Analysis of strata control monitoring in underground coal mine for apprehension of strata movement

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***Abstract*—Final extraction in underground coal mining is associated with hazards and risks of accidents relating to fall of roof and sides due to in equal strata movement in active mining zone. Strata movement exhibits dynamism on loading effect during Bord and Pillar extraction in proportion to increase in goaf span and area leading to formation of dynamic loading zone and effect within working areas including at goaf-edges. The loading effect generally happens to be maximum near the goaf-edges with diminishing effect farther in the dynamic loading zone requiring advance support in depillaring panels. Any presence of geological disturbances or weak zones in the working area may attract release of such mining induced stress, further leading to collapses or un-eventualities. State of strong overlying rock formations may even lead to sluggish caving characteristics, enlarging dynamic loading zone with erratic strata behavior. Release of stress can be controlled by proper apprehension of strata movements including delineating, dynamic loading zone with effect and subsequent preventive measures. Strata control instrumentation and monitoring with proper analysis has emerged as a leading global solution for apprehension of strata movement during final extractions. The study deals with preliminary analysis of strata control monitoring in an Indian underground coal mine, Churcha underground mine of SECL, Coal India Limited. Depillaring in the mine is associated with constrains/difficulties such as high depth of cover, hill cap cover, geological disparities and very hard overlying rock formations. The basic objective of the study is to apprehend strata movements so that subsequent preventive measures can be initiated against any un-eventualities relating to roof and sides**

Keywords—underground coal mine, bord and pillar, goaf span, dynamic loading, depillaring, strata control, roof fall, caving, instrumentation.

I. INTRODUCTION

Final extraction in underground coal mining is associated with hazards of accidents relating to fall of roof and sides due to in equal strata movement in active mining zone. Process of final extraction induces strata movement with multifold dynamism of ultimate mining stress having variability of input parameters, including size of goaf, height of extraction, depth of cover, physico-mechanical properties of overlying superincumbent, methodology of mining and rate of extraction etc. Strata behavior in case of Bord and Pillar extraction is even complicated with respect to longwall method of extraction because of left out rib pillars in the goaf as remnants and bleak-homogeneity on extraction front..

Dynamism of strata movement is experienced upon Bord and Pillar extractions, further leading to formation of dynamic loading zone and effect within working areas including at goaf-edges. The loading effect generally happens to be maximum near the goaf-edges with diminishing effect farther in the dynamic loading zone requiring advance support in depillaring panels. Any presence of geological disturbances or weak zones in the working area may attract release of such mining induced stress, further leading to collapses or un-eventualities. In addition, strong overlying rock conditions may even lead to sluggish caving characteristics, enlarging dynamic loading zone with erratic strata behavior. Such un-eventual strata characteristics can be controlled by proper apprehension of strata movement, followed by creating either adequate support resistance or release mechanism. Strata control instrumentation and monitoring with proper analysis has emerged as a leading global solution for apprehension of strata movement during final extractions.

The study deals with preliminary analysis of strata control monitoring during Bord and Pillar extraction in an Indian underground coal mine, Churcha underground mine of SECL, Coal India Limited. Depillaring in the mine is associated with constrains/difficulties enumerated as under,

a) Higher depth of cover (maximum 400m)

b) Tangential loading due to hill cap formations and subsequent in-equal cover confinement.

c) Hard and massive roof formations almost throughout in the cover (average RMR, about 70).

d) Presence of very hard Dolerite sill of a thickness of 89.88m to 162.9m within the cover, at a horizon of about 26.5 - 120m above the roof level.

e) Presence of Dirt/Shale Bands in the coal making the pillar sides vulnerable for disintegration.

f) Vertically/angularly cleated coal formations giving rise to the potency of side spalling and subsequent collapses.

The basic objective of the study is to apprehend strata movements so that subsequent preventive measures can be initiated against any un-eventualities relating to roof and sides. Apart from apprehension of strata movement, the case study is an exposition of safe extraction scenario in Indian coal mining conditions. In the case study, instrumentation outcome such as dilation, convergence, load and stress are taken into different forms of analysis in one of the depillaring panels, 38LE panel of the mine.

II. Geology and General Information

Churcha mine R.O. is in Sonhat coalfield, which is the eastern extension of the main Sohagpur master basin. A prominent Dolerite sill occurs roughly in the middle part of the basin. In Churcha west block, only Barakar formation and thick Dolerite sill are exposed. There are various minor and major faults and dykes existing in the seam.

