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Geological and Geotechnical Characterisation Using Geophysical Logs – An Example from Adriyala Longwall Project of Singareni Collieries, India

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SUMMARY

The studies conducted at Adriyala longwall block of Singareni Collieries Company Limited (SCCL) in the state of Telangana, India conclude that geophysical logs comprising electrical, density, neutron, caliper, Full Waveform Sonic (FWS) and acoustic images can provide reliable geological and geotechnical models required for longwall mining. The P wave velocities obtained from sonic logs are correlated with the lab determined strength parameters such as uniaxial compressive strength (UCS), Tensile Strength (TS) and Young's Modulus. The empirical equations provided a means to construct UCS map of interburden strata of coal seams from sonic data. The integrated study of various maps prepared from geological and geophysical inputs provided an effective means to analyse the competency of immediate overburden and roof of Seam-I, which is considered for longwall mining.

Back analysis of behaviour of strata will allow developing of predictive models and appropriate strata control strategies to be applied at Adriyala and other mines and also for multiseam extraction.

Key words: Seam-I, SS-80, Vp, UCS, GSR

INTRODUCTION

Longwall mining depends on good understanding of mode and mechanism of caving (goafing) of strata during the extraction of coals. Green and Ward (2002) remarked that subsidence takes place in different forms at three different depth ranges during the longwall mining. The zone-1 lying immediately above the seam collapses as broken rock into the mining void and eventually fills up the free space through bulking. The height of zone-1 is generally taken as nine times the mined thickness but can be less in stronger strata. The various beds of zone-1 cantilever into free space and subject to unrestrained release under gravitational loading, with detachment occurring along planes of weakness. The goafing behavior would also depend on combinations of several factors such as bed thickness, strength homogeneity, and presence of strong and weak beds and the juxtaposition of beds of contrasting character. Hanson *et al.* (2005) concluded that detailed geological and geotechnical studies of zone-1 form the first step towards understanding the caving/goafing mechanism and designing suitable roof support and strata management systems. The layout of longwall panels also requires information of major and minor principal horizontal stress directions, magnitude, the predominant joint and cleat orientation, and geological structures because poor panel layouts lead to gate end stress concentrations, roof falls and loss of production.

Hatherly *et al.* (2009) used density, natural gamma and sonic logs to define the competency of rocks in terms of Geophysical Strata Rating (GSR) similar to CMRR (Mark and Molinda, 2005). CMRR and GSR generally deliver values between 10 and 100 depending on overall quality of the strata. GSR can be determined at exploration stage thereby enabling its evaluation during mining. It is also demonstrated that GSR evaluates the competency of overburden strata of coals in a manner better than UCS models.

The present paper has considered all these aspects and applied geophysical logs to assess the caving zone (zone-1) along one of the proposed longwall panels of Adriyala block of Singareni Collieries Company Limited (SCCL) located in the state of Telangana, India.

GEOLOGICAL SETTING

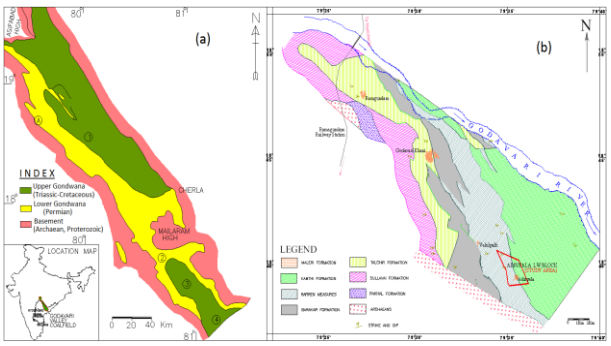

Figure 1. (a) Pranhita-Godavari Valley and its subbasins. (1) Godavari sub-basin, (2) Kothagudem sub-basin, (3) Chintalpudi sub-basin and (4) Krishna-Godavari sub-

basin and (A) Ramagundam coalbelt (b) Ramagundam coalbelt and Adriyala longwall project.

SCCL carries out exploration and extraction of coal deposits of Pranhita Godavari Valley, which is a major NNW-SSE trending belt on the pre-Cambrian platform extending over 470 km in strike length from Eluru on the east coast of Andhra Pradesh in the SE through the state of Telangana in the central parts up to Boregaon of Maharashtra in the NW (Figure 1). The Early Permian Barakar Formation contains seven to ten correlatable coals of 1m to 22m thickness and the Late Permian Raniganj Formation contains intercalated carbonaceous horizons.

