PEAK GROUND HORIZONTAL ACCELERATION ATTENUATION RELATIONSHIP FOR LOW MAGNITUDES AT SHORT DISTANCES IN SOUTH INDIAN REGION

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ABSTRACT

Attenuation relationships for peak horizontal ground acceleration for short distances and low magnitudes have been developed for Kolar Gold Fields mines region in South India. The distance range upto 5 km and the magnitudes ranging between 0 and 3 have been used for the development of the attenuation relationship. Two steps multiple regressions have been made by analyzing the decay of individual magnitude classes with distance using it with the whole data set. The model used in the present study is

$$log (A) = c_1 + c_2M - c_4\, blog (X + e^{c3M})$$

Where y is the peak ground horizontal acceleration, X is hypocentral distance and m is local magnitude M_L, and c_i's and a_i's are regression coefficients. The discussions of the attenuation characteristics of the ground motion at shorter distances and low magnitudes have been discussed. The comparison of strong ground motion at similar distances using relationships developed from higher magnitudes reveals the difference in the observed peak ground horizontal accelerations with respect to the strain levels involved in the generation of the respective earthquakes.

INTRODUCTION

India has faced several devastating earthquakes in the past. The largest of these have originated in the Himalayan plate boundary region, which has remained a region of great scientific and engineering interest. Not surprisingly, considerable data and earthquake related literature are available about the northern part of India. On the other hand very little information is available seismological about Peninsular India (PI), which is taken here as south of 24° N latitude. This situation is changing, in response to the three recent devastating events: the Khillari (30.9.1993), Jabalpur (22.5.1997), and Kutch (26.1.2001) shocks. But the available quantified information is so sparse, engineers presently face a daunting problem in estimating ground motion levels for future events in PI. The present paper is motivated by this need, to have a simple approach to understand attenuation in PI from the engineering point of view. The paper consists of the data base from Kolar region and the development of the attenuation relationship. Finally, attenuation relationship for low magnitude and shorter distances is proposed for the region.

GEOLOGY OF THE STUDY AREA

The region of the Indian subcontinent south of 24^{0}N latitude is taken here as Peninsular India (PI). This landmass is far away from the Himalayan collision zone, which is a well known boundary between the Indian and the Asian plates. Nonetheless, it is recognized that Cambay and Rann of Kutch in Gujarat are among the very active regions of India. Leaving this region and the Andaman-Nicobar Islands, the remaining part of continental PI has reliably experienced some 400 earthquakes in a period of 600 years. This number will be much larger if all instrumentally recorded shocks of small magnitudes were also included. The seismicity of PI, from a seismological perspective has been discussed in the past notably by Chandra (1977), and Rao (1984). A catalogue of earthquakes of magnitude ≥ 3 for PI has been compiled by Guha and Basu (1993). Seeber et al (1999) have studied the seismicity of PI with particular reference to Maharashtra. They concluded that between 1960 and 1990 the seismicity of PI showed a threefold increase. This was the period during which industrial development also increased several fold in PI. Thus, engineers have to recognize that the looming seismic risk to man made structures in PI is more than what was previously believed.

In regions lacking strong motion data, seismological models (Boore 1983) are viable alternatives and are used worldwide for deriving attenuation relationships (Atkinson and Boore 1995, Hwang and Huo 1997, Toro et al 1997). Singh et al (1999) have used a seismological model for estimating ground motion in parts of PI, but no specific attenuation equation has been proposed by them. The theory and application of seismological models for estimating ground motion has been discussed in detail by Boore (1983; 2003).

KGF Gold Mines are situated in a belt of highly metamorphosed schists which runs 80 North –South and 4 kms East-West, the major rock types are schist of lower Dharwar age which are surrounded by Granites and Genisses of Achaean Age, the schists is popularly known as

Kolar Schists Belt. At the southern tip of the 80 km, KGF mines are situated, there are about 26 known lodes and out of which champion lode is gold bearing schist and it is of economic importance. The schists are folded and faulted with intrusion of Dolerite dykes and pegmatites. The fold dips westward from 30^{o} near the surface to 85^{o} in the deeper working mines. Each side of reef calcite, beds of pale green augite and micaceous and chlorite are seen. Figure-1 shows the geology of Kolar Gold Fields.