Fig 1. Key plan showing the location of 38 LE panel

38 Level East is a depillaring panel in Churcha West block of Churcha Mine R.O. with a notable fault of 1.2m downward throw, spread across the span of the panel, opposite to the line of extraction. Operations in the panel was being done with drilling- blasting and LHD combination.

Particulars about the working of the panel:

- Name/No. of panel : 38 level east panel, Churcha West
- Size of panel: length-745m, width-180m
- Height and width of working : Height-2m to 2.9m, width-4.2m to 4.8m
- Size of pillar center to center : Maximum- 50mx35m, minimum-35mx35m
- Nature of roof and floor : Massive sand stone
- Thickness of cover : Maximum-236m, minimum-208m
- Percent of sandstone in cover : Sandstone-51.61%, Dolerite-45.74%
- Crossing & Ignition point temp :Crossing point-1500C;Ignition point-1700C
- Expected incubation period : 10 month

Operations in the panel was being done with drilling-blasting and LHD combination.

III. Strata Control Monitoring in 38 Level East Panel

A. *Support System:*

Advance support: All the original galleries, heightened galleries and split galleries lying within two pillars from pillar under extraction were kept supported by full column grouted roof bolts of length 1.5m and set at an interval of 1.2m between bolts. Unsupported span between the bolts and the sides of the galleries was not more than 1.2m. All, the junctions of original and split galleries lying within two pillars of working pillars were supported by full column grouted roof bolts in conjunction with 3 numbers of W-straps placed at 1.2m interval between the rows and between the bolts.

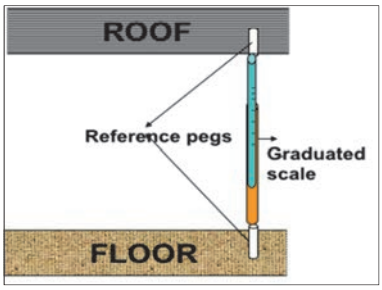

Fig 2. (a)Telescopic Convergence Indicator

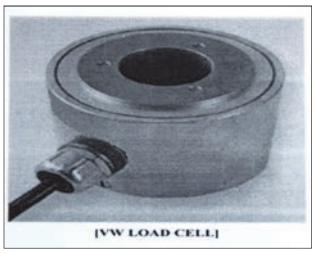

Fig 2. (b) Load Cell

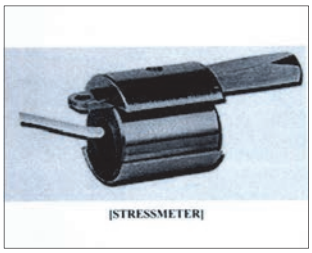

Fig 2. (c) Stress meter / Stress Cell

At working places: For a slice before opening from the split/original gallery, the entrance was supported by 2 rows of grouted roof bolts in conjunction with 3 numbers of W-

straps set at an interval of 1.2m between bolts and between rows. The slices were supported with cogs set at rib side, intervals not exceeding 2.4m.

At Goaf Edges: Integrated Steel framed cogs of 50 Ton capacity, topped by wooden sleepers not less than 30% of total height of the cogs were set skin to skin at all along goaf edges. A row of steel prop/rigid props were also set as breaker props of 20 Ton capacity, at strategic points and also at immediately behind the goaf edge cogs at intervals not exceeding 30cm. Sufficient numbers of Indicator props were fixed in goaf and other vulnerable places for apprehending thegoaf movement to take safe withdrawal of persons during goaf fall.

B. Instrumentation & monitoring:

Instruments used: Strata control instruments (Fig.2) installed in the panel, include TCI (Telescopic convergence indicator), Load Cell and Stress Cells. Installation layout is as mentioned in the instrumentation plan (Fig.3).

Data generation**:** Instrumentation monitoring was done by competent personnel round the shifts, generating enormous data/information, which was stored and processed in the integrated computer based data bank of the mine for further analysis. In addition to instrumentation outcomes, monitoring of other physical activities such as roof weighting, roof fall details and changes in working geometry was concurrently going on for further analysis.

IV. ANALYSIS

There after the processed data from the data bank are subjected to regular analysis, every afternoon by a group of mining engineers including Strata control Engineer, Panel Engineers, Safety Officer and Colliery Manager. Principal objectives of such analysis are to,

- Identify vulnerable zones/places of load concentration.
- Trend of loading characteristics.
- Evaluation of support efficacy.
- Apprehension of dynamic/periodic load in the workings and subsequent preventive measures.

