Transmission of Ground-Borne Vibration in Buildings

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1. Introduction

A project has been carried out at the Danish Acoustical Institute in which the connection between the vibration level in the ground outside a building and the vibration level on the floors of the building was investigated. The project is a continuation of an earlier investigation into the propagation of vibration from rail traffic (1).

Based upon measurement results from six buildings, a set of typical transfer functions between a point in the ground and points inside buildings were determined.

The work was sponsored by the Danish National Agency of Environmental Protection and carried through by the Danish Acoustical Institute.

2. Measurement Sites

Six houses situated close to railway lines were chosen for the measurements. The houses were chosen as representative of different types of Danish dwelling houses. There were two blocks of flats and four one-family houses. In the following the results from a bungalow-type house will be looked at in some detail. The house is shown in Figure 1.

3. Measurement Techniques

Vibration was measured at eight points simultaneously, one point in the ground outside the house (reference point) and the remaining points inside the house. The vibration signals were picked up by piezoelectric accelerometers and recorded on FM tape recorders. After having recorded the signals from 8-15 trains passing, the seven indoor accelerometers were moved to other points, while the transducer at the reference point was left in place. Measurements were made at between 12 to 28 points in each building.

The signals from 3 or 4 undisturbed train passings were analysed with a 1/3-octave real-time analyzer for the period where the signal was significantly higher than the background level, about 2-20 sec. Transfer functions were calculated by subtraction of the vibration level at the reference point from the vibration level at the measurement point. In this way 3 or 4 transfer functions were measured for each point. The transfer functions to the same measurement point were averaged.

It was found that more general results would be obtained by splitting the transfer functions into:

A: reference position to foundation, vertical direction
B: foundation, vertical direction to various points on floors in the building

4. Vibrations of Foundations

In Figures 2 and 3 the transfer functions between the reference position in the ground and points on the foundations of five of the buildings are shown. It is seen clearly that the vibration level is attenuated less when transmitted to a frame-type foundation (Figure 3) than when transmitted to a basement (Figure 2).

In Figure 2, the curve marked with asterisks is from the bungalow and the two other curves from multi-storey blocks of flats. These results suggest that the loading of the soil by the building's weight has some influence upon the transfer of vibration into the foundation.
GROUND-BORNE VIBRATION IN BUILDINGS

Figure 1  Drawings of the bungalow-type house, section and plan view.

Figure 2  Transmission functions between reference positions in the ground and 3 points on different basement floors.
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Figure 3  Transmission functions between reference positions in the ground and two points on different frame-type foundations.

Figure 4  Transmission functions between a point on the basement floor and points near the midpoints of the floors of three rooms in a bungalow.

5. Vibration of Floors

Figure 4 shows the transfer functions from foundation to the midpoint of the floor in three different rooms in the bungalow with wooden beamdeck and wooden floor. It is obvious that the vibration level is much higher on the floors than on the foundation, and it is seen that the three curves have maxima at different frequencies. The span of the beams is different in the three rooms, and it is natural to ascribe most of the observed dynamic amplification to resonance of the floors.

In Figure 5 results from four points on the same floor in the bungalow are shown. The curve marked with open circles is from a point near the corner of the room, and the remaining curves are from points about the middle of the room. The resonance peak in the 12.5 Hz band which is significant on the three curves from near-middle points is not visible in the curve from the corner point.
6. Averaged Results

To make the results more generally usable, the transfer functions were divided into a few very broad groups and averaged. The groups were:

A1: Foundation, frame type
A2: Foundation, basement
B1-1: Floor vertical. One-storey building (or ground floor of two-storey building) with wooden floor.
B1-3: Floor, vertical. Multi-storey building with concrete deck, with/without wooden floors.
B2-1: Floor, horizontal. As B1-1.

These averaged transfer functions per 1/1-octave are shown in Table 1. Also shown is an expression for transfer function from propagation in the ground from reference (1).
<table>
<thead>
<tr>
<th>1/1-octave frequency band</th>
<th>4 Hz</th>
<th>8 Hz</th>
<th>16 Hz</th>
<th>31.5 Hz</th>
<th>63 Hz</th>
<th>Total, weighted</th>
<th>Group</th>
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<td>0-8.5</td>
<td>b</td>
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<td>+15</td>
<td>+14</td>
<td>+10</td>
<td>+10</td>
<td>+12</td>
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<td>+20</td>
<td>+23</td>
<td>+22</td>
<td>+8</td>
<td>+20</td>
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<tr>
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<td>+12</td>
<td>+5</td>
<td>+4</td>
<td>+4</td>
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<td>+20</td>
<td>+23</td>
<td>+7</td>
<td>+20</td>
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<td>0</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>B2-3</td>
</tr>
</tbody>
</table>

Table 1
Transmission path transfer function for vibration during propagation, and transfer of vibration from ground into and inside buildings

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7. Prediction Method

These averaged results may be used as an empirical prediction method when the vibration level from e.g. railway traffic in a planned building is to be determined. The method is illustrated in Figure 6.

The vibration level (weighted acceleration level) is measured in the ground in a point not too far from the railway line at distance \( a \) (m), and the level at distance \( b \) (m) is estimated by use of the expressions in the top line of Table 1.

According to the foundation principle, the vibration level of the planned foundation is found by addition of the numbers in line A1 or A2, and according to the type of building the vertical vibration levels of floors is found by addition of the numbers in line B1-1 to B1-3, respectively.

The accuracy of such empirical methods is seldom high. It must be expected in concrete cases to find deviations between predicted and measured values up to about 10 dB. Especially, the transfer functions B1-2 and B2-2 (upper floor, two-storey building with wooden floor) are to be regarded as crude estimates, as they are based on a small number of measurements.

8. References