# Structure-borne sound power from vibrating sources into building elements

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## Introduction

The reception plate method is used to characterise structure-borne sound sources in laboratories [1]. The so obtained source data can be used to predict the sound transmission in buildings using parts of EN 12354. The advantage, of the reception plate method, when compared to other methods such as the free velocity and mobility method, is the easy application and handling of the data. So far, reception plates with free edges have been used in laboratories. In the case considered here, the vibrating sources are lightweight stairs which are treated as active components with respect to an external excitation e.g. by the tapping machine [2]. Connection of stairs to free reception plates offers practical difficulties and thus a characterisation using a "real" wall as receiver appeared initially to be straightforward and was thus investigated.

## Reception plate method

The power input into a single freely suspended plate equals the bending wave energy loss on the plate according to (1) (Figure 1).

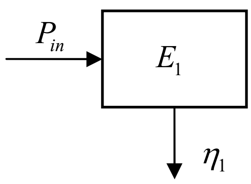


**Figure 1:** SEA model of a single freely suspended plate

$$P_{in} = \omega E_1 \eta_1 \tag{1}$$

The bending wave energy conserved in the plate equals the product of plate mass and spatial average velocity in the far field (2).

$$E_1 = m\overline{\tilde{v}}^2 \tag{2}$$

In [1] and [2] it is experimentally validated that the reception plate power equals the cross-spectral power from a connected shaker for free plates but not for walls or floors with the edges bonded into surrounding walls and floors like in real buildings. For the latter case a constant underestimate of the installed power was found in previous investigations. Subsequently the problem was addressed using a simplified SEA model.

Consider a case where the excited plate is connected to a second plate at one edge (Figure 2).

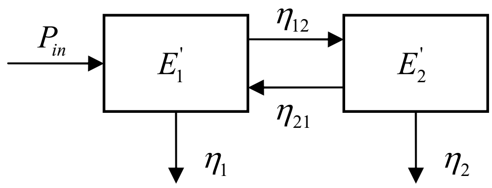


**Figure 2:** SEA model of two connected plates

The power balance equation for plate 1 is now a function of internal and coupling loss factors (3).

$$P_{in} = \omega E_1'(\eta_1 + \eta_{12}) - \omega E_2' \eta_{21} \tag{3}$$

The power balance equation for plate 2 is (4).

$$\omega E_2'(\eta_2 + \eta_{21}) = \omega E_1' \eta_{12} \tag{4}$$

Substitution of equation 4 into equation 3 yields (5).

$$P_{in} = \omega E_1'(\eta_1 + \eta_{12}) - \frac{\omega E_1' \eta_{21}\eta_{12}}{\eta_2 + \eta_{21}} \tag{5}$$

With the assumption that the shaker power into the single free plate 1 is the same as into plate 1 when connected to plate 2, then from (1) and (5) the discrepancy of the plate 1 energy can be expressed as (6).

$$\frac{E_1}{E_1'} = 1 + \frac{\eta_{12}}{\eta_1} - \frac{\eta_{21}\eta_{12}}{\eta_1(\eta_2 + \eta_{21})} \tag{6}$$

Consider now two similar plates such that $\eta_1 = \eta_2; \eta_{21} = \eta_{12}$ to simplify matters. Estimates for the coupling and internal loss factors in buildings can be found in [3]. The first term in equation (7) represents the coupling loss factor and the constant the internal loss factor.

$$\eta_{tot} = \frac{1}{\sqrt{f}} + 0.015 \tag{7}$$

Using these loss factors the ratio $E_1 / E_1'$ is about 2 at low frequencies and about 1.5 at high frequencies and thus for two connected plates, the reception plate method would underestimate the exact power by about 2 to 3 dB.

In buildings, walls and floors are usually connected to many more plates (side walls, etc). With the gross assumption of N similar plates with the connected plates only interacting with the directly excited plate 1, all connected plates have the same energy and the energy discrepancy is obtained from (8).

$$\frac{E_1}{E_1'} = 1 + N\frac{\eta_{12}}{\eta_1} - N\frac{\eta_{21}\eta_{12}}{\eta_1(\eta_2 + \eta_{21})} \tag{8}$$

For 4 connected plates the reception plate method would underestimate the exact power by about 4 dB at high frequencies to 6 dB at low frequencies again with the loss factors from (7).