Initially, caving characteristic of hang out goaf was constrained with release of induced stress, leading to formation of hanging goaf area of about 25000 sq.m., which was a big concern from strata control point of view. The first main/major roof fall came after 75 days of start of depillaring operation, covering a goaf area of 23088.50m^2. Total 50 numbers of goaf falls were witnessed including 32 major falls. Total, 306 numbers of convergence monitors (TCIs-Telescopic convergence indicators), 36 Load cells and 16 Stress cells were installed in the panel to monitor convergence, load and induced stress during extractions. The Instruments were installed on the level and split galleries covering junctions and midways, facilitating monitoring near active goaf-edge, in due course of time and subsequent apprehension of strata movement for safe withdrawal of men and equipment from the vulnerable places.

For the study, three, out of the 36 major falls (The first one, fall in the midst of the panel and the last one) were taken into strata control analysis, apprehending strata movement for ultimate safe scenario of mining. Fall wise details (Fall A, B & C)of analysis are as follows.

A. Major roof fall - A, dated 28.09. 2013 (Goaf area of fall – 23088.50m2)

Major roof fall on dated 28.09.2013 was the first main fall of the panel, which occurred covering a goaf area of 23088.50m^2. Analysis of convergence, apprehending the fall was done based on readings from Telescopic Convergence Indicator(TCI) stations at 39 ½ L / 19 X cut Junction, 39LW / 20 X cut Junction and 38L / 21 X cut Junction (ref. instrumentation plan, Fig.3) Convergence profile at 39 ½ L / 19 X cut junction (Fig. 4) confirms the following out come.

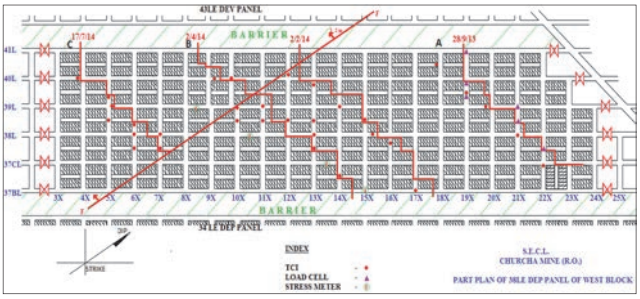

Fig 3. Instrumentation layout plan

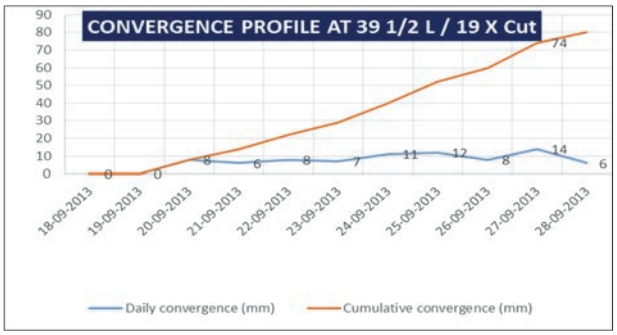

Fig 4. Convergence profile at 39 ½ L / 19 X cut

Dynamic loading influence of goaf upon workings was started with a rate of change in convergence of 8mm / day on 19.09.2013, i.e. 10 days before the main fall, while the monitoring station was about 70m away from goaf edge.

- Highest daily and cumulative convergence of 14mm / day and 74mm was recorded on 27.09. 2013, a day before main fall, the station being about 30m away from goaf edge, which indicates breakage of roof stratum facilitating main fall.

Convergence profile at 38 L / 21 X cut junction (Fig. 5) confirms the following out come

- Dynamic loading influence of goaf upon workings became active with a rate of change in convergence of 11mm / day on 20.09.2013, i.e. 11 days before the main fall, while the monitoring station was about 50m away from goaf edge.

