FINAL REPORT

Subsidence Monitoring at forest area above the underground working within mining lease of UCIL Jaduguda

Sponsored by

URANIUM CORPORATION OF INDIA LIMITED.

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Executive Summary

Subsidence impacts occur at every underground mining operation bringing about changes to surface landforms, ground water and surface water. Although the same impacts to mining operations, man-made surface structures and other features are relatively well known and studied, the environmental impacts related to subsidence at underground mines are not well known and have not been extensively described. The job of Subsidence Monitoring at forest area above the underground working within mining lease of UCIL Jaduguda was awarded to ISM vide the WO no. UCIL/GM (MINES)/ 09-(01)/2015.

It was noted that systematic subsidence monitoring at forest area above the underground working within mining lease of UCIL Jaduguda was being carried out by UCIL using Total Station and Auto-Level since October 2010 at an interval of six month. ISM Dhanbad was engaged to carry out precise 3D Subsidence monitoring at the established control stations (survey pillars established earlier by UCIL) using Total Station and Digital Level for comparing the results with the previous monitoring data taken by UCIL during various phases and finding any deviations/movement of the survey pillars in the forest area.

This report presents a brief description of mine, geology, mining methods, subsidence monitoring methodology, results of 3D subsidence monitoring of the established control stations (survey pillars) at forest area above the underground working within mining lease of UCIL Jaduguda using Total Station and Digital Level for finding any deviations/ movement, field data processing and plotting the control stations on a grid for assessment of ground movement (if any).

Elevations data during October, 10 to March, 15 at Subsidence Monitoring stations located in the forest area above the underground working within mining lease of UCIL Jaduguda were analysed and graphically represented. From analysis of result it was revealed that the maximum unsystematic elevation variations (some time increasing and sometime decreasing) were in the tune of 5 mm – 10 mm for a period of three years, which may be attributed due to observational errors or the local settlement of some of the stations due to improper protection of pillars.

The variations in 3D coordinates of subsidence monitoring stations lying in the forest area above mine workings within lease hold of UCIL Jaduguda were insignificant as reflected from the monitoring results of last five years (Annexure – III). Some minor variations were observed from the analysis of past data. However, these variations were not regular and systematic. Hence these variations did not confirm ground movement. The variations might have been attributed to observational errors or pillar disturbances.

Subsidence is an important aspect of underground mining activity. As the mining activity at UCIL Jaduguda is carried out at greater depth (> 500m) and stowing is done in the void created by Horizontal cut and fill mining method, so no surface subsidence is anticipated. Moreover, rock mass of Jaduguda mine was considered to be competent enough to stand the induced stress, therefore, no surface subsidence is anticipated.

Subsidence Monitoring at forest area above the underground working within mining lease of UCIL Jaduguda

1. INTRODUCTION

Mining subsidence occurs when overlying strata start moving to fill the mine voids and extend to the ground Surface. The potential for subsidence exists for all forms of underground mining. Subsidence may manifest itself as sinkholes or troughs. Sinkholes are usually associated with the collapse of part of a mine void (such as room and pillar mining); the extent of the surface disturbance is usually limited in size. Subsidence of large portions of the overlying Strata of underground void forms trough on the surface, typically over areas where most of the resource had been removed. Block caving creates large subsidence features on the surface, such as sinkholes. As a result of removing large continuous masses of rock, the overlying ground surface inevitably collapses to fill the void.

Subsidence is an inevitable consequence of underground mining – it may be small and localized or extend over large areas, it may be immediate or delayed for many years. Underground mining causes impacts to hydrologic features like lakes, streams, wetlands, and underground aquifers. Modern hard-rock metals mining, using large-scale methods like block caving and room-and-pillar mining creates large areas of hydrologic and subsidence related impacts. Most studies of subsidence impacts and their associated environmental effects have been done on underground coal mines. However, the fundamental engineering principle of subsidence is the same for coal and metals mines.

Some underground mining methods like block caving by their very design affect subsidence to the surface almost immediately. Other underground mining methods, like room and pillar mining, result in short-term impacts to aquifers and longer-term subsidence impacts. The effects on the environment may develop slowly over years in the form of degraded water quality, lowering of the water table, and chronically unstable ground. Methods used to predict subsidence is not reliable when applied to the more complex geologic conditions found at most hard-rock metal mines. Hard-rock mines often contain faults and folds and altered rocks, which complicate and exacerbate subsidence impacts. Once mining begins, it is very difficult to mitigate the effects on the environment. There is little evidence in the scientific literature demonstrating effective mitigation of subsidence impacts at hard-rock metal mines. Consequently, the environmental impacts from mining may worsen over time as the ground continues to settle and aquifers are de-watered or degraded.

ISM Dhanbad was engaged to carry out precise 3D Subsidence monitoring at the established control stations (survey pillars established earlier by UCIL) using Total Station and Digital Level for comparing the results with the previous monitoring data taken by UCIL during various phases and finding any deviations/movement of the survey pillars.

A visit to UCIL Jaduguda was made by the ISM team during March 11 – 13, 2015 to carry out 3D Subsidence monitoring at the established control stations (survey pillars established earlier by UCIL) using Total Station and Digital Level for finding any deviations/ movement in the subsidence monitoring stations above the underground working within mining lease of UCIL Jaduguda. During this phase 39 (Thirty nine) subsidence monitoring stations were made available on the ground to the survey team of ISM for monitoring of their possible movement.

This final report mainly depicts the following:

- A brief description of mine highlighting location, layout, mining lease etc.
- A brief description of the geology of the rock type and its strength, hardness, mineable reserve etc. [The required information have been provided by UCIL].
- U/G mining stopping method, access to the mine etc. [The required information have been provided by UCIL].
- Citation of technical and scientific literatures related to subsidence due to mining in hard rock and various techniques of surface subsidence monitoring.
- Methodology adopted for 3D Subsidence monitoring using Total Station [X, Y] and precise digital level [z].
- Field data processing and plotting the subsidence monitoring stations on a grid for assessment of ground movement (if any).
- Results of subsidence monitoring at 39 established monitoring stations (survey pillars) using Total Station and digital level.
- Comparison of the results with the previous monitoring data taken by UCIL during various phases and finding any deviations/movement of the survey pillars in the area.

1.1 Scope of Work

The Subsidence monitoring work at forest area above the underground working within mining lease of UCIL Jaduguda was awarded to ISM vide the (WO: UCIL/GM (MINES)/ 09-(01)/2015).

The scope of work is mentioned as under:

- Setting of the base line
- Closed traversing of near about 2.279 km covering the established control stations for getting the coordinates (x, y, z) with respect to the available Rectangular (Grid) coordinates at mine site as supplied by the surveyor of UCIL Jaduguda.
- 3D Subsidence monitoring at the established control stations (survey pillars established earlier by UCIL) using Total Station and Digital Level for comparing the results with the previous monitoring data taken by UCIL during various phases and finding any deviations/movement of the survey pillars in the forest area.
- Field data processing and plotting the control stations and Subsidence Monitoring Stations on a grid for assessment of ground movement (if any).
- Submission of Subsidence Monitoring Report.

1.2 Instrument used

The following instrument has been used during the monitoring of subsidence at subsidence monitoring stations for the purpose of subsidence surveys:-

Name of Instrument	Least count	Accuracy
For Horizontal controls [X, Y coordinates]: Reflectorless Electronic Total Station (Fig. 1) with reflector prism/ reflecting sheet	Angle: 1” Linear: 1 mm	+ 3” + 5mm
For Vertical Control [Elevation/R.L, Z]: Digital Level, DNA 03 of Leica Geosystems (Fig. 2)	0.1 mm	+ 0.3 mm

Fig. 1: Topcon TS 101AC Total Station for the horizontal control (X, Y)

Fig. 2: Leica DNA 03 Digital Level and bar coded staff for vertical control (Z)

2. ABOUT THE MINE

Jaduguda Uranium deposit is located in the Dhalbhumgarh subdivision of East Singhbhum district of Jharkhand state. The mine complex is located at 22^0 40’ 16.49” N to 22^0 38’ 25.95’’ N and longitude 86^0 19’23.34’’ E to 86^0 21’ 58.08’’ E, and is covered by Survey of India top sheet no. 73J/6 on R.F. 1:50,000 (1978). The national highway NH 33 runs from northwest to southeast and the Jaduguda main road runs from west to east and is the only metalled road that leads to Jaduguda mines. The South Eastern railway passes through the region. The nearest railway station is Rakha mines and nearest Junction is Tatanagar station. The distance from the Tatanagar station to Jaduguda is 25 km in a straight line.

