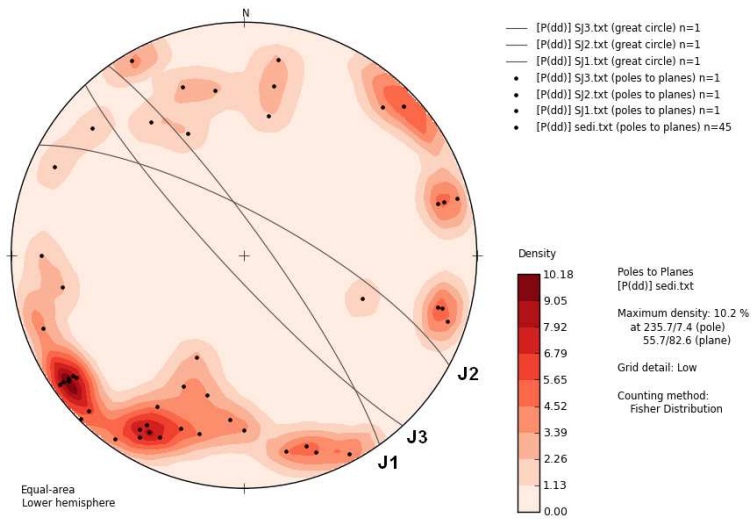


Figure 4 Stereographic projections of joint poles of Sedimentary benches

c. Folding:

Besides faults, strata were subjected to Roll-over structure (?) in the SE part of the block as evidenced by Incrop of coal seams and exposures in the quarry of the Mine. Part limb of Roll-over structure was faulted in SE part of the block as evidenced by Incrop of I seam. Based on the Incrops of II and IIIA seam, the axis is derived to be in N750E, since these two seams in the Roll-over structure area are free from faults. However, Plunge of the Roll-over structure could be derived only from the floor contour of IIIA seam as the strata between Incrop of IIIA to Incrop of II seam are intact in the sense, free from faults. The plunge of the Roll-over structure is derived to be 70 based on BH data of BH.NO's-817 and 819. Similar structure is observed in RG OC-I block located in NE extension of RG OC-II MINE block.

During normal faulting, in order to prevent formation of void space, the segment of the hanging wall in the neighborhood of the fault bends down towards the fault with respect to the segments away from the fault giving rise to the typical reverse drag or Roll-over structure also called Roll-over-anticline. Development of Roll-over structure is especially favoured by displacement along normal faults (where the dip of the fault plane decreases with depth) with successive blocks showing higher throw towards the direction of down throw.

d. Faults:

In the southern side of RG OC-II MINE, major fault F1 forms the limit of the block. Apart from the major fault F1, the blocks are intersected by several normal faults with varying throw amount and are abutting the major fault F1. Most of these faults were exposed in the quarry during the process of mining. Locations of these faults were surveyed. During the course of present mapping, some of the faults are located within the metamorphic benches, between metamorphic & sedimentary benches and within the Sedimentary benches. Along these fault planes, fault gouge between Metamorphic and Sedimentary benches, displacement within the metamorphic rocks, drag of the strata within the Sedimentary benches are recorded.

Reference to *"Structural Geology"* by De Sitter (1956), "A process of geological deformation is no laboratory experiment, and we can try to read the direction of the deformative stress only from the orientation of fold or fault structure. From a general point of view the problem is not difficult to solve. One of the principle stresses is always assumed to be necessarily vertical, because the surface of the earth with gravity perpendicular to it's by far the most important plane of discontinuity that enters into the stress field. In the horizontal plane, we can determine the largest principle stress as either bisecting the acute angle of a set tear-faults, or, better still, as perpendicular to the longer axis of folding or to the strike of the thrust planes."

Based on the studies conducted by Basavachary, M., Babu Rao, Y. S.& Sharma, D. N (1996), similar failures of benches were recorded in RG OC-I and GK OC, SCCL and concluded that

- The failures occurred in the vicinity of major boundary fault where the Gondwana formations abut against metamorphic.
- Clay formations (Incrop of coal seams) and the presence of water have also affected the slope stability.
- There is an influence of joints, fractures and bedding planes, too.

