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Environmental Impacts of Open Pit Mining Blasting: Particular Discussions on Some Specific Issues

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Abstract. This paper will substantially deliver and discuss causative factors, prediction method, related issues and case studies of environmental impacts of blasting. Major impacts of blasting that frequently and widely analysis by researchers are flyrock, blast vibration, and dust. Environmental effects of blasting can be caused by controllable factors such as blast design as well as uncontrollable factors such as geological condition of rock mass. The empirical models to predict the environmental effect are site specifics, the researchers construct their empirical models based on the available research data in the field, future empirical model can also be build based on new specific site data. Artificial intelligence approach has been applied by researched as alternative way to predict environmental impacts of open pit mining blasting. More than one approach to asses environmental impacts of blasting give more alternative ways to prevent the impacts.

Keywords: *Blasting, Environment, Impacts, Cause, Prediction.*

1. Introduction

Environmental impacts, apart from technical and economic factors, are an important issue in mining blasting. Blasting is an effective method for mining to separate rock fragment from rock mass so that it can be prepared for the next stage in mining activities. Blasting on the other hand has the potential to have environmental impacts on humans, structures, living things and the surrounding environment as well. Major impacts of blasting that frequently and widely analysis by researchers are flyrock, blast vibration, and dust. Assessment and prevention of environmental impacts are standards that mining companies must pay attention to. Engineers are required to be able to assess and prevent the impacts of blasting, which may be performed technically by adjusting the blasting design in the field.

Environmental impacts of mine blasting can cause hazards for booth objects in mining areas and in areas close to mining activities. Erten et al. (2009) reported that as many quarries in Turkey have effectively been surrounded by residential structures as a consequence of Turkey’s increasing population, there has been an increase in the number of complaints concerning possible excessive intensities of ground vibration induced by blasting. The most common complaints include annoyance to people, possible structural damage and disruption to some businesses. It has become imperative that the intensity of blast-induced ground vibrations be optimized in such a way that the structures in the vicinity of these quarries will not be damaged as a result of blasting operations. It has been found that a basic concern for the safety of property was the main response. The study suggested that the human response criteria when considering blasting within 400 m of habitations must be considered (Raina et al., 2004). Kecojevic & Radomsky (2004) reported that a total of 45 fatal and 367 non-fatal accidents in coal, metal and non-metal surface mines had occurred between 1978 and 1998. The lack of blast area security and flyrock accounted for 281 (68.2%) accidents.

Study and adjustment of vibration are not only give benefit for mining activities but also can be beneficial for other areas such as for example in dam development. Nateghi (2011) reported the study that took place during construction of Gotvand dam, located in Zagros Mountains in the south-west of Iran. The 178 m height and 730 m length embankment dam, which regulates the water of the Karun River, also serves power generation, flood control and irrigation needs. Time duration after concrete has been prepared is a consideration in how much the PPV limit is allowed. Aksoy et al. (2019) applied estimation of potential dust emission from blast design to find suitable emission respect to the allowable permissible limit for quarry mining. Suitable assessment and prevention of blasting impacts in addition to the safety of object in mining area are also to ensure the surrounding environment safety from mining activities. Environmental care is also a fundamental part of the company's environmental responsibility. Considering environmental impacts of blasting is an integral part of the blast design in the field. This paper will substantially deliver and discuss causative factors, prediction method and related significant issues of environmental impacts of blasting.

2. Method

This paper in general is the elaboration of the issues related to the environmental impacts of open pit mining blasting according to the previous studies. The descriptions are based on significant issues in related themes. Furthermore, examples of predictive cases for the environmental impacts of blasting are presented. Discussions and conclusions are drawn to state important elements consisting of key information and significance facts that support existing issues in order to fulfill the desired substance points.

3. Environmental Impacts of Blasting

The environmental impacts of blasting are the effects caused by blasting activities that can be felt by humans, give damages to structure buildings and surrounding ecosystem. The impacts can be small, medium and heavy. The environmental impacts of blasting such as flyrock, vibration, air overpressure and dust will be described below. Each part will be described regarding to the causative factors and prediction models.

