SOURCE PARAMETERS OF SEISMIC EVENTS IN THE MINES OF KOLAR GOLD FIELDS

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ABSTRACT

Rockbursts are a common phenomenon in mines during mining operations. A network of geophones was used to locate and assess the stability of mine workings. An important parameter needed to assess the damage potential and severity of a rockburst is the Richter local magnitude (M_L). It was not possible to obtain M_L measurements from the records of the geophone network due to saturation effects. A strong-motion accelerograph was installed after the closure of the mines and recorded many rockbursts. The strong-motion accelerograms, recordings of rockbursts, were used to obtain Wood-Anderson synthetic seismograms for getting accurate and reliable values of M_L. Using 100 typical strong-motion accelerograms of rockbursts in the mines, magnitudes were computed. The maximum magnitude obtained from several rockbursts during has been found to be 2.8. The strong-motion seismic data have also been used to compute the source parameters of seismic events. Analysis of the seismic events revealed that the local magnitudes of these events were between -2.78 and 2.8. Seismic moment varied between 7.94×10^{19} and 2.00×10^{22} dyne-cm, seismic stress drop varied between 7.5 and 118 bars, source radius between 35 and 136 m, and average corner frequency between 3 and 10 Hz. The results of the source parameters of the mining tremors completely agree with corresponding results for natural earthquakes. The regression trend-line obtained from the plot of dynamic shear stress difference as a function of magnitude for rockburst $M_L < 2.8$ and earthquake $M_L > 3$ has been found to be $\log(R\underline{a}) = 0.31 + 0.89\, M_L$. The details are discussed in this paper.

OBJECTIVES

The objective of this study is to use strong-motion data in the mines of the Kolar Gold Fields to compute source parameters.

RESEARCH ACCOMPLISHED

Rockbursts have been a common phenomenon since the beginning of the 20th century in the mines of the Kolar Gold Fields (KGF), which is situated in Karnataka. Rockbursts have caused severe damage to buildings on the surface and underground mine workings in several instances. An important parameter needed to assess the damage potential and severity of a rockburst is M_L. However, it has not been possible to obtain M_L from the records of conventional seismographs due to saturation effects. The rockbursts had been monitored using a seismic monitoring system since 1979. Rockbursts were the usual phenomenon in the KGF mines during mining activity (Krishnamurthy and Srinivasan, 1980). However, rockbursts continued to occur even after the closure of the mines. Rising water levels in the structure of the mines may be one possible cause of frequent rockbursts as was reported elsewhere in the world. Normally, the frequency and severity of rockbursts increase during the rainy season (Srinivasan et al., 2000). Figure 1 shows the surface mining region of the KGF and the location of the strong motion accelerograph.

The strong motion accelerograph has been able to record several rockbursts, as it is in close vicinity to the mines of the KGF, which has formed the basis for the estimation of their local magnitudes. The accelerograms of rockbursts have been used to compute local magnitudes and the source parameters.

DATABASE USED

A noticeable major rockburst occurred on 02/11/2005 at 18:14:56 in the old and abandoned mines of the KGF. The rockburst was very severe and the effect was felt by residents of adjoining areas and surrounding townships. The rockburst caused panic among the residents and it is reported that the people came out of their houses. The peak ground acceleration recorded due to this rockburst was 0.22g. This level of acceleration falls in the category of caution zone for houses and buildings, many being very old and in depilated condition. Following the major rockburst, many seismic events were recorded by the strong motion accelerograph. The data were used to compute the source parameters using the software *Seisan*.

METHODOLOGY

A single triaxial seismogram of accelerometer traces, recorded at the KGF has been used to estimate location and source parameters. While the data is not sufficient for calculating a moment tensor or focal mechanism, estimates of location (based on polarization of the *P*-wave) and *S*-*P* separation are possible by fitting a Brune acceleration spectrum to the spectra of these waves. Figure 2 shows the seismogram for the event's *P*-arrival at 18:14:51.04. All three components are superimposed in the seismogram. Figure 3 shows the acceleration spectra of the *S*-wave for the event, with a Brune acceleration model.

