INSTRUMENTATION FOR MONITORING LOAD ON SUPPORTS IN UNDERGROUND COAL MINES – CASE STUDIES

Singam Jayadarshana¹ Prof Singam Jayanthu² and Singam Sai Sreeja³
¹MTech student EIE-CET-Bhubaneswar, ²Professor, Mining Engg Dept., NIT Rourkela, Odisha, ³BTech-CSE-SUIT-Burla

ABSTRACT

This paper presents an overview of various types of instrumentation including load cells, and techniques of evaluation of load on supports in underground coal mine emphasizing the importance of Vibrating Wire type of load cells for monitoring load on supports in underground mines. Support systems used in typical blasting gallery panels in three typical underground coal mines are critically reviewed. In general, the capacity of the hydraulic supports used in underground coal mines for the development and depillaring workings is about 40 to 50 tons. Vibrating wire type sensors have been predominantly used for the measurement of load on these supports. Maximum load observed on the supports is about 50% of the capacity of the maximum support indicating adequacy of the support system in the respective underground mines with adequate safety factor. Recent innovations and the need of wireless sensor networks for continuous online monitoring for load cells is also emphasized for better understanding of behavior of supports.

INTRODUCTION

The progress of the technology in many branches of engineering is quite rapid in recent years. However, in case of underground mining, the progress is not as expected. It remained a lot with traditional systems, and only a few attempts were made to adopt/absorb recent trends. Although it could be attributed partly to availability and adoptability of the modern mining machinery, but also mainly due to limitations of available strata control technology, be in underground (suitable designs of workings and support systems) or opencast mines (suitable design of pit slopes, and stabilization of high walls/spoil dumps etc).

In olden days, due to lack of proper instruments, qualitative observations with limited possibility of quantification lead to some empirical relations/thumb rules. However, now-days, with improved technology of mining/instrumentation, numerical models - computer applications for analysis of data; investigators gained enhanced satisfaction through observational approaches. Acceptability of such studies by the field personnel may be improved by proper interpretation of the data so generated by experts in the strata monitoring. There is a need to be more innovative in application of the existing instrumentation with proper planning by experienced strata control engineers which may lead to possibility of modification in existing practices for better safety and economy of mining venture. India has large resources of coal deposits for underground mining and lot of coal was blocked in existing underground mines. Safe extraction of these can be made possible by effective strata management. Accidents due to movement of strata in underground coal mines had been a major concern for the mining industry and it is largest contributing factor of underground coal mine accidents. Continuous efforts were being made by all concerned to reduce the hazard of strata movement. The analysis of the accidents due to strata movement for last two decades revealed that the roof fall and side fall accidents accounted for 59% of all below ground fatal accidents in coal mines. All types of strata were involved in roof and side fall accidents (shale, coal, sand stone, shaley coal, shaley sand stone etc.). Accidents due to fall of roof occurred in almost same proportion in bord& pillar development as well as depillaring districts. The condition of strata and the stress environment around any working place is always dynamic in nature. No two working place are having identical strata condition. It is therefore essential to assess the roof condition of the working places at regular intervals by scientific methods. The analysis of the accidents, observations of the DGMS officers during the inspection of mines revealed that a system of monitoring of strata movement was not in vogue. Most of these accidents
can be prevented by effective monitoring the strata movement and implementing SSR. Therefore, it is essential to further emphasis on the issue of strata control mechanism to reduce the accidents due to strata movement (fall of roof & sides). Accident statistics since 1900 as shown in Fig 1 indicates drastically decreasing trend of fatalities since nationalisation of companies in 1970s (DGMS, 2015). However, there was no ostensible change in the trend over five decades signifying importance of new look and trans-disciplinary research to minimise the accidents in mines due to various reasons deliberated in many conferences including National safety conferences conducted from time to time.