5. Kinematic analysis:

The average orientations of the discontinuity sets determined from the geotechnical mapping were analysed to assess kinematically possible failure modes (Planar, Wedge and Toppling) involving structural discontinuities. The basic concept of Kinematic analysis for plane failure is straight forward. Two conditions must be for sliding to occur. First discontinuity must dip more steeply than its frictional angle. Secondly, for sliding to occur, the discontinuity must daylight slope face in a down dip direction. These two conditions must be represented on a stereo net in the form a crescent shaped critical zone. Dip vectors which daylight the critical zone dip more steeply than the friction angle but less steeply than the slope face. The most vulnerable area within the critical zone occurs within + 20 degrees of the slope face dip direction.

"Kinematic analysis" with the DIPS software was taken up both for PK OC-II MINE and RG OC-II MINE Mines with the help of National Institute of Rock Mechanics (NIRM).

a. PK OC-II Mine:

Using the mapping data in the DIPS software, the following projections were drawn (Figures 5 & 6). Kinematic analysis of the projections is also shown in the subsequent figures (Figure 7). Both direction and amount of dip of J1 & J2 Joints and fault F16 are 086/088,084/189 & 061/133 respectively. The same is depicted in the Figure 8. In conclusion, it is found that no failure of the slopes is anticipated, except along the plane of Fault F16.

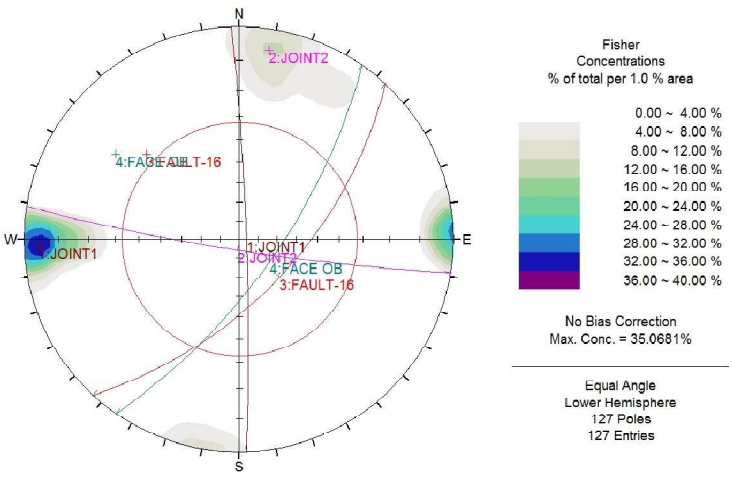


Figure 5 Pole projection of the joint data (friction angle, ϕ=32˚, is marked as a red circle)

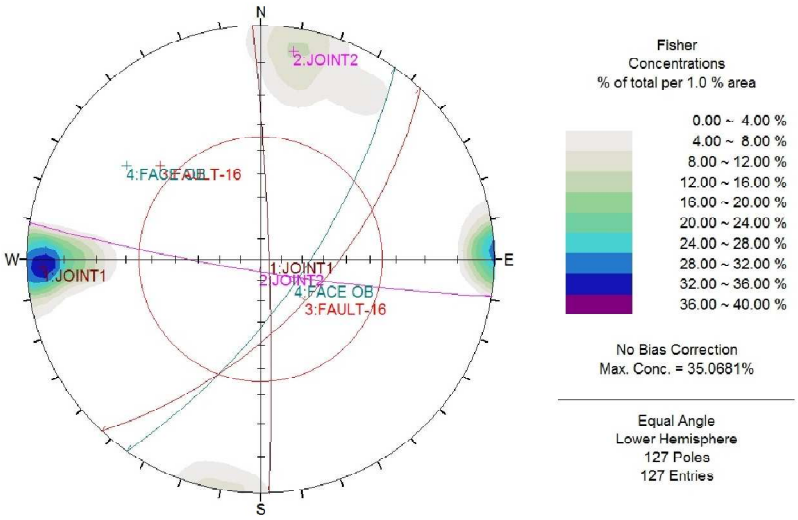


Figure 6 Pole projection of the joint data (friction angle, ϕ=34˚, is marked as a red circle)

