International Conference on Case Histories in Geotechnical Engineering

(1984) - First International Conference on Case Histories in Geotechnical Engineering

09 May 1984, 9:00 am - 12:00 pm

Assessment of Earthquake Size from Rock Fracture Dimensions of Seismic Source in Geotechnical Earthquake Engineering Investigations

L. S. Srivastava

University of Roorkee, Roorkee, India

Assessment of Earthquake Size from Rock Fracture Dimensions of Seismic Source in Geotechnical Earthquake Engineering Investigations

L. S. Srivastava

Professor, Department of Earthquake Engineering, University of Roorkee, Roorkee, India

SYNOPSIS   The paper presents two case histories of rock fractures resulting in strong ground motion. Case I describes the November 27, 1971 rockburst involving 270 m long rupture with displacement of 15 mm in Nundydroog mine in Kolar Gold Field in Karnataka State, India, which resulted in damage to buildings on the surface and underground works in the mine. The event was recorded as an earthquake by seismic stations and the computed magnitude $m_l = 3.9$ of the rockburst compares well with magnitude $m_b = 4.6$ determined from the recorded seismogram. Case II describes April 5, 1976 rockburst in an open cast granite quarry at Shravanbelagola, in Hassan district in Karnataka State, resulting in 60 m long fracture with estimated average displacement of 0.5 mm. The rockburst accompanied with loud noise produced strong ground motion in the area. The magnitude of the rockburst is estimated as $m_l = 2$. The estimated intensity of ground motion in the area match well with the ground motion at the epicentre of an earthquake of similar magnitude. The two studies provide guidelines for assessment of earthquake size and indicates the importance of detection and delineation of tectonic lineaments and determination of ambient seismic activity along lineaments which are capable or have potential for earthquake occurrence.

INTRODUCTION

Identification and demarcation of the seismic source in the immediate environs of a project site governs the choice of design earthquake parameters as part of geotechnical earthquake engineering investigations.

Evaluation of magnitude of design earthquake to estimate the intensity of ground motion at a particular project site is made based on various correlations relating magnitude with the seismic source dimensions. The length of rupture and slip (displacement) along the fault have been correlated with magnitude by Bonilla (1970) and other workers, which shows that earthquake magnitude increases with length of faulting. The length of the seismic source (fault) along which movement could occur (active zone) controls the magnitude of the earthquake and consequently the intensity of strong ground motion which might occur. The active zone being under tectonic stress would be the source of microearthquakes in the area. Composite fault plane solutions from the recorded microearthquakes, in relation to known tectonic features, give the probable directions of the active lineaments.

The true length (and width) and displacement of the slipped fault at the focus can not be determined precisely. The length of the seismic source (fault) is estimated from the displacements of the fault observed on the surface. The long axis of the foreshock-aftershock region or area of microearthquake (ambient) activity could also be taken to indicate the length of the seismic source.

Rockbursts in underground and open cast mines occur when the stress in the rock exceed its

strength and the accumulated strain energy is unable to dissipate by some form of plastic deformations. The phenomenon is similar to earthquakes. However the generated strong ground motion is of shorter duration. The length of rupture surface and displacement observed in a rockburst thus provide direct correlation between the magnitude of the event and resulting strong ground motion with the dimensions of the source.

NOVEMBER 27, 1971 ROCKBURST AT NUNDYDROOG MINE AT KOLAR GOLD FIELDS

Kolar Gold Field is situated in the centre of 80 km long narrow Pre-Cambrian Dharwar schist belt in Kolar District, Karnataka State. Gold occurs in quartz veins in amphibolites. Two major auriferous veins striking N-S are being worked and their dip is almost vertical to steep angle of about 80°. The folliation of the country rock in general is parallel to the veins.

A major rockburst occurred in Nundydroog mine of Kolar Gold Field in the early hours of November 27, 1971, which resulted in considerable damage in the underground mine, and many houses on the surface were badly shaken producing cracks and fissures in the walls and along openings. The ground motion was reported to have been felt upto distances of 70 to 100 kms from the mine and the event was recorded at various seismological observatories in southern parts of India. The main rockburst tremor recorded at Hyderabad (Andhra Pradesh) was reported to have magnitude $m_b = 4.5$.

Damage to buildings had been reported in Kolar Gold Field during rockbursts in the past, which

535

Fig.1 - Cracks in buildings during the rockburst

consisted of fall of plaster, cracks in masonry walls and arches, and collapse of portions of random rubble stone masonry walls. During the November 27, 1971 rockburst damage to buildings was of similar nature (Fig.1), but it extended over a large area of the Estate of Bharat Gold Mines Private Limited (BGML) and Factory and Township of Bharat Earth Movers Limited (BEML).

