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GUIDE TO VIBRATION ISOLATION FOR RAILWAYS

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1. Introduction

By comparison to noise, environmental vibration is rarely an issue. However, when vibration is an issue it tends to be a significant one. Mitigation, as with noise, can generally be applied by way of three approaches: treating the source, impeding propagation or treating the receiver. This paper discusses the design of vibration isolation which is one of the main treatments at either source or the receiver. The principle concept is to de-couple either the source or receiver, or both, from the medium that supports the propagation of the vibration between the two.

This paper focuses on railway vibration and groundborne noise, as railways are generally the major source of environmental vibration. Difficulties associated with design of isolation treatments at source are discussed. Solutions identified by Arup Acoustics during many projects to some of the difficulties is presented. Whilst Arup's project experience includes the design of vibration isolation for many buildings, ranging from small residential to the largest of air-rights developments [refs. 1 to 4], this topic falls outside the scope of this paper.

The operation of trains generates vibration at the wheel/rail interface which can pass through the trackform, into the supporting formation or tunnel lining and thence into the surrounding ground and neighbouring buildings. Once in a building such railway vibration may give rise to two types of adverse impact:

<u>i) Groundborne Noise:</u> The vibrating walls, floors and ceilings of the building radiate an audible rumbling sound into the rooms of the building. Groundborne noise is generally associated with "higher" frequency railway vibration typically occurring in the range 30 to 250 Hz, and tunnelled sections of railways.

<u>ii) Perceptible Vibration:</u> This is vibration that one can feel on the surfaces of a building. This is distinct from the vibration giving rise to groundborne noise as it is greater in magnitude and is governed by lower frequency vibration typically occurring in the range 1 to 80 Hz. Perceptible vibration is generally associated with surface sections of railways.

The principal, and generally the only realistic, method for reducing groundborne noise and vibration at source is through the design of an appropriate trackform. More precisely, it is the design of a trackform that interacts appropriately with the type of rolling stock under consideration, as it is the train/track system, as opposed to the trackform on its own, that reduces the vibration.

Whilst there are many successful examples, world-wide, of trackforms which successfully reduce groundborne noise and vibration there are equally many failures. The four main stumbling blocks to successful design are:

- the complexity of the systems involved (e.g. train/trackform/supporting system);
- the absence of validated methods for predicting the performance of the systems;
- the often conflicting requirements of vibration reduction and reliability, accessibility, maintainability and occasionally safety; and
- cost.

2. Types of Vibration Isolating Trackforms

2.1 Railway Trackforms

The generic types of ballast and non-ballast trackforms can be categorised in terms of their groundborne noise/vibration reduction and cost as shown in Table 1. Figure 1 presents the principle features of the layout of these different generic designs and the location of the principle resilient component in each case.

Ballast Trackforms	Non-ballast Trackforms	Acoustic Performance	Cost
	Direct fixation with "hard" rail pads	|	|
	Direct fixation with "soft" rail pads	|	|
Modern & High-speed ballast	"Hard" resilient baseplates	|	|
Old & Low-speed ballast	"Soft" resilient baseplates	Increasing Groundborne Noise	Increasing
Ballast and sleeper soffit pads	"Hard" booted sleepers	and Vibration	Cost
Ballast and "hard" ballast mat	"Soft" booted sleepers	Reduction	|
Ballast and "soft" ballast mat	Light mass-spring systems*	|	|
Resiliently supported ballast trough	Medium mass-spring systems*	|	|
	Heavy mass- spring systems*	V	V

TABLE 1: CATEGORISATION OF BALLAST AND NON-BALLAST TRACKFORMS BASED UPON GROUNDBORNE NOISE AND VIBRATION REDUCTION AND COST

Notes: * Also known as floating slab track or floating track slab systems

3. Difficulties Associated with Design of Isolation Trackforms

3.1 Prediction of Groundborne Noise and Vibration and the Isolation Provided by Trackforms

Arup's consultants have developed a number of models for predicting groundborne noise and vibration and the vibration isolation provided by trackforms [e.g. Refs. 5 to 9]. Models for predicting the performance of trackforms vary in their complexity from reasonably simple multiple degree of freedom to detailed finite element models. The complexity of the model generally reflects the complexity of the trackform under consideration and particularly of the system that supports it. The frequency range of interest can also influence the most appropriate modelling technique.