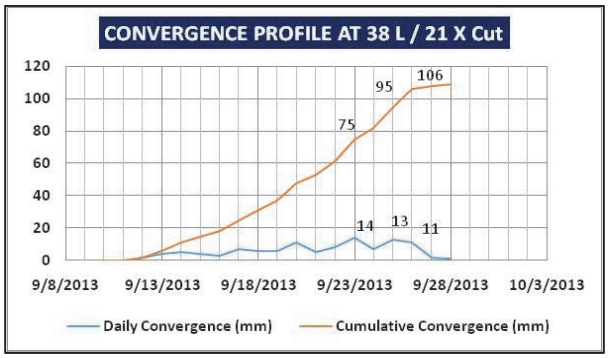

Fig 5. Convergence profile at 38 L / 21 X cut

- Maximum daily convergence of 14mm / day was observed on 23.09.2013 and the loading effect was very active upto 26.09.2013, i.e. 3 days before fall, which indicates breakage of roof stratum by then, facilitating main fall.
- Peak cumulative convergence of 109mm was observed at the time of main fall on 28.09.2013, the station being about 10m away from the goaf edge.
- Smooth and gradual dynamic loading influence of goaf upon workings was observed at this station.
- Maximum daily convergence of 16mm / day was observed on 27.09.2013, i.e. 2 days before fall, which indicates breakage of roof stratum by then,
- Peak cumulative convergence of 124mm was observed at the time of main fall on 28.09.2013, the station being at goaf edge.

Convergence profile at 41 L / 19 X cut junction (Fig. 6) confirms the following outcome.

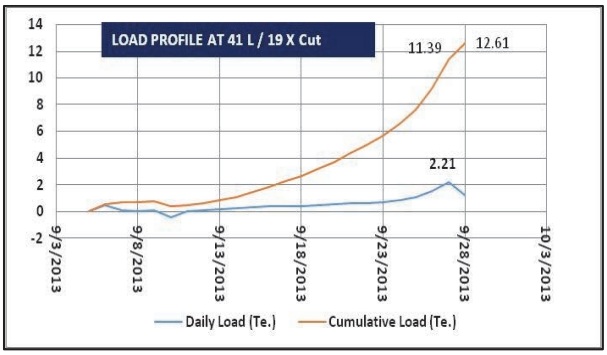

Fig-6 Load profile at 41 L / 19 X cut

Analysis of load on support system, apprehending the fall was done based on readings from Load Cells, installed on cog supports at 41 L / 19 X cut, 40 L / 19 X cut, 38 ½ L / 21 X cut and 37 1/2 CL / 22 X Cut (ref. instrumentation plan, Fig.3).

Referring to Fig. 11, gradual effect of dynamic loading was observed at 41L / 19 X cut with peak,daily and cumulative load of 2.21 Te. / day and 12.61 Te., respectively, near goaf edge, indicating breakage of roof stratum, a day before main fall. Referring to Fig. 7, repetitive loading effect was observed at 40 L / 19 X cut junction with peak daily and cumulative load of 1.65 Te. / day and 7.84 Te near goaf edge, on 27.09.2013 and 28.09.2013 respectively, stating, periodic weight of dynamic loading on workings for a period of 5 days before main fall. it is ascertained that a repetitive loading effect was there in this part of the workings, leading to a local fall on 20.09.2013 with daily load of – 0.02 Te. There was a peak, daily and cumulative load of 1.89 Te. and 6.15 Te. on 27.09.2013 and 28.09.2013 respectively, before main fall. Negative loading effect on 29.09.2013 indicates release of stress, induced of extraction and subsequent dynamic loading.

