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Measurements of junction vibration level differences of timber framed constructions

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ABSTRACT

Flanking transmission of supporting walls of timber framed constructions limits the sound insulation properties in multi storey buildings. Both transmission from the floor construction to the supporting walls and the transmission from wall to wall and to either floor or ceiling through the junction is a part of this challenge. This article presents a method of how to measure the vibration transmission properties well fitted for in-situ measurements. The method is applied on some common Norwegian solutions and results will be presented and compared with similar results from other investigations. There is also a lot of research going on to improve the calculation of sound insulation in lightweight constructions according to EN-ISO 12354. Beside the method itself it includes studies on necessary input data regarding the vibration index, K_{ij} and vibration level difference. The article will give some contribution regarding the distribution of the vibration level from the in-situ measurements.

Keywords: Wall Construction, buildings, vibration level, transmission and attenuation in solid structures

1. INTRODUCTION

Reliable estimates of junction attenuation are important for validating junction models and as input data for building acoustic prediction models, for instance EN 12354 (1). However, the in-situ junction attenuation which is required for the prediction may not be known for the construction under evaluation. The estimate of junction attenuation is based on theory and therefore as good as the theory and associated assumptions suggests, see for instance (2) and the predicted junction attenuation differences for concrete structures cannot be directly applied to lightweight constructions. Investigating lightweight wood constructions, both standardized predictions methods (1) and related standardized laboratory measurement methods for characterizing building elements and junctions have to be taken into account. Much work have been carried out the last years to use the EN 12354 framework, but modifying it to take into account particularities as non-uniform vibration field, high attenuation (high internal loss factors) and non-resonant fields, see (3). Among researchers on this item, questions have arisen concerning characterization of junction between elements. Obviously, characterization of in-situ junction is quite resource demanding. The large variety of element types and junctions is also a problem with respect to physical characterization. Numerical simulation (for instance with FEM software) may be efficient, but due to complicated geometry and unknown coupling losses it is necessary with validation of results from these methods with laboratory or in-situ measurements. In combination with other investigations and research work we have sometimes the opportunity to conduct vibration level difference measurements. Results from in-situ measurements presented in this paper is based on measurements carried out several years ago named "SKI", but further analysed now in connection with the progress on this item after the COST Action FP0702 work, see (4, 5) and a number of new articles.

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2. VIBRATON LEVEL DIFFERENCE

The vibration level difference, $D_{v,ij}$ can be measured in laboratory or in-situ for different types of junctions, for instance to build up a data base, validate with calculations or compare with standardized measurements. The direction averaged velocity level difference is, according to (6) defined by:

$$\overline{D}_{v,ij} = \frac{D_{v,ij} + D_{v,ji}}{2} \qquad (1)$$

and the normalized direction averaged velocity level difference recently proposed, see (4) as a junction invariant given by:

$$\overline{D}_{v,ij,n} = \frac{D_{v,ij} + D_{v,ji}}{2} + 10log\left[\frac{l_{ij}}{\sqrt{(S_{m,i} \times S_{m,j})}}\right] \qquad (2)$$

Where l_{ij} represents the length of the junction between elements i and j, the $S_{m,i}$ and $S_{m,j}$ are the measurement surface areas. The second term on formulae is here a frequency independent number. In our case with timber frame work, the elements are largely damped and the structural reverberation time is not very relevant. But it seems relevant to include the average attenuation in dB per meter from the geometric spreading of the elements. For timber frame work it is important to clarify if the main direction of the frame is perpendicular or parallel to the energy flow into the junction and similar on the receiving side, from the junction.

In the measurement procedure the vibration velocity (or acceleration) of the surfaces is sampled simultaneously using a pair of accelerometers which are connected to (at least) a dual-channel real-time analyser. Further spatial averaging is accomplished by choosing multiple accelerometer positions on both the source and the receive surfaces. More descriptions on the measurement principle and procedure are given in chapter 3.

3. MEASUREMENT APPROACH

Measurement of the vibration level difference is based on exciting element "i" connected to the junction, determining its average normal velocity also from element "j". The vibration level difference $D_{v,ij}$ is then calculated from the difference between the average normal velocity on element "i" and element "j". In this case a structural excitation of the element has been used. The implementation of a structural excitation is much easier than an airborne one since it is not necessary to shield other flanking elements.

In these measurements, a shaker is used to excite the construction. But the shaker is mounted on a beam, which have been fastened to the wall or floor with three screws. With this setup, we could therefore achieve more than one point excitation simultaneously, and in that way increase the number of source positions. A drawing of the excitation setup is presented in figure 1. In this example, the upper wall is excited. A disadvantage with this excitation concept is the necessity to put screws into the wall or floor surface. Therefore, these measurements have normally been carried out in only one direction.

