A Geotechnical Approach to Assess Roof Rock Instability In Underground Coal Mine

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ABSTRACT

MVK-5 Incline block of Singareni Collieries Company Limited, forms an integral part of Dorli-Belampalli coal belt in Godavari Valley Coalfield. In this mine, two coal seams viz., Salarjang and Ross seams were under development stage. Difficulty in progress due to severe roof rock instability was experienced. The mine authorities have opined to conduct a detailed study of Ross seam for the systems of extraction and support of roof and sides. As a pre-requisite and to ascertain the reasons for the unstable roof rock conditions so as to establish a system, detailed geotechnical studies were taken up by underground mapping, recording the discontinuities viz. faults / slips, joints, cleat and conducting different studies like lithological characteristics of roof, geo-engineering properties of roof strata, geographic features of the study area and trend of roof falls in Ross seam workings. Based on these studies, the reasons for the roof rock instability are found to be poor strength of roof rocks, "crevasse splay", sandstone dykes, structural features like slickensides, faults/slips, joints, cleat and geographic features viz. streams and Madaram hill. Roof falls in the study area belong to bi-directional showing no preferred orientation.

Keywords: underground, coal mine, incline, roof rock stability, extraction and support design.

1. INTRODUCTION

MVK-5 Incline in Singareni Collieries Company Limited (SCCL) is situated in the Dorli- Belampalli coal belt. In this mine two coal seams were under exploitation viz. Salarjang and Ross seams. In the underground workings of Ross Seam, width of the gallery was 2.80 to 3.0 m and size of the pillar varies from 22.5 X 22.5 m to 36 x 36 m. Roof falls associated with severe unstable roof conditions in the underground workings of Ross seam were reported. A detailed geotechnical study for the assessment of roof rock instability to help systems of extraction and supports of roof were taken up in Ross seam workings.

2. GEOLOGY AND STRUCTURE OF MVK-5 INCLINE BLOCK

The Gondwana Group, within the study area is represented by Talchir, Barakar and Barren Measure formations, which are well exposed on the surface. The coal bearing Barakar and Barren Measure formations are exposed in the dip side in the northeast and forming part of Madaram hillock. The stratigraphic sequence based on surface and exploratory borehole data is furnished in the Table 1. The Barakar formation being principal coal bearing strata, is well exposed along the base of Madaram ridge. The top 120 to 130m strata comprises of coarse grained to medium grained sandstone with a seam in the middle part. The next 30m of strata contain the persistent and workable coal seams viz. Salarjang and Ross seams while the basal 130m predominantly medium grained sandstone becoming finer and silty towards the base.

Table 1 - Stratigraphic succession of MVK-5 Incline Block

	Age	*Formation*	*Strata*
Lower Gondwanas	Upper Permian	Barren Measures (130m+)	Fine to Coarse grained red and reddish brown and stones, clays and shale.
	Lower Permian	Barakar (280m)	Medium to coarse grained white felspathic sandstone, carbonaceous clays, shale and two persistent coal seams viz. Salarjang and Ross seams.
	Upper Carboniferous	Talchir (17m+)	Fine to medium grained soft light green sandstone of friable nature greenish shale and clays, siltstones with pebbles.

In the MVK-5 Incline block, the beds trend in $N50^0$ W with 1 in 2.80 to 4.0 gradient. About 36 exploratory surface boreholes were drilled with a total length of 4060m in this block. Salarjang seam is the top most workable seam with a varying thickness of 2.44 to 7.32 m. Ross seam occurs underlying the Salarjang seam with a parting variation of 7.62 to 18.59 m. Thickness of Ross seam varies from 1.37 to 3.66 m. The Ross seam is being worked with a height of extraction of 3.00 m. keeping the sandstone as floor. The block is situated along the western slope of the Madaram hill and shows a gradual rise in gradient in the northeasterly direction. Sufficient borehole data is not available in the Southern side due to hill and estimation of reserves and roof conditions has become difficult. With the available exploration data, in addition to minor slips encountered in the mine five faults with a throw ranging from 5 m to 185 m have been deciphered (Fig. 1). All these faults are normal gravity faults of which, one is strike fault and the remaining are dip /oblique faults. Trend of the strike fault is ENE with down throw towards SSW. Whereas the remaining faults are almost trending NE with down throw towards SE. To find the causative factors of roof falls in underground coal mine of MVK-5 Incline, the subsurface geology viz. lithological characters of roof strata, sandstone dykes and structural features like slickensides, faults / slips, joints and cleat pattern was examined. The observations of all these factors are discussed hereunder.

