inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

A VALIDATED CAE METHOD FOR PREDICTING RAILWAY VIADUCT STRUCTURE-BORNE NOISE

J. Hargreaves*, R. Sturt*, M. Willford**

* Ove Arup & Partners, The Oaks, Westwood Way, CV7 7DL, Coventry, United Kingdom

** Ove Arup & Partners, Asta House, 55/65 Whitfield St., W1 5RJ, London, United Kingdom

Tel.: +44 (0) 1203 856069 / Fax: +44 (0) 1203 856240 / Email: james.hargreaves@arup.com

Keywords:
RAIL, ROUGHNESS, NOISE, ARUP

ABSTRACT
In common with many industries today the rail industry has to meet many noise and vibration requirements. The impact of train pass-by noise on the surrounding environment is of particular importance where high-speed lines operate and where new railways are being designed. The work presented in this paper demonstrates how predictive methods can be used to quantify the structure-borne noise levels radiated from a railway viaduct during a train pass-by event and demonstrates the accuracy of the solution by making comparisons with noise measurements made around an existing operating viaduct. Predicted and measured structure-borne noise, in the frequency range below 300Hz, for a particular viaduct during the passage of a high-speed passenger train is then presented. A-weighted sound exposure levels in the 1/3rd octave band along with total noise levels are compared and shown to be in good agreement.

1 - INTRODUCTION
It is commonplace nowadays to make an acoustic appraisal of a new railway viaduct design as early as possible in the development programme so that the various mitigation considerations can be addressed and where necessary fed into the design process. Consideration of noise and vibration falls into three main categories:

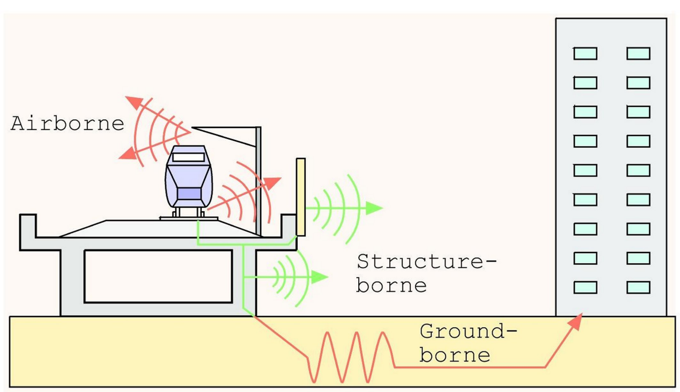

Figure 1: Noise propagation from a railway viaduct.

1.1 - Air borne noise
This is the noise propagated directly from the vibration of the wheels and rails and to a lesser extent at the pantograph. The vibration arises from the movement of the wheel treads (which have surface roughness) over the railheads (which also have roughness and vertical undulation), and to a lesser extent from the deflections of the rail spanning between the sleepers as the axle passes over. Vibration increases

with increasing train speed, so that airborne noise becomes particularly important for high-speed trains, where speeds in excess of 300 kph are now achieved.

1.2 - Structure borne noise

Structure-borne noise results from the vibrational forces generated at the wheel/rail interface being passed into the bridge deck through the rail pad, sleeper and ballast. The panels of deck structures are flexible at acoustic frequencies and typically have hundreds of modes of vibration even below 300 Hz. The presence of these modes means that noise can be radiated from the deck sidewalls and soffits, and also from trackside barriers which are attached to the deck.

1.3 - Ground borne noise and vibration

This is the component of noise caused by the railway-induced vibration propagating through the ground and into adjacent buildings through their foundations. Once into the columns of a building the vibration is amplified in the vibrational modes of the walls and floors, whereupon it is then radiated as noise into the building interior and/or directly felt by occupants.

2 - NOISE MITIGATION

Mitigation is necessary if the predicted or actual noise levels exceed the legislative or contractual requirements of developing a new railway. Criteria are often expressed as sound exposure limits over specified time periods (e.g. day/evening/night or 24 hours) in the vicinity of the railway such that disturbance to people living and working nearby is minimised. Various units used in the measurement and assessment of railway noise are described in [1]. When mitigation is required, the designer has to develop a system that meets not just noise and vibration targets but also cost, durability and other critical performance criteria associated with railways such as RAMS (Reliability, Accessibility, Maintainability and Safety). These issues have been discussed in [2].