From the *S*-*P* separation of the relatively clear *P*- and *S*-arrivals seen in Figure 2 and assuming respective *P*- and *S*-wave velocities of 5.5 km/s and 3.5 km/s, the hypocentral distance appears to be around 3,100 m. From the polarization of the *P* wave, the source is deduced to be approximately 1,994 m south and 831 m east of the KGF, and between 1,100 m and 2,200 m deep (assuming surface effects in the observed Z-component with a scaling factor of between 1.0 and 2.0). The quality of the polarisation is not very high, so some error in this estimate is to be expected.

From the acceleration spectra in Figure 3, we derive that the event has a corner frequency of between 4 Hz and 5 Hz, and by fitting a Brune acceleration spectrum, the seismic moment is estimated as being approximately 6.4×10^{12} Nm using the single station at KGF. Again, as this is a single station, the actual scalar seismic moment at source could be different, due to a possibly non-isotropic focal mechanism.

The typical seismic signal picked up by the strong motion accelerograph is shown in Figure 4. The strong motion data have been converted to *Seisan* format and source parameters of seismic events were computed. The *Seisan* output file is shown in Figure 5. The results obtained for several events are shown in Table 1.

Table 1. Source parameters of seismic events recorded by the strong motion accelerograph.

Event	Date	Time	M_L	Source Radius (m)	Stress Drop (bars)	Seismic Moment (Dyne-cm)	Average Corner Frequency
1	2005.11.02	04:35:33.3	1.70	136.2	13.1	7.94×10^{19}	9.25
2	2005.11.02	04:35:36.5	0.45	0.13	10.1	2.00×10^{22}	9.45
3	2005.11.02	05:30:05.3	1.87	0.54	56.0	5.01×10^{19}	2.32
4	2005.11.03	01:50:47.1	1.68	0.42	76.7	1.26×10^{22}	3.12
5	2005.11.04	15:40:03.2	2.50	0.42	40.8	6.31×10^{21}	3.05
6	2005.11.05	07:15:50.5	-1.17	0.32	7.5	5.01×10^{20}	3.91
7	2005.11.06	08:35:31.2	1.82	0.48	35.4	1.00×10^{22}	2.59
8	2005.11.18	15:01:08.0	2.46	0.127	118.0	3.98×10^{20}	10.66
9	2005.11.20	04:48:39.7	1.97	0.35	58.0	5.01×10^{21}	3.61
10	2005.11.20	05:19:38.2	-2.6	0.42	118.20	2.00×10^{22}	3.05
11	2008.05.20	03:58:15.07	2.0	0.50	9.5	2.80×10^{21}	2.59
12	2008.04.02	01:21:27.0	1.9	0.6	11.6	6.02×10^{20}	2.18
13	2008.03.08	12:50:54.0	2.7	0.1	3.5	2.34×10^{21}	9.24

The source parameters computed for a deep gold mine in South Africa and deep mines of the KGF are shown for comparison in Table 2.

Table 2. Comparison of source parameters

Source Parameters	**KGF Mine**	**South African Mine**
Seismic Parameters	1.7	0.8
Seismic Moment(D-cm)	2.94×10^{22}	6.4×10^{19}
Stress Drop (MPa)	1.01	0.5338.3
Source Radius (m)	130	38.3
Corner Frequency	9.45	5.0

The rockburst picked up by the strong motion accelerograph in the mines of the KGF as well as the earthquakes recorded in Koyna dam were compared and similarities found. The mines of the KGF filled with water after their closure during 2001.

The acceleration of rockbursts and earthquakes along with their hypocentral distances are plotted in Figures 6 and 7. Hypocentral distances were estimated from the interval between *P*- and *S*-waves, assuming velocities of 5.5 and 3.5 km/sec for the *P* and *S* velocities respectively (McGarr, 1974).

