STRUCTURE BORNE-SOUND EXCITATION AND TRANSMISSION OF LIGHTWEIGHT STAIRS

PACS Reference: 43.55.TI

Fischer, Heinz-Martin (1); Moeck, Thomas (2); Petzold, Evi (1); Scheck, Jochen (1)
Fachhochschule Stuttgart/University of Applied Sciences (1), STEP GmbH (2)
(1) Schellingstr. 24, D-70174 Stuttgart, Tel. +49 711 121-2839, Fax: +49 711 121-2698, E-mail: fischer.fbp@fht-stuttgart.de
(2) Brueckenstr.9, D-71364 Winnenden, Tel. +49 7195 9147-70, Fax: +49 7195 9147-10 E-mail: info@steponline.de

ABSTRACT

Lightweight stairs often cause severe acoustical problems. Therefore a research program was started with the following main topics:

- construction of an appropriate test facility
- analysis of excitation mechanisms on lightweight stairs
- suitable measurement procedure in agreement with realistic noise excitation
- vibration behaviour of the stairs (modal analysis) and transmission of structure borne-sound to the building
- model for prediction of impact noise of stairs
- technical improvements of lightweight stair constructions.

The contribution will give a survey of the mentioned investigations and outline some main results of the actual work.

INTRODUCTION

Lightweight stairs often are used in double and row houses. Typical constructions are made of wood or with metal frames. In most cases the requirements (in Germany: $L'_{n,w} \leq 53$ dB) and in many cases even the recommendations for improved impact sound isolation (in Germany: $L'_{n,w} \leq 46$ dB) are fulfilled. Nevertheless inhabitants often complain of high impact noise caused by such constructions. Different investigations [1] have outlined that the main problem is a low frequency problem. Two main reasons for this can be stated:

- partition walls, where in most cases the stairs are mounted, suffer from high structure borne sound transmission in the low frequency range.
- the impact caused by walking persons mainly generates low frequency noise.

From timber floor constructions similar problems are known since a long time and many publications are concerned with this problem. In recent times new investigations [2] again have tackled this problem. It could be shown that the standardized tapping machine is not able to represent the walking process in an appropriate way. Therefore the draft of a new ISO-standard [3] defines additionally to the common tapping machine a modified tapping machine and a "standard heavy/soft impact source" (rubber ball) for the purpose of adequate excitation of lightweight floor constructions.

It can be assumed that similar problems hold true for the case of lightweight stair constructions. But in fact nearly nothing is available on this special subject. To solve the existing problems within a research program some main problems of measuring methods, impact noise excitation and transmission are investigated. The present report outlines some results of the actual work.

A NEW TEST FACILITY FOR TESTING IMPACT NOISE OF STAIRS

In building acoustics it is common use to characterize the acoustical behaviour of building components (e.g. walls, floors, windows etc.) by experimental tests which are executed in appropriate test facilities. Measuring procedures and test facilities clearly are standardized an the results of those investigations are used for the acoustical description of the products, for planning the sound protection in buildings and for improvements of the constructions. All this is not the case for stairs and therefore appropriate methods to solve the acoustical problems of lightweight stairs are not available. To overcome this shortcomings the first step in the described research program was to design and establish a suitable test facility for testing the acoustical characteristics of stairs.

The most essential requirements for the intended test facility have been the following topics:

- representation of typical building constructions (heavy solid or lightweight constructions)
- single or double leaf constructions for the partition walls
- vertical, horizontal and diagonal transmission of impact noise
- different ground plans of the investigated stairs
- implementation of the relevant and applicable requirements of the ISO-140 standards concerning test facility and measuring methods of impact noise.