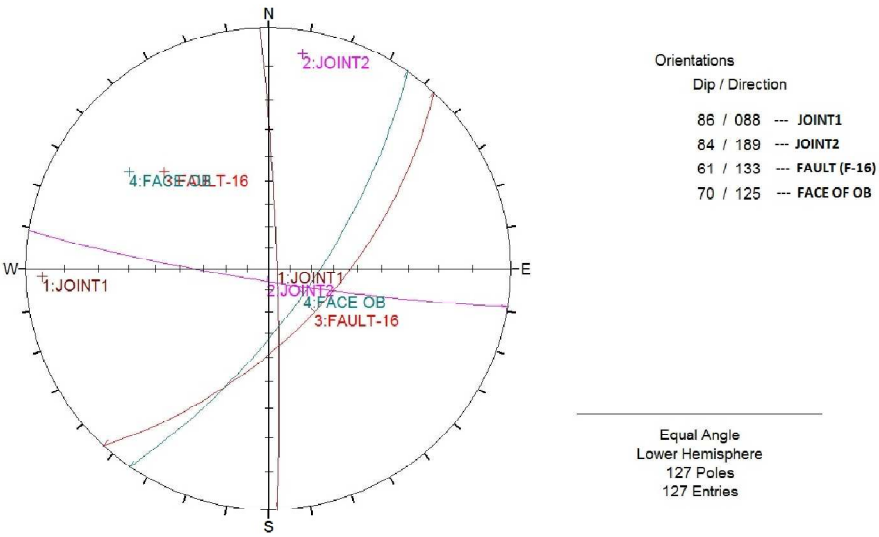


Figure 7 Pole projections of the joints data, Fault F16 and Face of OB.

b. RG OC-II Mine:

Using the mapping data in the DIPS software, the following projections were drawn along with Kinematic analysis (Figures 8 & 9). From the stereo projection of the planes of the joints (the great circles) in sandstone benches, it is observed that most of the joints are parallel to each other and also parallel to the bench / pit slopes. However, the joints dip at angles steeper than the slope face, so are not unfavorable. Therefore, no planar

failure can be expected in the sandstone benches, the wedge formed by the two steep joints J1 and J2 has its intersection plunging steeply into the bench, so this too will not cause any wedge failures.

In the case of the metamorphic rock, the joints J1, J3 and J4 are normal to the bench face, so are quite favorable for stability. On the other hand, the joint J2 is day lighting into the face, and so is potential for planar failures. The intersection of J1 with any other joint is not likely to influence the slope stability in any way. But intersections of J2, J3 and J4 are potential for creation of some low angle wedges, and may cause some unstable conditions locally. The fault plane is exactly parallel to the bench angle, so it can be taken as the slope face itself, and has no significant influence on the stability of the slope.

