6. INDICATOR FOR VIBRATION ANNOYANCE

6.1 Introduction

The fourth objective of this desk study is the determination of one or more indicators for vibration annoyance without knowledge about the actual vibration magnitudes.
Plausible indicators are:

- distance from the source that emits vibrations. For railway-induced vibrations it has been shown that percentage of people annoyed by vibrations is an increasing function of the vibration magnitude measured in the dwelling up to high vibration magnitudes and then remains constant for higher magnitudes. Since vibration magnitude is a decreasing function of distance from the source, it is obvious that actual vibration magnitudes in dwellings and percentage of people annoyed are determined by both the distance from the source and the magnitude of the vibrations emitted by the source. Therefore, it seems plausible that categories of sources have to be distinguished with respect to their vibration emission. Then, for the separate categories distance may be a useful indicator;
- number of vibration events per 24 hours or parts of the 24 hours period. In the investigation by Woodroof and Griffin (1987) it was shown that the number of trains passing a site had a higher correlation to vibration annoyance than any vibration magnitude measure;
- measures related to the noise from the same source that also emits vibrations.

In section 6.2 two field studies (Fields and Walker, 1982; Öhrström and Skanberg, 1994,1995) and a compilation of field studies (Miedema and de Jong, 1993) which present information about possible descriptors will be summarized.

6.2 Information about field investigations

Fields and Walker (1982; see also Fields, 1979) carried out an investigation concerning annoyance from railway noise and vibration in residential areas. Extensive noise measurements have been made, but no vibration measurements. Four types of reactions to vibration have been recorded from the answers of 1453 respondents to the questionnaire. These reactions have been related to the distance of the dwelling to the railroad. The result is given in figure 6.1. Although the reactions are plotted as a function of distance, the authors state that a better fit would be obtained using a logarithmic transformation. The specific effects of vibration which caused the disturbance were not identified. Thus, it is not known whether and to what extent annoyance is caused by, e.g., disturbance of activities, anxiety about supposed damage of the building or a disagreeable physiological sensation.

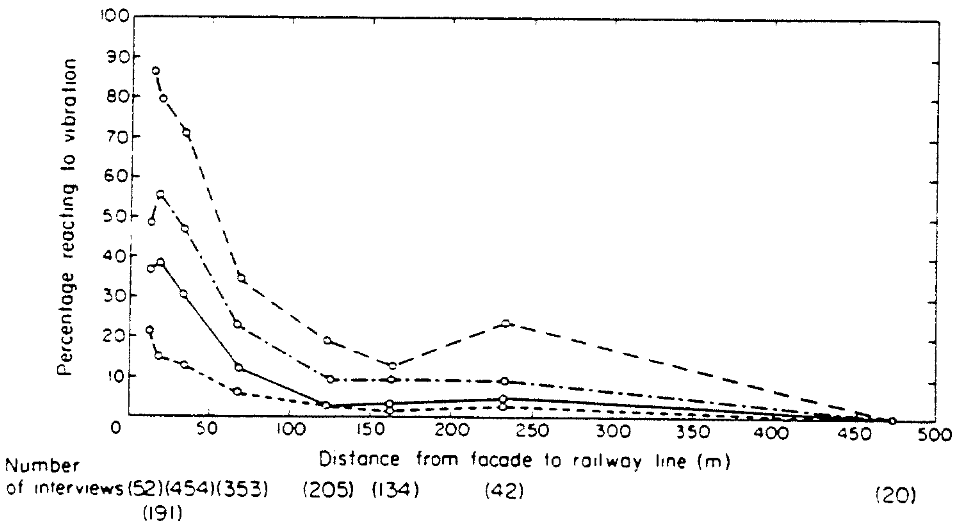
Figure 6.1 Four reactions to vibrations as a function of the distance of the railway to the house.

- - - - do the trains ever make your house or things in it vibrate or shake or rattle?

-.-.-.-. if vibration is noticed, are you at least a little annoyed?

——— if vibration is noticed, would you say that the vibration caused by the trains is a problem or not?

. . . . . if vibration is noticed, are you very annoyed when the trains make the house vibrate or shake?



