# Noise and Vibration Control in Crusher Plant Activities to Enhance Health and Safety of Workers

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**Abstract**

Fulfillment of human needs necessitates activities that have their positive and negative aspects. Crusher plant operation is not an exception. One of the major concerns related to these activities is its impact on worker health and safety. Although noise and vibration related legislation focus on reduction at the source, provision of personal protective equipment is considered as an effective method of control. The focus of this study was to look for control strategy for noise and foot transmitted vibration hazards related to fixed machineries in crusher plants. Six crusher plant sites were selected based on their varying production capacity for the study. Accordingly, selected sites were visited to carry out area noise and whole-body vibration surveys. Plant arrangement, details of crusher units, prevailing meteorological conditions and ground conditions were also recorded. Daily exposure levels were determined and sound and whole-body vibration contour maps were developed based on Control of Noise and Vibration at Work Regulations Act 2005. Relationship of areas of hazardous zones with production capacity was determined using statistical tools and the level of worker awareness was studied through one to one interviews. Cost effective controls are recommended by studying the best practices.

**Keywords:** Fixed machinery, Foot transmitted, Production capacity, Regulations

## 1. Introduction

Due to the rapid growth in demand for aggregates in Sri Lanka, metal crushers are in operation in every part of Sri Lanka. This sector contributes a considerable amount to the Gross Domestic Product of the country [1]. The productivity and the general attitude towards this sector is debatable as there is little concern towards health and safety of workers.

Thus, anticipation, recognition, evaluation and control of hazards in quarrying activities becomes vital to avoid days of lost work and long term ill health of workers in the industrial process.

Quarrying is identified as a dangerous industry [2], thus, recognizing the health and safety risk as early as possible will help in the implementation of preventive measures.

Health and safety risks recognized in quarrying activities can be due to the inhalation of airborne pollutants, high noise level, excessive vibration, awkward body postures due to badly designed work places and exposure to ionizing and non-ionizing radiation [3].

Out of these, noise and vibration are two major hazards and the effects of these are currently seen as global health concerns [4]. Exposure of over 2 million people to harmful noise level [5] and lose of over 5 million working days due to back pain [6] reveals the severity of these hazards.

Hence, demarcating zones of noise and vibration hazard in quarrying activities will act as an initial step to potentially improve workers health and safety, as this will give rise to actions of risk control.

## 2. Methodology

### 2.1 Site Selection

Six crusher plant sites with varying production capacity (mt/hour) were selected for the study based on the accessibility.

### 2.2 Premeasurement Preparation

Through walk-through survey, the position of setting lines were decided and 1m interval was chosen to take the measurements in each radial setting lines. Based on the barriers (piles, positioning of loaders, etc.) in the path of the survey the intervals were modified from one site to another and, each points at which readings were taken is located using GPS coordinates using Magellan eXplorist 510 GPS receiver. In addition to this, this walk-through survey was used to identify currently applied noise and vibration control measures.

### 2.3 Measurement and Data Processing

#### 2.3.1 Meteorological Measurement

Noise and vibration progression depends on prevailing weather conditions such as temperature, wind speed, wind direction, humidity. Thus, these were measured in one hour time interval to understand the anomalies of noise and vibration intensities.

#### 2.3.2 Area Noise and Whole-body Vibration Survey

##### 2.3.2.1 Area Noise Survey

Noise level was measured using SoundPro SE/ DL Sound level meter. As mentined above points of interest were marked in radial lines, and measurement of LA,eq was taken at 1.5m above ground (for a standing person) [1]. As crusher plant sites are steady noise generating areas, short term measurement of LA,eq was chosen as an appropriate measurement. Thus, 1 minute measurement was taken to ensure the value of LA,eq was representative [8]. Microphone was calibrated before and after the measurement as it is sensitive to humidity and pressure.

