NxGnMiFu-2017

NexGen Technologies for Mining and Fuel Industries

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Preface

Efficient management and sustainable development are two key elements, which need to be addressed for optimal utilization of natural resources. The challenges for development of mining and fuel sectors include scientific mining, conservation and proper utilization of low grade mineral resources, clean coal initiatives, management of mining waste and above all, the environmental protection. In Indian scenario, coal is the mainstay of the energy mix. Hence, it is equally important to address the issues related to efficient and optimum utilization of coal as well as exploitation of alternative cleaner fuels.

An International Conference on "NexGen Technologies for Mining and Fuel Industries" is, therefore, being organized during February 15–17, 2017 at Vigyan Bhawan, New Delhi by CSIR-Central Institute of Mining and Fuel Research, Dhanbad, India to deliberate on the subject among the stake holders.

The proceedings of the conference, in two volumes, include the contributions from authors across the globe on the latest research in mining and fuel technologies, focussing on:

- *Innovative Mining Technology*, highlighting novel ideas for futuristic developments in mining.
- *Rock Mechanics and Stability Analysis*, covering both laboratory and field evaluation of rock characterisation and stabilisation based on modern mechanics approaches.
- *Advances in Explosives and Blasting*, dealing with the recent developments in the field of explosives and blasting with special emphasis on rock fragmentation.
- *Mine Safety and Risk Management*, stressing upon the global and regional safety evaluation techniques in mining areas and importance of risk assessment.
- *Computer Simulation and Mine Automation*, describing the application of advanced numerical modelling techniques for design optimisation and mechanisation in mining.
- *Natural Resource Management for Sustainable Development*, discussing recovery from low grade ores and wastes with emphasis on better conservation and sustainability.
- *Environmental Impacts and Remediation*, narrating the impact evaluation and mitigating techniques for environmental protection.
- *Paste Fill Technology and Waste Utilisation*, covering utilization of waste for mine filling and reclamation.
- *Fly Ash Management*, dealing with utilisation and value addition of fly ash through various means.
- *Clean Coal Initiatives*, discussing judicious and scientific utilisation of coal vis-a-vis clean coal technologies.

- *Mineral Processing and Coal Beneficiation*, talking about recent developments in processing of coal and minerals for gainful utilisation.
- *Quality Coal for Power Generation*, narrating the role of coal quality for improved coal-fired power generation.
- *Conventional and Non-conventional Fuels and Gases*, including recent developments in the area of alternative fuels.

I, along with my co-editors gratefully acknowledge the help and co-operation we have received from all the members of the International as well as National Steering, Advisory and Organising Committees. The authors have immensely added value to the proceedings, for which we are indebted to them. Our sincere acknowledgements are due to the researchers who have critically peer-reviewed all the submissions, which greatly helped to maintain high standard of the publication. The services of M/s KW Conferences are also thankfully acknowledged.

Lastly, organizing an event of this magnitude, as NxGnMiFu-2017, would not have been possible without the generous financial support by our sponsors, to whom we owe a debt of gratitude.

I wish all our distinguished guests, participants and colleagues, attending this international event, a very fruitful and joyous stay at New Delhi.

February, 2017 Pradeep K Singh
New Delhi

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Tapping of electrical energy from ground vibrations caused due to blasting: An innovation

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ABSTRACT: Generation of electrical energy has become a basic aspect in power system, because of increasing demands from citizenry in electrical distribution system. Power may be generated in different ways. Numerous developments took place in power generation technology for the generation of electricity, but those are all dependent on conventional sources. In the present research, generation of electrical energy using piezo sensors was done by tapping electrical voltage from undesirable ground vibrations generated from blasts in mines.

Blasting operations in mines and quarries always result in ground vibrations, which are of major environmental concern. Studies were carried out in three different limestone mines and two different sandstone formations of coal mines, situated in Southern India, to assess and analyze the seismic energy resulting from the blast induced ground vibrations. In total, 116 blast vibration events in limestone formation and 94 blast vibration events in sandstone formation were studied from various blasts. It was observed that there is a potential for tapping of electrical energy from the ground vibrations generated due to blasts carried out in mines and quarries, using piezo sensors. Piezo generator circuits were developed and used in addition to the seismographs at different distances, from short to long range, in all mining locations, to tap the ground vibrations. Electrical voltage was tapped from the blast induced ground vibrations during studies, which later was used for running low powered VLSI systems as ambient power source. Also, it was noticed that the obtained electrical potential is in direct proportion to the input vibration intensity.