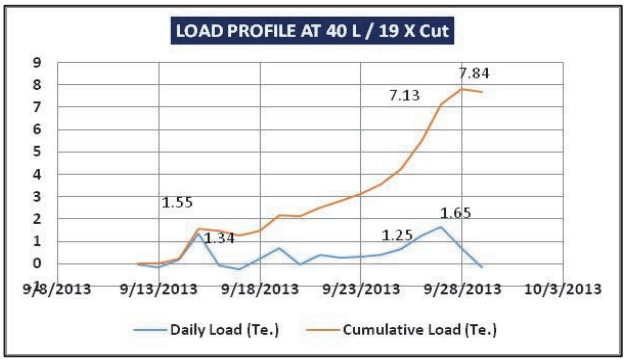

Fig-7 Load profile at 40 L / 19 X cut

Referring load profile at 38 ½ L / 21 X cut (Fig. 8),

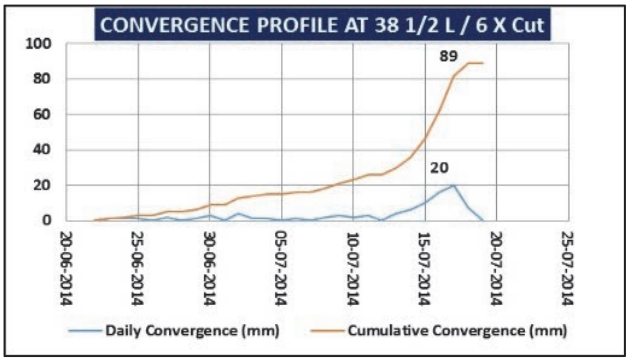

Fig-8, Load profile at 38 ½ L / 21 X cut

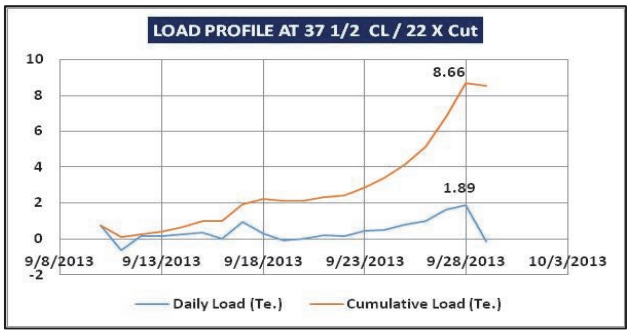

Fig-9, Load profile at 37 ½ CL / 22 X cut

Load profile at 37 ½ CL / 22 X cut (Fig. 9) says about a longer period of loading effect on the workings for about 6 days before the main fall, due to hanging goaf and barrier side of the panel. There was a peak, daily and cumulative load of 1.89 Te. and 8.66 Te. on 28.09.2013, before main fall.

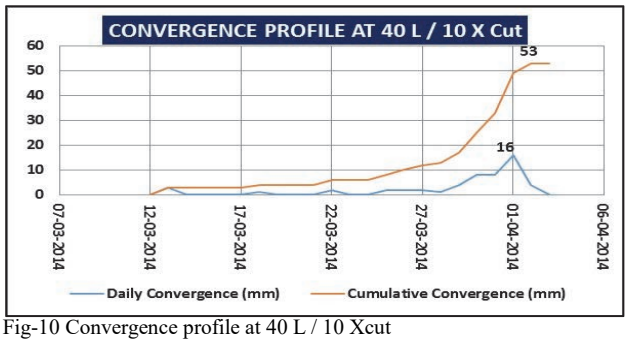

Fig-10 Convergence profile at 40 L / 10 Xcut

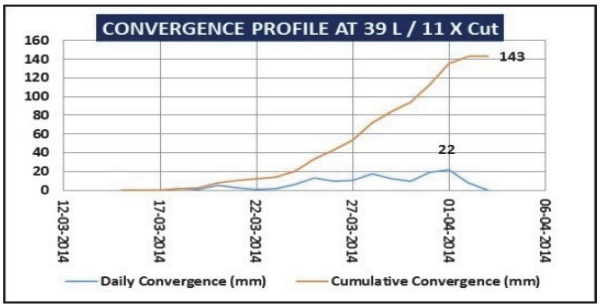

Fig-11, Convergence profile at 39 L / 11 X cut

B. Major roof fall - B, dated 02.04.2014 (Goaf area of fall – 7949m2)

Major roof fall on dated 02.04.2014, covering goaf area of 7949m^2 had intersected a long fault plane, which had crossed the panel by length; almost diagonally, (Ref. Fig.3). Apprehension of roof fall was done analyzing convergence from stations at 40 L / 10 X cut, 39 L / 11 X cut & 38 L / 13 X cut and stress from stations at 38 LE / 10 -11X cut, 39 LE / 8-9 X cut & 37 CL / 13-14 X cut.

Convergence profile at 40 L / 10 X cut (Fig. 10) indicates peak loading effect upto 01.04.2014, a day before main fall with a daily rate of change in convergence of 16mm / day and cumulative value of 53mm on the day of main fall. Analysing the convergence profile at 39 L / 11 X cut (Ref. Fig. 11), it was ascertained that period of dynamic loading effect was for about 9 days before main fall and there was a peak daily and cumulative convergence of 22mm on 01.04.2014 and 143mm, on the day of fall respectively. Such long period of loading effect and high value of convergence indicates influence of the geological disturbance (Fault line) nearby Convergence profile at 38 L / 13 X cut (Fig. 12) indicates peak loading effect upto 01.04.2014, a day before main fall with very high value daily rate of change in convergence of 26mm / day and cumulative value of 187mm on the day of main fall. The high value of convergence indicates the influence of the geological disturbance on the loading effect. Referring Fig. 13, 14 & 15, stress profiles at 38 LE / 10-11 X cut, 39 LE / 8-9 X cut and 37 CL / 13-14 X cut, indicate peak daily stress and cumulative stress as 2.8, 2.96 & 3.55 ksc / day 17.51, 17.57 & 18.08 ksc respectively. Abrupt reduction of stress in all the stress cells, on 03.04.2016, just after the fall says about a major main fall with complete release of induced stress.