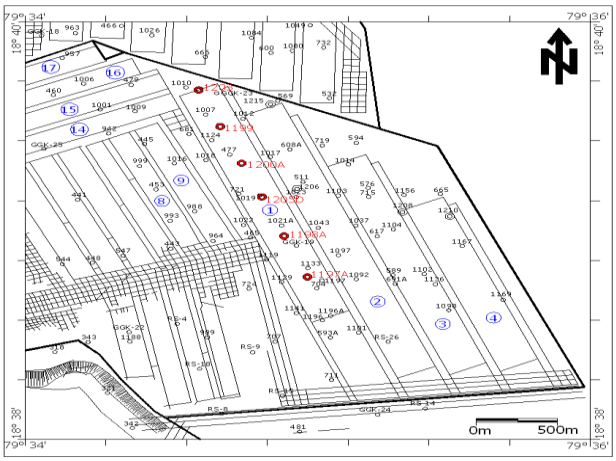

Figure 2. Location Map of boreholes and longwall panels, Adriyala longwall project. (Boreholes marked in red colour) are considered for present study.

The Adriyala longwall project lies in the southern part of Ramagundam coalbelt, located on the western margin of Godavari sub-basin of Pranhita Godavari Valley (Figures 1 & 2). The Adriyala longwall project is bounded between latitudes 18°38' and 18°40' and between longitudes 79°34' and 79°36' spanning an area of 4.635 sq km extending over a strike length of 2.75 km. Longwall panels of 2.60 km length are being planned in Adriyala block to produce 2mt of coal per annum from the top section of 6m thick coal locally known as Seam-I. The immediate overburden strata of Seam-I is around 22m to 26m thick mostly containing medium grain to coarse grain sandstones and is called SS-80.

The general trend of the coal measures is north-northwest (NNW) to south-southeast (SSE) direction with slight swings at places with northeasterly dips. The gradient of the coal seams in the northern part of the block is 1 in 6 to 1 in 6.8 and flattens in the central part to 1 in 8 then the gradient gradually becoming steeper in the southern part.

METHOD AND RESULTS

Geophysical Logs and Estimation of Rock Strength

Extensive drilling followed by geophysical logging established geological and geotechnical characters of the interburden strata of Early Permian coals of Barakar Formation of Adriyala block. The geophysical logs of six boreholes falling along the proposed longwall panel are considered for the present study. The geophysical logging was carried out by deploying the geophysical logging equipment of Ms Robertson Geologging, Deganby, UK whose probes are called SPRN, GLDS, HRAT and TRSS. The SPRN probe contains single point resistance (SPR), short normal resistivity (SNR), self potential (SP), single detector of neutron and ^{241}Am-Be radioactive source of 37GBq strength. The GLDS probe contains far and near density detectors to compute bulk density (DENS), natural gamma (NGAM), focussed resistivity (FRES) and caliper (CALP) and ^{137}Cs of 3.70GBq strength is the radioactivity source. The HRAT is the high resolution acoustic televiewer imaging probe and TRSS is the tri-receiver monopole full waveform sonic probe. The interpretation of geophysical logs was carried out using the standard procedures and the various modules of Wellcad software. The interpretation of geophysical logs was also reviewed and correlated with the available core data. Figure 3 shows the basis of geophysical log interpretation. Hatherly *et al.* (2009) provided the guidelines to compute GSR from geophysical logs.

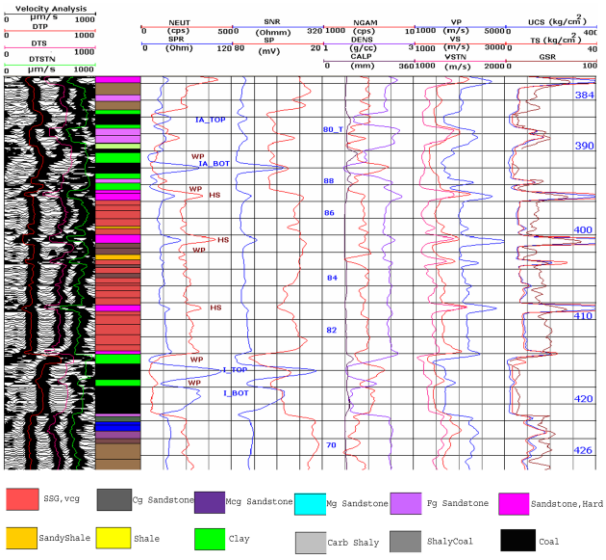

Figure 3. Interpretation of basic lithological details and strength parameters using geophysical logs, Borehole 1197A (location in figure 2).