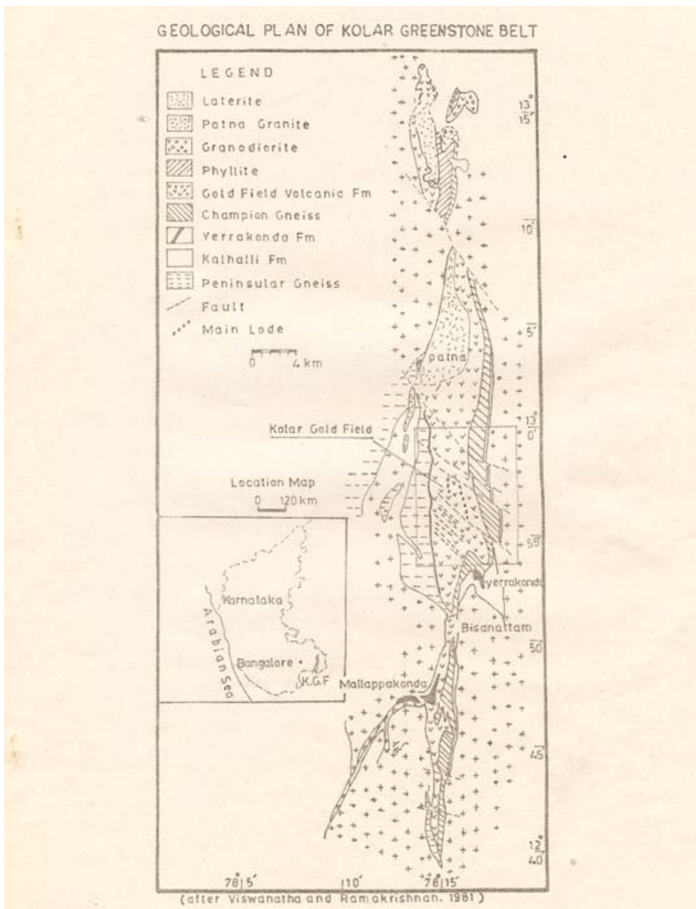

Fig. 1 Map showing geology of Kolar Gold Fields.

DATA SET

Rockburst is a common phenomenon since the beginning of 20th century in the mines of Kolar Gold Fields which is situated in Karnataka. Rockbursts have caused severe damages to buildings on surface and mine workings in underground several instances. The rockbursts were monitored using seismic monitoring system from 1979. Department of Science and Technology under World Bank assisted project installed one Broad Band seismic Monitoring station during 1999 and one Strong Motion Accelerograph during 2005. The Strong Motion Accelerograph has recorded several rockbursts as it is in the close vicinity of the mines of Kolar Gold Fields. The Strong-motion accelerogram generated due to rockburst were used to obtain Wood-Anderson synthetic seismogram which provide useful basis for getting accurate and reliable values of local magnitudes. The three components of a total of 795 strong motion records obtained from seismic events in different zones of the mines before and after the major rockburst which occurred on 02.11.2005 were used. The local magnitudes of these seismic events were in the range from 0.5 to 3.0 at a distance of radius 4.76 km. These accelerograms have been recorded by strong-motion Accelerograph installed in the campus of National Institute of Rock Mechanics. Data having hypocentral distance less than one is removed since there was a drastic change in PGA values for the recording having less than one kilometre hypocenter distance.