The result was a complete new and unique ensemble of seven rooms being arranged according to **figure 1**. The test building completely is isolated from the surroundings and consists of three individual sections divided completely each from the others by constructional breaks. The two rooms lying on top of each other at the left side represent a heavy solid construction with CaSi-blocks at the side walls and concrete plates for the floors. The position and size of the staircase windows in the floors are in accordance with the most common situations in real building practice. So different types of stairs with different ground plans can be build in and tested. Some examples are shown in **figure 2.** The separating walls to the adjoining rooms in the middle section of the test building are exchangeable and can be constructed as single as well as double walls. So the stairs can be tested in combination with any type of heavy partition walls. The same principle can be realized at the two rooms at the right section for lightweight building constructions. In this section also the floor between the superimposed rooms is exchangeable. The reason is to represent lightweight constructions by a certain combination of lightweight floor and lightweight separating wall and to investigate the acoustical behaviour of a stair under these conditions. The rooms in the middle section serve as receiving rooms. Additionally in these rooms impact noise transmission from spiral stairs can be investigated on heavy as well as on lightweight floors. So altogether this test facility offers an unique test field for acoustical testing and improvement of stairs. In the meantime the new test facility could be used for a number of investigations some of which shortly will be reported in the following sections.

IMPACT NOISE EXCITATION OF LIGHTWEIGHT STAIRS

With respect to the situation being found at lightweight floor constructions it seems to be one of the most important tasks also to have a realistic description of the excitation and transmission processes being typical for lightweight stairs. For this reason different noise sources were used for different investigations. Excitation by an impulse hammer was used to define the relevant transfer functions of the transmission paths. Force spectra and sound pressure level spectra were measured for the excitation of stair constructions by the standardized tapping machine, a modified tapping machine as being described in [3], a rubber ball similar to that being described in [3] and by walking persons. Similar to the case of lightweight floors it can be stated that also in the case of lightweight stairs the tapping machine does not deliver a reliable description of the real walking excitation by human walkers. The walking person generates a force spectrum with predominant low frequencies whereas the tapping machine (as well known) produces a spectrum with increasing amplitudes at high frequencies. In contrast to this the modified tapping machine (which is defined in [3] as the standardized tapping machine placed on an elastic layer with specified dynamic stiffness) gives a good characterization of the real walking process.

Additionally it could be shown that also the specified rubber ball [3] delivered a force spectrum being suitable to describe the excitation of the lightweight structure by persons. But in this case it was not the complete walking process over the complete staircase but the single step on only one step which properly can be characterized by the single impulse of the rubber ball.

Comprehensive studies were executed to investigate the characteristics of noise excitation by different walking situations. For this purpose a lightweight stair construction as being shown in **figure 3** was mounted at a heavy single leaf wall (CaSi-blocks). Each of the wooden steps of this stair is mounted by a pair of steal bolts directly to the wall using elastic coverings of the bolts inside the wall. The characteristic features of the walking situations were: male/female walkers, walking upstairs and downstairs, different weight of the walkers, different footwear, individual walking velocity and intensity. The complete spread of sound pressure level spectra (measured in the adjoining room behind the wall) is shown in **figure 4.** Altogether the excitation by a walking person can be described as an reproducible process. Different weight of the walking persons does not influence the spectra very much whereas different shoes have an substantial influence on the shape of the spectra and the amplitudes. Differences between walking upstairs or downstairs are not significant in the interesting low frequency range. **Figure 5** shows a comparison between a walking person (walking downstairs), the tapping machine and the modified tapping machine. Again it can be seen that only the modified tapping machine delivers a realistic description of the walking process. Additionally it can be shown by other experiments, that the rubber ball characterizes rather well a single step of a person or a jumping child.

ANALYSIS OF VIBRATION BEHAVIOUR BY MEANS OF MODAL ANALYSIS

The vibration behaviour of the stair described in **figure 3** was investigated by means of modal analysis. **Figure 6** shows the mean transfer function which was gained for one step of this stair (see **figure 7**). In the interesting low frequency range up to about 800 Hz the vibration behaviour of a step is characterized by predominant eigenfrequencies. It could be shown that the same frequency pattern can be obtained at the other steps of the stair so that the described vibration behaviour is characteristic for this stair. Additionally a very similar vibration behaviour was found for the same stair type which was mounted in a real building under comparable building conditions. So it can be assumed to describe the essential vibration behaviour of the stair sufficiently by adequate laboratory tests. Some examples for the measured vibration pattern are shown in the **figures 8 - 10**.

