Human response to blast-induced vibration and air-overpressure: an Indian scenario

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Abstract Ground vibration (V_{max}) and air-overpressure/noise (p) are some of the negative effects of blasting. The associated human annoyance and complaints are expected to show an increasing trend in the future as there is no economically viable alternative to blasting in mines in India.
A study of the human response to blasting in four mining localities across India has shown that the response is not simply political, as frequently assumed. It has been found that irrespective of those questioned, a basic concern for the safety of property was the main response. There was a greater response from the middle-aged and middle-educated while fewer women than men responded. Assuming that a 100% negative response from the inhabitants will translate into complaints, a methodology is suggested to take account of the human response criteria when considering blasting within 400 m of habitations.

Résumé Les vibrations sismiques (V_{max}) et les ondes aériennes de surpression (p) font partie des effets négatifs de l'abattage à l'explosif. A l'avenir on doit s'attendre à l'expression d'un mécontentement croissant des populations dans la mesure où il n'existe guère de méthodes alternatives à l'abattage à l'explosif dans les mines indiennes.
Une étude des réactions humaines aux opérations d'abattage à l'explosif, dans quatre localités minières de l'Inde, a montré que ces réactions ne sont pas simplement politiques comme cela est souvent affirmé. Il a été montré que quelque soient les personnes interrogées, des préoccupations essentielles concernaient la sécurité des biens. Les plus fortes réactions provenaient des classes d'âge intermédiaires et des populations de niveau d'éducation moyen. Considérant que ces réactions négatives se traduiraient par des plaintes des habitants, une méthodologie a été proposée, prenant en compte ces réactions négatives dans un rayon de 400 m autour de la zone de travaux d'abattage à l'explosif.

Keywords Mining · Blasting · Human response · Vibration · Air-overpressure

Mots clés Opérations minières · Abattage à l'explosif · Réactions humaines · Vibrations · Ondes aériennes de surpression

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Introduction

Blasting is a process where rock is broken into fragments with the use of explosive energy. Despite advancements in other earth moving and rock breaking equipment, explosives still remain the cheapest method of rock breaking, although the process has its environmental consequences (see Table 1).
Ground vibration has received maximum attention from researchers while air-overpressure has been considered to a lesser degree. The enormity of the literature and variety of topics discussed therein precludes the annexation of a whole range of literature to this paper. Most of the reference material deliberating on the subject can be traced in Siskind et al. (1976), Bollinger (1980), Siskind et al. (1980), Dowding et al. (1981), Dowding (1985) and the ISEE CDROM database (1998).
The human body differs from structures as, with its own natural frequency (Rathbone, 1963), it can respond to vibration and air-overpressure differently in different postures (Wiss and Paramlee, 1974) while an element of psychological/social environment influences the response. The generation, prediction and control of ground vibrations (V_{max}) and air overpressure (p) are complex to understand in themselves (Fig. 1). Adding the human factor, the process becomes more complicated as a host of considerations must be involved in the process of evaluation or prediction (Fig. 2). In practice it is difficult to

Table 1
Unwanted effects of blasting in mines—explained

Effect	Quantity	Unit	Symbol	Damage potential	Prediction descriptors
Ground vibration	Peak particle velocity	mm/s	V_{max}	Structural and human response/ annoyance.	Scaled distance, maximum charge per delay used
Air-overpressure	Over-pressure	Pa	p	Structural and human response/annoyance	Same as above
Noise	Loudness	$db_{A,B,C}$	–	Annoyance	Level of noise
Flyrock	Throw and size of fragment	m, kg	–	Serious, fatal incidents and damage to equipment thus resulting in human annoyance and reduced confidence of people living in and around the mines	Initial velocity of the fragment
Dust and toxic fumes	Parts present per unit volume of air	ppm	–	Hazardous to health	Measured in terms of suspended particulate matter and noxious fumes

keep so many parameters constant in order to obtain differential responses and establish a relationship. Significant research exists on whole body steady state vibration due to vehicle movement and sonic booms, as summarised in such texts as Postlethwaite(1944) and Griffin (1990). Guidelines exist for steady state whole body vibrations in different standards e.g. ISO, ANSI, DIN.

