Proceedings of The Institute of Acoustics

# USING STATISTICAL ENERGY ANALYSIS FOR STRUCTURE-BORNE SOUND TRANSMISSION AT LOW FREQUENCIES

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## INTRODUCTION

Statistical Energy Analysis (SEA) is a method well suited to the prediction of sound transmission through building structures, particularly if a number of transmission paths need to be taken into account. The walls, floors, columns, rooms, etc of the structure are considered as connected subsystems, the response of each which must be controlled by resonant modes. This is a fundamental requirement of SEA. However this requirement can lead to problems at low frequencies where there may be few modes, particularly in small structural subsystems.

Although this limitation has been understood since the introduction of statistical techniques there is no established lower frequency limit below which SEA is considered to be unreliable. Estimates of the number of modes per frequency band necessary in a structural subsystem have varied considerably, between more than 2 [1], and more than 23 [2] modes per 1/3 octave band.

A more accurate indicator is the modal overlap [1] which takes into account not only the number of modes but also the damping of the subsystems. Building structures are highly damped (typically 0.1 at 100Hz) and therefore the bandwidth of individual modes is high.

## MEASUREMENTS

Detailed measurements were made of structure-borne sound transmission in a three storey building. The walls and floors were split into three groups: big walls (typically 3.5 x 2.3 x 0.15m); small walls (typically 0.8 x 2.3 x 0.15m); and floors (typically 3.5 x 2.6 x 0.165m). The source subsystem was excited impulsively over the whole surface with a plastic-headed hammer for a period of 15 seconds. The response of both the source and receiving subsystems were measured at one position. This was repeated over a number of measuring positions until the mean level difference was known with a 95% confidence interval of $\pm 2$ dB. The energy, E, in each subsystem can then be found.

Five different types of joint were considered with 10 examples of each joint type being measured. The damping, $\eta$, of each receiving subsystem was measured using the reverberant decay method [3].

The coupling loss factor between any two connected subsystems, assuming no flanking transmission is then:

$$\mathrm{CLF} = 10\mathrm{Log}\frac{E_2}{E_1} + 10\mathrm{Log}\eta \qquad (1)$$

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## PREDICTED SOUND TRANSMISSION

The coupling loss factor between each pair of subsystems considered was predicted [4]. The effect of flanking transmission was also calculated and taken into account. These predictions were then subtracted from the measured coupling loss factors to give the error in the predicted coupling loss factor.

Modal density and hence 1/3 octave mode count were estimated for each wall using simple predictions [1]. Predictions were also made of the modal overlap which statistically is equivalent to the proportion of each 1/3 octave band controlled by resonant response.

## RESULTS

For each joint the difference between the measured and predicted results was computed as a function of: i) 1/3 octave band modal overlap; ii) mode count per 1/3 octave band and iii) the first resonant mode, $f_{11}$. This was done for source and receiving subsystems over the frequency range 63-3150 Hz.

In general it is found that the error increases at lower frequencies and is negative. The aim of the analysis was to determine the variable which would be the best predictor of the low frequency limit.

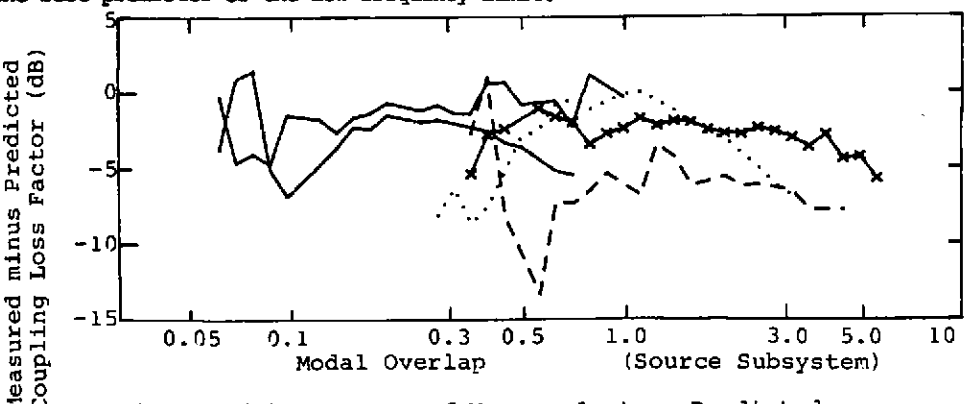


Figure 1(a). Average of Measured minus Predicted Coupling Loss Factor for the five joint types vs. Source Subsystem Modal Overlap.

Figure 1 shows the average difference against 1/3 octave modal overlap for (a) source, and (b) receiving subsystems. In Figure 1(a), (source), it is clear that the increase in the prediction error occurs at different places for different joint types. Since modal overlap is a function of frequency it might be expected that the SEA prediction would become progressively more accurate for all joint types with increasing modal overlap. This is not the case and therefore the modal overlap of the source subsystem cannot be used as an estimator of the lower limit to SEA.

