Structure-borne sound transmission in lightweight buildings: Consideration of an equivalent single receiver mobility

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Introduction

Recent work, conducted at the University of Applied Sciences Stuttgart and the University of Liverpool, has shown that for heavyweight buildings the structure-borne sound power from a wide range of mechanical installations can be obtained using a single value of source power obtained by a laboratory reception plate method [1]. This value, in combination with a single value of the receiver mobility (the characteristic mobility) gives the predicted power when the machine is installed in the building. However, for other building structures, particularly lightweight framed constructions, such as gypsum board walls and timber joist floors, the point mobility may vary significantly with location and the use of an equivalent single mobility, which is the average of the effective point mobilities over the contacts, may be problematical. In order to assess the use of an equivalent single receiver mobility, the spatial variations of common lightweight constructions are considered. The equivalent mobility preserves the clarity of a single point excitation even for sources with multiple contact points. In this contribution measurements of point- and effective receiver mobilities are shown and compared for several typical lightweight building constructions.

Lightweight building constructions

As for heavyweight situations, a proper prediction of the structure-borne sound transmission from a source installed in a lightweight building requires an estimate of the receiver mobility. In contrast to heavyweight structures, where the mobility of a source generally significantly exceeds that of the receiver, the source-receiver mobility relation in lightweight buildings is not obvious. Receiver mobilities may be greater than, less than or in the same order as that of the source. In addition, the mobilities in lightweight buildings, particularly in framed constructions, may vary considerably with location.

Figure 1: Examples for lightweight building structures.

Since there is relatively little information on the dynamic behaviour of lightweight building structures, the mobilities of a range of wall and floor structures were measured. Figure 1 shows two common structures in lightweight buildings: a timber joist floor with a single layer of chipboard above the joists, and a metal framed wall with gypsum sheets on both sides. Other tested structures included: timber-frame wall and floor constructions, single and double layered gypsum board walls, dry floating floor systems, lightweight solid gypsum wall, wood layer floor, etc.

Measured receiver point mobilities

The mobilities were measured with a calibrated impulse hammer. The dynamic condition therefore corresponded with many practical situations where sources stand on top of receiver structures without fixing. Usually the positioning of structure-borne sound sources on building structures is not known in advance and contact points are not necessarily above a joist or on a stud. Even if the sources are rigidly mounted to the basic structure on some points, there might be many more contact points which are not. In general, the fixing condition determines the resulting mobility.

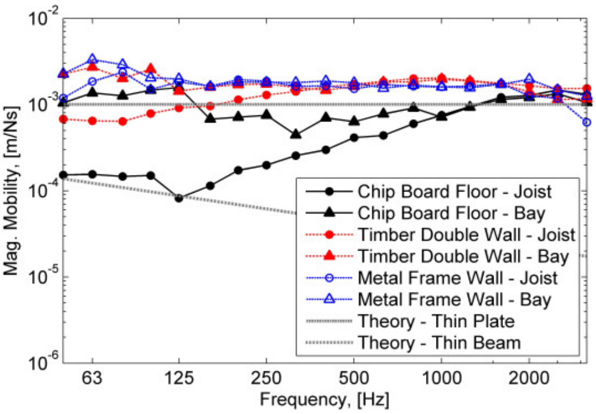

Figure 2: Measured mobilities of lightweight structures; --o-- on joist, --^-- in bay (midway between joists)

Figure 2 clearly shows the difference, especially in the low frequencies, between point mobilities measured on a joist or a beam and in a bay. At a fixing point, e.g. where the chip board panel is screwed to the joist (solid line), the measured mobility indicates characteristic beam behaviour at low frequencies. However, above a certain frequency, which is dependent on the structure, a plate like behaviour (characteristic plate mobility) is observed. For metal frame walls the behaviour is plate-like over the whole frequency range. The survey indicated that a high percentage of the point mobilities are determined by a plate like dynamic behaviour. Somewhat surprising is the small spread of values of point mobility for the wide range of building receiver structures.

Single equivalent excitation

Typically, vibrational active sources are connected to receiving structures through multiple contact points. At each contact, up to six components of excitation and response (three translations and three rotations) are possible. Furthermore, there are dynamic interactions between the different contacts and components. For N contacts, up to $6N$x$6N$ matrices of source and receiver mobility data are required and the expression for the complex power W is given as,

$$\overline{W} = \left\{\overline{v}_{Sf}\right\}^{*T} \left[\overline{Y}_S + \overline{Y}_R\right]^{*T-1} \left[\overline{Y}_R\right] \left[\overline{Y}_S + \overline{Y}_R\right]^{-1} \left\{\overline{v}_{Sf}\right\} \quad (1)$$

with $\{v_{sf}\}$ is the free velocity vector and $[Y_S]$, $[Y_R]$ the complex mobility matrices.

