Being a good neighbour – Reducing vibrations near railway lines

RIVAS – an ambitious European collaborative rail research project aims at finding solutions for vibration mitigation measures at source including track and vehicle and the mitigation of ground-borne propagation until 2013

A need for vibration mitigation in Europe

The transport system is the backbone of Europe’s economic and social prosperity. Therefore in its White Paper on the future transport policy, the European Union has expressed its vision for its future transport needs across the continent that is a transport system that is high-capacity, efficient, cost-effective and yet also meets its environmental targets. Rail is promoted as the most sustainable surface transport mode for regional and international transport both for freight and passenger movements.

The forecasts for railway transport in Europe underline this approach. The Strategic Rail Research Agenda 2020 [1] of the European Rail Research Advisory Council (ERRAC) expects, in its Railway Business Scenarios, rail to double its share of both the freight and the passenger markets compared with 2000.

A specific European Union strategy is to promote rail freight transport as the most sustainable way to increase inter-member state economic activity. However, noise and vibrations, as side-effect of rail transport, are often perceived as weaknesses in rail’s environmental credentials. While noise is an issue for all modes of transport, vibration is specific to rail and therefore stands out all the more as a criticism of rail transport.

RIVAS – A collaborative rail research project facing the challenges

Early 2011, twenty-six partners from all over Europe formed the RIVAS (Railway Induced Vibration Abatement Solutions) consortium under the patronage of the European Commission (FP 7) to face the challenges of vibration mitigation measures and to come up with implementable solutions after three years of project life time. The partners, lead by the International Union of Railways (UIC), represent Infrastructure Managers, Train Operating Companies, Manufactures (e.g. Bombardier, Alstom among others) and Suppliers as well as universities, research institutes consultants and associations (e.g. UNIFE and UITP). The central approach of the project is to develop practical products and technologies meeting the specific needs of the end users. As the first step to ensure this, potential end users are strongly represented in the consortium. (e.g. ADIF, DB, SBB, SNCF, Trafikverket)

Vibrations – The background

A number of mechanisms of vibration generation can be significant. Dynamic forces are generated by trains rolling with irregular wheel profiles over irregular track profiles. This is a similar mechanism to the excitation of rolling noise by rail and wheel roughness. In the case of vibration, however, general unevenness of track and wheel with much longer wavelengths is involved. On the wheel it is represented by out-of-roundness. Additional dynamic forces are generated as the wheels traverse switches and crossings or badly maintained rail joints. Uneven track support (at sleeper pitch or at longer wavelengths) may give rise to additional dynamic behaviour under the loads of the vehicles.

Another generation mechanism arises from the time-dependent displacement of the ground beneath the moving axle loads. This is sometimes called the 'quasi-static' excitation mechanism. For conventional train speeds this vibration remains in the near field.

Various types of rail traffic give rise to vibration in different frequency ranges from different mechanisms.

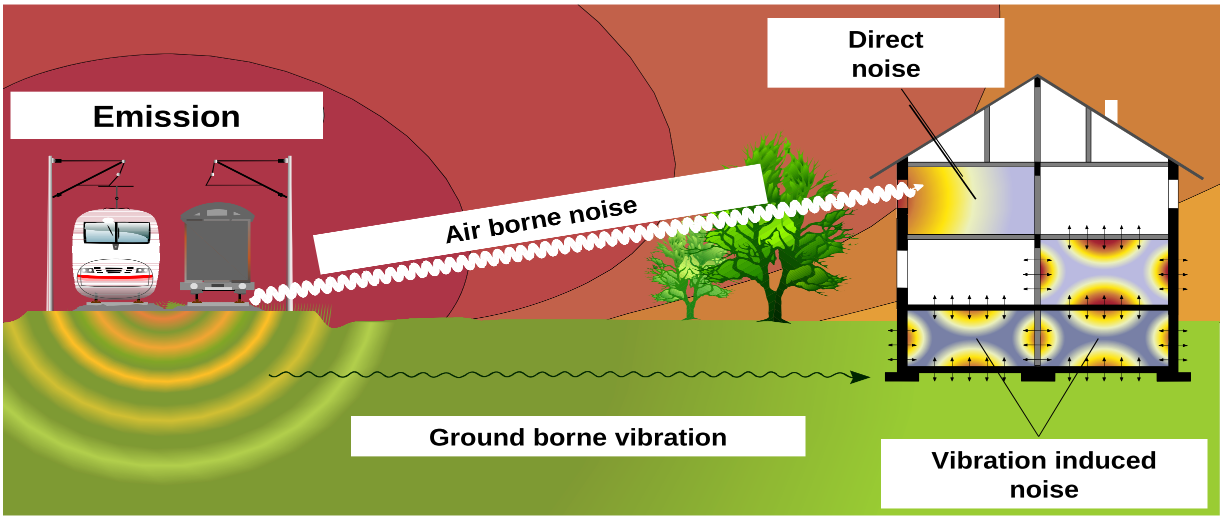
The most important frequencies in free-field vibration range from about 5 Hz to 100 Hz. The corresponding wavelengths of unevenness depend on the train speed as shown in Table 1. The shaded area in the upper right of the table indicates the range of frequency that is excited at different speeds by track irregular profile measure as ‘track top quality’ by track recording cars. Conversely the shading in the lower left of the table indicates the range which is excited by wavelengths in the ‘acoustic roughness’ range.

