Rock Bursts in Deep Excavations with Special Reference to Bharath Gold Mines Ltd., Kolar Gold Fields, Karnataka

M.M.Swamy*

Abstract

Rock burst is a spontaneous, violent fracture of rock that occurs generally in deep mines/ tunnel excavations under certain combination of geologic and mining conditions. The opening of a mine shaft/ tunnel at depth relieves neighboring rocks of tremendous pressure which literally cause the rock to explode as it attempts to re-establish equilibrium.

Kolar Gold Fields, the deepest mine with the richest gold deposit has encountered innumerable incidences of rock bursts since centuries. The scientific studies have revealed the occurrence of these hazardous events mainly due to sudden release of accumulated strain energy in such regions where the brittle rocks like dykes, pegmatites and quartz reefs in juxtaposition with the fault systems are intercepted by the deep excavations.

Intoduction

The phenomenon of rock burst was first reported in England in 1738 continued by number of reports thereon from all over the world. In recent years the importance of this geological hazard has become appreciated in mining, railway infrastructure, hydropower construction etc, thus attracting the high degree of attention of engineering geology and rock mechanics.

Incidence of rock bust is related with the depth of mining, size and orientation of the opening, brittleness and E module of the insitu rock, excavation speed, active tectonic conditions and the ratio between the strain and stress energy at that geological situation. Such violent fracturing of rock essentially require two conditions for their occurrence: a stress in the rock mass sufficiently high to exceed its strength, and physical characteristics of the rock which enable it to store energy up to the threshold value for sudden rupture.

According Zang et.al (1994) rock burst is a type of brittle failure which occurs in the rock around tunnels and is associated with sudden large release of latent pressures. Tao (1996) considered it occurs as a result of mechanical disturbance when a large quantity of strain energy accumulated with in a rock mass is released suddenly, triggering a violent fracturing of the rock.

Experience indicates that deeper an opening is made in hard rock, more vulnerable it becomes to rock burst. Manifestation of spalling and release of micro seismic energy may be the first sign of the incidence which might later result in spontaneous breaking out of several thousands of tons of rock in the form of an explosion releasing seismic energy of a mild earthquake. Rock bursts are serious hazards in deep underground mining as seen in South Africa, roughly killing 20 miners every year (Monroe and Wicander, 1996) and endangering the existence of mine openings, equipments at large.

According to Griffith theory, the cracks/ fracture in rock in deep mine openings get propagated if the strain energy released per unit area of new crack surface is more than the surface energy of the new crack surface. According to Jaeger and Cook (1969) quantifying the strain energy released as rock bust **W** is the difference between the strain

*Geological Survey of India, Kolkata.

energy released by the elastic zone **We** and the energy absorbed by the broken zone **Wb.** This energy will be converted in to kinetic energy of rock pieces and the energy of the seismic waves. This energy increases rapidly with increasing in size of the under ground opening.

The centre of seismic events leading to rock burst is the highest stress concentration in the elastic zone. Such events as per the records occur generally not more than 30 meters from the face of an excavation. Such seismic events ending up with such rock bursts are assessed to be of the order of only 5% of all events.

Attempts are made in recent years to assess burst prone rocks utilizing Burst Energy Release Index (S.P Singh 1988). Gravity methods are also used to the predict the rock bursts in deep coal mine in Germany based on the relationship between the development of a dilatancy process in the exploited rock and the time-dependent gravity anomalies induced by this phenomena (Casten.U & Fajklewicz 2006). Various other methods of prediction like: study of strain energy analysis with the aid of numerical modeling (Wang J.A & Park H.D 2001) and evaluation by employing a suit of macro and micro-indices gained from test drilling and laboratory testing on rock cores (Xiao-Zhao Li & An-Zeng Hua 2006) are suggested recently in order to overcome the hazard.