Because of the plate-like behaviour of the measured point mobilities of most lightweight structures, data reduction can be invoked by the introduction of effective mobilities [2]. The concept of effective mobilities preserves the clarity of a single point single component representation of equation (1). Using this approach, the power can be estimated at each contact individually but with the interaction of other contacts and components included. The total power from a source to a receiver through N contacts is then given by the sum of all contact powers.

$$P = \sum_i^N \left|\overline{v}_{Sf\,i}\right|^2 \frac{\mathrm{Re}\left\{\overline{Y}^{\Sigma}_{Ri}\right\}}{\left|\overline{Y}^{\Sigma}_{Si} + \overline{Y}^{\Sigma}_{Ri}\right|^2} \quad (2)$$

P indicates the real part of the complex power, $\overline{v}_{Sf\,i}$ the free velocity vector and $\overline{Y}^{\Sigma}_{Si}$, $\overline{Y}^{\Sigma}_{Ri}$ the effective source and receiver mobility vectors for each contact. For a source with multiple contacts with a receiver and where perpendicular forces are dominant, the effective mobility at the i_{th} contact can be written as:

$$\overline{Y}^{\Sigma}_i = \overline{Y}_i + \sum \frac{\overline{F}_j}{\overline{F}_i} \overline{Y}_{i,j} \quad (3)$$

$\overline{Y}_i$ is the point mobility at the i_{th} contact, $\overline{Y}_{i,j}$ are the transfer mobilities between the i_{th} and j_{th} contacts and $\frac{\overline{F}_j}{\overline{F}_i}$ are the ratios of the forces at the j_{th} and i_{th} contacts. Equation (3) reveals a requirement for the force distribution at the contacts and therefore of the dynamics of both the receiver and source structures. In the absence of detailed knowledge of the contact forces, the forces can be assumed to be of equal magnitude, with either zero phase difference between contact forces, or with a random phase [3].

Equivalent single receiver mobilities

Equivalent single receiver mobilities are obtained from the mean of effective contact mobilities. In this investigation, four contact points, located at the corners of a square with edge length of 30 cm, are assumed. Thereby two measured points are located on a joist or beam and two points are midway between in a bay. This is supposed to be a common practical mounting situation for many structure-borne sound sources on lightweight building structures.

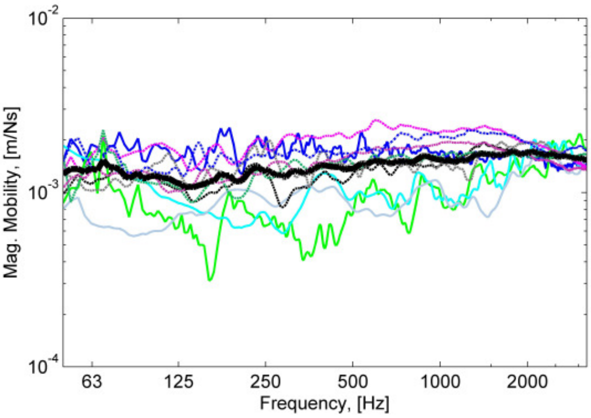

Figure 3: Equivalent single receiver mobilities of different lightweight building structures with mean (solid thick line)

Figure 3 shows measured data for ten different lightweight building constructions and again, the narrow range of the equivalent mobilities is noteworthy. For this assumed mounting condition the equivalent receiver mobilities show plate-like dynamic behaviour. Although two points are located on a joist or beam, the significantly higher point mobilities in a bay are predominant. However, there will be situations, e.g. rigidly fixing a source with all contacts to a joist, where the equivalent receiver mobilities indicate beam-like behaviour, at least in the low frequencies.

Conclusion

A measurement survey of common lightweight building structures has shown that the point mobilities are of the order of 10^{-3} [m/Ns]. They mostly indicate plate-like dynamic behaviour, which allows a consideration of equivalent single receiver mobilities. For the considered installation condition the equivalent mobilities can be determined by the mobilities measured in the bay.

Literature

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