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INCORPORATING MEASURES TO REDUCE GROUND VIBRATION PRODUCED BY BLASTING FOR QUARRY SAFETY MANAGEMENT: A CASE STUDY

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Abstract:

Ground vibration is a significant factor to be considered for safe blasting operation. Ground vibration can damage the structures situated near blasting sites. It can be controlled by adopting proper blast designing techniques. The scope of this study is to control ground vibration by identifying safe blasting parameters for quarry safety management through measuring ground vibrations and study their relationship with quantity of explosives and drilling parameters.

Key words: Drilling, Blasting, Limestone quarry, Ground vibrations, Peak particle velocity, Explosive.

Introduction:

After agriculture, mining is considered as the oldest occupation of human. Minerals are the backbone of economic development of a country. Those national economies which are based on minerals are considered as the richest economies in world. Minerals are used as a fuel, food and raw material for process industries. In mining, most of the minerals are extracted through drilling and blasting. Blasting is done by drilling holes into the rock, charging explosive with specific calculations and blast it for rock fragmentation.

After invention of latest equipment for mining, still blasting is the cheapest and highly productive source for loosening materials from their parent rocks. Blasting may have different types of environmental hazards like dust, chemical fumes, fly rock, ground vibrations, and air blasts which can effect environment or surrounding structures. This study is based on experimental blasts to identify parameters for controlling ground vibrations. Importance of topic is also defined in different researches as:

Blasting produces dust, toxic gases, noise, fly rocks and ground vibration. The most concern is ground vibrations which can cause damage to structures. In most cases worldwide, after blasting activities there are the usual complaints about damage to residences .

Ground vibrations originating from bench blasting may cause damage to slopes, structures, and underground workings in close proximity to an operating open-pit mine. It is important to monitor and predict ground vibration levels induced by blasting and to take measures to reduce their hazardous effects. .

Blasting is widely used in quarries and mining production processes. It is the beneficial industrial technology which provides achievement of expected results in a short period of time with relatively low cost. Never one less, blasts produce undesirable vibrations and sounds which effects surrounding..

Construction and industrial dynamic sources can produce environmental vibration problems for adjacent and remote structures. High vibrations and unacceptable dynamic settlements could disturb sensitive devices, people and even be the cause of structural damage. .

Ground vibration is a significant factor to be considered for safe blasting operation. Ground vibration can damage the structures situated near blasting site. It can be controlled through proper blast designing, drilling parameters, quantity and type of explosive. In Blasting chemical explosives are used for fragmentation of rock from deposit. In Punjab, Salt range is richest in lime stone mineral and blasting is required to detach rock for further process.

Theoretical research framework:

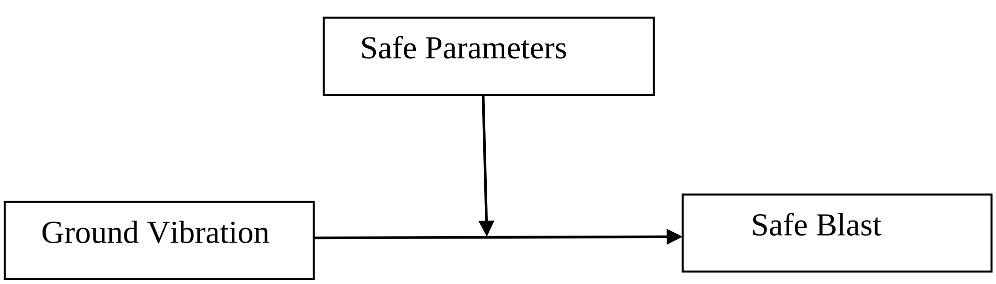

Fig. 1: Theoretical Research Framework

Theoretical research framework for this study shows the relationship between independent and dependent variables. Safe blasting depends upon ground vibration. Ground vibration can be controlled by adopting safe parameters suggested after experimental blasts.

Ground Vibration:

Ground vibration is seismic movement of energy in the ground. In mining, energy is produced due to blasting. Ground vibration can damage contiguous structures when it crosses permissible limits. Ground vibrations are normally measured in terms of Peak Particle Velocity (PPV). The unit of ground vibration is millimeter per second (mm/s). Seismographs is the instrument which is used to measure and record ground vibrations widely. During blasting activity at quarry only about 20 to 30% energy produced by explosive is utilized to fragment rocks in surroundings, rest energy propagates through strata in the form of seismic movements.

