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Human reaction to vibrations from blasting activity – Norwegian exposure–effect relationships

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ABSTRACT

Rock blasting may cause disturbances, fear, and annoyance in residential and community areas affected by such activities. These community reactions can be quite strong, even when the blasting activities and the resulting vibrations are unlikely to cause physical damage to building foundations or buildings. A socio-vibrational survey was undertaken to assess residential reactions to blasting activities. Vibration velocities were obtained for 520 respondent dwellings located in seven study areas, and compared to the residents' assessments of environment quality. Even at low vibration values, many people report annoyance. Exposure–effect relationships with acceptable statistical error bands were obtained. The level of annoyance from long-term blasting activities (quarry blasting) was not higher than from finite periods of more intense blasting activities (road and rail tunnels). Providing information in advance of the blasting activities, can reduce community reactions. Self-reported sensitivity to vibrations was associated with significantly increased annoyance. Sensitivity to vibrations was uncorrelated with exposure to vibrations. Sensitivity to noise and sensitivity to vibration were moderately correlated.

1. Introduction

1.1. Background

Guideline values in the Norwegian Standard NS 8141-1, "*Vibration and shock – Guideline limit values for construction work, open-pit and pit mining and traffic – Part 1: Effects of vibration and air blast from blasting on construction works, including tunnels and rock caverns*" [1], are designed to avoid damage to building foundations and constructions from blast-induced vibrations. However, residents' reactions to blasts at construction sites in their neighborhood may also cause fear, and annoyance, and may lead to complaints, work delays and legal processing. To provide blasting professionals, entrepreneurs and authorities information on residents' reactions to blast-induced building vibrations, it was decided to undertake a socio-vibrational survey, the results from which were to be included as an informative annex to this Norwegian Standard [2].

The aim of the study was to:

(a) Obtain vibration measurements and calculations for each building in residential areas near construction sites with recent blasting activity.
(b) Obtain responses to questions on how the residents experienced and how they were affected by the vibrations.
(c) Estimate exposure–effect relationships between an indicator for vibration magnitude and people's reactions.

It was not known beforehand if it would be possible to establish exposure–effect relationships. However, provided that the study design and execution was of sufficient quality, failure to do so would also provide useful information.

In many exposure–effect relationships, log-transformed exposure values are applied since it is the relative, and not the absolute, increases that count. This is well known from noise research where the logarithmic scale is used [3,4]. For human reactions to vibrations in dwellings from passing rail and heavy road traffic, we have previously found that the log-transformed values were better predictors of annoyance [5,6].

If successful, the study would provide information on how community reactions increase with the magnitude of the vibration, and on the potential influence of modifying factors on these relationships. This would provide blasting professionals guidance

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on planning and execution of the blasting, enabling them to take preventive measures.

1.2. Literature review

A literature review on community reactions to vibrations revealed only a few studies, most of them on vibration from transportation sources [7–15]. Waddington et al. [12,16] discuss the relative merit of different descriptors of exposure to vibration. Only a few papers deal specifically with blasting activities [17–19].

Some standards set threshold values for human exposure to vibration at buildings, based on different types of sources, also for transients from blasting.

Latest ISO 2631-2 [20] states that situations exist where significantly higher vibration magnitudes can be tolerated, particularly for temporary disturbances and transient events, e.g. construction projects. However, the ISO community did not manage to agree on the limits that where given in the previous edition from 1989, and the limits where deleted from the edition in 2003. Later, construction experts adopted the previous limits in ISO 10137 [21] where threshold values for acceptable vibration are given also for transient vibrations from construction, mining or quarry blasting and other construction activities (pile driving, compaction, excavation, etc.).

They seem to be based on studies by Dowding [22]. It is also stated that the relationship between the number of events per day, their magnitudes and durations seem not to be well established.

Gidlöf-Gunnarsson et al. [13] and Öhrström et al. [7] found that people are more annoyed by noise from railway, if they also were exposed to vibration from railway (and also the other way around). Klæboe et al. [15] found no significant difference in annoyance between vibration from road traffic and railway. Waddington et al. [12] found that people were somewhat less annoyed by vibration from railways, than vibrations from construction work. People are more annoyed by a few blasting's with high intensity, than a higher number of blasting's with low intensity [18]. The duration of the blasting can influence the level of annoyance [23].