Uranium Corporation of India Limited (UCIL), a Government of India undertaking under the Department of Atomic Energy (DAE) has the sole responsibility of mining and processing of uranium ore in India. At present UCIL is engaged for mining at Jaduguda Mine, Bhatin Mine, Bagjata Mine, Turamdih Mine, Narwapahar Mine, Mohuldi Mine & Banduhurang Open Cast Mine and ore processing plant at Jaduguda and Turamdih in the East Singhbhum District of Jharkhand state to produce U_3O_8.

Uranium Corporation of India Limited, a company registered under company’s Act 1956 and having its registered office at Jaduguda. UCIL has planned to harness the potential of uranium deposit utilizing their vast experience of over 50 years of mining and processing of this strategic mineral. UCIL, an ISO 9001:2008, ISO 14001:2004 and IS 18001:2007 company has adopted the latest state-of-art technology for its mines & process plants. Uranium ore extracted at Jaduguda, Bhatin, Bagjata and Narwapahar Mines are brought and processed at the Jaduguda Ore Processing Plant.

The installed capacity of the project is as under:

Jaduguda Mine	:	1000 TPD Ore Extraction.
Ore Processing Plant	:	2500 TPD Ore Processing

The land use 531.21 hectares of lease area is given in Table 1. Out of 531.21 ha forest land is 134.424 ha and remaining 396.786 ha is non forest land. The ministry of Environment and Forest, GOI, vide letter no. 8-49/1997-FC, dated 20th April 1998 has accorded approval to Uranium Corporation Of India Limited for diversion of 154.464 ha forest land for non-forest use. The Land use of lease hold area has been calculated in accordance with the actual use for different purpose.

Only 56.5 hectare i.e. 10.63 % of total lease hold has been utilized for mining, ore processing and related activities remaining 474.71 hac i.e 89.37% area still exists in the natural way. In Jaduguda lease area being underground operations, excavation of area and topsoil removal is nil.

The land use pattern of the leasehold area is shown in Table 1

At Jaduguda, a very little land use alteration has been done for mining activities, as an underground mining is in operation, which will not have much impact on land other than the civil constructions occupying a very small fraction of the total area. Rather aesthetic beauty of the area has been enhanced due to the planned plantation in and around mine and colony.

Table 1: Land use Pattern of Lease area

S.No	Land Use	Area in Hectare	% of Total area
1	Agriculture	153.71	28.94
2	Forest	134.42	25.30
3	Waste disposal area	24.67	4.64
4	Industrial Establishments	31.83	5.99
5	Green belt plantation	80.00	15.06
6	Settlement	100.29	18.88
7	Open land	5.29	1.00
8	Major Water bodies	1.00	0.19
	Total	531.21	100

Figure 3 shows surface plan of mining lease area of Jaduguda of UCIL.

2.1 Geology

The area under study is situated in Singhbhum shear zone, which is characterized by gentle to moderately steep or steep slopes. The leasehold area is to the north and west of a small hill range. The ground level elevation of the site varies between 100–155 m RL with peak at the 193 mRL. General ground level gradually slopes towards the NE. The NE quadrant of the study area is slightly undulating but devoid of hills. In the buffer zone, forest on the hills in south and southeast directions exists. Flat area is dotted with small villages.

The natural drainage system is distinct due to hilly topography and well defined gradients in parts of the study area. The River Subarnarekha flows from the NW to the SE to the northeast part of the lease area. The lease area lies in a valley of about 5 km wide extending in the NW to SE direction. The area is drained by the Gara Nalla, which flows in north eastern part of the lease area and joins the Subarnrekha River at about 5 km southeast of the lease boundary near Digri Ashram. Major part of the area has dendritic drainage pattern. The hill ranges are drained by seasonal streams, which form the part of the Subarnrekha River system. The Gara Nalla receives water through streams flowing down from the hills on both its banks. High flood level of the Gara Nalla and Subarnarekha River is well below the mining lease. Geological map showing Singhbhum Shear Zone and Geological section are given in figure 4 and figure 5.

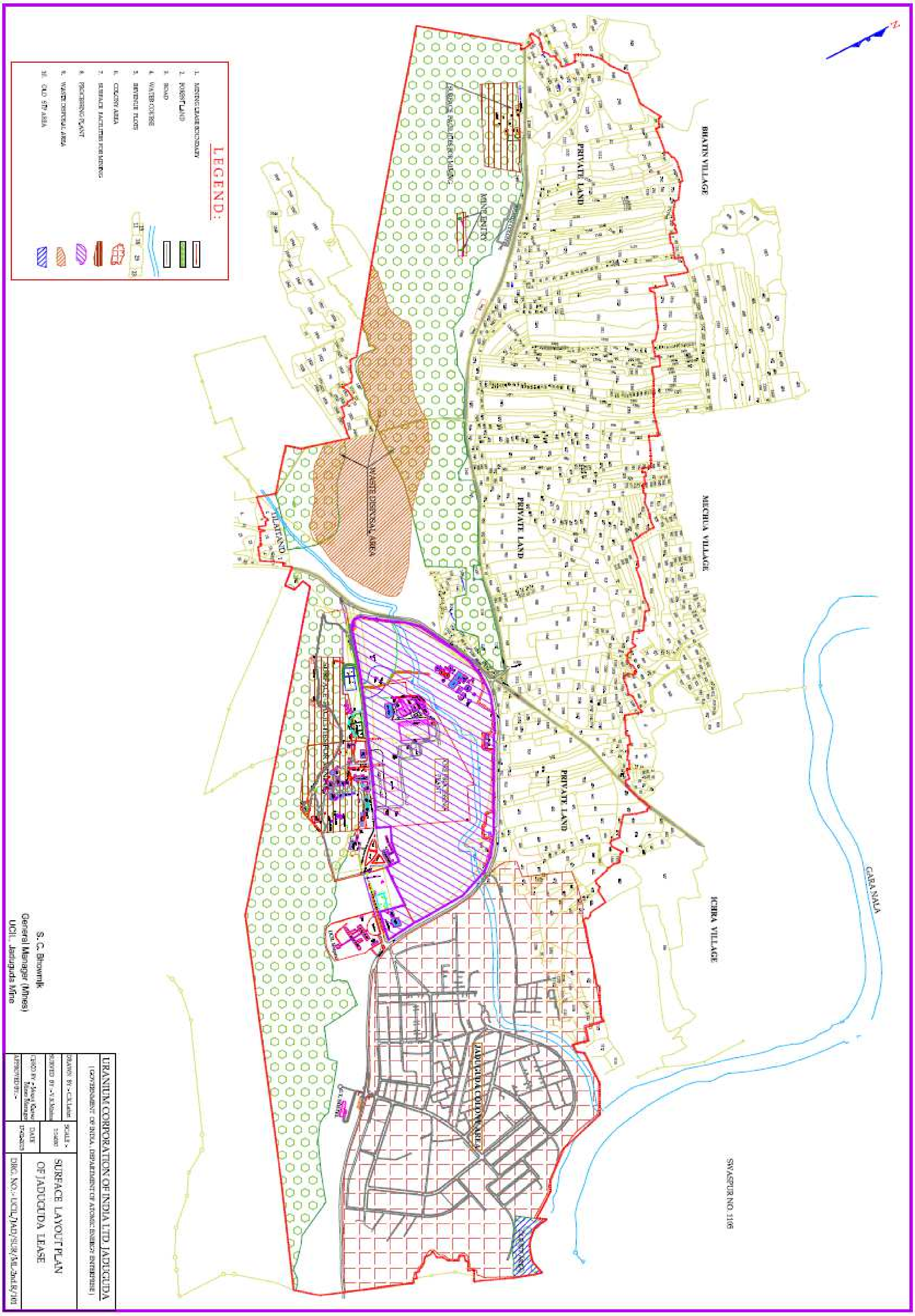
LEGEND:
1. MINING LEASE BOUNDARY
2. FOREST LAND
3. ROAD
4. WATER COURSE
5. REVENUE PLOTS
6. COLONY AREA
7. SURFACE FACILITIES FOR MINING
8. PROCESSING PLANT
9. WASTE DISPOSAL AREA
10. OLD STP AREA
BHATIN VILLAGE
MECHUA VILLAGE
ICHRA VILLAGE
PRIVATE LAND
PRIVATE LAND
PRIVATE LAND
WASTE DISPOSAL AREA
MINE ENTRY
JADUGUDA COLONY AREA
GARA NALA
SWASPUR NO. 1106
S. C. Bhowmik
General Manager (Mines)
UCIL, Jaduguda Mine
URANIUM CORPORATION OF INDIA LTD. JADUGUDA
(GOVERNMENT OF INDIA, DEPARTMENT OF ATOMIC ENERGY ENTERPRISE)
SURFACE LAYOUT PLAN
OF JADUGUDA LEASE
DRAWN BY :-
SURVEYED BY :-
CHECKED BY :-
APPROVED BY :-
SCALE :-
DATE
DRG. NO.:- UCIL/JAD/SUR/ML-2nd.R/101

