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VEHICLE-MOUNTED SHIELDS AND LOW TRACKSIDE BARRIERS FOR RAILWAY NOISE CONTROL IN A EUROPEAN CONTEXT

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ABSTRACT
The control of railway rolling noise by a combination of vehicle-mounted shields and low, close, trackside barriers, has been investigated experimentally in the past by railway administrations with varying success. Within the EC 4th Framework projects Silent Freight and Silent Track, the concept has been further developed by formulating a system which was analytically optimized prior to manufacture and testing, and which would be acceptable, in gauging terms, for full interoperability across Europe. The paper presents the analytical and design process which was applied in specifying the parameters of the new interoperable system, as well as the results of subsequent full scale acoustic assessments. These results and their implications are discussed and compared with previous studies, and recommendations for factors to be considered for a practical implementation of this approach are made.

1 - INTRODUCTION
The control of railway rolling noise has received considerable attention in recent years. Various techniques, such as wheel shape optimization, tuned absorbers on wheel or rail, or constrained layer dampers on the wheel are available to reduce this at source. However, when such techniques are not sufficiently practical, cost-effective or efficient to provide adequate reduction to meet environmental requirements, modification of the propagation of sound energy to the wayside can be applied. The conventional approach to this is normally to install tall barriers at the trackside, preferably with an absorbent lining to improve acoustic efficiency. A reduction in environmental rolling noise of 10 dB(A) is comparatively easy to achieve by these means, but the disadvantages of tall barriers for railway application do not always make them a practical proposition. They can be visually intrusive for lineside residents and passengers, and can have safety implications if staff are trapped between train and barrier, while the substantial foundations they require are costly and disruptive to install retrospectively. For this reason, the alternative approach of combining vehicle-mounted shields with low, close, barriers to provide an encapsulation of the noise-producing wheel and track elements has been investigated by railway research organizations in recent years (eg [1], [2]).

Previously developed systems have shown benefits of a similar order to that of conventional tall trackside barriers. However, this has only been possible because they have had the advantage of being able to provide a significant shielding of the wheels and track by virtue of an overlap between vehicle mounted devices and the low barriers. Such an advantage may often be possible on railway systems within one national administration, especially where stock is dedicated to that system and therefore where gauging restrictions may be comparatively relaxed. However, if railway vehicles are to be interoperable between countries within Europe, such beneficial conditions cannot apply due to the wide range of railway structure gauges which exist.
The Brite Euram 4th Framework projects "Silent Freight" (BRPR-CT95-0047) and "Silent Track" (BRPR-CT96-0258), which were led by the European Rail Research Institute (ERRI) and were completed early in 2000, considered means by which railway noise might be controlled at source. In addition to this, however, they also investigated the concept of vehicle-mounted shields and low trackside barriers for European interoperability. As it was known that the gauging restrictions would be likely to prevent the overlap of shields and barriers, therefore allowing sound energy to propagate more freely to the environment, careful consideration of the acoustic design of the system was required for optimum performance.
Participants in this study were Corus (Formerly British Steel, UK) [barrier manufacture], DB (Germany) [on-track testing], Integral (formerly Jenbacher, Austria) [design and gauging], ISVR (UK) [modeling], Müller BBM (Germany) [on-track testing], SNCF (France) [project development], TNO (Netherlands) [static testing], AEA Technology Rail (Formerly British Rail Research, UK) [project management]. Assistance was also received from Railpro and NS Materieel of the Netherlands, and VUZ of the Czech Republic.

2 - PROJECT OBJECTIVE

The objective of the study was to develop a practicable system of rolling noise control by means of vehicle-mounted shields and low, close, trackside barriers capable of universal application within Europe. The system was to be optimized acoustically by analytical techniques prior to manufacture and static testing, followed by testing under operational conditions.