![Fig 1: Fatal accidents during years -1900 to 2014 in mines (DGMS, 2015)](image)

In every coal mining company, strata control cell shall be established at corporate and area levels within one year as per recommendations of the 10th National Conference of Safety in Mines held at New Delhi 26-27th Nov, 2007. However, till now strata control cell not establish in all the coal mining areas as required. This may be attributed partially due to lack of proper responsiveness among the officials of some coal mining Industries. Strata control cell in coal mines can assist mine managers, for formulation of Systematic Support Rules, monitoring strata control measures in a scientific way to ensure efficacy of support system and, for procurement/supply of quality supporting materials. This issue can be addressed by proper monitoring of strata and taking adequate control measures in time. Geotechnical instrumentation although has been extensively used in the coal mines, still there is no standard procedures for undertaking the investigation as well as type of instrumentation for monitoring of the strata behaviour. Keeping this in view, two short term courses were held at NIT-Rourkela on “Trends in strata control techniques and instrumentation for enhancing safety in coal mines” during July 28th-31st, 2008, and Nov 19th -22nd, 2009. The Mining Engineering department of NIT-Rourkela also conducted Workshop/ Training programs in coalfield areas of M/s SCCL, SECL, WCL, MCL etc. under the TEQIP sponsored by the World Bank through National Project Implementation Unit during Oct-Dec’08. Strata control technologies have undergone considerable change and it is pertinent that the field engineers must be trained in the state of the art instrumentation for effective implementation of the strata control measures in coal mines.

In the light of experience of past few years, the norm for designing of Systematic Support Rules in development roadways needs re-examination and modification. Life of the roadway should also be considered while designing the system. The galleries of a Bord and Pillar system may be self-supporting under a very strong roof or the immediate roof may be supported by props, roof bolts or roof stitching depending on the local conditions (Mathur, 1999). The weight of the main strata is borne by coal pillars. During pillar extraction, props, cogs, roof bolts have been conventionally used in splits, slices etc., with skin-to-skin chocks near goaf edges (Mobile Roof Supports in USA). Performance of the support systems have been extensively studied worldwide for understanding the strata mechanics. Higher bond strengths and anchorage capacities with reduced annulus were indicated (Tadolini, 1998). Developments in support systems are related to material for bolts (cuttable bolts, tendon, resin, acconex, etc., for grouting, swellex, truss bolts), mobility of supports (mobile roof support), capacity of supports (high capacity shields, props) (Gupta and Prajapati, 1997; Khan and Hassani, 1993). Mobile supports have been successfully deployed for depillaring (Larry, 1998). Support capacities up to 800 tons are available and need introduction in Indian coalfields. It provides an upward active force on the immediate roof strata and results in normal cave line pushed back into goaf. This allows a wide stook to be mined while depillaring, thereby costly and relatively unproductive cycle of splitting of pillars and associated support can be minimised. In near future, the concept of man-less mining needs to be adapted to the maximum possible extent for improved safety, production, and productivity.
Continuous monitoring of strata behaviour in terms of convergence of openings in advance on either side of the extraction line, and stress levels over pillars, stooks in advance of the extraction and ribs in the goaf was required through remote monitoring instruments for understanding the strata mechanics at critical conditions of roof falls. Continuous monitoring of support pressures was attempted to investigate the rock mass response to mechanised pillar extraction (Follington IL and Huchinson, 1993). Integrated Seismic System (ISS) was introduced for an experimental trial at Rajendra mine, SECL, for prediction of strata movement during coal extraction by longwall mining. The system developed by South Africa works on the principle of monitoring micro seismic activities through geophones. The concept of remote monitoring or online monitoring is yet to be established to improve the safety aspects in underground coal mining. The use of Borehole TV Camera for caveability studies is the need of the hour for detailed analysis of strata behaviour during mining.

PURPOSE OF GEOTECHNICAL INSTRUMENTATION

Geotechnical instrumentation although has been extensively used in the coal mines, still there is no standard procedures for undertaking the investigations as well as type of instrumentation for monitoring the strata behaviour. Over the years, geotechnical instrumentation and strata control technologies have undergone considerable change and it is pertinent that the field engineers must be trained in the state of the art instrumentation for effective implementation of the strata control measures in coal mines. Purpose of the instrumentation should be clear for the planners before commissioning any instruments for understanding strata behaviour. Inadequate number or improper selection of instruments may lead to unsafe decisions by mine planners, while more than required number/type of instruments, not only lead to confusion but also uneconomical. Therefore, experienced strata control engineers with proper understanding of the field problem, and sufficient knowledge on interpretation of the so generated data are primary requirements for a successful instrumentation program. Some of the common requirements for use of the strata monitoring instruments in underground coal mines are as follows:

- Comparison of effectiveness of different strata control practices
- Prediction/warning of roof falls
- Generation of data base/formulation of guidelines/ Evaluation of applicability of existing guideline

About 250 records of convergence were available for different monitoring stations before local/major falls in the four depillaring panels. The distance between the monitoring station and the goaf edge was in the range of 5 to 50 m, and about 30 records were also available for the convergence inside the goaf. Maximum convergence recorded in panel #15, #16 , #17 and #18 in advance workings/split/galleries was 26 mm, 20 mm, 28 mm, and 37 mm respectively (Jayanthu,etal 2004). Statistical analysis was conducted on the data eliminating the readings of some of the disturbed stations. Maximum rate of convergence before the major roof fall increased up to 4 mm/day within 10 m from the line of extraction, while it was within 1 mm/day beyond 50 m in advance of line of extraction. It also indicated poor probability of warning of roof falls on the basis of cumulative convergence or the rate of convergence on daily basis. However, based on this data it can be said in general terms that cumulative convergence exceeding 20 mm has a probability of 80% for warning of fall, while the rate of convergence exceeding 1.5 mm/day has 60% probability of warning the major roof fall in case of the instruments located within 60 m in advance of line of extraction. The present practices of some of the strata/support monitoring instrumentation is shown in Fig 2.

ELECTRONIC INSTRUMENT- LOAD CELL

Underground excavation of minerals causes disturbance in earth surface. Therefore mine strata needs to be supported by means of artificial support systems. These support systems are of two types; active and passive. Active support system consists of props, chocks, roof bolts etc whereas Passive support systems include mesh, straps, shotcrete, and steel sets etc. The active supports i.e. props, chock, roof bolt need continuous monitoring as these are of certain capacity. If the pressure coming upon the roof supports exceeds its capacity, it can cause failure of roof supports and this can lead to disturbance of roof which may also lead to roof fall. To avoid these accidents, condition of the roof supports should be monitored time to time with reference to the variation of load on the support at different stages of extraction of mineral. For this purpose, load monitoring of roof support systems is necessary. There are different types of props, such as hydraulic, friction, and wooden. According to load measurement arrangements, props are also classified as Open circuit and Close circuit Props. The images of various support systems used in Blasting gallery panel at SCCL mines are shown in Fig 3. Open circuit props are monitored using
load measuring gauges. These are known as load cells. In earlier days there was no technology to monitor load on supports. It was done manually by observing visible changes such as crack on wooden props, subsidence of roof etc. It was an unhealthy practice as it could not predict the failure of the support system within a safe time period. Thus, there was a need for monitoring of load coming upon the support. This is why load cells were introduced into underground mine support system. There are different types of load cells, such as hydraulic, mechanical, strain gauge, vibrating wire type.

![Fig 2: Typical instrumentation for strata monitoring Around underground workings.](image)

Vibrating wire load cells are very useful and give an important data when they are used in compressive load applications. These are available in three gauge wire or six gauge wire construction to eliminate positioning effect or tilt effect. The average of three or six independent gauge data provides very accurate load measurement. The three or six gauge wires are positioned at 120° spaced vertically on the periphery of a cylindrical stainless steel element of load cell. When a compressive load acts on the load cell, the gauge wire get compressed and tension in wire is reduced and at the same time the length of gauge wire. This changes the natural frequency of the wire. Vibrating wire readout model SME 2460-S provides a low voltage pulse signal to a magnetic coil near gauge wire, which in turn, makes wire to vibrate at its natural frequency. The readout selects the frequency corresponding to peak voltage produced in the coil being the resonant frequency. Readout unit indicates the signal in terms of frequency, time period, or load direct in units such as tons.

