Applied Acoustics 71 (2010) 587–596

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Vibration transmission through plate/beam structures typical of lightweight buildings: Applicability and limitations of fundamental theories

Laurent Galbrun

School of the Built Environment, Heriot-Watt University, Riccarton, Edinburgh EH14 4AS, UK

ARTICLE INFO

Article history:
Received 18 September 2009
Received in revised form 11 December 2009
Accepted 8 January 2010
Available online 12 February 2010

Keywords:
Building acoustics
Sound transmission
Statistical energy analysis

ABSTRACT

This paper examines the modelling of vibration transmission through plate/beam structures typical of lightweight buildings. Key experiments have been carried out on simple structures to identify the applicability and limitations of fundamental theories. The systems tested included a single plate connected along its centre to a beam, two parallel plates attached along their centre to a beam (plates opposite or offset), and four plates connected along their edges to a beam. The analysis focused in particular on the applicability of modelling a beam as a one-dimensional element in point connected systems (widely spaced screws in terms of bending wavelength). Statistical energy analysis (SEA) was the framework of analysis used for all predictions, but the theories examined were independent from SEA. The results obtained indicate that simple point models are only applicable to the single plate and beam system, and to the parallel opposite plates connected along their centre to a beam; even then, the applicability of such models is limited to low and mid frequencies (below 2 kHz for the structures tested). Transmission between two parallel plates connected to a beam with screws closely spaced was also examined, and it was found that rigid and pinned line predictions can provide limits for transmission between panels on the same side of a wall (where junctions with shallow beams tend to behave rigidly, whilst junctions with deep beams are better modelled as pinned).

1. Introduction

This paper examines the applicability and limitations of basic theories used to predict structure-borne sound transmission through plate/beam structures. The analysis focuses on junctions representative of lightweight partitions and timber floors, but the models discussed are not restricted to timber-framed buildings, as similar junctions can be found in other systems.

Although basic theories are well established, modelling transmission through simple plate/beam structures is not straightforward, as numerous factors need to be considered. These modelling factors include connection type, beam modelling options, beam modal properties and anisotropic characteristics of materials. Some of the modelling difficulties are well known, but only a limited number of applications have been tested to date. This paper aims to use a variety of examples as a means of understanding the difficulties involved in modelling. This is particularly relevant for lightweight buildings, as timber and plasterboard junctions are often far from the idealised conditions considered by fundamental theories. It is also important to note that the study is based on fundamental theories and is not concerned with the application or development of complex models.

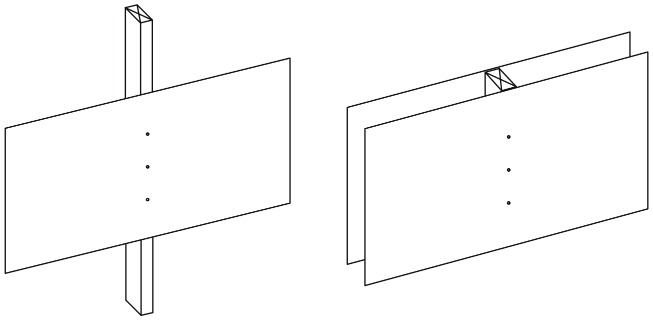
The structures examined consist of a timber beam connected to a varying number of parallel plasterboard plates, as found in lightweight buildings (Fig. 1). The spacing used between screws was typical of timber-framed constructions (i.e. screws widely spaced), which is the reason why the analysis has been mainly concerned with point connected transmission. The focus of the study was in particular on the applicability of modelling a beam as a one-dimensional system in point connected structures.

Measured data has been compared to predictions obtained from Statistical Energy Analysis (SEA) models, but it should be noted that the fundamental problems discussed are independent from SEA and are related to boundary conditions and other fundamental modelling options. In other words, problems would be identical if, for example, finite element modelling had been used.

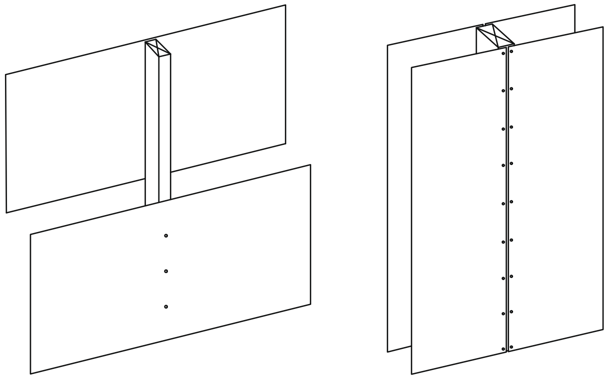
The paper begins by reviewing in details the background theory of vibration transmission in plate/beam systems. This allows defining modelling factors, as well as describing the complexity of the problem and theories available. It then uses a series of experiments to highlight the difficulties of modelling this type of structures and to identify systems for which basic models are valid and systems for which more complex models are needed.