3.1 Flyrock

3.1.1 Causative Factors

Many factors have been identified as the cause of flyrock. Inadequate burden and spacing can cause flyrock. A burden dimension less than 25 times the charge diameter gives high specific charge, hence the excess energy results in long flyrock distances. Spacing appreciably less than the burden tend to cause premature splitting between blastholes and early loosening of stemming. Both these effects encourage rapid release of gases to the atmosphere and flyrock is considerable. Overload holes; a high specific charge throws flyrock to a longer distance than a low specific charge. This means that overloading of holes may result in excessive flyrock. Geological condition like zones of weakness and voids are often cause flyrock. Any explosive loaded in this zone will have the line of least resistance and ‘blow out’, causing flyrock. If stemming column is inadequate, the explosion gases are not forced to heave up the partly fractured ground but are simply allowed to ‘rifle’ out of the top of the blasthole at very high velocity causing considerable flyrock and air blast. Faulty delay timing and initiation sequence, if the delay is not sufficient, movement from the back rows (in multi rows blast) will be upward rather than forward, giving rise to flyrock (Bhandari, 1997).

Controlled and uncontrolled factors that cause flyrock in the field have been more explored. 150 data fields and important factors affecting flyrock distance such as burden, spacing, stemming, blasthole diameter, powder factor, mean charge per blasthole in copper mine were recorded. Only fragments have the approximate diameter of 10 cm were considered. By using Monte Carlo and sensitivity analysis it was found that the most effective parameters were powder factor, stemming and burden (Ghasemi et al., 2012). One of the main reasons for improper predictions is the lack of data on flyrock in comparison to blast vibrations owing to statutory restrictions, avoidance of reporting and consequent constraints on experimentation. While fragmentation and throw of rock accompanied by subsequent vibration and air overpressure are essential constituents of the blasting, flyrock is not. This probably is one of the main errors in predictive domains. In addition, rock mass properties play a major role in heaving of rock fragments during blasting (Raina et al., 2014). Kecojevic & Radomsky (2004) reported that a total of 45 fatal and 367 non-fatal accidents in coal, metal and non-metal surface mines had occurred between 1978 and 1998 where the primary causes were the lack of blast area security, flyrock, premature blast, and misfires. The lack of blast area security and flyrock accounted for 281 (68.2%) accidents. Investigations of flyrock accidents have revealed one or more of the following contributing factors: discontinuity in the geology and rock structure, improper blasthole layout and loading, insufficient burden, very high explosive concentration, and inadequate stemming.

3.1.2 Prediction of Flyrock

Estimating distance of flyrock throw on bench blasting has been proposed for example by Lundborg et al. (1975). A simple empirical formula was recommended taking into account diameter of blasthole. The equation was site specific not necessarily applicable in all places but at least the relationship between the diameter of the blast hole and the distance of rock throws can provide an initial reference of what flyrock conditions will be. In other places the empirical relationship of the two under consideration variables can be proposed based on existing data at concerned location. The relationship between flyrock range in m (Lm) and blasthole diameter in inches (d) purposed by Lundborg et al. (1997) in Bhandari (1997) is presented in Eqn. 1.

$$Lm = 260\ d^{2/3} \tag{1}$$

In addition to the empirical method, artificial intelligence (AI) approaches have also been involved in flyrock prediction. It can provide alternative way to perform predictions. Availability of data and personal AI experts is also the conditions that can support the application of this method. Results of application of Particle Swarm Optimization (PSO) which involved 76 blasting events in three quarry sites, Malaysia, show more reliable than Multiple Linear Regression. Based on sensitivity analysis results, it was also found that the RD was the most effective parameter on the flyrock in the studied cases (Hasanipanah et al., 2017).