Blast vibration and air-overpressure are transitory phenomena lasting for a second or so. There is only a limited literature on the response of the human body and communities to blasts (a regular phenomenon in mining). Hendron and Oriard (1972) give an account of the differences in perception of people and their response to impulse vibration with and without noise (Table 2).

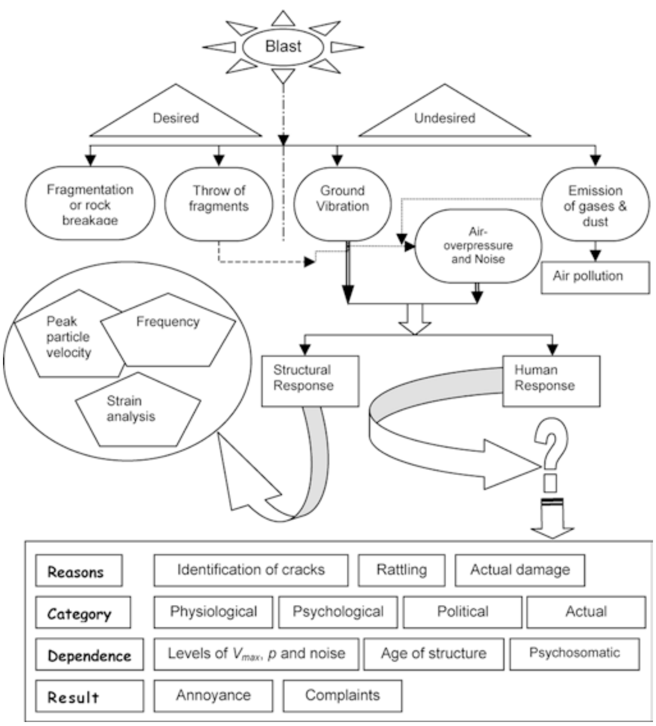

Fig. 1
Conceptual diagram of the association of human response with blasting

It is difficult to gauge human behaviour, particularly when some underlying interests are camouflaging the actual response. Under such circumstances, it is hard to distinguish between real and apparent response. While international standards are in vogue, at least for whole body vibrations, they are not generally a major consideration in India and little literature is available in the public domain; the main texts being Pal Roy (1990), Raina et al. (2002) and Raina et al. (2003). In the absence of corroborated unbiased data the complaints received from inhabitants residing around mines in India are most often arbitrarily attributed to political reasons.

Wiss and Paramelee (1974) demonstrated that the human response to transitory vibrations is related to damping of the motion rather than frequency. Siskind et al. (1980) attempted to correlate the response with human annoyance. Walter and Walter (1979) describe a subjective assessment of human behaviour and ground vibrations. Heggie (1988) compares other vibrations and noise to those produced by blasting. Very little is known about the combined effect of ground vibrations and air-blast (Wilton, 1984) and the human response to low frequency (Blackteman et al. 1983); see Bollinger (1980) for a helpful reference list on this aspect. George et al. (1983), Schomer and Averbuch (1989), Schomer et al. (1994), Schomer et al. (1997), St. George (1998) and Schomer and Sias (1998) conducted detailed investigations on community responses to both military and mine blasting, vibration and air-overpressure.

The present study is an initial attempt to evaluate the response of people residing near mines (metal mines) in India. It is hoped that this study, in conjunction with a detailed study, will allow the formation of guidelines that are helpful to regulatory bodies/mine management in mitigating the human annoyance.

Investigations were conducted in four mines, two manganese and two limestone and response of their respective adjacent villages. These are referred as Mine 1, 2, 3 & 4, respectively. These cover a broad spectrum of the