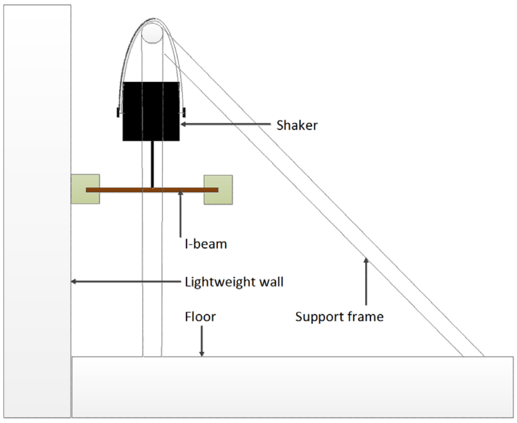

Figure 1 - Excitation concept with a shaker, beam with (on figure not visible) screws

Sufficient S/N-ratio is reached through serial measurement steps in this case with a relatively small shaker. According to experiences on such constructions, the flanking transmission is not limiting the airborne sound transmission in the high frequency range, and to reduce the measurement time on site, the frequency range of measurements have been limited to third octave bands between 50 Hz and 1600 Hz. Each measurement value is from an average time of 20 seconds. Normally, at least eight accelerometer positions have been used on each side of the junction. The measurements procedure is as far as possible based on descriptions in EN 10848 series, see (6).

Figure 2 show a front view of the frame construction of the upper wall and the lower wall. The position of the excited beam and principal positions of the accelerometers on both source and receiving side is also shown. We have consequently used measurement positions between the excitation "line" (beam) and the junction, i.e. the "incoming" energy. On the receiving side, measurement positions have been distributed all over the radiating surface of the room, but limited to the area below the common junction line. In these measurements, two to three accelerometers have been positioned directly outside the studs, while the rest of the accelerometer positions have been randomly positioned between the studs. This was done to investigate overall level differences and possible differences due to framework positions.

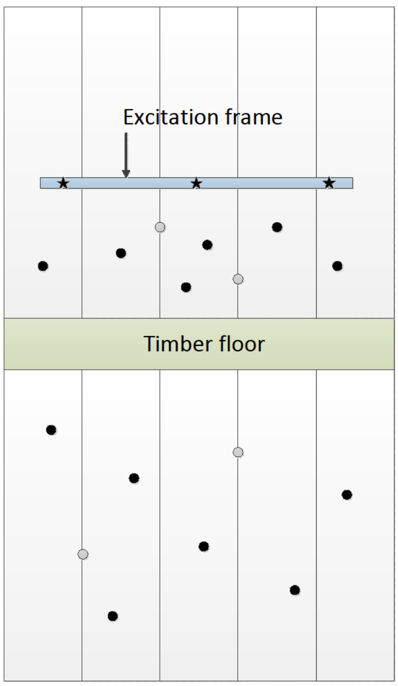

Figure 2 - Front view of the frame construction of upper and lower wall with excitation and principal measurement positions

4. MEASUREMENT OBJECT

Flanking transmission measurements presented in this paper have been carried out in a field object named "SKI". This was a three storey, multifamily house under construction but with all essential timber frame elements finished. Therefore standardised sound insulation measurements have also been carried out beside the measurements of vibration level difference and structural reverberation time. Vibration level differences have been measured between; upper Wall and lower Wall, upper Wall and Ceiling, upper Floor and lower Wall and upper Floor and Ceiling. Measurements have been carried out in two buildings. The only difference between these two cases is alternative solutions of the connection between the lower Wall and the resilient Ceiling, and the connection between a load bearing beam and the resilient Ceiling. This paper will mainly focus on results regarding the transmission from Wall to Wall with the framework principle shown in figure 2. Figure 3 shows a drawing of the timber construction at the T-junction between the upper Wall, timber floor construction (with the resilient ceiling) and the lower Wall. In these cases, all construction elements are load bearing. It means that the timber joist is perpendicular to the junction, but therefore the joists run in the same direction as the wall studs.