##### 2.3.2.2 Whole-body Vibration Survey

The arrow on top of the Geophone was pointed in the direction of the source (in this study Jaw crusher was kept as the main source and centre of radial setting lines). The Geophone was securely fixed to the ground with the spikes in a levelled position. Then, sensors were checked to ensure proper connection. Similar to the area noise survey the whole-body vibration (WBV) survey was planned. Interval length for monitoring was set as 1 minute in geophone trigger disabled mode and average transverse, vertical and longitudinal acceleration ($a_w$) over

20 second interval within 1 minute interval were recorded [9].

### 2.3.3 Calculation of Daily Noise Exposure (8 hour shift)

Daily noise exposure levels were calculated using Eq.(1),

$$L_{EP,d} = L_{Aeq,Te} + 10\log_{10}\frac{T_e}{T_o} \quad \text{.........(1)}$$

Where,

$L_{Aeq,Te}$ Sound level in decibels (equivalent A-weighted sound pressure level) measured over a stated period of time

$T_e$ Duration of the working day (seconds)

$T_o$ eight hours (28800 seconds)

Daily whole-body vibration parameter A(8) was calculated using Eq.(2).

$$A(8) = a_w\sqrt{\frac{T_e}{8}}\ m/s^2 \quad \text{........(2)}$$

Here,

$$a_w = \max(K_x a_{wx}, K_y a_{wy}, K_z a_{wz})$$

Where:

$$K_x = K_y = 1.4; K_z = 1$$

### 2.3.4 Development of Sound and Whole-body Vibration Contour Map

Sound and whole-body vibration contour maps were developed using "Surfer 8" software. Here the LEP,d and A(8) value were plotted in 2D UTM coordinate system based on GPS coordinates obtained.

**Table 1 - Color key used in sound contour map**

| Threshold values given in control of noise at work regulations 2005 | Colour |
|---|---|
| <80 dB (A) | Safe |
| 80-85 dB (A) | Need PPE |
| 85-87 dB (A) | Double protection |
| >87 dB (A) | Danger |

**Table 2 - Colour key used in whole-body vibration contour map**

| Threshold values given in control of vibration at work regulations 2005 | Colour |
|---|---|
| <0.5 $m/s^2$ A(8) | Safe |
| 0.5 – 1.15 $m/s^2$ A(8) | Need control |
| >1.15 $m/s^2$ A(8) | Danger |

Developed contour maps for noise and whole-body vibration intensity were used to calculate the area of the hazard zones.

Calculated area of hazard zones were plotted against production capacity of the crusher plants for both noise and whole-body vibration. Using the plotted graphs, correlations were determined using "Minitab 16" software. Linear relationship was examined using Pearson correlation and, p-value was used to determine whether the correlation coefficient is significant (if p-value >0.05, it is considered as insignificant). In case of insignificant correlation coefficient Spearman correlation coefficient was used to examine the monotonic relationship between variables.

### 2.3.5 Administration of Questionnaire

A sample of 20 workers from four different crusher plant sites was interviewed (one to one) using a structured questionnaire. This interview focused on a simple yes/ no answer for ailments suffered and personal protective equipment used.

## 3. Results and Discussion

### 3.1 Determination of Relationship between Percentage Area Associated with Hazard Zones

**Table 3 - % Area related to different production capacity in sound contour map**

| Capacity (t/h) | Area % | | |
|---|---|---|---|
| | 80-85 dB | 85-87 dB | >87 dB |
| 35 | 48.36 | 20 | 31.64 |
| 90 | 48.97 | 19.59 | 31.44 |
| 100 | 56.15 | 22.46 | 21.39 |
| 126 | 38.62 | 15.45 | 45.93 |
| 150-site A | 23.03 | 9.21 | 67.76 |
| 150-site B | 45.03 | 18.01 | 36.96 |

**Table 4 - % Area related to different production capacity in WBV contour map**

| Capacity (t/h) | Area % | |
|---|---|---|
| | 0.5-1.15 m/s² A(8) | >1.15 m/s² A(8) |
| 35 | 63.72 | 36.28 |
| 90 | 0 | 0 |
| 100 | 100 | 0 |
| 126 | 32.00 | 68.00 |
| 150 | 0 | 0 |