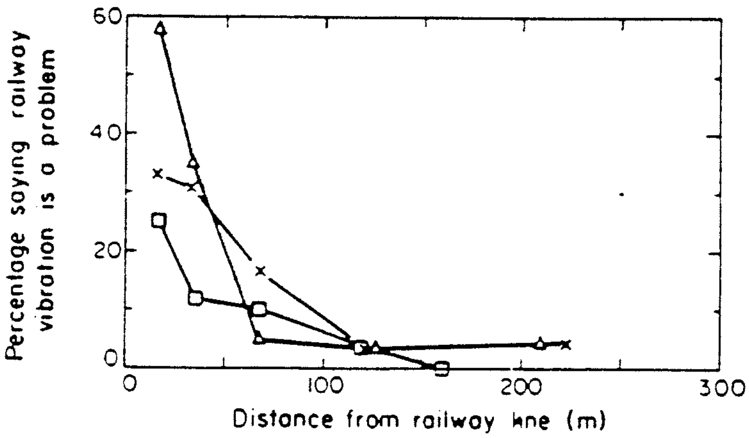
The figure suggests that over 200 m from the railroad negative reactions are still observed. However, this observation should be interpreted with care since only a small number of respondents lived beyond 200 metres from the railway: 42 (2,9%) between 200 and 300 meters and 20 (1,4%) between 300 and 500 meters.

In addition to distance, other variables have been related to vibration reactions. These are, ordered from high to low correlation with vibration reactions:

- train traffic density (log number of trains per 24 hours);
- night usage of railroad (percent of trains per night);
- speed of the trains;
- nearness to railway property;
- visibility of trains.

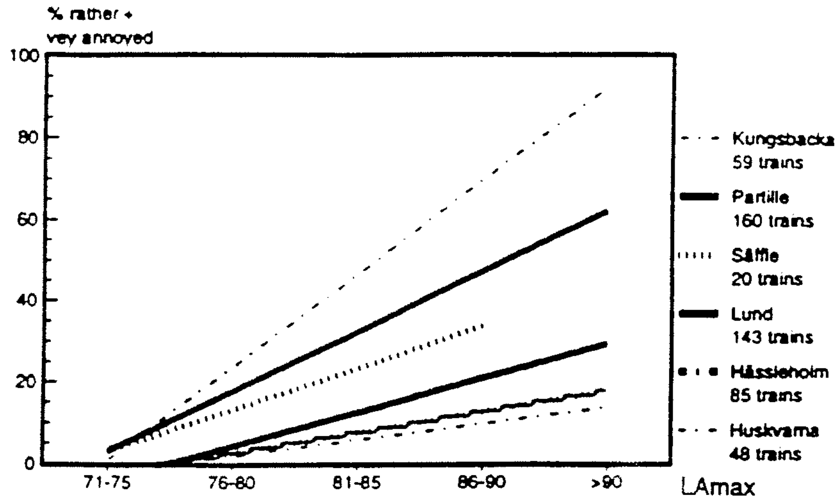
Figure 6.2 shows the effect of night-time usage of the railway. It suggest that at the short distance from the railway (< 50 m) night-time railway traffic is a factor related to the percentage of people having problems with railway-induced vibrations. This is contrary to the results of the investigation with respect to noise exposure: night-time railway-induced noise did not have a larger effect on annoyance than day-time railway-induced noise. For the other possible indicators no other information than the correlation coefficient is given in the publications.

Figure 6.2 Effect of night-time traffic on reports of vibration as a problem. Percentage of the total number of trains at night [], 0-5%; x, 6-21%; Δ, 22% or more (Source: Fields and Walker, 1982).



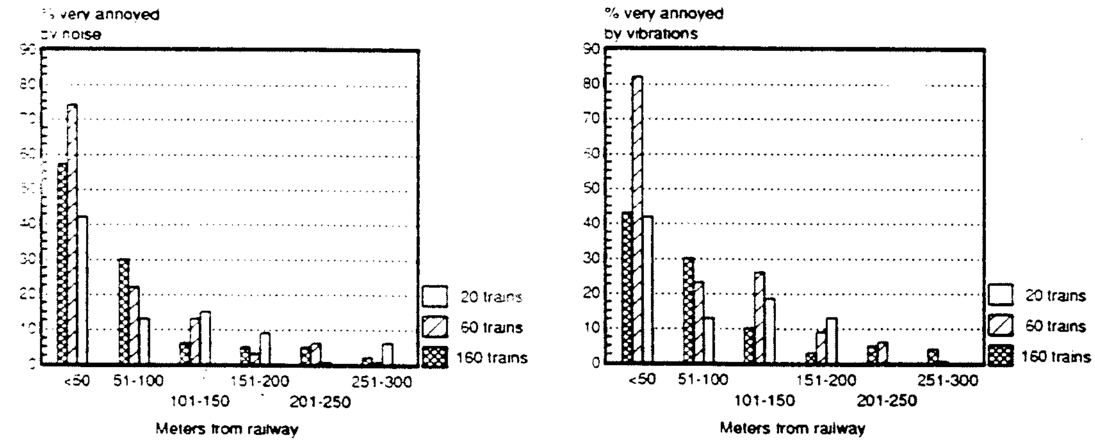
Öhrström and Skanberg (1994, 1995) present results of a field investigation on effects of exposure to noise and vibrations from railway traffic. Fifteen different sites located near railway lines were investigated. The study covered areas with different number of trains per 24 hours and different vibration magnitudes. The areas were divided into two classes: one with vibrations 'weaker than 1 mms^{-1}' and one with vibrations 'exceeding 2 mms^{-1}'. In both papers this vibration magnitude measure has not been defined nor explained. A postal questionnaire was filled up by 2833 respondents. The results in figure 6.3 show that railway *noise* is experienced as (much) more annoying in areas where there is simultaneous exposure to railway-induced vibrations.