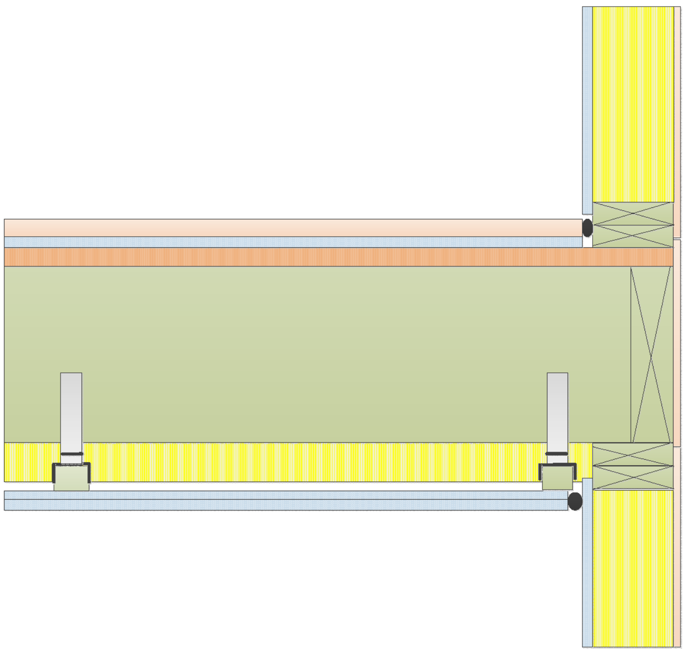

Figure 3 - T-junction between upper wall, floor construction and lower wall of measurement object "SKI"

5. MEASUREMENT RESULTS

Figure 4a and b show all velocity levels from the wall to wall measurements, respectively on the source surface and the receiving surface. The figures illustrate the total spreading of the vibration levels. According to our experiences, this spreading is within a typically range of about 20 dB over a very broad frequency range. When we separate the accelerometer positions, figure 5 show significant lower levels at positions on the gypsum board directly outside the studs from the other positions in the low frequency range. This was a typical trend from these measurements, probably due to high stiffness of the studs compared with the gypsum board. On the receiving surface, comparable results varied depending on the connection at the junction. The calculated $D_{v,ij,n}$ results will therefore depend both on the specific junction and the accelerometer positions. Unfortunately we had no possibility to recover the exact distance from each measurement position to the junction to look into the attenuation dB per meter. But studying all measurement positions we could hardly find a significant difference in the frame direction both on the source side (approximately 1 m) and receiving side (2,4 m) of the T-junction. This result coincide with results presented in (2) with an attenuation approximately zero for parallel framing members.

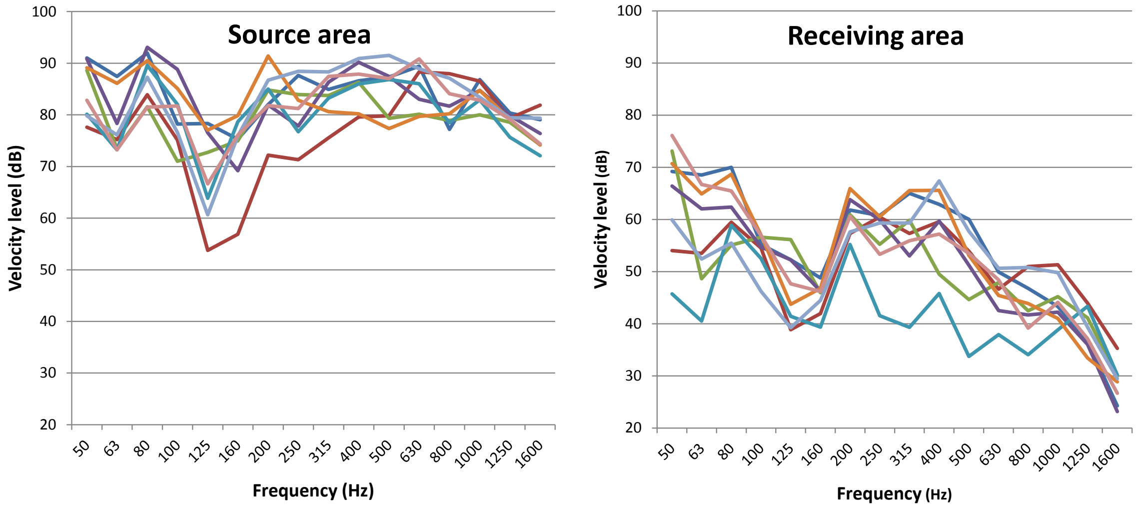

Figure 4a and b - Velocity levels, respectively on the source and receiving side of the T-junction