2.1 - Sound exposure limits

For a quantitative assessment of the harmful effect of a noise comprising varying amplitudes and frequencies, the sound exposure $L_{Aeq,\ 18\ h}$ (for the period 6 am to midnight) or even $L_{Aeq,\ 24\ h}$ measures are often used. This is defined as the average acoustic pressure of an imaginary continuous sound, which would have the same impact on the hearing as the sum of the fluctuating noises, measured during the same exposure time.

2.2 - Sound pressure level

For the purposes of making a noise prediction it is necessary to express the environmental limit in the form of an engineering quantity that would typically emerge from a prediction or analytical model.

3 - TRAIN PASS-BY MEASUREMENT

3.1 - Measurement scenario

The measurement of a full train pass-by was performed by positioning microphones alongside at the site of a viaduct supporting a high-speed rail system.

Figure 2: Viaduct at which noise measurements were recorded.

The objectives of making the measurements were:

- To quantify structure-borne noise
- To provide some insight into the nature of structure-borne noise
- To provide data to correlate a predictive model

Four microphones were used with positions mainly determined by the need to separate as far as possible direct air borne noise from structure-borne noise.

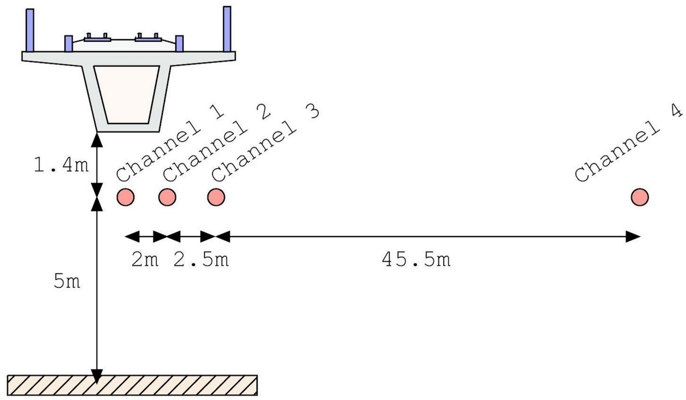

Figure 3: Microphone locations.

4 - CAE ANALYSIS METHODOLOGY

A detailed modeling approach, well-researched input parameters and an understanding of the sensitivity of the results to the inevitable uncertainties in the input are required to make a reliable estimate of structure-borne noise. A deterministic approach was adopted for the prediction discussed in this paper and took the form of a combination of finite element (FE) and boundary element (BE) methods. Although the problem size appears to be large, it can in fact be comfortably solved with a combination of a modern computer and efficient modeling practice.

4.1 - Viaduct FE model

The development of the viaduct FE model requires a consideration of the following:

- Proper simulation of the generation of vibration from wheel/rail contact roughness.
- Design of meshes valid to predict structural waves at all frequencies up to 300 Hz.
- Developing a suitable level of simplification of an entire viaduct structure.

4.2 - Simplifying the viaduct structure

It is unnecessary and computationally infeasible to represent an entire multi-span viaduct, which may extend for over 1 km in length, in this type of analysis. Ways to simplify the system are required so that the methodology is efficient and produces a problem size which is possible to run on a modern computer. The first step in simplification is to model only one span with a detailed 3D model. Using this approach the model consists of:

- A detailed 3D model of a single span (45 m long)
- A detailed model of the train (three cars) and trackwork on this span
- A beam element representation of the remaining spans of the bridge

The reduction in problem size is justified on the basis of *sampling* the entire pass-by event.

4.3 - Wheel/rail contact model

The remaining part of the model that needs to be included is a simulation of the effects of the train passing over a rough track on the bridge deck response and, in turn, how resonances within the deck and track system affect the forces at the wheel/rail interface. The fundamental mechanism generating