Figure 6.3 Relations between percentage of people rather and very annoyed by railway-induced *noise* as a function of L_{Amax} for several areas with different number of trains per 24 hours and different vibration levels. Säffle, Kungsbacka, and Partille are high vibration areas and the other three are low vibration areas (Source: Öhrström and Skanberg, 1995).



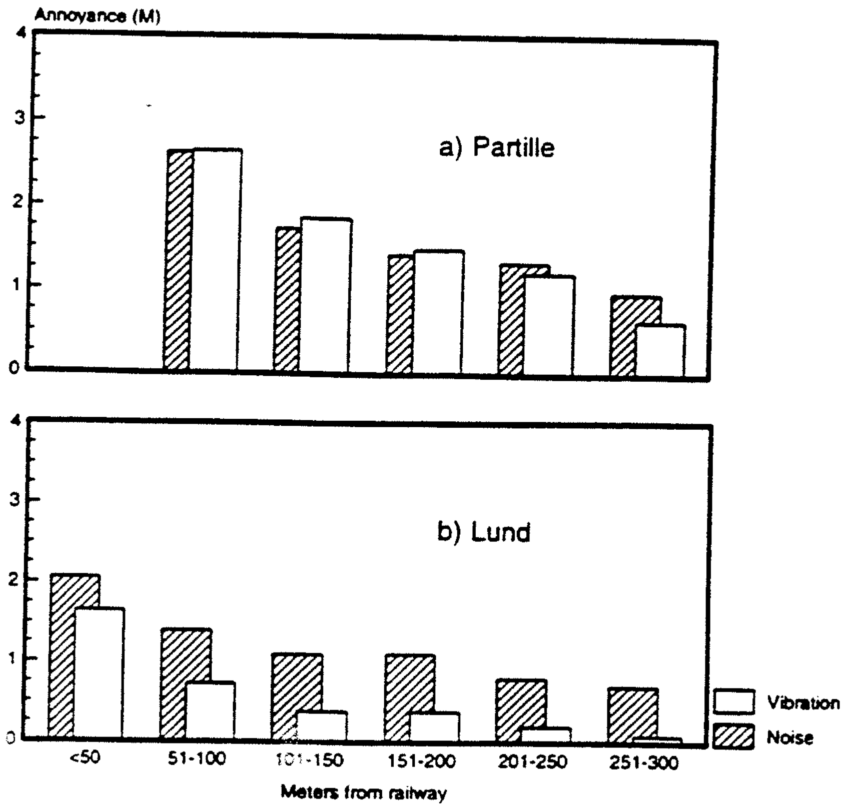
In figure 6.4 the percentage of people very annoyed by vibrations due to railway traffic is given as a function of the distance from the railway. On average for a given number of trains per 24 hours, this percentage decreases with increasing distance from the railway. When the results for the different number of trains are compared, at most distances the percentage of people very annoyed by vibrations is larger for 60 trains than for 160 trains. The same seems to hold for noise-induced annoyance, as is also shown in figure 6.4.

