# DIRECT MEASUREMENT OF STRUCTURE-BORNE TRANSFER FUNCTIONS IN ONE-THIRD OCTAVE BANDS

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## Abstract

Transfer functions can be used to analyse the frequency-dependent behaviour of linear, time-invariant structures. While traditionally derived from complex narrowband data, direct one-third octave band measurement offers an alternative for building acoustic applications. This study investigates the feasibility and accuracy of determining structure-borne transfer functions directly in one-third octave bands compared to the standard narrowband approach. The methodology compares narrowband reference measurements with the direct acquisition using a two-channel sound level analyser considering a separating floor in the laboratory. The investigations cover the direct relationship between sound pressure level and force level, as well as the determination of the installed structure-borne sound power level as a reference. This study demonstrates that direct one-third octave band acquisition can be a viable, efficient method to evaluate transmission paths, providing a robust experimental foundation for building acoustic analysis and standardized calculation procedures. By utilizing two different screed systems to represent varying mobility ratios, the study further applies this experimental data to performance predictions according to EN 12354-5 [1].

The resulting comparison between a power-based approach accounting for receiver mobility and a simplified force-based assumption excluding receiver mobility serves to evaluate the impact of structural coupling on overall prediction accuracy.

**Keywords**: *structure-borne sound, building acoustics, source characterization, blocked force*

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## 1. Background and motivation

The prediction of structure-borne sound transmission from building service equipment according to EN 12354-5 [1] is a challenge in building acoustics. Characterizing structure-borne sound transmission requires knowledge of the coupling situation at the contact points between the equipment and the building structure. Based on the mobility ratio the standard distinguishes between a General Case and a Specific Case, shown in Figure 1.

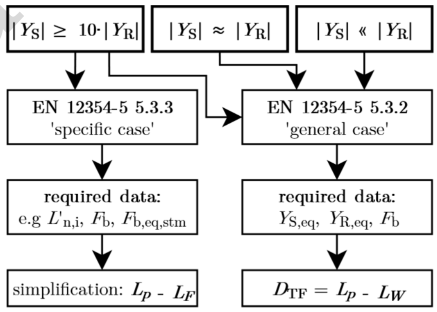


**Figure 1:** Chart that indicates the cases of distinct mobility ratios and required data in EN 12354-5 [1].

The Specific Case approximation streamlines this interaction by assuming heavy and stiff receivers, where the source mobility $|Y_S|$ is significantly higher than the receiver mobility $|Y_R|$. For this condition, the equipment acts as a force source, meaning the force transmitted to the structure closely approximates the blocked force $F_b$ of the equipment. This assumption reduces the required data and simplifies both the measurement method and the prediction.
To apply the prediction according to EN 12354-5 [1], input data is required to characterize both the source and the receiver, including the transmission. The methods to determine the source activity as well as the source and receiver mobilities are described in EN 15657 [2]. The transmission across the building is described by a global transfer function, $D_{TF}$ that relates the sound pressure to the structure-borne sound power injected. This quantity can be measured according to ISO 10848-1 [3]. In EN 12354-5 [1] $D_{TF}$ is rewritten as an apparent sound pressure level for a source with a

structure-borne sound power level of 120 dB (1 W), $L'_{\mathrm{ne,s,0.}i}$. This correlates the approach to the well-known normalized impact sound $L'_{\mathrm{n}}$, where the sound pressure for a well-defined source, the standard tapping machine (stm) is defined. From this EN 12354-5 [1] defines the prediction for the General Case equation (1) and the Specific Case, equation (2).

$$L'_{\mathrm{ne,s},i} = L'_{\mathrm{ne,s,0.}i} + L_{W\mathrm{s},i} - L_{W0} \quad (1)$$

$$L'_{\mathrm{ne,s},i} = L'_{\mathrm{n.}i} + L_{F\mathrm{b,eq}} - L_{F\mathrm{b,eq,stm}} \quad (2)$$

