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IMPROVEMENT OF IMPACT SOUND INSULATION OF FRAMEWORK STAIRCASES

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1. INTRODUCTION

The transmission of impact noise due to walking on staircases in terraced or in semi-detached houses is still a major reason of disturbance of privacy for the dwellers. Insufficient impact sound insulation according to German Standard DIN 4109 "Sound Insulation in Buildings" represents an acoustically inferior quality of the building, and hence the building company is often forced to reduce the selling price of those flats or houses.

This paper deals with stairs which are built of wooden or steel steps mounted on a framework of wood beams or steel profiles (open stairs). The framework itself is mounted at the lower and upper floor and it is also attached to the neighbouring walls which are often party walls of terraced houses. Sometimes stairs consist just of steps which are individually mounted on to a wall (e.g. see Fig. 4). Because of the rigid wall mountings the impact noise is intensively transmitted into the walls and thus into the adjacent dwellings. The impact noise annoyance can be reduced by applying a resilient covering to the steps such as carpeting, linoleum, or by means of resilient connections of the staircase framework to the walls. The performance of this type of noise control measure has not been systematically investigated up to the present time. Measurements have been made only on a few individual cases. The aim of the present paper is to learn about the state of the art of impact sound insulation and to investigate to what extent elastically supported staircase steps and resilient mountings at the wall can improve the impact sound insulation of stairways [1].

2. IMPACT SOUND INSULATION OF FRAMEWORK STAIRCASES

To evaluate the impact sound insulation of staircases, the numerous measurement data of the Fraunhofer Institute of Building Physics (IBP) were statistically analysed. The results are shown in Figure 1. The impact sound transmission takes place via the common partition wall of adjacent terraced houses, and thus the design of that wall is of importance. In former investigations it could be shown that in comparison with a single-leaf wall a double wall of the same weight can improve the impact sound insulation rating index by about 10 dB to 12 dB [2].

The distribution of the TSM values (Impact Sound Insulation Rating Index according to German Standard DIN 52 210) shown in Fig. 1 clearly indicates that with only single-leaf walls and without additional impact sound insulation measures at the stairway, TSM values of about 10 dB can be achieved. The values with the highest probability occur between about -5 dB and 0 dB. Therefore, the minimum impact sound level criterion of 10 dB can only be met with the use of an additional impact sound insulation. For double-leaf wall constructions, the TSM values are already greater than 10 dB. Most results had values which occurred between 12 dB and 17 dB. Provided that there are no structure-borne sound bridges between the two separated walls, the TSM values can be 20 dB or even higher.

The achievable impact sound insulation rating index (TSM) depends on several different effects as the widely spread distributions of the TSM values in Fig. 1 suggest. Figures 2 and 3 show the dependence of the impact sound insulation rating index (TSM) on the airborne sound insulation rating index of the partition wall. Because all walls are of about the same thickness and weight, the effect of the staircase mounting on the wall can be clearly seen in Fig. 2. The worst cases expected are those where the staircase-steps were individually mounted on the wall (Fig. 4). The data for double walls are shown in Figure 3. The investigated double walls were of nearly the same construction with respect to wall thickness, weight and separation. The measured differences of the airborne insulation rating index are most probably due to faulty connections of the two wall shells. Those sound bridges are difficult to prevent under practical building conditions. Badly built up double walls will therefore have also an inferior impact sound insulation whereas correctly built walls usually meet the suggested minimum impact sound criterion of TSM = 10 dB. The transmitted impact sound level obviously depends on the impact sound excitation of the staircase-bearing wall. Despite of a good airborne sound insulation of about R_W = 63 dB the impact sound insulation level reaches only TSM = 7 dB because of poor step mountings (see Fig. 4). The expected impact sound insulation index in this case was about 17 dB.

The main conclusions from these findings are:

- Single-leaf partition walls of practical dimensions ($m'' = 450 - 500$ kg m^{-2}) are not suited to provide sufficient impact sound insulation for staircases.
- The usage of single-leaf partition walls requires additional impact sound reducing measures such as carpeting or resilient mountings.
- Double-leaf partition walls generally provide an effective impact sound insulation to meet the minimum impact sound level criterion.
- At double walls with good airborne insulation ($R_W > 57$ dB) additional measures to improve the impact sound insulation do not provide a measurable higher insulation.

3. REDUCTION OF IMPACT SOUND TRANSMISSION BY RESILIENT MOUNTINGS AND CLAMPS

There are two possibilities of reducing the excitation of the wall onto which the staircase is mounted:

- resilient mounting of the staircase-framework on short levers rigidly mounted to the wall
- resilient clamping of framework supports between elastic constraining layers in the wall.