3.2 Vibration

3.2.1 Causative Factors

Several factors that affect ground vibration will be described in this section. The burden is one of the important factors which affect ground vibration. Excessive burden increase the ground motion because the explosives energy which is insufficient to break the burden rock will be converted into vibration. Amount of explosive; charge weight per delay is most important factor which controls the intensity of ground vibration. The larger the quantity of charge detonated per delay, the higher the vibrations. There is an optimum length beyond which further increments in stemming column serve no useful purpose. Smaller stemming columns of less than 20 times the diameter of hole may result in more ground vibrations. Ground vibration levels are reduced by the use of delay detonators because each delay generates its own pulses. The propagation of the ground vibration is strongly influenced by the lithology of the rock mass. Since the rock masses are in homogenous, ground motion waves travel through strata of different acoustical impedance. Scattering of the ground motion waves, at discontinuities, lowers the peak vibration levels. Distance and conditions of structures also affect the ground vibration, as the distance from shot increase, the particle velocity and frequency of ground vibrations decrease due to absorption, dispersion and dissipation of elastic waves. The natural frequency of the structures varies with the foundation, condition and age of structure and construction of the structure (Bhandari, 1997). A total of 1089 published blast data of various researchers in different rock sites have been collected and used to propose generalized empirical model for PPV by considering the effects of rock parameters like unit weight, rock quality designation (RQD), geological strength index (GSI), and uniaxial compressive strength (UCS). The proposed PPV model has a good correlation coefficient and hence it can be directly used in prediction of blast-induced vibrations in rocks (Kumar et al., 2016).

3.2.2 Prediction of Ground Vibration

Prediction of ground vibration has been performed by many researchers. They recommend equation based on existing field conditions. Equation 2 was proposed by Duvall and Petkof; (1959) in Ghasemi et al. (2013), an equation that has been widely used by many researchers applied in various different locations. It can be seen in Eqn. 2 that the PPV value can be predicted by involving the amount of (maximum) explosive used per delay (W) and the distance from the location of the explosion to the location of the vibration measuring device (D). K and β are site specific constants. The equation is a regression equation of PPV and Scaled Distance ($D/W^{0.5}$) so that the K and β values will change at every different location according to the rock mass conditions.

Discontinuity spacing will affect the blast vibration in the field. Hakan & Konuk (2008) examined the impacts of the discontinuity frequency parameter derived through geological measurements carried out on the blasting benches or nearby in a quarry mine (Supren, Eskisehir) in Turkey. The model was formed by adding a discontinuity frequency (λ) parameter other than the distance between the observation point and location of detonation (D) and the maximum charge per delay (W), α represents the discontinuity frequency coefficient, see the Eqn. 3. PPV attenuates more rapidly with in the steeply dipping multiple bed rock masses down and up dip compared to a long the strike. The attenuation rate of PPV within the rock mass at the low wall and high wall are very much influenced by their incident angles relate to dip direction. Number of coal layers influences the attenuation rate of PPV such that the higher the number of coal layers, the higher the attenuation of PPV. A new relationship was developed to improve prediction of PPV in steeply dipping multiple coal bed of open pit mine by accounting the direction of propagation and number of coal seams. Purposed model shown by Eqn. 4, where R is distance between the observation point and blast location, W is maximum charge per delay, Cos θi is Cosine of the incident angle, the incident angle is defined here as slope between the direction of the vibration propagation and the dip direction of the bedding plane, log Nc is logarithmic of the number of coal layers, n and k are constants (Simangundong & Wahyudi, 2015).

$$PPV = K\left[\frac{D}{\sqrt{W}}\right]^{-\beta} \tag{2}$$

$$PPV = K\left[\frac{D}{\sqrt{W}}\right]^{-\beta} \lambda^{\alpha} \tag{3}$$

$$PPV = k\left[(1+\cos\theta_i+\log N_c)\frac{R}{\sqrt{W}}\right]^{-n} \tag{4}$$

AI approaches have also been tried to solve vibration prediction. Iphar et al. (2008) investigate the applicability of adaptive neuro fuzzy inference system (ANFIS) to predict PPV in an open pit magnesite mining. The distance from the blasting site to the monitoring stations and the charge weight per delay were selected as the input parameters of the constructed model, the output parameter being the PPV. This study does not involve other parameters such as blast geometry, slope geometry, rock mass conditions. The comparison has indicated that the proposed ANFIS-based model exhibited better prediction performance than the classical regression-based model.