Figure 6 shows the dependence of dynamic shear stress differences defined by $\tilde{\sigma} = \rho R a_{\max}$ (with ρ as density taken as 2.8 gm/cm^3, R as distance in kilometer and a_{max} as the peak ground acceleration in cm/sec^2) on the estimated strong-motion magnitude values. The events with magnitudes below zero have been deleted as they might also occur due to a different source mechanism than that for the rockbursts. The magnitude dependence of $\tilde{\sigma}$ is defined by the following least-squares equation.

$$\mathrm{Log}\ \tilde{\sigma} = 0.31 + 0.89\ M_L \qquad (1)$$

The equation is similar to the equation obtained by McGarr et al. (1981) for different mining conditions. The data for several significant earthquakes in the Koyna dam area are plotted in Figure 7. The trend line for tremors from the mine fits quite well to the larger magnitude earthquakes in the Koyna area. Thus, the KGF rockbursts are generated by a similar mechanism to the Koyna dam earthquakes. Both may be of triggered nature due to pore-pressure diffusion. The similarity between the rockbursts in the KGF and the earthquakes in the Koyna area is further established by the dependence of the peak velocity v on the magnitude as shown in Figure 7, which can be defined by the following least-squares equation,

$$\text{Log } Rv = 3.74 + 1.12 \quad M_L, \tag{2}$$

where Rv is in cm^2/sec. The magnitude dependence for defines the dependence for the Koyna earthquakes equally well.

CONCLUSIONS AND RECOMMENDATIONS

The seismic signals recorded using geophones in the near field are generally saturated and are not suitable for estimating the true magnitudes. The strong-motion accelerograms recorded due to rockbursts are therefore used to obtain the Wood-Anderson synthetic seismograms in the present study. The methodology adopted to compute the local magnitudes from strong-motion data has used an improved correction factor for distance attenuation and has applied the correction for the site soil condition to get very realistic estimates of the magnitude. The magnitudes are found to be quite consistent for some events for which independent estimates based on broadband records could be made. The dynamic shear-stress difference as a function of magnitude for tremors from mine (M_L <2.8) and the earthquakes in Koyna area (M_L >3) is seen to have strikingly similar nature. The identical scaling of dynamic shear-stress of tremors from mine and earthquake lends support to the mechanical similarity of mine tremors and earthquakes in the Koyna area. This is also supported by the dependence of the velocity on magnitude for the two types of events.

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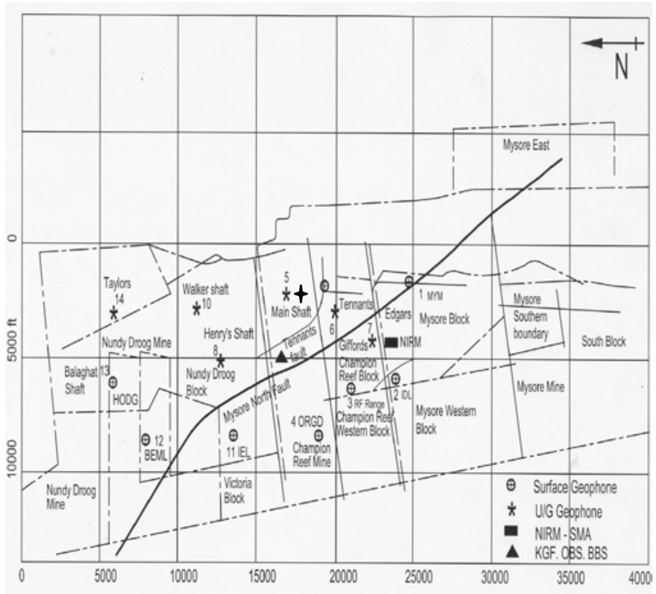

Figure 1. Surface plan showing mining region of the KGF. The strong-motion accelerograph was installed at the National Institute of Rock Mechanics. The epicenter of major rockburst recorded on 2.11.2005 was 500 ft south of main shaft (5). Line traces are the Mysore North Fault, the Tennant Fault, and the Gifford Fault.

