IMPACT SOUND TRANSMISSION FROM DECOUPLED HEAVY STAIRS

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ABSTRACT

To improve the impact sound insulation heavy stairs are decoupled from the building using resilient supports. In many countries in Europe (e.g. in Germany) this is actually required to meet legal requirements. However, at present there are no standard procedures available neither for measurement in the laboratory nor for the prediction of the impact sound transmission in buildings. Investigations on representative constructions were carried out in a building-like staircase test facility in order to identify and quantify the parameters that are relevant for the sound transmission. Based on the results a standard test method is proposed that gives data that can be used to predict the sound transmission in buildings using EN 12354-2.

INTRODUCTION

Heavyweight stairs are encountered in apartment buildings. To improve the impact sound insulation heavy stairs are decoupled from the building using resilient supports. In many countries in Europe (e.g. in Germany) this is actually required to meet legal requirements. It is known from field investigations that such isolation measures can effectively reduce the impact sound transmission such that $L'_{n,w} < 46$ dB in heavyweight buildings. However, at present there are no standard procedures available neither for measurement and characterisation in the laboratory nor for the prediction of the impact sound transmission in buildings. In cooperation with a manufacturer of resilient stair supports (Schöck Bauteile GmbH) investigations on representative constructions were carried out in a building-like staircase test facility in order to identify and quantify the parameters that are relevant for the sound transmission.

There are two variants for the acoustical improvement of heavy stairs that are encountered in buildings as illustrated in Figure 1. The first variant is to decouple the stair landing from the surrounding walls. The flight of stairs is either rigidly connected to the landing or separated by an acoustically non effective thin isolation layer. In the second variant the stair landing is rigidly connected to the surrounding walls and the stair landing is decoupled from the landings / ceilings. This requires an additional floating floor on the landing. The effect of floating floors on the impact isolation of ceilings is well known. Therefore the experimental investigations described here focus on the effect of isolation of landing and flight of stairs. Based on the results a standard test method is proposed that gives data that can be used to predict the sound transmission in buildings using EN 12354-2 (1).

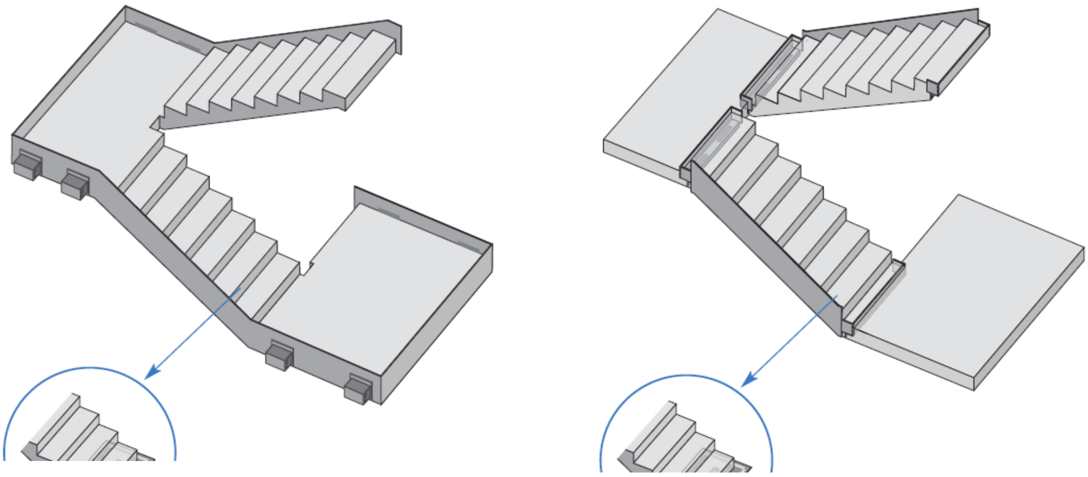

Figure 1: Decoupled stair systems, left: decoupled landings, right: decoupled flight of stairs
(pictures provided by manufacturer Schöck Bauteile GmbH)