In the equations, index $i$ represents the excited element. $L'_{\mathrm{ne,s},i}$ is the apparent-normalized sound pressure level for equipment. $L_{W\mathrm{s},i}$ is the installed structure-borne sound power of the considered source. $L'_{\mathrm{n.}i}$ is the apparent-normalized impact sound, i.e. the sound pressure level due to the force injected by the standard-tapping machine $L_{F\mathrm{b,eq,stm}}$. Finally, $L_{F\mathrm{b,eq}}$ is the blocked force of the source that is considered. The Specific Case approximation is more practical as it reduces the input data requirements for both the source and the receiving structure. From the equations above it can be seen that measured impact sound pressure levels can be utilized. However, this approach introduces constraints at higher frequencies or on lightweight structures due to contact stiffness and non-compliant mobility ratios.

To address this issue, this paper focuses on the measurement of structure-borne transmission functions and receiver mobilities. The determination of the receiver mobility is essential to verify whether the requirements for the Specific Case are met. The transfer function, either power or force-related, is required for prediction according to equations (1) and (2).

It is important to note that the calculation framework specified in EN 12354-5 [1] is inherently an approximation, as it operates without the use of complex narrowband data. Building on this, the main question addressed in this study is whether it is possible to determine the required input data in one-third octave bands using typical sound level meters common in building acoustics and avoiding the need for narrowband complex analysis.

## 2. Methodology

To investigate the experimental feasibility of the proposed method, a case study was carried out in the laboratory. The investigation focuses on a direct comparison between narrowband analysis and a direct one-third octave band measurement strategy using a sound level meter with two channels. Structural impact excitation was implemented using a modal hammer. This was chosen specifically to support the development of a simple and quick experimental setup that can be applied on-site.

The measurements were performed on an existing laboratory mock-up, comprising two distinct configurations of a separating floor, varying in base floor, screed composition, and suspended ceiling elements, as well as two receiving room types with varying reverberation times. One room highly damped with $T \approx 0.2$ s and the other with $T \approx 0.5$ s. The data acquisition involved two parallel measurement chains: a multi-channel system (PAK MKII, MBBM-VAS) served as the narrowband reference, while a portable two-channel analyser (Nor150, Norsonic) was used for the direct one-third octave band acquisition. The sensors included an accelerometer to measure the structural response, a force transducer on the modal hammer and a microphone.

This study focuses on the evaluation of the deviation between the narrowband reference and the direct one-third octave band method. For this purpose, two excitation positions on each floor and two microphone positions were used. For each unique excitation-receiver pair, the transfer functions were analysed directly without spatial averaging.

Figure 2 illustrates the methodological differences in the processing of the measured data.

The schematic demonstrates how both chains, narrowband and one-third octave band derive the force-based ($L_p$-$L_F$) and the power-based ($D_{\mathrm{TF}} = L_p$-$L_W$) transfer functions from the two fundamental measurement steps.

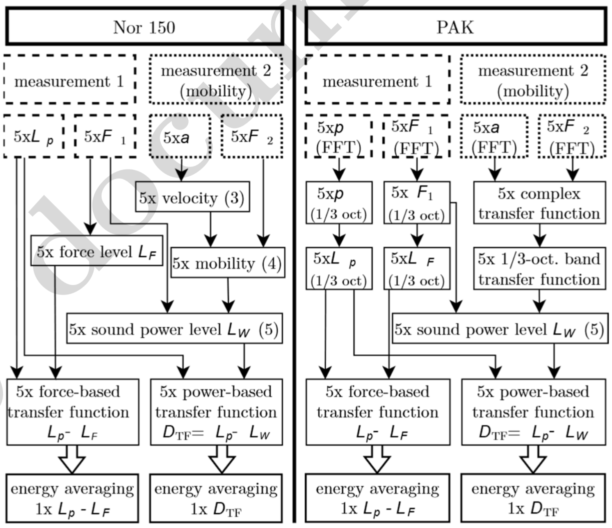


**Figure 2:** Schematic representation of the data acquisition for five hammer hits and calculation steps, contrasting the direct determination of transfer functions via one-third octave band levels (Nor150) against the high-resolution FFT reference system (PAK).