3 - DEVELOPMENT OF THE SYSTEM

The design procedure for the system commenced with the choice of the vehicle type to be considered, and the definition of the envelopes available for vehicle-mounted devices and low trackside barriers. Flat railway freight vehicles with Y25 bogies (4 axles per vehicle) were chosen, as these are common within Europe. Although vehicle body-mounted shields would have been preferable for practical reasons, this proved impossible due to gauging limitations, and so only bogie-mounted devices were considered. A 3-dimensional envelope was defined for possible locations of shielding material around the bogie, taking into account all suspension movement and relative motion between body and bogie, as well as the limits defined by the Union Internationale des Chemins de Fer, for all normal track geometries likely to be encountered. The position of the bottom edge of the shield is dependent on the loading of the vehicle and the amount of wear on the wheels. The geometry chosen was for a fully laden vehicle with 1/2-worn wheels. Figure 1 shows the outer limit of this envelope.
The envelope within which low barriers could be placed for interoperability of all stock was defined by considering the various structure gauges within Europe. The "Worst Case European Gauge" which emerged from this is presented in Figure 2, together with one possible barrier location and the bogie shield outer envelope. It can be seen from Figure 2 that there is a considerable vertical gap between the lower edge of the shield and the upper limit of the combined gauge. It has to be stressed that this configuration represents the most unfavorable situation imposed by consideration of the full range of structure gauge limitations, and that individual administrations might be able, should they wish, to install taller trackside structures, allowing the gap to be reduced or, preferably, eliminated. However, the decision had been taken that it was necessary for the Projects to establish what could be achieved by acoustic optimization under the most difficult circumstances likely to apply across Europe, hence the choice of the outer combined gauge.

4 - ACOUSTIC OPTIMIZATION

The envelopes for both the shields and the low barriers were considered as a single entity for optimization purposes. Initially the entire system was modeled using Statistical Energy Analysis (SEA), allowing the acoustic effectiveness of various configurations and materials to be assessed. Subsequently the analysis was complemented with a 2-dimensional Boundary Element model to account for diffraction effects over the barrier for sound energy emanating from the rail, as well as a consideration of the potential for sleeper

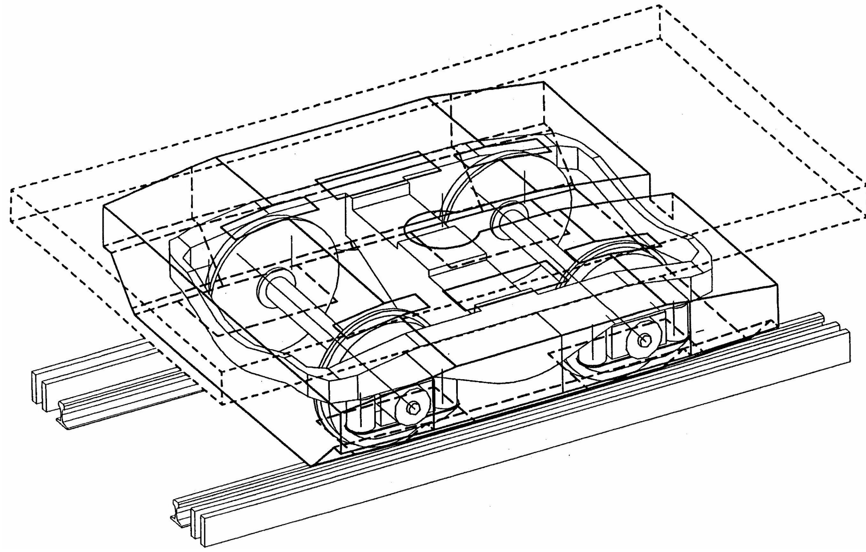

Figure 1: Outer shield envelope and potential barrier locations.