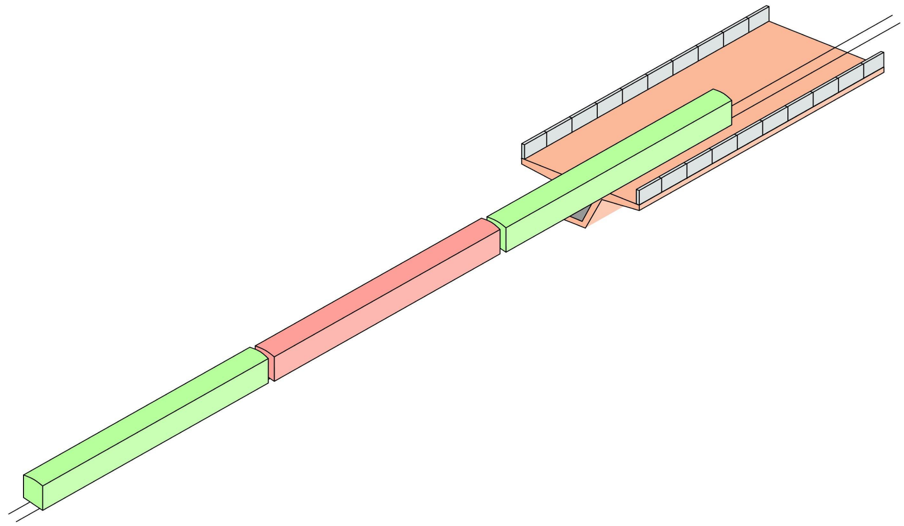

Figure 4: Full viaduct model.

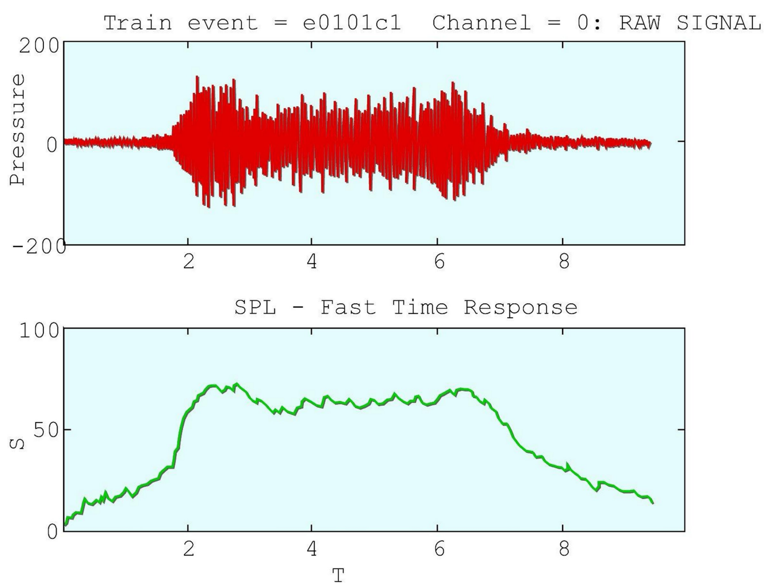

Figure 5: Time-history sampling.

vibration and thence noise is the small amplitude rise and fall of the wheels of a train to follow the track and wheel roughness profiles.

5 - BOUNDARY ELEMENT ANALYSIS

5.1 - Boundary element model

A boundary element (BE) model was used to make the prediction of radiated noise from a particular span on the viaduct. It was first necessary to process and transform all the time-history data into the frequency domain to form a 'vibrating-panel' type boundary condition. In this case the field points were located in the same position as the microphone. A boundary condition corresponding to velocity amplitude and phase defined over the 30-300 Hz frequency range was then specified.

5.2 - BE solution

This class of problem is very large, with the viaduct geometry producing some 13,000 boundary elements. The problem was solved on a HP N4000 machine using the frequency based parallel solver in SYSNOISE. The output from this solution was narrow-band SPL at the field points corresponding to the microphone locations

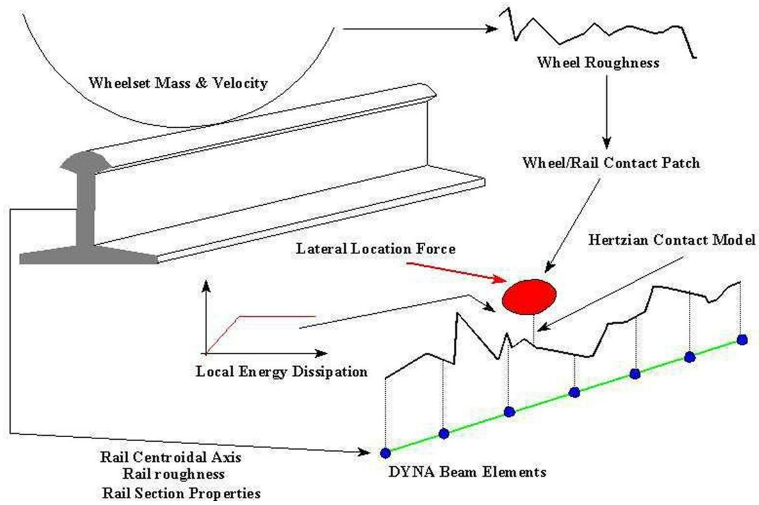

Figure 6: Wheel/rail contact model.