Determining the power-based transfer function $D_{\mathrm{TF}}$ requires the acquisition of the receiver mobility at the excitation position. In the proposed direct one-third octave band approach, this is achieved by first measuring the acceleration directly in one-third octave bands. Integrating the acceleration in the frequency domain for each one-third octave band using the band centre frequency yields the velocity (3):

$$v = {}^{a}\!/_{(2\pi f)} \quad (3)$$

The magnitude of the receiver mobility $|Y_{\mathrm{R}}|$ is subsequently calculated via (4) as the ratio of the measured root-mean-square (rms) values of the velocity and the applied impact force $F_2$ (see Figure 2):

$$|Y_{\mathrm{R}}| = {}^{v}\!/_{F_2} \quad (4)$$

Using the acquired mobility $|Y_{\mathrm{R}}|$ and the force $F_1$ from the actual sound transmission measurement, the

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installed structure-borne sound power level $L_W$ is determined:

$$L_W = 10\lg\left(\frac{{F_1}^2 \cdot |Y_\mathrm{R}|}{W_0}\right) \tag{5}$$

where $W_0 = 10^{-12}$ W denotes the reference sound power. Finally, the power-based transfer function is determined with the measured receiving room sound pressure level $L_p$.

$$D_\mathrm{TF} = L_p - L_W \tag{6}$$

## 3. Results

### 3.1 Profile duration

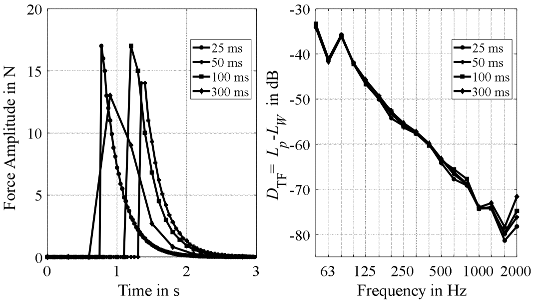


**Figure 3:** Influence of varying profile durations on the signal processing of an impact excitation. Left: Logged force amplitude profiles of a single impact captured with different profile durations (25 ms, 50 ms, 100 ms, and 300 ms). Right: The resulting one-third octave band transmission function $D_\mathrm{TF}$, demonstrating independence from the specific logging resolution applied during data acquisition.

To evaluate the robustness against logging parameters, the influence of profile durations was analysed.

In Figure 3, the left plot shows the logged force amplitude of a single structural impact, captured with four distinct profile durations (typical for usual level meters): 25 ms, 50 ms, 100 ms, and 300 ms. These curves represent the temporal logging resolution of the sound level analyser when recording the transient signal. The right plot presents the corresponding one-third octave band transmission functions $D_\mathrm{TF}$ calculated from these respective temporal profiles. The frequency-domain results show little deviations across the entire frequency range considered. Despite the variations in the time-domain amplitude profiles caused by the different logging resolutions, the resulting transmission function $D_\mathrm{TF}$ remains consistent. This demonstrates that the direct one-third octave band determination is robust and independent of the specific profile duration set in the analyser.

### 3.2 Time constants

To quantify the influence of the time constants set in the analyser on $D_\mathrm{TF}$, comparative measurements were executed using 'Fast' (125 ms) and 'Impulse' (35 ms) weighting. The resulting spectra are shown in Figure 4. For the tested configurations, the curves show good agreement in the low and mid-frequency ranges.

However, time weighting 'Impulse' gives systematically lower results.

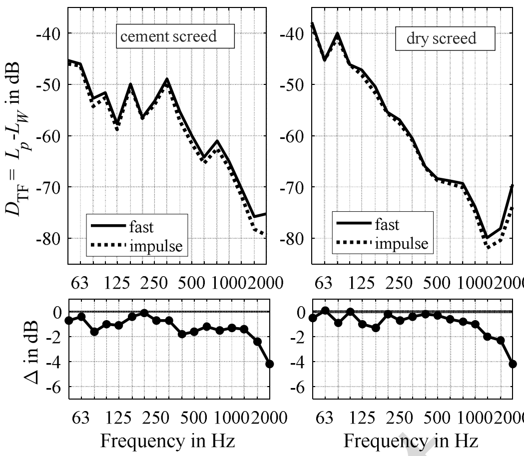


**Figure 4:** Power-based transfer function $D_\mathrm{TF}$ comparing different temporal weightings for two distinct setups. Top plots display absolute spectral levels; bottom plots show corresponding level differences.

