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# GROUND VIBRATION AND STRUCTURE RESPONSE DUE TO ROCKBURSTS AT KOLAR GOLD FIELDS, INDIA


## Abstract

Even though the underground mines of Kolar Gold Fields, India, have been closed, rockbursts continue to occur. Some of these rockbursts are strongly felt in the mining township, causing concerns to local residents. Ground vibration induced by rockbursts and response of a building were monitored continuously for a period of five months. The observed vibration characteristics were compared with the permissible limits specified by the Director General of Mines Safety. The study revealed that the ground vibrations induced by the rockbursts were low to cause damage to surface structures.


## Introduction

Underground openings created in the process of mining disturb the state of stress. Due to the disturbance, stresses are concentrated in and around mine openings. The phenomenon of sudden and violent failure of rock mass in and around mine openings releasing a tremendous amount of energy is termed as rockburst. Rockbursts are quite common at Kolar Gold Fields (KGF) in Karnataka, India, where underground gold mines were in operation for more than 100 years and from depths exceeding 3000 m from the surface. On many occasions, rockbursts had caused fatalities, extensive damage to surface and underground structures. Although underground gold mines have been closed for economic reasons, rockbursts continue to occur. As the lower levels of the mines are filled with water, rockbursts mostly occur at shallow depth, usually at less than one kilometer. They are believed to be triggered by seepage, accumulation and gradual spreading of rain water through critically pre-stressed weak zones of underground workings [1].

Because of the heavy rains, a large number of rockbursts took place during 2005. Some of them being large, the local residents were concerned for their safety and the safety of their houses. Despite a number of seismic and microseismic investigations carried out for KGF mines earlier [1-3], it was not possible to assess the vibrations induced by rockbursts. In order to address the problem, ground vibration induced by rockbursts and response of a structure were monitored from 24 November 2005 to 23 March 2006.

## Permissible levels of ground vibration

Ground vibrations due to blasting or rockburst propagate in all directions from the source and adjacent structures may respond or shake. If ground vibrations are strong enough, the structures get damaged. In order to protect surface structures, the Director General of Mines Safety (DGMS) has specified the permissible limits of ground vibration for different types of structure (Table 1). Surface structures have been divided into two categories based on the ownership. For each category, there are three types of structure for which permissible peak particle velocity has been specified depending on the frequency. Because of the similarity of the seismic effects of rockbursts and rock blasting, these limits can be applicable for rockbursts as well.

Table 1 Permissible levels of ground vibration in terms of peak particle velocity (mm/s) [4]

| Type of structure | Dominant excitation frequency, Hz | | |
|---|---|---|---|
| | < 8 Hz | 8 – 25 Hz | > 25 Hz |
| *A) Buildings/ structures not belonging to the owner* | | | |
| Domestic houses/ structures (Kuchha brick and cement) | 5 | 10 | 15 |
| Industrial Buildings (RCC and framed structures) | 10 | 20 | 25 |
| Objects of historical importance and sensitive structures | 2 | 5 | 10 |
| *B. Buildings belonging to owner with limited span of life* | | | |
| Domestic houses/ structures (Kuchha brick and cement) | 10 | 15 | 25 |
| Industrial buildings (RCC & framed structures) | 15 | 25 | 50 |

**Monitoring procedure**

Two units of Instantel seismographs - MiniMate Plus with external tri-axial transducers, same as those used for monitoring ground vibration due to blasting, were used in this study. These transducers had the capability of monitoring peak particle velocity up to 254 mm/s and had a frequency response of 2 to 300 Hz.

Ground vibrations induced by rockbursts were monitored at the north-west corner on the ground floor of the new office building of the National Institute of Rock Mechanics at KGF. Structure responses were monitored at the same corner on the first floor of the same building. The longitudinal axis of the transducers was aligned parallel to the longer wall and the transverse axis parallel to the shorter wall of the office building. The transducers were leveled and mounted using plaster of paris. These transducers were connected to their respective units and the triggering level was set to 0.5 mm/s as vibrations of this magnitude are hardly noticed by human beings. Moreover, this was necessary to avoid false triggering of the seismographs.

**Results**

About 100 rockbursts were recorded. The date and time of rockbursts along with the measured parameters of ground vibration are given in Table 2. Depending on the vibration levels, the transducer on the ground floor did not record a few rockbursts that were recorded by the transducer on the first floor and vice versa. The structure response related parameters due to rockbursts are given in Table 3 along with some computed parameters.