## Experimental investigation

Experiments have been carried out in a staircase test facility on a single-leaf receiving wall built of 24 cm CaSi and density 2000 kg/m$^3$ connected to 2 similar side walls and 2 concrete floors. A shaker with a force transducer for direct power measurement was attached to a central wall contact and driven with random noise.

In Figure 2 the direct power measurement is compared to the power obtained by an indirect method described in [2] and the reception plate method. The spatial average velocity was accurately measured using a Polytec laser scanning vibrometer on a scanning grid with in total 1100 points distributed over the whole wall surface. For the evaluation of the reception plate method positions in the near field were excluded. The total loss factor was measured using the decay rate method.

The directly and indirectly measured powers are in good agreement while the reception plate power underestimates the real installed power. The discrepancy is about 5 dB at low frequencies and reduces with frequency. Both tendencies were expected from the simplified SEA model as illustrated above. So far loss factors according to [3] were used for the prediction of the discrepancies. It is well known that the coupling loss factor in (7) tends to overestimate the edge losses in modern buildings [4]. Therefore a more detailed investigation involving measured coupling loss factors is in progress.

## Power calibration

The reception plate method as applied so far yields a systematic underestimate of the real source power for non free reception plates. The discrepancy obviously depends on the "properties" of the receiving wall - primarily the boundary conditions – but in a linear system, it is independent from the source. Therefore a power calibration function [5] can be used to correct for the discrepancies.

Figure 3 shows the power from a vibrating stair - attached to the same contact point as the shaker in the previous measurement - obtained by the reception plate method, using the power calibration function and by the indirect method. The power obtained from the indirect method is used as benchmark here since direct power measurement was not possible.

Again a significant underestimation of the stair power by the reception plate method is observed. Using the power calibration function an acceptable agreement is obtained. The method is thus found very useful for the purpose of characterising sources where the use of non free reception plates is not possible or practical.

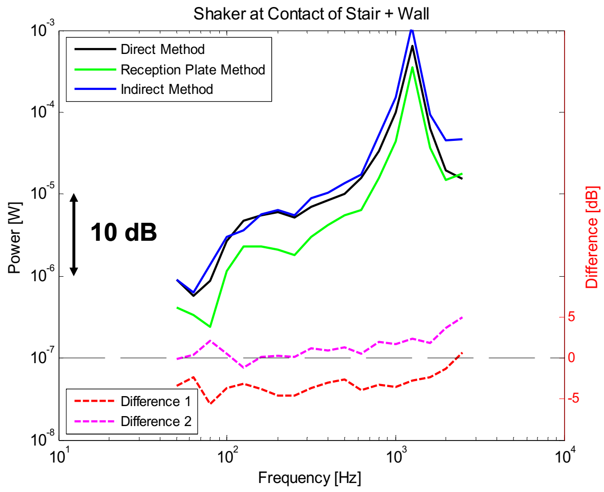


**Figure 2:** In-situ power from a shaker source (driven with random noise) attached to a central wall contact by different methods

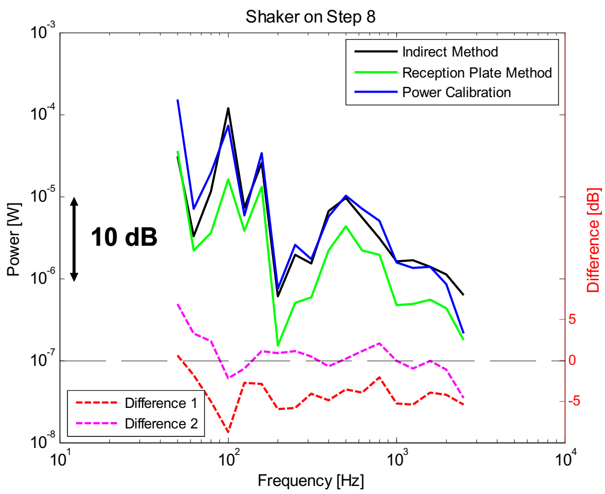


**Figure 3:** In-situ power from a vibrating stair (excited by a shaker driven with random noise) attached to the contact of shaker and wall as in Figure 2

## References

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