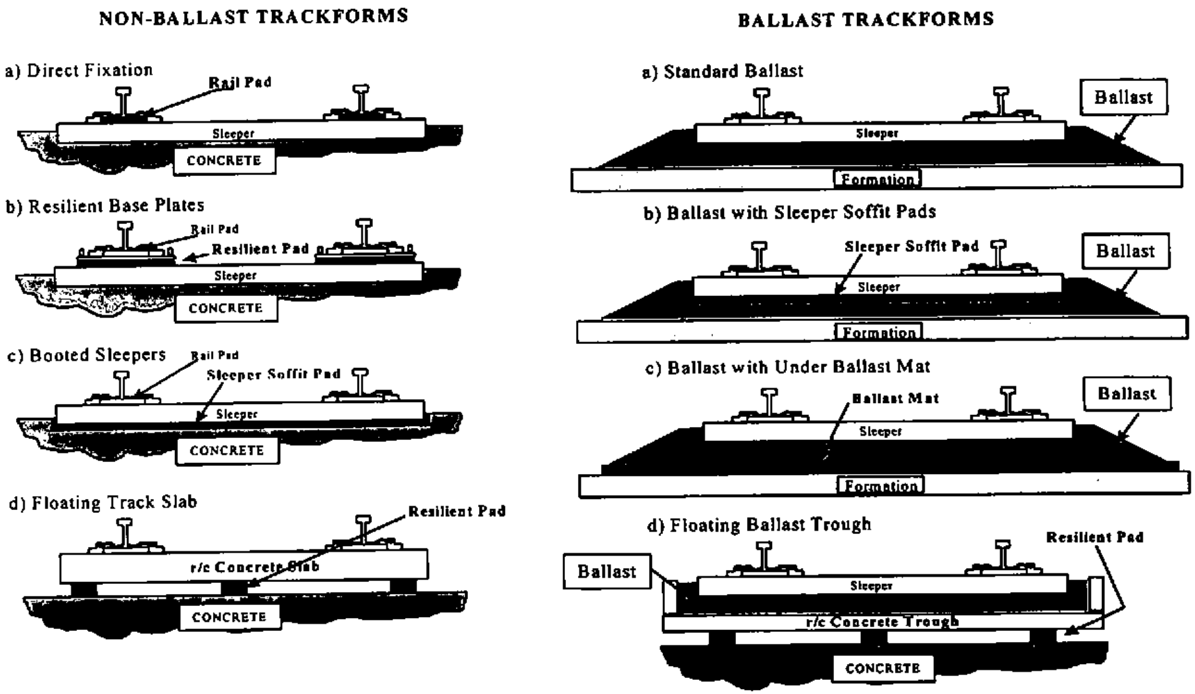

Figure 1: DIAGRAMMATIC REPRESENTATION OF GENERIC TRACKFORM DESIGNS WITH RESPECT TO GROUNDBORNE NOISE AND VIBRATION

For example, the model required to support the design of a trackform to be installed inside a tunnel can be somewhat simpler than the model required to predict the performance of exactly the same trackform installed on a light-weight elevated structure. This is because the performance of the trackform is influenced by the response of the supporting system. In the case of a tunnel, the assumption of *an inertial reference* may, in some hard rock ground conditions, be reasonable. However, for a light-weight elevated structure detailed consideration of its dynamic response is critical to understanding the performance of a trackform. Figure 2 shows modelling undertaken by Arup Acoustics for a mass transit system. The Figure compares the insertion loss predicted for a given track-form based upon a simple lumped parameter model and that predicted by a detailed FE model of the trackform *and* the supporting structure. It is clear from the comparison that use of the simplified model in this situation would have resulted in an over-optimistic estimate of the reduction in structural vibration, and hence structure borne noise, at higher frequencies.