Table 2 Characteristics of ground vibration induced by rockburst at Kolar Gold Fields

| Rockburst | | | Peak particle velocity, mm/s | | | Frequency, Hz | | |
|---|---|---|---|---|---|---|---|---|
| No. | Date | Time | Trans | Vertical | Long | Trans | Vertical | Long |
| 1 | Nov 23 /05 | 15:37:10 | *Not recorded in the ground* | | | | | |
| 2 | Nov 24 /05 | 14:12:34 | 1.40 | 0.38 | 1.02 | 30.0 | | 18.0 |
| 3 | Nov 24 /05 | 16:14:29 | 4.70 | 1.78 | 3.43 | 24.0 | 14.0 | 34.0 |
| 4 | Nov 25 /05 | 1:36:34 | 4.83 | 1.78 | 2.41 | 6.6 | 12.5 | 9.6 |
| 5 | Nov 28 /05 | 5:30:34 | 1.27 | 0.64 | 1.14 | 6.6 | 6.7 | 9.1 |
| 6 | Nov 28 /05 | 10:41:02 | 15.00 | 3.43 | 8.64 | 20.1 | 13.8 | 29.6 |
| 7 | Nov 29 /05 | 23:37:02 | 10.00 | 3.30 | 4.70 | 19.1 | 15.4 | 10.5 |
| 8 | Nov 30 /05 | 13:44:09 | 0.64 | 0.76 | 1.40 | 6.7 | 12.9 | 17.6 |
| 9 | Dec 1 /05 | 17:20:11 | *Not recorded in the ground* | | | | | |
| 10 | Dec 7 /05 | 4:32:49 | 0.92 | 0.71 | 1.48 | 7.0 | 15.5 | 20.0 |
| 11 | Dec 7 /05 | 21:40:19 | 0.29 | 0.38 | 0.56 | 6.7 | 14.3 | 20.1 |
| 12 | Dec 8 /05 | 7:01:31 | 0.79 | 0.24 | 0.32 | 6.9 | 6.9 | 17.4 |
| 13 | Dec 8 /05 | 11:08:38 | 0.54 | 0.21 | 0.25 | 7.5 | 7.5 | 18.0 |
| 14 | Dec 8 /05 | 15:37:38 | 2.44 | 0.70 | 1.16 | 8.0 | 8.0 | 8.0 |
| 15 | Dec 8 /05 | 16:07:40 | 1.51 | 0.56 | 0.60 | 5.5 | 13.0 | 7.0 |
| 16 | Dec 8 /05 | 17:48:01 | 1.71 | 0.40 | 0.62 | 6.5 | 6.5 | 18.0 |
| 17 | Dec 10 /05 | 12:55:20 | 0.29 | 0.56 | 0.54 | 14.0 | 14.0 | 18.0 |
| 18 | Dec 11 /05 | 20:46:04 | 0.87 | 0.67 | 0.95 | 7.0 | 7.0 | 7.0 |
| 19 | Dec 13 /05 | 6:19:46 | 0.32 | 0.16 | 0.84 | 7.0 | 7.0 | 20.0 |
| 20 | Dec 13 /05 | 18:56:55 | 1.41 | 1.43 | 1.67 | 7.0 | 12.0 | 7.0 |
| 21 | Dec 14 /05 | 14:18:49 | *Not recorded in the ground* | | | | | |
| 22 | Dec 14 /05 | 18:26:28 | 0.33 | 0.22 | 0.71 | 8.0 | 15.0 | 11.0 |
| 23 | Dec 15 /05 | 12:18:55 | 0.71 | 0.48 | 0.97 | 10.0 | 14.0 | 10.0 |
| 24 | Dec 15 /05 | 20:33:32 | 0.84 | 0.32 | 0.49 | 18.5 | 13.0 | 11.0 |
| 25 | Dec 16 /05 | 3:39:26 | 0.73 | 0.59 | 1.29 | 7.0 | 13.0 | 11.0 |
| 26 | Dec 16 /05 | 21:51:04 | 0.30 | 0.25 | 0.52 | 7.0 | 7.0 | 7.5 |
| 27 | Dec 18 /05 | 19:47:19 | 0.37 | 0.16 | 1.22 | 21.0 | 16.0 | 21.0 |
| 28 | Dec 19 /05 | 0:01:49 | 0.64 | 0.33 | 1.22 | 20.0 | 14.0 | 20.0 |
| 29 | Dec 19 /05 | 8:14:30 | 2.65 | 0.62 | 1.35 | 7.0 | 12.0 | 11.5 |
| 30 | Dec 19 /05 | 13:31:57 | 0.27 | 0.14 | 0.54 | 10.0 | 20.0 | 33.0 |
| 31 | Dec 20 /05 | 22:08:20 | 5.51 | 2.11 | 4.10 | 7.0 | 13.0 | 11.0 |