Fig.2- Link Boring Machine, 20 tons in weight, which was moved 1 cm towards south. Shaded area shown in the photograph on the right was exposed after resetting of the steel pad

In addition to damage to buildings, overtoppling and sliding of loose objects was reported. Several heavy machines resting on circular steel pads in BEML were laterally moved to the extent of 5 to 10 mm (Fig.2). In several machines which were grouted, the bolts got loosened. The friction between the steel pads and the concrete was determined by test at

site, and the coefficient of friction was noted to be 0.5. This indicates that the peak ground acceleration during the tremor exceeded 0.5 g. But as the duration of strong shaking was not large the structures in BGML and BEML escaped major damage and collapse.

Considerable damage occurred underground in Nundydroog mine between 3400 and 6200 (feet below ground) level, with fall of loose rocks, debris and rock walls; shaking of back and front walls; lifting of haulage tracks; buckling of steel sets; collapse and closure at different points; and other underground damage. Greater damage was noted in an area between two dykes which traversed the reef. There was more crushing of the country rock at the contact of the porphyritic dolerite dyke in the north and the dolerite dyke about 240 m towards south, and the dyke rock itself was fractured and developed cracks from 3600 to 4500 level. The length of the damage zone along the levels was about 300 m, and in the cross cuts the damage was confined to the region within the porphyritic dolerite dyke towards its south. The rock fracture from 3600 to 4500 level thus appeared to be related with the rupture zone during the rockburst, and the damage at other levels was result of dynamic force resulting from the stress wave propagating from this rupture zone.

Slickenside striations were noted to have developed on fracture surfaces at 4000 level, which indicated a relative movement of the hanging wall towards north with respect to foot wall. No reliable estimate of the net slip of rock fracture could be observed. However displacements varying from few millimeter to 15 mm were noted along the fractures. The failure surface along which the rock mass ruptured during the rockburst thus extended from 3600 to 4500 level with the rupture length of about 270 m (900 ft). The magnitude of the rockburst evaluated from the following relation (Bonilla, 1970).

$$m_1 = 1.4 + \frac{\log L \ D^2}{1.9}$$

(where m_1 is Richter magnitude, and L and D are the length of the rupture surface and displacement along the rupture surface in cm respectively) is noted to be about 3.9 (L = 270 m D = 1.5 cm). This compare well with the magnitude m_b = 4.5 (Hyderabad) determined for this event from seismograph record.

APRIL 5, 1976 ROCKBURST IN GRANITE QUARRY AT SHARAVANBELAGOLA

Rockburst occurred on 5th, 6th and 16th April 1976 in the granite quarry south of Indrabett Hill (Fig 3) at Sharavanbelagola resulting in strong ground motion accompanied with loud sounds in the area. Some cracks in the groun were reported to have been noticed on the sou side of Indrabetta Hill. This side of the hi being covered with large size boulders, such cracks may have resulted due to shaking and readjustment of boulders.

The country rock around Indrabetta Hill consi of light grey biotite granite, which at place
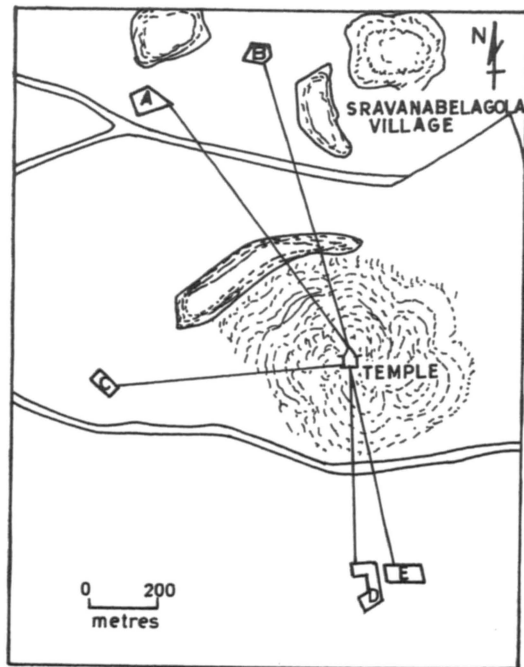
536

Fig.3 - Location of Granite Quarries
Leased around Svarnabelagola

is feebly foliated. The granites are transversed by few basic dykes and pegmatite veins. Figure 3 shows the location of granite quarries in the area. The general trend of major joint set in the granites is along N 70°E - S 70°W and dips 55° towards north west. Two sets of minor joints trend along N20°E - S20°W with vertical dip and along N-S with 75° dip towards west. The rock fracture associated with rockburst follow the trend of major joint set along N70°E-S70°W (Fig 4). The set of joints exposed during excavations in the quarries were noted to extend upto one or two metres, and mostly fresh sheet granites in exposed in the quarries.