The deviations calculated for all excitation positions are summarized in Figure 5. Up to 1 kHz, the mean deviation is approximately -1 dB. Above 1 kHz, the discrepancy between the two settings increases, reaching a maximum deviation of approximately -4 dB at 2 kHz.

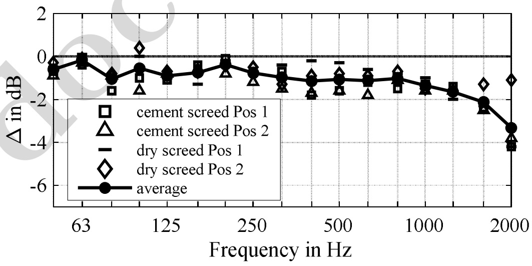


**Figure 5:** Level differences between the 'Fast' and 'Impulse' temporal weightings across all excitation positions. Markers represent discrete measurements for both floor configurations at two positions each, with the solid line indicating the arithmetic average.

### 3.3 Mobility measurements

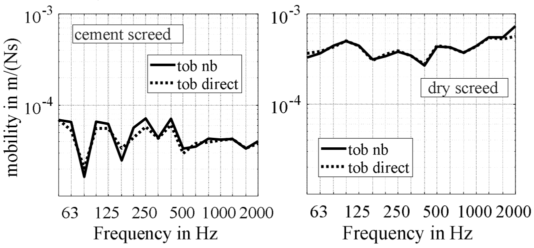


**Figure 6:** Structural mobilities for two distinct floor configurations. The plots compare synthesized one-third octave bands from narrowband reference data against direct measurements.

To investigate the direct one-third octave band approach, the receiver mobilities of the two distinct screed systems were analysed. Figure 6 presents the mobilities for both floor configurations and shows the different dynamic behaviours of the two test structures. Within both plots, a direct comparison is drawn between the established reference method and the

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proposed simplified approach. The solid line ("tob nb") represents the narrowband measurement, which was subsequently synthesized into one-third octave bands. The dashed line ("tob direct") represents the direct one-third octave band measurement. The results show good agreement between the two acquisition methods for both structural configurations.

### 3.4 Transfer function sound pressure-to-force

To evaluate the accuracy of the transmission path characterization, the structure-borne transfer functions acquired through both measurement methodologies were compared. The top plots of Figure 7 show the force-based transfer function for the two floors considered again for both narrowband acquisition and direct one-third octave band measurement.

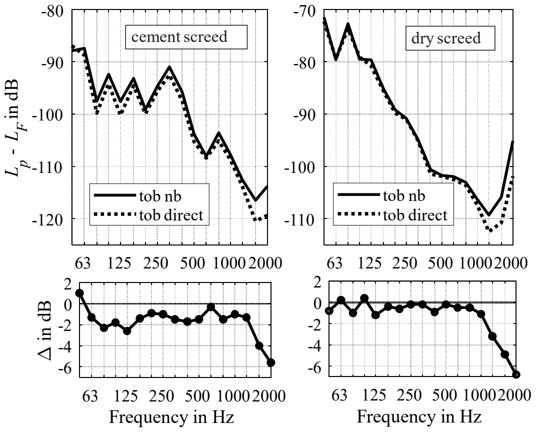


**Figure 7:** Force-based transfer function ($L_p$ - $L_F$) comparing narrowband reference data against one-third octave band measurements. Top plots: absolute values for two distinct setups; bottom plots: corresponding level differences.

The differences in Figure 8 show a similar characteristic for both floors, with systematic deviations between -2 dB and 0 dB up to 1 kHz. Above 1 kHz, the differences increase.