| 32 | Dec 21 /05 | 0:18:36 | 0.49 | 0.27 | 0.65 | 21.0 | 24.0 | 22.0 |
| 33 | Dec 21 /05 | 5:52:12 | 1.10 | 0.41 | 1.02 | 7.0 | 7.0 | 10.5 |
| 34 | Dec 21 /05 | 15:35:26 | 0.37 | 0.30 | 0.79 | 7.0 | 13.5 | 12.0 |
| 35 | Dec 21 /05 | 22:50:32 | 0.92 | 0.71 | 2.00 | 7.0 | 7.0 | 11.0 |
| 36 | Dec 21 /05 | 23:00:19 | 0.19 | 0.16 | 0.57 | 29.0 | 14.0 | 34.0 |
| 37 | Dec 23 /05 | 6:17:24 | 0.62 | 0.49 | 0.48 | 16.0 | 14.0 | 16.0 |
| 38 | Dec 23 /05 | 10:10:31 | 0.54 | 0.59 | 0.94 | 22.0 | 16.0 | 44.0 |
| 39 | Dec 25 /05 | 0:38:00 | 0.35 | 0.29 | 0.68 | 7.5 | 14.5 | 8.0 |
| 40 | Dec 25 /05 | 9:42:04 | 0.43 | 0.56 | 0.54 | 7.0 | 8.0 | 7.5 |
| 41 | Dec 26 /05 | 6:17:43 | 0.59 | 0.33 | 0.49 | 20.0 | 23.0 | 33.0 |
| 42 | Dec 26 /05 | 7:56:45 | 3.21 | 1.97 | 1.78 | 7.0 | 7.0 | 7.0 |
| 43 | Dec 27 /05 | 0:44:40 | 0.52 | 0.37 | 0.57 | 18.5 | 13.0 | 20.5 |
| 44 | Dec 27 /05 | 14:11:24 | 0.56 | 0.40 | 0.91 | 8.0 | 14.0 | 34.0 |
| 45 | Dec 27 /05 | 15:48:30 | 0.44 | 0.29 | 1.30 | 20.0 | 17.0 | 24.0 |
| 46 | Dec 30 /05 | 3:17:17 | 0.40 | 0.19 | 0.60 | 20.0 | 16.0 | 44.0 |
| 47 | Dec 30 /05 | 20:23:43 | 1.13 | 0.33 | 0.60 | 20.0 | 17.0 | 21.0 |
| 48 | Jan 2 /06 | 6:53:02 | 0.44 | 0.19 | 0.59 | 20.0 | 14.0 | 11.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 49 | Jan 4 /06 | 16:57:38 | 4.89 | 2.30 | 2.81 | 22.0 | 17.0 | 23.0 |
| 50 | Jan 5 /06 | 12:53:19 | 0.32 | 0.14 | 0.52 | 24.0 | 36.0 | 40.0 |
| 51 | Jan 5 /06 | 14:06:04 | 0.51 | 0.14 | 0.19 | 22.0 | 44.0 | 30.0 |
| 52 | Jan 6 /06 | 10:59:19 | *Not recorded in the ground* | | | | | |
| 53 | Jan 7 /06 | 14:39:57 | 0.43 | 0.16 | 0.54 | 30.0 | 16.0 | 22.0 |
| 54 | Jan 11 /06 | 1:27:53 | 0.86 | 0.44 | 0.41 | 19.0 | 14.0 | 11.0 |
| 55 | Jan 11 /06 | 3:51:34 | *Not recorded in the ground* | | | | | |
| 56 | Jan 15 /06 | 14:44:16 | 0.29 | 0.22 | 0.84 | 19.0 | 16.0 | 11.0 |
| 57 | Jan 16 /06 | 7:23:11 | 0.92 | 0.30 | 0.59 | 20.0 | 14.0 | 32.0 |
| 58 | Jan 16 /06 | 10:54:51 | 4.71 | 1.11 | 2.05 | 9.5 | 7.5 | 7.0 |
| 59 | Jan 17 /06 | 0:25:16 | 1.30 | 1.65 | 1.87 | 6.0 | 7.0 | 6.5 |
| 60 | Jan 17 /06 | 0:26:55 | 0.76 | 0.97 | 0.97 | 6.5 | 7.0 | 7.0 |
| 61 | Jan 21 /06 | 23:52:27 | 0.83 | 0.19 | 0.35 | 22.0 | 14.0 | 36.0 |
| 62 | Jan 22 /06 | 9:18:10 | 0.87 | 0.48 | 0.62 | 11.0 | 13.0 | 38.0 |
| 63 | Jan 25 /06 | 4:54:43 | *Not recorded in the ground* | | | | | |
| 64 | Jan 26 /06 | 1:56:12 | 0.35 | 0.25 | 0.59 | 30.0 | 15.0 | 24.0 |
| 65 | Jan 26 /06 | 4:36:05 | 0.65 | 0.56 | 1.32 | 7.0 | 15.0 | 24.0 |
