Study on human reactions to vibration from blasting activities nearby dwellings

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ABSTRACT

Human reactions to vibration were studied in connection to preparation of Norwegian Standard, NS 8141-1. The standard concerns vibration that may cause building damage. However, complaints, fear, disturbances and other human reactions on vibration from construction work, especially blasting activities are likely to occur at much lower vibration levels than those causing building damage. If the human reactions are not taken into account, delays and problems at construction work may occur. The aim of this study was to provide some guidance on expected level of annoyance, and factors affecting human reactions to the blasting activities.

The study was conducted as a socio-vibrational survey on people's annoyance on vibrations from blasting as a function of vibration indicators. Vibration velocities were obtained for 520 respondent dwellings in seven study areas nearby construction sites. The inhabitants got a written questionnaire that could be responded through a website. Exposure-effect relationships with acceptable statistical error bands were established with weighted (related to building damage) and unweighted peak values of vibration velocity. The resulting exposure-effect curves were included in an informative Amendment in the Norwegian Standard.

INTRODUCTION

Peoples' adverse reactions to vibration from blasting and construction works has been a topic among builders and within environmental health care in Norway during many years. People often get scared or annoyed, disturbed in their activities, afraid about building damage etc. These matters lead to complaints that have to be resolved during the daily construction work and may delay the building projects making the construction work much more costly. People's reactions occur at lower vibration levels than damage for the buildings. A need for research on this item was clearly identified during preparation of a Norwegian Standard on vibration and building damage, NS 8141 [3, 5].

In the literature, only few studies were found to concern blasting activities and human exposure. An early edition of the International standard ISO 2361-2 [1] stated that significantly higher vibration magnitudes can be tolerated, particularly temporary disturbances and transient events of short duration. Later, these human vibration exposure limits were not agreed on, and the limits were deleted in the 2003 edition. As a consequence, constructors adopted the previous limit values in ISO 10137 [2], probably due to lack of other qualified data.

During preparation of a revised Norwegian standard NS 8141 [3, 4, 5] at the years from 2008 to 2013, it was decided to make a survey at dwellings nearby construction sites and permanent open-pit mining/quarries [9, 11]. The aim of the study was to map peoples' reactions and relate these to the measured or estimated peak vibration values determined as given in the standard, i.e. exposure-effect relationships based on vibrations causing possible building damage.

EXPOSURE DATA

Study areas

We had experience from a previous socio-vibrational study [6, 7, 8] that was made in connection to preparation of Norwegian standard NS 8176 [10]. NS 8176 deals with measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings.

The present study areas were selected so that the blasting activity had happened less than 12 months before the survey. Seven areas were found to fulfil the criteria at sites where vibration data for the recent blasting activities were available. These seven study areas were as follows: three areas were in close proximity to rock quarries, one close to a railway tunnel site, one nearby a building construction site and two close to road tunnel construction sites. Three of these areas had ongoing blasting activities, and vibrations could easily be measured due to monitoring of the blasting.

In case of lack of measured vibration data for a dwelling, calculations were made from measurements on nearby buildings. Thereby, we could include some more areas where the vibration data were not directly available. The buildings were however close enough to be registered as affected sites by the constructors.

The building structures have influence on how the vibrations act on the building and the types of building materials were therefore registered. About 75 % of the buildings were wooden structures which is very common in Norway, and the rest of the buildings were either concrete or masonry structures.

Measurements

Vibration velocities were measured by using geophones. Primarily, measurements were made at the building foundation during the construction period, as it is advised in NS 8141-1 [5]. In case of lack of measurement data for a dwelling, vibration values were calculated from other buildings in the same area. Both frequency weighted and unweighted peak vibration values were available. The measured data were recorded as unweighted time series. Five time series with the highest registered unweighted peak vibration velocities were selected for each dwelling.

Time series were filtered using the frequency weighting described in NS 8141-1 [5]. This frequency-weighting filter is constructed in order to put weight on low frequencies that may cause building damages. This filter is therefore not comparable with the filters that are constructed for evaluation of people's sensitivity for vibrations, like in NS 8176 [10] and ISO

2631 [1]. The filter is constructed so that the signal passes through the filter unchanged at 80 Hz, and most weight is put on low frequencies that are likely to damage the building. Due to the differences in these filters, the exposure-effect analyses were made with both weighted and unweighted data.