![Fig 3: Support system in blasting gallery panel of a typical underground coal mine](image)

Vibrating-wire transducers are used in many instruments, including load cells, deformation gauges, surface and embedment strain gauges, earth pressure cells, pressure sensors for piezometers, and liquid level settlement gauges[15]. The working principle of Vibrating wire load cells is well known. A highly tensioned wire is fixed between two flanges inside the hollow casing across the length. A coil is positioned almost near the middle of the wire. When this coil is energised by using some external source, the magnetic field generated plucks the wire and
lets it vibrate in its resonant frequency reflective of the external force. These vibrations cause voltage fluctuations in the coil that corresponds to the vibrations. When stress or pressure comes upon the load cell, the tension on the wire changes as the two flanges are physically moved towards each other and this in turn causes small decrease in the effective length and tension of the wire. Thus the vibration frequency of the wire also changes. A vibrating wire type load cell under testing in laboratory and installed and being monitored in the field is shown in Fig 4, and 5, respectively. A read out unit is used to extract readings from the load cell. It provides a low voltage pulse signal to the magnetic coil which in turn causes the wire to vibrate at its natural frequency. The read out unit selects the frequency corresponding to peak voltage generated in coil being the resonant frequency. If continuous read out is needed then two coil vibrating wire transducers are used. One coil electronically plucks the wire and senses the vibration caused voltage fluctuations. This frequency is calculated. The second coil vibrates the wire at the same frequency. As frequency changes, so does the plucking frequency of the second coil. The vibrating wire theory thus can be expressed as follows:

\[ \varepsilon = \frac{\Delta L}{L} = \frac{4L^2 \rho}{E} \left( f^2 - f_0^2 \right) \]

Where,
- \( f \) = resonant frequency of wire vibration
- \( \Delta L \) = change in length of vibrating wire
- \( L \) = initial length of vibrating wire
- \( E \) = Young’s modulus of the steel wire
- \( \rho \) = volumetric weight of wire

Fig 4: Vibrating wire type load cell under calibration at Ground Control laboratory of NIT-Rourkela (Jayanthu, 2014)

There are three coils placed inside the load cell 120° apart. The reason behind this is when load comes upon the upper platen; it is not uniform throughout the surface. Thus reading should be taken from various parts of the surface and then averaged get the accurate reading. For this study, the load cell has four different colour wires (red, yellow, green and black) coming out of it for measurement purpose. Red, yellow and green wires represent the positive end of the wires inside and the black one is the negative end. While taking readings every coil is connected to the readout unit one by one i.e. red-black, yellow-black and green black. Then the readings are noted down. If it comes in frequency or time period then it is multiplied by a constant named gauge factor to obtain the load reading and finally these three readings are averaged to obtain the final reading. Now-a-days, there are read out units available which gives load reading instead of frequency or time period. The readout unit used these days are microprocessor based. These are programmed to display the reading in frequency or time period or directly in engineering unit like Ton or kg/cm². It has a double line alphanumeric LCD, internal real time clock and battery backed 64 KB memory. It has two different ports for charging and interfacing with the sensor. Its weight is 1.5 kg approx. The readout unit sends a low voltage pulse signal to the magnetic coil which in turns makes the wire to vibrate at its natural frequency. The readout unit selects the frequency corresponding to peak voltage generated in coil being the resonant frequency (Jayadarshana Singam, 2018).

EVALUATION OF LOAD ON SUPPORTS –CASE STUDIES
CASE STUDY-1 MINE
Thickness of Queen Seam is about 9.5 m with an average gradient of 1 in 12 towards S 39W with F grade of coal. Coal face mechanization in the panel consists of jumbo drills and remote controlled Load Haul Dumpers (LHD) loading on to chain conveyors in the levels. Geo-mining details of the panel are summarized below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of cover (minimum)</td>
<td>176 m</td>
</tr>
<tr>
<td>Depth of cover (maximum)</td>
<td>196 m</td>
</tr>
<tr>
<td>Thickness of seam</td>
<td>9.5 m</td>
</tr>
<tr>
<td>Width of the development gallery</td>
<td>4.2 m</td>
</tr>
<tr>
<td>Height of the development gallery</td>
<td>3.0 m</td>
</tr>
<tr>
<td>Length of the panel</td>
<td>960 m</td>
</tr>
<tr>
<td>Width of the panel</td>
<td>870 m</td>
</tr>
</tbody>
</table>