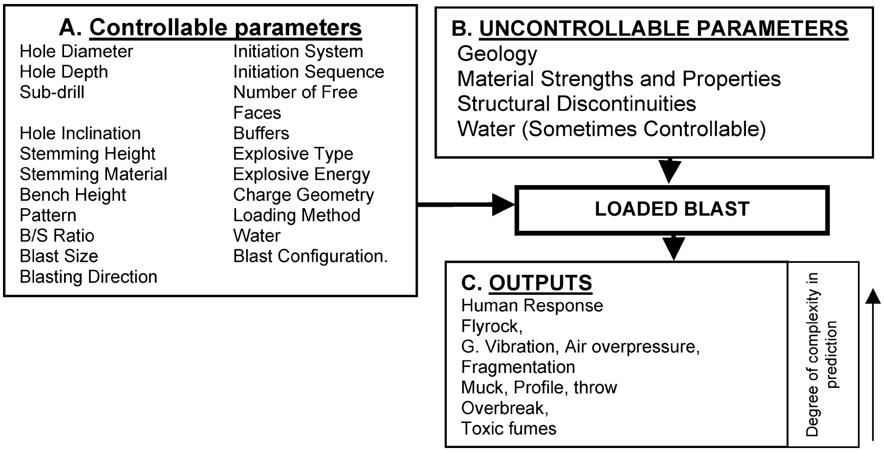

Fig. 2
Complexity in prediction of the response to blasting-related environmental problems

Table 2
Human perception levels for vibrations (after Hendron and Oriard, 1972)

V_{max} (mm/s)	Steady state	Vibration (impulsive, no noise)	Vibration (impulsive, with noise)
<0.5	Not detectable	Not detectable	Noticeable
0.8	Noticeable	Not detectable	Noticeable complaints possible
1.5	Noticeable	Noticeable	Noticeable complaints possible
5.0	Disturbing	Noticeable	Severe complaints likely
10.0	Very disturbing	Disturbing	Severe complaints
>15.0	Severe	Very disturbing	Severe complaints

population, as they are located in different regions of India. General details of the mines investigated are provided in Table 3.

Methodology and results

Seismographs and noise meters were used for assessing ground vibration, air-overpressure and noise. Response data of significant population samples were collected on a random basis using a standard data sheet prepared in consultation with a psychologist and a psychiatrist. Details of the individuals, including his or her mental state, social status, economic status, education, profession as well as the type and age of their houses, were recorded. These data were classified and analysed statistically by the critical path method (CPM), multiple response analysis (MRA) and regression analysis. The results are summarised in Table 4.

Table 3
Brief details of the mines investigated

Sl no	Name of the mine	Ore	Host rock	Adjacent villages
1	Mine-1	Manganese	Schist	4+1
2	Mine-2	Limestone	Limestone/ dolomite	1
3	Mine-3	Limestone	Limestone/ dolomite	5
4	Mine-4	Manganese	Schist	1

Critical path method

The critical path analysis (Sharma, 2000), normally undertaken for market research, was carried out in order to determine trends in the response data generated from villagers residing near the four mines and to establish a cause-effect relationship. The relative influence of the different factors affecting the villages is detailed below for each of the mining localities.

Mine-1 (Manganese)

1. Effect of noise (44.19%)
2. Effect of ground vibration (24.37%)
3. Combined effect of noise and ground vibration (22.85%)

The main reason for annoyance here is noise, as vibration limits are well controlled.

Mine-2 (Manganese)

1. Effect of flyrock (42.84%)
2. Effect of ground vibration (21.42%)
3. Combined effect of noise, ground vibration and flyrock (21.42%)
4. Combined effect of ground vibration and noise (4.76%)

Non-fatal and/or serious incidences involving flyrock due to small diameter blasting had been experienced in this area. This is reflected in the responses obtained, irrespective of the magnitude of the blast.

Mine-3 (Limestone)

1. Combined effect of ground vibration and noise (48%)
2. Effect of noise (38%)

Table 4
Vibration (V_{max}), noise and response data recorded in and around selected mines

Sl no	Location	V_{max} (mm/s)	Noise (dBA)	Total response (%)	Response (to ground vibration, noise, flyrock)	No response (to ground vibration, noise, flyrock)	Total	Average distance from mine (m)
1	A	0.16	48.6	0.22	29	102	131	950.0
2	B	NA	NA	0.33	60	124	184	500.0
3	C	0.08	40	0.75	21	7	28	500.0
4	D	NA	NA	0.24	8	26	34	225.0
5	E	0.12	40	0.65	13	7	20	400.0
6	F	0.81	65.4	0.71	12	5	17	500.0
7	G	1.02	65	0.92	12	1	13	400.0
8	H	0.91	56.5	0.89	8	1	9	450.0
9	I	1.38	82	0.96	51	2	53	300.0
10	J	1.02	60.5	0.95	39	2	41	400.0
11	K	7.96	79.3	0.91	50	5	55	265.0
12	L	1.11	65	0.95	42	2	44	225.0

NA Not available, A to E: Five villages around Mine-1, F to J: Five villages around Mine-4, K: One village near Mine-3, L: One village near Mine-2

3. Effect of ground vibration (14%)

The combined effect of ground vibration and noise is predominant as no other problems exist in this mining area.