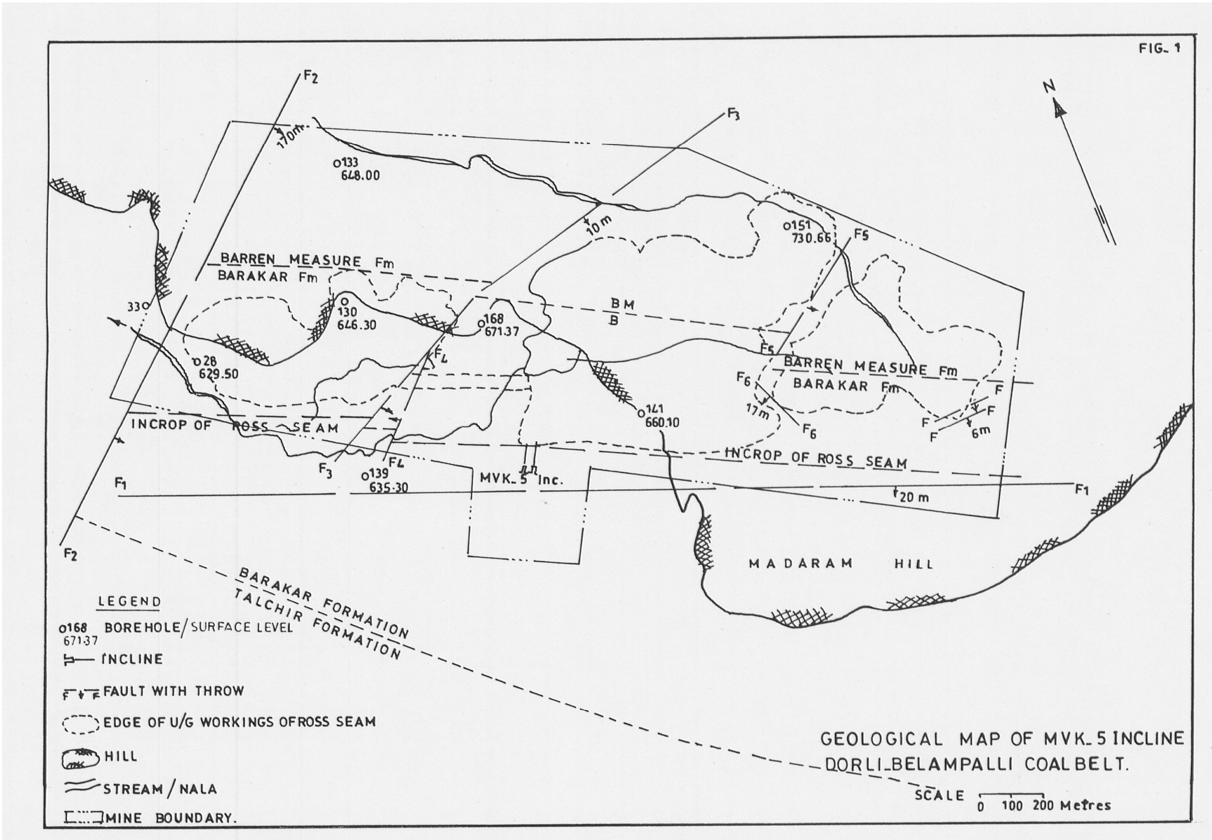
FIG. 1
N
BARREN MEASURE Fm
BARAKAR Fm
BM
B
INCROP OF ROSS SEAM
MVK_5 Inc.
MADARAM HILL
BARAKAR FORMATION
TALCHIR FORMATION
LEGEND
BOREHOLE/SURFACE LEVEL
INCLINE
FAULT WITH THROW
EDGE OF U/G WORKINGS OF ROSS SEAM
HILL
STREAM / NALA
MINE BOUNDARY.
GEOLOGICAL MAP OF MVK_5 INCLINE
DORLI_BELAMPALLI COAL BELT.
SCALE 0 100 200 Metres