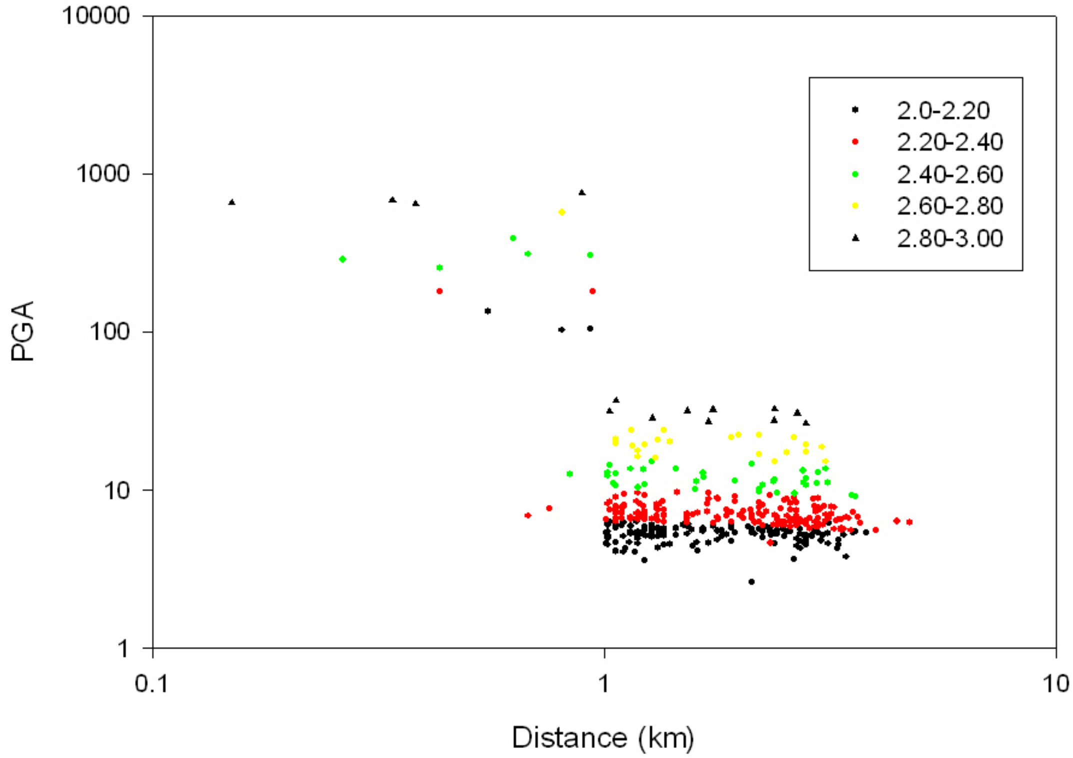

Fig. 2 Plot of all seismic events PGA versus Distance.

The data is plotted in fig. 2. Dataset finally used for the regressoin is shown in fig. 3.

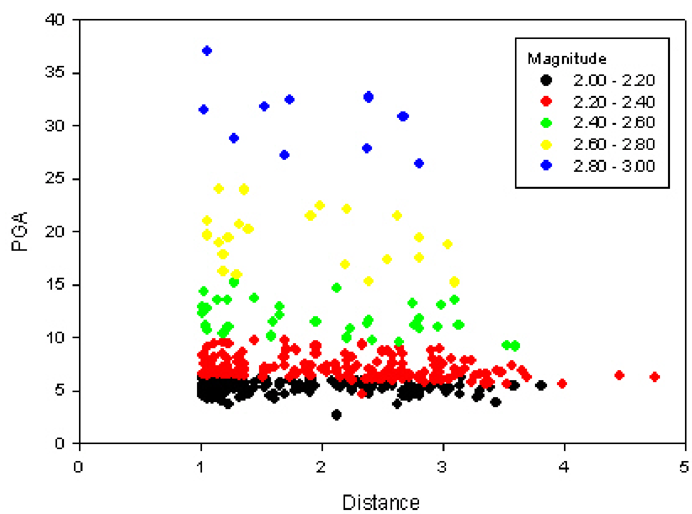

Figure-3.   PGA versus Distance for data set used for regression.

DEVELOPMENT OF ATTENUATION RELATIONSHIP

To work out the attenuation relation, as a first step, a linear regression analysis was carried out considering a simple relation. The attenuation of PGA with the distance was regressed to obtain the decay factor as given in the following equation.

$$\log(A) = -b \log(X) + c \quad (1)$$

Where, A is acceleration, X is the hypocentral distance, and b and c are the regression coefficient. Strong ground motion are usually recorded on three orthogonal components. In this study, we are dealing with horizontal components. One must decide how the horizontal components are to be treated. Various ways of treating horizontal component is, largest of the two components or both components or the mean of both components or vectoral combination of both components or Random selection of components

Method of combining components should be taken into consideration to ensure consistency. However recent studies reveal to use geometric mean of two horizontal components. In this study Geometric mean of two components (Horizontal components) is calculated and used for the regression.