EXPERIMENTAL INVESTIGATIONS IN A STAIRCASE TEST FACILITY

Experimental investigations have been carried out in a staircase test facility (Figure 2) that was constructed in 2001 to enable acoustic measurements on light- and heavyweight stairs in building-like situations but under controlled laboratory conditions. The general requirements are according to ISO 140-1 (2). The facility is of heavyweight construction and erected on isolation material to provide isolation from the ground plate. The permanent walls are of 24 cm CaSi with density 2000 kg/m^3, all permanent ceilings are of 18 cm concrete with density 2300 kg/m^3. To prevent flanking transmission, the facility is divided into three separate areas by a 60 mm cavity.

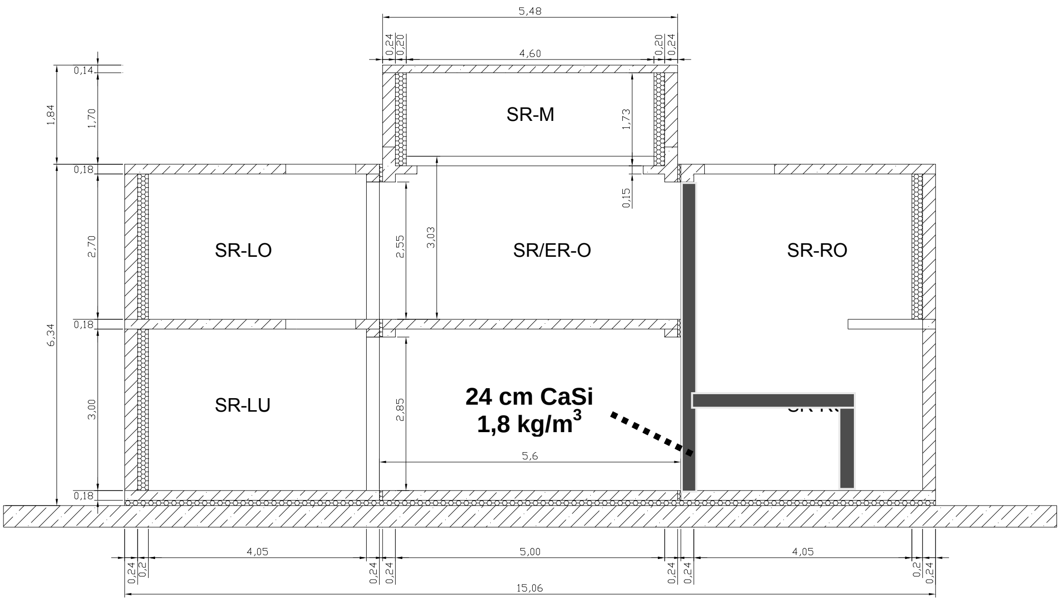

Figure 2: Staircase test facility; stair wall and stair landing indicated in grey

The landing with dimensions of 2,8 m x 1,3 m x 0,18 m (length x width x height) is resiliently supported in the separating wall (24 cm CaSi with density 1800 kg/m^3) and a similar second wall (not involved in the transmission) using PUR-Elastomer elements provided by Schöck-Bauteile GmbH (Figure 3). Like in the building there are two supports in the separating wall. Unlike in buildings there is only one support on the other end of the landing. This turn able set-up was chosen to ensure that the same pressure acts on both resilient layers in the separating wall (3). The sound transmission of the resiliently supported landing was investigated first. Later the landing was rigidly connected to the separating wall for investigations on a resiliently supported flight of stairs (also shown in Figure 3). In this paper the main focus is on the sound transmission of landings.

Figure 3: Experimental set-ups to investigate the sound transmission of 1.) resiliently supported landing and 2.) rigidly connected landing and resiliently supported flight of stairs.