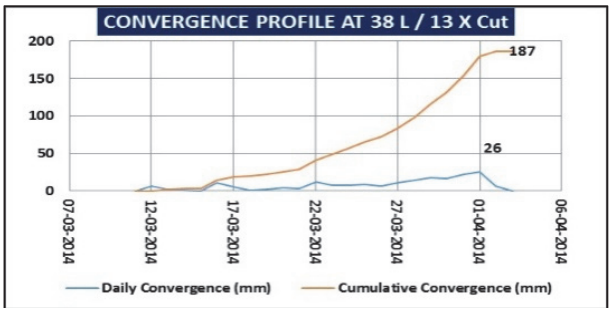

Fig-12, Convergence profile at 38 L / 13 X cut

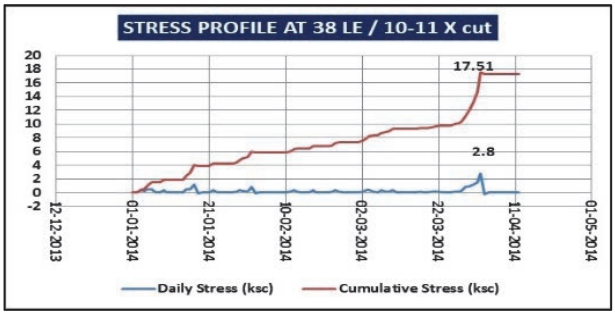

Fig. 13, 38 LE / 10-11 X cut

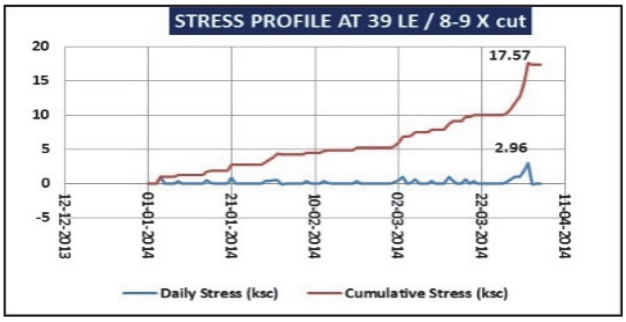

Fig. 14 39 LE / 8-9 X cut

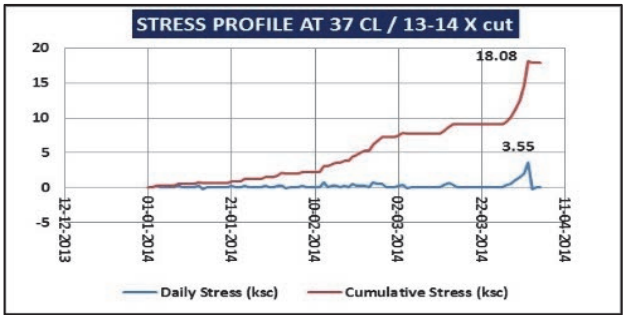

Fig. 15, 37 CL / 13-14 X cut

C. Major roof fall - C, dated 17.07.2014 (Goaf area of fall – 6343m2):

Major roof fall on dated 17.07.2014, covering goaf area of 6343m2 refers to one of the main falls to the end of extraction in the panel. As per extent, this fall was having origination from the fault plane in the panel, already discussed, (Ref. Fig.3). Apprehension of roof fall was done analyzing convergence from stations at 40 L / 4 X cut, 38 ½ L / 6 X cut & 37 ½ CL / 7 X cut.