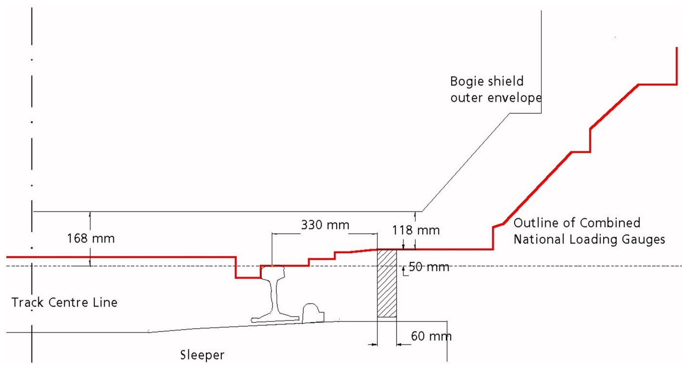

Figure 2: The "Worst Case European Gauge".

vibration to result in undesirable re-radiated sound from the barrier. Two potential barrier positions were considered in the models, being either as close as possible to the rail (the upper closest corner being 200 mm from the rail-head center) to maximize shielding or at a position where the gap between shield and barrier was minimized (330 mm from the rail-head center).

The findings of these studies were that the barrier should be placed with its inner face 330 mm from the center-line of the rail head. The barrier should be made acoustically absorbent, and protected from water saturation by means of a polythene membrane. Flexible rubber mat should be fitted at the lower edge of the barriers, to seal them acoustically to the ballast, and to provide some damping to the barrier structure. 1 mm steel, which had been proposed for the construction of the experimental shield system and the low barriers for testing purposes, has adequate acoustic transmission loss while ensuring low radiation efficiency. The best compromise to minimize vibrational input to the barrier without it being too flexible would be to attach it to every third sleeper. The best shield configuration for acoustic performance within the structural limitations of the vehicles comprised a top covered to the greatest extent possible, an open bottom, and as much absorbent material as possible within its interior. To guard against resonances of the vehicle mounted shields, they should be vibration-damped with a constrained layer treatment. If possible, the rails should be fitted with tuned absorbers, (a treatment being considered elsewhere in Silent Track) to constrain vibrational energy within the vicinity of the shields, rather than letting it propagate along the track to sections where barriers alone were located.

This recommended configuration produced predicted attenuations of wayside noise of

Shields and barriers	5 dB(A)
Shields alone	2 dB(A)
Barriers alone	1 dB(A)

Table 1.

5 - STATIC TESTING

The optimized design was then implemented, following the recommendations of Section 4. The geometry of the optimized system resulted in the lower edge of the shields being 168 mm above the plane of the rail heads, while the top edge of the barrier was 50 mm above that plane, leading to a vertical gap of 118 mm (Figure 3).

Figure 3: The optimized shield and barrier system.

Shields were installed on the adjacent two bogies in the center of a pair of flat wagons, which were positioned on a section of track fitted on both sides with 25 m lengths of low barrier, at Railpro's sidings in Hilversum. A reciprocity technique was applied to establish the effectiveness of the treatments. This involved the measurement of transfer functions between vibration at the wheel, or rail, and sound at the trackside, enabling the insertion loss resulting from shields and barriers, for partial sources, to be determined. The transfer functions may be conveniently measured by the use of loudspeakers at the trackside to create a sound field which excites the wheels and rail, leading to a vibration response which may be measured with accelerometers on the parts of the structure considered to be partial sources. The wheels were de-coupled from the rails for this exercise using jacks. Although the recommended tuned absorbers were not fitted to the rails at this site, the track had wooden sleepers, which provide a higher decay rate to rail vibration than do concrete sleepers. These tests yielded the attenuations:

Shields and barriers	6±1 dB(A)
Shields alone	1±1 dB(A)
Barriers alone	2±1 dB(A)

Table 2.