Fig. 1

2.1 Detailed Underground Mapping

Underground mining in general is hazardous venture, as it is a continuous struggle against nature and natural forces. The baffling problem is the weak roof resulting into unstable roof conditions. Roof rock instability in development galleries of underground mines is a major factor to accidents resulting in injuries & fatalities and loss of production. .A cause-wise analysis of fatal accidents in SCCL show that the accidents caused due to roof falls claim the largest share i.e 39% during 1977 to 2004 shows the gravity of the problem. As per the available data, about 17% of the roof fall accidents were due to geological reasons, while for the remaining 83% no geological reasons were attributed. Various geological factors contributing for the weak roof in the study area are discussed hereunder.

Lithological Characters of Roof Strata

Usually, roof of working section is fine grained to medium grained sandstone with carbonaceous laminae and intercalated with shale bands very often. Some beds are poorly cemented, friable and disintegrated into loose sand, while other beds separate readily along mica rich bedding planes into flaky slabs. In some places micaceous laminae permit the roof to separate in layers and to break in large slabs. The shale is susceptible to moisture slaking and over long periods of time large falls develop. The planar-bedded siltstone is marked by closely spaced regular partings of carbonaceous matter with in bedding planes. The rock easily splits and separates along these partings, and spectacular roof falls are common (Fig. 2).

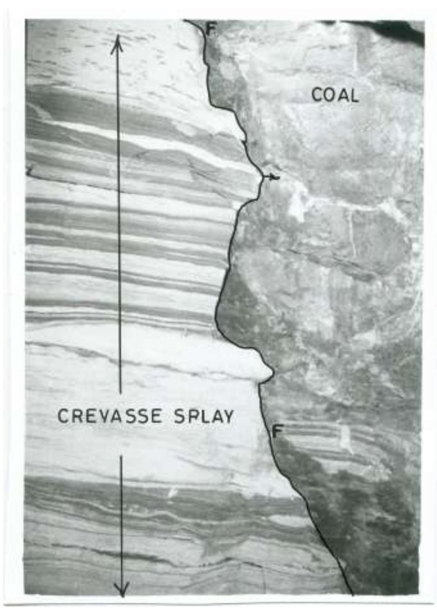

Fig. 2 – Example of crevasse splay type deposit in mine roof. A high angle fault is also seen

Moebs and Ellen Berger (1982) Coined term “Crevasse splay”, in a non-genetic descriptive sense, designates a litho logic unit consisting of sandstone thinly inter bedded with shale, or thin-bedded, laminated, micaceous sandstone. Roof falls in splay sequences generally occur when a separation along a bedding plane occurs and at or above the horizon of the roof bolts anchors, and the bolts are unable to maintain the integrity of the rock spanning the immediate roof. In the SE part of the block, it is observed that thickness of the Ross seam has increased to a maximum of 6.50 m, where mostly shale forms the roof of working section, leading to unstable conditions.

Sandstone Dykes

Clay veins, clay stone dykes or sandstone fillings are wedge – shaped masses that occur in crevice of a coal bed. These generally range up to 1 m. in width at the top of the coalseam. The pattern and character of these structures suggest that they formed as tension fissures in coal which later filled with clayey / sandy material and then were compacted after burial. Such sandstone dykes are observed in the Ross seam workings of the study area (Fig.3). Moebs and Ellen Berger (1982) opined that these structures occur chiefly in areas that were slightly above the level of the surrounding swamp, such as a peat island, and were therefore more subject to desiccation and fissuring. In addition to forming a discontinuity in the coal bed and immediate roof is likely to break away from the top as supporting coal bed mined.