Rock Bursts in Kolar Gold Fields

Kolar Gold Fields is located at 12° 57" North and 78° 17" East, in the south eastern part of Karnataka and proved to be the richest gold deposit of India. The modern phase of mining at this area was started some time in 1880 and continued thereon till 2002. There are indications that some of the old workings are as old as 1000 years earlier. The mining activities in this area were concentrated mainly along the NNW-SSE trending gold bearing reef extending for a strike length of nearly 8km occur within the hornblende schist of Dharwar super group surrounded by gneisses and granites. The rocks are intruded by basic dykes, pegmatite and quartz veins and are cut across and displaced by number faults. The lodes dip 40° to 45° towards west on the surface, but gradually changes to near vertical at depth. Width of the lode varies from 1 to 6m. Mining for gold has gone beyond 3000m depth (3200m. in Nandidroog mines). Out of many lodes explored, the champion and oriental lodes have contributed rich deposit of gold and has been extensively mined in Mysore, Champion and Nandidroog mines. The mines are now closed since 2002 due to uneconomical mining conditions.

As per the available record, the first rock burst in KGF was occurred in 1898 in a stope below 293m level in the erstwhile Oorgaum mine and continued causing severe ground control problems there after. These events were termed as "Air blasts" during the early days where the ejection of rock from the working face was accompanied by explosive noise with blast of air, confined to local strain. The term "Quake" was then used where the air blast resembled an earthquake. The events of rock bursts at shallow depth were generally mild and mainly due to over stressing on shaft pillars and ore shoots in juxtaposition with faults. They were serious at deeper levels particularly where the mining of the ore shoot was intersected by faults, pegmatites and dykes, all concentrating along plane of weakness causing huge damage to the ore shoot as well as the buildings over ground within a radius of 2-3km.from the epicentral region. In the later case, the main rock burst was usually followed by series of mild tremors for several days. The intensity of such major rock burst tremors at KGF were in the range of 4.5to 5.0 on Richter scale and are recorded by the seismographs located more than 760km from KGF.

All the events of rock bursts of KGF have been systematically recorded by the following seismic recording systems since 1957.

Brief descriptions of some of the significant rock bursts encountered in KGF in different mining areas are as follows.

From	To	Seismic System
1957	1981	Wirchart's Seismograph
1982	1996	Seismic Network
1997	1998	Short Period Seismograph
1999	May 2005	Broad band Seismometer
Oct.2005	Continuing	Strong Motion Accelerograph

Number of rock bursts recorded year wise at KGF mines is as follows.

(Ref: Centenary Souvenir 1980, BGML data up to 1978 and of BGML/NIRM Seismology Section thereon)

Year	No. of Rock Bursts recorded/ reported	Year	No. of Rock Bursts recorded/ reported	Year	No. of Rock Bursts recorded/ reported
1957	386/ 23	1974	643/14	1991	281
1958	537/30	1975	419/10	1992	317
1959	549/29	1976	434/09	1993	358
1960	877/33	1977	366/10	1994	297
1961	589/47	1978	479/14	1995	136
1962	851/44	1979	160	1996	132
1963	632/43	1980	192	1997	165
1964	478/21	1981	140	1998	488
1965	748/12	1982	1452	1999	157
1966	1096/04	1983	847	2000	355
1967	1109/09	1984	1344	2001	288
1968	1157/05	1985	1520	2002	71(system down)
1969	1480/02	1986	919	2003	288
1970	762/03	1987	639	2004	453
1971	1155/10	1988	465	2005	644(up to 5'2005)
1972	1202/14	1989	347	Mid jan 06	960
1973	852/12	1990	253		

Rock burst of 23rd January 1952

This event occurred at 0704 hrs. just below the surface of the 16th level at a vertical depth of 463m in the Glen's section of Champion Reef Mine and at the 27th level at a vertical depth of 614m in Gilbert's and Tennant's sections of Mysore Mine for a distance of nearly 760m along and parallel to the main fault system of Champion lode causing heavy damage in the mine and to the buildings above the fault system. The main tremor was followed by as many as 71 tremors in a period of 48 hours. The first tremor is recorded in the observatories located in Colaba, Bombay and Kodaikanal.