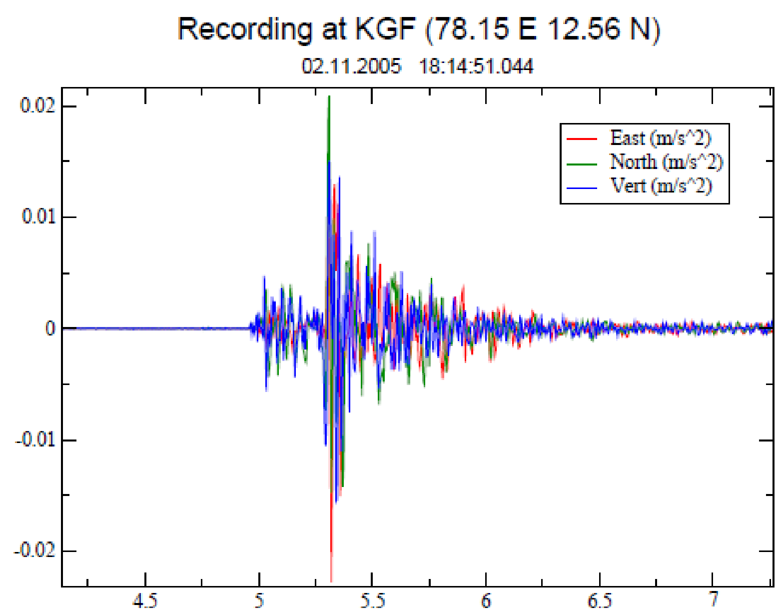

Figure 2. Seismogram for the event with *P*-arrival at 18:14:51.044 + 4.95.00.

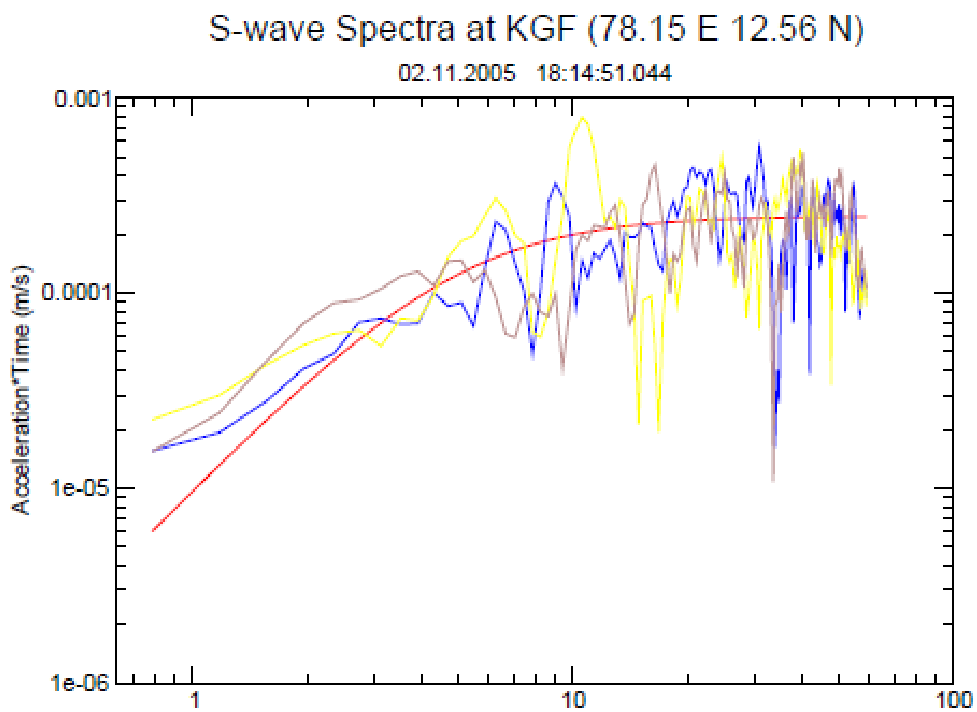

Figure 3. Acceleration spectra of the *S* wave for the event, with a Brune acceleration model (red line). The spectra have been truncated to not include the low sensor response above 50 Hz.