FURTHER INVESTIGATIONS

As a first approach for a prognosis model of impact noise of a stair the procedure being described in [4] and [5] for waste water systems and technical equipment was adopted for lightweight stairs. In this case the excitation quantity of the stair measured in a laboratory is adjusted to the individual transfer function in a certain building. Despite of some severe restrictions for the application of this model the preliminary results seem to be encouraging.

The next investigations will deal with acoustical improvements of lightweight stairs. All investigations will be executed in the new test facility using the alternative impact noise sources and including the experimental results of modal analysis and of transmission functions. Additionally psychoacoustic studies have been started to rate the impact noise of lightweight stairs by psychoacoustic quantities.

REFERENCES

[1] Kurz, R., Schnelle, F.: "Schallschutz von Montagetreppen", Fortschritte der Akustik, DAGA 2000 Oldenburg

[2] Scholl, W., Maysenhölder, W.(1999): "Impact Sound Insulation of Timber Floors: Interaction between Source, Floor, Coverings and Load bearing Floor", Journal of Building Acoustics, Volume 6, number1: 43-61.

[3] ISO/CD 140-11 (2001): Acoustics – Measurement of sound insulation in buildings and of building elements, part 11: "Laboratory measurements of the reduction of transmitted impact noise by floor coverings on lightweight framed standard floors"
[4] prEN 14366 (Febr 2002): "Laboratory measurement of noise from waste water installations"
[5] Fischer, H-M.: "Determination and Use of Transfer Functions to Describe Structure-borne Sound Transmission Caused by Equipment and Installations", 17th International Congress on Acoustics 2001, Rome

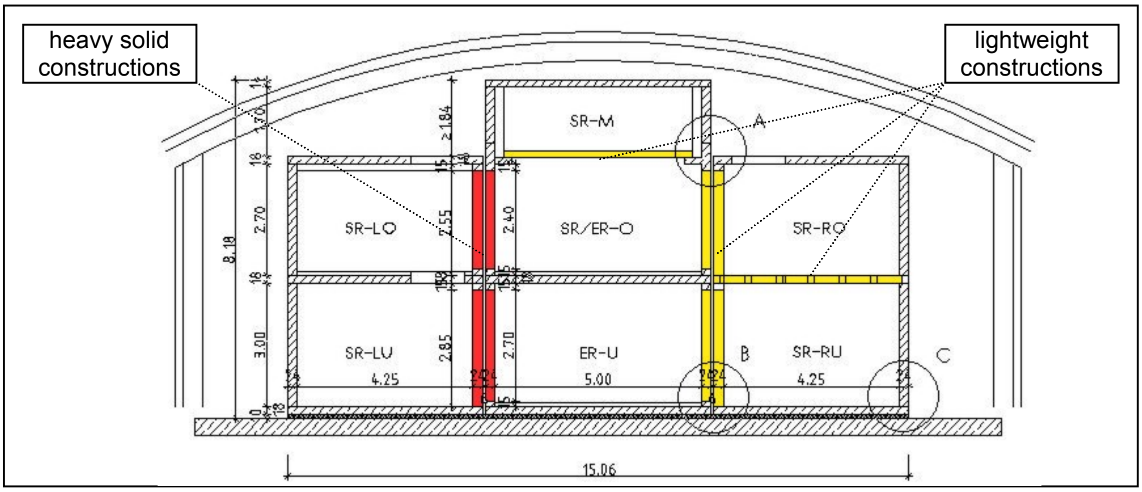
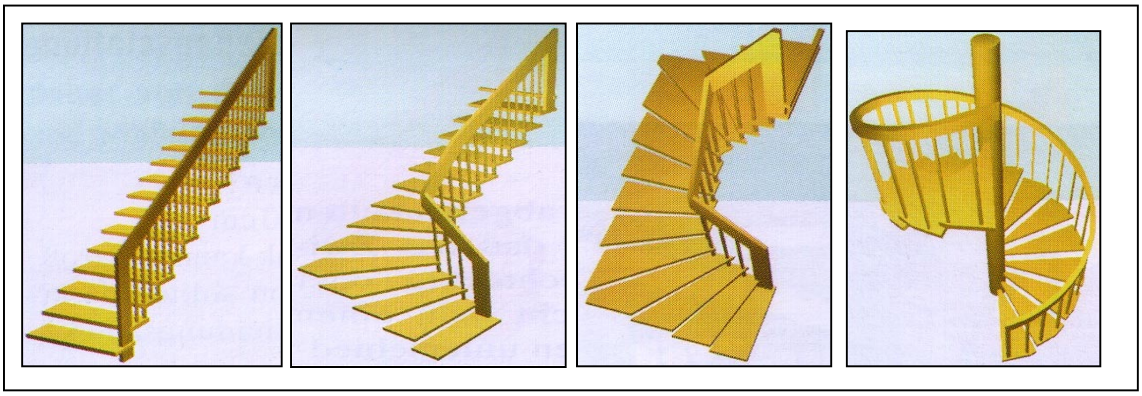