Coals are identified by high resistance/resistivity, low density of 1.40 to 1.70g/cc, low neutron and natural gamma values of about 50 cps and 30 to 50 cps respectively (Figure 3). The P (Vp) and Stoneley (Vstn) wave velocities of coals are around 2300m/s and 1200m/s respectively. Coals and clays are characterised by the absence of propagation of shear wave (Vs). The Vp, Vs and Vstn of very coarse to medium grained grey-white sandstones are around 3000m/s to 3500m/s, 1500m/s to 1750m/s and 1200m/s to 1600m/s respectively and bulk density of 2.30g/cc to 2.50g/cc. Hard and strong sandstones marked 'HS' are characterised by high resistance/resistivity, neutron (400cps to 500cps), density of 2.65g/cc to 2.80g/cc and Vp of 4500m/s to 5500m/s. Fine grained sandstones, sandy shales, shales and clays show low neutron (50cps to 125 cps) and high gamma (200 to 300 cps) values and densities of 2.20g/cc to 2.50g/cc. Some of the clays and shales are prone to caving as observed from the increase in borehole diameter on caliper logs and are considered weak planes and marked 'WP'.

The site specific empirical estimates of Vp-UCS are established all over Australia (Hatherly 2013). In the present study also, P wave velocities (Vp) obtained from sonic logs are correlated with the lab determined strength parameters such as

uniaxial compressive strength (UCS), Tensile Strength (TS) and Young's Modulus. The equations are as follows

$UCS=0.0789\ e^{0.0014Vp}$ (R^2=0.72) ---------- (1)

$TS = 8.7749E\text{-}13Vp^4 - 9.9760E\text{-}09\ Vp^3 + 4.2466E\text{-}05\ Vp^2 - 0.0798\ Vp + 55.9746$ (R^2=0.59) ---------- (2)

$YM = 0.0069e^{0.0017\ Vp}$ (R2=0.73) ---------- (3)

Where UCS is uniaxial compressive strength in Mpa,
TS is Tensile Strength in Mpa
YM is Young's Modulus in Gpa
Vp is P wave velocity in m/s

The above equations are applicable only to the sandstones. It would need to establish similar relationships for other sediments.

Geophysical and Geotechnical Maps

The lithofacies maps are constructed by using neutron and Vp logs and by considering the floor of Seam-I as the datum to provide details of bedding surfaces/planes contained by the sandstones of SS-80 (Figures 4 & 5). The UCS and GSR maps are also constructed to depict the strength and competency of rocks (Figures 6 & 7). All these maps put together can help understanding the salient features of SS-82, SS-84, SS-86 and SS-88 making up SS-80 and define its overall performance.