Fig. 3 – Sandstone dyke in the coal seam and roof of working section

2.2 Structural Features

Slickensides

The most common hazardous roof structure occurring throughout the Ross Seam workings is the slickensides. It is well developed and most common in highly argillaceous rocks such as shale, clay etc. , Some slickensides in abundance around the margins of some minor cut-and-fill structures where differential compaction has occurred, are also known as horizontal slickensides. The other slickensides occur near the fault / slip planes and are referred to structural slickensides, which is smooth, polished, and some times striated or grooved surface resulting from movement of rock on either side of the surface. The slickensides constitute a discontinuity in the roof and therefore weaken the roof, creating a potential hazard.

Faults/Slips

Faults are discontinuities or fractures in the earth's crust. According to Anderson, (1951), there are three types of faults (normal, reverse and wrench) caused by differences in orientation of the maximum, intermediate and minimum principal stresses (σ_1, σ_2 and σ_3 respectively) with respect to the earth's crust. In the Godavari valley coalfield all faults are normal gravity faults.

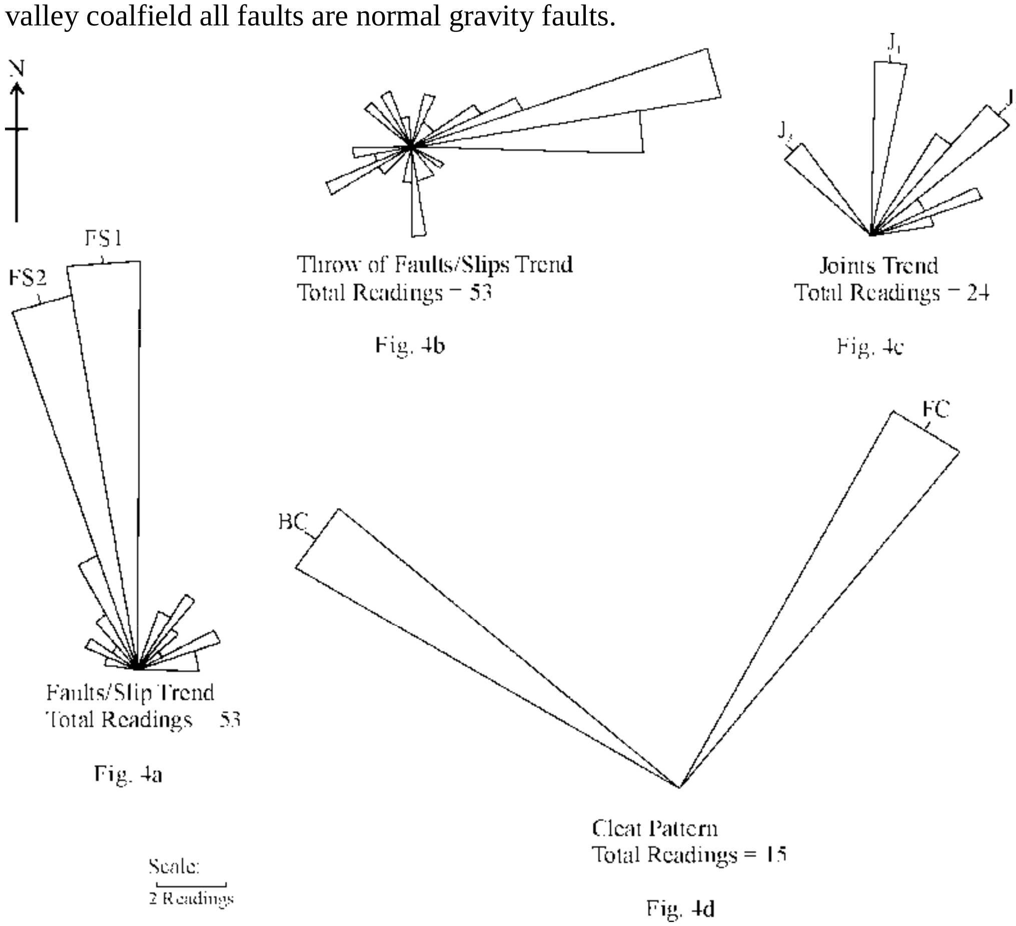

Fig. 4 – Rose diagram of Ross seam, MVK5 incline

Faults/slips are hazardous as they accelerate roof falls. MVK-5 Incline block is surrounded by two major faults on southern side and northwestern side with throw of 100 and 200 m respectively. Within the block, five faults with throw varying from 3 m to 20 m are intersected. Besides this, numerous slips are traced in the underground workings of Ross Seam with varying throw of 0.50 m to 3.00 m. The trends of these faults / slips are shown in Rose diagram (Figs. 4a & 4b). The most prominent fault / slip FS_1, trends in $N6^0W$ direction