Level of the ground vibrations depends on:

i. Charge quantity of explosive (charge per delay).
ii. Distance from blasting site.
iii. Rock characteristics.
iv. Ratio and type of explosive.

International Standard of United States Bauru of Mines for Ground Vibration:

There is no Pakistan standard to set safe blasting criteria for ground vibrations. But different international standards are there which defines the safe limits of ground vibrations. These standards describe the effects of ground vibrations and allowable limits for the safe blasting practices. In this study United States Bureau of Mines standard is followed. Following table shows general outline for damage criteria with respect to the ground vibration defined by Oriard, Lewis L. .

Table 1: Ground Vibration Criteria by Oriard, Lewis L.

12.7 mm/s (0.5in/s)	Bureau of Mines recommendations for weak structures (RI 8507)

19.1mm/s (0.75in/s)	Bureau of Mines recommended guideline for sheet rock construction near surface mines (RI 8507)
25.4 mm/s (1.0in/s)	OSM regulatory limits for residences near surface mine operations at distances 92-1524 meters (301-5000 feet)
50.8 mm/s (2.0 in/s)	Widely accepted limit for residences near construction and quarry blasting (USBM 656, RI 8507)
137mm/s (5.4 in/s)	Minor damage to the average house subjected to quarry blasting vibrations (USBM 656)
229 mm/s (9 in/s)	About 90% probability of minor damage from construction or quarry blasting. Structural damage to some houses depending on vibration source and character of the vibrations.
501 mm/s (20 in/s)	For close-in construction blasting, minor damage to nearly all houses and structural damages to some. For low-frequencies, major damage to most houses.

Impacts of Ground Vibration

Ground vibration may cause Sliding of boulders, danger for working faces, disturbs the environment, collapse road, hindrance for water ways and damage structures situated in surroundings as shown in Fig. 2.