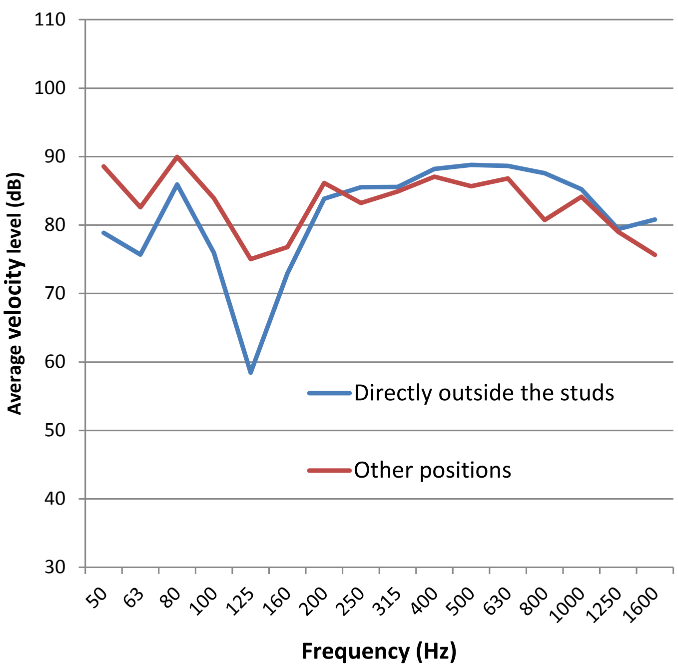

Figure 5 - Average velocity levels on the source area depending on accelerometer position relative to the framework, see figure 2

Figure 6 presents $D_{v,ij,n}$ results according to formulae (2) regarding the wall-to-wall vibration transmission. Results are given for two different connections between the lower wall and the resilient ceiling. The results are comparable in the frequency range above approximately 125 Hz, but different connections or setup conditions give significant different $D_{v,ij,n}$ in the lowest frequency range.

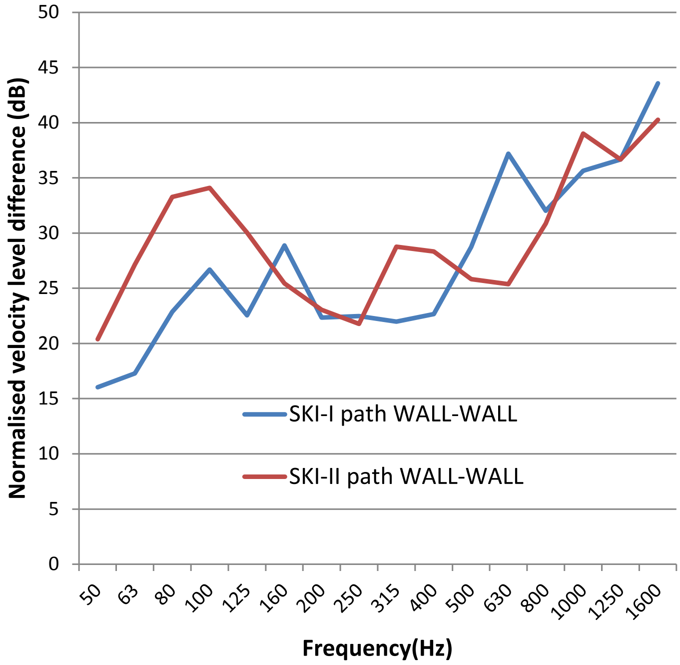

Figure 6 - Measured normalized velocity level differences of the two "SKI" T-junctions

6. COMPARISON OF RESULTS

A number of studies have been carried out on this item and presented in different articles with focus on calculation method, measurement approach, results from applied solutions or a combination of these items. Therefore, it is of interest to compare the measurement approach, junction solutions and of course the results itself. Beside this study, we have found three other investigations with $D_{v,ij,n}$-results for comparable timber-frame T-junctions with the wall-to-wall path. Figure 7 present results from four independent studies. Beside one result from this study, these results are reproduced from reference (5), (7) and (8). According to information given, these construction details are almost identical.