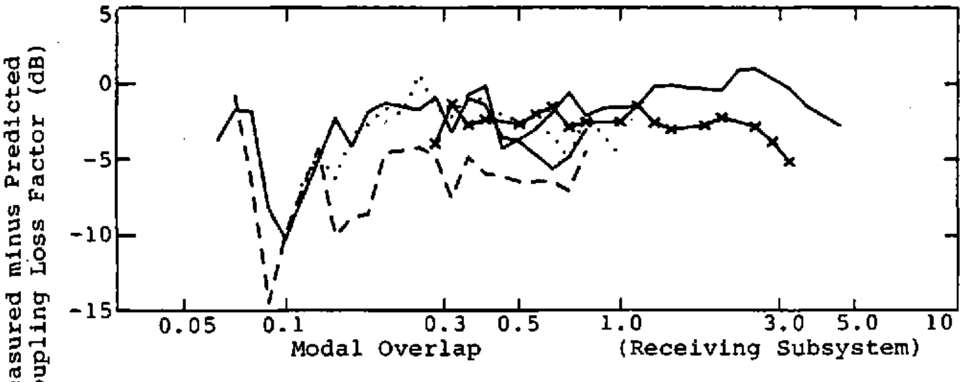


Figure 1(b). Average of Measured minus Predicted Coupling Loss Factor for the five joint types vs. Receiving Subsystem Modal Overlap.

In Figure 1(b), which shows the difference between the measured and predicted results against the modal overlap of the receiving subsystem, it can be seen that for all joint types the error decreases with increasing receiving subsystem modal overlap. From these and other results it appears that it is the modal overlap of the **receiving** wall of any pair which should be taken into consideration when establishing a low-frequency limit to SEA. In this case that limit is about 0.3 and there is little improvement in the predictions when modal overlap is above this value.

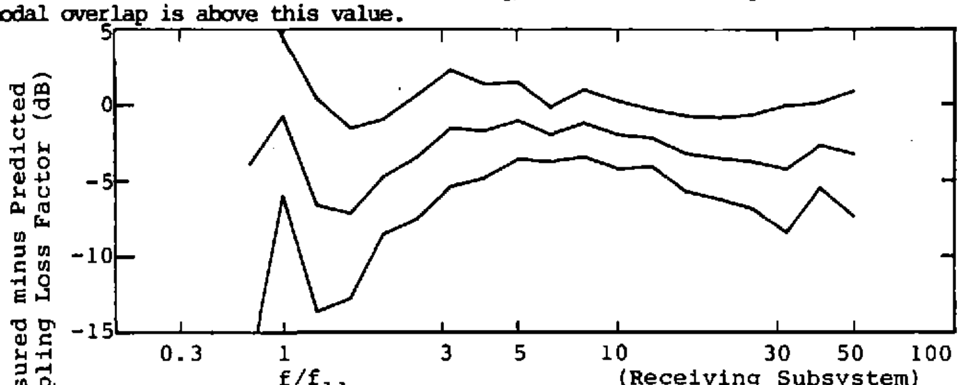


Figure 2. Mean and 95% Confidence Limits of Measured minus Predicted Coupling Loss Factor for ten joints of various types vs. $f/f_{11}$ for the receiving subsystem.

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At the lowest values of modal overlap there are pronounced peaks and dips which may be due to the response of individual modes in the receiving subsystems.

Similar results were found when the prediction errors were plotted against 1/3 octave mode count. Again there was no clear pattern when the results were plotted against the mode count of the source subsystem, but a clear trend emerged for the receiving subsystem. It was found that the minimum number of modes required is one or more per 1/3 octave band.

To investigate further the low-frequency fluctuations, the prediction errors were plotted against frequency divided by measured $f_{11}$ for source and receiving subsystems. Figure 2 shows the mean difference between measured and predicted results, and 95% confidence limits, for ten of the joints. A peak in the results appears clearly at $f_{11}$ with a dip on either side. This explains the low frequency peaks in the results of Figure 1. It also shows that at low frequencies the actual mode frequencies have to be considered and that statistical averaging is insufficient. No such effects were observed when the results were plotted against source subsystem $f_{11}$, so this is further evidence for considering mainly the receiving subsystem properties.

## CONCLUSIONS

It has been found that when predicting sound transmission between two structural subsystems by SEA, it is mainly the properties of the receiving subsystem which should be taken into account when establishing a low-frequency limit.

For the walls measured here, it seems that at least 1 mode per band should be present and there should be a modal overlap of at least 0.3 (i.e. 30% of each band controlled by modal response) to obtain a reasonable prediction.

At low frequencies the measured coupling loss factor is consistently less than theory would predict.

## ACKNOWLEDGEMENTS

This work was funded by the Science and Engineering Research Council of Great Britain.

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