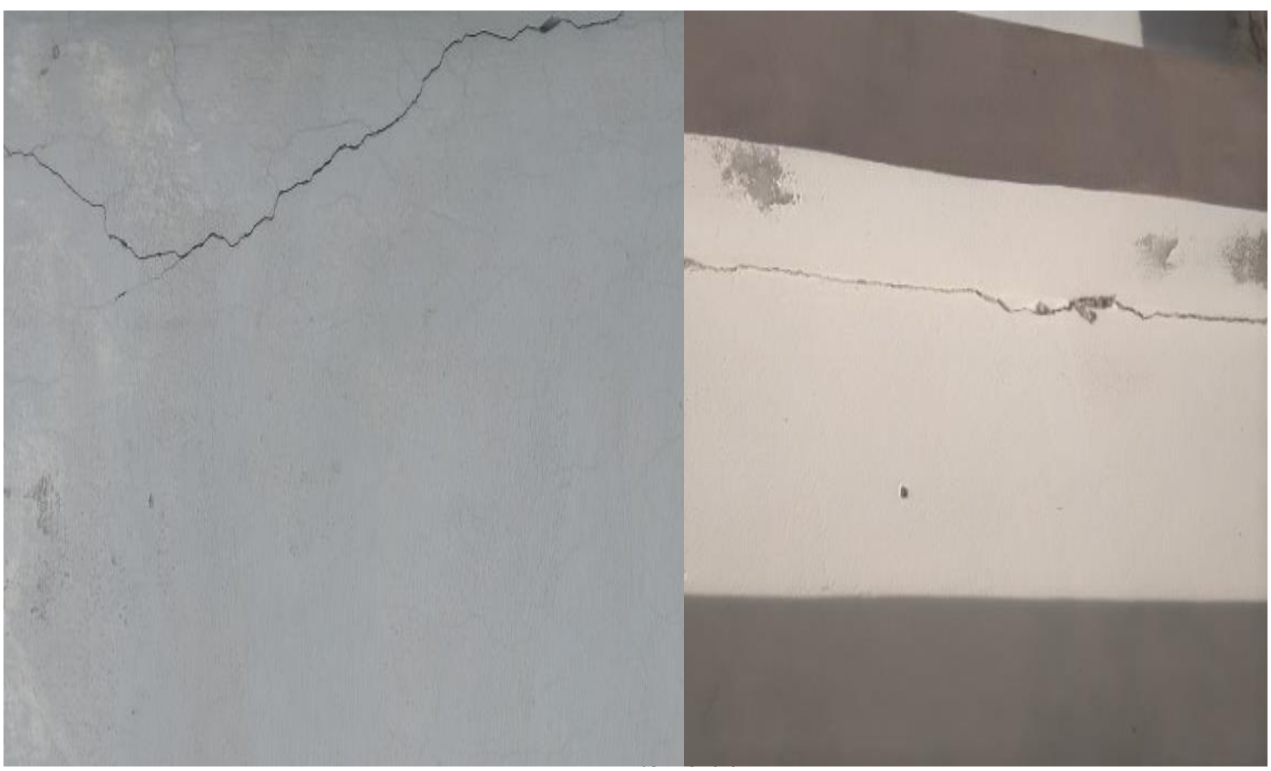

Fig. 2: Cracks appear in structures due to Ground Vibration in Wahola Village

Formula for Prediction of Ground Vibration:

Many researchers tried to investigate the problem of ground vibration prediction and have proposed various formulae. Following formulae is put forwarded by well known in the world which is known as Langefors Formula.

$$V = k\ \sqrt{Q}/D^{1.5}$$

Where:

V= Peak vibration (mm/s)

K = Rock transmission factor

Q = Instantaneous charge mass (kg)

D = distance (m)

This formula was based on early research by U. Langefors and Björn Kihlström into blasting in hard Swedish granite. The rock transmission factor allows for varying rock types and confinement conditions, e.g. for hard granite K = 400.

Scaled Distance Formula:

The square root scaled distance formula describes typical way of combining distance and explosive energy is to divide the true distance by the square root of the maximum explosive charge weight per delay to obtain a normalized or scaled distance as follows:

$$SD = d/{}^{2}\sqrt{W}$$

where:

SD = Scaled Distance in $m/kg^{0.5}$

d = distance from in meters

W = Maximum explosive charge weight per delay in Kgs

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To predict ground vibrations in Peak Particle Velocity following equation was used by by Oriard, Lewis L & ISEE.

$$PPV=K(SD)\text{-}\alpha$$

PPV = Peak Particle Velocity in mm/s,

K is the site factor (particle velocity at scaled distance = 1 and is defined as a measure of how much vibration energy is transferred to the ground near the explosive charge)

α = Curve slope (decay exponent – always negative and is defined as how fast the energy attenuates with distance).

Parameters Influencing Propagation and Intensity of Ground Vibrations:

There are two types of Parameters Influencing Propagation and Intensity of Ground Vibrations.

1. Non-controllable Parameters: These are the normally natural factors which cannot be controlled by engineering techniques. These parameters are generally a big challenge for blast designs and should be kept in view while designing a blast. These parameters can be:

i. Geological formation of the area.
ii. Physical characteristics of the rock
iii. Distances of the structures from blast site.

2. Controllable Parameters: Those factors which can be controlled by engineering techniques are known as the controllable parameters. Some of the controllable parameters are given below:

i. Time of delay Interval
ii. Burden and spacing
iii. Direction of blast
iv. Explosive charge weight
v. Distribution of explosive charges
vi. Type and ratio of explosive

Case Study:

Problem Statement:

Wahola limestone quarry is situated in salt range, Punjab, Pakistan and produces limestone for construction industry. Limestone is obtained through Blasting. Coal mines are running at the distance of 300 meters from Wahola limestone quarry. Coal mines were at safety risk due to ground vibration of blasting so they complained several times about adverse effects of ground vibrations and finally area of bench no. 5 near to coal mines was stopped for all type of blasting due to which a large area about 50 acres was useless for mining of limestone. Therefore, life of limestone quarry was reduced from 50 years to 32 years.

Fig. 3: A view of blasting site from coal mines at Wahola limestone quarry

Ground vibration is a major hazard of mining industry due to this issue many accidents happens causing loss of properties situated in surroundings. Therefore, it is very important to study the parameters which are responsible for ground vibration. The study of environmental issues can play significant role for safety management of the area. This will leads to safe mining operation.