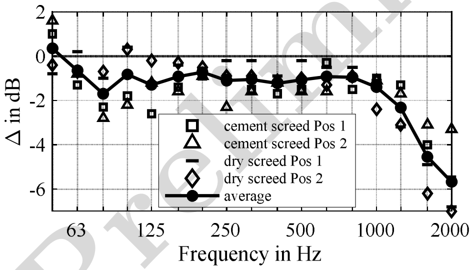


**Figure 8:** Level differences between the direct one-third octave band approach and the narrowband reference method. The data points represent discrete measurements across two different floor configurations at two excitation positions each. The solid line indicates the arithmetic average of the deviations across all evaluated positions.

### 3.5 Transfer function sound pressure-to-sound power

Building upon the structural and acoustic data presented in Sections 3.3 and 3.4, the power-based transfer functions $D_{TF}$ were calculated for all configurations according to the methodology outlined in Section 2. The objective is to evaluate the accuracy of the proposed direct measurement by comparing the directly acquired one-third octave band levels against the one-third octave bands derived from the narrowband data. Figure 9 illustrates the $D_{TF}$ spectra for selected excitation-receiver combinations, comparing the FFT-derived data (solid lines, "tob nb") with the direct acquisition (dashed lines, "tob direct"). Across the low and mid-frequency ranges, both measurement strategies demonstrate good agreement.

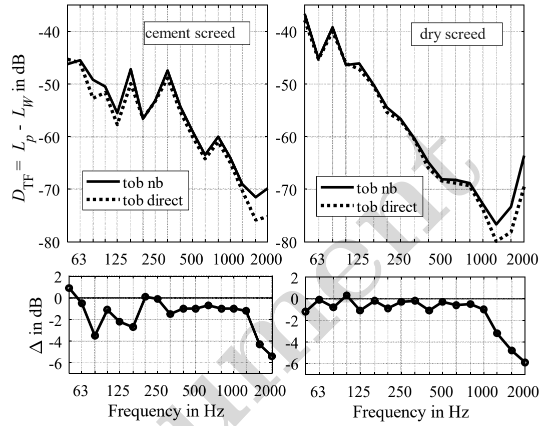


**Figure 9:** Power-based transfer function ($D_{TF}$ = $L_p$ - $L_W$) comparing narrowband reference data against one-third octave band measurements. Top plots display the absolute values for two distinct setups; bottom plots show the corresponding level differences.

Figure 10 shows the differences for all four tested positions (two on the cement screed, two on the dry screed), alongside the calculated mean difference. Up to 1 kHz, the mean remains well with approximately -2 dB deviation. At higher frequencies (1 kHz to 2 kHz), the mean deviation steadily increases, reaching approximately -5.5 dB at 2 kHz.

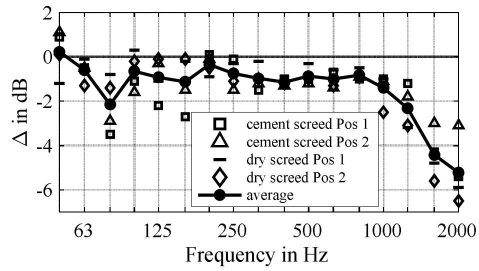


**Figure 10:** Level differences $\Delta D_{TF}$ between the direct one-third octave band approach and the narrowband reference method. The markers represent discrete measurements across two different floor configurations at two excitation positions each. The solid line indicates the arithmetic average of the deviations across all evaluated positions.

### 3.6 Discussion

For the mobility as well as the force and power-based transfer function measurement, there is good agreement between the data measured directly in one-third octave bands and the data derived from narrowband measurements. In particular, the transfer function data indicated systematically lower values for the one-third octave band data. A potential reason for this systematic

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deviation is the utilization of the Fast-weighted maximum values in the level analyser. The time-weighted level of the impulse detected with the analyser is determined by the chosen time-constant. This can be expected for both the force level and the level of the sound pressure or acceleration. However, in the sound field of the receiving room there is an additional influence related to the reverberation time in the room. For long reverberation times, i.e. a time constant of the room, the time-constant chosen for the weighting in the analyser has less impact on the detected level. Since in the narrowband data acquisition the actual peak value is detected, there is no influence of a time-weighting in both signals. Nevertheless, the results indicate, that for rooms with typical reverberation times, the difference with this method is within 2 dB up to 1 kHz. Above 1 kHz the force level decreases due to the hammer tip and the stiffness of the receiver yielding lower signal-to-noise ratios.