Rock burst of 11th February 1956

This incidence occurred at 0119 hrs. in Biddick's shaft section of Champion reef mines between 95 and 102d levels at a vertical depth of 213m. The damage to the Biddick shaft was extensive. The entire concrete lining along the east wall between and inclusive of the byatts between the 94th and 98th station was completely blown out/ most severely damaged. All the shaft equipments were either missing or severely damaged.

Rock burst of 25th May 1960

Series of major rock bursts occurred in the night affecting a large area in the Edgar's middle section, Edgar's pillar area in the Mysore mine extending for nearly 600m along the strike from Gilbert's shaft to about 60m North of North of Reclamation Winze; extending from15th level of Tennant's to 45th level of Edgar's affecting Edgar's shaft, Gilbert's shaft, Tennant's shaft, and Hancock's shafts. The affected mines remained unproductive for nearly three months. Many buildings above this area were damaged. Later studies have indicated that this incidence occurred due to movement along the mysore north Fault.

Rock burst of 27th November 1962

The rock burst occurred at 0220hrs causing severe damage to the whole of the stoping areas on the northern and southern wings of the Glen Ore shoots in Champion reef mines between 85th and 107th levels at a vertical depth of about 550m. Extensive falls of ground in the Heathcoat and Osborne shaft cross-cuts, foot wall drives and their complementary cross-cuts in the Champion Reef Mine are encountered as a result of this rock burst. The main tremor was followed by as many as 59 fore tremors during the next 24 hours, and abnormal bursting continuing for nearly two weeks.

Rock bursts of 16th and 23rd July 1963

These rock bursts have resulted in severely damaging the southern wing of Glen Ore shoot between 86th and 111th levels in Champion reef mines, making the ore shoot almost non productive. Wide spread damage to buildings over ground were also recorded. This event has been recorded at the Madras observatory.

Rock bursts of 25th December 1966

Series of rock bursts occurred from 0807hrs damaging the Northern Folds area below 97 level, Auxiliary shaft at 97/98 levels in Champion reef mine. The reef drives up to 100m level were severely damaged. This includes the falls of the ground in the unsettled portion of drives and cross cuts. Bursts continued for several days after these incidents.

Rock bursts of 27th November 1971

Major rock bursts occurred at 0210 hours in Nandidroog mines causing severe damage to the West Reef workings and the buildings over ground. Most of the under ground damages were concentrated between N17 dolerite and N23 porphyry dyke. Damage to buildings was significant over an area of 3sq.km.

Rock burst of 28th December 1972

A major rock burst occurred resulting in severe damages to under ground workings between 50 and 59 levels on West reef in Nandidoorg mine causing little damage to the surface structures

Studies carried out related with Rock bursts In KGF

Systematic studies related with the rock bursts and the problems of ground controls in KGF were started in 1955 with the help of a special committee followed by rock burst research unit which conducted number of research studies in collaboration with the University of Newcastle-upon-Tyne, U.K. The study includes analysis of the available statistical data, laboratory testing of the elastic properties of the rock under both static and dynamic conditions and the field studies of the rock movements during under ground excavations. These studies have revealed many interesting results, thus helping in understanding the causes and mechanism of these hazardous events. The results in nutshell are as follows.

1) Statistical analysis of the available records of the rock bursts have indicated:
   a) Only a small percentage of recorded rock bursts noticed underground.
   b) Significant peak in the occurrence of rock bursts during the time of stope blasting or soon afterwards
   c) Frequency and severity of rock bursts directly related with depth
   d) Specific relations existing between the rain fall and rock bursts
   e) Frequency of recorded rock bursts minimal on Sundays and maximum on Fridays
   f) Rock burst events dependent on many factors like physical properties of the rock, stress conditions, size and shape of the excavation and inhomogeneity of the rock such as faults, pegmatite, dykes, calcite stringers etc. all involving planes of weakness either in themselves or at the contacts.
2) Laboratory studies conducted on the host rock as well as the gold bearing quartz reef (lode) have indicated the following:

A. Host rock

Average Uniaxial compressive strength, young's modulus and poison's ratio in the direction parallel and perpendicular to schistosity are:

2670kgs/sq.cm&440kgs/sq.cm; 8.790X10^5kgs/sq.cm & 7.030X10^5kgs/sq.cm; and 0.23 & 0.18 respectively.

