A Case Study of Statistical Energy Analysis: The Police Launch Deodar II

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Introduction

Statistical Energy Analysis (SEA) is a method which allows the prediction of audio frequency sound or vibration levels in acoustically complex structures such as buildings and vehicles [1,2]. Although SEA is used widely in automobile, aerospace and marine industries overseas, its potential has been little exploited in New Zealand.

Industrial Research Limited is currently involved in developing improved statistical modelling methods and in exploring the possible benefits of SEA for New Zealand industry. As part of this ongoing research, a study was undertaken to demonstrate the use of SEA in analysing engine noise on board the police launch Deodar II.

A simple SEA model comprising nine subsystems was developed using nominal estimates of structural properties.

With this model, and with measurements of the vibrational and acoustic powers input by the engines, predictions were made of sound pressure levels in key acoustic spaces which compare favourably with measured levels.

General principles of SEA

Many problems involving sound and structural vibrations, such as the prediction of building response to earthquake disturbances or the low frequency behaviour of an automobile interior, can be solved by so-called 'exact' methods such as finite element analysis. However, at the higher frequencies typical of acoustic problems, the wavelength is small and the field tends to be very spatially intricate. For a number of reasons, 'exact' analysis then becomes inappropriate. One concerns the sensitivity of the details of the field at high frequencies to small, unknown and possibly unmeasureable variations in properties such as fluid density or enclosure dimensions—field detail cannot be modelled arbitrarily accurately in practice. A further limitation of 'exact' analysis concerns computational cost. Since the response must generally be evaluated at a density of several points per wavelength, the computational cost, even for moderate audio frequencies, can be prohibitive.

It was in response to difficulties of this kind that the techniques of statistical room acoustics were first developed. SEA shares many of the concepts used in statistical room acoustics, but provides a framework for dealing with more general systems made up of both acoustic and structural elements.

In modelling the flow and steady state distribution of vibrational energy in a structure, SEA takes only limited account of structural detail. The structure is notionally divided into a collection of interconnected subsystems and its response to excitation is described in terms of time- and space-averages of sound or vibration levels in each subsystem. Beams, plates and acoustic spaces are typical subsystems.

Uncertainty concerning the detailed properties of the structure is incorporated into the analysis by assuming that the system is drawn from an ensemble of systems which have the same gross properties, but which differ randomly in detail. The main quantity of interest is then the average of the responses over the members of this ensemble.

SEA predictions are most accurate for structures in which the subsystems are weakly coupled, reverberant, have high modal overlap and when there are many interacting modes in the frequency band of analysis. The wave fields in the subsystems are assumed to be diffuse and vibrational energy is assumed to flow between the subsystems in a manner analogous to the flow of heat energy between coupled conductors. The ‘temperature’ of each subsystem is the mean energy of the modes in the subsystem and the rate of energy transfer is assumed to be proportional to the difference in subsystem temperatures. Subsystems can then be described in terms of a small number of coarse parameters such as damping factor and modal density, and the coupling between subsystems in terms of a quantity analogous to the damping factor, known as the ‘coupling loss’ factor.

Given the SEA subsystem and coupling parameters and the powers delivered to subsystems by the action of external forces, it is a relatively simple matter to predict the subsystem energies (or sound levels). The vectors of subsystem input powers Pin and energies E are related by

$$\mathbf{P}_{in} = \mathbf{L}\,\mathbf{E}$$

where

$$\mathbf{L} = \omega \begin{bmatrix} \eta_1 + \eta_{12} + \eta_{13} + \ldots & -\eta_{21} & -\eta_{31} & \cdots \\ -\eta_{12} & \eta_2 + \eta_{21} + \eta_{23} + \ldots & -\eta_{32} & \cdots \\ -\eta_{13} & -\eta_{23} & \eta_3 + \eta_{31} + \eta_{32} + \ldots & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

and where η_j is the damping loss factor associated with subsystem j and η_{ij} is the coupling loss factor associated with energy flow from subsystem i to j [1].

The police launch Deodar II

The Deodar II is operated in Auckland by the Police Maritime Unit. The hull of the Deodar is made of an aluminium alloy and the superstructure is made principally of fibreglass. Its general specifications are given in Table 1.