The events were classified according to the magnitude ranges as $2.00 < M < 2.20$, $2.20 < M < 2.40$, $2.40 < M < 2.60$, $2.60 < M < 2.80$, and $2.80 < M < 3.00$. The individual decay factor, i.e., b is given in the Table 1. The average value of the decay parameter that is, b, is came out to be 0.103

Table 1. b and c values computed using equation (1)

Magnitude Range	b	c
$2.00 < M < 2.20$	0.0360	0.724
$2.20 < M < 2.40$	0.1220	0.885
$2.40 < M < 2.60$	0.1280	1.100
$2.60 < M < 2.80$	0.0954	1.310
$2.80 < M < 3.00$	0.1350	1.520

Next, a general multiple regression analysis was performed for the whole data set by assuming the basic regression model as

$$log\ (A) = aM - b\ log\ (X) + c \qquad (2)$$

Where M is the magnitude and a, b and c are the regression coefficients. Using above equation, the value of the decay parameter while considering the whole data set came out to be 0.1135 (0.0054), (The figure in the parentheses is the standard error of coefficient) which is much closer to the average value of each earthquake, that is 0.1030

The regression model thus selected for the attenuation relation is considered as follows:

$$log\ (A) = c_1 + c_2M - c_4\ blog\ (X + e^{c3M}) \qquad (4)$$

Where c_1, c_2, and c_3 are the regression coefficients and b is the decay parameter. The decay parameter when fixed as per the regression using equation (2) the coefficient namely c_1, c_2, c_3, c_4 and decay parameter b is coming out to be as shown in table below.

Coefficients	Value	Standard Error
c_1	-1.25430	0.0545000
c_2	0.93770	0.0162000
c_3	-3.1000	31.766500
c_4	34.9123	2040.3784
b	0.11350	0.0269000

From the regression it is found that, coefficient namely c_4 is having relatively larger error, so the regression is again carried out by removing coefficient c_4 and also decay parameter b is unconstrained. The results obtained are given in table given below.

Coefficients	Value	Standard Error
c_1	-1.3489	0.0280
c_2	1.0095	0.3820
c_3	0.1272	0.0689
b	0.1956	0.0183

Finally the equation obtained is as follows:

$$\mathbf{log(a) = -1.3489 + 1.0095M - 0.1956log\ (X+e^{0.1272M})}$$

Where a is in cm/sec^2. Standard deviation is computed as 0.20.

The comparison with the observed data for various magnitude ranges is shown in fig. 4 to 8 for magnitude 2.1, 2.3, 2.5, 2.7 and 2.9.