| 66 | Jan 26 /06 | 8:25:16 | 0.46 | 0.43 | 0.81 | 7.0 | 24.0 | 23.0 |
| 67 | Jan 31 /06 | 7:34:06 | *Not recorded in the ground* | | | | | |
| 68 | Feb 1 /06 | 10:47:09 | 0.56 | 0.21 | 0.27 | 19.0 | 15.0 | 10.0 |
| 69 | Feb 1 /06 | 12:58:06 | 0.19 | 0.10 | 0.67 | 22.0 | 10.0 | 26.0 |
| 70 | Feb 5 /06 | 0:09:58 | 1.33 | 0.67 | 0.62 | 19.0 | 14.0 | 32.0 |
| 71 | Feb 7 /06 | 21:16:34 | 0.76 | 1.03 | 1.79 | 18.0 | 16.0 | 36.0 |
| 72 | Feb 8 /06 | 9:03:38 | 3.98 | 1.71 | 2.41 | 6.5 | 9.5 | 11.0 |
| 73 | Feb 8 /06 | 10:31:19 | 0.57 | 0.14 | 0.35 | 7.0 | 14.5 | 11.0 |
| 74 | Feb 8 /06 | 10:31:25 | 0.60 | 0.21 | 0.44 | 6.5 | 15.0 | 11.5 |
| 75 | Feb 12 /06 | 13:57:37 | 0.87 | 0.41 | 0.89 | 6.5 | 6.5 | 10.5 |
| 76 | Feb 12 /06 | 19:24:15 | 0.37 | 0.29 | 0.83 | 21.0 | 14.0 | 21.0 |
| 77 | Feb 17 /06 | 17:51:59 | 0.62 | 0.32 | 0.32 | 21.0 | 14.0 | 20.0 |
| 78 | Feb 18 /06 | 9:58:35 | 2.56 | 1.38 | 4.05 | 9.5 | 12.5 | 11.5 |
| 79 | Feb 19 /06 | 1:30:04 | 0.25 | 0.21 | 0.57 | 7.0 | 15.0 | 11.0 |
| 80 | Feb 21 /06 | 8:14:43 | 1.27 | 1.13 | 1.51 | 20.0 | 14.0 | 18.5 |
| 81 | Feb 21 /06 | 16:12:42 | 0.43 | 0.51 | 0.43 | 7.0 | 14.5 | 6.5 |
| 82 | Feb 21 /06 | 20:52:06 | 1.79 | 0.73 | 0.68 | 19.5 | 13.5 | 13.5 |
| 83 | Feb 22 /06 | 5:23:43 | 0.59 | 0.41 | 0.65 | 15.0 | 15.0 | 39.0 |
| 84 | Feb 22 /06 | 19:59:23 | 0.71 | 0.25 | 0.71 | 10.0 | 15.0 | 22.0 |
| 85 | Feb 23 /06 | 9:41:58 | 0.59 | 0.18 | 0.38 | 17.0 | 14.0 | 17.0 |
| 86 | Feb 23 /06 | 9:58:35 | 0.71 | 0.25 | 0.49 | 17.0 | 14.0 | 17.0 |
| 87 | Feb 23 /06 | 10:25:35 | 0.89 | 0.38 | 0.62 | 17.0 | 19.0 | 17.0 |
| 88 | Feb 23 /06 | 16:17:22 | 0.92 | 0.83 | 1.06 | 6.5 | 6.0 | 5.5 |
| 89 | Feb 25 /06 | 6:30:16 | 0.43 | 0.44 | 0.56 | 6.0 | 6.5 | 6.5 |
| 90 | Feb 26 /06 | 15:08:17 | 1.11 | 0.83 | 0.94 | 28.5 | 14.5 | 17.0 |
| 91 | Feb 28 /06 | 11:07:43 | 0.83 | 0.32 | 0.48 | 22.0 | 15.0 | 11.0 |
| 92 | Mar 4 /06 | 9:45:33 | 0.81 | 0.29 | 0.62 | 17.0 | 14.0 | 17.0 |
| 93 | Mar 4 /06 | 9:54:14 | 0.84 | 0.27 | 0.60 | 17.0 | 14.0 | 17.0 |
| 94 | Mar 4 /06 | 17:17:46 | 2.33 | 0.91 | 1.90 | 19.0 | 17.0 | 11.0 |
| 95 | Mar 8 /06 | 16:14:58 | 0.49 | 0.21 | 0.59 | 21.0 | 15.0 | 15.0 |
| 96 | Mar 10 /06 | 4:34:49 | 0.54 | 0.22 | 0.27 | 7.5 | 13.5 | 18.0 |
| 97 | Mar 15 /06 | 20:09:10 | 0.51 | 0.29 | 1.00 | 22.0 | 12.0 | 23.0 |
| 98 | Mar 18 /06 | 0:21:18 | 0.21 | 0.16 | 0.52 | 21.0 | 15.0 | 33.0 |
| 99 | Mar 23/06 | 7:34:30 | *Not recorded in the ground* | | | | | |