3.3 Air Overpressure

3.3.1 Causative Factors

Several factors that affect air overpressure will be described in this section. The burden is one of the important factors which affect air overpressure. If the burden is less than optimum the gaseous energy is dissipated into atmosphere without doing useful work thereby causing flyrok and air blast. This early release of gases generates air waves of large amplitude. It has been reported that strong air blast overpressure can be produced by the adjacent movement of a face during blasting if spacing between holes is less than the distance travelled by a sound wave during the delay time between adjacent blasthole destinations. The explosives which produce more gaseous energy than shock energy such as ANFO, are more likely to produce ejection of gases and thereby producing higher amplitude air blast overpressure. The air blast levels created due to blasting are a function of the amount of efficiency of stemming. Whenever top priming is carried out the probability of air blast generation will increase. The bottom priming on other hand, however, produces less overpressure levels because of more confinement. Whenever the burden rock consist of highly fractured or jointed strata, there exists a possibility of escape of gases through them and which on reaching the atmosphere produce high air overpressure levels (Bhandari, 1997). Wiss & Linehen (1978) in Bhandari (1997) conducted experimental showed that air blasts were at least 6 dB higher when the observation point was perpendicular to the firing pattern rather than parallel to blast face, due to blasthole reinforcement. If a blast is detonated in a motionless atmosphere in which the air temperature is constant then the air overpressure intensity will solely depend on the distance of the source and will reduce by 6 dB as the distance from source doubles (Bhandari, 1997). **Kuzu et al. (2009)** confirmed that the result of air overpressure directly relates to the confinement properties of explosives. The best confinement quality exists in the shots of competent zones according to the low level of occurred gas, escaping from explosives detonation through the discontinuities on the face or stemming blowout. These results indicate the role of discontinuities of rock structures in the formation of air blast which could be directly related to the gas releases from the face and the stemming areas.

3.3.2 Prediction of Air Overpressure

The generalized predictor equation for the prediction of AOp is given in Eqn. 5, Siskind et al. (1980) in Mohamad et al. (2016). According to the equation, AOp is air over-pressure, H and β are the site factors.

$$AOp = H\left[\frac{D}{\sqrt[3]{W}}\right]^{-\beta} \tag{5}$$

H and β are site specific constants. The equation is a regression equation of PPV and Scaled Distance ($D/W^{1/3}$) so that the H and β values will change at every different location according to the rock mass conditions.

Artificial intelligence (AI) methods for predicting specific blast-induced air over-pressure (AOp) are also alternative approaches. 113 blasting events have been recorded at the Deo Nai open-pit coal mine (Vietnam). Seven parameters including maximum charge weight per delay, measurement point distance from blast resource, Burden, Spacing, Stemming, Powder factor and Air humadity were used to predict blast-induced AOp. Seven AI methods was applied include random forest, support vector regression, Gaussian process, Bayesian additive regression trees, boosted regression trees, k-nearest neighbors, and artificial neural network (ANN). The results indicate that AI techniques provide better performance than the empirical method. Of the seven AI models, ANN was the most dominant model based on RMSE, R^2, and MAE (Bui et al., 2019). Another ANN based approach to predict air over-pressure (AOp) also was applied by Mohammad et al. (2016) by using more less amount of data and variable. 76 blasting operations were investigated and relevant blasting parameters were measured in Hulu Langat granite quarry site, Malaysia. Maximum charge per delay and the distance from the blast-face were considered as model inputs or predictors. Empirical, artificial neural network (ANN) and a hybrid model of genetic algorithm (GA)–ANN were developed in the study. It was found that the GA–ANN technique can provide higher performance capacity in predicting AOp compared to other predictive methods.