Solution:

To solve this problem it was important to study and experiment different drilling and blasting parameters. Therefore 15experimental bench blasts are performed at Wahola limestone quarry with different explosive ratios and drilling parameters to study the results of ground vibration. The objective of this study is to control ground vibration for quarry safety management. During this study ground vibration of experimental blasts is recorded to study their relation with quantity of explosives, ratios of explosives and drilling parameters. To achieve this objective, data is carefully checked and recorded for all important parameters of experimental blasts. Ground vibration level for each blast is recorded separately by using micro mate. On the basis of results of these experimental blasts, new blasting parameters are suggested to control environmental hazards. Explosive for experimental blast was calculated very carefully. All possible hazards were identified and mitigation measures were taken before charging of explosive.

Following safety measures were adopted during blast.

i. All SOPs were followed during transportation and charging of explosives.
ii. Siren was used as a warning before blasting.
iii. Guards with red flag were employed at roadsides to keep the people away from the blasting site.
iv. Signal to the shot fired for initiating the detonation was given once area was cleared.
v. Boulders were placed as safety brim.

For collection of results of ground vibration micro mate was set at the distance of 300 meters from blast. Setting of micro mate is shown in Fig.4.

Fig. 4: A view of setting Micro Mate at Wahola limestone quarry

Design of Experiment (DOE): 15 experimental blasts are performed at the limestone quarry to study environmental impacts. Distance is constant during all blasts i.e. 300 meters and amount of explosive, explosive ratio, drilling parameters are variables. 8 to 20 numbers of holes were drilled for each blast in different drilling parameters with the drill bit diameter of 115mm.

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Explosive were used per hole with the ratio of 10-25 % as bottom charge of high explosive and 75-90 % column charge of ANFO.

Surface connector is used to connect blast holes for detonation which is fired by using safety fuse and plain detonator. Burden was 3 to 5 meters and spacing was 3.5 to 6 meters. Blasting Parameters are shown in Table 2.

Table 2: Blasting Parameter for Experimental Blasts

PARAMETER	UNIT	VALUES
Burden	Meter	3-5
Spacing	Meter	3.5-6
Sub drilling	Meter	0.5-2
Stemming	Meter	1-2
No. of holes	No	8-20
No. of rows	No	1-4
Powder factor	kg/m3	0.3-0.6
Explosive used per hole	Kg	112-207
%age of high explosive	%age	10-25
%age of low explosive/ANFO	%age	75-90
Detonating cord	Meter	Nil
Surface connector	Nos.	As per requirement
Yield	tons/kg	**4-7**
Ground vibration Recorded	PPV (mm/sec)	**10.88-15.1**
Fly rock	Result	**High**

In above table all drilling and blasting parameters of experimental blasting are shown. The blasting site which is selected for experimental blasting is shown in fig. 5.

Fig. 5: A View of Blasting Site at Wahola Limestone Quarry

The data of all blasts is collected and then placed in tabulated form separately for each blast. Summary of all blasts shows that Blast no. 6, 8, 9, 12 and 15 are within safe limits recommended by USBM i.e.12.7 mm/sec for ground vibration. All data can be compared easily. The relationship of weight of explosive and its impact on environmental hazards is shown in Table 3.

Table 3: Results of Ground Vibration

S. no	**Explosive (kg)**	**Distance (m)**	**Ground Vibration mm/sec**	**Remarks**
Limits	**-**	**-**	**≤12.7**	
Blast no. 1	187	300	13.9	Not in Limits
Blast no. 2	203	300	14.5	Not in Limits
Blast no. 3	171	300	14.1	Not in Limits
Blast no. 4	207	300	15.1	Not in Limits
Blast no. 5	161	300	13.5	Not in Limits
Blast no. 6	**112**	**300**	**11.6**	**Within Limits**
Blast no. 7	122	300	13.1	Not in Limits
Blast no. 8	**96**	**300**	**10.88**	**Within Limits**
Blast no. 9	**105**	**300**	**10.95**	**Within Limits**
Blast no. 10	166	300	13.56	Not in Limits
Blast no. 11	179	300	14.2	Not in Limits
Blast no. 12	**120**	**300**	**11.9**	**Within Limits**

Blast no. 13	121	300	12.9	Not in Limits
Blast no. 14	182	300	13.76	Not in Limits
Blast no. 15	**119**	**300**	**12.4**	**Within Limits**

It was noted that the result of blast no. 6, 8, 9, 12 and 15 are within safe limits of USBM i.e. vibration is less than12.7 mm/second.