Fig.1 shows the time histories of the transverse, vertical and longitudinal components of ground vibration due to rockbursts. The amplitudes vary with time. The largest amplitude in each of the components is referred as the peak particle velocity. By definition, peak particle velocity is 0.87, 0.67 and 0.95 mm/s in transverse, vertical and longitudinal components respectively.

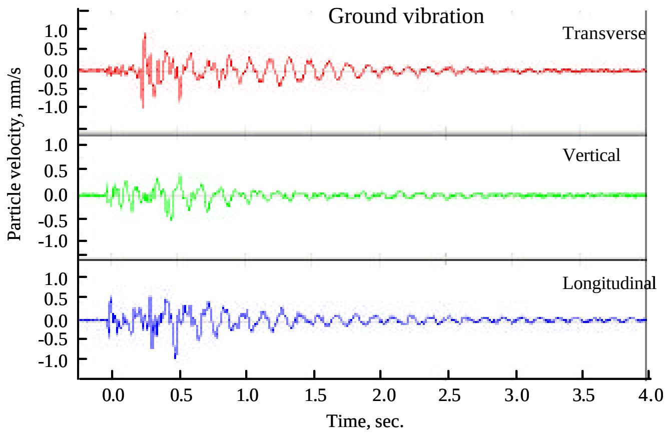


Figure 1 Time histories of ground vibration induced by rockbursts

Fig. 2 shows the frequency spectra of the time histories shown in Figure 1. The frequency was determined by Fast Fourier Transform method, which transforms the ground motion time histories (time domain) into frequency domain. The energy content (spectral amplitude) varies with frequencies. The frequency corresponding to the maximum spectral amplitude is called dominant frequency of the ground vibration. By definition, the dominant frequency in this figure is 7 Hz for all the three components.