BG 3E panel was started on 23/02/2012 and was sealed during the month of April 2013. Earlier 30 pillars were extracted but later another 3 pillars were permitted for extraction (Fig 6). The total area of the panel was 30,107 m² with 32m*29m size of panel. The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end. In each row there are two props and a girder, with a row spacing of 1.0 m (Fig. 3). Additional supports including chocks and props are being provided wherever required. W straps are used with 2.4m long roof bolts, Resin capsules are also used for providing better support to the roof. Hydraulic props of 40 T capacity were set at about 6 to 10 T in majority of the supports in the panel. Summary of observations of load on Hydraulic props are presented in Table 3. At station 67AL-(D1) the cumulative load has reached up to 10.15 T when it was nearly 10 m from the goaf edge, it was installed on 12th March 12 at about 20 m from the goaf edge. Maximum daily variation observed was 4.21T on 18th March 12 when it was 15 m from the goaf edge. Goaf sounds were heard when the cumulative load reached up to 10.15 Tons. Maximum daily variation of load observed at station 66AL- (F2) was 5.48 T when it was about 4 m from the goaf edge. At Load cell in 66AL-(F2), sounds were observed when the cumulative load reached up to 10.24 followed by stone fall on 25th April 12. Up to the end of August 2012, cumulative load reached up to 27.53 at station 65AL-(H4) when it was 3m from the goaf edge after which it was removed. On October 28 2012 after a natural fall on 21st October goaf sounds were heard when the cumulative load was 14.92 T, the maximum day load observation was also recorded on that day which was 4.33T at 13m GED. Up to the end of February 2013 maximum day load was observed to be 4.77 T with a cumulative load of 21.48 when it was 4m from the goaf.
CASE STUDY-2 MINE

Godavarikhani No.8 Incline, existing in the southern extension of – South Godavari Mining Lease. It falls in RamagundamTaluq of Karimnagar District of Andhra Pradesh State. It lies between Latitude: 18°50’ and Longitude: 79°07’ & 79°35’. The 5.60 Sq.K.m of the leasehold is a strip of 68.48 Sq.KM leased area of South Godavari Coal Field, belonging to Singareni Collieries Company Limited. The Mine is approximately 20 KM from Ramagundam Railway station, 10 km from Central screening plant & Railway siding of GDK.No.1 Incline. It is 60 KM from Karimnagar and about 220 KM from Hyderabad by Road. South side GDK 10 & 10 A Inclines. North side Identified for OCP 2 Mine extension Block, Dip side part of OCP 2 & part of OCM 1-Extension Phase-II. The Gondwana series slightly dipping in North-Easterly consists here in the property the Barker and Talchirformation. The production was started on 1974 with the life time about 38 years and extractable reserves of 36 MT. The average daily production was consistently more than 1400 t, with good production records. Till now 24 B G panels were successfully. The gradient of mine is 1 in 8. The grade of coal is ‘D’ grade. Total number of seams encountered the area are seven namely – 1A,1,2,3B,3A,3 and 4seams, of which No.1,2,3 and 4 seams are considered to be workable. The strata within the boundaries are gently anticlerical in structure.
The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end. In each row there are two props and a girder, with a row spacing of 1.0 m. Additional supports including chocks and props are being provided wherever required. The split galleries are supported with 1.8 m long roof bolts with 1m spacing and row is 1.2m apart. Advance supports are installed up to 40m in all the rooms. Junctions are supported by two sets of skin to skin MS girders of 150mm x 150mm and supported by two No. of 40T hydraulic props on each side. In addition to the above cable bolting was done at 1.5m interval in grid pattern anchored up to a length of 1.0 m above the coal seam into sandstone roof. Corners and Sides supporting is being done with 1.5 m length bolts with 1m grid pattern whenever required. Fig 7 shows variation of about 22.8 ton load on hydraulic support in a typical working place of Blasting gallery panel at GDK incline –SCCL.

Fig 7: Variation of load on support in a Blasting gallery panel at GDK-8 Incline-SCCL.