Table 1 Example wavelengths of unevenness generating vibration at different frequencies from trains running at different speeds

	40 km/h	80 km/h	160 km/h
5 Hz	2.2 m	4.4 m	8.8 m
10 Hz	1.1 m	2.2 m	4.4 m
20 Hz	0.55 m	1.1 m	2.2 m
50 Hz	0.22 m	0.44 m	0.88 m
100 Hz	0.11 m	0.22 m	0.44 m

range of acoustic roughness   range of track recording car data

Measurements in buildings show that freight traffic is generally the most important source of vibration and vibration-induced noise. A special problem arises for very soft grounds. Freight traffic causes more vibration at very low frequency (below 10 Hz) which can then be strongly perceptible up to distances of the order of 100 m from the track. Responsible for this are a number of parameters typical for freight trains but unfavourable in terms of vibration generation: single stage suspensions, large un-sprung masses, friction suspensions, the regular spacings of two-axled wagons, heavy axle loads and long trains.
Suburban, interregional and high-speed passenger trains may also cause significant levels of low-frequency, feelable vibration. However, urban traffic, metropolitan and light rail vehicles more often give rise to vibration that has a greater content at higher frequencies than vibration from freight trains. Vibrations, transmitted through the ground, from about 30 Hz to about 250 Hz, may excite bending in the floors and walls of a building which then reradiate noise directly into its rooms. Only the dynamic and possibly the sleeper passing excitation mechanisms are significant at this frequency range.



General scheme of emission, transmission and reception of air borne noise, vibration and vibration induced noise

A vast scientific basis to start from

A great deal of research has been supported and funded by the European Commission in recent years to reduce the impacts of noise from freight, high-speed and urban traffic [SILENT FREIGHT/TRACK, Eurosabot, STAIRRS, NOEMIE, HARMONOISE, Imagine, SILENCE, QCity, CONVURT]. These have led to new noise reduction technologies and strategies which are currently being implemented by the railways. Although noise has received this increased attention in terms of research and implementation of mitigation technology, the related issue of ground vibration has not because noise was more important in the perception. Nevertheless public sensitivity to vibration issues has also increased in recent years because noise disturbance is beginning to decrease. Most complaints of high levels of vibration addressed to mainline railways concern freight traffic on surface lines. This is a significant hindrance to the upgrading of lines for them to become part of a European Freight Corridor.

In the case of new lines, vibration mitigation already features heavily in the cost of making them acceptable to the public. Opposition to new lines is as much about the effects of vibration as any other topic, including noise.

Several surveys have been conducted in Europe to determine the nature and extent of the impact of railway vibration on residents.

A survey study in Switzerland [2, 3] found that a total of around 170 km of double track of Schweizerische Bundesbahnen (SBB) (around 5 % of the Swiss network) was responsible for about 30,000 people suffering vibration levels deemed unacceptable by the Swiss government [4]. There are approximately equal areas affected by low frequency vibration (104 track-km) and by vibration induced noise (132 track-km). Importantly, only about 5 km of this ‘conflict area’ are in tunnel. The costs of mitigation were estimated to be 1200 - 1400 Mio. €. This study is broadly representative of the situation faced by the other infrastructure managing partners of the RIVAS consortium.

A field study by Woodroof and Griffin looking at the railway network in Scotland [5] concluded, that 35% of the residents within 100 m from the railway notice vibrations. This conclusion is consistent with findings in Japan for the Shinkansen railway [6]. An extrapolation from this based on population densities and railway lines (STAIRRS project database) for EU 21 indicates a total of 2.2 million residents in the EU regularly exposed to vibration in their house. Fields and Walker [7] concluded that most of those residents who reported experiencing railway induced vibration were annoyed by it. The experts of the relevant ISO committee [8] confirm that this applies in many countries. Fields and Walker estimated that up to 2 % of the UK population was annoyed by railway induced vibration. Applying this rough estimate to the whole population of Europe would suggest an even greater number of people (up to 6 Mio. people) to be annoyed by railway vibration.

The public perception of noise reduction and that of vibration reduction are closely linked. A study by Öhrström and Skånberg [9] indicates that the presence of vibration increases the annoyance due to noise so that, without also reducing vibration, the effect of noise mitigation is impaired. They suggest that, were only noise to be mitigated, an additional 10 dB(A) reduction would have to be implemented to reduce the annoyance from the experience of combined railway noise and vibration unless the vibration is also reduced.

RIVAS – On the right track to improve the quality of life near railway lines

RIVAS will concentrate on the development of an integrated system of practice-orientated technologies for the reduction of vibration emitted from passing trains and transmitted into buildings close to the track. On open railway lines, vibration is always accompanied by the generation and reception of rolling noise which has its origin also at the rail/wheel contact. However, the parameters influencing the generation mechanism and the transmission to the receiver locations are different. This holds in particular for the respective mitigation measures, which are also different for vibrations and for rolling noise. Therefore rolling noise and other air-borne noise sources from railways in general are not within the scope of the project.