Mine-4 (Limestone)

1. Cracks on wall or fear of cracking (71.68%)
2. Combined effect of cracks on wall, noise and flyrock (24.22%)
3. Effect of flyrock (2.46%)
4. Effect of noise (1.64%)

Compensation appeared to be a major consideration for the people but cases reporting the combined effect of V_{max} and p are significant.

Multiple response analysis

Multiple response analysis is performed on data when there are two or more responses to a single question.

1. Adults (aged between 20 and 40) having a large dependent family or owning new property are more apprehensive about blasting hazards.
2. Psychological panic/fear is the prevalent response.
3. The unemployed showed little concern about the hazards and preferred to keep silent. The low-income group had different opinions; some were not concerned about the possibility of losing their possessions but others were apprehensive of even small things they had acquired through hard labour
4. Females were less responsive than males.

Regression analysis for complaint criterion

The overall response of the sample was taken into consideration for regression analysis; some erroneous data being eliminated. Regression between distance and response was carried out and a relationship deduced (Fig. 3). In order to assess the risk, it was assumed that when the percentage response is 1, there is every possibility of complaint. Based on the model in Fig. 3, a broad criterion for selecting blasting distance with varying levels of confidence was produced (Fig. 4). These results will need validation and further data are required. However, some initial recommendations are discussed below.

Other statistical inferences

1. The response to blasting was multiple in nature as the subjects responded in more than one way to a single event
2. In Indian conditions, fear is a major factor
3. Partial correlation between V_{max} and noise with overall response and controlling for distance of villages from the blast sites revealed that noise is a more important factor than V_{max} in generating human response

Discussion

Effects of blast vibration and air-overpressure on structures and whole body vibration has received much attention by researchers compared with the work undertaken

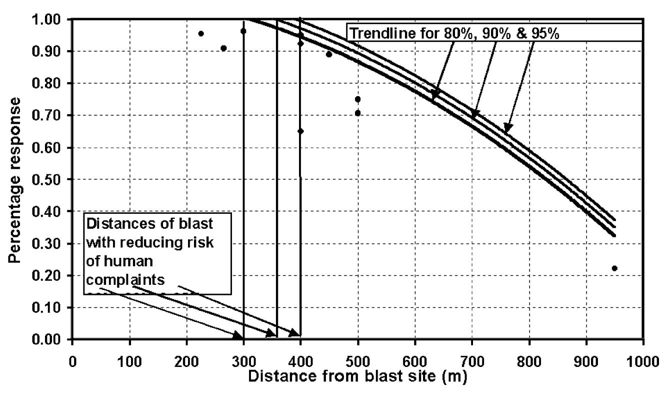

Fig. 3
Model for fixation of distance for deciding the risk of complaint (*trend lines* are for respective confidence intervals)