CASE STUDY-3 MINE
About 30 nos of BG panels were extracted in GDK-10 incline producing about 7 Million tons of coal. First Blasting Gallery method of extraction was introduced in SCCL in 1989 at GDK No.10 Incline and being worked successfully. Although, first BG in India was introduced in East Katras Colliery of Jharia Coal Fields, BCCL and Chora Colliery of Raniganj Coal Fields, ECL in 1987, the workings were abandoned in East Katras Colliery due to Strata Control Problem, and were discontinued in Chora Colliery due to premature Spontaneous heating problem. GDK-10 Incline mine falls in Godavari Valley Coal Fields of Singareni Collieries Company Limited and is situated in Andhra Pradesh. It was opened on 25-11-1976 with three workable seams viz., 3A Seam, 3 Seam and 4 Seam. The parting between No. 3A Seam and No.3 Seam is 40m and between No.3 Seam and No.4 Seam is 4.5 m to 5.5 m.

The coal measure formations observed in borehole # 637 within GDK 10 Incline area indicated that the thickness of III seam is about 11 m with an average gradient of 1 in 7 towards N 23½° E. The strata overlying the coal seam are composed of coarse to medium grained sandstone with carbonaceous shale bands. Cavability studies of roof of III seam at GDK 10 incline and the underground observations in the previous panels (NIRM, 1999), indicated a Maximum cavability index of the roof of about 2915 in the overlying rock mass in the BG panel-I of Block-C. First major fall conditions are anticipated at about 50 to 60 m clear span in the goaf without presence of any ribs. Induced caving of immediate roof up to 8 m (i.e., bed with cavability index of 1616) allows the overlying roof with low cavability index to fall on its own at about 21 m clear span in the goaf. It will also give cushioning effect during first major fall with no perceptible dynamic loading. As per the records submitted by the management, the maximum area of extraction at the time of major fall was about 6,800 m². Minimum and Maximum period of extraction of a panel is about 5 months to 1 year 4 months. Minimum and maximum depth covers of the BG panels worked so far are in the range of 11 to 199 in Block A and Block B. Many of the above panels were sealed off/closed prematurely due to occurrence of fire. Minimum and maximum width/length of the panels was about 125 m and 250 m. Main fall area was in the range of 1282 to 6800 m². Depth of Panels varied from 111 to 166 m in this block. In the above Block B, many of the above panels were sealed off/closed prematurely due to occurrence of fire/spontaneous heating. Minimum and maximum width/length of the panels was about 75 m and 180 m. Main fall area was in the range of 2885 to 6092m² Percentage of extraction varied from 50 to 90 in the above block. In the Panel no 2D of the above
block out of total reserve of 2,50,000 tons, 2,22,812 tons with percentage of extraction of 89, which may be considered as efficiently worked panel in the above block. Minimum and maximum width/length of the panels was about 103 m and 150 m in the above Block C. Total area extracted in the BG panels of above block are in the range of 7345 to 22080 m². Percentage of coal extraction in the panels are in the range of 35 to 89.

In the Panel no 2E of the above block, out of total reserve of 2,50,000 tons, 2,22,812 tons. The percentage of extraction was 89%, which may be considered as efficiently worked panel in the above block. Panel size in these workings is 150 x 128.5 m, and worked during 06-07-2005 to 08-02-2006 for a period of 7 months 2 days. Thickness of #3 seam is about 11 m with an average gradient of 1 in 5.5. The strata overlying the coal seam are composed of white sandstone with carbonaceous clay bands. Coal face mechanization in the panel consists of jumbo drills and remote controlled Load Haul Dumpers (LHD) loading on to chain conveyors in the levels.