Both constructions were investigated. The measurements took place on a brick masonry wall of 17.5 cm thickness ($m'' \approx 320$ kg m^{-2}). The wall was built up between two reverberation rooms in a laboratory. Measurement results are shown in Figures 5 and 6. The peaks at 400 Hz and 800 Hz in Fig. 5 are caused by resonant vertical or horizontal vibrations of the short lever. Supporting levers should be designed so that those resonances are excluded from the frequency range of interest. The resonance frequency can be approximately calculated by

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{B}{m'}} \cdot \frac{3.52}{l^2} \qquad (1)$$

where B - bending stiffness of the lever and m' - lever mass normalized to the free lever length l.

At frequencies below f_1, the lever acts as a pure spring. Thus the vibration reduction via the resilient layer is given by

$$\Delta L_V = 20 \lg \left(1 + \frac{s^*}{s}\right) \qquad (2)$$

with s^* the stiffness of the lever at the driving point and s the stiffness of the elastic layer.

There should always be the relation

$$s \ll s^* \qquad (3)$$

or

$$\frac{E \cdot S}{d} \ll \frac{3B}{l^3} \qquad (4)$$

to gain an effective vibration insulation (E - Young's modulus of the elastic material, S - supporting cross-section, d - thickness of the elastic layer).

For a certain frequency range immediately above f_1 the lever acts as pure mass and the vibration reduction is described by

$$\Delta L_V = 20 \lg \left[1 - \left(\frac{\omega}{\omega_0}\right)^2\right] \qquad (5)$$

where $\omega_0 = \sqrt{s/m^*}$. m^* means the dynamically effective mass of the lever which is given by

$$m^* = \frac{3B}{4\pi^2 l^3 \cdot f_1^2} \qquad (6)$$

Measurement results for a resiliently clamped lever are depicted in Figure 6. The insulation effect strongly depends on:

- the occurrence of stiff structure-borne sound connections which short-circuit the resilient layers

- the stiffness of the resilient constraining material around the lever.

Impact sound short circuits can readily be prevented by enclosing the lever completely inside the wall with elastic material. The effect of this on the impact sound insulation is shown by curve marked (b) in Figure 6. The improvement at higher frequencies can clearly be seen. Rubber-like materials are on the other hand nearly incompressible. Therefore, constrained elastic material layers have to be enabled to give space to deform in case they are compressed. That space can be provided by holes or airfilled profiles inside the elastic material. If there are no such spaces, the elastic materials will act like a stiff connector without any impact-sound reducing effect.

4. PROPOSALS FOR IMPROVING THE IMPACT SOUND REDUCTION OF STAIRCASES

From the measurements as well as from a few practical cases some recommendations can be drawn to reduce the impact sound transmission of staircases. Generally, a reduction can be achieved by

- reducing the excitation of the staircase itself and/or

- diminishing the structure-borne sound transmission into the neighbouring supporting walls.

A summary of a few important measures to improve the impact sound insulation is given in Figure 7. The usage of resilient intermediate layers between steps and framework requires also resiliently insulated screw connections. The feasibility of those floating mounted steps is nevertheless questionable. There are measurements that indicate that by using felt-strips as resilient layers even a deterioration of insulation may occur. Resilient mountings or clampings on to the supporting wall result in insulation improvements of about 3 dB to 5 dB. Those limitations of improvement are in practice given by the still rigid mountings of the staircase on to the floors. With resilient mountings even there an improvement of about 10 dB could be achieved.

5. REFERENCES

[1] H. Ertel Improvements of impact sound insulation of staircases by means of resilient connections to the wall
IBP Report BS 92/83 (1983) (in German)

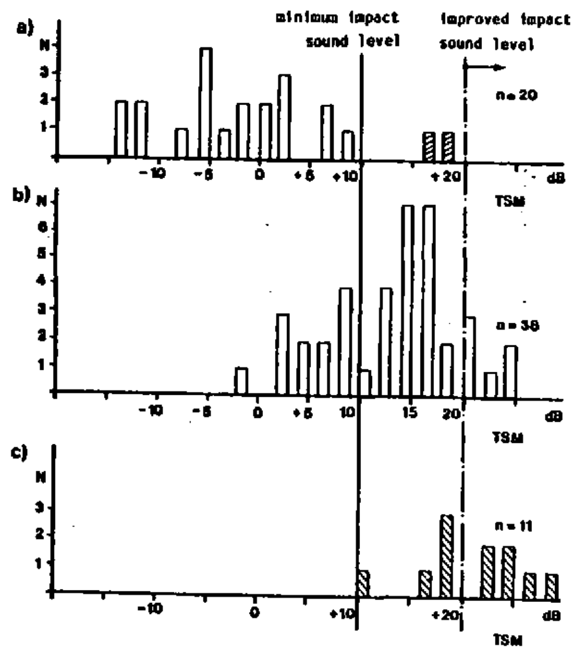
[2] K. Gösele Sound insulation between stairway and dwelling
FBW-Blätter, Folge 6-1971 (in German)

