Psychoacoustic Evaluation of Rock Crushing Plant Noise

Marko Antila, Heikki Isomoisio, Jari Kataja
VTT Technical Research Centre of Finland, Tampere, Finland

Juhamatti Heikkilä
Metso Minerals, Tampere, Finland

Summary

The noise of a rock crushing station was evaluated from psychoacoustics point of view. The noise emission of a crushing station was recorded at several locations. Psychoacoustic analysis methods were implemented and applied to the recorded noise. The objective of the research is to establish a link between the perceived noise quality and the sound absorbing and insulating materials.

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1. Introduction

The rock crushing is a process, where large pieces of rock are crushed into aggregate of various sizes and compositions. The process is carried out in 2 or 3 different phases: primary, secondary and tertiary phase. The process generates impulse, periodic and broadband noise components.

Methods to evaluate the effects of the industrial noise, including rock crushing noise are included in the Nordtest methods ACU 112 [1]. At EU level the environmental noise is assessed at EU legislation [2], and methods to evaluate environmental and crushing noise are in standards [3,4]. There are also several national Finnish studies [5,6], guidelines and statutory decrees for crushing noise (such as VNA 800/2010) but currently the most of them refer to statutory decree VNA 993/1992 concerning the environmental noise levels.

Currently, also the CEN working group CEN/TC 151 WG9 (Machines and plants for the production of cement, lime, and gypsum, including crushing, screening, sizing and recycling - Safety) is preparing the noise measurement test code for crushing and screening equipment.

However, the motivation of this study is to begin to establish a link from noise and sound quality properties to relevant sound absorption and insulation materials and structures. For this goal more information about current situation is needed. To get the data, work begun with the recording and the analysis of a rock crushing station noise.

2. Setup and methods

Sound pressure at 5 microphone positions was simultaneously recorded with a digital recorder at a sampling rate of 51.2 kHz. Microphones were arranged at various positions, elevations and distances around the crushing station. The microphones were at a height of 1.5 m above ground level. The ground level of the microphone 3 was about 5 meters higher than other microphone positions and it was located on the cliff. The positions are shown at Figure 1. Microphone 1 is near the primary crusher, microphone 2 near the secondary crusher, microphone 3 on the cliff 30 m from the crushing station, microphone 4 20 m from the screen and microphone 5 50 meters further from the microphone 4, on the same axis as microphone 4 and the crushing station.

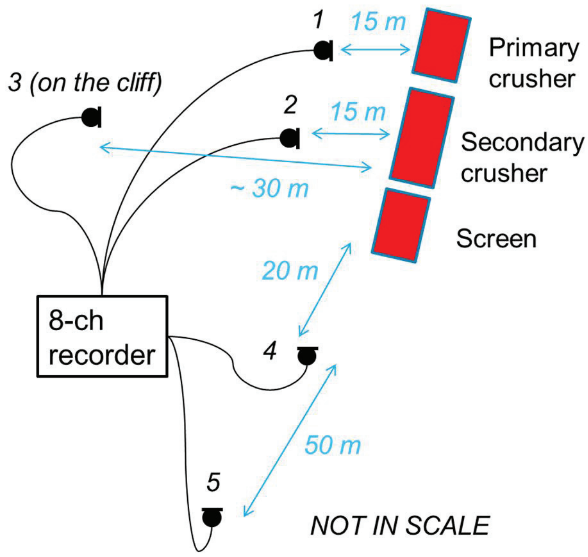

Figure 1. The measurement setup.

Figure 2. The rock crushing site.

3. Results and analysis

Recording #83 taken during run-up phase of the rock crushing plant was analyzed. The spectrogram, psychoacoustic parameters [7], and modulation indices were calculated from the calibrated, time-domain data. The different work phases of the recordings are shown in Table I.

3.1. Spectrogram

The spectrogram of the complete recording #83 below 200 Hz is in Figure 3. It also presents the L_{pAF} values (A-weighted sound pressure levels, fast time weighting) versus time for the full audio spectrum (the lower figure). In the spectrogram the strong periodic components are clearly visible, as well the broadband components when the process starts up at 9 seconds. There are several strong periodic components in the sound, listed in the Table II.

Table I. The work phases of the recording # 83.