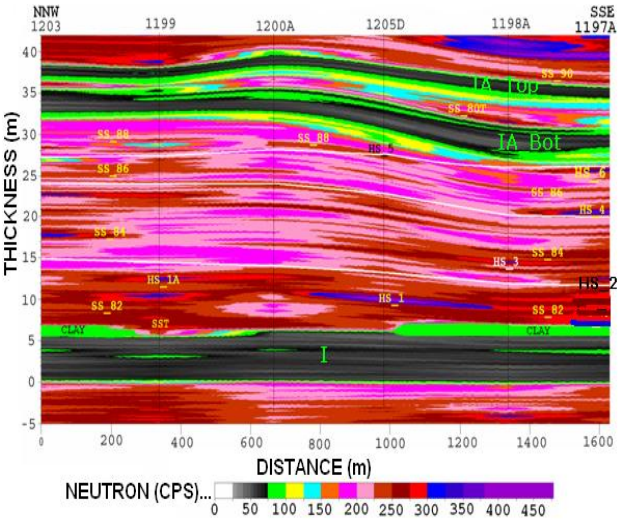

Figure 4. Neutron Map of SS-80 and SS-80T

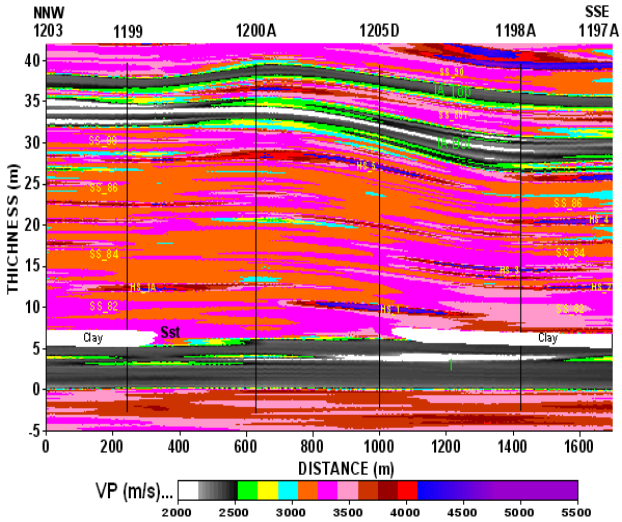

Figure 5. Vp Map of SS-80 and SS-80T

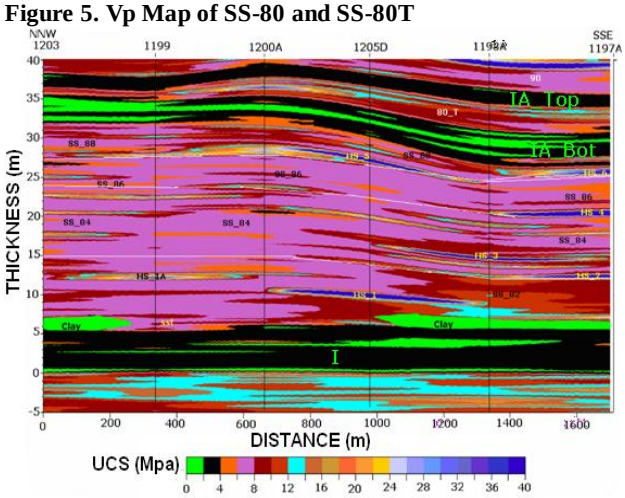

Figure 6. UCS Map of SS_80 and SS-80T

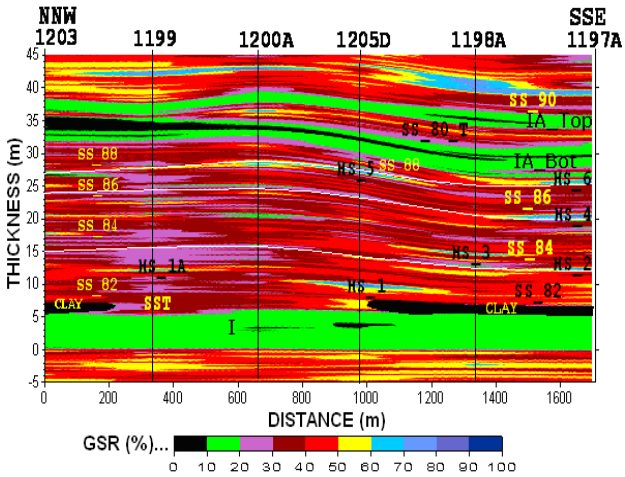

Figure 7. GSR Map of SS_80 and SS-80T

Borehole Breakouts and Stress Directions

The acoustic scanner image logging (Borehole Televiewer) enables measuring the directions of horizontal stress by identifying the breakout of borehole walls and orientation of cleats, joints and bedding planes. Borehole breakouts form as a result of the interaction of stresses induced by drilling and the existing stress regime of the country rock. Small brittle

fractures occur in the borehole around a rotating bit along the minimum horizontal stress direction because of the unequal horizontal stress regime in the formation

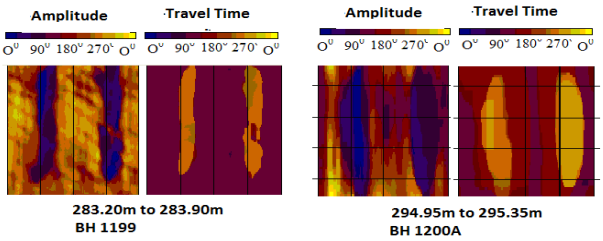

Figure 8. Borehole breakouts observed on acoustic amplitude and travel time images.