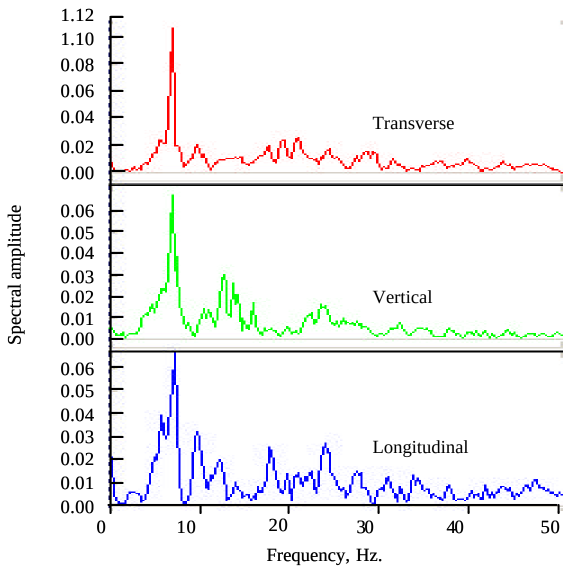


Figure 2 Frequency spectra of time histories of ground vibration shown in Figure 1

Fig. 3 shows the time histories of the transverse, vertical and longitudinal components of vibration recorded on the first floor of the office building. The vertical and horizontal scale in Fig. 1 and Fig. 3 being the same, it can be noted that the building has a tendency to vibrate more than the ground. In other words, there is some amplification due to the response of the building.

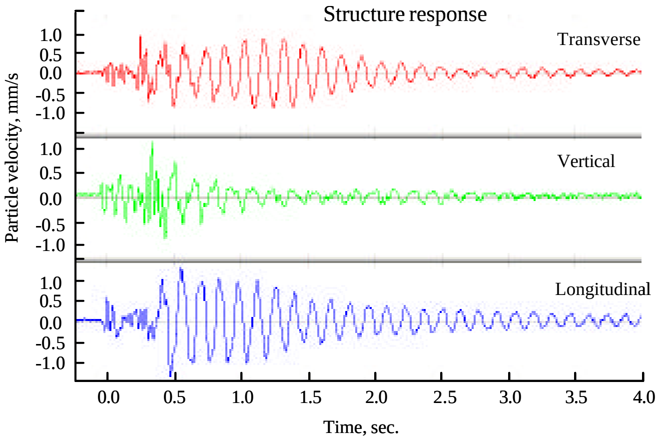


Figure 3 Time histories of structure vibration

## Analysis and discussion

### *Measured parameters of ground vibration*

Using the data from Table 2, peak particle velocity was plotted against the corresponding frequency (Fig. 4). The permissible levels for the domestic houses not belonging to the mine owner (Table 1) are also drawn in the figure. With an exception of only one value (15 mm/s at 20.1 Hz which is equivalent to 0.32g), vibrations induced by rockbursts are within the permissible levels. Since the threshold values of damage are several times higher than the permissible levels, even the highest value recorded (15 mm/s) is unlikely to cause any damage to surface structures [5]. However, vibrations of this magnitude will be felt strongly.

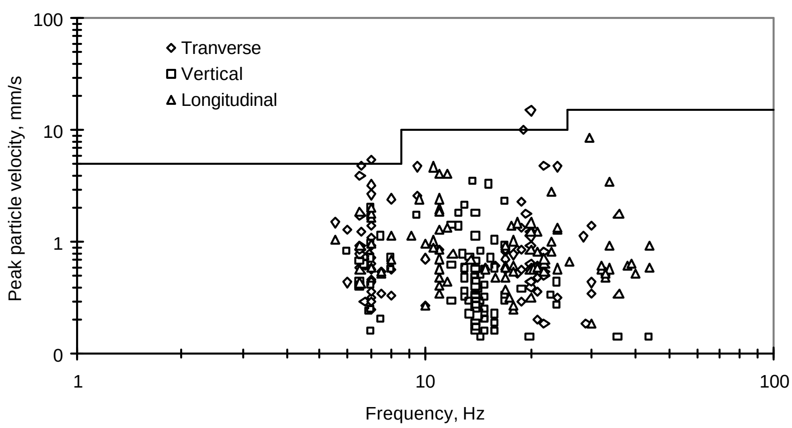


Figure 4 Peak particle velocity versus frequency of ground motion

Fig. 4 shows that peak particle velocity is normally below 5 mm/s and frequency varies from 6 to 40 Hz. These vibration parameters are comparable with those of surface mine blasts [6]. However, there is a marked difference between vibrations induced by rockbursts and blasting. Vibrations from blasting can be predicted and controlled. Vibrations from rockbursts, on the other hand, can be neither predicted nor controlled.