Several previous and ongoing projects have focussed on noise reduction for railways with the result that industrialised noise mitigation techniques are available and in regular use. The RIVAS partners are aware of the fact that some vibration mitigation measures implemented in the track can lead to an increase in air-borne noise. It will be an intrinsic part of the technology assessment to be carried out for all the developments in RIVAS to ensure that the vibration reduction technologies do not lead to increased air-borne noise. The RIVAS consortium comprises partners with the proven capability to assess the effect on rolling noise (e.g. using the TWINS software).

RIVAS will systematically follow the approach that the priorities are set according to the needs of the end-users.

The end-users are

- Railway Infrastructure Managers
- Operators of the rail services
- City planners / planners for railway infrastructure

As already explained above, RIVAS will focus on open lines as several established mitigation measures already exist for tunnels, which, however, cannot be applied to open lines. Furthermore, a systematic difference between railway lines in tunnels and on surfaces is that, in the latter case, vibration always occurs in combination with rolling noise. However, it can be anticipated that the RIVAS results, on the other hand, will be transferable to a large extent also to railways in tunnels.

With the focus on residents, effects on building structures and sensitive equipment are not within the scope of RIVAS.

A toolbox of measures and clear procedures for their assessment are needed. Without the close interaction of these two fundamental ‘building blocks’, efficient control of the impact of vibration from rail traffic on residents of railway lines is not possible at costs which do not endanger the competitiveness of rail. It is vital not to increase the costs of freight operations, which are already subject to a highly competitive market. Considering this, the following key objectives of the RIVAS project have been defined.

- Innovative solutions for vibration mitigation technologies. This will include the rail fastening system, sleepers, resilient elements for track and sub-grade and the rolling stock. Solutions will be developed mainly for ballasted track as this is the typical track type for the major freight corridors in Europe. However, slab track will also be considered. Innovative technologies will also be developed for the transmission path between track and adjacent buildings, these being typical retrofit solutions as they can be installed without interference with the track. Optimised rolling stock and new maintenance strategies for rolling stock and track have the potential to reduce vibration significantly for the whole network.
- Standardised assessment procedures for vibration mitigation measures. This involves the definition of a reference track/reference soil for the assessment in terms of physical parameters and a measurement procedure for the soil properties.

Since there is a threshold level of vibration below which it is not perceived by humans and vibration that is felt annoys residents as soon as it is perceptible, it is not necessarily required to develop mitigation techniques with a very high reduction potential. It is therefore only necessary to reduce vibration to values slightly below the threshold of perception. Similarly the vibration-induced noise has only to be reduced below the background level.

RIVAS will develop, and validate by field tests, the following practice-orientated solutions:

- Innovative resilient rail fastening system, where the stiffness can be adapted in order to obtain maximum reduction of vibration emission.
- Resiliently supported sleepers, where the focus will be on very soft elements.
- Optimised sleeper design for low vibration emission
- Low vibration slab track design for surface railway lines.
- Sub-grade and transmission measures: trenches, targeted ground stiffening, resonant reflectors.
- Vehicle characteristics for reduced vibration generation and improved maintenance of wheels.

- Maintenance strategies for track and rolling stock with the aim of low vibration emission

The approach of RIVAS is novel and outstanding compared to previous activities since it integrates all relevant aspects including generation and transmission of vibration, reception of vibration and potential impact of vibration mitigation measures on noise in a single project on European level.

Setting Standards

RIVAS will focus on low frequency vibration from open lines which is a concern mainly for freight traffic. However, it can be anticipated that RIVAS results will also be applicable to suburban, regional and high-speed operations.

Finally, the RIVAS results will contribute to European standards in particular to a harmonisation of metrics.

The key deliverables of the RIVAS project are

- Mitigation measures for ballasted and slab track + guidelines to develop an optimized / adapted mitigation solutions for each ground/track situation
- Guidelines for the design of transmission mitigation measures under/next to the track
- Guidelines for the design of low vibration vehicles
- Assessment of the benefits of mitigation measures in terms of human response
- Procedures for the evaluation of annoyance and exposure to vibration
- Measurement protocols to assess and monitor the performance of anti-vibration measures.
- Procedures to characterise vibration response properties of soils.
- Guidelines for maintenance of track and vehicles for low vibration.

Conclusions

Noise and vibration are often perceived as weaknesses in rail's environmental credentials. While noise is an issue for all modes of transport, vibration is specific to rail and therefore stands out all the more as a criticism of rail transport. By 2050 the European railways strive towards noise and vibrations no longer being considered a problem for the railways and its neighbours – meaning that noise levels are socially and economically acceptable and allow for 24-hour passenger and goods operations by 2050. [10]

RIVAS will deliver innovative technologies for efficient vibration reduction, a methodological approach towards measuring and assessing ground-borne vibration and come up with recommendations as well as guidelines both for the design of infrastructure and vehicles. This approach is an intermediate step to make life near railway lines more pleasant and to increase the quality of life "among good neighbours".

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