## 4. Case study

### 4.1 Introduction

The main motivation for this work is to streamline the application of the transfer functions in building acoustics. This requires an efficient measurement method to determine the necessary input data. Ideally, this process follows the most reduced engineering approach possible, relying on the "blocked force" condition [4]. If the receiving structure is sufficiently heavy and stiff to justify this assumption, the complex source-receiver coupling calculation can be bypassed, significantly reducing both time and experimental effort.

However, in practical building scenarios, the assumption that the receiver mobility is sufficiently low compared to the source mobility needs to be proven across the entire frequency range relevant for building acoustics. This case study considers examples for different mobility ratios by applying both the force approach and the power approach. For this case study, the direct one-third octave band data is used. It evaluates whether the simplified force-based prediction model can still provide reliable engineering estimates under these non-ideal conditions.

### 4.2 Source and receiver data

A typical building service equipment unit that is characterized according to EN 15657 [2] was selected. This particular source data in combination with the test structures was intentionally selected to exhibit distinct mobility ratios. In alignment with the practical objective of this study, the receiver mobility data, shown in Figure 11 relies on the direct one-third octave measurements, as previously shown in Section 3.3. The variation of the mobility ratio provides the opportunity to evaluate both the Specific Case condition, where the receiver is highly dominant (cement screed), and more complex coupling scenarios (dry screed) using the power-based method.

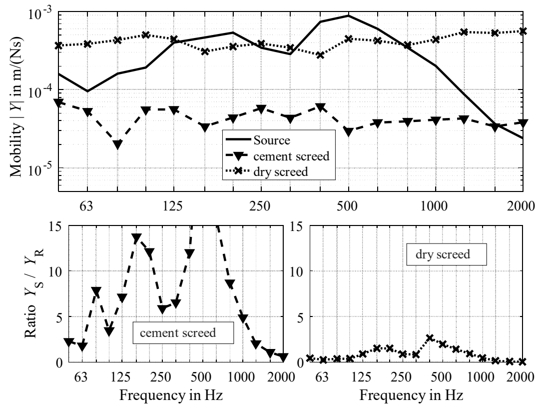


**Figure 11:** Mobilities and resulting mobility ratios illustrated for the investigated coupling scenarios. Top: Magnitude of mobility of the characterized machinery source $|Y_S|$ alongside the two distinct screed configurations $|Y_R|$ are shown. Bottom: Mobility ratios $|Y_S|/|Y_R|$ for both receiving structures are plotted.

### 4.3 Results

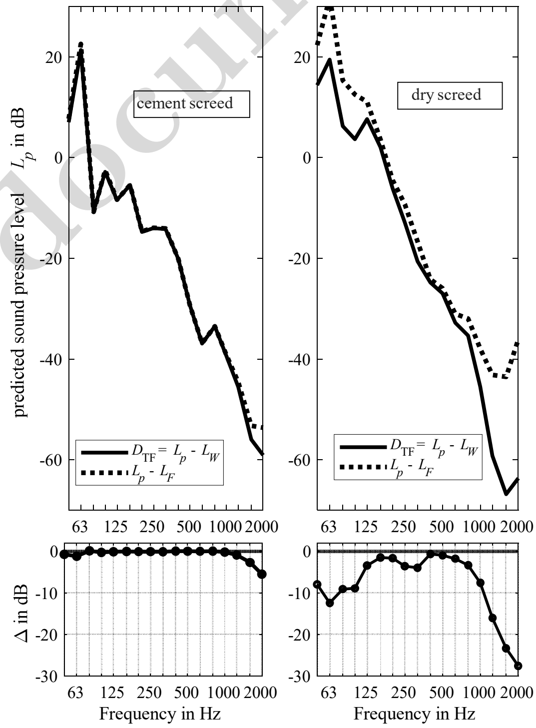


**Figure 12:** Comparison of the predicted sound pressure level $L_p$ calculated using $D_{TF}$ and $L_p$ - $L_F$. Top plots display the absolute predicted levels for two distinct structural coupling conditions; bottom plots show the corresponding level differences.