Figure 1: Sectional view of the new test facility for stairs



Figur**e 2**: Examples of different ground plans of stairs to be tested in the test facility

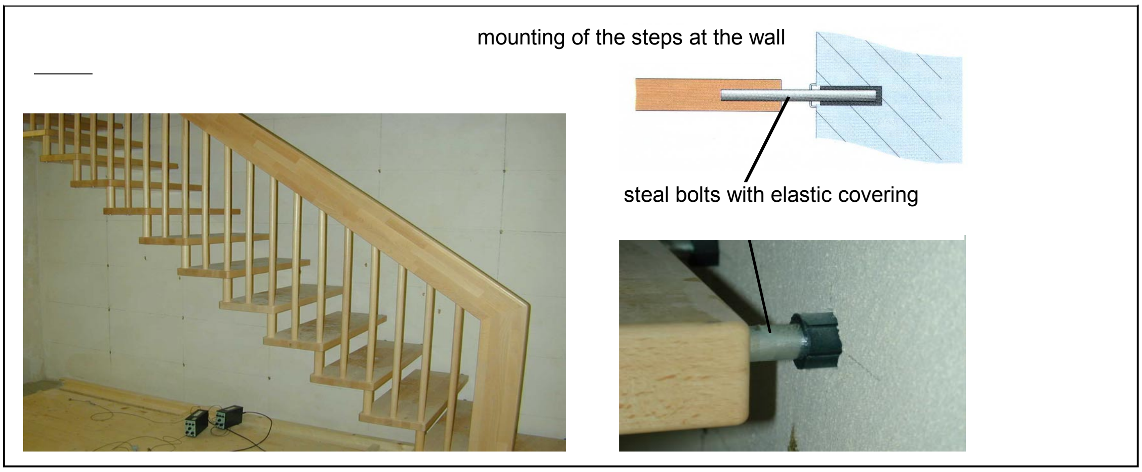


Figure 3: Investigated lightweight stair

Figure 4:

Spread of measured walking noise excited by different persons with different shoes (mean value and standard deviation)