3.4 Mining Blasting Dust

3.4.1 Causative Factors

Dust particle from mining blasting floating in the air is closely related to the fine material that resulted from mining blasting process. A hypothesis about fines (dust) generation in the blasting process was initially formulated in which the crushing near the blasthole plays an important role.

Crushing of the rock near the vicinity of the blasthole arises due to the enormous pressure caused by the detonation of the explosive. Several rock and blasting parameters affect dust generation. The type of rock is of course the most important parameter. In highly porous rocks during blasting, greater dissipation of energy results in considerable crushing and production of fines. Increase in number of joints may increase amount of dust produced. Filler material in the joints is released and may come out as fines and dust. Therefore, clay filled joints or packets would provide more dust as a result of blast. Low-density rock produces more fines (and also dust) than high-density rocks. As the strength of rock decreases the rock is more liable to crushing and hence there is an increase in fines and dust. Blasting parameters, which influence the generation of fines and dust are: type and amount of explosives, burden and spacing parameters if not optimum, delay timing and sub-grade drilling. If the various blasting parameters affecting the dust generation can be understood then more effective steps can be taken to reduce the generation of dust (Bhandari, 2004).

3.4.2 Prediction of Blasting Dust

The United States Environmental Protection Agency (USEPA) proposed equations for the estimation total suspended particle (TSP) and PM_{10} during open pit blasting at a mine, Amegbey et al. (2016), see Eqn. 6 and 7. Eqn. 8 is used to estimate TSP from uncontrolled-dust blasting which proposed in Turkey standard, Aksoy et al. (2019). Berry & Pistocchi (2013) recommends the box model equation to calculate the Mass Balance Concentration of dust, see Eqn. 9.

$$TSP = 0.00022\, x\, A1.5\; kg/blast \tag{6}$$

$$PM10 = 0.52\, x\, 0.00022\, x\, A1.5\; kg/blast \tag{7}$$

$$TSP = 0.08\; kg/ton \tag{8}$$

$$Pk = mk/(U\, x\, B\, x\, H) \tag{9}$$

In the above equation PM10 is particulate matter with a diameter less than or equal to 10 micrometers. TSP is Total Suspended Particles of all sizes. A is the blasted area (m^3). Pk is Mass Balance Concentration ($\mu g/m^3$), mk is Mass Input Rate (µg/s), U is Wind Speed (m/s), B as the distance from the dust source (m) and H is mixing height of the dust (m).

3.5. Case Study

3.5.1 Blast Vibration Case

Below is an example of vibration in open pit, the measurement data is quoted from Fişne et al. (2011), presented in Table 1. It can be seen from table 1 that 33 data of measurement of open pit blasting ground vibrations. D is distance from blasting location to the vibration measuring device, W is the maximum amount of explosive used per delay, scaled distance (SD) is relationship between D and W ($D / W^{0.5}$) and PPV is Peak Particle Velocity (PPV) from each blasting event.

Based on the data, the regression equation (power regression) which shows the relationship between PPV and SD of the 33 amount of vibration measurement data in Table 1 is $PPV = 116.95 \times (SD)^{-1.206}$. Prediction of PPV that will be generated from blasting with a certain amount of W and Distance D is presented in Table 2, prediction calculation is performed based on Eqn. 2, D is simulated constant. The simulation shows that using the same distance D = 500 m, how much value of PPV will be generated by applying different amount of W, in other word what is the maximum amount of W that can be applied based on allowable maximum PPV standard. Shown in Table 2, by consider the maximum PPV = 3 mm / s, the maximum amount of charge per delay that can be applied to blasting at a distance of 500 m from the protected structure/building is 400-500 kg.