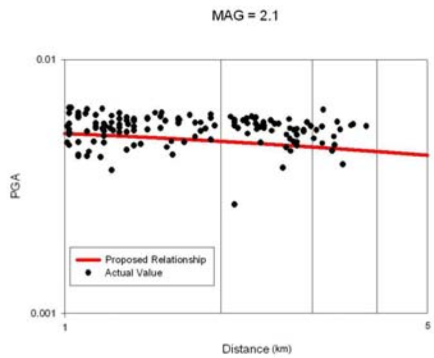

Fig 4. Plot showing the PGA versus Distance for dataset with magnitude 2.1

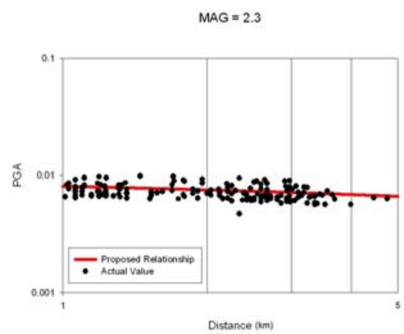

Figure-5. Plot showing the PGA versus Distance for dataset with magnitude 2.3

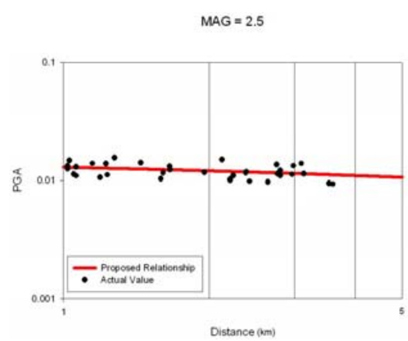

Figure-6. Plot showing the PGA versus Distance for dataset with magnitude 2.5

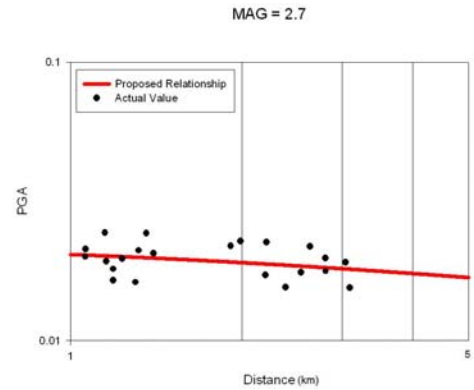

Figure-7. Plot showing the PGA versus Distance for dataset with magnitude 2.7

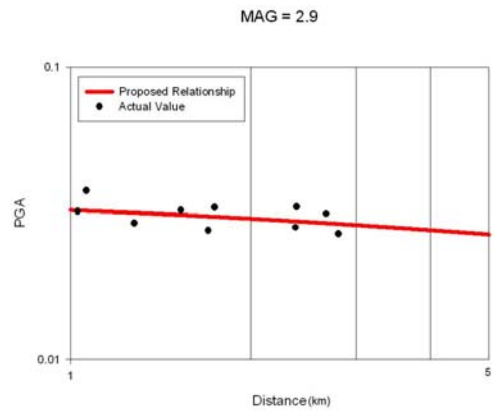

Figure-8. Plot showing the PGA versus Distance for dataset with magnitude 2.9

CONCLUSION

Rockbursts are minor earthquakes which are induced due to mining operations. These events have been used to look into the attenuation behaviour of strong ground motion. Attenuation relationships for peak horizontal ground acceleration for short distances and low magnitudes have been developed for Kolar Gold Fields mines region in South India. The distance range upto 5 km and the magnitudes ranging between 0 and 3 have been used for the development of the attenuation relationship. Two steps multiple regressions have been made by analyzing the decay of individual magnitude classes with distance using it with the whole data set. The recommended attenuation relationship has been shown to be representing the attenuation with distance. Since no such attenuation relationship have been found to exist the comparison could not be made. The general comparison with the higher magnitude and larger distance attenuation relationships shows lesser strong ground motion at shorter distance which could be attributed to the low strain levels at which the earthquakes are generated.

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REFERENCES

1. Atkinson, G. M. and Boore, D. M. (1995). Ground-motion relations for eastern North America. Bulletin of the Seismological Society of America, 85(1), 17-30.
2. Boore, D. M. (1983). Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra. Bull. Seism. Soc. Am., 73,1865-1894.
3. Boore, D. M. (2003). Simulation of ground motion using the stochastic method, Pure and Applied Geophysics, 160, 635-675.
4. Chandra, U. (1977). Earthquakes of Peninsular India-A Seismotectonic Study. Bulletin of the Seismological Society of America, 67(5), 1387-1413.
5. Guha, S. K., and Basu, P. C. (1993). Catalogue of earthquakes ($M \geq 3.0$) in Peninsular India, 1993, Atomic Energy Regulatory Board, Tech. Document No. TD/CSE-1, 1-70.
6. Hwang H. and Huo, J. -R. (1997). Attenuation relations of ground motion for rock and soil sites in eastern United States. Soil Dynamics and Earthquake Engineering, 16, 363-372.
7. Rao, B. R., and Rao, P. S. (1984). Historical Seismicity of Peninsular India. Bulletin of the Seismological Society of America, 74(6), 2519-2533.
8. Seeber, L., Armbruster, J. G. and Jacob, K. H. (1999). Probabilistic Assessment of Seismic Hazard for Maharashtra, Govt. of Maharashtra, Unpublished Report .
9. Singh, S. K., Ordaz, M., Dattatrayam, R. S. and Gupta, H. K. (1999). A Spectral Analysis of the 21 May 1997 , Jabalpur, India, Earthquake ($M_w = 5.8$) and estimation of Ground Motion from Future Earthquakes in the Indian Shield Region. Bulletin of the Seismological Society of America, 89(6), 1620-1630.
10. Toro, G.R., N.A. Abrahamson, and J.F. Schneider (1997) Model of Strong Ground Motions from Earthquakes in Central and Eastern North America: Best Estimates and Uncertainties. Seismol. Res. Lett., Vol. 68 No. 1, 41-57