Improvement due to isolation

In the left of Figure 4 is shown the normalized impact sound transmission of the resiliently supported landing (isolation with Schöck-Tronsole AZ, Figure 3) under different static loads and rigidly connected to the separating wall. Due to the isolation the single rated values reduce from $L_{n,w}$ = 68 dB to $L_{n,w}$ = 43 dB without extra static load e.g. $L_{n,w}$ = 48 dB under an extra static load of 5 tons. The additional static load was applied near the wall supports using a hydraulic device (also shown in Figure 3). From the measurement without and with isolation a frequency dependent insertion loss can be obtained:

$$\Delta L_n = L_{n,without\,isolation} - L_{n,with\ isolation} \quad (1)$$

This quantity characterises the improvement due to the isolation, likewise it can be applied for the single rated values:

$$\Delta L_{n,w} = L_{n,w,without\,isolation} - L_{n,w,with\ isolation} \quad (2)$$

The insertion loss of the Tronsole AZ is illustrated in the right of Figure 4. The isolation is increasingly effective with frequency. The difference of the single rated values is within $\Delta L_{n,w}$ = 18-23 dB depending on the extra static load.

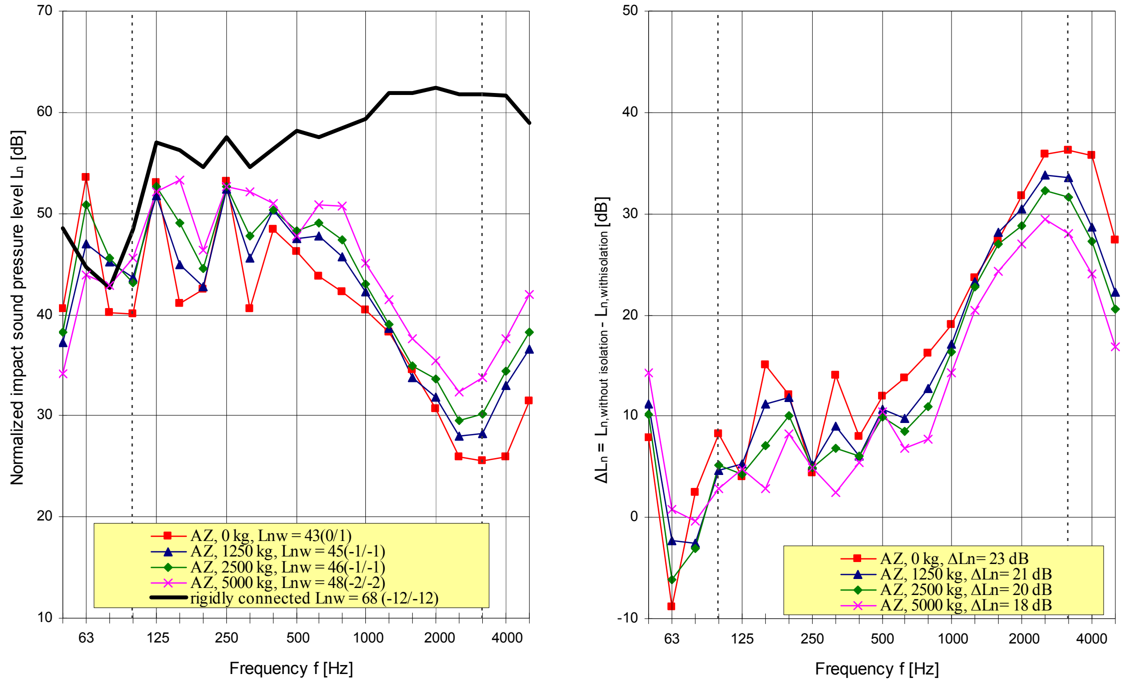

Figure 4: Left: Normalized impact sound pressure level of resiliently supported landing (isolation with Schöck-Tronsole AZ) under different static loads and rigidly connected
Right: Insertion loss with reference to the rigidly connected landing