Figure 1 Distribution of the impact sound insulation rating index (TSM) of staircases in terraced and semi-detached houses (evaluation period: 1981)

a) single-leaf partition without ( ) and with ( ) elastically supported staircase-mountings
b) double-leaf partition with rigid staircase-mountings
c) double-leaf partition with elastically supported staircase-mountings

N - absolute number of measured TSM values
n - number of investigated staircases

suggested requirements according to draft standard DIN 4109, 1984



• - staircases without impact sound insulation

o - staircases with impact sound insulation

Δ - single staircase steps rigidly mounted on the partition wall

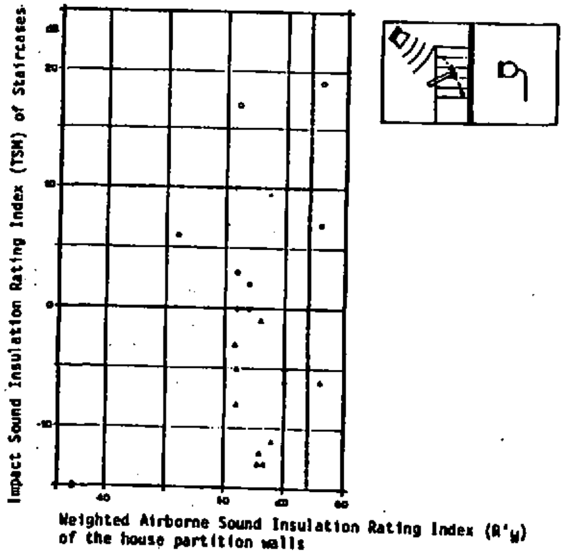
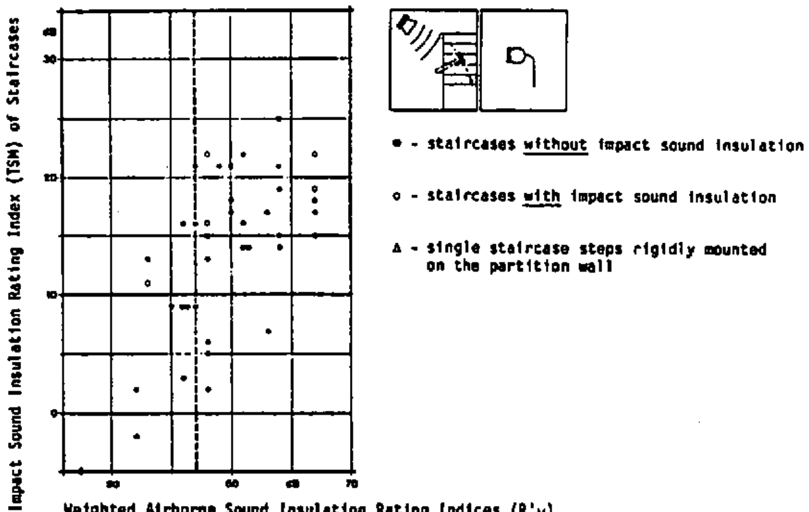


Figure 2 Impact sound insulation rating indices of framework staircases versus the airborne sound insulation rating indices of single-leaf party walls

(horizontal and oblique impact noise transmission)

Figure 3 Impact sound insulation rating indices of framework staircases versus the airborne sound insulation rating indices of double-leaf party walls

(horizontal and oblique impact noise transmission)