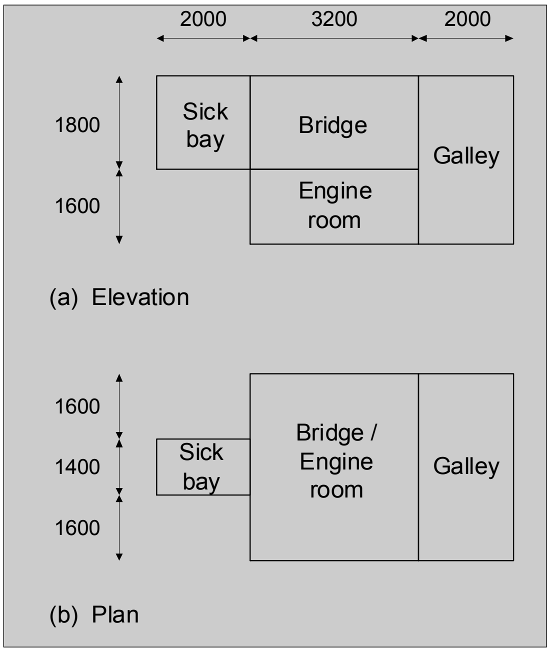

Figure 1. Approximate layout and dimensions of acoustic spaces.

The spaces of greatest interest for acoustic analysis are the engine room, bridge, galley and sick bay. Their approximate layout and dimensions are shown in Figure 1. The galley is situated at the forward end of the vessel.

The Deodar is driven by two 500hp Detroit diesel engines, each mounted on two alloy girders which vary in depth between 200 and 450mm over the length of the engine room. The surfaces which enclose the engine room are made of ribbed aluminium plate, and the ceiling and forward and aft walls are lined with a thick absorptive foam covered with a thin, acoustically transparent protective layer. Access to the engine room is from the galley via an air-tight aluminium door.

The walls which separate the three remaining acoustic spaces contain sub-stantial open areas: an open doorway connects the sick bay and the bridge, and an open doorway and a large open space above the engine control console connect the bridge and the galley.

The SEA Model

A simple SEA model comprising nine subsystems was constructed. Four of the subsystems were acoustic spaces representing the engine room, the bridge, the galley and the sick bay, and the five remaining were ribbed-plate subsystems representing the engine room ceiling, the forward wall of the engine room and the floors of the engine room, galley and sick bay. These subsystems and the principal energy flow paths (identified in subsequent analysis) are illustrated in figure 2.

In typical operating conditions, a number of mechanisms involving

Length	14.5 metres
Beam	4.75 metres
Draught	1.08 metres
Displacement	16.5 tonnes

Table 1. Specifications of police launch Deodar II.

the engines, the propellers and wave impacts on the hull deliver power to the structure. A relatively simple situation is considered here in which the two engines are run at constant 1500rpm with propellers disengaged and Deodar tied up alongside. The main input powers to the structure are then assumed to be the acoustic radiation from the engines into the engine room space, and the structural power delivered into the supporting girders via engine mounts.

The acoustically radiated power was measured using a two-microphone sound intensity probe. An estimate of the structurally injected power was found from accelerations measured at the engine mounts and the driving point impedances at those locations. Estimates of mechanical impedances were found for each mount by monitoring the acceleration response to impacts by an instrumented hammer.