The vibration exposure data varied mainly between 1 mm/s and 50 mm/s, with an average around 14 mm/s. A limited number of peak velocity values were significantly higher. Vibration velocities varied at the different construction sites [9, 11]. All values were included in the analyses.

Limitation in the exposure values is determined by the standard NS 8141-1 [5]. When the blasting activities comply with the standard, the vibration values should not exceed 50 mm/s. This upper limit was set in the standard to avoid excessive human reactions that are likely to appear above these values. Reconsideration of the limits is carried out at the writing moment due to complaints from constructors on considerable and costly reductions, or stop, in progress of an ongoing construction works.

SURVEY

Written questionnaire

A written questionnaire, based on the previous study [6, 7], was used for collecting human responses to blasting activities. The written survey (in Norwegian) may be found in an Appendix of ref. [11]. It was distributed to the inhabitants living at the seven study areas. They had the option to reply by using a website. The survey was introduced as a community study of the neighbourhood quality and living quality. The aim of it was not masked, and the main focus was obvious from the latter part of the survey.

The verbal scale of the questionnaire was similar to the one used in the survey on vibrations from landbased transport [6, 7, 8]. The response scale was: *highly annoyed*, *somewhat annoyed*, *slightly annoyed* and *not annoyed/did not notice*. The scale was selected in order to be able to compare the two Norwegian studies. The questions were formed in accordance with a Technical specification for evaluation of noise annoyance, ISO/TS 15666 [12].

In total, 1885 questionnaires were sent. On average 43 % of recipients, i.e. 520 people, responded to the questionnaire. Between the selected areas, response rate varied between 33 % and 58 % [9, 10]. These percentages comply with comparable studies in Norway, and the response rate was considered as good enough. A large portion of the returns without responses came from one student housing area, and some were from people that had changed residency from the study areas shortly after blasting activities started.

Modifying factors

As mentioned, environmental factors and other modifying factors were included in the questionnaire. One of the factors was sensitivity to noise and/or vibration. It has been shown in other studies, e.g. by Klæboe [14], to be a personal trait that influences the people's responses. This characteristic was treated, among others, as an explanatory or modifying factor in this survey.

The modifying factors that were used in the questionnaire were such as:

- general well-being, gender, age;
- if blasting had been performed during the last year;
- if the respondent had been annoyed by vibrations, noise or air pollution;
- if the respondent had been at home during the blasting;

- how the respondent had noticed the blasting (shaking of the house / indoor / fixtures / windows etc.);
- if the vibrations caused problems for the respondent in the dwelling (sleeping problems, worries about building damage or similar);
- if the respondent was satisfied with the information prior to the blasting activities.

EXPOSURE–EFFECT RELATIONSHIPS AND STATISTICS

This study aimed at getting exposure-effect relationship between the vibration exposure from blasting activities as the vibration indicator, and adverse human responses to these, as mentioned in the Introduction. These relationships have been based on log-transformed values that are found to be better predictors of annoyance in the previous study [6, 7, 8].

The present exposure-effect relationships between vibration indicators and annoyance responses were estimated by using ordinal logit models. Klæboe *et al*. [8] applied the same method with success in an earlier study. Klæboe *et al*. present details and results from the present statistical analyses in ref. [9, 11].

The ordinal logit analyses were run both for vibration velocity, v_f , and log-transformed vibration velocity, lg v_f. The explanatory power of both descriptors was similar. The logarithmic values, lg v_f, were used in the further analysis. Both unweighted and weighted vibration values gave similar results without significant preference.

The modifying factors that were a part of the questionnaire, such as gender, age, vibration or noise sensitivity, being at home during blasting, duration after latest blasting activities, duration of the blasting activities, information prior to blasting activities, etc., were controlled as far as it was possible within the limited financing [11].

RESULTS

Results of this survey show clearly that increasing vibration exposure increases people's annoyance reactions. As stated, there was no significant preference for unweighted and weighted vibration values. The human responses are much stronger than in the previous study with landbased transport [6, 7], as could be expected due to the high values of blasting exposure. Possibly, the high level of annoyance due to high exposure may wipe out the differences between unweighted and weighted values.