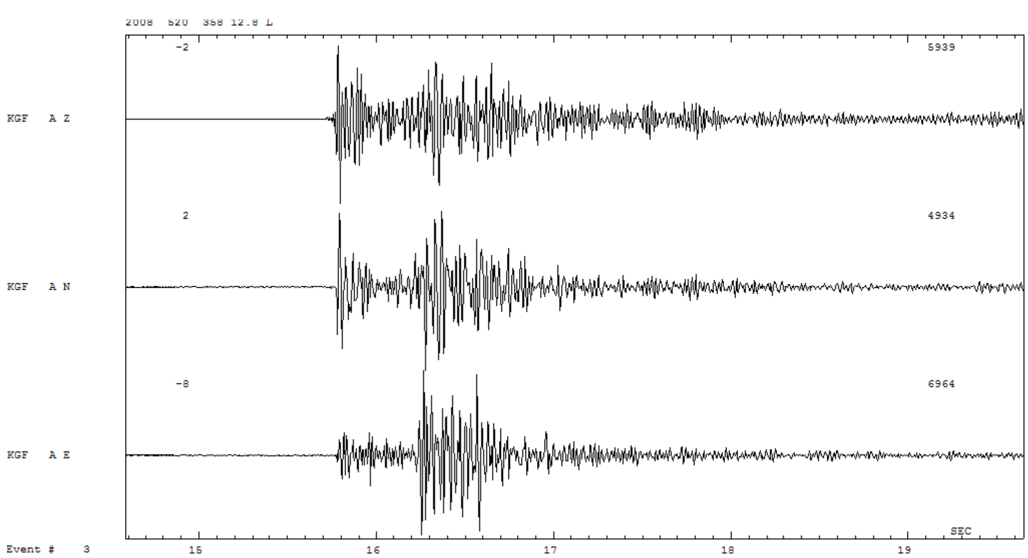

Figure 4. Typical seismic signal picked up by the strong motion accelerograph.

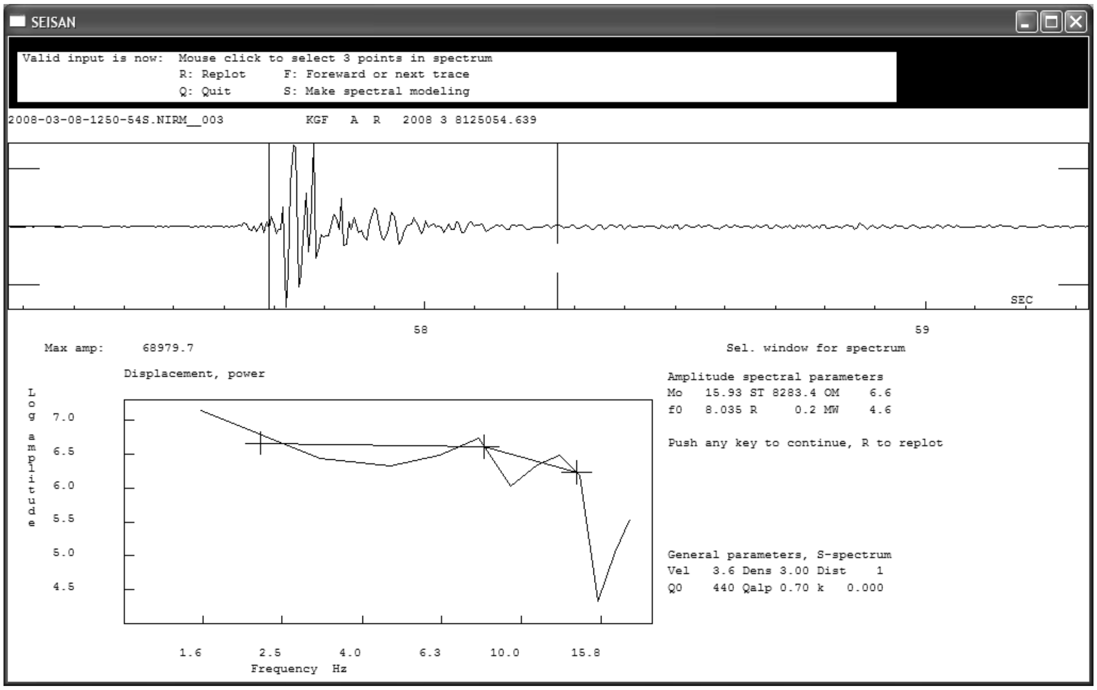

Figure 5. Typical output of source parameters computed using the *Seisan* software.