Influence of landing geometry on the sound transmission

The invariance of the impact sound reduction by the resilient layers with respect to varying landing geometries was investigated. In addition to the landing described above, investigations were carried out with a small landing with half size to account for maximum variations of the landing area in the field. Both landings have the same thickness. For an experimental modal analysis transducers were mounted on the landings and on a reference position on the stair wall.
The average transfer mobilities for excitation of all grid position on the landings to the reference positions are shown in Figure 5 in narrow band and 3rd octave bands. The vibration of the landings is represented by the upper curves. Peak values represent landing modes.
The modes are weakly damped and well separated. The vibration shapes as exemplarily shown in Figure 6 are typical for plates with free edges (4). Due to the reduced length the modes of the small landing are shifted about one octave compared to the large landing. The first mode of the large landing occurs at 133 Hz and the first mode of the small landing at 303 Hz. The wall exhibits a considerably higher modal density as the landings. The transmission represented by the lower curves in Figure 5 is thus dominated by landing modes. Due to the shift of the eigenfrequencies the different modal coupling of landing and wall modes results in maximum discrepancies of 20 dB in narrow-bands. In 3rd octave bands the maximum differences reduce to 3 dB in the frequency range above 200 Hz and to 10 dB below 200 Hz. Despite of the variations in geometry a relatively good agreement concerning the transmission from the large and the small landing is found. This also applies for a variation in thickness as was found from additional investigations of a 2,8 m x 1,3 m x 0,12 m landing This is promising regarding the prediction according to approach described later in the text. Actually the large landing with 0,18 m thickness is suggested as reference for standard tests.

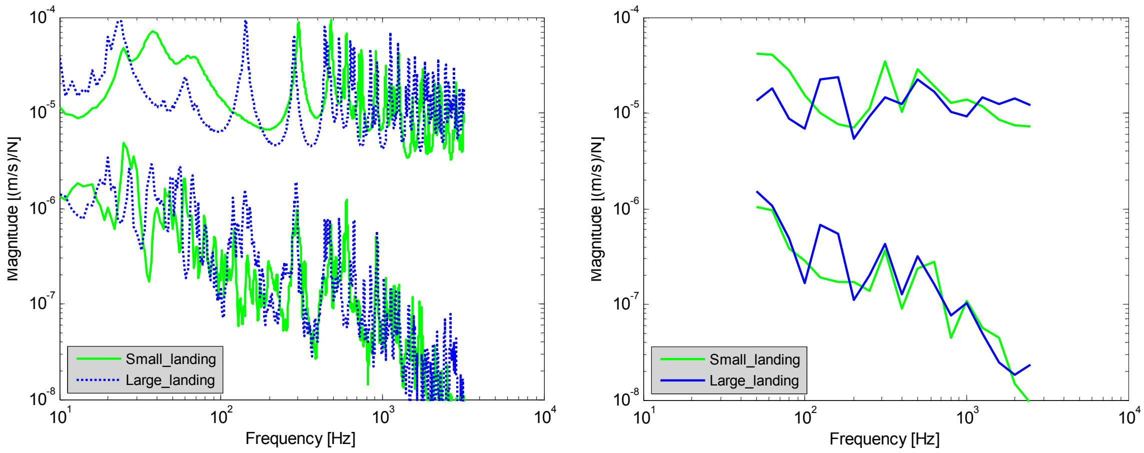

Figure 5: Average transfer mobilities to reference positions of the landings (upper curves) and to the wall (lower curves) in narrow bands and 3rd octave bands