The range of voltage tapped from ground vibrations is up to 4531.42 mV in limestone and 4277.51 mV in sandstone formations. Further, the amount of voltage acquired was used to obtain the intensity of blast vibrations. A very good correlation between seismic energy (obtained from ground vibrations using signal processing analysis) and electrical energy (obtained from piezo generator developed) was observed during the studies. Results also indicated that the working of piezo sensor in tapping ground vibrations is as accurate as conventional ground vibration monitors.

1. INTRODUCTION

When the explosive charge detonates in a blasthole under confinement, the chemical energy of the explosive is converted into heat and works to the surroundings with an enormous pressure according to the first principle of thermodynamics (Johansson and Persson[1]). Explosion of a spherical charge in an infinite rock medium results in three major zones: (1) Explosion cavity, where explosion energy is liberated and the process is hydrodynamic; (2) Transition zone, where plastic flow, crushing and cracking occur; and (3) Seismic zone, where strain waves travel as seismic waves (Atchison *et al*.;[2] Nicholls;[3] Sastry[4]).

Partitioning of explosive energy in a blast depends on the end effects involved. For instance, part of the fracture work is in its first stage intimately connected to the shock wave flow in the locality of the hole and, in later stages, also to the rock movement, which begins as the fractures burst open. All other energy transfer takes place obviously, as follows: (a) expansion work of the fractures, that is absorbed as elastic and plastic deformation of rock in the surface of fractures as they are penetrated by the gases; (b) heat transferred to the rock from hot detonation products; and (c) heat and work conveyed as enthalpy of the gases venting to the atmosphere through open fractures and stemming (Sanchidria´n *et al*.[5]).

Seismographs, high-speed video camera and fragmentation monitoring systems are used to measure the seismic field, initial velocity of the blasted rock face and the fragment size distribution, respectively, from which various energy terms are calculated.

2. PIEZO-GEN TECHNIQUE

Piezoelectricity is a phenomenon of electricity assembled in some solid materials (such as crystalline particles, certain ceramic substances, and biological composition for example—bone, DNA and various proteins) due to applied mechanical stress. Electricity resulting from applied pressure is known as piezoelectricity. The word “piezo” derived from the Greek “piezein”, means to squeeze or press, and “electric” or “electron”, derived from “amber”, which is an ancient source of electric charge. Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie (Anon;[6] Jacques and Curie;[7] Tingley[8]).

Piezoelectricity is the ability of some materials such as crystals and certain ceramics, to generate an electric potential in response to applied mechanical stress or heat (Jacques and Curie;[7] Pramethesth and Ankur[9]). However, piezoelectricity is not caused by a change in charge density on the surface, but by dipole density in the bulk. For example, a 1 cm^3 cube of quartz with 2 kN of applied force can produce a voltage of 12,500 V (Jacques and Curie[10]). Mechanical compression or tension on a poled piezoelectric ceramic element changes the dipole moment, creating a voltage. Compression along the direction of polarization, or tension perpendicular to the direction of polarization, generates voltage of the same polarity as the poling voltage (Figure 1).

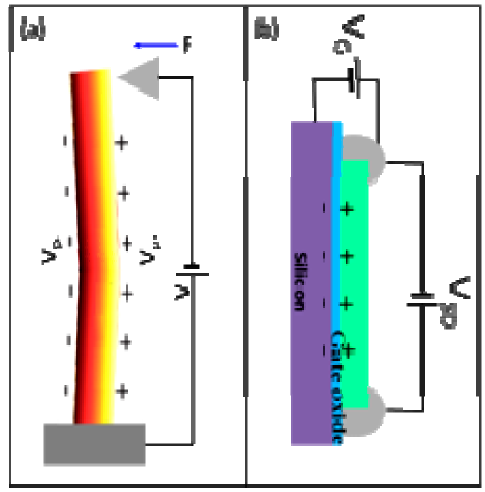


Fig. 1. Working mechanism of simple piezo transducer (Anon[11]).

3. VIBRATION MONITORING AND RECORDING INSTRUMENTS (SEISMOGRAPHS)

Many types of seismographs are available today. Each performs the basic function of measuring ground motion, but supplies much additional information. Most seismographs are equipped with meters that register and hold the maximum value of the vibration components and sound level. Other seismographs are equipped to produce a printout which gives a variety of information such as maximum value for each component, frequency of vibration for the maximum value, maximum displacement, maximum acceleration, vector sum, and sound level. Blast information such as date, blast number, time, location, job designation, and other pertinent information can also be added to the printout (Konya and Walter[12]).