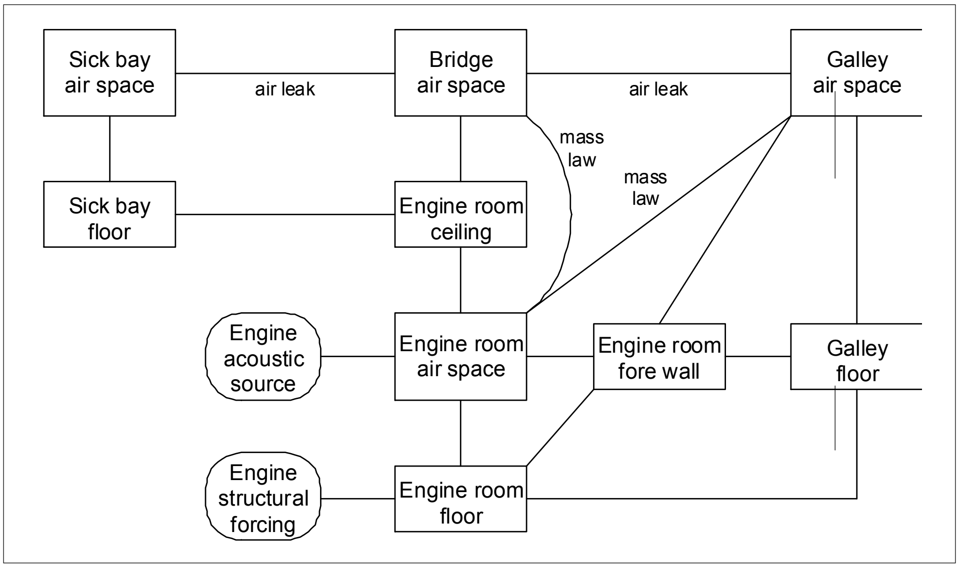

Figure 2. Power sources, subsystems and principal energy flow paths.

Other parameters of the SEA model were estimated from generally well-known formulae and tables of material coefficients [3].

Results

The estimated input powers delivered by a single engine are shown in Figure 3. The spectra indicate that the power is dominated at frequencies below about 200Hz by structural transmission through the engine mounts and at higher frequencies by radiation from the engines into the engine room space.

SEA provides a valuable tool for the ranking of energy transmission paths. Figure 4 shows, for example, the contributions made by a number of paths to the total acoustic power input to the bridge. This power is dominated at frequencies below 250Hz by non-resonant transmission from the engine room and acoustic leakage through openings from the galley. It is dominated at higher frequencies by radiation from the floor of the bridge.

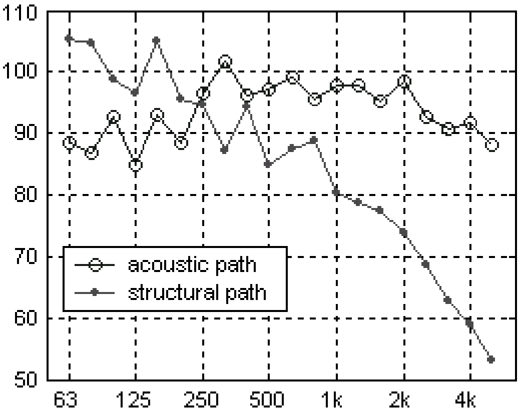

Figure 3. Structural and acoustic input powers.

Measured and predicted sound pressure levels in each of the principal acoustic spaces are shown in Figure 5. SEA predictions generally agree well with measurements, especially at higher frequencies. Factors which contribute to larger differences at low frequencies include the method that was used to synthesise one third octave levels from FFT-based measurements. Predicted and measured levels in the low frequency one third octave bands are less accurate than those in high frequency bands. A further cause for differences at low frequencies is the fact that the accuracy of SEA relies on 'resonant' transmission of energy between subsystems. There are few modes are resonant in some of the plate subsystems in the lower frequency bands.

The relatively large difference between predicted and measured levels in the bridge near 500Hz is due to difficulties associated with the estimation of the radiation efficiency of the ribbed engine room ceiling close to its coincidence frequency. The general underestimation by SEA of levels in the galley and sick bay is thought to be due to the simplicity of the model and the small number of included transmission paths.

Conclusions

SEA is typically used both in design applications and in the solution of existing sound or vibration problems.

Considerable flexibility is available in developing models that are appropriate to the level of knowledge available and the level of accuracy required. A model used as part of a design process might become increasingly detailed as the design becomes more nearly finalised, for example.

The mathematical form of the model also allows convenient ranking of the contributions of the various sources and transmission paths to the sound levels at any location and prediction of the effects resulting from changes made to materials or other properties of the structure. The example presented in this paper demonstrates that reasonable estimates of response levels and identification of key transmission paths can be achieved with a relatively simple model and moderate investment of effort.

