International Journal of Rock Mechanics & Mining Sciences 80 (2015) 79–88

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Blast vibration effects in an underground mine caused by open-pit mining

P.K. Singh [a,*], M.P. Roy [a], Ranjit K. Paswan [a], R.K. Dubey [b], C. Drebenstedt [c]

[a] Central Institute of Mining & Fuel Research, Barwa Road, Dhanbad, India
[b] Indian School of Mines, Dhanbad, India
[c] Technische Universitaet Bergakademie, Freiberg, Germany

ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form
3 September 2015
Accepted 11 September 2015
Available online 26 September 2015

Keywords:
Open-pit blasting
Underground stability
Blast design
Blast vibration
Underground protection

ABSTRACT

The Rampura Agucha open-pit lead zinc mine is producing 5.7 Mt/a of ore and has started its underground part, which is slated to produce initially 2–2.4 Mt/a and 4.5 Mt/a in the near future. The open-pit mine is currently working at 326 m depth and is designed to reach 421 m deep. It has been planned to operate the underground mine maintaining 50 m parting from the planned ultimate level of the open-pit mine. Presently, open-pit and underground mines are being operated simultaneously. The present average depth of underground working lies between 370 and 410 m below the surface level. Sometimes explosives up to 95,978 kg are being detonated in a blast round in open-pit mine for speedy removal of overburden. The impact of 86 open-pit blasts has been documented in the underground openings and 258 blast vibration data has been recorded. The vibrations were recorded simultaneously in the roof, sidewalls and at floor levels. The highest levels of vibrations were recorded in the roof and the lowest levels at the corresponding floor levels. The pillars experienced lower level of vibrations than those of the roof. Blast designs were optimised at open-pit mine to control vibration in view of long-term safety and stability of the underground openings. The underground development face blasts were also optimised for the safety and stability of underground workings. Vibrations generated due to detonation of explosives with shock tubes and electronic delay detonators have been recorded in underground openings for comparative assessment. Ground vibration recorded at roof, pillar and floor were analysed separately and threshold value of the vibration for the safety of underground workings has been determined based on the Rock Mass Rating of the roof rock and accordingly blast designs have been optimised.

1. Introduction

It is known fact that the safety and stability of underground mine openings, sidewalls/pillars, water dams, etc. in close proximity to operating open-pit mines are often endangered from blast induced vibrations. Mine operators attempt to get better fragmentation of rock even if a blast requires high consumption of explosives per tonne of the mineral produced, as improved fragmentation reduces the cost of loading, conveying and crushing of minerals. These blasts generate seismic disturbances, which in turn may damage the support system and may potentially affect the stability of roof and sidewalls/pillars of galleries in underground mines. It may induce opening of cracks in the strata rendering them unstable. Also, there is a possibility of spalling in adjoining workings. The seismic disturbances induced by blasting will depend on the total explosive energy released during blasting and the nearness of the underground workings to operating open-pit mine. There are several examples of underground mines which operate in close proximity to an operating open-pit mine. In such operations, the blast induced ground vibrations generated due to open-pit blasting may be a potential cause for the instability of adjoining underground mine workings and can be hazardous. Such situation exists at Rampura Agucha mine where open-pit and underground mines are being operated with a parting of 60 m and it is planned to have an ultimate parting of only 50 m. The blasts are being conducted on different benches of hanging wall, foot wall and ore benches of open-pit mine.

Explosive weight per delay, travel distance (depth) and transmitting media properties (elastic modulus and density) have significant impact on vibration characteristics generated at the underground structures due to nearby surface blasting.[1] Rupert and Clark[2] reported minor damage in the form of localized thin spalls and collapse of previously fractured coal ribs resulted from blast having an associated PPV in excess of 50 mm/s. No other major damage or changes in the mine condition (roof bolts and

* Corresponding author. Fax: +91 326 2296025
E-mail addresses: pradeep1_2@yahoo.com, pradeep.cimfr@gmail.com (P.K. Singh).

http://dx.doi.org/10.1016/j.ijrmms.2015.09.009
1365-1609/

convergence) were noted. Jensen et al.[3] reported no roof failures even at roof vibrations of 445 mm/s, and only a few loose stones at 127 mm/s. Lewandowski et al.[4] concluded that the theoretical maximum vibration limit for underground coal roadways is approximately 250 mm/s. He also addressed the question concerning the effects of the repetitive action of blasting and its impact on the rock strata behaviour and observed that the repetitive blasting does not have any significant impact on the roof stability of the adjacent underground colliery. Kidybinski[5] reported that damage to underground coal mine openings in the form of small roof falls or floor heave may occur when the PPV lies in the range of 50–100 mm/s, and large roof falls at 100–200 mm/s. The allowable limits of vibration for various types of surface and underground structures have been reported by various researchers.[1,6,7] In the case of primary mine openings (service life up to ten years), pit bottom, main cross entries and drifts, the allowable values reported were 120 mm/s for one-time blasting and 60 mm/s for repeated blasting. For secondary mine openings (service life up to three years), haulage break-through and drifts, the allowable values suggested were 240 mm/s for repeated blasting and 480 mm/s for one-time blasting. Stacey et al.[8] reported no collapse in water filled workings at 670 mm/s. Fourie and Green[9] came to the conclusion that allowable PPV (typically 50 mm/s) to avert damage to surface structures is much lower than that at which damage begins to become a concern in underground mines. They reported that PPV of as much as 110 mm/s produced only minor damage and serious extensive damage resulted when PPV reached 390 mm/s. Rossmanith[10] documented the mechanics of spalling in rock due to input wave produced by explosive action or high-velocity impact and the material behaviour. Masui and Sen[11] observed no damage in underground coal mine workings at 58 mm/s.