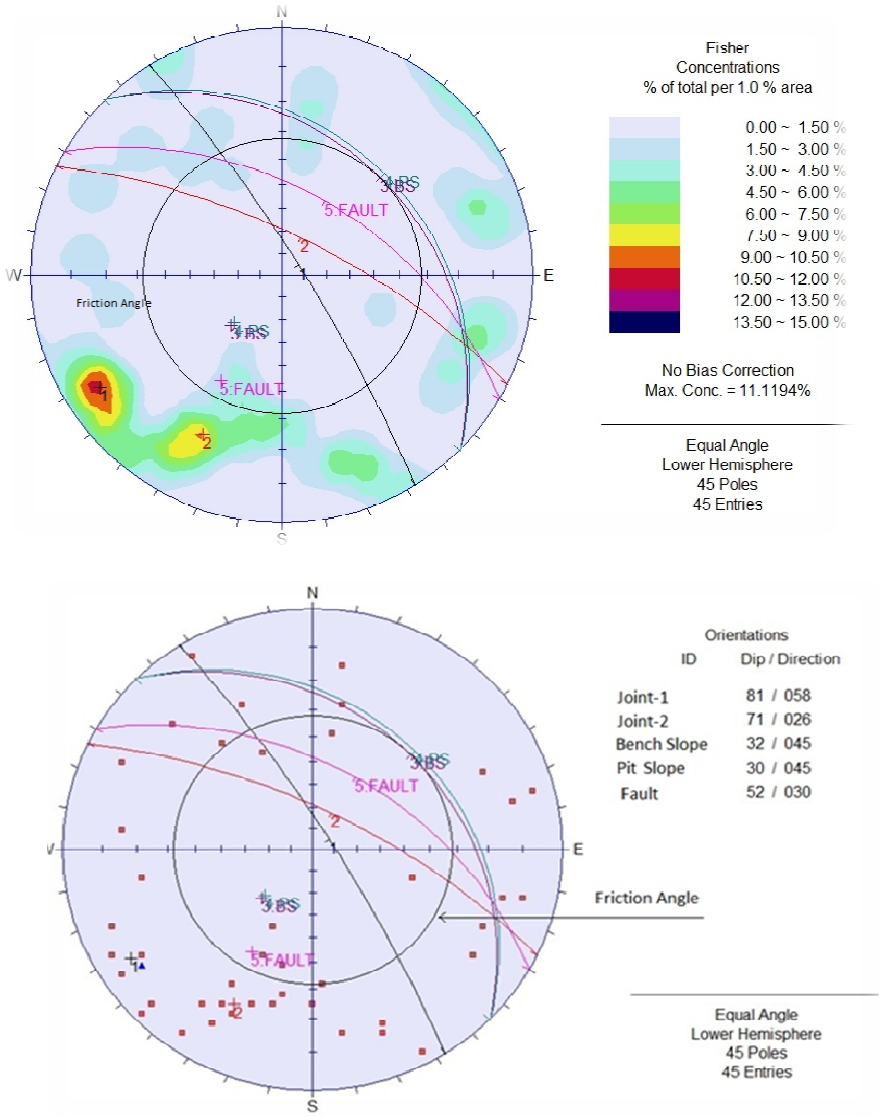
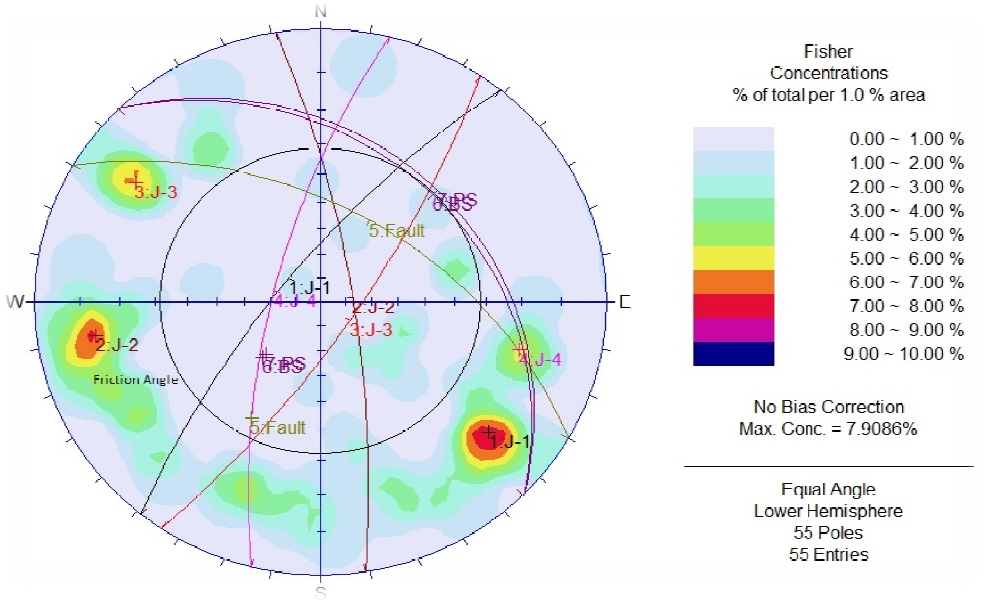