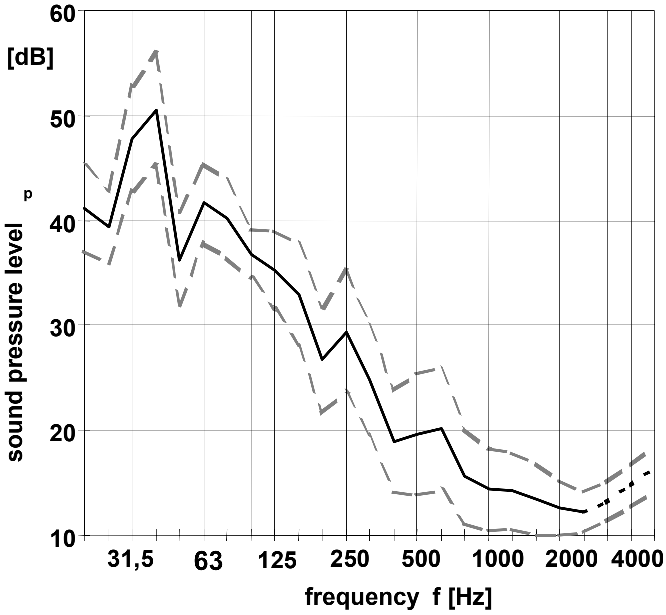


Figure 5:

Comparison of impact noise of the stair measured in the adjoining room

walking downwards

tapping machine

modified tapping machine

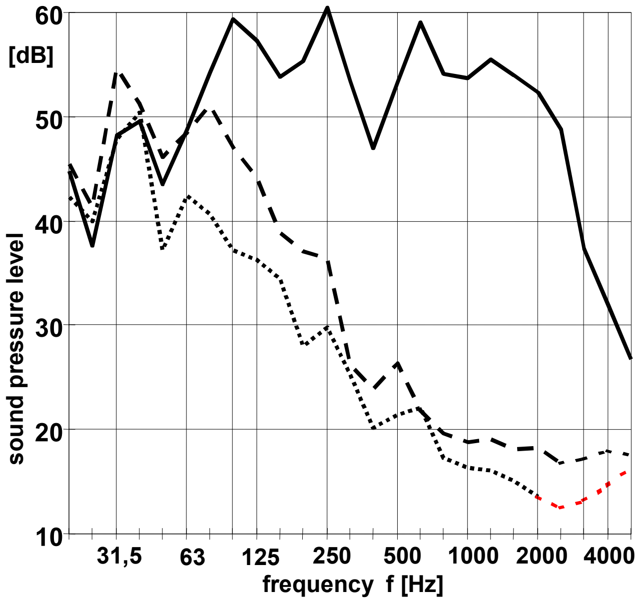


Figure 6:

mean value of transfer function obtained by modal analysis for step No. 8

investigated stair: see figure 3

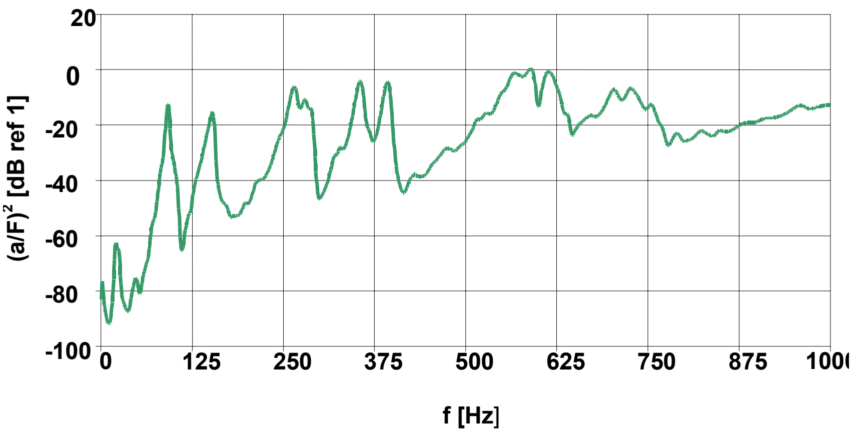
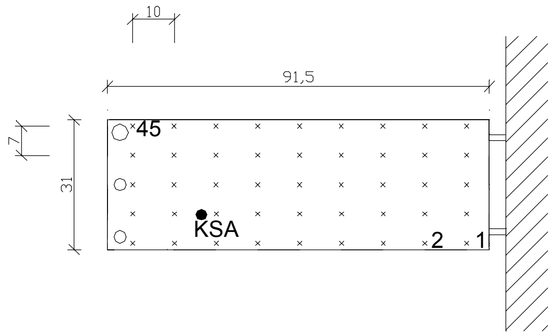