B. Quartz reef/ore lode

Average Uniaxial compressive strength and young's modulus in the direction and perpendicular to lamination are: 4350kgs/sq cm & 10050kgs/ sq cm; and 4,180X10^5kgs/sq.cm & 8.440X105kgs/sq.cm respectively.

3. **Field studies have indicated the following findings**

   a) Induced stresses higher than the regional stresses.

   b) Higher lateral stresses than superincumbent weight, in cases, greater than the vertical stresses.

   c) Ratio of the horizontal to vertical stress field varied from 1.6 to 4.0

   d) Natural stress field gets considerably modified both in direction and intensity.

Causes of Rock burst In KGF

Detailed studies have been carried out in KGF to understand and ascertain the causes of occurrence of rock bursts. The concept of energy balance offers a better explanation for occurrence of these events. The type and nature of the rock, their physico- mechanical properties, and the stress condition at site as briefed in the earlier chapters have played a dominant role in causing the rock bursts.

The studies have given an understanding that the brittle nature of the rock, especially the massive dykes, pegmatite and the quartz reefs in juxtaposition with the faults at depth are the loci of concentration of large amount of strain energy far exceeding the strength of the rock. When the excavations are made for exploiting the ore body through these sensitive media, the rock mass undergo a sudden mechanical disturbance/ natural imbalance in the stress regime wherein an enormous strain energy accumulated within this rock mass is suddenly released triggering violent fracturing/ spalling of rock resulting in the form of rock burst/ seismic event.

Many a times, as briefed in the earlier paragraphs, these spontaneous bursts have reactivated the ground movements along the faults, as a part of resettlement, thus generating series of tremors and bursts along such fault system even after the main events.

Conclusions

Kolar Gold Fields has hosted one of the richest and deepest gold mines in the world. Though the records indicates old workings in this area dates back to about 1000 years, the systematic and modern mining since 1880 has encountered recurrence of several thousands of events of rock bursts due to sudden release of accumulated strain energy, in most of the cases where the brittle rocks in juxtaposition with the fault system at dept are intercepted by the excavations. Such bursts have also induced persisted short term seismic tremors of varied magnitude.

Acknowledgements

The author expresses his sincere gratitude to the director general, Geological Survey of India for permitting to present this paper. The contributions of the scientists of BGML and NIRM in the field of rock mechanics related with rock bursts, under the stewardship of Sri.R.Krishnamurthy, Scientist, BGML which has contributed the material for this paper is sincerely acknowledged.

References

Taylor, J.T.M. (1960-61). Mining practices on the Kolar Gold Fields, India.-Transactions of the Institution of Mining and Metallurgy, London, Vol.70.

Krishnamurty, R. (1972). A review of rock burst research in the Kolar Gold Fields- Proceedings of the symposium on rock mechanics, Dhanbad, July.

Krishnamurthy, R. (1976). A review of rock mechanics research on the problem of stability of underground workings in Kolar Gold Fields, Proceedings, Golden Jubilee Symposium, B.H.U.

Huang. R. Q et al., (1999). Analysis of dynamic disturbance on rock burst- Bulletin of Engineering Geology and the environment, vol 57, Number 3.

Singh, S.P. (1988). Burst energy release index- Jour. Rock Mechanics and Rock Engineering, Vol 21, Number 2.

Casten. U. et al., (2006). Induced gravity anomalies and rock burst risk in coal mines-A case history, Geophysical Prospecting, Vol 41, Issue 1.

Xiao-Zhao Li (2006). Prediction and prevention of sandstone-gas outbursts in coal mines, International journal of Rock Mechanics and Mining Sciences, Vol 43, Issue 1.

Alcot J.M. (1998). Use of microseismic source parameters for rock burst hazard assessment, Jour. Pure and Applied Geophysics, Vol 153, Number 1.