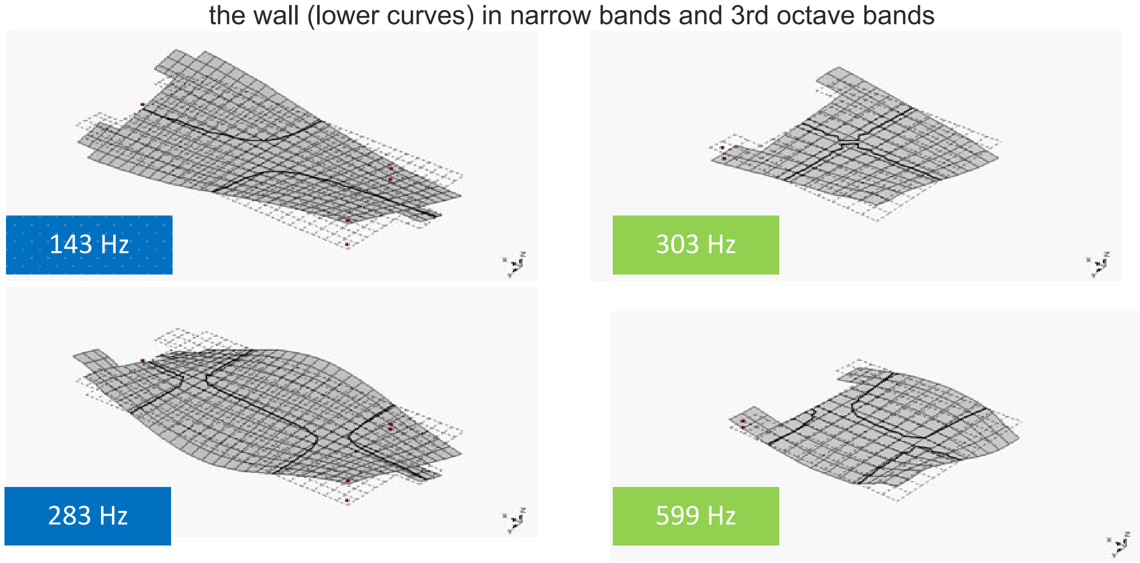

Figure 6: Vibration shapes of a large and a small landing by means of experimental modal analysis

APPROACH FOR PREDICTION MODEL

An approach for a prediction method of resiliently supported stair landings is based on the European standard EN 12354-2 (1). The model was developed for the prediction of the sound transmission through heavyweight ceilings but can similarly be used to predict the sound transmission from heavyweight walls including direct and flanking transmission in buildings. The improvement of the sound insulation of the wall through a resiliently supported landing can be described by the reduction of the sound transmission compared to the direct excitation of the wall. This is in analogy to the impact sound reduction of a ceiling through a floating floor that is measured according to EN ISO 140-8 (5).

$$\Delta L^{*}_{situ} = \Delta L^{*} = L_{n,ref,wall} - L_{n,ref,landing} \quad (3)$$

It must be noted that the improvement according to equation 3 is relevant for the prediction whereas the insertion loss according to equation 1 only characterises the improvement by the resilient element compared to a rigid connection. The experimental quantification of the impact-sound reduction of a resiliently supported landing is in two steps (Figure 7):