Figure 7:

investigated step with measuring points and mouting to the wall



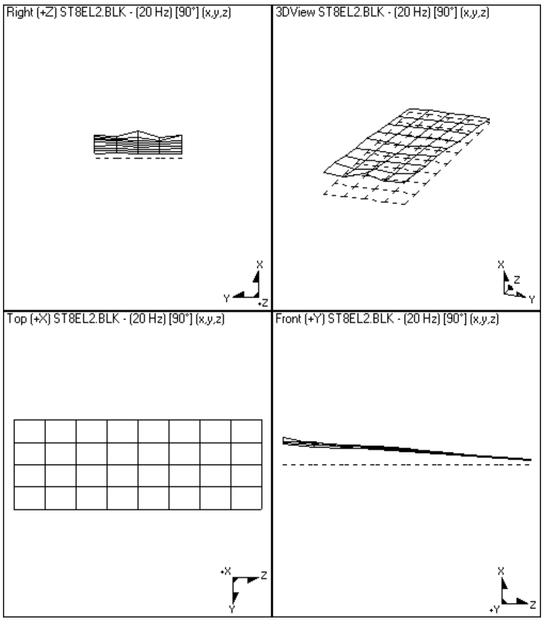


Figure 8: Vibration of the stair at 20 Hz

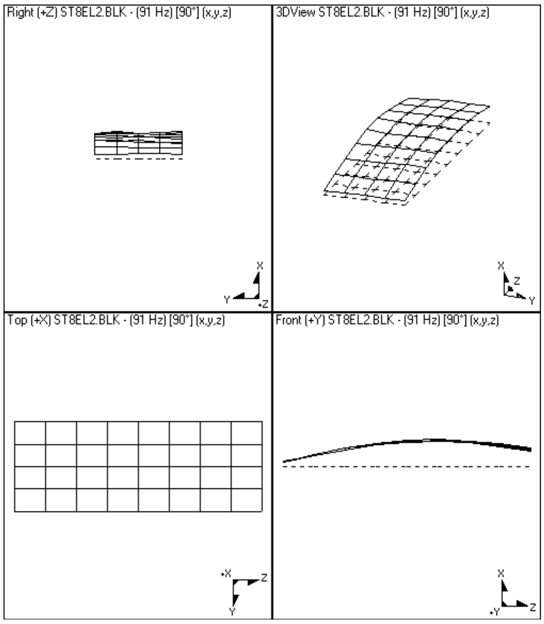


Figure 9: Vibration of the step at 91 Hz

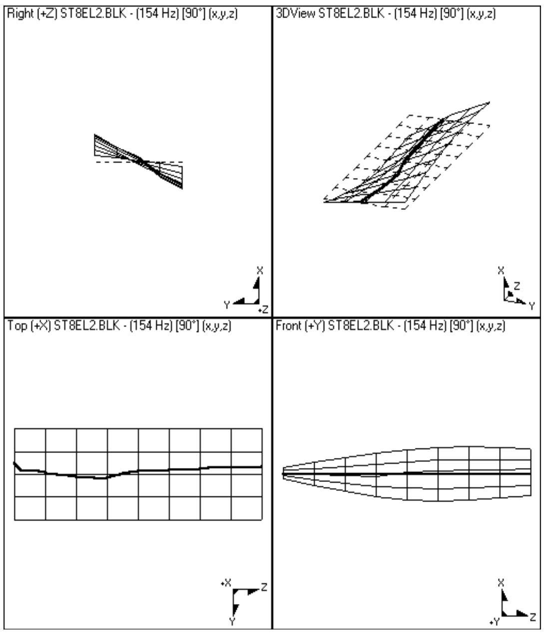


Figure 10: Vibration of the step at 154 Hz