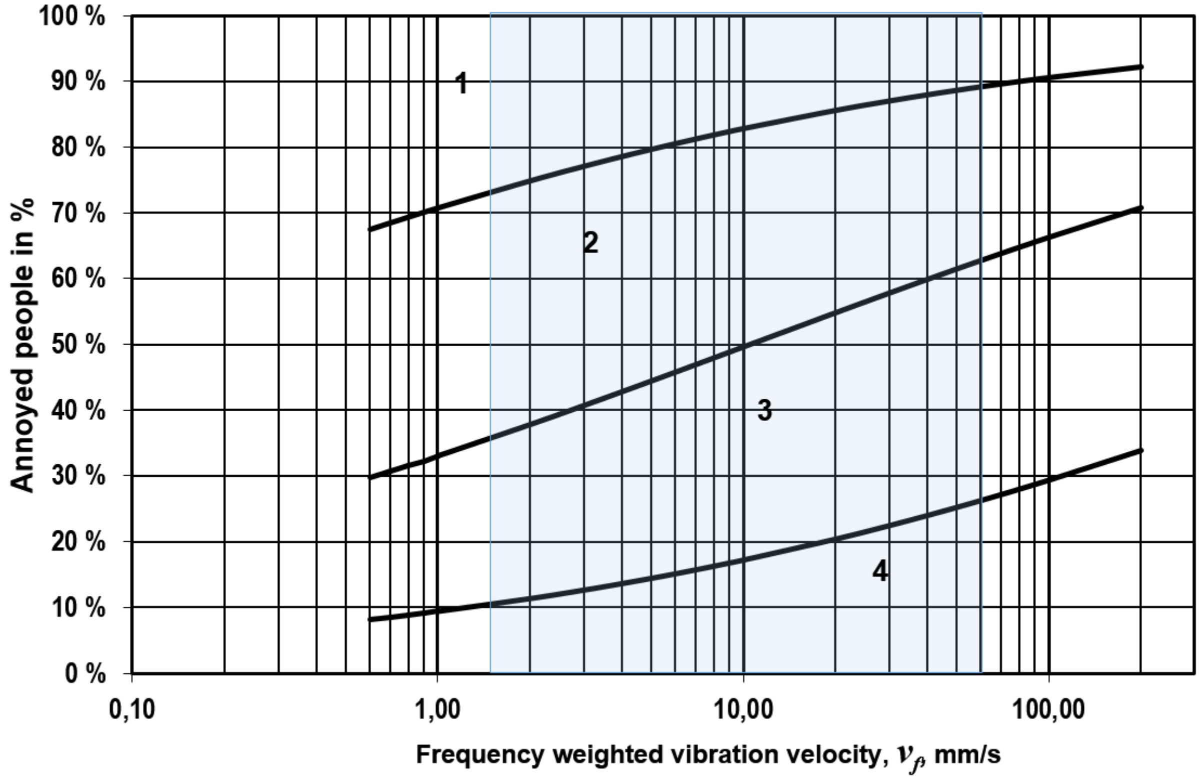
The difference between the exposure values in the present study and the previous one [6, 7] is the filtering. The exposure-effect curves are therefore not directly comparable with each other, as mentioned earlier. In addition, there is a great difference in the vibration exposure, i.e. the exposure is much higher. Unfortunately, there was not enough financing to run several analyses with the filters made for simulating human responses [1, 13].

In table 1, results on questions about annoyance from noise and vibrations indoors are shown as experienced by respondents. About 49 % of the subjects were *highly or somewhat annoyed* by vibration from blasting, around 19 % were *not annoyed*, or *did not notice*, the vibrations. In the same time, 37 % reported that they were *highly or somewhat annoyed* by noise from blasting. Combined effects of vibration and noise may influence these results.

Table 1: Annoyance due to vibration and noise from blasting activities in neighbourhood of living areas

Question	**Highly annoyed** %	**Somewhat annoyed** %	**Slightly annoyed** %	**Not annoyed** %	**Did not notice** %
Vibrations from blasting when *indoors* in your dwelling? (*N* = 490)	19.6	29.8	31.6	18.0	1.0
Noise from blasting when *indoors* in your dwelling? (*N* = 487)	16.2	20.9	26.9	32.9	3.1

In figure 1, exposure-effect curves for vibration velocity, v_f , and human annoyance are shown, see also [4]. Uncertainty curves for the results may be found in [8, 10] with 95 % confidence intervals for the estimated parameters.