In the Norwegian study of human reactions to vibrations in dwellings, a frequency weighting applicable for human responses was used [6]. This is a frequency weighting that puts more weight on frequencies between 4 Hz and 100 Hz.

The weighting factors used for vibrations according to NS 8141 targets building damages. The frequencies between 2 Hz and 20 Hz receive the greatest weight when calculating the velocity indicator v_f (see Fig. 1.1).

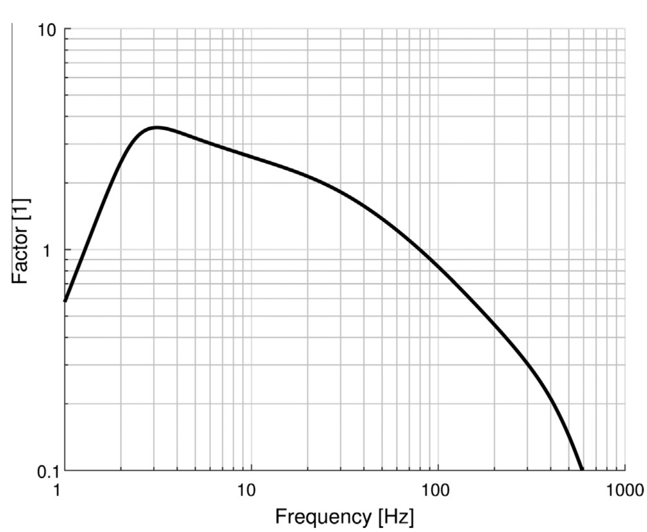

Fig. 1.1. Frequency weighting filter applied for evaluating building damage, used in [1].

Table 1.1
Guidance on effects of vibration levels from BS 5228-2 [24].

Peak level v	Effect
0.14	Vibrations might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibrations
0.30	Vibration might be just perceptible in residential environments
1.00	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents
10.00	Vibration is likely to be intolerable for any more than a very brief exposure to this level

The British Standard BS 5228-2 [24], Table 1.1 describes the expected level of human reactions to vibrations as a function of peak velocities.

To compare the results against the human responses as a function of the frequency weighted velocities, we have calculated the corresponding frequency weighted peak velocity values – see Table A.6 in the Appendix.

Since the main purpose of the new standard is to prevent building damages, the focus was on establishing exposure effect relationship with the same exposure measure as used in the standard.

2. Method

2.1. Study areas, dwelling characteristics and sampling procedure

Seven study areas from different parts of Norway with ongoing or recent blasting activities (less than a year ago) were selected:

- 3 areas in close proximity to rock *quarries*
- 1 area close to a *railway tunnel construction* site
- 1 area close to a *building construction* site and
- 2 areas close to *road tunnel construction* sites

75% of the buildings were of wood-frame structures, 17% concrete, and 8% masonry structures. 30% of the dwellings were founded on rock, 19% on harder soils, and 20% on soft ground. Information on foundation type was missing for 25% of the dwellings.

The socio-vibrational study was performed by using a written questionnaire. Vibration exposure indicators for blasting were found for each respondents dwelling. Between 2010 and 2013, the questionnaire was sent to residents by ordinary mail. These were addressed to the registered owners or tenants. In the cases were the dwelling was owned by more than one person, the respondents themselves could choose which one to answer the questionnaire.

In total 1885 questionnaires were sent. In one of the study areas we unfortunately got many of the questionnaires in return, this was an area with a lot of student housing, who had moved out of their apartment shortly after the blasting. All the unopened returned questionnaires were excluded. After reminders, 520 people had responded in total giving a response rate of 43%. This is less than in an ideal case, but better than expected for this type of surveys in Norway.

The response rate varied between 33% and 58% in the selected areas, see Table 2.1.

At three of the sites, participants were selected among dwellings where vibration measurements were performed during the construction work, i.e. dwellings close enough to the blasting site to be considered probably affected by the vibration from blasting. For the three quarry sites and one of the road tunnel sites, the questionnaire was sent to all households close enough to be