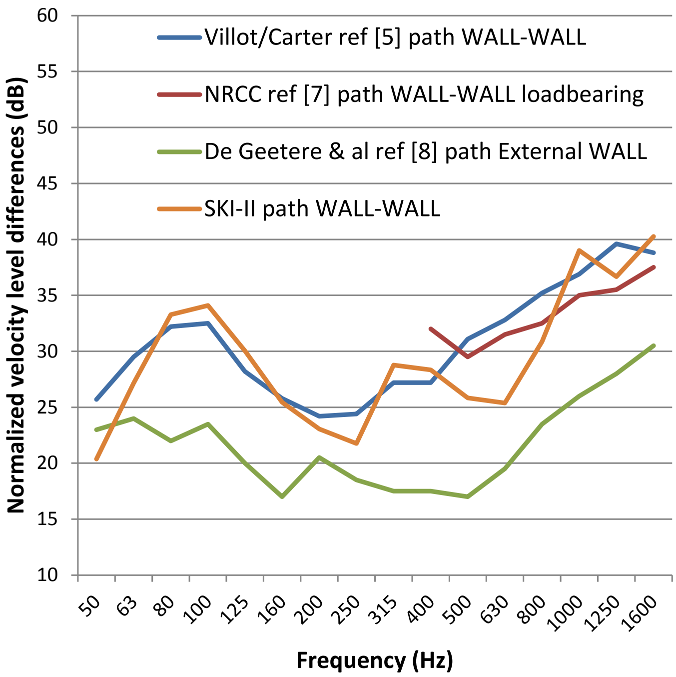

Figure 7 - Measured, normalized velocity level differences of timber-frame T-junctions

Three of the measurement curves show to a large degree comparable results. These three results are based on a measurement setup with structural excitation. The fourth results with much lower $D_{v,ij,n}$ are from measurements with airborne excitation. Figure 8 show only results with structural excitation, but in this case with average values of the two Norwegian SKI measurement objects.

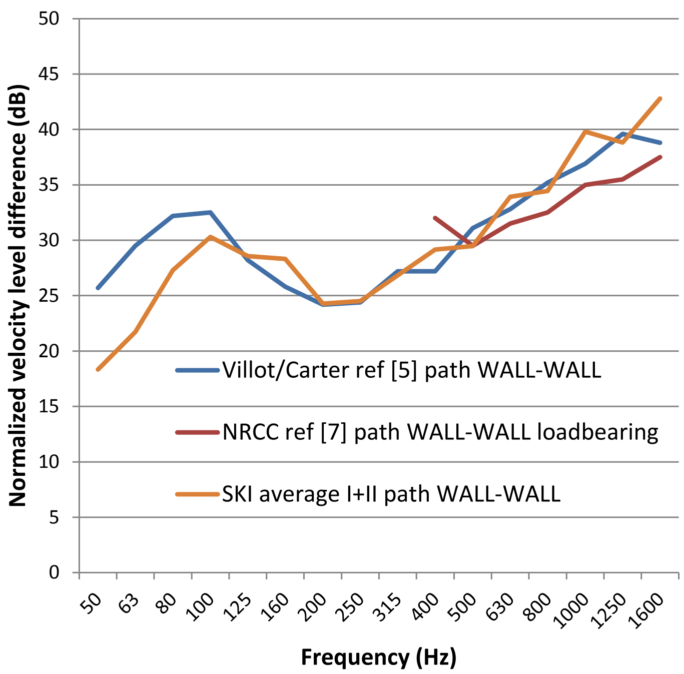

Figure 8 - Measured, normalized velocity level differences of timber-frame T-junctions with structural excitation

The results from these three measurements show comparable results in the frequency range above approximately 100 Hz. In the frequency range below 100 Hz, the results deviate. The reason for this is either the measurement approach or due to different solutions. But the SKI measurements show a very clear effect of the excitation and accelerometer measurement positions, see figure 5. At moment we therefore assume a main influence of these deviation caused by the measurement approach.

With respect to the in-situ solutions, there are small dimension differences, different plasterboards and of course effect of different workmanship. But to get such comparable results, a dominating effect must be the principal solution of the timber frames and couplings. Figure 8 show also that the measurement concept and determination of $D_{v,ij,n}$ may be a reliable tool for investigating flanking transmission also in lightweight constructions.

7. DISCUSSIONS

There are a lot of challenges to predict the contribution of flanking transmission in lightweight timber frame constructions. Among others, the estimate of junction attenuation is important. But it is different possibilities to carry out measurements and evaluate result to characterize the attenuation as assumed in the prediction model. This paper show a method to measure the vibration velocity difference based on structural excitation with a shaker applied in a multi-storey building. Results from measurements of the wall-to-wall path of a timber frame T-junction have been analysed and presented. Comparison with three other studies with similar timber frame solutions shows a high degree of coincidence regarding measurement with structural excitation. Based on a limited sample, it appears that the type of structural excitation (in these cases impacts and steady-state vibrations) seems to be of minor importance.

For the measured T-junction, the results show a frequency dependent slope from the medium frequency range and upward of approximately 20 x log(f). Such a slope is also seen in other similar measurements on lightweight constructions. But this is unlike the theoretical principles for the vibration transmission in (massive) junctions. The physical understanding of the frequency dependence and the reason for the starting frequency, in this case at approximately 200 Hz, is not investigated. In the low frequency range, the vibration attenuation also varies with the frequency. But as shown, it is construction dependent and may be sensitive for the excitation and measurement setup.

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