Start time [s]	End time [s]	Work Phase	Phase description
0	5	A	Feeder filled with stones and stopped, other equipment idling
5	9	B	Feeder starts
9	18	C	First rocks into the primary crusher
18	30	D	Primary crusher at designated load, secondary crusher idling
30	45	E	First rocks to the secondary crusher
45	90	F	The screen noise increases, the screen overflow at 60 s, after that normal operation conditions

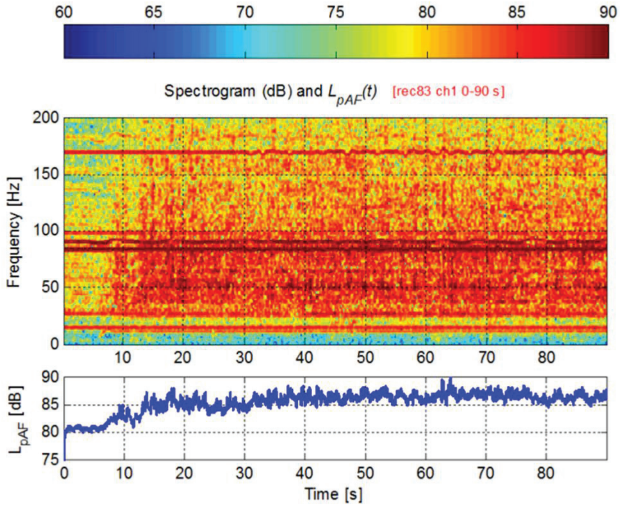

Figure 3. The noise spectrogram near the crushing station for the system run-up for frequencies below 200 Hz, at microphone 1 location.

Table II. The periodic components of the signal below 200 Hz.

f [Hz]	*Lp* [dB]	Notes
184	81	frequency fluctuates, 2 x 92 Hz
170	87	2 x 85 Hz
100	85	
92	91	frequency fluctuates
85	92	
29	86	
16	86	
13	83	begins at 6 s

4. Psychoacoustic analysis

The aim of this study is to create a link from noise and sound quality properties to relevant sound absorption and insulation materials and structures. The link may be for example an increased sound insulation or absorption on some frequencies, which are derived from psychoacoustic analysis and are not obvious in conventional noise analysis. The goal is to be able to decrease the noise-related annoyance of the citizens nearby the industrial noise source, such as a rock crushing station. For that purpose a psychoacoustic analysis of the noise data is needed.

In the psychoacoustic analysis the loudness (N), loudness exceeded in 10% of the time samples (N_{10}), mean Zwicker sharpness (S), and the overall fluctuation strength (F) were calculated for each work phase. From these psychoacoustic parameters a combination metric, Unbiased Annoyance (UBA) was calculated, using the formula proposed by Zwicker [8]

$$UBA = 1 + 0.25(S-1)\log(N+10) + \frac{0.3F(1+N_{10})}{N_{10}+0.3}$$

where S is mean Zwicker sharpness, N_{10} is the loudness exceeded in 10% of the time samples and F is the overall fluctuation strength. *UBA* was used as a starting point for a combination metric to evaluate overall effect of the rock crushing noise.

Table III. Sound quality metrics: loudness.

Phase	Loudness N_{10} [sones]				
	Microphone				
	1	2	3	4	5
A	54.1	40.7	29.4	30.9	15.9
B	57.8	41.6	33.1	31.8	17.0
C	68.3	47.0	40.4	33.9	19.4
D	76.3	52.9	48.2	37.8	23.6
E	75.6	50.4	44.0	36.6	22.3
F	79.7	57.5	50.9	45.5	25.2

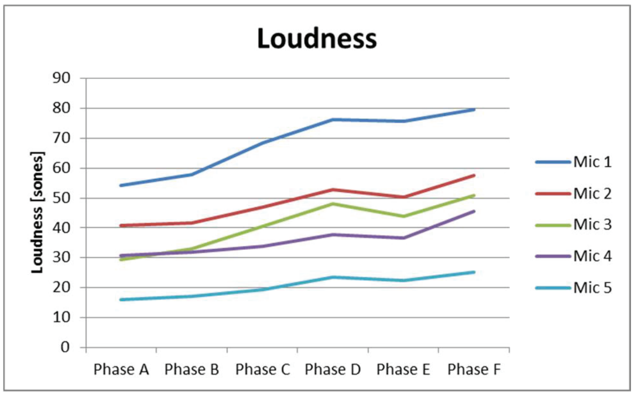

Figure 4. The loudness values for different work phases.

If the *UBA* formula is analyzed, it is obvious that the resulting *UBA* is not especially sensitive to the differences in N due to the logarithmic function. In Table III and Figure 4 the loudness levels are presented. Similarly to L_{pAF} values in Figure 3, they have an increasing trend over time when the crushing station starts up. Also, the distance from the crusher is correlated with the loudness values.