and next prominent fault / slip FS_2 trends in $N11^0W$. In many cases, intersection of multiple slips fans out in different directions / angles and and therefore it is difficult to take readings. In the area under investigation, roof falls along the faults/slips were observed.

Joints

Not all joints will affect roof stability. Closely spaced joints commonly contribute to bad roof. Sharma and Chandra (1988) found that the roof falls in the Queen Seam of VK-7 Incline are due to the most prominent tensional joints J1 aligned to the greatest principal stress direction (σ_1). The Rose diagram drawn for joints mapped in the study area reveal that most prominent joint J_1 is in the direction of N4^0E (Fig. 4c). Next prominent set J_2 falls in the direction of N 45^0 E and the least prominent set J_3 is in the direction of N 45^0 W (Fig. 4c). Joint spacing varies from 0.05 m to 1.00 m Apertures in the joints are present which varies from 3 mm to 20 mm. The intersection of J_2 joints with J_3 joints is at right angles as observed in the mine (Fig. 5). In few cases along the joints, apertures were filled with calcite. It is noticed that nature of joint surface varies between planar to undulating rough surface. It is evident from the above observations that joints also contributed for the unstable roof conditions in the study area.

Cleat

A distinct cleat pattern is developed in the coal bands of Ross seam. The trend of cleat pattern in the study area is mapped and depicted in Rose diagram (Fig. 4d). Face cleat trends in N 35^0 E and butt cleat trends in N 55^0 W. The interesting observation as shown in Fig.6 is that both face and butt cleats are parallel to dip gallery and level gallery respectively. However, it is observed in the underground workings that cleat pattern is not significantly having any bearing on unstable roof conditions.