Fig.4 - Major Joint Rock Fracture
along N70°E-S70°W direction

The 17.1 m (57 ft) high monolithic statue of Lord Gomateshvara carved out in light grey biolite granite is situated at the top of Indrabetta Hill at a distance of 730 m north of the rockburst location in the quarry. The largest rock fracture associated with the main rockburst on 5th April 1976 was 60 m (200 ft) in length with average displacement of 0.5 m (fracture opening). Gradual residual stress release due to quarry operations and consequent rock pressure developed along major joint lineament resulted in the rockburst. The stress wave generated by the rockburst impinging on the surface resulted in sheeting of rock along horizontal planes and consequential tilting and dislocation with openings from 25 mm to 50 mm. Taking into consideration the surface length of the fracture as 60 m and average displacement as 0.5 mm the magnitude of the rockburst is estimated as $m_1 = 2$. The estimates of effective peak ground particle acceleration due to such an event at an approximate distance of 730 m at the top of Indrabetta Hill, based on intensity of ground motion felt and reported in the region, vary from 0.02 g (strongly felt) to 0.2 g (sliding of objects on smooth surfaces - coefficient of friction 0.2). Development of hair cracks in the hardened lime plaster and mortar joints of stone masonry in the walls and parapet around the central sanctum of the temple reported to have been developed at few places indicated that ground particle velocity was greater than 50 mm/sec. However as the strong ground motion was of short duration with very short period vibrations, the tall statue of Lord Gomateshwara could not be excited and did not suffer any damage. Estimates of intensity of ground motion agree with the expected intensity at the epicentre.

GROUND MOTION

It is generally considered that the intensity of ground motion increases in proportion to the magnitude. In fact a large earthquake may produce complex ground ruptures and is made up of a succession of smaller event in space and time. Each of the individual rupture has Richter magnitude, m_1, which has an upper bound of 7.2 for earthquakes resulting from strike slip ruptures (Lomnitz, 1981), i.e., the near field effect of major earthquake is bounded. However in the far field the surface wave magnitude reflects the size of the total rupture, thus giving rise to surface wave magnitudes m_s in excess of 7.2. Thus, there is an upper bound of the intensity of ground motion expressing the effective peak ground acceleration in the epicentral region. However the duration of strong motion increases with increase in magnitude. Based on non-linear least-squares regressions of strong motion data, Bolt (1982) has shown "flattening of attenuation near to the source (<10 km) in the range $5.0 < M < 7.0$" with "no indication (from the small amount of data available) of any additional increase in acceleration for $m > 7$ earthquakes". The relatively large intensity of ground motion observed in above two cases indicate that high intensity of ground motion near the source would occur at the epicentre of events with magnitude less than 5. However the strong ground motion is of short duration in such events.

537

GEOSEISMOLOGICAL INVESTIGATIONS

The two case histories show that estimates of magnitude of earthquake in the area around a project site can be obtained from the dimensions of the seismic source. The schedule of geoseismological investigations for obtaining the probable dimensions of the seismic source (Srivastava, 1970) may be followed as below:

1. Regional geological mapping of the area and demarcation of fault zones (regional as well as local) and other tectonic lineaments, with special reference to Neotectonic movements and data on movements and offsets during past earthquakes.

2. Collection of data on earthquake occurrence in the area around the project site. If other regions with similar geotectonic set up and/or tectonic evolution show seismic activity and recent movements and offsets have been observed, the same level of seismic activity could occur in the area around the project site. If data on earthquake occurrence are not available, a network of seismic stations should be established to record the seismic activity in the area.

3. Establishment of an array of seismic stations around the project site to record micro-earthquakes in the area and evaluate association of epicentres and comparison of composite fault plane solutions with known faults and tectonic lineaments. If the long axis of the cluster of epicentres of microearthquake or the composite fault plane solution follow the known faults, such faults are most susceptible to movements in future. The trend of hidden faults or other active lineaments could also be indicated from this data.

4. Evaluation of magnitude of earthquake based on the length of the active (fault) zone (observed on the surface from recent breaks on the ground or length of long axis of micro-earthquake area) and depth of focii observed in the area to evaluate the dimensions of the seismic source.

REFERENCES

Bolt, B.A., (1982). Seismological Motion Parameters (Abstract), Intern. Symp. on Continental Seismicity and Earthquake Prediction, Sept. 8-9, 1982, Beijing.

Bonilla, H.G., (1970). Surface Faulting and Related Effects, Earthquake Engineering (Wiegel, R.L., Coordinating Editor), Prentice Hall Inc., Englewood Ciffs. N.J., U.S.A., Ch. 3, 47-74.

Lomnitz, R.K., (1981). Environmental Siting of Nuclear Power Plants., Bull. of Intern. Assoc. of Engg. Geol., No. 23, 33-36.

Srivastava, L.S., (1970). Seismotectonic Investigations for Engineering Projects, 4th Symp. Earth. Engg., University of Roorkee, Roorkee, India, 440-443.