4. SEISMIC ENERGY

Energy transferred into the strata in the form of seismic waves is calculated as an integral of the energy flow past a control surface at a given distance from the blast. Energy flux (power or rate of energy dissipated per unit area) is the scalar product of the stress at the surface and the particle velocity (Achenbach[13]). Calculations of seismic energy and its comparison with explosive energy have been reported by many researchers like Howell and Budenstein,[14] Fogelson *et al*.,[15] Berg and Cook,[16] Nicholls,[17] Atchinson,[18] and more recently by Hinzen.[19] Berta[20] attempted to use some of the energy concepts in his principles of blast design. The seismic energy dissipated by a ground vibration event at a given distance from blast site could be a critical component in assessing performance of blasts.

5. ASSESSMENT OF SEISMIC ENERGY

5.1 *Ground vibrations monitoring*

Intensity of ground vibrations generated due to blasting operations was monitored using three units of Minimate Plus, Instantel, Canada. These ground vibration monitors are of 8-Channeled instruments with six channels recording three mutually orthogonal ground vibration components, namely Transverse, Vertical and Longitudinal at two locations. The fourth and eighth channels record noise level using microphone. Minimates with geophones and microphones connected are placed at different distances covering both short and long range distances, from the blast site. The vibration events were later transferred to a computer using advanced blastware software. Using the full wave forms, the seismic energy was estimated for all the signals in three directions, based on the principle that the area within the curve is 'Seismic Energy Dissipated' using DADiSP Signal Processing software. Care was taken to filter the noise.

DADiSP is a signal processing tool/ software, using which shock energy dissipated in the form of waves is calculated. Longitudinal, Transverse and Vertical components of blast vibration events were imported from blastware software to digital signal processing software DADiSP in ASCII format. Fast Fourier Transformation was performed subsequently to find the frequency component of the time domain of blast wave signal as blast wave recorded by Minimate Plus and processed by Blastware falls in the category of random progressive signal. The estimation of absolute area describes the intrinsic energy of the blast wave signal distributed in various frequency bands. The energy of the signal x(t) is given by $\int_{-\infty}^{\infty} |x(t)|^2 \, dt$ (Sastry[21]).

6. FIELD INVESTIGATIONS AND RESULTS

Blasts were carried out in various mines for the extraction and assessment of seismic energy. Ground vibration monitors were placed near blast field at various distances to find the impact of blast on nearby structures. Geophones were glued to the ground with the help of Plaster of Paris for proper contact. The piezo generator circuits were placed beside the conventional seismographs for maintaining accuracy in the obtained data. In total, 55 blasts were analyzed for the assessment of seismic energy based on electrical energy generation technique, out of which 10 blasts were carried out in Choutapalli limestone mine, 11 blasts were carried out in Yepalamadhavaram limestone mine and 34 blasts were carried out in coal mines of The Singareni Collieries Company Ltd. The following are some photographs depicting obtained electricity from undesirable seismic waves, extracted through piezo-gen circuit in various mine locations (Figure 2).

Seismic data collected at various distances from different blasts were compared with the obtained electrical energy data as shown in Tables 1 and 2.

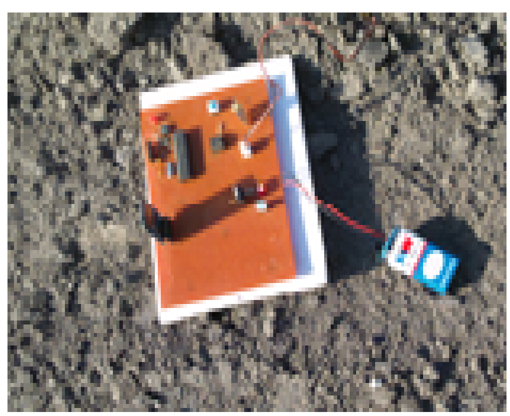


Fig. 2(a). Piezo-Gen circuit.

Fig. 2(b). Extraction of electricity using piezo-gen circuit from undesirable blast vibrations.

Fig. 2(c). Observation of obtained voltage from the blast vibrations undesirable by multimeter for the assessment of seismic energy.