### *Natural frequency of the office building*

Natural frequency is the frequency at which the structure freely vibrates after the cessation of the ground vibration. The free vibration resembles a sinusoidal motion with a single frequency. The sinusoidal portion of the waveform was selected and frequency analysis of the partial waveform was performed to compute the natural frequency of the office building. Some of the records of rockbursts, particularly their transverse components, did not show free vibration and hence the natural frequencies could not be determined. The natural frequency of the office building varied between 6 and 10 Hz (Table 3) which falls within the general range of natural frequencies for single or double storied houses reported earlier [7].

### *Amplification factor versus frequency of ground vibration*

Superstructure or portion above the ground level of any residential or industrial structure tends to amplify the ground vibration depending on its natural frequency and damping characteristics of the structure and the characteristics of ground vibration subjected to the structure. The extent to which ground vibrations are amplified is determined by amplification factor which is defined as the ratio of the peak structure vibration to the peak ground vibration. The computed amplification factors are shown in Table 3.

Table 3 Structure response, natural frequency and amplification factor

| Rockburst | Peak particle velocity, mm/s | | | Natural frequency, Hz | | | Amplification factor | | |
|---|---|---|---|---|---|---|---|---|---|
| No* | Trans | Vertical | Long. | Trans | Vertical | Long. | Trans | Vertical | Long |
| 1 | 1.78 | 1.40 | 1.40 | 7.0 | | 7.0 | | | |
| 2 | 1.14 | 0.76 | 1.02 | 8.0 | | | 0.81 | 2.00 | 1.00 |
| 3 | 2.41 | 2.03 | 1.78 | 8.0 | | 8.0 | 0.51 | 1.14 | 0.52 |
| 4 | 5.46 | 2.79 | 3.05 | 7.0 | | 7.0 | 1.13 | 1.57 | 1.27 |
| 5 | 1.14 | 0.76 | 1.14 | 7.0 | | 7.0 | 0.90 | 1.20 | 1.00 |
| 6 | 10.70 | 5.46 | 4.32 | 7.0 | | 7.0 | 0.71 | 1.59 | 0.50 |
| 7 | 5.46 | 5.46 | 3.94 | 7.5 | | 7.5 | 0.55 | 1.65 | 0.84 |
| 8 | 0.64 | 1.02 | 1.27 | 7.0 | | 7.0 | 1.00 | 1.34 | 0.91 |
| 9 | 0.56 | 0.37 | 0.68 | 10.0 | | 10.0 | | | |
| 10 | 0.59 | 0.94 | 0.95 | 7.0 | 7.0 | | 0.64 | 1.31 | 0.64 |
| 11 | 0.40 | 0.49 | 0.76 | 8.0 | 8.0 | | 1.39 | 1.29 | 1.37 |
| 12 | 0.86 | 0.30 | 0.43 | 7.0 | | | 1.08 | 1.27 | 1.35 |
| 13 | 0.64 | 0.25 | 0.35 | | | | 1.18 | 1.23 | 1.37 |
| 14 | 3.64 | 1.35 | 1.52 | 8.0 | | 8.0 | 1.49 | 1.93 | 1.31 |
| 15 | 1.87 | 0.79 | 1.21 | 7.0 | | 7.0 | 1.24 | 1.43 | 2.01 |
| 16 | 1.70 | 0.67 | 0.52 | 7.0 | | 7.0 | 0.99 | 1.68 | 0.85 |
| 17 | 0.24 | 0.64 | 0.64 | | | 7.0 | 0.83 | 1.14 | 1.18 |
| 18 | 0.98 | 1.16 | 1.38 | 8.0 | | 8.0 | 1.13 | 1.74 | 1.45 |
| 19 | 0.33 | 0.29 | 0.71 | | | 8.0 | 1.05 | 1.80 | 0.85 |
| 20 | 1.41 | 2.02 | 2.29 | 7.0 | | 7.0 | 1.00 | 1.41 | 1.37 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 0.38 | 0.52 | 0.27 | 8.0 | | 8.0 | | | |
| 23 | 0.57 | 0.76 | 0.78 | | | | 0.80 | 1.60 | 0.80 |
| 24 | 0.68 | 0.52 | 0.49 | | | | 0.81 | 1.65 | 1.00 |
| 25 | 0.75 | 0.76 | 1.22 | | | | 1.02 | 1.30 | 0.95 |
| 26 | 0.56 | 0.14 | 0.43 | 8.0 | | 8.0 | 1.84 | 0.56 | 0.82 |
| 27 | 0.57 | 0.32 | 1.03 | 7.0 | | 7.0 | 1.56 | 1.99 | 0.84 |
| 28 | 0.60 | 0.44 | 0.97 | 8.0 | | | 0.95 | 1.33 | 0.79 |
| 29 | 2.05 | 0.92 | 1.16 | 7.5 | | 7.5 | 0.77 | 1.49 | 0.86 |
| 31 | 5.73 | 2.95 | 3.79 | 7.5 | | 7.5 | 1.04 | 1.40 | 0.92 |
| 33 | 1.11 | 0.70 | 0.70 | 7.0 | | 7.0 | 1.01 | 1.69 | 0.68 |
| 34 | 0.46 | 0.57 | 0.67 | | | | 1.26 | 1.89 | 0.84 |
| 35 | 1.02 | 1.17 | 1.71 | 8.0 | | 8.0 | 1.11 | 1.64 | 0.86 |
| 37 | 0.44 | 0.67 | 0.73 | 8.0 | | 8.0 | 0.72 | 1.36 | 1.53 |
| 39 | 0.27 | 0.40 | 0.51 | 8.0 | | 8.0 | 0.77 | 1.39 | 0.74 |
| 40 | 1.13 | 0.73 | 0.87 | 7.0 | | 7.0 | 2.63 | 1.31 | 1.62 |
| 42 | 3.41 | 2.68 | 4.22 | 7.0 | | 7.0 | 1.06 | 1.36 | 2.37 |
| 43 | 0.86 | 0.59 | 0.67 | | | 7.0 | 1.64 | 1.61 | 1.17 |
| 44 | 0.37 | 0.65 | 0.46 | 8.0 | | 8.0 | 0.66 | 1.64 | 0.51 |
| 45 | 0.68 | 0.35 | 1.10 | 8.0 | | | 1.54 | 1.22 | 0.85 |
| 47 | 1.19 | 0.49 | 0.70 | 8.0 | | | 1.05 | 1.48 | 1.16 |
| 52 | 0.37 | 0.52 | 0.43 | 10.0 | | | | | |
| 54 | 0.91 | 0.67 | 0.41 | 7.0 | | | 1.06 | 1.50 | 1.00 |
| 55 | 0.64 | 0.38 | 0.49 | 8.0 | | 8.0 | | | |