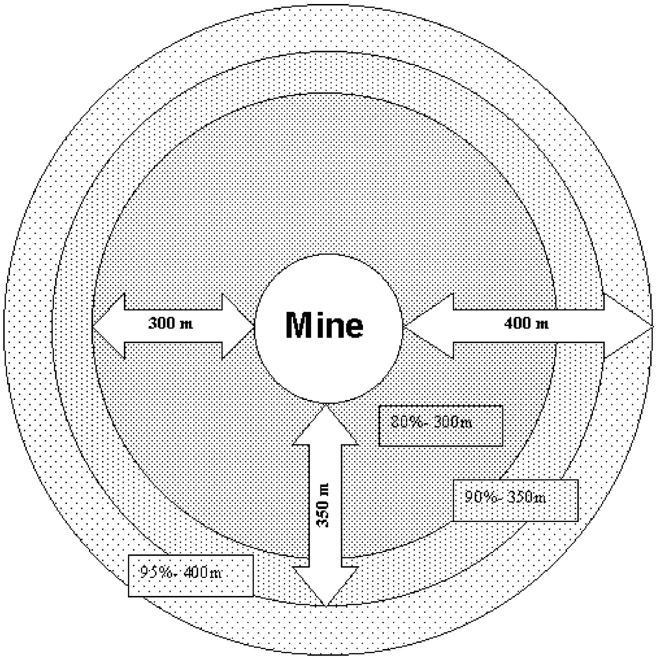

Fig. 4
Human response to blasting—criteria for operation of a mine

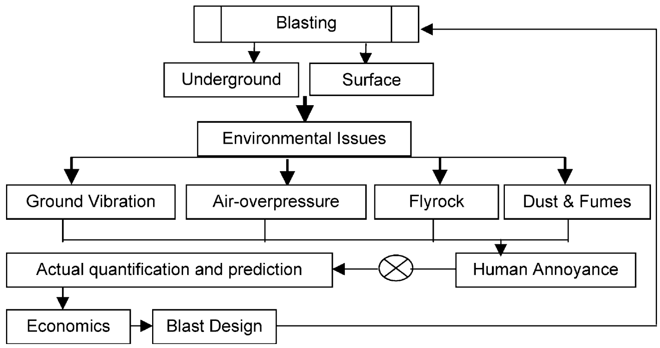

Fig. 5
Flowchart for evolving best blasting design, considering all environmental issues

on the human response to blast vibration and air-overpressure. It is a general practice to compare human response to steady-state harmonic vibration to that of the blast vibration and air-overpressure, although the latter is a transitory phenomenon. The validity of this assumption is questioned, however, as blasting is also associated with noise and air-overpressure.

It is obvious that a human response is subjective but types of responses in different populations and mine conditions can be traced by meticulously analysing the blasting practice. This Indian study confirms the basic fact that a concern for property and belongings is of prime concern to the population residing near mines.

Indian geo-mining conditions are different from those elsewhere in the world. The mindset of the people also varies from place to place and hence the response is likely to be different from that in other countries. This necessitates the formulation of rules and guidelines to assess human response before commencing blasting within a particular distance from the human habitat. Although attempts have been made to quantify the human response in various other countries, to date there have been no attempts in India. In view of this, some basic guidelines are given here and a preliminary risk-based criterion has been formulated as a way of considering the human response to blasting.

Although some individual factors of concern are apparent from the analysis, it is obvious that the combined effect of p and V_{max} is reflected more in the responses than any individual factors. However, this is not entirely the case, due to the fact that multiple responses were possible and the mining conditions could not be varied during the surveys. As stated above, more data is required to arrive at a firm conclusion but the conclusion that noise is more important than vibration in generating human response is consistent with the findings of Kringel (1960).

Based on the CPM, MRA and regression analyses undertaken, the following measures are suggested:

1. At the planning and/or execution stage, the mine developer should consult the middle-aged and moderately educated section of the population in the nearby area of interest.
2. Mitigation measures to reduce fear within the population should be adopted. These may include:
    1. Optimisation of the blasting process to reduce environmental hazards such as noise and flyrock.
    2. Regular dialogue between the mine management and local habitants.
    3. Dissemination of knowledge about the mitigation measures adopted to increase villagers' understanding of blasting and hence reduce annoyance.
    4. Monitoring ground vibrations, air overpressure/noise and flyrock on a regular basis, displaying the results to the inhabitants at some pre-defined locations. This should make the local population aware of the situation and of the honest efforts made by the mine authority to adhere to the safety limits.
    5. Joint participation of the affected habitants of nearby villagers and mine management in monitoring the blasts can be quite helpful.
3. The criteria suggested in Fig. 3 and Fig. 4 may be considered in deciding whether/how to blast in mines near human habitats, depending on the mining conditions. It may be possible to work at a lower confidence level if conditions mentioned in 2 above are strictly followed. The methodology suggested in Fig. 5 may be adopted to evaluate the blast design so as to take account of relevant environmental issues related to blasting and minimise complaints
4. The blasting may be carried out when most of the inhabitants are busy in their day-to-day work. This will draw less attention to the blasting.

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