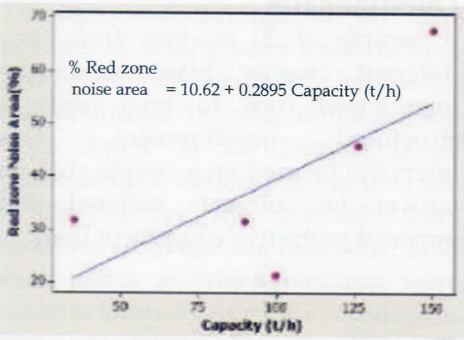


**Figure 1 - % high risk area (noise) vs. Capacity of Red zone considering 150 t/h-site A as highest capacity crusher**

| | |
|---|---|
| Pearson correlation | 0.697 |
| p-value | 0.191>0.05 |
| Spearman correlation | 0.6 |

Strong monotonically increasing relationship

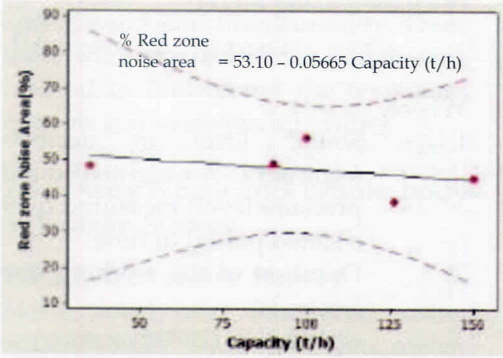


**Figure 2 - % high risk area (noise) vs. Capacity of Red zone considering 150 t/h-site B as highest capacity crusher**

| | |
|---|---|
| Pearson correlation | -0.385 |
| p-value | 0.523>0.05 |
| Spearman correlation | -0.5 |

Moderate monotonically decreasing relationship

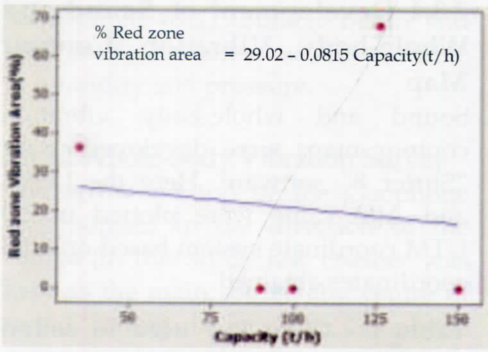


**Figure 3 - % high risk area (WBV) vs. Capacity of Red zone**

| | |
|---|---|
| Pearson correlation | -0.115 |
| p-value | 0.854>0.05 |
| Spearman correlation | -0.112 |

Very Weak monotonically decreasing relationship

### 3.2 Locating the Position of Office

**Table 5 - Distance to safe zone vs. Production capacity based on sound contour map developed**

| t/h | Maximum distance to 80 dB(A) contour(m) | % Red area | Distance/ (%Red area) |
|---|---|---|---|
| 35 | 262.05 | 31.64 | 8.28 |
| 90 | 72.5 | 31.44 | 2.31 |
| 100 | 73.53 | 21.39 | 3.44 |
| 126 | 13.64 | 45.93 | 0.30 |
| 150 | 75.83 | 36.96 | 2.05 |

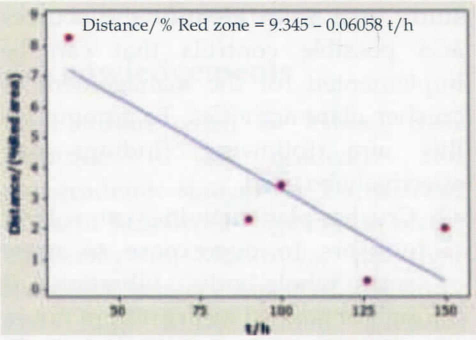


**Figure 4 - Production capacity vs Distance/ (% Red area)**

Pearson correlation -0.870
p-value 0.055>0.05
Spearman correlation -0.800
Very strong decreasing relationship

Here the data related to Figure 2 was used as % high hazard area due to the presence of similar crusher units.