Relationship between Explosive (kg) and Ground Vibration (PPV):

Relationship between Explosive (kg) and Ground Vibration (PPV) is shown in Fig.6.

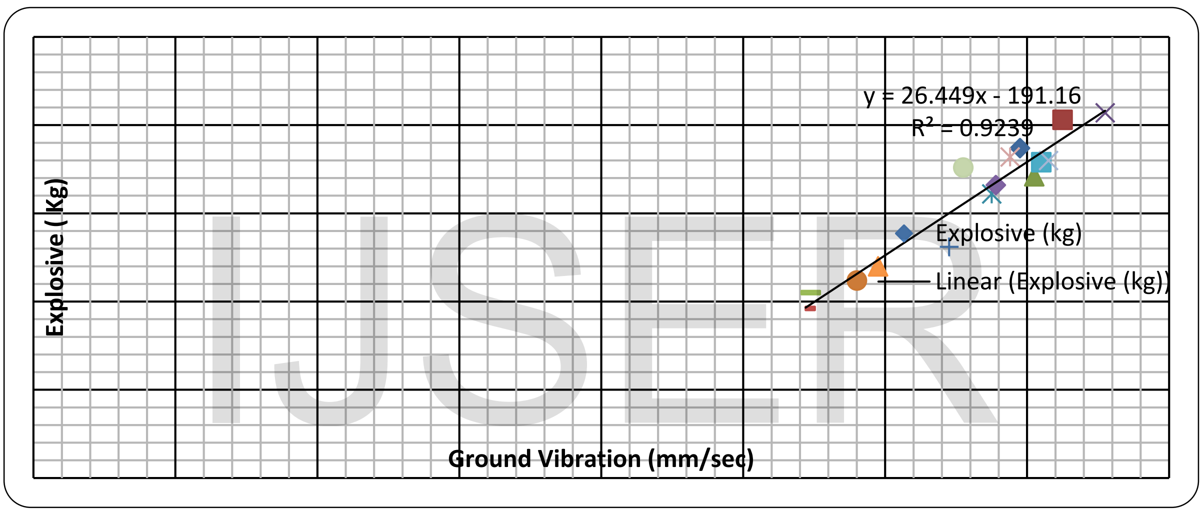

Fig. 6: Relationship between Explosive (kg) and Ground Vibration (PPV)

Above scatter plot shows direct relationship of explosive charge (kg) and ground vibrations (PPV). It can be noted that explosive charge increases from 112 kg to 207 kg and ground vibration ranges from 10.88 mm/sec to 15.1 mm/sec. Safe limits which are recommended for safe blasting operation is 12.7 mm/sec. So most of blasts are not in safe limits and but blast no. 6, 8, 9, 12 and 15 meets the requirement of safe limits i.e. less than 12.7 mm/sec so on the basis of results of experimental blasts following parameters are recommended.

Table: Recommended Standard for Safe Blasting Practices

PARAMETER	VALUES
Burden	$\leq$ 4M

Spacing	≤ 5M
Hole depth	6-16 M
Specific charge	0.3-0.4 KG / CUM
Maximum explosive	≤120 KG/HOLE
Ratio high explosive	≤15%
Ratio low explosive/ANFO	≤85%
No. Of blast hole/blast	≤10

These experimental blasting parameters can be recommended as standard for future safe blasting practices.

Result: Results of blast no. 6, 8, 9, 12 and 15 meets the requirement of safe limits i.e. less than 12.7 mm/sec. It can be concluded with satisfaction that 4 m burden, 5 m Spacing, 15 m hole depth and 0.4 kg / cum. specific charge, achieved good safe blasting results with required fragmentation. Maximum explosive 120 kg/hole with ratio of 15% high explosive and 85% ANFO is recommended. No. of blast holes should not be more than 10 for safe blast practices with single row. These parameters are safe in geological conditions of salt range, but it may show different results in other geological structures.

Conclusion:

Recommended blasting parameters lead to safe blasting practices in the area successfully without damaging any structures like coal mines. Results of ground vibrations are within safe limits as recommended by USBM. After examination of blasts with satisfactory results it was allowed by management of coal mines to blast in the area. Now safe blasting practices are started again and prohibited area is now being mined.

Findings of this study will be used as a guideline for other quarries which may have same sort of compositions and environmental issues. This study can also be helpful for persons involved in blasting operation at limestone quarries for safe blasting practices.

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