Fig.3: surface plan of mining lease area of Jaduguda of UCIL

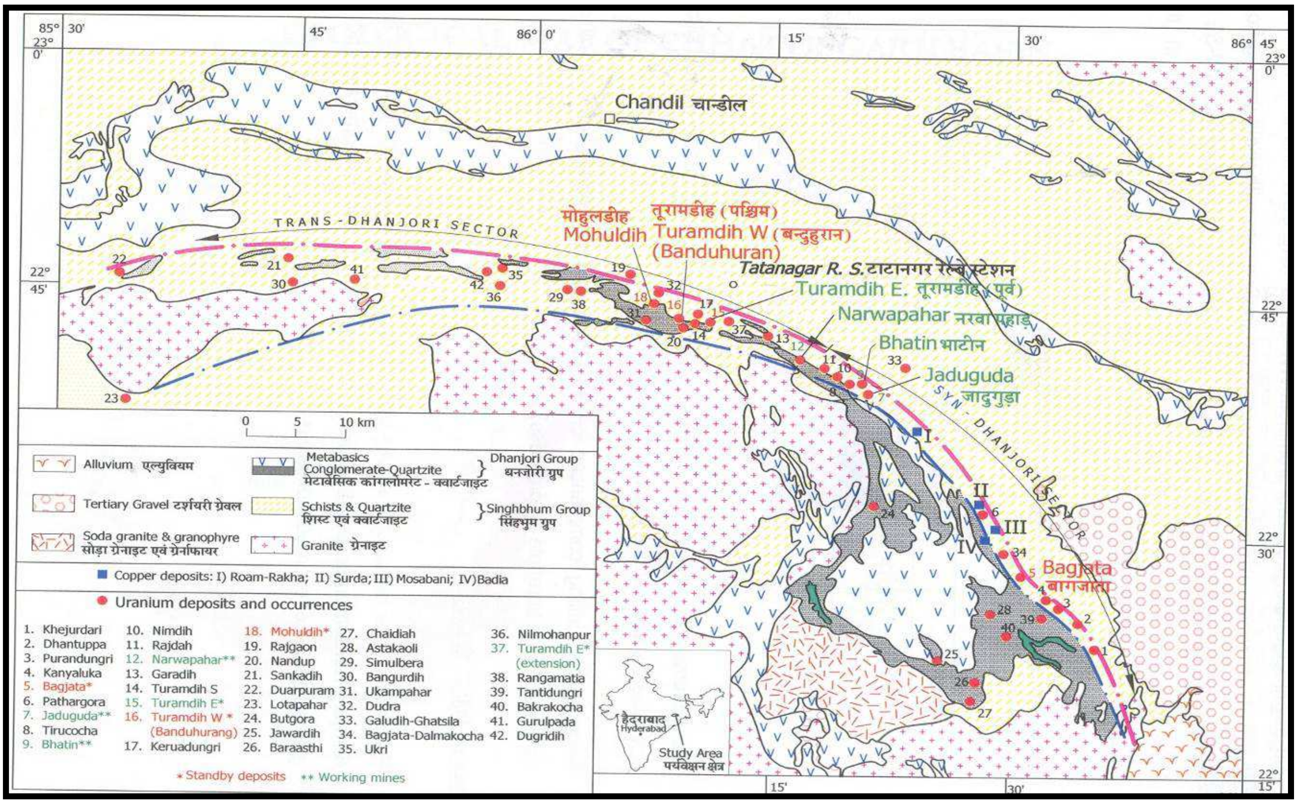

Fig. 4: Geological map showing Singhbhum Shear Zone

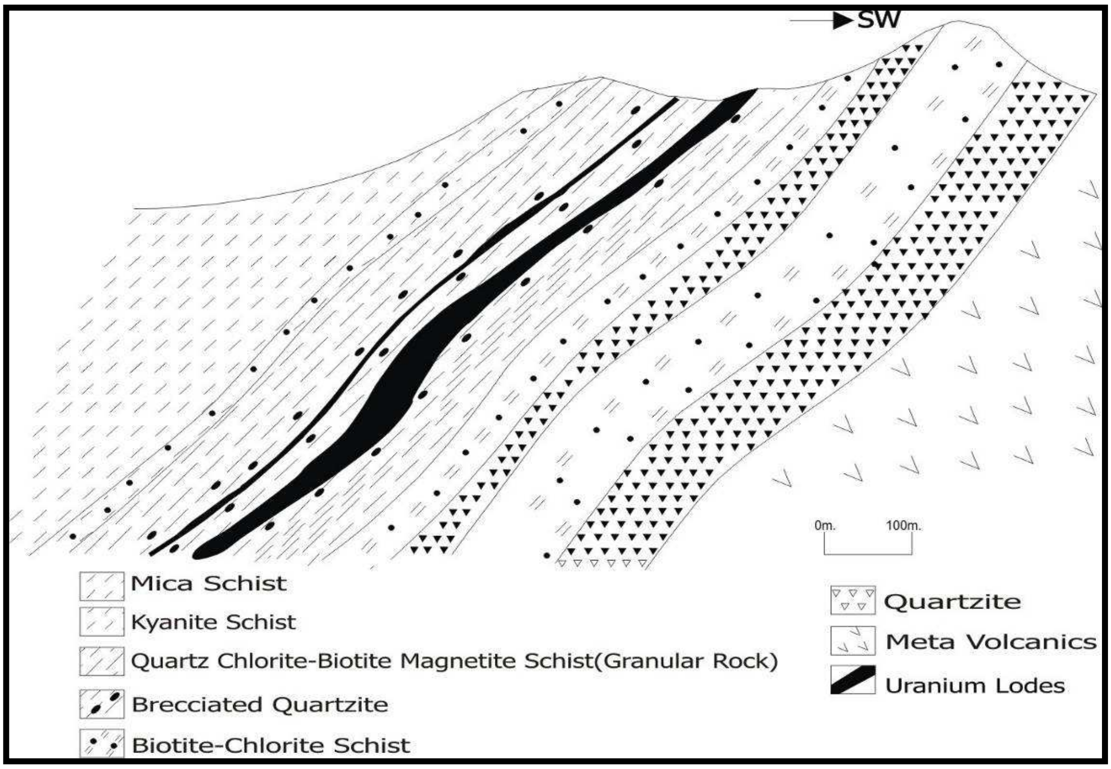

Fig. 5: Geological section

Mineable mineralization at Jaduguda is confined to two principal lodes – known as Footwall Lode (FWL) and Hangwall Lode (HWL) - extending as veins following the general trend of the schistosity. Persistence of lodes is fairly uniform both along strike (NW 20o) and dip (towards NE) with an average inclination of about 40o. Both the lodes are parallel and separated from each other by a distance of about 80 m.

In Jaduguda mine, the host rock and the adjoining strata are quite competent except the talc-chlorite schist zone in the footwall side. The increasing trend of uniaxial compressive strength of rocks with depth indicates better competency and self-supporting nature of rock.

2.2 Method of Mining

Jaduguda mine is the oldest and deepest uranium mine in India. The present working depth of mine is about 700 m and the deepest point is 905 m from the surface. The strike length is about 585 m at 685 ML. Reduction of strike length, width & grade of the ore body is observed with the depth.

The present vertical shaft of Jaduguda mine is extended up to 555 ML. The ore body up to 555 ML can only be exploited with the help of present shaft. Regular mining has almost depleted ore body up to 555 ML. To continue production from deeper levels the third stage shaft has been sunk up to 905 ML. The deeper level ore body at 620 ml, 685 ml, 750 ML, 815 ML and 880 ML are being worked with this shaft. Longitudinal and transverse sections of Jaduguda mine showing first; second and third stage of development is given as figure 6 and 7 respectively.
The method of working for Jaduguda mine is horizontal Cut & Fill. A slice of 2 m thick is cut and 2 m from bottom is filled up by classified ore processing plant tailings. The horizontal slice is taken by drilling upper hole or by horizontal holes. The method is cyclic in nature. The effective stope production time is the slicing only. The rest time is engaged in stope preparation and filling. Underground section showing cut & fill method is illustrated in figure 8.

Horizontal Cut and Fill (HCF) method of underground mining is being carried out since the inception of the mine, where the deposit is accessed by vertical shaft. As concentration of work is mainly below ground, insignificant land is degraded due to mining operation. Moreover, stowing is being carried out for filling the underground voids concurrent to the mining. The waste rock, produced through development of the mine is used for backfilling of voids in underground workings.