6 - TESTS UNDER OPERATING CONDITIONS

The modeling and static tests showed that the system could potentially provide sufficient attenuation to justify further validation testing, this time under operating conditions. As part of the Silent Freight and Silent Track final testing program at the Czech Railways' test track at Velim, a train including two flat wagons with the shields on two adjacent end bogies was run through two 50 m sections of track fitted with barriers. Both of these sections were constructed from conventional track with concrete sleepers, but one of them was also fitted with tuned rail absorbers which comprised lengths of steel bar resiliently mounted to either side of the rail web. The shields were identical to those tested statically, except for some structural strengthening for reasons of operational safety. The barriers were also identical structurally to those tested statically. Measurements of sound at the trackside were taken, with the train passing at 100 km/h, for the configurations "Shield & Barrier", "Barrier Alone", "Shield Alone" and "No devices". In addition, vibration measurements were taken on the shields and barriers to establish whether re-radiated sound from these components might be affecting the system's efficiency. The results of these measurements, compared with the previously reported results of modeling and static tests were as follows:

	Velim, standard track	Velim, tuned absorbers	Modeling results	Static test results
Shields and barriers	2 dB(A)	3 dB(A)	5 dB(A)	6±1 dB(A)
Shields alone	1 dB(A)	2 dB(A)	2 dB(A)	1±1 dB(A)
Barriers alone	1 dB(A)	0 dB(A)	1 dB(A)	2±1 dB(A)

Table 3.

As the Velim results were lower than predicted from the modeling and the static tests, the possibility that the shields or the barriers might be re-radiating significant levels of sound was investigated. Vibration levels measured on the shields and barriers at Velim were used to predict the radiated levels of sound from these devices, which were then compared with overall measured levels of sound at the trackside. The predicted levels of re-radiated sound were found to be substantially below the overall measured levels of sound, and it was therefore concluded that there was no likelihood of this phenomenon having led to reduced system performance. It has therefore been speculated that the modeling results could have been over-optimistic because the absorption within the shield, and also of the ballast, might have been over-estimated, while the results of the static tests might have been affected to a greater extent than expected by the decay rate of vibration in the track at Hilversum.

7 - DISCUSSION OF RESULTS

The results of this study have shown that the gauging constraints imposed by the requirements of interoperability lead to a vertical gap between vehicle-mounted shields and low trackside barriers which has serious acoustic consequences. Previous systems, such as the "Low Noise Train" project of the German, Italian and Austrian Railways [2] and the earlier British Rail experiments [1], have benefited acoustically from not being designed for full interoperability. This has permitted shields and barriers to overlap, allowing attenuations of around 8 dB(A) to be achieved, although both projects have raised concerns over re-radiated sound from sleeper-mounted barriers. The current study has overcome this particular problem by designing low−vibration, low radiation-efficiency barriers, but has nevertheless been unable to overcome the significant disadvantage of the 118 mm air gap, even when rail absorbers are fitted.

However, the work to date on this concept has shown that it is possible to introduce a system of bogie shields and low barriers capable of full interoperability within Europe which can provide a 3 dB(A) reduction in rolling noise, and which could be of great benefit in certain marginal situations. Practical implementation of the system would require careful consideration of a number of factors such as inspection and maintenance of vehicles and track, build-up of debris, leaves, snow and ice within shields and between barriers, brake heat dissipation, and hot axle box detection. Further study in order to understand the discrepancy between modeling/static testing and testing under operating conditions would be advisable before implementation, so that the effectiveness of the system may be maximized.

8 - CONCLUSIONS

It has proved possible to devise a bogie shield and low trackside barrier system capable of reducing railway rolling noise by at least 3 dB(A) which would be acceptable, in gauging terms, for interoperability across Europe. A modeling approach using Statistical Energy Analysis and the Boundary Element method has enabled the system to be acoustically optimized prior to construction. There is a significant acoustic disadvantage due to the large vertical gap between the lower edge of the shield and the top of the barrier, necessitated by gauging requirements, although this may be overcome, to some extent, by constraining the vibrational energy of the track within the shielded area by means of tuned absorbers on the rail. On a railway with dedicated stock, or with a limited range of stock, it might prove possible to increase the noise reduction from both the combined system and its component parts by minimizing or eliminating the vertical gap between shield and barrier. Where full interoperability is required, the most appropriate application of such a system would be in circumstances where it is not possible, or permissible, by any other means to reduce noise levels sufficiently to meet statutory noise limits.

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