Fig. 5 – Intersection of J2 and J3 joints at right angle

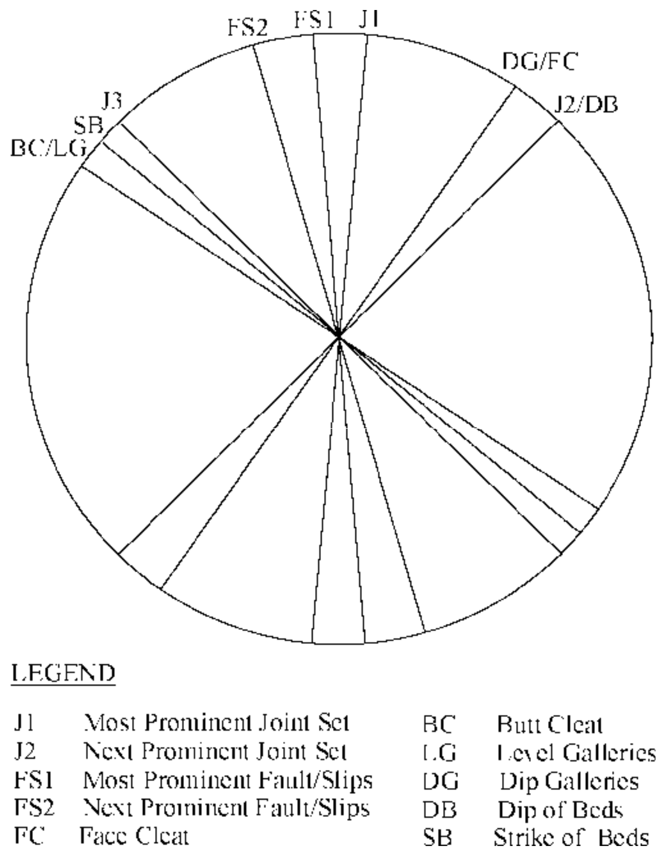

Fig. 6 – Trends of discontinuities

3. GEO- ENGINEERING PROPERTIES OF ROOF STRATA

The stability of the roof strata depends on its strength property viz. compressive strength, tensile strength, shear strength, Young's modulus, impact strength index, etc. Geo-engineering properties of parting strata of Ross and Salarjang seam are available for borehole no.168 and the range of these properties are given in Table 2. The data indicates that roof strata of Ross seam are incompetent as the compressive strength ranges from 3.1 to 30 MPa. Considering the classification of Rocks based on compressive strength (Blyth and Defrieates, 1974), roof strata of Ross seam is classified as "Weak Rock". Along with the strength parameters of roof rocks, other information comprising micro logging of borehole core samples such as nature of bedding/lamination, formational contacts of various litho units, RQD, structural features, core dip, spacing of fractures, etc., were also studied for a better assessment of roof rocks. RQD of the roof strata ranges from 35 to 51 %, indicating the roof is "Poor" to "Fair" class. Based on this data, Geotechnical log is prepared for the roof strata of coal seam. On physical examination, the sandstone of the roof is found to be friable in many parts of the underground mine. Sandstone with high percent of clay, which is common in several locations, tend to be friable and on exposure to humid mine air, disintegrate gradually into loose grains of sand.

Table 2 – Geo-engineering properties of roof strata of Ross seam

Parameter	*Range*
Density (gm/cc)	1.76-2.24
Compressive strength, MPa	3.1-30.0
Tensile strength, MPa	0.16-4.48
Shear Strength, MPa	0.39-10.44
Young's Modulus, GPa	0.5-2.9
Impact strength Index.	0.18-2.01
RQD, %	35 - 51

4. GEOGRAPHIC FEATURES

There are several geographical features that have been identified as potential indicators of bad roof conditions. These features are discussed below.

4.1 Streams

Surface run of water that cuts through a weak rock zone or an area of high fracture density generally creates a stream channel. Streams tend to follow surface fractures. If the fractures are induced by regional tectonic activities, they will most likely reflect the trends and locations of predominant underground fracture system (Overbey et al., 1973.; Ealy et al., 1979). It is generally known that in the coal mines area, the roof rocks immediately under and adjacent to an active stream is less stable and liable to fall. Over the study area, two active streams are passing through the block and contributing for the unstable roof conditions (Fig.1). Since the streams are following the incrop of Ross seam and further cutting across the major faults, the seepage of water into the workings of Ross seam through the roof strata have adversely affected the roof stability. As experienced in some of the coal mines of SCCL, the active streams passing through the block have largely contributed for the seepage into the underground mine workings and the roof conditions have deteriorated, so also in the area under consideration.

4.2 Large Topographic Relief

High topographic relief may cause a large local stress concentration and leads to failure. Ferguson (1967) described a case of deformation and fracturing caused by stress relief at the valley bottom in the Allegheny Plateau that has affected engineering projects that cut into the flanks and bottom of the valley. Mculloch (1976) also reported that bad roof is common in the Pocahantas no. 3 coal seam where the surface relief changes rapidly.

In the MVK-5 incline block, majority of the area is covered by Madaram ridge and its affect on roof instability is clearly reflected in the form of roof falls (Fig. 2). In the southeastern part of the block, the surface elevation is about 280 m above MSL and the elevation reaches a maximum of 350m towards northeast. Also it is examined that unstable roof conditions are prevailing under this hillock.