Figure 6.4 Percentage of people very much annoyed by noise (left figure) and vibrations (right figure) from railroad traffic as a function of the distance to the railway (Source: Öhrström and Skanberg, 1993)



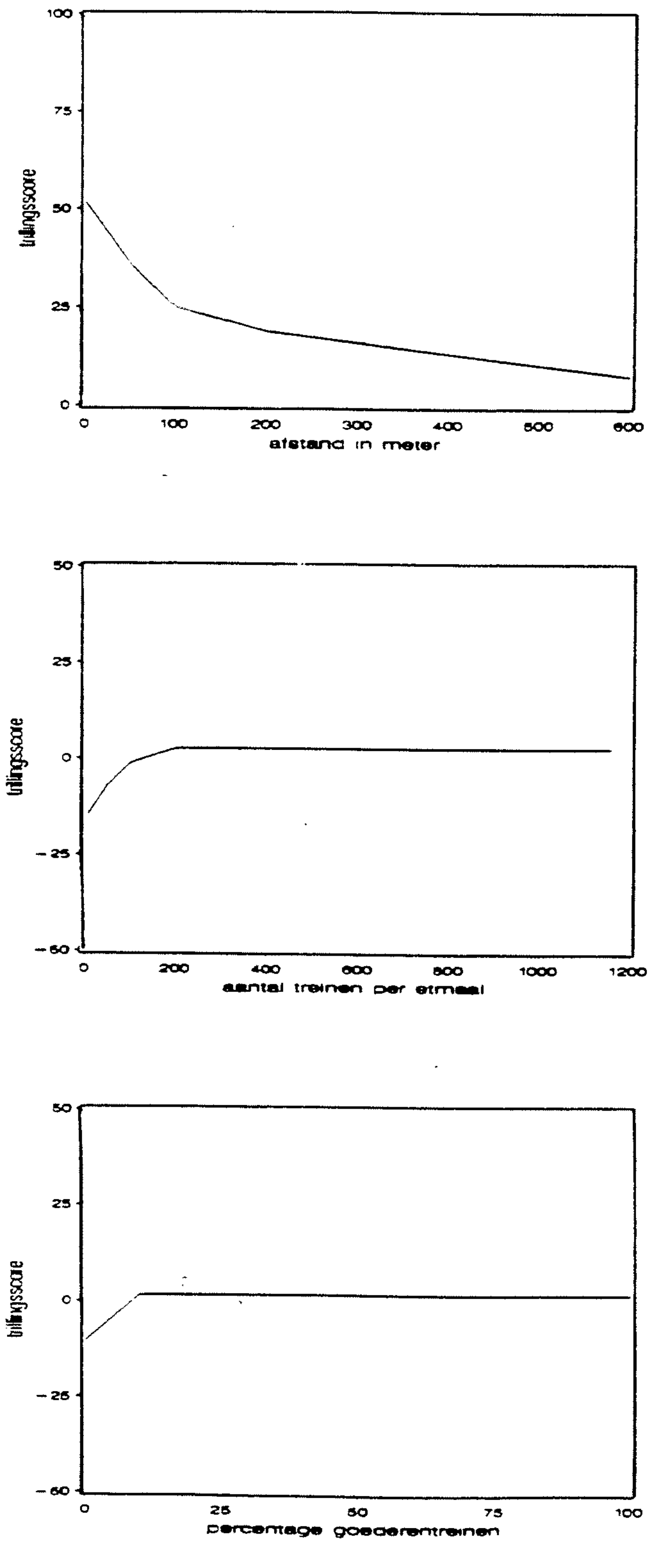
The most recent Öhrström and Skanberg paper also compares vibration-induced annoyance with noise-induced annoyance in two areas with approximately the same number of trains per 24 hours (Lund: 143; Partille 160). The mean annoyance scores have been given as a function of distance in figure 6.5. In the area where vibrations are reported to be weak or absent (Lund) the mean *vibration* annoyance score is about the same as the mean *noise* annoyance score at the shortest distance from the railway. In the Partille area annoyance due to vibrations from the railway appears to be about as large as annoyance due to noise from that railway. There is a large discrepancy in mean vibration annoyance score between Partille and Lund at the same distance from the railroad.

Figure 6.5 Mean annoyance scores with respect to vibration and to noise as a function of the distance from the railway for the Partille area ('high vibration area') and for the Lund area ('weak or absent vibration area') (Source: Öhrström and Skanberg, 1995).