### 3.3 Controlling Noise Pollution

These findings resulted in the identification of several control measures as two crusher plants have equivalent production capacity per day showing dissimilar behavior in spearman analysis (Figure 1, Figure 2).

- ***Difference in energy consumption:***

Both crusher plants have same production capacity but one consuming higher energy (3816 kWh/day > 3088 kWh/day) implies higher possibility of energy dissipation in other forms such as noise and vibration.

This implies the need of designing the plant with optimum energy usage to reduce the dissipation of energy in the form of noise and vibration.

- ***Difference in crusher units:***

Highest noise levels were recorded near secondary crushers and out of these, impact crusher shows highest noise level compared to cone crusher due to working mechanism. Comparing these it can be concluded that using less noisy alternatives whenever it is compatible will reduce the most hazardous zones.

- ***Attenuation of sound due to atmospheric condition:***

Attenuation ranges are 0.32-0.36 dB/100 meters, 0.8-1 dB/100 meters and 2.4-2.6 dB/100 meters respectively in 1000Hz, 2000Hz and 4000Hz [10]. Since these ranges result in negligible changes in small distances the effect of temperature and relative humidity is considered to be negligible in this study.

- ***Arrangement of plant:***

Piles of aggregates placed around the crusher in circular arrangement showed a rapid decrease of noise. 3-4 dB(A) difference were recorded in both side of the piles and this also acted as a contributor for this difference.

### 3.4 Controlling Vibration Pollution

Considering the relationship between plant capacity with the area of high hazard zone it shows very weak decreasing relationship (Figure 3). This implies the need for looking at other factors than the capacity of the plant.

- *Difference in crusher units:* Primary crusher showed the highest A(8) value near its mounting. This is explicit due to the highest possibility of transmission of vibration through the mounting.

### 3.5 Analysis of Interview

Analysis of responses with a margin of error of 22% at a 95% confidence level indicates the following results:

- Although the percentage of workers suffering due to ailments are low; presence of workers suffering with headache and earache implies the need for control measures.
- Further, presence of workers not using personal protective equipment (PPE) implies lack of awareness regarding noise and foot transmitted vibration.

### 3.6 Limitations

- Based on accessibility and time constraints, number of sites where interviews were conducted was restricted and margin of error was allowed to be 22%.
- In this study, area noise and WBV (place oriented) were considered rather than personal noise exposure (task oriented) due to time limitation and availability of number of instruments.
- Number of sites visited was limited due to time constraint.

### 3.7 Future Directions

- Number of crusher plants investigated will increase the significance of the study.
- In this study, workers exposure to high risk zones are confirmed, but the health effect of this exposure was identified as a hardly studied area in Sri Lanka and studies correlating the finding of this study with the effect will further help in identification of proper control measures in metal crushing industry.
- Studies regarding task oriented personal noise exposure is another possible area of study that will help to identify workers who need more consideration due to overexposure.

## 4. Conclusions

The primary aim of area noise and whole-body vibration survey in the study area is to identify the sources and possible controls that can be implemented for the management of crusher plant activities. To accomplish this aim following findings can effectively be used:

- Crusher plant activities can subject workers to overexpose to noise and whole-body vibration if proper control measures are not in place. Area noise and whole-body vibration survey mainly focusing on fixed machineries in crusher plants indicates sound and whole-body vibration levels high enough to be potential sources of worker overexposure depending on time of exposure.
- High noise level zones showing two contrasting relationship with capacity reveals the benefits of incorporation of control measures which were identified by comparison of study areas.
- Whole-body vibration showing very weak monotonically decreasing relationship with capacity indicates the low dependency of WBV in capacity. This implies the need for considering other factors such as selection of the right crusher unit, designing plant with minimum WBV effect and proper mounting.

- The (Distance/% Red area) = 9.345 – 0.06058 production capacity (t/h) conjunction with %Red area = 53.10-0.05665 production capacity (t/h) can be used to find the best location for the office based on the area noise survey conducted.
- Further, interview results reveal the need for creating more awareness regarding noise and foot transmitted vibration. This shows the need for providing proper training to workers and continuous monitoring.

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