5. TRENDS OF ROOF FALLS

In the area under reference, locations of roof falls are mapped and plotted on underground working plan. Some of the roof falls, however, could not be mapped since all these spots are not accessible for a variety of reasons, such as unsafe roof conditions, water logged areas, etc. These roof falls are not following any particular trend, i.e. neither they are confined to level nor to galleries or dip galleries. However, some falls are more in junctions. Kent (1974) observed roof falls of two types. They are, unidirectional which are parallel to passageways and bi-directional showing no preferred orientation. Unidirectional falls were attributed to tension or release type joints and bi-directional roof falls were caused due to disrupted shale and channel-fill sandstone. Sharma and Chandra (1988) found that the roof falls in the Queen seam of VK-7 Incline are of unidirectional type as the falls occurred only along level galleries and same time dip galleries were stable. In the present area of investigations, thickness of roof fall ranges from 0.50 m to 3.50 m. Some of the roof falls are associated with faults / slips and joints, whereas other falls are because of friable sandstone or due to “crevasse splay” (Fig. 2). Accordingly, different profiles of the roof falls are noticed.

Further these studies have helped in numerical modeling and obtaining Rock Mass Rating (RMR) to decide the system of extraction followed by support design conducted by Singh et al. (2001).

6. SUMMARY & CONCLUSION

The following conclusions have been drawn on the basis of present investigations carried out in the study area through detailed geotechnical approach and attributed for the roof rock instability:

- Roof rocks are weak in strength causing roof instability.
- “Crevasse splay”, thinly interbedded and intercalated sandstone and shale in the roof is the potential hazardous zone contributing for roof falls. Further, sandstone dykes when exposed in the roof are also causing roof falls.
- Both compaction horizontal and structural slicken sides when exposed in the roof are contributing for the roof falls.
- The structural features such as faults / slips, joints have been found to be responsible for roof falls.
- Geographic features viz. stream and Madaram hills are also responsible for unstable roof conditions.
- Roof falls in the study are belonging to bi-directional showing no preferred orientation. However, more roof falls are encountered in junctions.

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References

Anderson E.M. (1951). The dynamics of faulting and dyke formation, 2d ed, 206 Oliver and Boyd. London.

Blyth and Defrietas,M.H. (1974). A Geology for Engineers-Edward Arnold Publishers, London.

Ealy, D.L., Mazurak, R.E and Longrand. E. L. (1979). A geological approach for predicting unstable roof and floor conditions in advance of mining; Mining Congress Journal, 65(3), pp.17-22.

Ferguson, H. F (1967). Valley Stress release in the Allegheny Platean. Association of engineering geologists, 4(1), pp.63-71.

Innacchione, A-T., Ulery, J.P., Hyman, D.M and Chase, F.E. (1981). Geologic factors in predicting coal mine roof rock stability in the upper Kittanning coal bed, Somerset county, Pa; USBM, RI – 85 75, 40,USA.

Kent (1974). Geologic causes and possible preventions of roof falls in room and pillar coal mines, Pennsylvania Geological Survey Information, Circular,75, 17.

Krausse, H.F., Damberger, H.H., Nelson, W.J., Hunt, S.R., Ledvina, C.T., Treworgy, C.G. and White, W.A. (1979). Roof strata of the Herrin (No.6) coal member in Mines of Illinois: Their Geology and stability, Illinois State Geological Survey, 205,USA.

Moebs, Noel N. (1977). Roof rock structures and related roof support problems in the Pittsburgh coal bed of south western Pennsylvania, USBM, RI 8230, 30, USA.

Moebs and Ellenberger (1982). Geologic structures in coal mine roof, USBM, RI 8620, 16, USA.

Overbay, W.K. Jr., Komar, C.A. and Pasini. J. (1973). Predicting probable roof fall areas in advance of mining by geological analysis, Min. Health, Safety Rasea Prog., Tech. Prog. Report, 70,17,USA.

Sharma, D.N. (1988). Anticipating coal mine roof conditions with reference to geological factors in the Venkatesh khani – 7 incline of Godavari valley coalfield, The Mining Engineer (UK), 147 (321), pp. 553 – 555.

Sharma, D.N. and Chandra, D. (1988). Analysis of structural discontinuities and their bearing on roof falls in Venkatesh khani-7 incline of Singareni Collieries, India, Mining Science and technology (Netherlands), 7, pp. 237 – 241.