Table 1. Results of Blast-Induced Ground Vibration Measurements

Event No.	Distance, D (m)	Charge Weight Per delay, W (kg)	Scaled Distance/SD, ($D/W^{0.5}$) ($m/kg^{0.5}$)	Peak particle Velocity, PPV (mm/s)
1	21	145	1.74	41.70
2	25	288	1.47	40.10
3	30	330	1.65	51.80
4	32	425	1.55	46.50
5	34	163	2.66	46.50
6	35	216	2.38	49.50
7	35	400	1.75	51.10
8	45	291	2.64	35.10
9	50	215	3.41	31.70
10	50	350	2.67	54.10
11	50	366	2.62	54.50
12	55	365	2.88	51.50
13	65	209	4.50	32.30
14	70	318	3.93	37.70
15	75	325	4.16	36.10
16	80	262	4.94	24.70
17	80	233	5.24	13.80
18	80	337	4.36	20.80
19	90	250	5.69	15.10
20	100	370	5.20	10.90
21	100	315	5.63	14.80
22	100	311	5.67	10.20
23	100	350	5.35	13.50
24	115	267	7.04	7.54
25	120	161	9.46	12.50
26	150	300	8.66	8.11
27	155	320	8.66	8.58
28	175	450	8.25	3.31
29	180	300	10.39	5.10
30	195	310	11.08	4.08
31	210	350	11.22	12.30
32	220	370	11.44	4.13
33	225	347	12.08	7.92

Table 2. PPV Calculations with Variations of W

No	D	W	PPV
1	500	700	3.38
2	500	600	3.08
3	500	500	2.76
4	500	400	2.41
5	500	300	2.03
6	500	200	1.59
7	500	100	1.04

3.5.2 Blasting Dust Case

An example of blasting dust calculation is given in this section, extracted from Aksoy et al. (2019). Dust calculation is performed using Turkey dust emission factor standard for uncontrolled blast mining, 0.08 kg dust emission per ton of blasted rock. The amount of limestone rock (2.6 ton/m^3 in density) to be exploded in shot which is planned as one shot per week is found to be 9750 tons, 3750 m^3. Aksoy et al. (2019) applied 80% of the dust resulted from blasting produces 10 micrometers or smaller in diameter, it means PM10 = 20 % TSP. The calculations can be seen in Table 3. Based on the calculations in Table 3, PM10 dust emission resulted from the blasting is

156 x 10^9 ug, if it is assumed that will be completely dispersed in 1 hour, then at a point with a distance of 2050 m from the blasting source, it is predicted that there will be a 143 ug / m^3 of dust emission.

Table 3. Dust Emission Tabulation and Calculation

NO	PARAMETERS	RESULT
1	Volume of blasted Rock	3750 m^3
2	Rock density	2.6 ton/m^3
3	Rock tonnage	9750 ton (3750 x 2.6)
4	Dust emission TSP	780 kg (0.08 kg/ton x 9750 ton)
5	Amount of PM10 (%20), kg	156 kg (780 kg x 0.2)
6	Amount of PM10 (%20), ug	156 x 10^9 ug
7	PM10 1 hour dispersion, Mk	43.3 x 10^6 ug/hour (156 x 10^9 ug / 3600)
8	PM10 1 day dispersion, Mk	1.8 x 10^6 ug/second (156 x 10^9) / (3600 x 24)
9	Wind speed, U	3.7 m/s
10	Concentration point distance from Blast pattern, R	2050 m
11	Dust height, H	40 m
12	Mass balance concentration, ug/m^3, **Pk = Mk / (U x R x H),** 1 hour dispersion	**143 ug/m^3** (43.3 x 10^6 ug/second) ÷ (3.7 m/sn x 2050 m x 40 m)
13	Mass balance concentration, ug/m^3, **Pk = Mk / (U x R x H),** 1 day dispersion	**6 ug/m^3** (1.8 x 10^6 ug/second) ÷ (3.7 m/sn x 2050 m x 40 m)