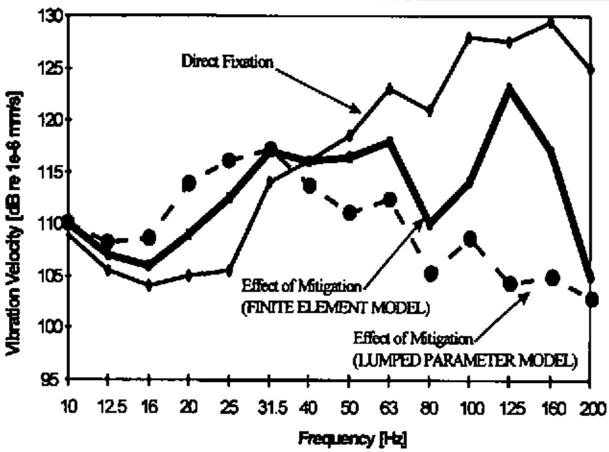

Figure 2: VIBRATION REDUCTION PREDICTED USING DIFFERENT MODELS

3.1 <u>Insertion Loss and its depends on a "Reference"</u>

It is impossible to measure the absolute reduction in vibration and groundborne noise provided by a particular trackform. For this reason it is common place to present the reduction provided in terms of an insertion loss or gain. This in itself presents a difficulty because there is no standard approach to defining insertion loss/gain for track systems. This makes comparing the performance for different vibration isolation designs at best difficult and at worst completely misleading. This also makes it difficult to identify trends in the insertion loss/gains presented by other research which in-turn hinders the evolution of trackform design with respect to groundborne noise and vibration as it is difficult to extrapolate from previous work and experience.

Figure 3 presents diagramatically, the process by which insertion loss/gain is either measured or predicted and, therefore, the dependence of the result on the trackform used as the *Reference* for the analysis.