The main method of supporting is by Rock Bolts (Full column grouted type rock bolts). However, detailed rock mechanics study for design of pillars and support system of Jaduguda mine has been carried out by Central Institute of Mining and Fuel Research (CIMFR), formerly, Central Mining Research Institute (CMRI) and the recommendation of the study is in practice.

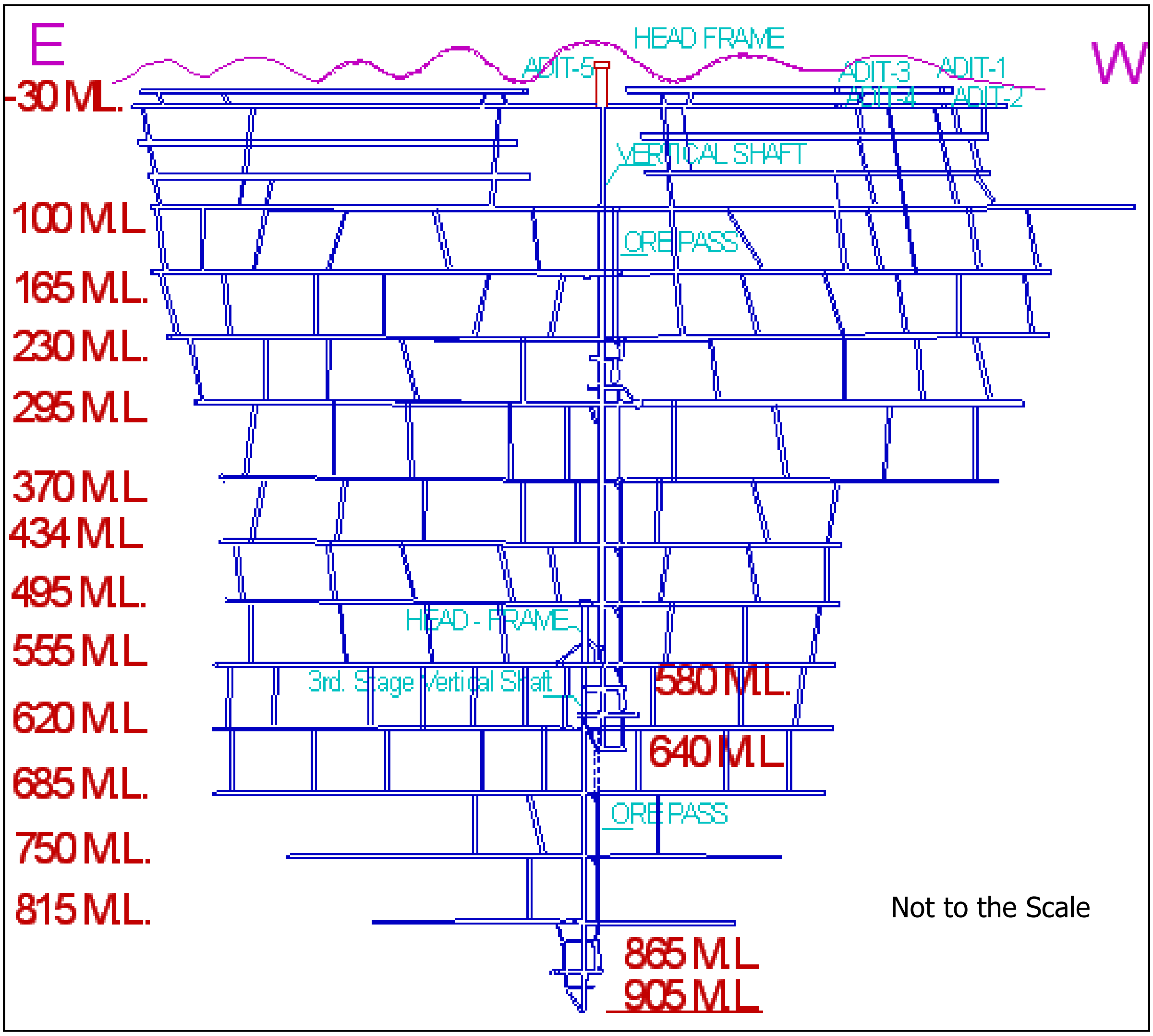

Fig. 6: Longitudinal Section

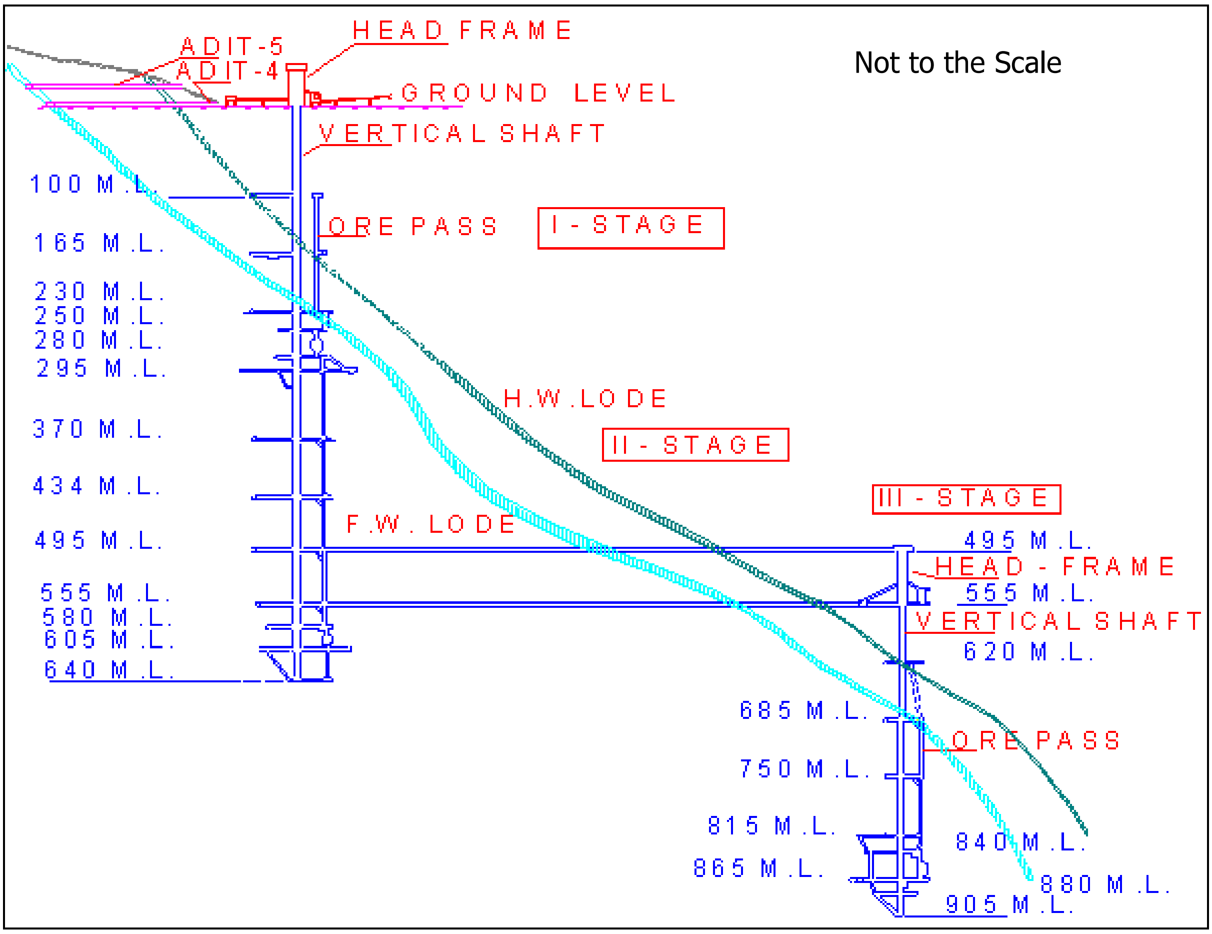

Fig.7: Transverse Section

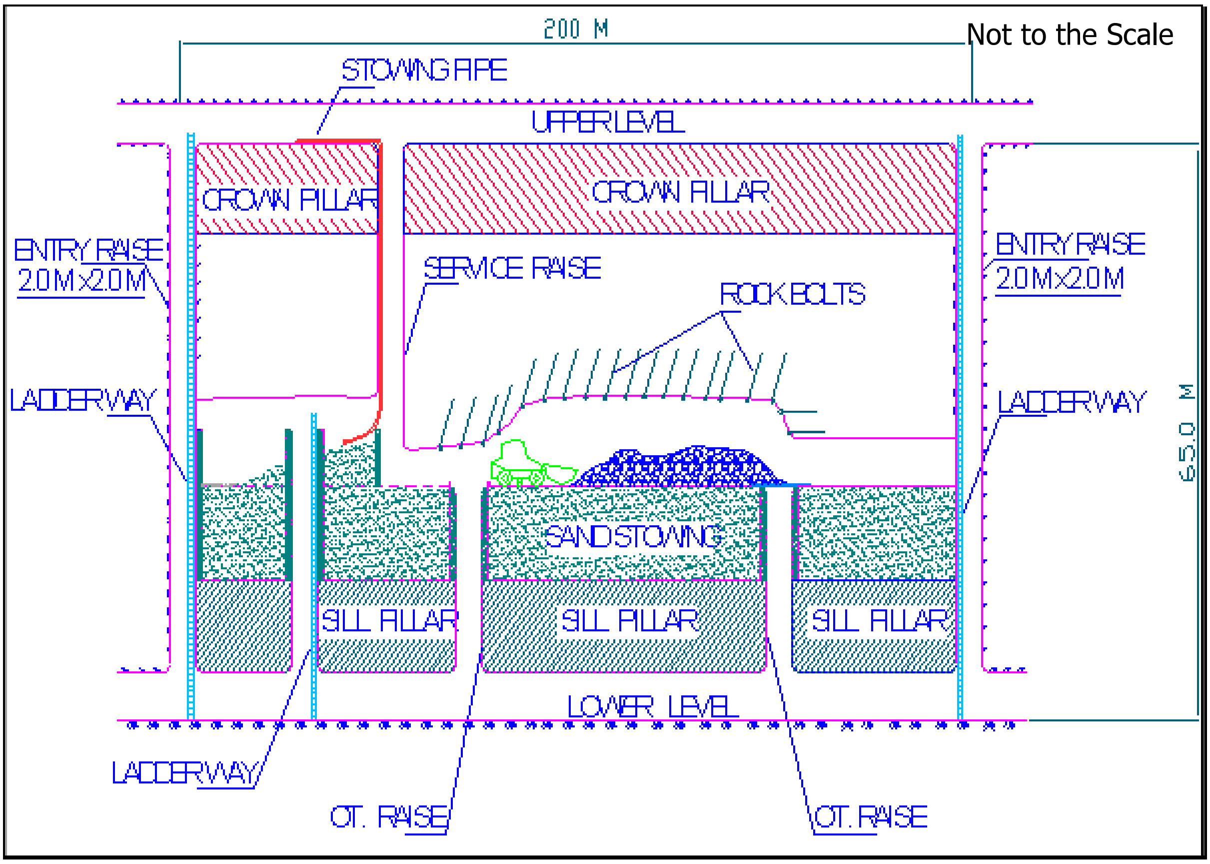

Fig. 8: Section of Cut & Fill Method of Mining

The mine has been developed in levels with a vertical level interval of 65 meters. The mining cycle involves the following steps in sequence:

- Identification & delineations of ore body
- Preparation of stope
- Drilling & blasting of the ore body
- Collection of the broken ore (mucking operation)
- Transportation of ore to the central ore pass
- Underground survey

Negligible quantity of waste rock is generated during development of permanent excavations like crosscuts, pump chambers, substations and ore transfer raises. Waste rock produced is dumped in underground working area.

The sequence of operation followed at Jaduguda mine for the horizontal cut and fill method are as follows:

- The level drive of 3.0m X 2.5 m size is taken in the ore body following the strike.
- The raises 2.0 m X 2.0 m are driven at a distance not exceeding 160m along the strike of the ore body to connect the consecutive levels.
- Sill level drive of 4.0m X 3.0m are taken along the strike direction having 5.0m vertical pillar from lower level.
- Where the width exceeds 6.0m, post pillars of 6.0 X 6.0 m size, as support to the back are left in situ and spacing not exceeding 14.0m along the strike and 12m in dip direction.
- The heightening of the sill level is taken up for 2.0 m such that height of the stope from stope floor does not exceed 5.0 m at any place.
- The slice height in the ore is taken as 2.5m vertically.
- The back of the stope (i.e. freshly exposed roof) is supported with rock bolts made of tor steel of 20mm diameter. The spacing of the rows is around 1.0m and distance in between the rows is around 1.4m. The length of the rock bolts is not less than 3.0m, where the width of the working is more than 6 m.
- The deslimed mill tailings (minimum water percolation should be 350 cc per hour)/sand is filled in the stoped out area leaving open height not exceeding 3.0 m.
- The extraction and filling are cyclic in manner.
- The maximum height of the unfilled stope does not exceed 5.0m at any place
- A 5.0 m thick crown pillar is left to support the upper level drive.

2.4 Environmental management plan (EMP)

Subsidence

Subsidence is an important aspect of underground mining activity. As the mining is carried out at greater depth (> 500m) and stowing is done in the void created by Horizontal cut and fill mining method, so no surface subsidence is anticipated. Moreover, rock mass of Jaduguda mine is also quite competent enough to stand the induced stress, therefore, no surface subsidence is anticipated. Based on the result of subsidence monitoring being carried out by UCIL, it is understood that no subsidence is occurring at present.

Solid Waste Management

Jaduguda is an old underground mines, the solid waste generation is insignificant (<1.4 % of ore production). Total waste generated during mining is used to fill the void in underground workings. Practically no solid waste is generated from the mining operation.

3. MINE SUBSIDENCE PREDICTION

Subsidence is a natural and man-made phenomena associated with a variety of processes including compaction of natural sediments, ground water dewatering, wetting, melting of permafrost, liquefaction and crustal deformation, withdrawal of petroleum and geothermal fluids, and mining of coal, limestone, salt, sulphur and metallic ores (Soliman, 1998). Most subsidence is either created or accelerated by humans (Prokopovich, 1972).