Singh et al.[12] found that peak particle velocity of 48 mm/s did not cause any damage to the underground workings. Andieux et al.[13] studied over-break and crack extensions from blasting which have the potential to influence long term stability of excavations. They found that most distant effect on the extension of existing cracks extended to 4.5 m at the most. The peak particle velocity at this distance ranged between 300 and 398 mm/s. On the other hand, with poor quality rock (RMR=49), which had been loosened by previous open-pit blast vibrations, minor visible damage at peak particle velocity of 46 mm/s and major damage at a peak particle velocity of 379 mm/s were observed. Singh et al.[14] have observed development of cracks in the coal roof at peak particle velocity of 297 mm/s but spalling of coal chips from pillars and roof started at a level of 125 mm/s. Tunstall [15] suggested that peak particle velocity of 175 mm/s did not cause any damage to underground opening when very good quality rock (RMR=85) was encountered. Lewandowski et al.[16] set a conservative criterion of targeted maximum PPV of 50 mm/s for the safety of coal underground heading. They further stated that this conservative value of PPV was decided after investigations indicated a possible limit of 250 mm/s. Singh[1] conducted an extensive study in six coal mines in India and established the threshold value of vibration (PPV) for different RMR of roof rocks in underground workings for safe and efficient exploitation of coal from opencast and underground mines simultaneously. Established guidelines are based on results of 202 blasts conducted in open-pit mines and 622 blast vibration signatures were recorded in corresponding underground openings. Singh [1] suggested that PPV of 100 mm/s will not cause damage to the underground coal mine workings having RMR of 50.

The formation of excavation damaged zone around tunnel under geo-stress environment involves a coupled damage evolution process, whose main mechanism is growth of cracks owing to unloading and stress redistribution apart from blasting. [17] Loading stiffness and stress distribution in the surrounding rock mass, resulting in both stable and unstable shear failures along discontinuities as the excavation proceeds, influence the stability of underground workings apart from ground vibrations generated due to blasting.[18]

2. Description of the experimental site

Rampura Agucha mine is located at 225 km north-northeast of Udaipur, Rajasthan and is the largest and richest Lead Zinc deposit in India containing ore reserves of 107.33 Mt with grade of 13.9% zinc and 2% lead. The Rampura Agucha mixed sulphide deposit is a massive lens shaped ore body with a NE–SW strike length of 1500 m and a width varying from a few metres in the NE direction widening to as much as 120 m in the central to SW section. At present Rampura Agucha open-pit mine is producing 5.7 Mt/a of ore and with present system of the mining method (open-pit) the mine will be operative up to depth of 421 m below the surface. The present depth of open pit mine is 326 m.

Rampura Agucha is a stratiform, sediment-hosted Lead Zinc deposit, occurs in Pre-Cambrian Banded Gneissic complex and forms a part of Mangalwar complex of Bhilwara geological cycle (3.2–2.5 billion years) of Archean age and comprising of magmatites, gneisses, graphite mica schist, pegmatite and impure marble. The rocks have been subjected to polyphase deformations and high-grade metamorphism. The geological evolution of south-eastern Rajasthan occurred during three major orogenic cycles represented by the terrains named Banded Gneissic Complex (BGC), Aravalli Supergroup and Delhi Supergroup.[19]

The conceptual underground study has been carried out and deposit has potential to carry out concurrent mining in open-pit as well as in underground. It has been planned to approach to the deposit below ultimate pit by a decline and a shaft from surface. Decline development (1 in 7 ramp gradients) of size 5.3 m(H) × 5.6 m(W), i.e. 29.68 m^2 cross section areas has been taken. The access to underground mine workings from surface is though a single decline that branches into north and south decline for providing access to lower levels below 60 m high crown pillar from −5 to −65 m RL extending to full strike length of the ore body. To access the ore, footwall drive and crosscuts are developed by drill and blast method at each of the drill (+13 m RL) and extraction level (−5 m RL). Longhole production drilling (76–89 mm down holes) is carried out from +13 m RL to −5 m RL. Ore extraction is done at −5 m RL. The slot raise is being developed by drop raising method by drilling holes and then the slot raise is widened up to the full width of the stope. Against the free face, so developed by the slot, the ring blasting is being carried out in retreating pattern. All drives, crosscuts and junctions are being systematically supported using rock bolts, cable bolts, wire mesh, shotcreting etc. The mined out stopes are being filled with cemented rock fill (CRF). The mechanical properties of rocks are given in Table 1.

Table1
Mechanical properties of rocks at Rampura Agucha mine.

Rock type	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio	Tensile strength (MPa)	BRMR
AMP	74	18.6	0.13	8.7	62
GBG	59	14.8	0.10	7.6	60
GBSG	44	12.3	0.17	6.8	50
ORE	68	23.2	0.07	7.9	62
PEG	76	13.2	0.05	6.5	72

*AMP – Amphibolite; GBG – Garnet biotite gneiss; GBSG – Garnet biotitesilimanite gneiss; PEG – Pegmatite.