# Approach for the Characterization of a Wooden Staircase as Structure-borne Sound Source

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## Introduction

At present it is not possible to predict the sound transmission into adjacent rooms, from footfalls on lightweight stairs, which are connected to the separating wall. Especially at low frequencies excitation by human footfall and transmission is high and often causes annoyance to the inhabitants. To reduce problems in the future a characterization of lightweight stairs as structure-borne sound sources is required. In particular, a test method is required which will provide data, which will indicate the noisiness of the stair system when installed in a building. Concerning this matter investigations have been carried out on a wooden staircase with string board which is a common type of stair in Germany. In this paper the investigation of the vibration behaviour of the stair and an approach for the characterisation as structure-borne sound source is outlined.

## Wooden Staircases with String Board

Structure-borne energy enters the building through the contact points which are shown in figure 1.

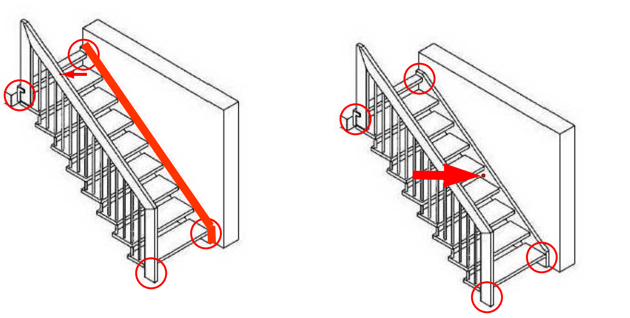


**figure 1:** contact points and dominant transmission paths

The stair is supported by the ceilings e.g. the floating floors. Up to now it is common practice to mount the string board directly at the wall using screws. In this case the transmission from the string board into the wall is significant. Experience shows that with the string board in contact with a common separating wall annoyance cannot be avoided. Even the normative requirements on the normalised impact sound pressure Level $L'_n$ can hardly be met. The string board must be moved away from the wall as indicated in the right sketch of figure 1. However, the string board still has to be fixed at the wall, for safety reasons (stability when walking on the stair). This can be done through one connection [1]. Investigations show that in general transmission through this wall contact is the dominant transmission path. A detailed investigation of the structure-borne energy transmission through a single wall contact therefore is the topic of this current study.

## Investigated System

The experimental investigation of a wooden staircase with string board was carried out in the staircase test facility. The string board was moved away from the wall and resiliently supported at both ends. The contact with the wall was through one rigid screwed connection, shown in figure 2. It was confirmed experimentally that, in this set-up, the dominant structure-borne sound transmission was through the screwed contact.

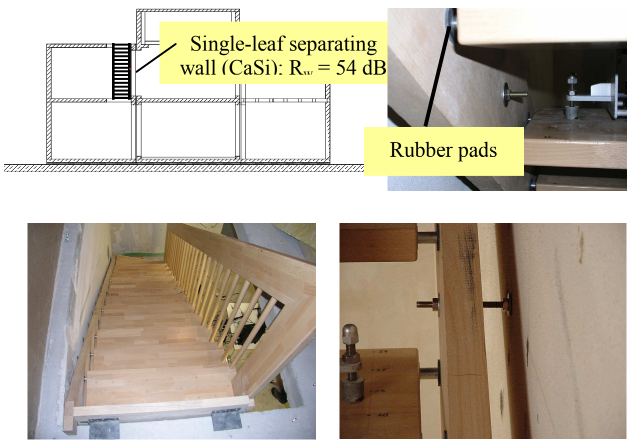


**figure 2:** investigated system

## Experimental modal analysis of the stair

The vibration behaviour of the stair is a major influence regarding the excitation of the wall. To get an insight into the dynamic behaviour of the stair, an experimental modal analysis was conducted, using an instrumented hammer. Accelerometers were placed on a central step (the $8^{th}$ step from the floor), near the contact point and also on the edge of the $5^{th}$ step. Due to reciprocity, the measured operating deflection shapes, shown in figure 3, result from excitation at the accelerometer positions. In the frequency range below 100 Hz the vibration of the stair is determined by beam modes of the handrail (47 Hz, 77 Hz) and string board (67 Hz). The vibration strength at a particular frequency is therefore strongly dependant on the position of the excited step. The excitation of steps, situated at antinodes of the handrail / string board, causes significant vibration of the whole stair assembly. In contrast, excitation of steps at nodal positions, results in reduced vibration. For example the strong vibra tion of the stair at 77 Hz only occurs for excitation at step 5 since step 8 is situated at a nodal point of the corresponding handrail beam mode. In the frequency range above ≈ 100 Hz the vibration of the single steps is determined by plate modes (the first plate mode occurs at 106 Hz). The handrail acts as "deliverer" of vibration energy within the stair-system. At frequencies where step plate modes and handrail beam modes coincide, the vibration of the whole stair is strong (99 Hz). At frequencies where no handrail beam modes occur, the excitation energy is mainly contained in the directly excited step (e.g. 106 Hz). This is also the case if the handrail has a beam mode but the excited step is situated at a node. The beam modes of the string board determine the motion at the contact, perpendicular to the wall, and thus influence the excitation of the wall. Strong vertical motion at the wall contact follows if the wall contact and the excited step are situated at an antinode of the string board (67 Hz). On the other hand, in case of the excited step at a node of the string board, there can still be motion at the wall contact by energy transmission within the stair system due to handrail modes.