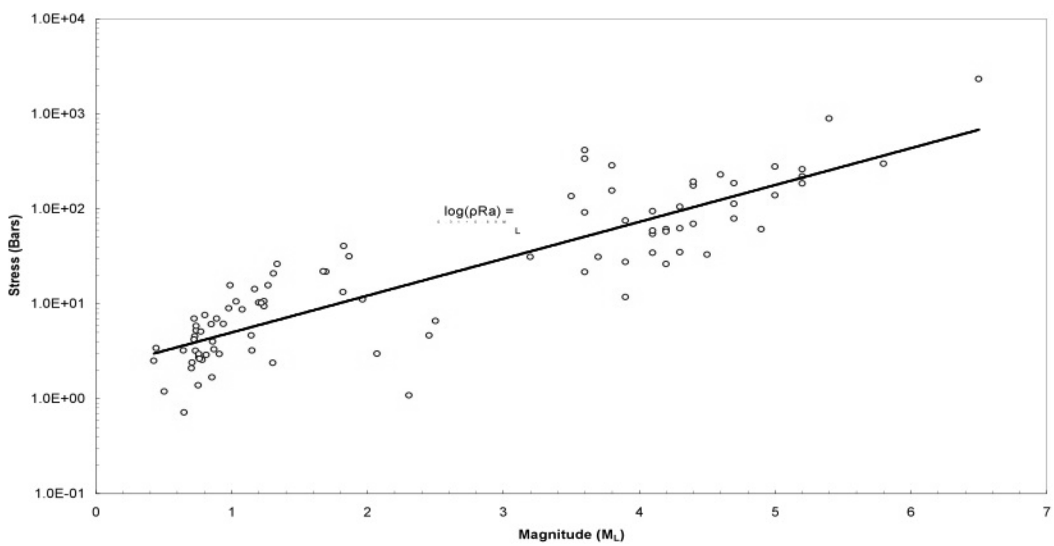

Figure 6. Dynamic shear stress difference as a function of magnitude for tremors of M_L < 2.8 and earthquakes of M_L > 3.

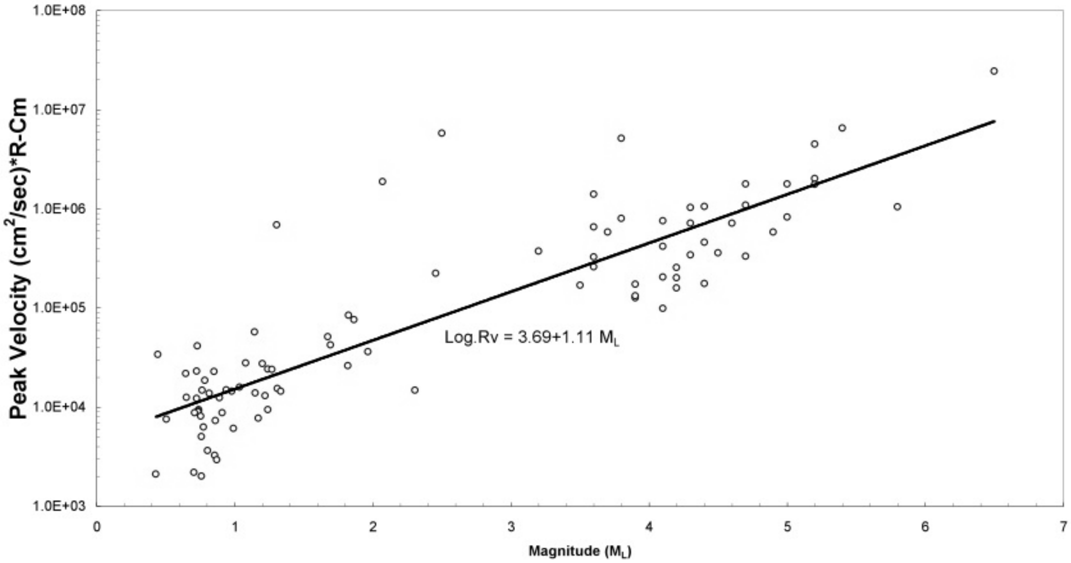

Figure 7. Peak ground velocity as a function of magnitude for tremors of M_L < 2.8 and earthquakes of M_L > 3.