Table 1. Summary of seismic energy extracted as electricity from blasts conducted in limestone mines

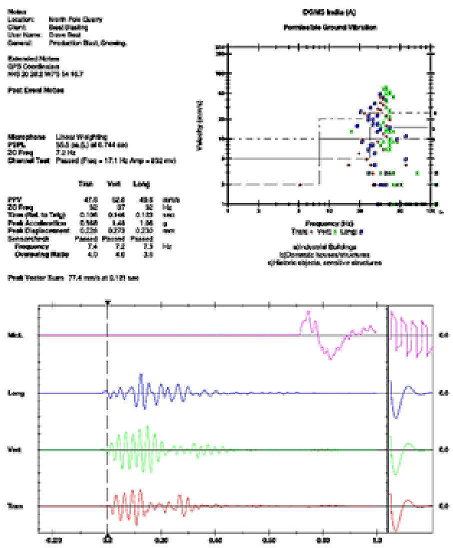
Sl. no.	Distance (m)	MCD (kg)	PPV (mm/s)	Seismic energy from three mutually orthogonal ground vibrations (MJ)	Electrical energy extracted from blast vibrations (MJ)
1	30	38.33	64.4	42256215	4509139.6
2	40	38.33	39.2	18524598	1963630.3
3	45	38.33	37.5	17108152	1709115.6
4	50	38.33	26.3	6729443	299095.23
5	55	38.33	22.5	14013633	1526210.7
6	60	38.33	11.8	6377533	248069.74
7	40	37.5	55.6	26656654	2424915.1
8	50	37.5	35.6	11103330	1041516.2
9	55	37.5	29.3	5419536	234614.75
10	60	37.5	27.3	3903284	103863.11
11	65	37.5	26.4	18419851	1634399
12	65	37.5	22.7	7523677	460683.92
13	50	70.14	61	25837627	2571913.8
14	65	70.14	41.9	13666773	1407946
15	65	70.14	39.4	9824630	833789.96
16	70	70.14	32.5	2895806	64473.335
17	40	36.57	40	6548821	283286.87
18	50	36.57	30.1	4453486	123605.68
19	55	36.57	28.2	3232849	88722.367
20	70	36.57	16.1	712081	16118.334
21	75	36.57	10.4	964048	18693.452
22	80	36.57	3.43	306033	1931.3388
23	40	39.06	32.2	6893020	326396.26
24	50	39.06	28.2	6264554	243229.47

Sl. no.	Distance (m)	MCD (kg)	PPV (mm/s)	Seismic energy from three mutually orthogonal ground vibrations (MJ)	Electrical energy extracted from blast vibrations (MJ)
25	80	39.06	2.41	156568	95.374756
26	134	39.06	11.7	359719	3433.4912
27	40	39.28	171	59727766	7186831.2
28	50	39.28	181	99699604	11691266
29	55	39.28	68.8	27009086	3014047.3
30	75	39.28	10.3	2040307	40081.241
31	80	39.28	38.6	28970681	3120027.8
32	85	39.28	7.75	1901915	36266.251
33	50	51.4	118	21503717	2142627.3
34	60	51.4	126	111259278	13291238
35	65	51.4	91.4	58338415	6943699.5
36	90	51.4	38.1	5758561	262356.88
37	95	51.4	30.9	24691269	3269370.3
38	100	51.4	12.3	3366361	88722.367
39	30	24.58	44.7	23418621	2961119.1
40	38	24.58	42	38133182	4654974.8
41	50	24.58	23.7	9264400	633502.97
42	90	24.58	19.8	3331585	88722.367
43	95	24.58	18.4	4060162	110253.22
44	100	24.58	15	6492304	348280
45	40	14.35	34.8	3185760	80210.17
46	50	14.35	14.4	627148	13733.965
47	75	14.35	8.76	473566	8607.5717
48	80	14.35	8.13	240986	1168.3408
49	85	14.35	6.73	446799	6103.9844
50	40	30.36	34.4	12451737	1122775.5
51	50	30.36	23.1	8552912	550884.59
52	60	30.36	14.6	5350973	168241.07
53	70	30.36	11	1241977	24415.938
54	40	28.33	37.6	14565085	1699792.7
55	45	28.33	35.4	12675683	1164549.6
56	55	28.33	23.1	8573518	572844.63
57	70	28.33	15.5	4502870	137721.15

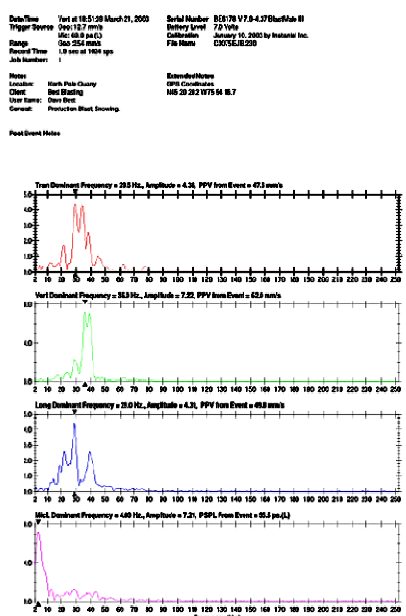
Table 2. Summary of seismic energy extracted as electricity from blasts conducted in coal mine