4. Discussion

Environmental impacts of blasting can be caused by controllable factors such as blast design as well as uncontrollable factors such as geological condition of rock mass. Environmental impacts of blasting that most often have an impact in the field on the surrounding environment are flyrock, vibration, air overpressure and dust. Dealing with controllable factors must be performed in serious effort in order to minimize environmental impacts so that the environmental impacts of blasting can be conditioned below the allowable standard limit. Burden and delay timing, among other factors, are controllable factors that significantly influence flyrock, vibration, air overpressure and dust. Burden is a blasting geometry that practically will affect other blast geometries. Burden plays important rule to the others blast geometries design as well as to the environmental impacts, therefore burden is a significant issue in discussing blast design and projected environmental impacts.

The empirical models to predict the environmental effect are site specifics, the researchers construct their empirical models based on the available research data in the field, future empirical model can also be build based on new specific site data. Empiric models can help to provide an overview of the impacts that will be generated and how actions should be taken to avoid bigger impacts. Artificial intelligence approach has been applied by researchers as alternative way to predict environmental impacts of open pit mining blasting. Some cases of this approach even show better performance than conventional empirical and another statistical method. Applicability of the empirical method and the AI approach are based on field conditions, data availability and experience. More than one approach to asses environmental impacts of blasting give more alternative ways to prevent the impacts.

Table 4. Influence Factors and Empirical Formula of Blasting Impcats

No	Environmental Impacs	Causative and Influence Factors	Empirical Formula
1.	Flyrock	• Burden, Spacing, Stemming • Overload holes • Geological condition • Faulty delay timing and initiation sequence • Powder factor • Rock mass properties • Discontinuity	Lm = 260 $d^{2/3}$ Lundborg et al. (1997)
2	Vibration	• Burden, Stemming • Delay • Distance and conditions of structures • Amount of explosive • Charge weight per delay • Distance from blast source • Lithology • Spacing and Orientation of discontinuity	$PPV = K\left[\frac{D}{\sqrt{W}}\right]^{-\beta}$ Duvall and Petkof; (1959) $PPV = K\left[\frac{D}{\sqrt{W}}\right]^{-\beta} \lambda^{\alpha}$ Hakan & Konuk (2008) $PPV = k\left[(1 + \cos\theta_i + \log N_c)\frac{R}{\sqrt{W}}\right]^{-n}$ Simangunsong & Wahyudi (2015).
3.	Air overpressure	• Burden, Spacing, Stemming • Priming • Rock strata condition • Observation point orientation to the face • Atmosphere condition • Discontinuities	$AOp = H\left[\frac{D}{\sqrt[3]{W}}\right]^{-\beta}$ Siskind et al. (1980)
4.	Dust	• Type of rock • Number of joints • Filler material of joint • Strength of rock • Type and amount of explosives, • Burden, Spacing, Delay	TSP = 0.00022 x $A^{1.5}$ kg/blast (USEPA, 1994) PM_{10} = 0.52 x 0.00022 x $A^{1.5}$ kg/blast (USEPA, 1994) TSP = 0.08 kg/ton (Turkey Standard, 2009) $P_k = \frac{m_k}{U\ x\ B\ x\ H}$ (Berry & Pistocchi, 2013)

5. Conclusion

There are some critical conclusions that can be drawn from all existing explanations and discussions:

- The environmental impacts of blasting are the effect caused by blasting activities that can be felt by humans, give damages to structure buildings and surrounding ecosystem.
- Environmental impacts of blasting can be caused by controllable factors such as blast design as well as uncontrollable factors such as geological condition of rock mass.
- Dealing with burden and delay timing are effective ways to control the impacts to compensate geological conditions and other rock mass characteristics which are uncontrollable factors.

- The empirical models to predict the environmental effect are site specifics, the researchers construct their empirical models based on the available research data in the field, future empirical model can also be build based on new specific site data.
- Artificial intelligence approach has been applied by researched as alternative way to predict environmental impacts of open pit mining blasting.

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