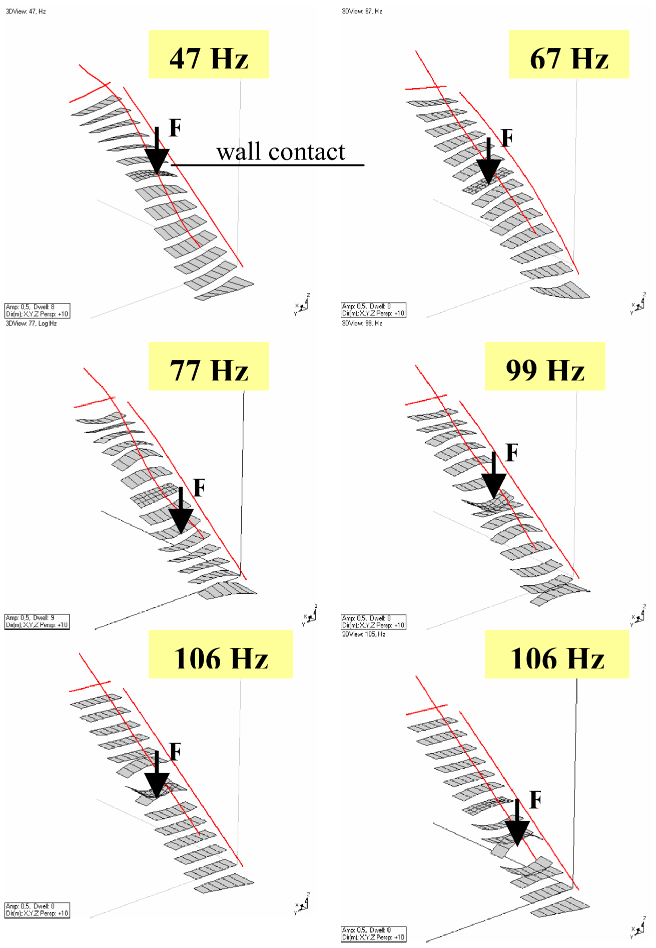


**figure 3:** measured operating deflection shapes at low frequencies

## Stair as Structure-borne sound source

How can the stair be described as a structure-borne sound source? The stair assembly is a passive structure until it is excited on one or several of its steps. It then can be treated as an active source, which vibrates and transmits structure-borne power into the separating wall. The stair now can be treated in a similar manner to that used to predict the structure-borne power from vibrating machines in buildings and other structures. Accordingly the source descriptor concept [3] can be applied. It allows a characterisation of the stair as structure-borne sound source on a power basis. The source descriptor by definition is an inherent quantity of the source. The required quantities are the free velocity and mobility at the contact point formed by the rigid screw connection (figure 2). As shown the vibration behaviour of the stair strongly depends on the location of the external source. This effect can be considered e.g. by means of averaging the free velocities to be measured over all steps. From the receiver (wall) mobility the coupling function can be calculated and thus the power transmission of the stair in the installed condition can be predicted for a defined receiving wall.

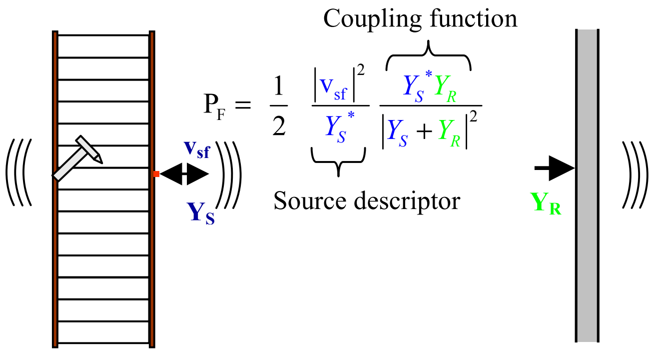


**figure 4:** stair as active component – source descriptor concept

## Predominant components of excitation

For a single contact point, there are up to six degrees of freedom (3 translational; 3 rotational), which can contribute on the excitation of the wall. None can be neglected a priori. The structure-borne power imparted to the wall due to forces and moments is given by [2].

$$P_F = \frac{1}{2} F^* v \quad ; \quad P_M = \frac{1}{2} M^* w \tag{1}$$

In the next stage of this study, the components of excitation of the wall will be identified by means of reciprocal methods. This will allow the components to be identified which contribute to the structure-borne sound transmission into the wall and thence to the resultant sound pressure level in the adjacent room.

## References

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