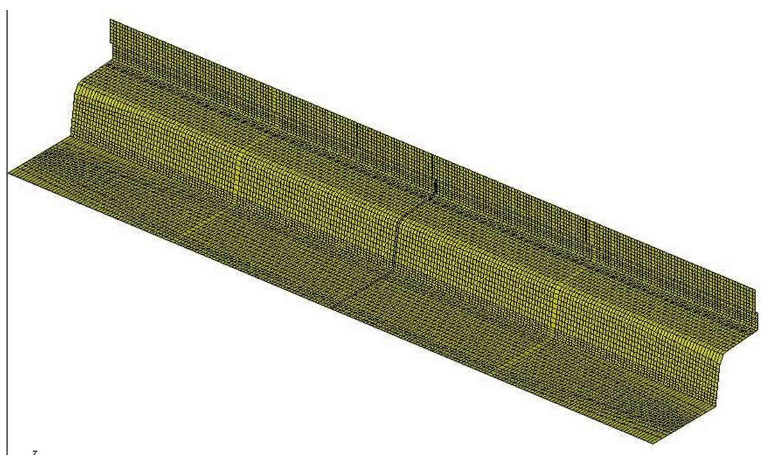

Figure 7: Boundary element model.

6 - RESULTS

Comparisons between measured and predicted noise for channel 4 are presented as A-weighted decibels in the 1/3rd octave band. The total level, equal to the sum of all frequency bands, is also shown.
A good level of correlation between predicted and measured *total* noise is possible, since the effects of differences in the natural frequencies tends to be reflected in the individual 1/3rd octave band and not the total noise levels. In order to apply this methodology to a new viaduct design it is necessary to establish confidence levels in the prediction so that a judgement can be made on the extent and cost of the mitigation measures.

7 - CONCLUSIONS

A means of predicting structure-borne noise from railway viaducts has been established with validated accuracy, creating a design tool that can be deployed during the concept phase so that informed design choices can be made before the bridge drawings are effectively frozen. This design tool can also be applied during the detailed phase or even during deck construction, but here the choices become limited to ameliorative counter-measures on the track system. The use of this tool has significant commercial benefits, including the expectation of reduced capital cost for mitigation measures through reduction of assessment tolerances, and reduced design and programme risk.

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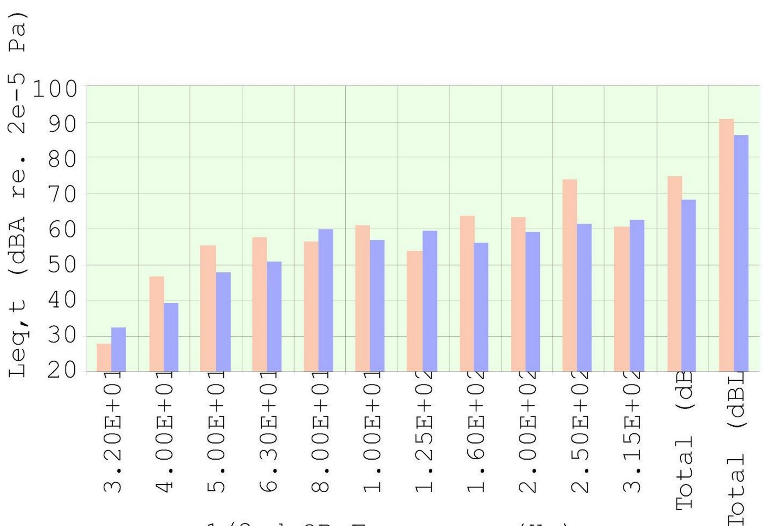

Figure 8: Noise-CAE v TEST-Channel 4 − (test: dark bars).