Using the methodology from EN 12354-5 [1] the resulting sound pressure levels in the receiving room were predicted for both test configurations. For both floors, the force approach and the power approach is applied. Figure 12 illustrates the predicted sound pressure levels and the corresponding differences for two representative excitation-receiver combinations. For the cement screed (left plots), where the source mobility significantly exceeds the receiver mobility $|Y_S|»|Y_R|$ the simplified force-based prediction shows

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good agreement with the $D_{TF}$ method. Across the low and mid-frequency ranges, the deviation remains negligible, confirming that the machinery effectively acts as a pure force source. Minor deviations only begin to emerge at frequencies above 1 kHz, where contact stiffness and shifting mobility ratios introduce slight underestimations.

The dry screed configuration (right plots) shows the limits of the force approach when the underlying mobility conditions are violated. Because the source and receiver mobilities are in a similar magnitude range $|Y_S| \approx |Y_R|$, the blocked force condition is not met. Consequently, the simplified calculation deviates from the power-based approach. Interestingly, even in this proximity where $|Y_S| \approx |Y_R|$, a systematic error of approximately 3 dB can be observed. As the receiver mobility increases further relative to the source $|Y_R| > |Y_S|$, this deviation increases significantly, reaching approximately -30 dB at high frequencies. Note that this involves the simplified assumptions of EN 12354-5 [1] in the coupling term.

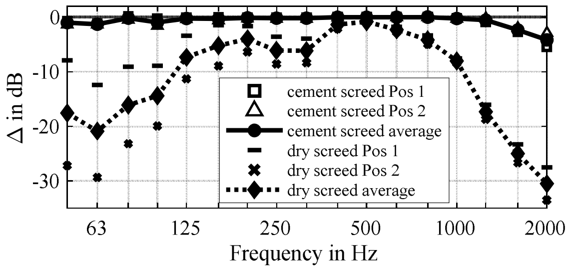


**Figure 13:** Level differences between predicted sound pressure using simplified approach and the comprehensive transfer function method. The markers represent discrete measurements across two different floor configurations at two excitation positions each, with the solid line indicating the arithmetic average of the deviations.

To quantify the trend and the variability of these prediction differences, Figure 13 presents the frequency-dependent level differences for all measured positions across both floor configurations. The data clearly separates into two distinct clusters. The measurements on the cement screed remain consistently within a narrow tolerance band around the 0 dB line up to 1 kHz, proving the reliability of the simplified approach for stiff, heavy receivers. In contrast, the dry screed positions exhibit underestimations in several distinct frequency ranges. The resulting arithmetic average is skewed by these differences, emphasizing that the mobility condition needs to be checked to avoid prediction errors.

## 5. Summary

This study addressed whether the complex input data required for structure-borne sound prediction in building acoustics can be determined directly in one-third octave bands. For this purpose, a two-channel level analyser was used. By systematically comparing narrowband reference data with direct one-third octave band measurements, it was demonstrated that the latter can offer a viable, time-efficient alternative. The investigation confirmed that up to 1 kHz the power-based transfer function $D_{TF}$ can be determined with good approximation using a standard two-channel sound level analyser. In this study, only discrete source and receiver positions were analysed. However, these are ready to be spatially averaged.

For instance, the proposed direct measurement strategy could serve as an efficient input basis for standardized spatial normalization techniques discussed by Rieger et al. [5] or be integrated into fully validated full-scale prediction models as presented by Kruse et al. [6]. Nevertheless, the demonstrated feasibility of this direct one-third octave band acquisition is promising for practical applications of the methodology. Beyond the laboratory determination of transfer functions, the proposed methodology could potentially be adapted to simplify the in-situ evaluation of building service equipment. By bridging the gap between simplified Specific Case assumptions and rigorous General Case requirements, this work provides an experimental basis for further developing efficient structure-borne sound characterization and prediction.

Further work is required to investigate systematic deviation by analysing the influence of time weighting. In the next step the validation against measured SPLs is required.

## References


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