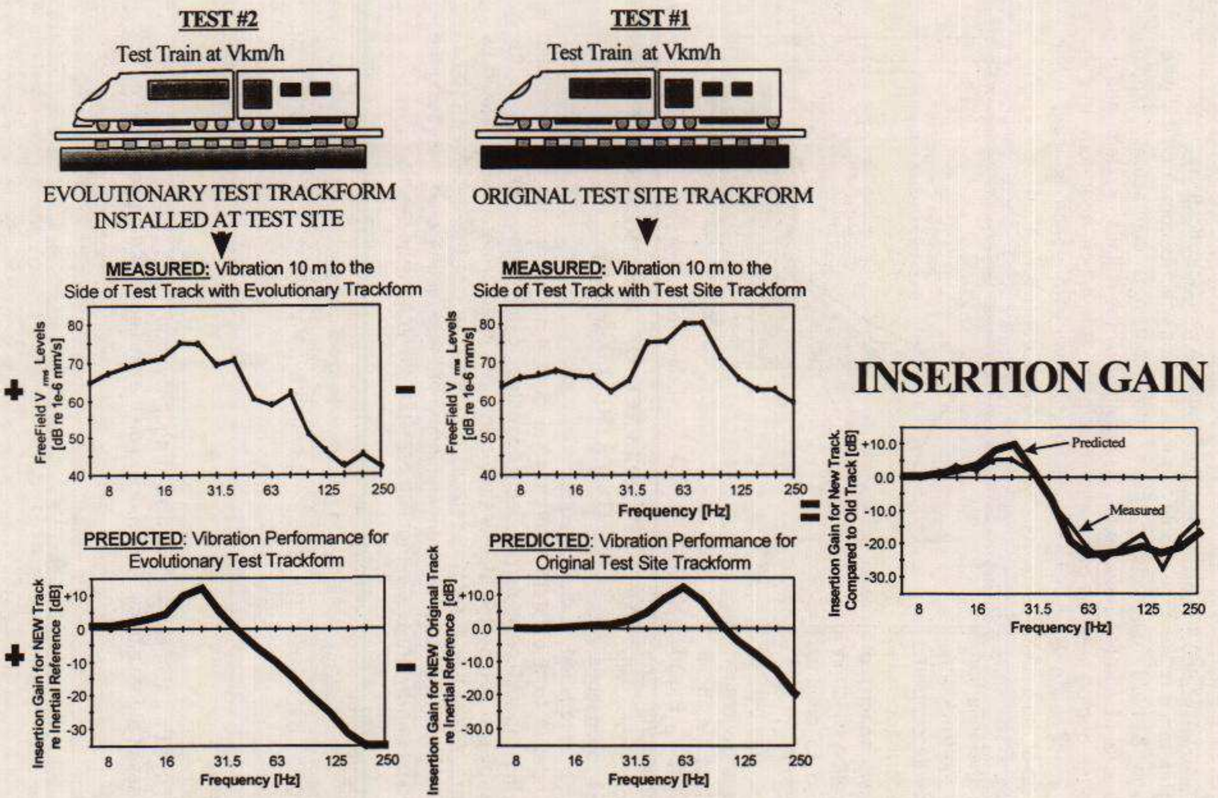

Figure 3: CALCULATION AND MEASUREMENT OF INSERTION LOSS/GAIN

3.2 Measuring Insertion Loss/Gain and Identifying Conformance with Specifications

The issue of what Reference is used for quantifying insertion loss/gain becomes critical when entering into "design & build" contracts. These often contain a contractually binding specification for the level of vibration reduction to be provided by the isolation system, and the specifications are often quoted in terms of insertion loss/gain. It is critical, therefore, that the reference for the specification is identified and that the same reference is used when developing the design of the trackforms for comparison against the specification.

Figure 4 presents the insertion gain for a particular the trackform product predicted by its supplier. This claimed performance is shown superimposed against a contractual specification which in turn was formulated to ensure, for this particular rail project, compliance with a number of groundborne noise and vibration targets in the buildings set above the new railway tunnel. Based upon this comparison, the supplier claimed compliance with contractual obligations. However, the predicted performance was relative to a different reference. Figure 4 also presents the predicted insertion gain for the product once it has been corrected to the same reference as the specification. This revised perspective demonstrates that the claim of compliance should be viewed with caution. Whilst this in no way reflects on the efficacy of the trackform product itself, it highlights the importance of a clear understanding of these issues when assessing the cost and risks faced by railway projects in meeting particular environmental targets.

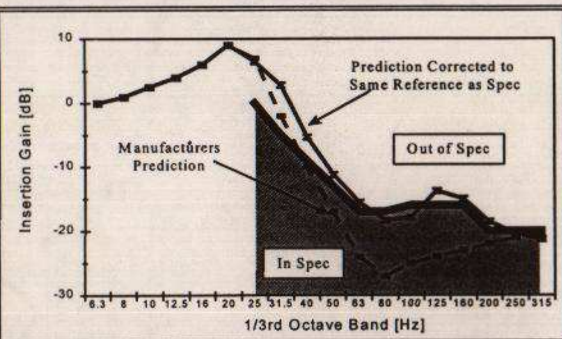

Figure 4: INFLUENCE OF THE "REFERENCE" ON INSERTION LOSS/GAIN

3.2 Component Specification

The insertion loss/gain for a trackform is dependant on many parameters. The most critical of these are:

- static stiffness;
- dynamic stiffness;
- variation off dynamic stiffness with load and frequency; and
- effective mass of the train/track system acting on the resilience of the trackform.

Figure 5 shows a typical rail deflection curve under the load of a train's axles. From a wear, rail stress, passenger comfort and safety perspective, it is critical to control the degree of rail deflection, and particularly inter-rail deflection. This requires a high vertical modulus for the trackform as seen at the rail head, whereas the reduction of groundborne noise requires a low modulus. The first part of optimising the trackform design is therefore to reach a compromise between these conflicting requirements. This compromise will determine the static modulus(stiffness) of the resilient elements in the trackform. However, this is only part of the story.