1.) Measurement of the normalized impact sound level when the wall is excited

2.) Measurement of the normalized impact sound level when the landing is excited

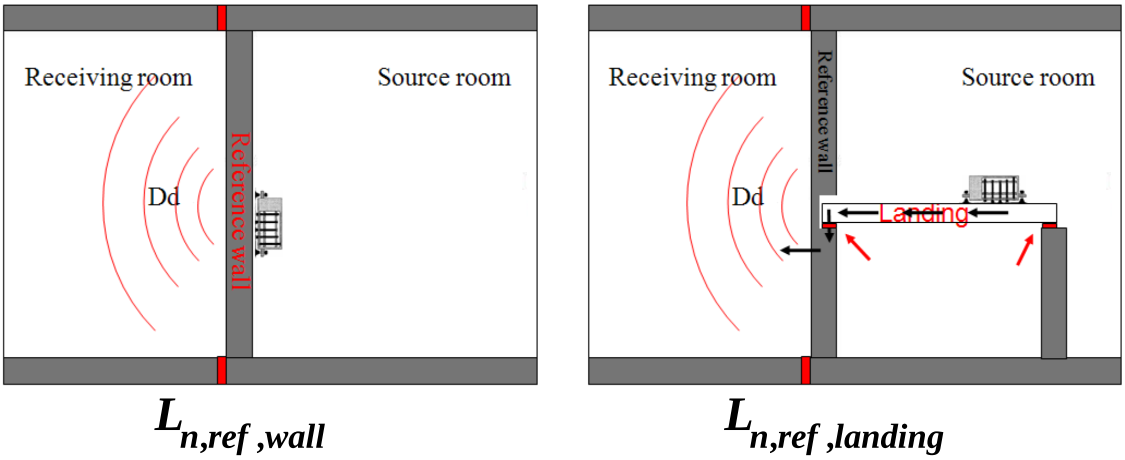

Figure 7: Quantification of the impact-sound reduction of a resiliently supported landing in order to predict the sound transmission in buildings using EN 12354-2 (1). For measurements on the wall an electrodynamic tapping machine with similar force as the standard tpm was used (6).

The proposed measurement setup consists of a reference wall and a reference landing as described above. The advantage of using measured quantities is that all influences on the sound transmission, especially the improvement through the elastic element and the junction reduction, are included. A purely analytical description of the transmission is not feasible due to the complexity of the transmission process. For the assumption that the impact sound reduction is an invariant quantity the sound transmission in a building involving direct and flanking transmission can be predicted.

$$L'_{n,situ,landing} = L'_{n,situ,wall} - \Delta L^{*}_{situ} \tag{4}$$

For decoupled flights of stairs the approach is similar. For both, decoupled landing and decoupled flight of stairs, the ΔL^* was determined in the laboratory and used for the prediction of the normalized impact sound transmission in building situations.

TRANSFERABILITY OF LABORATORY DATA TO THE BUILDING SITUATION

Decoupled landing

The sound transmission from pre-fabricated stairs consisting of a small landing and a flight of stairs was investigated in a building situation (Figure 8). The situation is comparable to the landings investigated in the staircase test facility in terms of that the stairs are supported by the walls with the same resilient elements. However the geometry is considerably different than that of the landings investigated in the laboratory. The stair wall is of similar construction as in the staircase test facility. For the case considered the normative instructions in ISO 140 for determination of the normalized impact sound level are not clear as the position of the tapping machine is not well defined. Therefore measurements were taken for excitation of all steps and the landing. The maximum variation with frequency for excitation of different steps is ca. 8 dB whereas the variation of the single rated values is between 46 dB and 49 dB. The sound transmission is considerably higher for excitation of the landing with single rated values of 52 dB. Obviously the vibration behaviour differs from that of the previously investigated plates in the staircase test facility. For the building situation the “worst case” is given for excitation of the landing. Therefore this is taken as reference for the subsequent comparison with the laboratory situation.