Sl. no.	Distance (m)	MCD (kg)	PPV (mm/s)	Seismic energy from three mutually orthogonal ground vibrations (MJ)	Electrical energy extracted from blast vibrations (MJ)
1	100	66	53.5	2738832.38	547766.476
2	110	66	33.8	1511665.32	151166.532
3	120	66	29.3	1470468.86	147046.886
4	150	66	18.92	6916156.65	4841309.66
5	160	66	17.4	5245447.1	3147268.26
6	170	66	17.3	8461652.43	7615487.19
7	184	50	5.33	1562458.55	1249966.84
8	178	88	22.61	9277651.8	7422121.44
9	188	88	20.2	4747405.68	2373702.84
10	200	88	17.9	366544.54	36654.454
11	292	88	4.06	376992.65	188496.325
12	150	85	19.81	10544797.7	10544797.7
13	209	85	10.7	2280225.67	456045.134
14	234	85	8.89	1055142.78	105514.278
15	295	85	3.3	134876.62	53950.648
16	696	450	3.56	513484.49	205393.796
17	719	450	1.52	136859.22	82115.532
18	750	450	1.52	171645.3	102987.18
19	800	450	1.02	1.836	1.836
20	603	460	7.11	1980472.55	594141.765
21	636	460	2.29	160142.93	112100.051
22	678	460	1.9	166647.59	66659.036
23	721	460	1.27	45698.08	45698.08
24	220	100	9.4	8769781.29	9646759.42
25	380	100	1.4	172599.58	172599.58
26	1591	1953	1.02	79583.75	79583.75
27	1856	1953	0.89	71031.38	71031.38
28	2033	1953	0.89	49481.5	49481.5
29	2121	1953	0.63	1.134	1.134
30	304	90	3.43	638174	638174
31	332	90	2.67	164876	98925.6
32	379	90	1.14	61901.33	111422.394
33	280	100	4.32	615873.463	123174.693
34	290	100	2.92	73406.109	44043.6654
35	300	100	2.03	402677.92	402677.92
36	440	100	1.27	108396.33	108396.33

Typical sample event report and FFT reports generated from the blastware software are shown in Figure 3. Seismic energy was obtained from the events recorded using signal processing tool, DADiSP. Sample of signal processing window is shown in Figure 4.

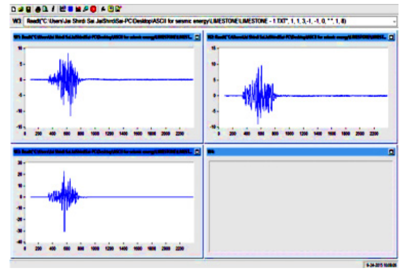


(a) Typical event report.

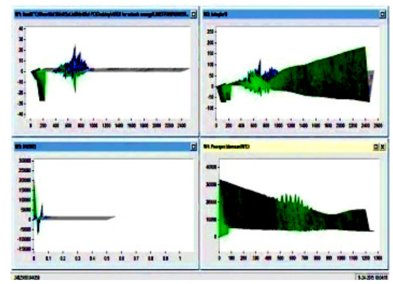


(b) Typical FFT report from blastware.

Fig. 3. Screenshots of vibration events recorded by minimate plus.



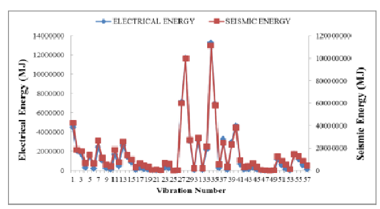
(a) Signal processing window



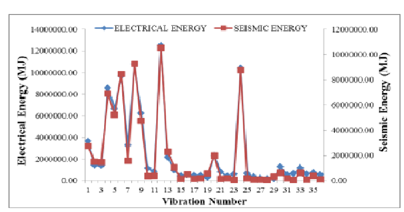
(b) Estimation of seismic energy.

Fig. 4. Finding of shock energy dissipated using DADiSP.