Surface subsidence can be caused by a number of activities and mechanisms, the most common being:

- Underground coal extraction.
- Underground mineral extraction.
- Pumping of oil and gas from underground reservoirs.
- Dewatering of sandy or fissured sub-soils.
- Withdrawal of geothermal fluid.
- Erosion or leaching of fine particles in the surface soils and underlying rocks.
- Swelling and Shrinkage of cohesive sub-soils due to changes in moisture content.

Surface subsidence occurs due to the removal or displacement of solid or liquid materials below ground and the consequential creation of voids or change in hydrostatic pressure, which result in subsidence of the overlying strata. The amount of subsidence that is likely to develop is dependent upon the nature of the surface soils and underlying strata and the extent of the underground voids that are created by mining and other activities.
Stope mining, combined with the development of adits, drifts and shafts, has historically been the most prolific form of hard-rock metals mining and has been done at both large and small scales. Stope mining is applicable to most vein-type ore bodies typical of base and precious metals deposits. The subsidence created by stope mining is usually the result of unintended cave-ins, inadequate support, pillar robbing, mining too close to the surface, and eventual collapse of the workings over time as the inevitable consolidation of the strata takes place. Most often subsidence is limited to the hanging wall side of underlying stopes.

A number of geologic and mining parameters can affect the magnitude and extent of subsidence. These include the thickness of extracted materials; overlying mining areas; depth of mining; dip of mining zone; competence and nature of mined and surrounding strata; near surface geology; geologic discontinuities; fractures and lineaments; in-situ stresses; degree of extraction; surface topography; ground water (including water elevation and fluctuation); mine area; method of mining; rate of advance; backfilling; time; and structural characteristics (SME, 1986).

There are two basic methods of subsidence prediction: empirical and phenomenological. However, as many as five principal methods of predicting mining subsidence has been developed: empirical relationships; profile functions; influence functions; analytical models; and physical models (Whittaker and Reddish, 1989). All of these methods fall into the basic categories of empirical and phenomenological.

Empirical methods are based on field observation and experience and are generally applied to regions where adequate empirical data are available. Empirical methods for prediction of subsidence consist of graphical, profile function and influence functions that are constrained by the availability of observed data (SME, 1986). Empirical methods are quick, simple to use, and relatively accurate. These methods provide satisfactory results and are widely used in coal mining. However, the methods are site-specific and are only applicable to areas having identical geological and mining conditions (Bahugana, 1991). Phenomenological methods are based on modelling principles, which use mathematical representation of idealized materials with the application of continuum mechanics. The Phenomenological methods though can give an insight to help in understanding the subsidence mechanism qualitatively but do not give correct quantitative results because of their limitations in correctly representing the complex behaviour of rockmass. Therefore, they do not find wide application for exact predictions of mine subsidence and associated parameters (Bahugana, 1991).