The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end (Fig 3). In each row there are two props and a girder, with a row spacing of 1.0 m. Additional supports including chocks and props are being provided wherever required. The split galleries are supported with 1.8 m long roof bolts with 1m spacing and row is 1.2m apart. Advance supports are installed up to 40m in all the rooms. Junctions are supported by two sets of skin to skin MS girders of 150mm x 150mm and supported by two No. of 40T hydraulic props on each side. In addition to the above cable bolting was done at 1.5m interval in grid pattern anchored upto a length of 1.0 m above the coal seam into sand stone roof. Corners and Sides supporting is being done with 1.5 m length bolts with 1m grid pattern whenever required. Hydraulic props of 40 Tons capacity are set at about 6 to 8 T in majority of the supports in the panel. At station L3-66AL the cumulative load has reached up to 6 T when it was nearly 8 m from the goaf edge, it was installed with a setting load of 5.35 T at about 19 m from the goaf edge. Maximum daily variation observed was 1 T on 24-08-11 when it was 13 m from the goaf edge.Load cell at station L4-66BL the maximum variation of load was recorded about 6 Tons. When it was nearly 13 m from the goaf edge. Maximum daily variation observed was 2.3 T on 29-08-11 when it was 15 m. At station L5-67BL about 4.5 Tons variation of load was recorded when it was nearly 3 m from the goaf edge, it was installed with a setting load of 9.8 T at about 18 m from the goaf edge. Maximum daily variation observed was 1 T on 02-08-11 when it was 15 m from the goaf edge. Max. load was observed when station was within 10 meters from goaf. Table 2 presents summary of observations of load on hydraulic props in 66AL (LOAD CELL-3).

**Table 2: Summary of observations of load on hydraulic props in 66AL (LOAD CELL-3)**

<table>
<thead>
<tr>
<th>DATE</th>
<th>GED m</th>
<th>GREEN Sensor – Ton</th>
<th>YELLOW Sensor– Ton</th>
<th>RED Sensor– Ton</th>
<th>AVG LOAD– Ton</th>
<th>DAILY VAR. LOAD–Ton</th>
<th>CUM LOAD–Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-08-2011</td>
<td>19</td>
<td>13.12</td>
<td>4.81</td>
<td>-2.18</td>
<td>5.250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13-08-2011</td>
<td>19</td>
<td>13.40</td>
<td>4.98</td>
<td>-2.20</td>
<td>5.393</td>
<td>0.143</td>
<td>0.143</td>
</tr>
<tr>
<td>14-08-2011</td>
<td>19</td>
<td>13.89</td>
<td>4.62</td>
<td>-1.53</td>
<td>5.660</td>
<td>0.267</td>
<td>0.410</td>
</tr>
<tr>
<td>16-08-2011</td>
<td>19</td>
<td>13.95</td>
<td>4.68</td>
<td>-1.51</td>
<td>5.707</td>
<td>0.047</td>
<td>0.457</td>
</tr>
<tr>
<td>17-08-2011</td>
<td>19</td>
<td>14.08</td>
<td>4.79</td>
<td>-1.52</td>
<td>5.783</td>
<td>0.077</td>
<td>0.533</td>
</tr>
<tr>
<td>18-08-2011</td>
<td>19</td>
<td>14.25</td>
<td>4.95</td>
<td>-1.50</td>
<td>5.900</td>
<td>0.117</td>
<td>0.650</td>
</tr>
<tr>
<td>19-08-2011</td>
<td>17</td>
<td>15.92</td>
<td>3.61</td>
<td>0.78</td>
<td>6.770</td>
<td>0.870</td>
<td>1.520</td>
</tr>
<tr>
<td>20-08-2011</td>
<td>17</td>
<td>16.28</td>
<td>4.15</td>
<td>1.58</td>
<td>7.337</td>
<td>0.567</td>
<td>2.087</td>
</tr>
<tr>
<td>21-08-2011</td>
<td>17</td>
<td>16.16</td>
<td>4.44</td>
<td>2.19</td>
<td>7.597</td>
<td>0.260</td>
<td>2.347</td>
</tr>
<tr>
<td>22-08-2011</td>
<td>15</td>
<td>17.05</td>
<td>3.71</td>
<td>2.63</td>
<td>7.797</td>
<td>0.200</td>
<td>2.547</td>
</tr>
<tr>
<td>23-08-2011</td>
<td>15</td>
<td>17.47</td>
<td>4.10</td>
<td>3.88</td>
<td>8.483</td>
<td>0.687</td>
<td>3.233</td>
</tr>
<tr>
<td>24-08-2011</td>
<td>13</td>
<td>17.35</td>
<td>5.32</td>
<td>5.88</td>
<td>9.517</td>
<td>1.033</td>
<td>4.267</td>
</tr>
<tr>
<td>25-08-2011</td>
<td>11</td>
<td>15.85</td>
<td>7.19</td>
<td>6.93</td>
<td>9.990</td>
<td>0.473</td>
<td>4.740</td>
</tr>
<tr>
<td>26-08-2011</td>
<td>11</td>
<td>15.21</td>
<td>9.03</td>
<td>6.55</td>
<td>10.263</td>
<td>0.273</td>
<td>5.013</td>
</tr>
<tr>
<td>27-08-2011</td>
<td>10</td>
<td>15.87</td>
<td>9.64</td>
<td>5.72</td>
<td>10.410</td>
<td>0.147</td>
<td>5.160</td>
</tr>
<tr>
<td>28-08-2011</td>
<td>10</td>
<td>12.50</td>
<td>10.43</td>
<td>5.59</td>
<td>9.507</td>
<td>-0.903</td>
<td>4.257</td>
</tr>
<tr>
<td>29-08-2011</td>
<td>8</td>
<td>11.63</td>
<td>9.73</td>
<td>9.81</td>
<td>10.390</td>
<td>0.883</td>
<td>5.140</td>
</tr>
</tbody>
</table>
CONCLUSION