E-mail address: l.g.u.galbrun@hw.ac.uk

0003-682X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apacoust.2010.01.009



(a) Plate and beam (b) Two parallel plates opposite



(c) Two parallel plates offset (d) Four parallel plates opposite

Fig. 1. Schematic of plate/beam structures examined.

2. Background theory

The options available to model structure-borne sound transmission through a simple plate/beam system are given in Table 1 and are discussed in detail below. These include connection type, beam and plate modelling options, finite or infinite length modelling for the beam, and material characteristics. For the theories examined, no references are made to equations, as these are well covered in the literature (e.g. [1,2]). Equations of coupling loss factors used for specific applications are given in Section 3.

2.1. Connection type

In timber-framed constructions, the plates and beams are attached together with screws or nails. Depending on the spacing between screws, it has been shown that the coupling occurs along a line (screws close to each others in terms of bending wavelength) or at points (screws widely spaced in terms of bending wavelength) [3], as shown in Table 1.

2.1.1. Line connection

Most of the basic theories for line connections were developed by Cremer et al. [1], who used wave models for semi-infinite plate structures connected along a line. Refinements of line models were made over the years by including all types of waves (bending, longitudinal and transverse), as in-plane waves were found to be important for structure-borne transmission [4–6]. Line connected plate/beam systems have been examined by several authors [7–10,3]. Bhattacharya et al. [7] developed a model for transmission between two infinite plates joined by a tie plate clamped to each plate. Langley and Heron [8] examined junctions of complicated structures made of multiple plates connected at arbitrary angles, where the number of plates was arbitrary and these were coupled through a beam or directly coupled along a line. Heron [9] used line wave impedances to calculate plate to plate coupling loss factors and tested the theories on a two plate assembly, where parallel plates were connected by an *I* beam (*Z* shape of the assembly). Bosmans and Nightingale [10] examined transmission in a rib-stiffened structure, while Craik and Smith [3] examined transmission between parallel plates connected by beams of different thickness (details of the findings from these papers are given in Section 2.2).

The models used in these studies were based on a wave approach and consisted of systems of continuity and equilibrium boundary conditions, with the exception of Heron [9], who used line wave impedances.

2.1.2. Point connection

When screws are widely spaced in terms of bending wavelength, the connection behaves as a series of points. The basic theory for point connected systems was developed by Cremer et al. [1], who examined point-acting sound bridges (short rods used in double plate structures for interconnection or stiffening purposes). They developed a theory based on impedances and calculated the power transmitted between the plates through the rod, taking into account both forces and moment excitation. Bhattacharya et al. [7] adapted this wave line model to calculate transmission through a narrow tie beam, by simply multiplying the plate to plate CLF by the ratio of the tie width and the plate width along the junction length. The tie was modelled as a subsystem, despite its very low mode count, and no experimental data was provided to validate predictions. Lyon and DeJong [11] used SEA to calculate the power transmitted between point connected structures. Coupling loss factors were derived using mobility functions and two different approaches were used, the wave approach and the modal approach. Craik [2] used electrical analogues to derive CLFs of plates connected by wall ties. Ties being generally very soft in bending and relatively stiff in compression, it was assumed that power is transmitted by forces through the wall tie. Craik and Smith [3] used the same approach for lightweight structures, and found that an appropriate transition frequency between the line and point theories was where a half bending wavelength on the plate fitted between the nails or screws that connect the plate to the frame.

In all these point models, the coupling is independent of the tie/screw positions, as it is assumed that each tie/screw acts independently, unless screws are arranged to be opposite each others (see Section 3.2). The total power flow is then the power transmitted across one tie, times the number of ties. Mobilities used in such models assume transmission at an idealised point, but sophisticated mobility measures including the effective contact area can be found in the literature [12,13]. Bosmans and Vermeir [14] developed a more complex model which can take into account the distance between points, as well as the influence of the density and the width of point connections. This model is based on a wave approach for elastically coupled semi-infinite plates (plates at right angles and inline plates), where local rigid connections are modelled using an elastic interlayer characterized by a space-dependent stiffness and periodic boundary conditions are assumed in the calculations. This model is appropriate to describe point connected plates where plates are connected by a mass-less junction beam, but for a plate/beam system a new model would have to be developed. It can be noted that it is at present the only model that can cover the transition region from line to point connections, but is very computational intensive and often unsuitable for regular applications.

2.1.3. Discussion

This review on connection type shows that wave models of semi-infinite plates are commonly used to describe line junctions,