3.1 Subsidence Monitoring

Subsidence monitoring mainly involves measurement of vertical and horizontal displacements, from which subsidence, slope and curvature of subsidence profile, and horizontal strains are calculated. Surveying techniques are generally deployed for such measurements. Sometimes direct measurements of displacements or slope or deformations in rockmass or convergence in the workings may be carried out for some specific studies. The measurements of horizontal and vertical displacements is accomplished by laying down a number of survey monuments or stations on the surface along fixed lines and measuring the changes in their spatial positions by surveying techniques.

3.1.1 Layout of Survey Lines

The layout and number of survey lines should be such that the shape of the subsidence trough could be represented and it enables subsidence contours be drawn. Since the time-based displacements are required to be determined, laying out of too many survey lines should be avoided in order to reduce the time gap between the first and the last measurement. Larger time taken in each survey will give misleading conclusions as there may be a significant change in the face position within this time. The survey lines should be laid straight as far as possible ensuring inter-visibility and direct measurements between consecutive stations. One long line in the direction of mining and at least one perpendicular to this should pass nearly through the centre of the area such that the points expected to undergo maximum subsidence, slope, and strain could be surveyed. Layout should also enable points laying on the diagonals and corners of the area of influence to be surveyed. The layout should also provide connection to at least two horizontal control points and preferably two permanent bench marks situated well outside the area of influence and which are not liable to get disturbed so that each time monitoring is carried out, the surveys could be tied up to these control points and bench marks for reference. The selection of survey lines also depends on the topography of the surface. Since the influence of subsidence extends beyond the extraction area the survey monuments should also be made beyond the mined out area to a distance equal to the overburden cover on each side to delineate the limit of influence.

3.1.2 Survey Stations

Survey stations should be robust and permanent in nature and should be designed for the life of the project, so as to enable repetitive measurements to be taken over them, otherwise deployment of sophisticated instruments and procedures are worthless. The stations should normally be made on masonry pillars having a pipe or iron rod in the centre with a mark on its top. Stations may also be made on permanent structures such as on the plinth of a building parapet of a culvert or bridge or even on a rock in-situ, which are not liable to be disturbed. The pillars should be driven deep (not less than 0.5 m) inside the earth with a small portion protruding outside.

The spacing between the stations should be such that the measured movements on these stations give fairly good representation of slope, curvature and surface strains. The spacing between the stations have been recommended to be 0.05 times ($1/20^{th}$) the depth of the seam however, larger spacing upto 0.07 times the depth has also been used during some studies. Provision for about 25 per cent extra survey stations should also be made for probable wash out or wear and tear of station monuments.

3.2 Measurement Techniques

There are a variety of methods available to monitor land subsidence. They include vertical extensometers, baseline and repeated surveys of benchmarks using Global Positioning System (GPS) or conventional survey methods, and Interferometric Synthetic Aperture Radar (InSAR).

The various methods of subsidence monitoring and their applicability are depicted in Table 5

Table 5: Comparison of various methods of subsidence monitoring and their applicability

Methods	Use	Advantages	Disadvantages
Vertical Extensometer	To monitor all types of subsidence	Data can be obtained on daily basis and thus can be used to monitor active subsidence	1) Borehole are needed to be drilled which is a costly process 2) The accuracy depends on the precision of construction, accuracy of stakes anchored, accuracy of distance
Levelling by Precise level	To monitor all type of subsidence	Accurate method for monitoring of subsidence up to 0.2 to 1 ppm of the length	Cannot be used in the areas which are not accessible due to the presence of water
Levelling by Global positioning System	Can be used to monitor all type of subsidence	Autonomous operation of the system and no requirement for survey sites to be inter-visible	The data acquired can be highly deviated from the accurate result due to satellite orbital error, tropospheric error and ionospheric
DInSAR technique using high wavelength waves or L-band (~1/4 m)	Used to monitor all type of subsidence	This method is suitable for areas of high vegetation and agriculture land. Less sensitive to the noise disturbances.	Resolution of ground is less thus the monitoring of
DInSAR technique using low wavelength waves or C-band (~5-6 cm)	Used to monitor all type of subsidence	The resolution of the area is high and thus monitoring the movement is very accurate	Cannot be used in the areas where there is high vegetation cover.
Remote sensing using LandSat ETM+ data with DInSAR fusion	Only used to monitor the subsidence occurring due to underground mine fire	Can be able to identify the areas affected by mine fire and thus monitoring of subsidence.	Disturbance of signal due to noise.
Optical Technique distance measurement	This technique can be a proper tool for measuring displacement on a granular model material surface caused by trough type	The surface of any material, including granular or viscous materials, and digitally measure vertical distances with an extremely high accuracy and resolution can be scanned. With this new technique, the effect of cavity shape and size, depth, and material parameters can be analyzed.	The model is used for Sand only till now. Thus its reliability on other methods is yet to be determined

LiDAR Airborne Method	Used to monitor all type of subsidence	1) Airborne LiDAR (Light detection and ranging) technology which has the decimetre level measurement accuracy is suitable for mine surveying and mapping in large areas. 2) LiDAR has a high resolution (point density can up to 10 point/m^2), high efficiency (airborne platform can cover 100km^2/h), 3) Less affected by environmental conditions (terrain, weather conditions, etc.)	Small variations on the ground are not visible from air and thus we cannot monitor

Monitoring is undertaken on a regular basis to measure ground surface movements. This data is used to assist with making future subsidence predictions. It is also used to compare predictions with observations.

3.3 Some facts about subsidence due to hard rock underground metal mine

Hard-rock Mine Characterization

- Most hard-rock mineral deposits exhibit extensive faulting and intrusions by dikes, stocks, and sills; hydrothermal alteration of rocks caused by ore-bearing solutions; clays and clay-like minerals, with a subsequent reduction in rock strength. Sulphide ore bodies are often strongly weathered by acid generation, resulting in reduced rock strength.

Subsidence

- Subsidence is an inevitable consequence of underground mining and it will result in impacts to the overlying strata.
- Mining at any depth can result in subsidence, and the affected surface area is generally larger that the extraction area. Greater depth of overburden does not prevent subsidence, but may prolong the time period before subsidence effects are observed at the surface.
- There is a direct relationship between the thickness of the extracted materials and the amount of surface subsidence that possibly results. A greater thickness results in a greater amount of surface subsidence.
- Geologic discontinuities such as faults, folds and other inconsistencies in the overlying and surrounding strata may increase subsidence potential.
- The amount of subsidence has been observed as a direct function of time. Even in cases where vein deposit mining methods are employed in competent rock at great depths with low extraction ratios, the surface expression of subsidence is not eliminated, but may not appear for some time.

- Other factors that affect subsidence include nature of overburden; surface and near- surface geology; degree of extraction; surface topography; ground water; mining method; and backfilling.

4. METHODOLOGY

4.1 Available Control Data

The whole work was based on the coordinates of two control points, supplied by the Survey Office of Jaduguda Mine, UCIL as listed in Table 6.

Table 6: Coordinates of Control Points used as baseline as supplied by Survey office of Jaduguda Mine, UCIL.

Sl. No.	Station ID	Description	Northing/ Latitude, Y (m)	Easting/ Departure, X (m)	Elevation/ RL, Z (m)
01.	D6	Marked on the top of steel rod embedded in Concrete cast near security office at rear gate, UCIL	-114.509	-540.958	110.427
02.	M2	Marked on the top of steel rod embedded in Concrete cast left side of road to adit 5	-149.130	-526.289	112.754

4.2 Establishing Control Stations and Subsidence Monitoring Stations

It was required to establish permanent subsidence monitoring stations at forest area above the underground working within mining lease of UCIL Jaduguda and fixing of the coordinates (X, Y, Z) at all such monitoring stations with an aim to monitor any deviations in 3D positions (X, Y, Z) at all permanent subsidence monitoring stations. These monitoring stations were established by casting and embedding concrete pillars to a depth of at least 50 cm (Fig. 9) with a steel rod inserted into the cast block. Figure 10 shows the surface plan of Jaduguda Mine, UCIL containing the positions of subsidence monitoring stations on which observations (x,y,z) were taken using Total station having 1 mm least count.

Fig. 9: Establishment of Permanent Subsidence Monitoring Stations

4.3 Monitoring of Subsidence over Established Subsidence Monitoring Stations

In order to trace any visible movement of subsidence monitoring stations established during the previous phases of the study by UCIL, the 3D coordinates (X,Y,Z) of all such subsidence monitoring stations were observed using EDM traversing by Total Station having least count of 1mm for horizontal control (x, y). The stations D6 & M2 as mentioned above were considered as base stations lying outside active mining area within lease hold area of UCIL Jaduguda. The coordinates of control stations D6 & M2 were made available by the survey officer of Jaduguda Mine, UCIL. Figure 11 and Figure 2 show monitoring of 3D coordinates (x,y,z) of permanent subsidence monitoring stations laid in the forest area within lease hold boundary of UCIL Jaduguda.