In Adriyala longwall block, the borehole breakouts of 15-70 mm length are observed in the interbedded shale sequences of Seam IA, I, II and IIIA. The borehole breakouts are tiny features appearing as linear features of a limited extension of 15-70 mm opposite to each other and apart by 180° and aligned along the minor horizontal stress direction. Figure 8 shows the acoustic amplitude and travel time images of borehole breakouts observed in some boreholes.

The breakouts indicate that the minor horizontal stress is aligned along N110^o-120° and is perpendicular to the major/principal horizontal stress component (N24±14°) determined by hydrofracturing and are shown in Figure 9.

Figure 9 indicates that the major horizontal stress (red colour) aligned along N24^o±14° and cleats (magenta) along N30^o to N40^o are close to each other. Most of the geological faults (blue) trend in N110^o-150° to N290^o-330° direction and close to N110^o-120°, along which the minor horizontal stress (green) is aligned. The longwall panels (brown) are aligned N148^o to N328°. NNW-SSE is the geological strike direction of Adriyala longwall project.

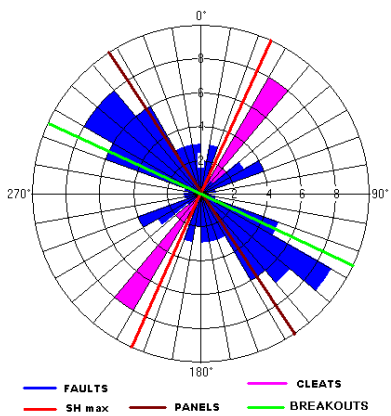

Figure 9. Orientation of stress, geological Faults, cleats and longwall panels.

SUMMARY AND CONCLUSIONS

A thorough understanding of geological and geotechnical environment of overburden strata of coals is a basic prerequisite to extract coal from greater depths by longwall mining. The identification of potential geotechnical hazards prior to intersection is vitally important to ensure a hassle free longwall mining. The geophysical logs are an important means to identify such risks. The geophysical logs established the stratigraphic distribution of beds of various strengths and thicknesses making up SS-80 and SS-80T which might influence goafing and subsidence during longwall mining of Seam-I. The presence of weak planes in the form of clay/carbonaceous shale/carbonaceous clay beds along the middle portions of Seam-I, and intertonguing of clay and sandstone of contrasting strengths along the immediate roof of Seam-I could influence working sections and roof support system. The lensoids of strong beds at different stratigraphic levels might produce weighting of different magnitudes and extents at the face in the active caving zones. The juxtaposition of stronger and less strong sandstones induce differential compaction and development of geotechnical features in the form of fractures/joints and weak planes along their contact zones. The scattering/diffraction of S waves along the contact planes of some of the HS beds could indicate fractured mode of contacts. The fractures/joints could also be water filled leading to a drop in resistance/resistivity, neutron, and Vp in comparison to the strong beds having very high resistance/resistivity, neutron and Vp and GSR values, which could be containing dry fractures. The SP logs also indicate contrasting values against the 'HS' beds which might be related to contrasting permeability levels of water filled and dry fractures.

The gradual reduction of SS-80 from about 26m in the NNW to 22m in SSE is due to the gradual pinching of SS-88 and reduction in the thickness of various sub-units. The Seam-IA overlying SS_80 indicates near coalescence of Seam IA Bottom and IA Top at the NNW and diverge towards SSE due to the development of SS-80T (fine grained and medium to coarse grey sandstones, shales and clays) attaining maximum thickness of about 5m at SSE, along which SS_88 pinches out. As such, the pinching and disappearance of SS_88 in a way is compensated to an extent by the development of SS-80T along the same direction of SSE. The splitting of Seam-IA and pinching of SS-88 rolls down the Seam-IA Bottom towards the SSE. The various beds making up the sub-units of SS-80 also display similar rolling phenomena towards SSE. Thus the said sedimentary features might help defining the caving during longwall mining of Seam-I.

Back analysis of behaviour of strata will allow developing predictive models and appropriate strata control strategies to be applied at Adriyala and other mines and also for multiseam extraction.

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