Also, comparison of seismic energy with the generated electrical energy was made to observe the amount of undesirable vibrations which were converted to electricity (Figure 5). From the analysis, it was observed that amount of seismic energy extracted in the form of Electricity is 80–90% of the total seismic energy in limestone mines and that is about 75–80% in the case of coal mines.



(a) In limestone mines.



(b) In coal mine.

Fig. 5. Amount of electrical Energy extracted from blast induced vibrations with its corresponding seismic energy in various blasts.

7. CONCLUSIONS

Based on the study, the following conclusions are drawn:

- Studies indicated that the amount of seismic energy increased with increase in maximum charge per delay. Hence, the optimal usage of MCD improves the performance of blasts by reducing seismic energy loss and improving explosive energy utilization.
- Seismic waves in the form of ground vibrations induced due to blasts can be efficiently tapped and converted with the help of Piezo-Gen circuit into useful electrical energy.
- The amount of seismic energy obtained in case of limestone mines is higher than in coal mines.
- The Piezo-Gen circuit may become a renewable source for generation of electricity from ground vibrations caused by blasting operations and further will be more useful in assessing the seismic energy in blast field.

REFERENCES

[1] Johansson, C.H. and Persson, P.A. (1970). Detonics of high Explosives (Academic Press: London).

[2] Atchison, T.C., Duvail, W.I. and Pugliese, J.M. (1964). Effect of decoupling on explosion generated strain pulses in rock (USBM RI: 6333).

[3] Nicholls, H.R. (1962). "Coupling explosive energy to rock" Jl. of Geophysics, 27(3), 305–16.

[4] Sastry, V.R. (1989). A study into the effect of some parameters on rock fragmentation by blasting, Ph.D. Thesis, BHU, India.

[5] Sanchidrian Jose´ A., Segarra Pablo and Lina M. Lopez (2007). Energy components in rock blasting, *International Journal of Rock Mechanics and Mining Sciences*, 44, 130–147.

[6] Anon (2015). All About Heven, web Site http://www.allaboutheaven.org/science/149/121/piezoelectricity (accessed on 28 August, 2015).

[7] Jacques and Pierre Curie (1880). On electric polarization in hemihedral crystals with inclined faces, 91, 383–386.

[8] Tingley, R. (2013). "Method and application of piezoelectric energy harvesting as a mobile power source", Research and Design Project, New Hampshire.

[9] Pramethesth, T. and Ankur, S. (2013). Piezoelectric Crystals: Future Source of Electricity, *International Journal of Scientific Engineering and Technology,* 2(4), 260–262.

[10] Jacques and Pierre Curie, 1881. Contractions and expansions produced by voltages in hemihedral crystals with inclined faces, 93, 1137–1140.

[11] Anon, 2016. "Piezotronics", web link https://en.wikipedia.org/wiki/Piezotronics, (accessed on Sept. 14, 2016).

[12] Konya, C.J. and Walter, E.J. (1990). Surface Blast Design (Prentice Hall Publishers: USA).

[13] Achenbach, J.D. (1975). "Wave propagation in elastic solids. Amsterdam." *Elesevier*, 166.

[14] Howell, B.F. and Budenstein, D. (1955). "Energy distribution in explosion generated seismic pulses", *Geophysics,* 20(1), 33–52.

[15] Fogelson, D.E., Atchison, T.C. and Duvall, W.I. (1959). "Propagation of peak strain and strain energy for explosion-generated strain pulses in rock." *Proc. of the 3rd US Symp. on Rock Mechanics, Colorado School of Mines*, Golden, 271–284.

[16] Berg, J.W. and Cook, K.L. (1961). "Energies, magnitudes and amplitudes of seismic waves from quarry blasts at Promontory and lakeside, Utah." *Seismol Soc. Bull.,* 51(3), 389–400.

[17] Nicholls, H.R. (1962). "Coupling explosive energy to rock", *Geophysics,* 27(3), 305–316.

[18] Atchinson, T.C. (1968). "Fragmentation principles." in: Pfleider EP, editor. Surf Mining. New York: The American Institute of Mining, *Metallurgical and Petroleum Engineers,* 355–72.

[19] Hinzen, K.G. (1998). "Comparison of seismic and explosive energy in five smooth blasting test rounds." *Int. J Rock Mech Min Sciences*, 35(7), 957–67.

[20] Berta, G. (1990). "L esplosivostrumento di lavoro". *Milan: Italesplosivi,* 31–64.

[21] Sastry, V.R. (2014). "Assessment of Performance of Explosives/Blast results based on Explosive Energy Utilization", *Unpublished R&D Project Report, submitted to Coal India Limited.*