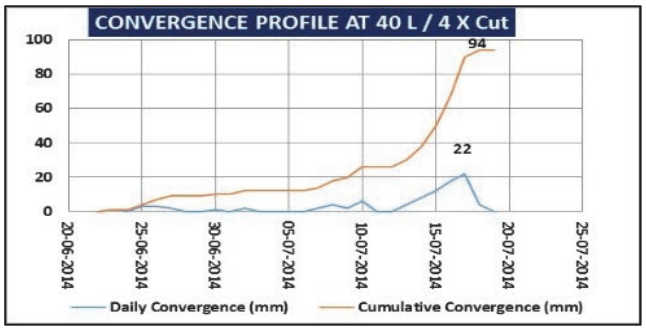

Fig. 16, 40 L / 4 X cut

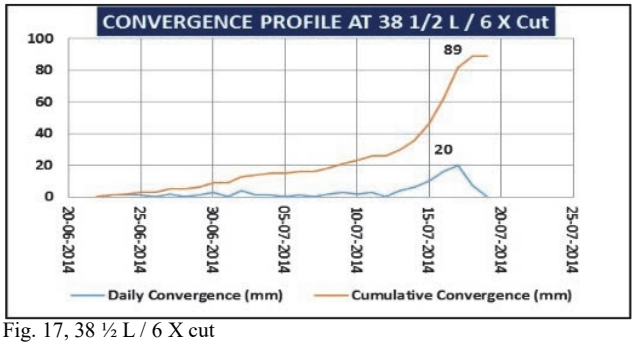

Fig. 17, 38 ½ L / 6 X cut

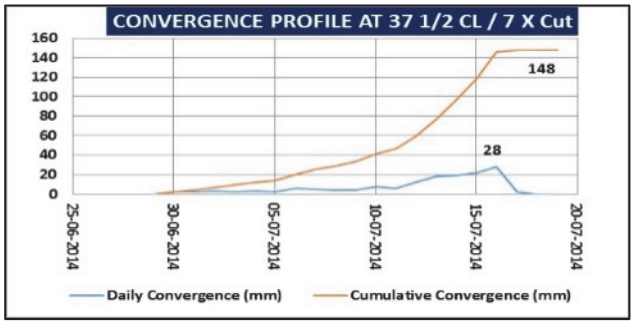

Fig. 18, 37 ½ CL / 7 X cut

Referring Fig. 16, 17 & 18, convergence profiles at 40 L / 4 X cut, 38 ½ L / 6 X cut & 37 ½ CL / 7 X cut, indicate peak daily and cumulative convergence as 22, 20 & 28 mm / day and 94, 89 & 148 mm respectively. High value convergence at 37 ½ CL / 7 X cut says about influence of the geological disturbance (Fault plane) on extraction

V. Discussion

Analysing further, the trends of peak strata control parameters are as follows. Referring Fig.19, trend of peak convergence during Fall- A (dated 28.09.2013) gives an inference that attainment of a range of 14-16 mm/ day of daily convergence and 74-124mm of cumulative convergence was an indication of first main fall, covering a vast hanging area of goaf (23088.5m2). Similarly referring Fig. 20, a range of 1.65-2.21 Te / day of daily load and 5.8-12.61Te of cumulative load was the indication of the first main fall.

Referring Fig. 21, trend of peak convergence during Fall-B (dated 02.04.2014) gives an inference that attainment of a range of 16-26 mm/ day of daily

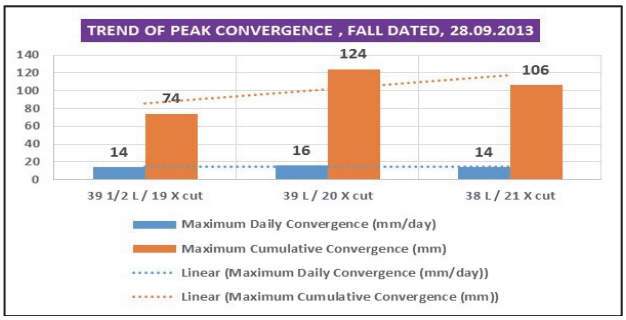

Fig. 19, Trend of Peak Convergence (Fall-A)

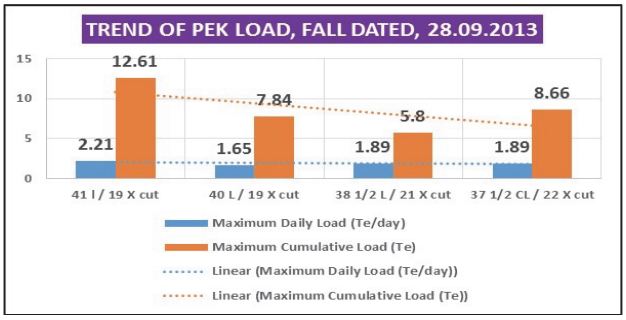

Fig. 20, Trend of Peak Load (Fall-A)