In Miedema and de Jong (1993) some preliminary results with respect to the subjective response to railway-induced vibrations have been presented. The results are based on three surveys, mainly concerned with subjective responses to railway-induced noise (British study: Fields and Walker, 1980 (see above); Netherlands study: Peeters, Jong de, Koper and Tukker, 1984; German study: Schümer-Kohrs, Schümer, Knall and Kasubek, 1983). These three surveys are summarized in Miedema (1992). In Miedema and de Jong (1993) the preliminary relation between distance from the railway and subjective response to railway-induced vibrations is given, together with the effect

Figure 6.6 Vibration annoyance score as a function of three variables. From the upper figure the vibration annoyance score can be determined, the middle figure presents a correction to be added to this score based on the number of passages of trains in 24 hours and the lower figure presents the correction to be added to the score based on the percentage of goods trains. The figure only presents a preliminary estimation of the size of the score at a given distance, number of trains per 24 hours and percentage of goods trains, since variables which determine exposure to a large extent have not been taken into consideration and data for larger distances from the railway are scanty (Source: Miedema and de Jong, 1993).



on this relation of the number of trains passing in 24 hours and of the percentage of goods trains. According to the authors, the result should be considered with caution since "important factors for which information is lacking are construction of the railroad and condition of the underground. This limits the usefulness of the relations between the variables which influence the exposure and the vibration annoyance score. However, there is a strong suggestion with respect to the influence of the number of trains and the percentage of goods trains. In principle the effect of these variables might be due to a variation in unknown factors being related to these variables, such as condition of the underground and construction of the railway. But the required relation between, for instance, the condition of the underground at a certain location and the percentage of goods trains passing that location does not seem plausible". Especially the relations at larger distances should be considered as a first step, since these relations are based on a few observations only: the Netherlands study did not include sites at distances larger than 150 m, the British study (see elsewhere in this report) included only 62 respondents living at more than 200 m from the railway, and the German study included 85 respondents living at one site at about 350 m from the railway. The results are given in figure 6.6.