** Some of the rockbursts were not recorded on the structure*

Fig 5 shows the amplification factor against frequency for different components. In all the components, there is amplification in the frequency range of 6- 22 Hz whereas the maximum amplification is around 7 Hz which is the natural frequency of the building. The building at this frequency absorbs most of the energy of ground vibration and oscillates with larger amplitude for a longer duration. There is no amplification at frequencies higher than 22 Hz. That is the reason why permissible levels of ground vibration (Table 1) are higher at high frequencies.

The response of the office building or amplification factor due to rockburst is lower than that of the typical low-cost houses around coal mines in India [7]. The characteristics of rockbursts and blasts being similar, the lower amplification factors may be attributed to the type of building.

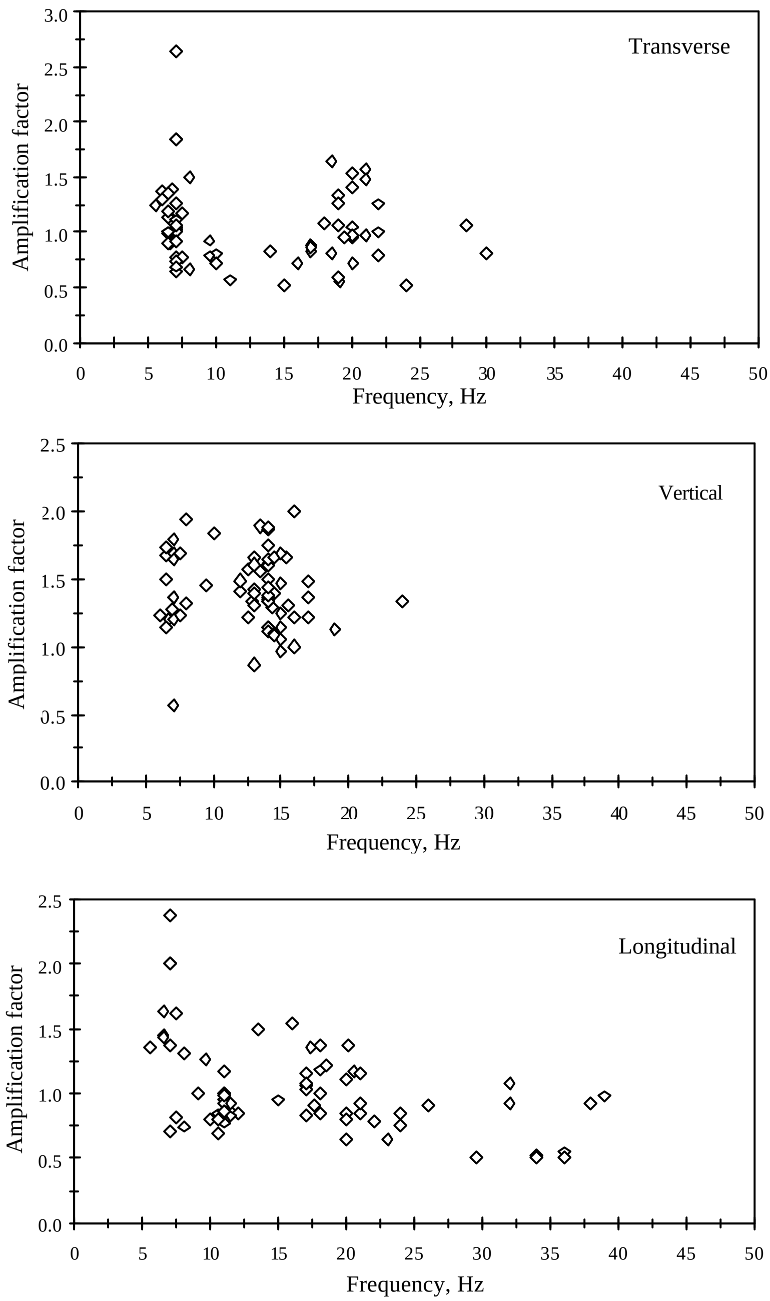


Figure 5 Amplification factor versus frequencies of ground vibration

***Amplification factor versus ground vibration***

In accordance with the work of Richards and Adrian [8] who studied responses of brick veneer houses due to blasting in coal mines in Australia, amplification factor was plotted against ground vibration for rockbursts data. Fig. 6 shows that higher amplification factors correspond to lower peak particle velocities and vice versa. The amplification is greater than 1.0 when peak particle velocity is greater or equal to 5 mm/s. At higher peak particle velocity, amplification factor is less than 1.0. However, no scientific reasons for this relation could be established.

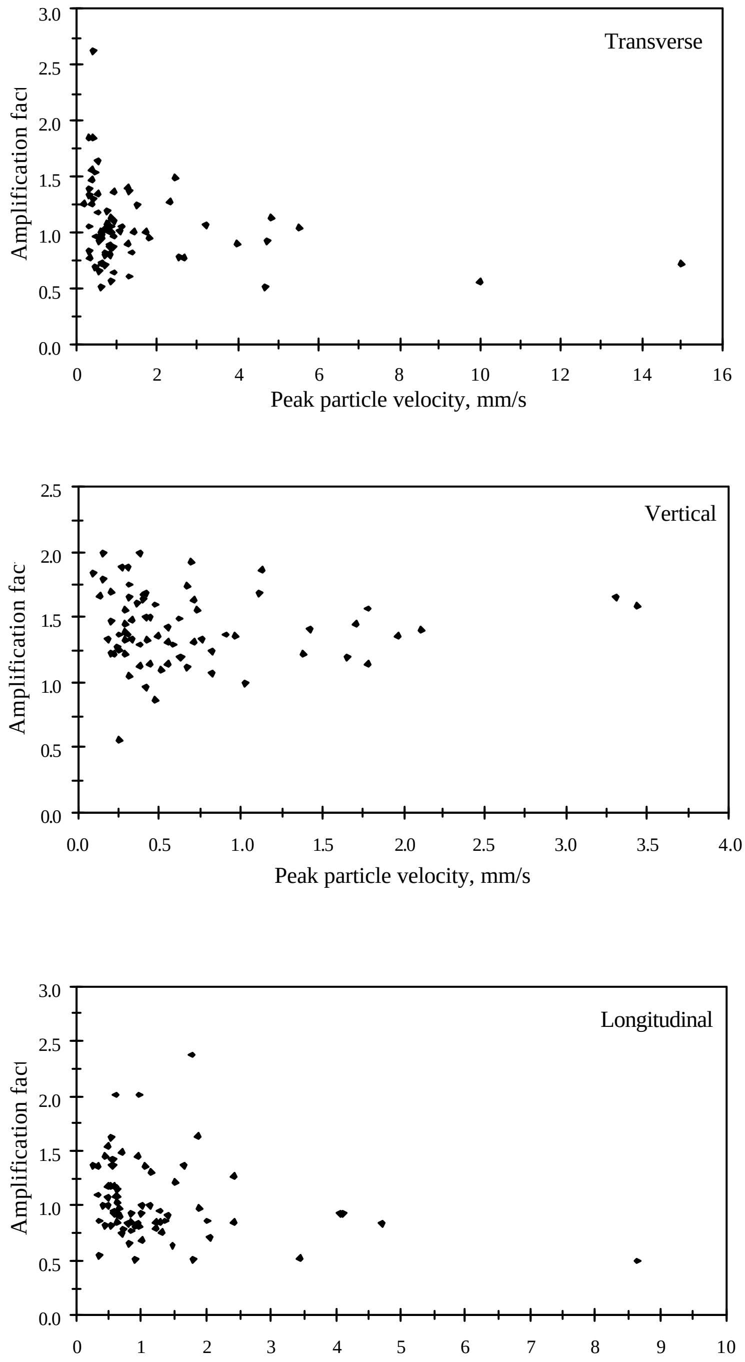


Figure 6 Amplification factor versus ground vibration

## Conclusions

This work provided an assessment of ground vibration induced by rockbursts at Kolar Gold Fields and the response of an office building. For most of the rockbursts, the measured ground vibrations were within the permissible levels. Only in one case, the measured vibration exceeded permissible level but still safe to the structures. As the mines are closed, possibilities of large rockbursts threatening the peaceful life of KGF are remote.

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