Key
1 Not annoyed or did not notice
2 Highly, somewhat and a little annoyed
3 Highly and somewhat annoyed
4 Highly annoyed

Figure 1: Cumulative exposure-effect curves with percentages of annoyed people in dwellings, related to frequency weighted vibration velocity. Light blue colour indicates the main range of results. Outside this range, the number of respondents is less

Most of the respondents reported other occurrences like rattling of fixtures, fittings, windows and similar, see table 2. About 50 % of the respondents were also worried about building damages in their dwellings. Almost 25 % were scared or worried in general.

Table 2: Annoyance reported due to rattling of house, fixtures, fittings, windows and similar, indoors

Question	At every blast %	At some blasts %	Never %
Dwelling trembled/vibrated (*N* = 463)	53.3	38.7	8.0
Fixtures and fittings were rattling (*N* = 444)	27.3	50.2	22.5
Windows were rattling (*N* = 425)	13.2	36.5	50.5
Feeling vibrations on the body (*N* = 446)	24.4	46.2	29.4

In general, the respondents considered building construction work as the most annoying matter in their living area. Around 53 % were annoyed. 35 % of respondents were annoyed by road traffic. Noise from neighbours annoyed more than 11 %. Less than 10 % of respondents were annoyed by each of conditions as industry, loud music, dust from fireplaces, train and air traffic.

Modifying factors like gender, age or sensitivity to noise did not have significant correlation with vibration annoyance. Reactions to vibration and noise from blasting when being indoors, were highly correlated (Pearson r = 0,80, Spearman ρ = 0,79), for statistical details see [9]. Long-term exposure from open-pit mining or quarries was not significantly different from that from other construction sites. The low number of responses from areas nearby these sites may influence this result.

The information given prior to the blasting activities had a significant influence on people's reactions. Those who rated the information as satisfactory, reported less annoyance than those who were not satisfied with the information. The responses show that about 29 % of the respondents considered the information as very good and 55 % as good. About 11 % considered the information poor and 5 % as very poor.

Approximately 60 % of the participants reported sensitivity to noise and vibration. Self-reported sensitivity to vibration had strong correlation with the degree of reported annoyance. Less than one-fifth reported that they were very sensitive to both vibration and noise.

The elapsed time after the latest blasting and reported annoyance had a clear correlation. A shorter time from the last blasting resulted in a higher annoyance response. Those who had the last blasting activities between 0 to 3 months before the survey, showed the highest annoyance. Gradually, the annoyance score became lower from 3 to 6 months, and from 6 to 12 months. Those who reported being at home in the daytime, were somewhat more annoyed.

CONCLUSIONS

The main purpose for all limit values in NS 8141-1 [5] is to avoid building damage. The limits for vibration velocity from construction work are lower than those causing building damage, but human experience of vibrations may be quite strong. Due to lack of knowledge, the aim of the study was to get more information about people's reactions to vibration from blasting activities.

The exposure-effect curves in this study are related to vibration velocities measured at the foundation of the buildings, i.e. measured as described in the standard. This study shows about the same correlation between vibration velocity and degree of annoyance regardless the exposure values are weighted or not. This might be due to the generally high levels of vibration. Compared to our previous study, the vibration values here may be 10 to 100 times higher than those from landbased transport.

The results from the study were used for giving guidance to describe human reactions in the Norwegian standard, i.e. Amendment A2 [4] was prepared to NS 8141-1 concerning human reactions. The amendment is intended as guidance for planning of the construction work and for evaluating expected reactions of people in the neighbourhood. The constructors may apply this information for modifying their blasting activities, especially at densely populated areas. Good planning of the construction work and time frames can reduce the costs and delays in the work.

Maybe the most essential matter is that the constructors give good quality information to inhabitants in the nearby dwellings, before starting their blasting activities. Annoyance responses depended significantly on the information the respondents received. Disseminating information on upcoming blasting may reduce the complaints and breaks in the construction work.

These results show also that vibration limits for landbased transport differ considerably from vibration velocities caused by constructions works. Use of such low limits as those for landbased transport will stop carrying out construction work. Vibration class limits for landbased transport in NS 8176 [10] are at the range from 0,1 mm/s to 0,6 mm/s. These are sometimes applied as limits for blasting vibration from quarries and other similar sites. Additional analysis of the data with parameters related to human exposure would benefit the comparisons and solutions.

Other means of avoiding strong vibration annoyance is to offer the inhabitants to move temporarily to another place during the worst blasting activities, as it is already practised.

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