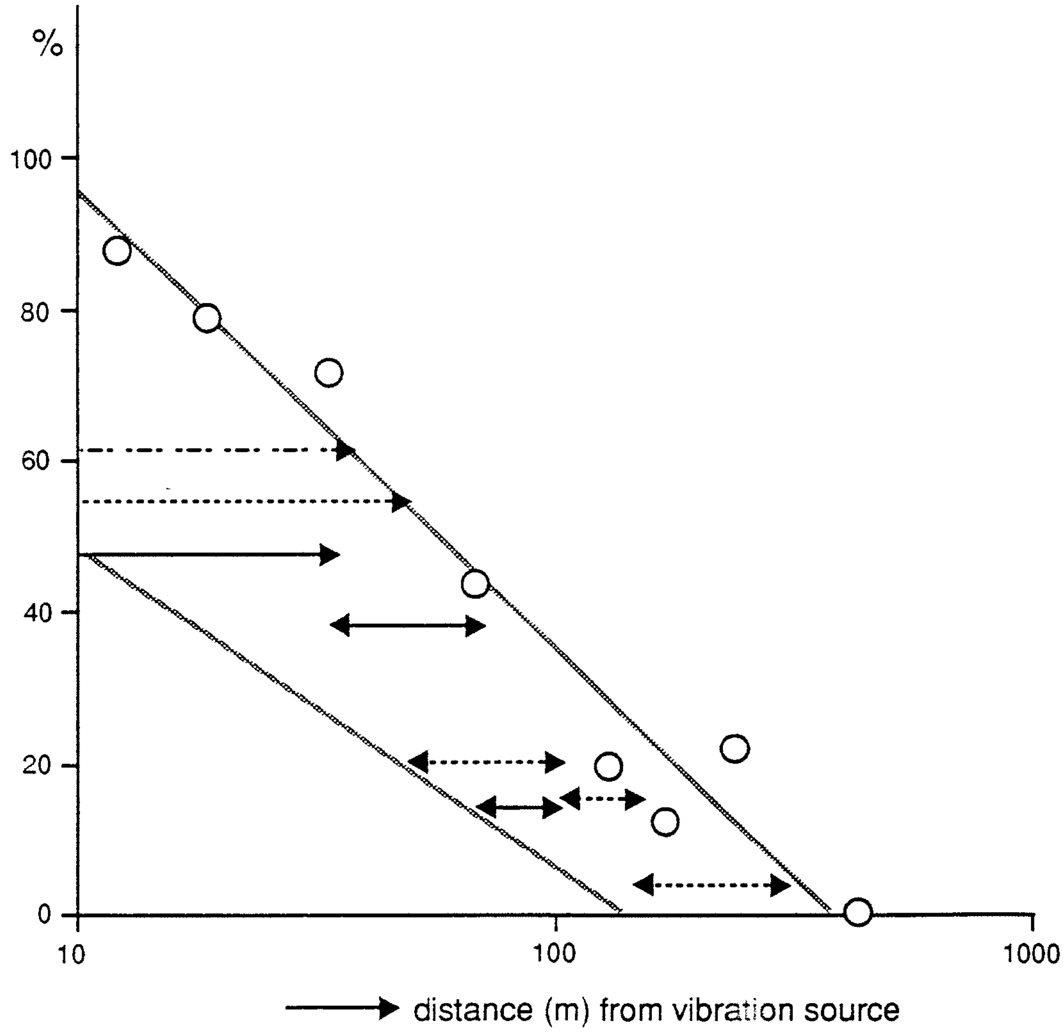
6.3 Conclusions

In figure 6.7 results have been plotted as a function of the distance from the vibration source. All studies involved concern railway-induced vibrations except one which concerned road traffic induced rattles. The results obtained from the investigation by Öhrström concern the percentage very annoyed people. They have been obtained by averaging the values given in figure 6.4. The other results concern the percentage of people noticing vibrations. The percentages of people that observe vibrations or are annoyed by vibrations have been plotted as a function of the log distance from the vibration source. Two straight lines are presented which more or less represent a maximum and minimum response. The equations of both straight lines are given by:

upper values: $\% = -60 \log d + 155 \qquad d \geq 10$ m

lower values: $\% = -41.5 \log d + 89.5 \qquad d \geq 10$ m

Figure 6.7 Percentage of people as a function of the distance from the vibration source.
○ Fields and Walker (1982), percentage of people noticing railroad-induced vibrations;
<——> Woodroof and Griffin (1987), percentage of people noticing railroad-induced vibrations;
<- - - > Öhrström and Skanberg (1993), percentage of people very much annoyed by railroad-induced vibrations;
-.-.-.-.-> Watts (1984), percentage of people noticing rattles due to road traffic induced vibrations.



The results presented by Watts (1984) (see section 4.2.3) suggest that for persons living in areas close to dual-carriageways or close to heavily congested urban roads the percentage of people very much annoyed by vibrations induced by road traffic can be estimated from the equivalent sound level from 06.00 to 24.00 hours, measured outdoors. At values of $L_{Aeq,06\text{-}24h}$ below 60 dB(A) the percentage people very much annoyed by road traffic induced vibrations would be virtually zero and at a value of 72 dB(A) about 20%. However, whether this result is also applicable for situations other than those examined in the survey is unclear.

7. CONCLUSION

Only in one of the social surveys effects of *road traffic* induced vibrations have been examined. Vibration magnitudes in that survey have been determined for window vibrations, and not for vibrations of the floor or the objects (seat, bed) with which persons are in contact in their domestic environment. Thus, no information is available on relations between currently used vibration magnitudes and vibration-induced subjective effects for the most annoying vibration source considered on a national level. Information about effects from *air traffic*, inducing vibrations in dwellings through *air-borne radiated sound*, is also lacking.

More research has been carried out with respect to *railway-induced* vibrations. Two social surveys and a number of laboratory studies, in which railway-induced vibrations recorded in real life situations have been used as stimuli, investigated various aspects of railway-induced vibrations. The social survey by Woodroof and Griffin (1987) failed to show a statistical significant relation between vibration magnitude and vibration-induced subjective response. However, their statistical analysis has been based on only 52 subjects. The Zeichart et al. (1993) survey shows a high correlation between various vibration magnitudes, determined at the same location in dwellings. The Zeichart et al. report suggests that all vibration magnitudes have been determined using the frequency weighting specified in DIN 4150, Teil 2: 1992. Thus, the conclusion that railway-induced vibrations can equally well be evaluated by KB, r.m.s. or VDV measures still leaves the question of the frequency weighting of these measures open.
The results of a British laboratory study (Howart and Griffin, 1988) on railway-induced building vibrations suggest the use of VDV in the evaluation of vibrations. However, this and other laboratory tests do not permit a definite conclusion whether there exists a vibration measure which should be preferred, and what that measure is.

The various synopsises in the report showed that laboratory tests covered only a small part of the possible test conditions. Most laboratory experiments concerned vertical vibrations to which sitting subjects have been exposed. With respect to recumbent persons some laboratory experiments have been carried out only to determine the perception threshold for sinusoidal vibrations. For standing persons laboratory experiments also include the determination of equal sensation contours for sinusoidal vibrations. Also, there is only one laboratory study with a very limited scope about dual-axis vibrations and none with respect to simultaneous exposure to vibrations in three directions.