Vibrating wire type load cells are preferred as compared to strain gauge, hydraulic, mechanical types for monitoring load on the supports in underground coal mines. Maximum load on support in depillaring workings at 21 incline, GDK 8 incline etc of SCCL reached up to 30 Tons without any adverse strata or support conditions. Maximum load on support and convergence of workings upto the end of August 2011 in BG panel #3A are 14 Tons, and 32 mm, respectively at GDK 10 incline. Maximum rate of convergence and load on support recorded was about 4 mm/day, and 2 Tons/day, respectively in typical BG panel. In 67 Level maximum bed separation of about 10 mm was observed within 0.5 to 2.5 m horizon in the overlying roof. Goaf falls were regular with induced caving up to 1.5 m in Sandstone roof conducted for seven times till the end of August, 2011, and natural falls occurred with adequate filling.

Overview of performance of previous BG panels at GDK 10, and cavability of roof indicated that in near future, BG panels may be planned with panel sizes of about 120x120 m, so that the major fall with adequate span may occur at an area of about 8000 m². This size of panel may minimize the chances of premature sealing/closure of panels reducing chances of fires/spontaneous heating in subsequent BG panels besides goaf treatment with inert gas. In general, readings of load on supports in BG method are taken manually once in every one or two days. Carrying the readout unit which is of approx 1.5 kg to every load cell and taking reading out of it is a tough job taking lot of time as well as requires a skilled person who can operate the readout unit. If the load cells can be digitized, monitoring of the load can be much easier, and continuous load monitoring is also possible. Thus digitization of vibrating wire type load cell for mine support systems is required in view of the requirement of online real-time monitoring of load on supports for improved safety of underground workings. The experimental set up available for testing and calibration of load cell in Mining Engineering department of NIT-Rourkela will be utilized for conducting the tests, and also for future developments of WSN system for real-time monitoring of load on supports for better safety of workings.

ACKNOWLEDGEMENTS

Some of these studies on strata behaviour were conducted under Science and Technology projects sponsored by Ministry of Coal, Government of India, and also sponsored by the management of SCCL. The support and encouragement provided by the management of M/s Singareni Collieries Company Limited in some of the projects are gratefully acknowledged. The first author gratefully acknowledges the consistent encouragement and guidance of Dr T N Singh, former Director, CMRI, Dhanbad and Prof D P Singh, Emeritus Professor, IIT-BHU, Varanasi, Sri S Iliah, former Rope Splicer of SCCL, and Sri G Laxman, Former General Manager of SCCL on various studies of strata behaviour and methods of extraction in coal mining.

BIBLIOGRAPHY

1. CMRI, 1987. Development of roof supports for mechanized bord and pillar workings and fast drivage and their field evaluation, S&T Project Report, 72 pp