It is also essential to specify other parameters particularly the dynamic stiffness of the same resilient elements. Figure 5 compares two nominally identical trackforms with the same rolling stock and revenue service patterns. The only difference between the two situations was degree of vibration reduction provided. Both systems had the same static characteristics, as shown in the Figure, with maximum static deflections of approximately 1.2 mm under each axle. However, despite the similarity in the static performance under the same train, the reduction in groundborne noise provided by one trackform was over 10 dB greater than the other. On closer examination of the two systems it transpired that this difference in groundborne noise performance resulted from the resilient pads for the respective trackforms being procured from different suppliers based upon a specification for the static stiffness only. Whilst both pads met this specification, one had a ratio between static and dynamic stiffness of approximately 1.5 whilst the other had a ratio of approximately 5. This was sufficient to re-tune the primary natural mode of the train/track system from the 50 Hz to the 80 Hz 1/3rd Octave bands, which accounted for the dramatically different reductions in 'higher' frequency vibration identified.

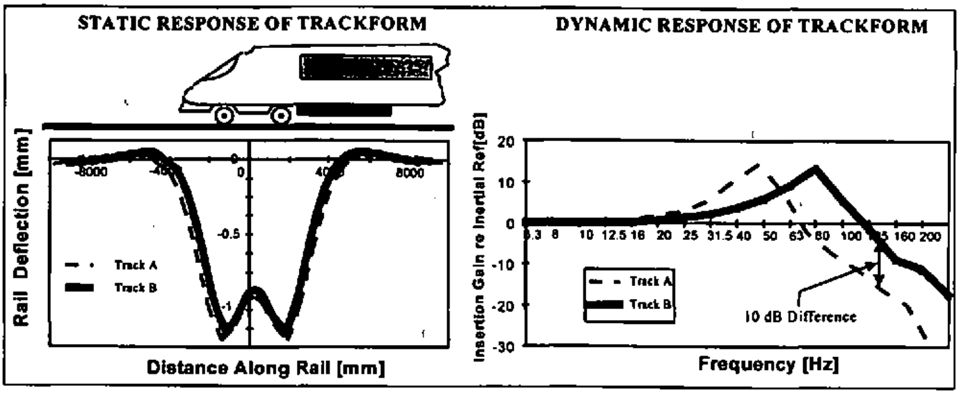

Figure 5: INFLUENCE OF DYNAMIC STIFFNESS TO INSERTION LOSS/GAIN

3.3 Testing and Procurement

Component Testing

The essential part of the procurement process for the isolation system is to provide a tight, well defined specification for each of the components that are critical to the system's performance. It is also essential to require detailed quality assurance and pre-delivery testing to ensure that the components supplied meet the required specification. For individual components conformance tests are generally undertaken on test rigs. In this situation it is important to ensure that the test conditions reflect, as accurately as possible, the actual conditions under which the components will operate. The most critical component of the trackform is generally the main resilient element and ensuring its dynamic stiffness meets the required specification is the most important parameter to focus on.

Testing the Complete System

Whilst modem test rigs will allow a reasonable approximation of the operational conditions, the approximation is still at variance with the complex transient load conditions that actually occur in reality. For example, in practice the resilient element in a trackform will be loaded simultaneously by both totally transient and quasi-static loads (pre-loads of possibly 3000 kg but dynamic load of perhaps only 400 kg), at frequencies between 10 and 250 Hz. This is too complicated a situation to be realistically reproduced in the Lab. Hence, the only method of improving confidence that the in situ performance of the trackform will meet the predicted performance is to test a prototype of the complete system on a representative railway. Testing the complete system is also sometimes necessary because the way in which it responds may differ from the response estimated from the measured behaviour of each of the component parts considered in isolation.

4. Conclusions

- Developing trackforms that are cost effective and are successful in reducing groundborne noise and vibration requires robust validated prediction models.
- The vibration isolation provided by a trackform is generally measured in terms of an insertion loss or gain. By definition this is relative to a "reference" and currently there is no standard reference defined in the railway industry.
- Because no "standard" reference exists a) the vibration reduction quoted from different sources and promotional material must be compared with caution; and b) it is essential that when comparing predicted insertion losses against contractual specifications, the prediction and the specification are relative to the same reference.
- Ensuring that the track will perform in situ requires a) detailed specifications for every component; and b) testing of each component and, where practicable, the complete system.

5. References

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