In conclusion, laboratory and field investigations do not provide a sufficient basis for the choice of a vibration measure. Thus no unambiguous answer is possible with respect to the first objective of this desk study. The three Standards, with which the results of the analyses in this report have been compared, use different measures. ISO 2631-2: 1989 favours the use of the acceleration r.m.s. value, BS 6472: 1992 the use of VDV, and DIN 4150, Teil 2: 1992 the use of KB_{Fmax} and KB_{FTr}. For a practical application to exposures other than continuous exposures during either the total day- or night-time, the British Standard is most straightforward: all exposures, except those to blast-induced vibrations, are evaluated by comparing their VDV with the base value applicable for day- or night-time. This implies a trade-off between vibration acceleration magnitude and duration of exposure of $at^{1/4}$ = constant. Both other Standards use for intermittent exposures a trade-off of $at^{1/2}$ = constant. Therefore, the choice of a Standard would have implications for the evaluation of intermittent exposures to constant vibrations. Obviously, however, the available information does not permit to choose among the Standards in this respect.

In two other aspects there are differences between the three Standards: measurement location and frequency weighting. The German Standard specifies the measurement location to be on the floor of the room under consideration, whereas the British and ISO Standard both specify that measurement of vibration should be taken on a structural surface supporting the human body at the point of entry to the human subject. If measurements have to be made at another point, transfer functions need to be determined and applied. It is unknown to the present author whether in field applications of these Standards these transfer functions actually are taken into account. If so, this would mean that differences in the weighting function specified by DIN and the one specified by ISO and BS for recumbent persons would be substantially reduced. Differences, however, remain between on the one hand the British Standard and on the other hand the DIN and ISO Standards when the orientation of the occupants of dwellings is unknown. The frequency-weightings of the vibration magnitudes specified in ISO and DIN are then equal, but the frequency weighting at frequencies below 4 Hz of the British Standard would then deviate from that in the ISO and DIN Standards. For many practical applications, e.g. with respect to vibrations induced by passenger trains in the Netherlands, such a discrepancy would be irrelevant since those vibrations do hardly contain such low frequency components. It may, however, have an impact on the evaluation of vibrations induced by goods trains in the Netherlands.

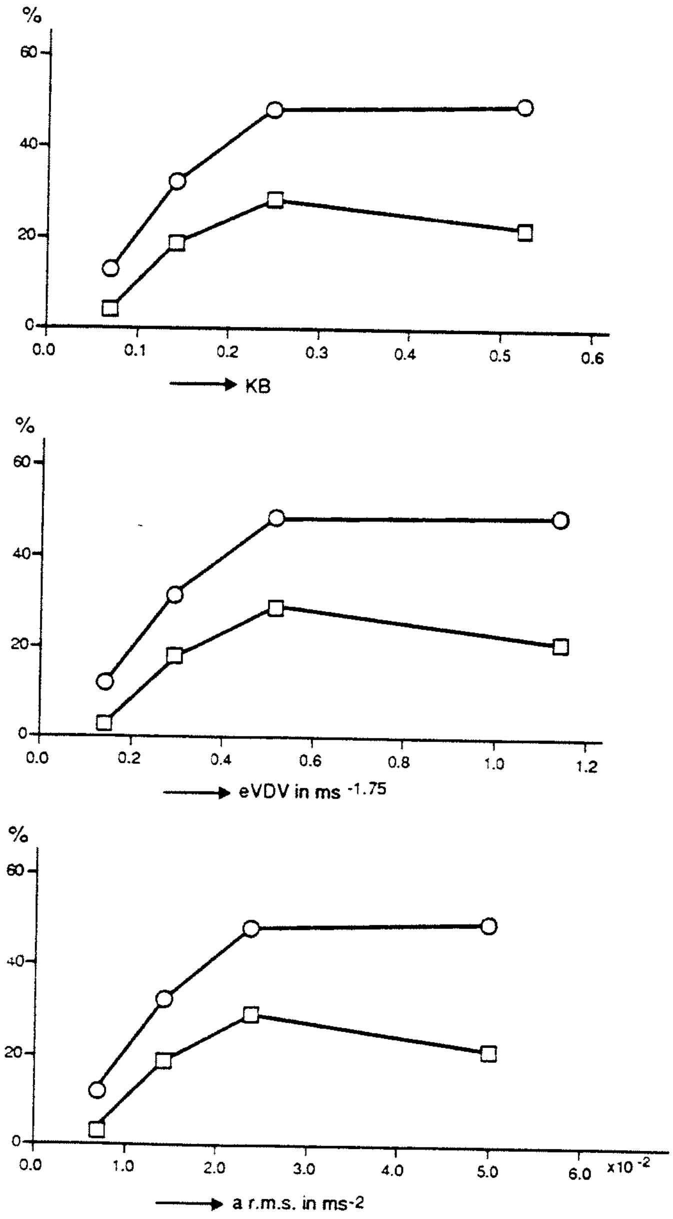
The second objective of the desk study is to collect data about exposure-effect relations. The exposure-effect relations given in Zeichart et al. (1993) constitute the only available information.