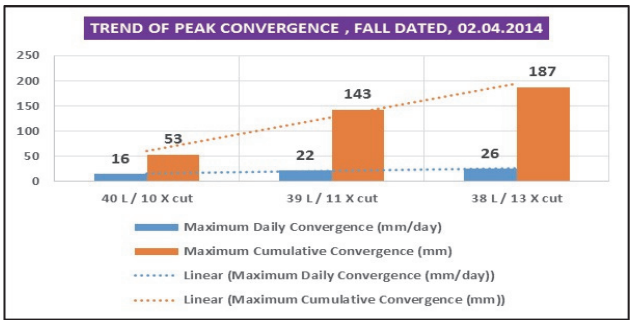

Fig. 21, Trend of Peak Convergence (Fall-B)

convergence and 53-187mm of cumulative convergence was the indication of the main fall, covering a hanging area of goaf (7949m^2), which was intersected by a prominent fault plane, across the panel. Similarly referring Fig. 22, a range of 2.8 ksc / day of daily stress and 17.51 – 18.08 ksc of cumulative stress was the indication of the same main fall. The high peaks of convergence and stress were the attribution of the prominent geological disturbance.

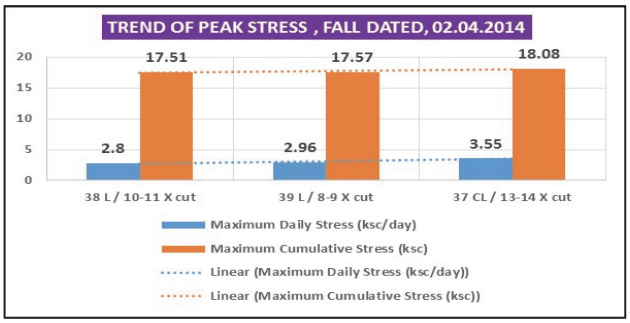

Fig. 22, Trend of Peak Stress (Fall-B)

Referring Fig.23, trend of peak convergence during Fall- C (dated 17.07.2014) gives an inference that attainment of a range of 20-28 mm/ day of daily convergence and 89-148mm of cumulative convergence was the indication of the main fall, covering a hanging area of goaf (6343m^2), which was representing the end of extraction in the panel.

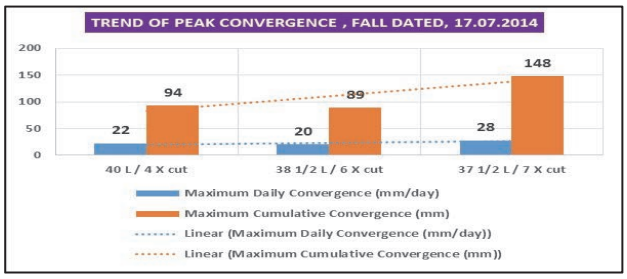

Fig. 23, Trend of Peak Convergence (Fall-C)

Summarily, based on such profile & trend analysis and mine observations during periodic weighting, further intense assessment was taken up to land with local warning limits of various parameters to draw out lines of 'do's and 'do not's of operations for safe withdrawal of men and equipment from vulnerable zones ensuring safety. Such local warning limits are highly situation and place specific and subjected to intense scientific validations. However, as a mine practice and pertinent to the panel, the local warning limits taken into apprehension are as follows.

- Rate of change in convergence of 6mm/day on the level galleries and 10mm/day on the dip-rise galleries, in general, during extractions in the panel.
- Rate of change in convergence of 10mm/day on the level galleries and 12mm/day on the dip-rise galleries, during extractions near prominent geological disturbances.
- 50 mm of cumulative convergence at any place of workings during extraction was taken as an local warning limit for strata movement.
- Rate of change in stress of 0.5 ksc/day and cumulative stress of 5 ksc at any place of extraction, were taken into limits of apprehension of active strata movement.

VI. Conclusion

Issues relating to strata control tend to be very uncertain in terms of underground coal mining. Many unseen geo-technical factors may also influence, strata behavior during final extractions, making the situations complex and vulnerable for strata failures, leading to un-eventualities. Prevention of all these necessiates ultimate mining practices, which are based upon proper work experience and scientific knowledge of the practitioners / professionals. Apprehension of strata movement is the basic requirement on scientific approaches for prevention of accidents due to fall of roof and sides. Intense scientific studies for apprehension of such strata movement may require strategic actions including a considerable span of time, limiting it for urgent hours of need. In addition, this necessitates a preliminary level of strata control assessment / analysis equipping the technocrats at operational front, which has become an effort at Churcha, underground mine of SECL, the study area of the paper.

This effort of preliminary strata control analysis has equipped the mine with early apprehension of strata movement, not only further preventing related accidents, but also enhancing safety awareness and confidence level of operational people in the mine.

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