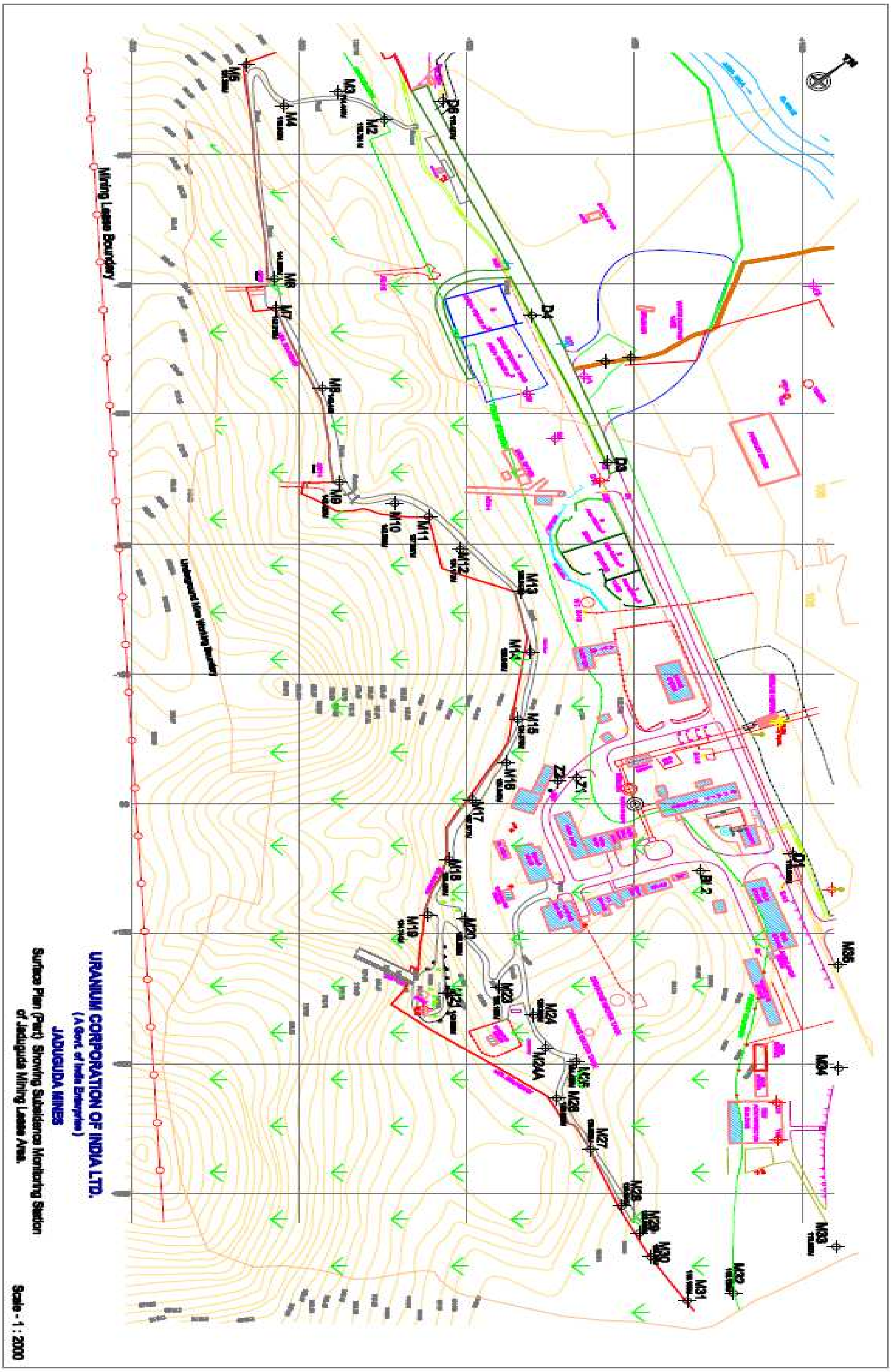

Fig. 10: Surface Plan of UCIL Jaduguda showing the locations of Subsidence Monitoring Stations.

Fig. 11: Monitoring of coordinates (x, y) over the permanent subsidence monitoring station using Prism monitoring (EDM) at D6

Fig. 12: Monitoring of coordinates (x,y) over the permanent subsidence monitoring station in the forest area using total station

In order to trace any visible precise vertical movement of Survey stations established by UCIL in the forest zone under active mining within leasehold area of UCIL Jaduguda, the elevation (Z) of all such control stations were observed using double run levelling with digital precise level (L.C. 0.1 mm). The elevation of all such monitoring stations were determined with an accuracy in the range of ± 0.1 - 0.5 mm to bring into observations of any deviation of elevation values of such control stations from its initial established RLs during the various phases of study conducted by UCIL. Figure 13 shows processing of digital level data.

Fig. 13a: Monitoring of elevations at subsidence monitoring stations using precise digital level

Fig. 13b: Monitoring of elevations at subsidence monitoring stations using precise digital level

4.4 Procedure adopted

A Precise EDM closed traverse of 2.279 km was carried out to join all the subsidence monitoring stations for the purpose of monitoring subsidence on all subsidence monitoring stations lying in the forest are above mine workings within lease hold of UCIL Jaduguda. The horizontal angles were observed upto 1” least count and distances and coordinates upto 1 mm with Electronic Reflectorless Total Station for establishing horizontal control (X & Y) coordinates for all the control stations and subsidence monitoring stations. Subsidence monitoring at all these stations were carried out for finding possible movement using total stations. The elevations (Z) at all the monitoring stations were measured using digital level with a vertical accuracy of in the range of ± 0.1 - 0.5 mm for comparing the results with the previous monitoring data taken by UCIL during various phases and finding any deviations/movement of the survey pillars in the forest area.

5. RESULT

The computations of the coordinates [X, Y, Z] of control stations and subsidence monitoring stations established through closed EDM polygonic traverse circuit and double run levelling using digital levels, were carried out through computer programmes.

The computations of the coordinates [X,Y,Z] of control stations established through closed EDM polygonic traverse circuit and double run digital level is given in Annexure – I.

Annexure – II lists the R.L. (Elevation, Z) as observed by UCIL during the previous phases of all the subsidence monitoring by UCIL on the established monitoring stations and comparison of results with the current monitoring data taken by ISM for finding any deviations/movement of the survey pillars in the forest area.

Annexure – III lists all the 3D coordinates of subsidence monitoring stations measured by UCIL during various phases.

Figure 14 shows the graphical representation of ground elevations variations during October, 10 to March, 15 at Subsidence Monitoring stations located in the forest area above the underground working within mining lease of UCIL Jaduguda.