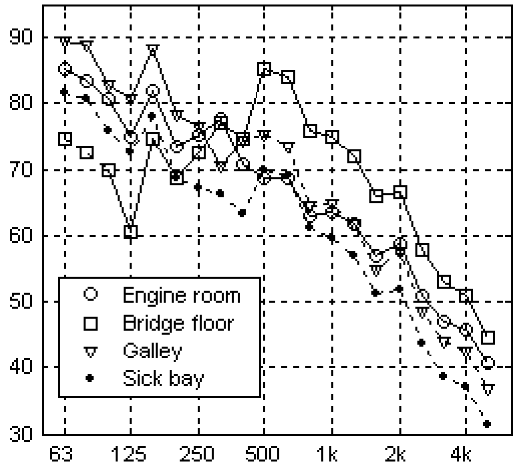

Figure 4. Power inputs into the bridge space. — inward flow, - - - outward flow.

Acknowledgement

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References

1. **R. Lyon and R. DeJong**. *Theory and application of Statistical Energy Analysis*. Butterworth-Heinemann, Boston, 1995.

2. **C. H. Hodges and J. Woodhouse**. Theories of noise and vibration transmission in complex structures. *Reports on Progress in Physics*, **49**, 107-170, 1986.

3. **R. J. Craik.** *Sound transmission through buildings using Statistical Energy Analysis*. Gower, Hampshire, 1996.❑

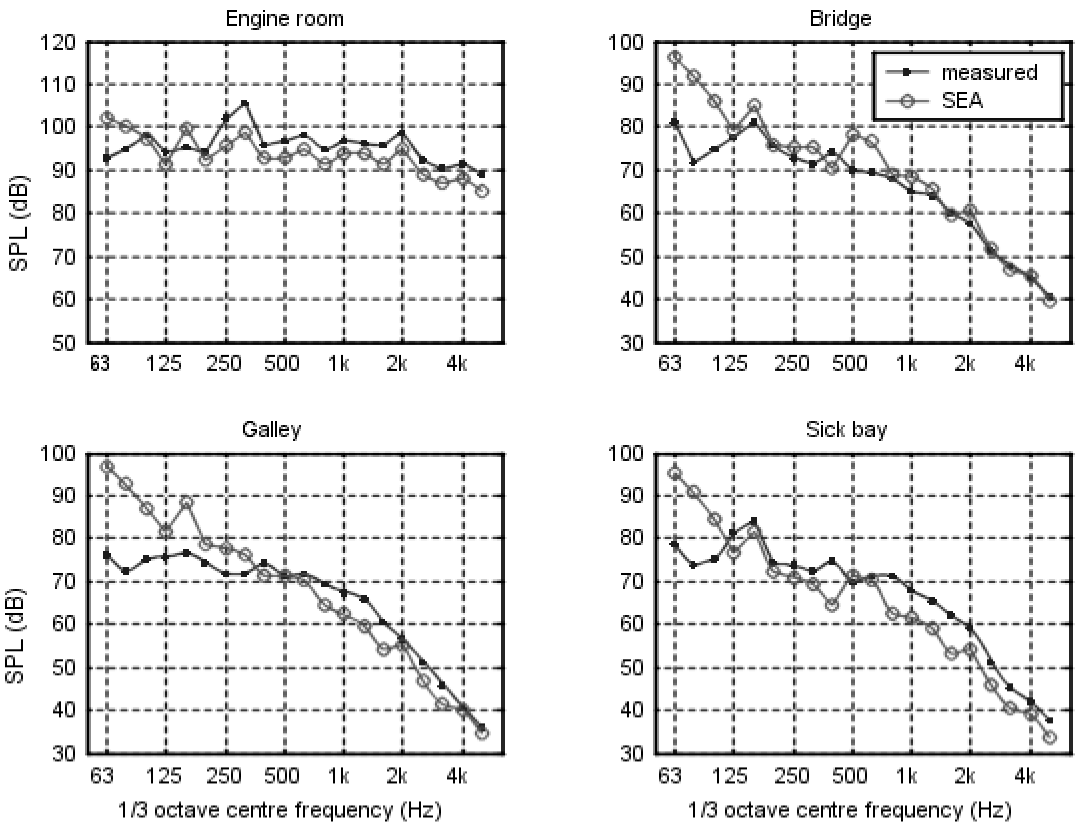

Figure 5. Measured and predicted sound pressure levels.