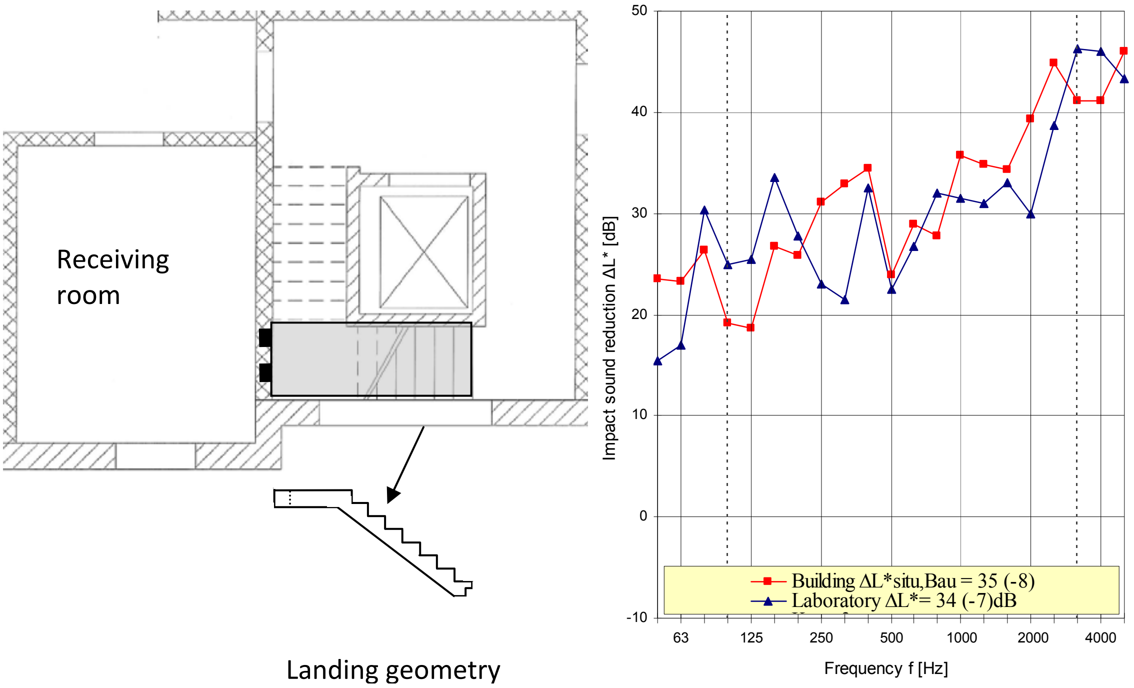

Figure 8: Left: Decoupled stair element in a building situation. Landing (1,0 x 1,0 x 0,18 m) with flight of stairs; stair wall: 24 cm CaSi, density 1800 kg/m³; Right: Impact sound reduction according to equation 3 in the building and of the reference landing in the laboratory

The impact sound reduction according to equation 3 is compared in Figure 8 for the reference landing in the laboratory and for the landing in the building situation. In the frequency range up to 5 kHz variations up to 10 dB are observed that can be referred to a different vibration behaviour of the plate in the laboratory and the pre-fabricated element in the building. Despite those big variations the single rated values differ only about 1 dB which is promising regarding the prediction of the impact sound transmission to ensure that normative requirements are fulfilled.

Decoupled flight of stairs

With the measured impact sound reduction of the flight of stairs in the laboratory as illustrated in Figure 3, the impact sound transmission in a building situation was predicted and measured in-situ (Figure 9). Althouth the geometry and thus the vibration behaviour of the flight of stairs in the building differs from the reference flight of stairs in the laboratory, the agreement is acceptable, except for the low frequency range. The predicted single rated value is 1 dB lower than measured.

CONCLUSIONS

The impact sound transmission from heavy stairs can be effectively reduced by isolation measures. For the laboratory characterisation of decoupling elements a reference situation with a reference wall, landing and flight of stairs is suggested as the characterisation can not be seen independent from the whole system. The normalized impact sound level of resiliently supported landings and flight of stairs can be predicted using EN 12354-2 and input data from laboratory measurements. The proceeding is in principle similar to the prediction of the sound transmission from ceilings with floating floors. The proposed methods were investigated by means of field measurements. The agreement of prediction and in-situ measurement is promising in consideration of the extreme variation in geometry.