Figure 8 Pole projections of the joint data of Sedimentary benches



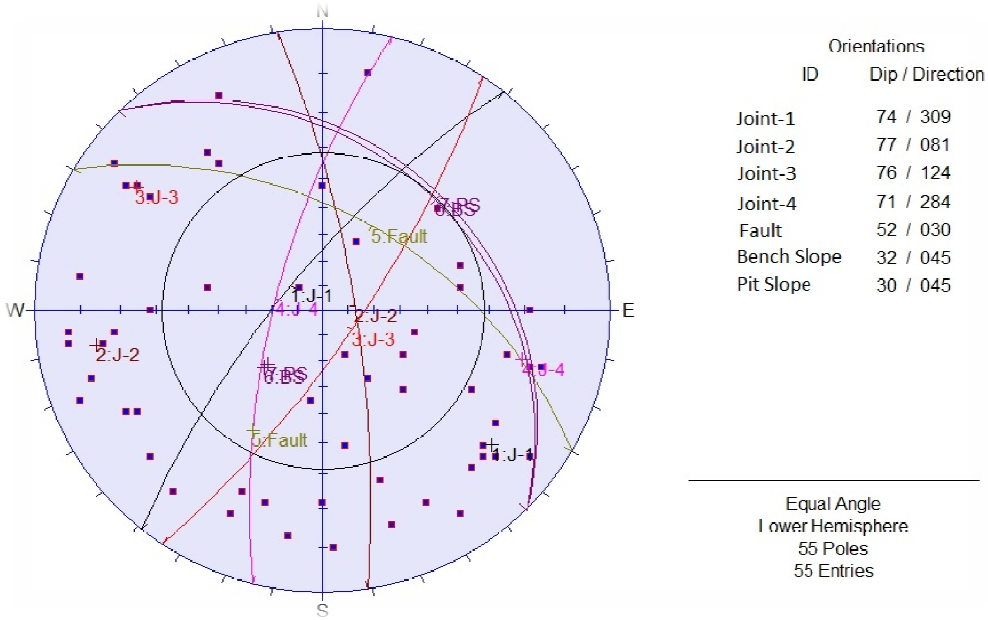


Figure 9 Pole projection of the joint data of Metamorphic benches

6. Conclusions:

Based on the mapping carried out in the two Opencast Coalmines, the findings are concluded as follows-

- In view of in-accessibility in generating more data, the experience in use of SIROVISION technique by CSIRO, Australia at RG OC-II MINE 6 is found to be much helpful and recommended to take up in all Opencast Coal Mines.

- In RG OC-II MINE, it is found that the trends of Joints are controlled by Structural elements viz. Roll-over structure, folds, major fault etc. and are localized. Whereas in PK OC-II MINE, no much variation is observed between the joint sets in the vicinity of fault F16.

- Using the mapping data in the DIPS software for "Kinematic Analysis" is found to be more helpful in predicting the stability of slopes.

- Findings of the Kinematic analysis technique are -
  i) In PK OC-II Mine, no failure of slopes is anticipated and all slopes are stable, except along the Fault F16.
  ii) However, in RG OC-II MINE, failure of benches are found to be result of unfavorable orientation of discontinuities viz. Joints, faults etc.

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References:

1. Sharma, D.N., Gopal, O. and Srinivas, D. (2015): Assessment of Slope Stability in Opencast Coal Mine through Structural mapping, Manuguru, Singareni Collieries., Sp. Publication J of EG, Oct 2015, pp 936-945.
2. Sharma, D. N., Vinay Kumar, R. and Rajendar, G. (2015): Assessment of slope stability with structural mapping in RG OC-II, SCCL., ISRM(India) Journal,Vol-4,No.1,Jan 2015, pp 15-21.
3. De Sitter (1956): Structural Geology, Text book of International Student Edition, McGraw-Hill Publishing Co. Ltd, London.
4. Basavachary, M., Babu Rao, Y. S & Sharma, D. N (1996): Geological Factors affecting stability of slopes in opencast Mines. Proceedings- National Conference on Ground Control in Mining. Banaras Hindu University, Varanasi.,pp-474-490.
5. DIPS Software: https://www.rocscience.com
6. SIROVISION Software: https://research.csiro.au/msci