These relations are restricted to railroad-induced vibrations. No information is available with respect to road traffic and other sources of vibration in the domestic environment. The results obtained by Zeichart et al. show an unexplained difference in vibration-induced annoyance due to different types of trains. Therefore, it was concluded in this report that exposure-effect relations obtained for one type of environmental vibration source may not be valid for other environmental vibration sources.

In Zeichart et al. (1993) exposure-effect relations are expressed with KB values as vibration magnitude measure. Taking into consideration the high correlation between various measures of the magnitudes of railway-induced vibrations, the relations might also have been expressed in terms of eVDV or acceleration r.m.s. values. Taking eVDV and acceleration r.m.s. values as vibration measure, preliminary exposure-effect relations for railway-induced vibrations are given in figure 7.1. The results for the two highest vibration magnitude classes in the Zeichart et al. report have been taken together because the number of subjects in each subgroup was relatively low. The vibration measures relate to day-time exposures during 16 hours. For railway-induced vibrations eVDV is then estimated to be 2.04 KB_{Fmax} and the acceleration r.m.s. value is then estimated to be equal to 9.41×10^{-2} KB_{Fmax}.

Figure 7.1 Percentage of people much and very much annoyed by railway-induced vibrations as a function of the vibration magnitudes:

- r.m.s. value of the KB_{Fmax} values of the train passages (upper figure);
- eVDV of the train passages during 16 hours (middle figure);
- acceleration r.m.s. value of the train passages during 16 hours (lower figure).



The third objective of the desk study is to consider a possible interaction effect of noise and vibration in people exposed simultaneously to both environmental factors. The results of laboratory investigations do not exclude the existence of a small interaction effect, but substantial evidence for such an effect could not be found. Future investigations with higher values of the vibration component in the simultaneous exposure to noise and vibration are needed to arrive at a more definite conclusion.

Zeichart et al. (1993) also considers a possible interaction between vibration and noise exposure in their analysis of the results of their field investigation. A statistical analysis resulted in a chance of 0.07 of such an interaction, which implies that the hypothesis that such an interaction does exist should be rejected. However, as Zeichart et al. states, an analysis in which the nightly disturbance was not taken into account, showed a statistical significant interaction effect ($p = 0.03$). Indeed, there are some indications of a negative interaction between noise and vibration at higher exposure magnitudes. Calculations suggest that such an interaction would be negligible in real life situations with vibration magnitudes which are not more than a factor 4 higher than the base curve values presented in ISO 2631-2: 1989.

The fourth objective of the study is to determine one or more indicators that can be used on a statistical basis in large scale environmental surveys for the estimation of vibration annoyance without knowledge of the actual magnitude of the vibration measures.

One indicator is the distance from the vibration emitting source. Nearly all investigations which could be used for estimating vibration-induced effects concern railroad-induced vibrations. Only one investigation dealt with road traffic induced vibrations. The percentage of people observing or being annoyed by vibrations might by first approximation be estimated from two equations of this percentage as a function of log distance from the source, representing a maximum and minimum response. At a distance of 10 m the percentage of people noticing or being annoyed by railway-induced vibrations is thus estimated to be between 48 and 95%, at a distance of 100 m this percentage is estimated to be between 7 and 35%. However, considering the very limited information, these estimates would need verification by research. The equations are related to vibrations transmitted through the ground, and not to vibrations from air-traffic transmitted through air from the source to the dwellings.

From the British survey carried out by Watts (1984) it has been deduced that for situations in the vicinity of roads with a dense traffic flow, the equivalent sound level for 06.00 to 24.00 hours allows a rough estimate to be made of the percentage of people very much annoyed by road traffic induced vibrations. However, whether these results are also applicable for (Netherlands) situations different from those examined in the survey, and if so under which conditions, is unclear.