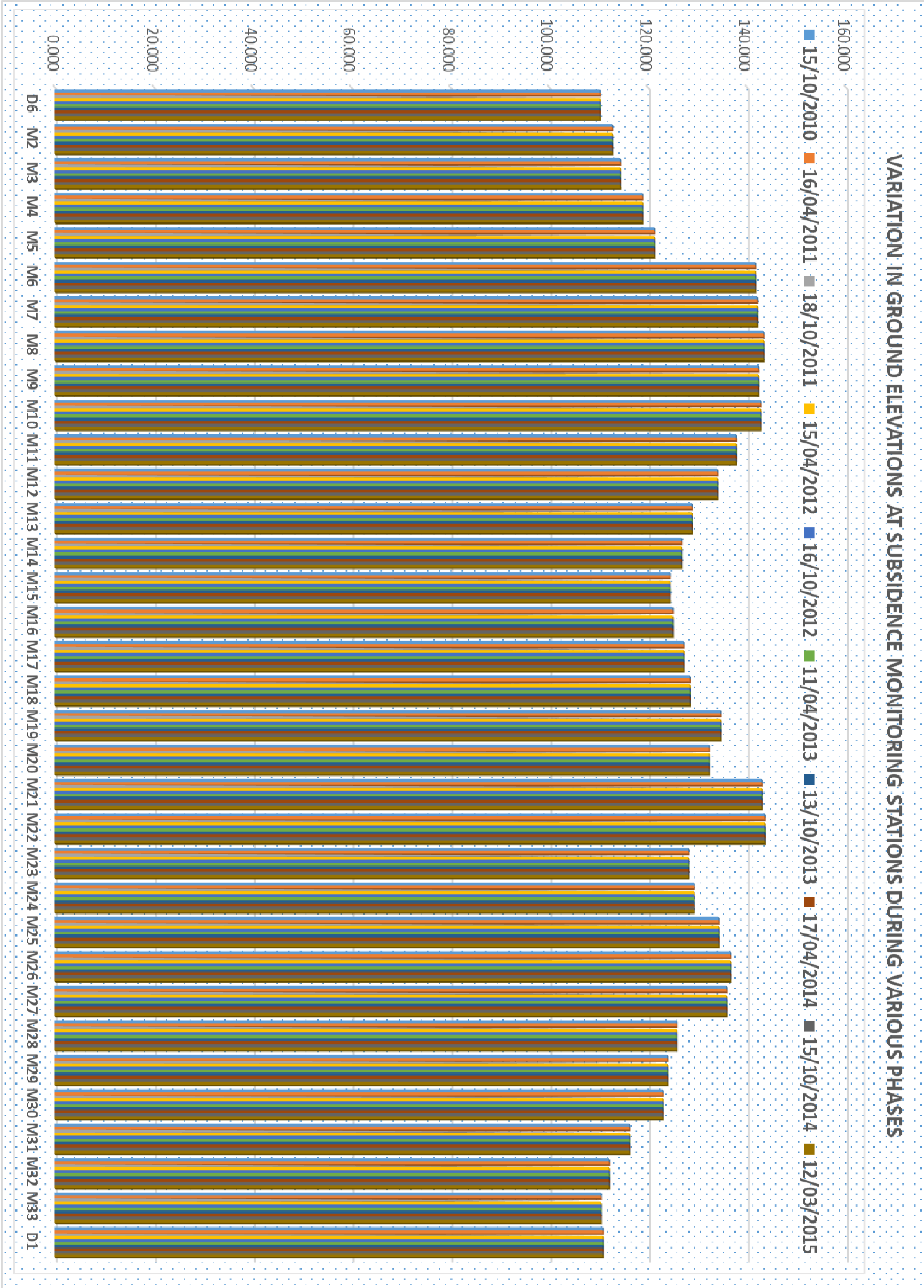

Fig. 14: Graphical representation of ground elevations variations during October, 10 to March, 15 at Subsidence Monitoring stations located in the forest area

From this figure it is revealed that the maximum elevation variation is in the tune of 5 mm – 20 mm for a period of three. That may be attributed due to observational errors or the local settlement of some of the stations.

A plan on a suitable scale showing the positions of control stations and Subsidence Monitoring Stations in a grid system is also submitted with the reports at Annexure – IV and Annexure - V.

6. SUBSIDENCE CONTROL AND PREVENTION

Four types of measures may control subsidence damage: alteration in mining techniques; post-mining stabilization; architectural and structural design; and comprehensive planning (SME, 1986; Mining, 1997). None of these measures entirely prevents subsidence, and most of the measures address only impacts to man-made structures and facilities and not impacts to land use, including aquatic species, wildlife habitat and human recreation, or water quality and flow.

Alteration in mining techniques can be accomplished through a variety of methods including partial mining, backfilling, mine layout or configuration, and extraction rate. Partial mining involves leaving protective features such as pillars. It should be noted that in areas supported by protective zones, water might become perched at a higher level than the surrounding ground that has subsided. If a water table was high, the area intended for protection may become an island or experience a lowered water table (SME, 1986). This may be an important limitation with respect to establishment of protective zones to protect surface water such as lakes or wetlands.

Backfilling may be done by hydraulic or pneumatic techniques, using a variety of materials including run- of-mine waste rock, milled tailings, or other materials, and may include the use of cement or other modifiers to increase strength. It may also have a beneficial effect on the environment by addressing water quality impacts (such as from acid drainage), reducing waste rock disposal requirements, reducing ground fissuring, and increasing long-term strata stability and providing roof support. Backfilling does not eliminate subsidence entirely, but only reduces the amount of subsidence (Mining, 1997; SME, 1986).

Post-mining stabilization techniques include backfilling, grouting, excavation and fill placement, and blasting (SME, 1986). The extent to which post-mining stabilization techniques can be relied on to mitigate subsidence damage is uncertain, as they require assessment of long-term stability. But analytical methods to predict the long-term stability of overburden in room-and-pillar (Mine, 1986) and other mining methods need significant improvement.

However, Without appropriate management sub-surface workings such as stoping can result in changes to the ground surface (including local and regional settlement, cracking, subsidence or collapse) for a variety of reasons including (but not limited to) surrounding geology, general rock mass conditions, size and shape of the excavations and time dependency.

The following measures as listed below can be effective in the Ground Surface stability:

- Selection of appropriate stoping method depending on the specific nature of potential future ore bodies, and management techniques can be used to ensure ground surface stability.
- Geotechnical mapping of ore development drives and detailed characterisation of the rockmass prior to stoping operations to ensure stable stoping spans.
- Prompt back-filling of all stope voids in the mining cycle and some development drives where necessary to ensure long-term stability.
- Selective cable bolting of discrete structures to improve stope stability where structures may affect stability.
- Leaving a sufficiently sized remnant pillar to separate new workings from the ground surface
- Sufficient parting will be left between surface and the stoped out area as a measure against subsidence. Besides, parting among lenses will provide natural support to the strata.
- Post-mining stabilization techniques include backfilling, grouting, excavation and fill placement, and blasting might be adopted.
- Ongoing use of advanced numerical modelling services calibrated with data collected from the monitoring strategy for continued updating of modelling forecasts.
- Sterilisation of ore and/or premature cessation of mining if unacceptable levels of ground surface subsidence are forecasted with numerical modelling or measured through the monitoring strategy

Monitoring the rock mass response to mining activities may take the form of:

- Use of instrumentation such as multi-point borehole extensometers, vibrating wire stress meters, and survey traverses underground to measure displacement of the rockmass during mining.
- Installation of a micro-seismic monitoring system to measure and monitor ground noise activity and rock mass and structure response to mining.
- Periodic use of physical monitoring techniques such as surface network of survey stations to measure displacement above the proposed underground Mine using prism monitoring (EDM), interferometric synthetic aperture radar (InSAR/DInSAR) satellite technology, GPS observations etc. to determine location, magnitude and rate of ground surface settlement or subsidence related to mining activities.

7. CONCLUSIONS

- Subsidence monitoring is an important part in developing a method or theory of its prediction irrespective of the approach followed. Economical, accurate and quick measurements are obtainable using modern surveying methods and instruments such as combination of EDM- theodolite – precise level or electronic tachometers (Total Station System).

- Elevations data during October, 10 to March, 15 at Subsidence Monitoring stations located in the forest area above the underground working within mining lease of UCIL Jaduguda were analysed and graphically represented. From analysis of result it was revealed that the maximum unsystematic elevation variations (some time increasing and sometime decreasing) are in the tune of 5 mm – 10 mm for a period of three years, which may be attributed due to observational errors or the local settlement of some of the stations due to improper protection of pillars.

- The variations in 3D coordinates of subsidence monitoring stations lying in the forest area above mine workings within lease hold of UCIL Jaduguda were insignificant as reflected from the monitoring results of last five years (Annexure – III). Some minor variations were observed from the analysis of past data. However, these variations were not regular and systematic. Hence these variations did not confirm ground movement. The variations might have been attributed to observational errors or pillar disturbances.

- Subsidence is an important aspect of underground mining activity. As the mining activity at UCIL Jaduguda is carried out at greater depth (> 500m) and stowing is done in the void created by Horizontal cut and fill mining method, so no surface subsidence is anticipated. Moreover, rock mass of Jaduguda mine was considered to be competent enough to stand the induced stress, therefore, no surface subsidence is anticipated.

- The amount of subsidence has been observed as a direct function of time. Even in cases where vein deposit mining methods are employed in competent rock at great depths with low extraction ratios, the surface expression of subsidence is not eliminated, but may not appear for some time. Based on the result of subsidence monitoring being carried out by UCIL, it is understood that no subsidence is occurring at present. Even no historic foot-print of subsidence was observed during the field visit to UCIL Jaduguda.

- Regular monitoring of subsidence on the surface over and around the working area

and impact on natural drainage pattern, water bodies, vegetation, structures etc. should be continued throughout life of mining activities.

RECOMMENDATIONS

- Measurement of ground level constitutes baseline data for subsidence study and hence it is therefore recommended for periodical monitoring of the 3D coordinates at the identified subsidence monitoring stations and analysis of result thereafter during the operational phase of mine is mandatory.
- It is recommended that the subsidence monitoring stations should be preserved carefully without causing any ground disturbance at the surroundings.
- Suitable arrangements may be made so that these stations should not be disturbed by someone.

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