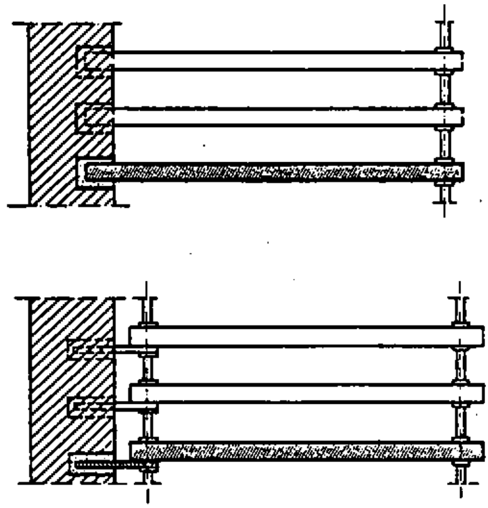


Figure 4 Bad example of staircase mountings on to supporting partititon walls

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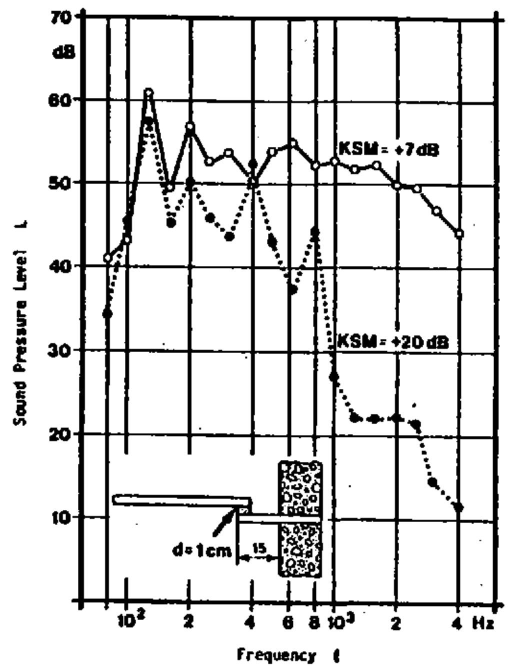


Figure 5 Frequency dependence of the sound pressure level in the receiving room by structure-borne sound excitation of the wall via a short lever with elastic mounting

mounting details:
elastic material: Polyurethane-foam, ρ = 600 kg m^{-3}
supporting area: 4 cm x 4 cm
thickness of the resilient layer: 1 cm

wall construction details:

17.5 cm brick masonry, m'' = 320 kg m^{-2}

o——o reference measurement with rigid mounting

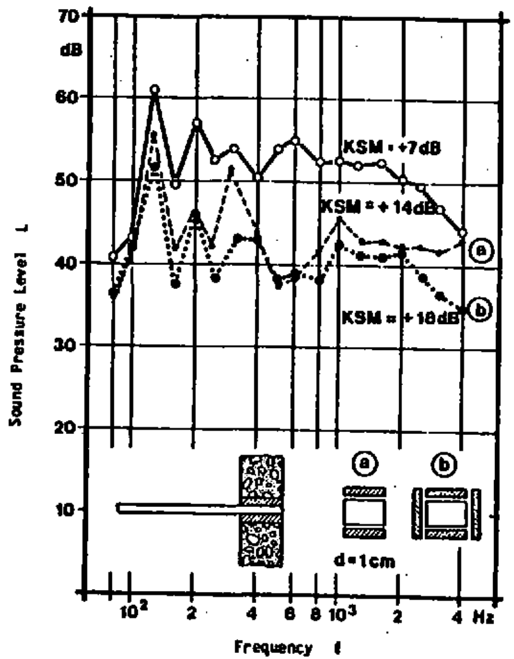


Figure 6 Frequency dependence of the sound pressure level in the receiving room with structure-borne sound excitation of the wall via a resiliently clamped lever

clamping details:
elastic material: rubber-based material, Shore-hardness: 40

thickness of the constraining elastic layers: 1 cm

wall construction details:
17.5 cm brick masonry, m'' = 320 kg m^{-2}

o——o reference measurement with rigid clamping

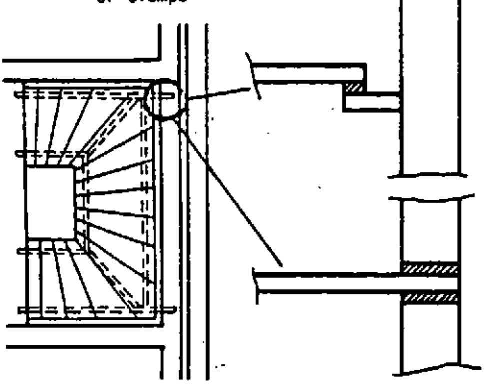
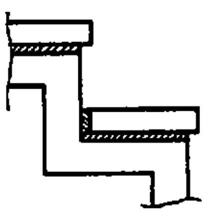
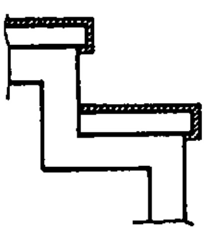
measures to improve the impact sound insulation	anticipated improvement of the impact sound insulation rating indices
1) resilient mountings or clamps 	ΔTSM ≈ 3 dB - 5 dB; these approximate values are based on measurements made on resilient staircase-mountings but with rigid mountings to the lower and upper floor. With additional impact-sound isolators on the ceiling, a larger ΔTSM can be expected.
2) elastic supporting layers between frame and staircase steps 	ΔTSM ≈ 4 dB - 6 dB; the staircase steps must be attached without rigid connections between steps and staircase frame
3) elastic surface coverings 	ΔTSM ≈ 10 dB; usage of surface coverings with an impact-noise reduction of about 20 dB, i.e. carpeting materials

Figure 7 Recommendations to improve the impact sound insulation rating indices of framework staircases