The *UBA* values are shown in Table IV and in Figure 5. In the first work phase, the highest *UBA* is at the microphone 5 which is the farthest from the crushing station and the closest microphones have lower values. When the process advances, the balance shifts between the microphones but the changes are small. The real significance of the differences is a subject for the further study.

So, listening tests and further analysis is required to determine whether used Zwicker's *UBA* realistically models the subjective annoyance of this type of noise. This also requires a more detailed analysis of the components of *UBA* to weight the level of each component properly. Studies related to the noise and annoyance [9,10] and also industrial type of noise [11] have been carried out. Nevertheless, there are few studies of the annoyance of the impulse type of rock crushing noise, as far as authors are aware of.

Table IV. Sound quality metrics: Unbiased Annoyance (*UBA*).

Phase	Unbiased annoyance				
	Microphone				
	1	2	3	4	5
A	1.64	1.67	1.72	1.74	1.77
B	1.69	1.67	1.76	1.71	1.82
C	1.94	1.76	1.95	1.72	1.84
D	1.92	1.76	1.98	1.82	1.88
E	1.88	1.76	1.91	1.78	1.81
F	1.81	1.74	1.86	1.81	1.80

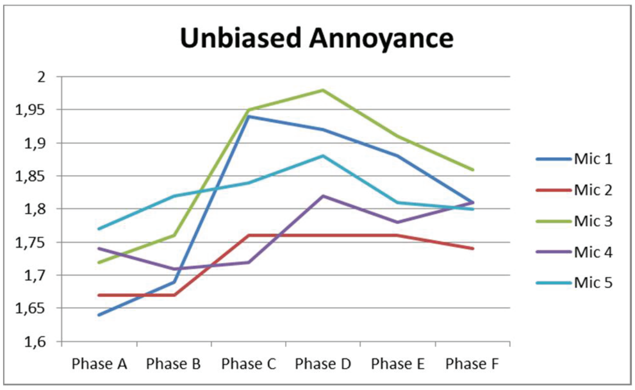

Figure 5. The Unbiased Annoyance values for different work phases.

4.1. Modulation analysis

The calculation of the modulation spectra is a good to get insight of the phenomena of the noise excitations. As such, it is also a link between the sound quality and mechanical, noise generating structure.

The sound pressure time series data was divided into sections according to work phases. The data of each time section and microphone was processed into 22 modulation spectra. Figure 6 illustrates detected amplitude modulation candidates in this dataset. The most probable amplitude modulation occurs at a modulation frequency of 3.8 Hz which is the cycle frequency of the primary crusher. Notably, there is no modulation at 1.9 Hz.

Modulation probably occurs also at the screening frequency 15.8 Hz with carrier frequencies from 1 kHz corresponding well with the perception of a rough wide-band noise. Modulation frequency 3.8 Hz modulates carrier frequencies at about 50...1200 Hz, 3300...3700 Hz and 5500...6000 Hz. Modulation depth is not accounted for in the figure and all dots are of equal opacity.

5. Conclusions and discussion

The run-up noise of a crushing station was recorded and analyzed. The analysis included the noise levels, spectrogram, psychoacoustic metrics and modulation. Each of these analyses reveals different views into the signal.

As future work, listening tests and more analysis are needed to evaluate the annoyance factor and relevance of unbiased annoyance in that sense.

That is especially important when assessing the effects of different sound insulation and absorption measures at the crushing station, as the primary motivation of the study is to establish a link between sound quality and sound absorbing and insulating materials.

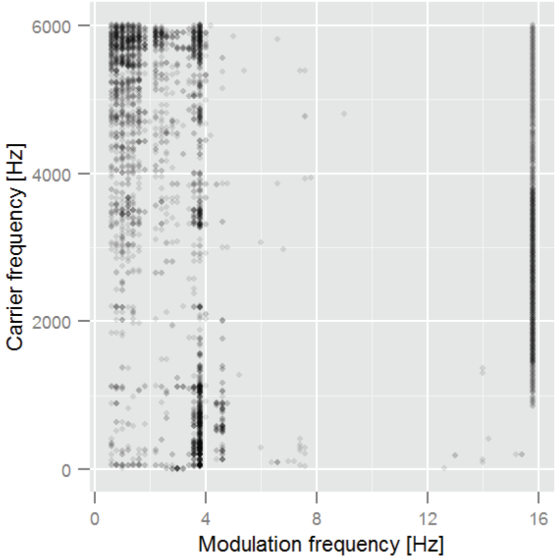

Figure 6. Scatter plot of modulation spectra.

This study was a first trial to assess these factors and also served as a tool for process development and evaluation of the methods.

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