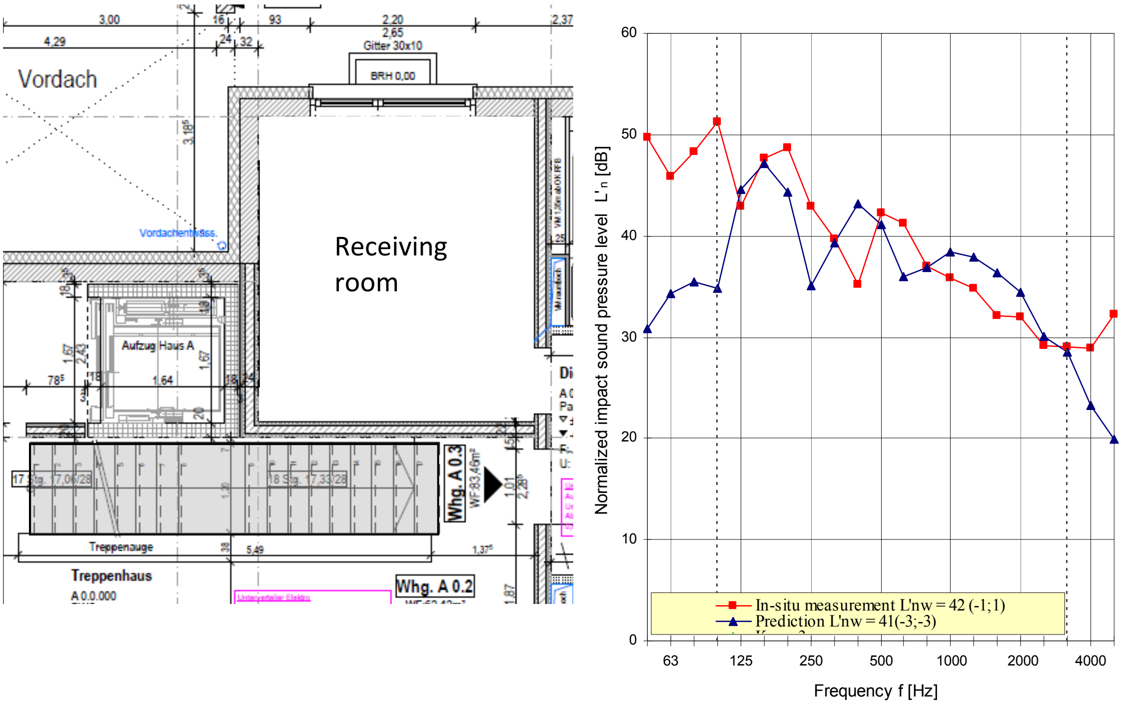

Figure 9: Left: Decoupled flight of stairs in a building situation (5,70 x 1,3 x 0,20 m); stair wall: 24 cm reinforced concrete, density 2300 kg/m³; Right: Predicted normalized impact sound pressure level and in-situ measurement

REFERENCES

(1) EN 12354-2: Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Impact sound insulation between rooms, (German version) 2000.
(2) EN ISO 140-1: Acoustics - Measurement of sound insulation in buildings and of building elements - Requirements for laboratory test facilities with suppressed flanking transmission, March 1998.
(3) Fichtel, C.; Schneiderhan, T.; Scheck, J. Conception of test setups for investigations on the sound transmission from landings in the staircase test facility. Nederlands Akoestisch Genootschap / 35. Tagung der Deutschen Arbeitsgemeinschaft für Akustik, Rotterdam, Netherlands, March 23-26, 2009, CD-ROM, pp. 460-461.
(4) Taşkan, E.; Scheck, J.; Fischer, H.-M. Vibration Behaviour and Structure-Borne Sound Transmission of a Resiliently Supported Landing. The Sixteenth International Conference on Sound and Vibration, Kraków, Poland, July 5-9, 2009, CD-ROM.
(5) EN ISO 140-8: Acoustics - Measurement of sound insulation in buildings and of building elements - Laboratory measurements of the reduction of transmitted noise by floor coverings on a heavyweight standard floor, (German version) 1997.
(6) Fichtel, C.; Scheck, J.; Kurz, R. Ein neues Hammerwerk für Geh- und Trittschallmessungen. 33. Tagung der Deutschen Arbeitsgemeinschaft für Akustik, Stuttgart, Germany, March 19-22, 2007.
(7) Taskan, E.; Scheck, J.; Fichtel. C.; Fischer, H.-M., Approach to predict the normalized impact sound pressure level of resilient supported stairs by means of EN 12354, Internoise 2010, Lisbon, Portugal, 2010.
(8) Fichtel, C.; Scheck, J.; Kurz, R. Untersuchung der Schallübertragung von entkoppelten Treppenläufen im Prüfstand und am Bau, 34. Tagung der Deutschen Arbeitsgemeinschaft für Akustik, Düsseldorf, Germany, March 21-24, 2011.

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