RIVAS

Railway Induced Vibration Abatement Solutions

Collaborative project

Definition of reference cases typical for hot-spots in Europe with existing vibration problems

Deliverable D1.5

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1. EXECUTIVE SUMMARY

This report shall provide a definition of reference cases typical for hotspots in Europe with existing vibration problems.

Reference cases typical for hotspots are defined according to the experience of 6 European countries. For vibration the following circumstances can occur (see chapter 3.2) and may be summarized as follows:

1. Many persons are involved.
2. There is a significant impact of vibration.
3. The mitigation measure costs to solve the problem are immense.

In the project RIVAS, reference cases are therefore defined as typical situations where many people can be protected by mitigation measures leading to a relevant vibration reduction. Normally the railway companies differentiate depending on the situations: new line, upgraded line, and existing line.

The RIVAS consortium comprises Infrastructure Managers from different European Countries. The problematic situations (i.e. typical hot-spots) and legal requirements are specific for each country. Therefore hotspots cannot be defined uniquely European wide and, hence, the reference cases are country-dependent. Detailed descriptions of the typical hotspots are given for some examples.

For the final proof of efficiency of mitigation measures, the vibration reduction (vibration-efficiency) has to be calculated for reference cases (Deliverable D1.12, see [1]) and assessed by the procedure defined in ref. [2]. Besides the efficiency of the vibration mitigation measure also the cost-efficiency has to be considered in the final assessment, which will be carried out in the final phase of RIVAS and will be summarized in Deliverable D1.12. Therefore, a procedure for performing cost-benefit calculations will be developed within RIVAS and documented in a separate report.

2. TABLE OF CONTENTS

3. CHAPTERS

3.1 INTRODUCTION

The aim of the RIVAS project is to develop efficient mitigation measures at source, track, transmission / propagation path and vehicle [1]. In order to focus only on relevant measures, the developments will be based on the results of the state-of-the-art reports written within the project [3-5]. Prototypes of developed mitigation measures will be tested in laboratory and field tests. To obtain the efficiency of mitigation measures in field tests, measurements of the vibration emission and of the influencing parameters will be typically performed at near-track positions [6-7] and all data will be stored in the RIVAS database [8]. For the final proof, the efficiency has to be calculated for typical hotspot configurations [1] and assessed by the procedure defined in ref. [2]. Besides the efficiency of the measure, also the costs have to be considered in the final assessment.

The following report starts with a definition of hotspots. Then, problematic situations and legal aspects faced by the infrastructure managers involved in RIVAS will be discussed. Afterwards, detailed descriptions of the example hotspots are given.

3.2 Definition of Reference Situations

3.2.1 General Aspects

In the project RIVAS, reference cases are defined as typical situations where many people can be protected by mitigation measures leading to a relevant vibration reduction.

Typically, a hotspot involves a number of buildings with vibration problems situated next to a track as schematically shown in Figure 1. For the description of hotspots, detailed information on the trains, the track, the soil and the buildings are needed. The information can be provided by measured data (e. g. vibration emission and transfer functions) or by a detailed description of all influencing parameters. Here, realistic scenarios should be used neglecting untypical situations arising under extreme conditions.

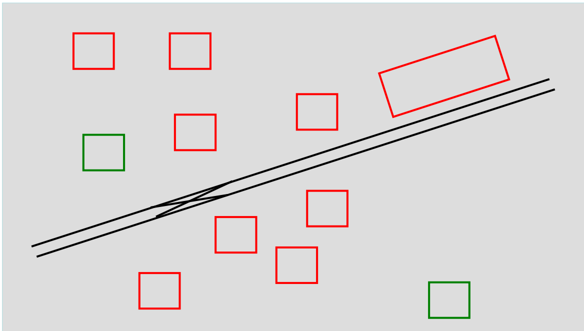

Fig 1: Typical hotspot situation situated next to a track. At the red buildings, vibration problems occur. At the green buildings, vibration problems do not occur.

Because the appearance of vibration problems depends also on the specific legal practice in the different countries, the situation of the involved partners will be considered in the following sub-sections. In addition, typical examples will be given.

3.2.2 German Situation

In Germany, the vibration immission is assessed by the procedure defined in the German standard DIN 4150-2 [9]. Here, the maximum weighted vibration strength KB_{Fmax} and the mean vibration strength KB_{FTr} are used as descriptors for the vibration immission inside the building. In the standard, guide values depending on the building area and the assessment period (day or night) are also given.

For the structure borne noise, in Germany no clear regulation concerning the vibration-induced noise inside buildings exist and the situation was unclear and controversial in the past. From the point of view of DB and the German regulatory authority (Eisenbahn-Bundesamt), guide values derived from inside noise levels of the regulation 24. BImSchV have to be used [10]. This leads to the following guide values:

Assessment period	Noise level L_r (L_{Aeq}) [dB(A)]
Day (6h-22h)	40
Night (22h-6h)	30

Table 1: Guide values for the inside noise according to [10]

Concerning the heavy rail traffic in Germany, situations with vibration problems can mainly be separated into the two cases of problematic situations caused by upgrading an existing line and caused by building a new line. From legal point of view, both situations have to be treated differently. This will be considered in the following.

Upgrading of existing tracks: Before the upgrade of a line, already in the initial state vibrations will in general occur and may even exceed the guide values defined by the standard and the regulation mentioned above. Measures like e. g. adding a further track, increasing the train speed or moving a track closer towards existing buildings, can lead to an increase of vibration immission. If the vibration levels predicted for the final situation exceed the guide values of the standard [9], the German legislation demands installation of mitigation measures guaranteeing that the final vibration magnitude does not exceed the initial magnitude by more than 25 %. This 25% criterion is based on the result of studies showing that this is the minimum change in vibration magnitude, which can be noticed by residents [2], [11]. It is not demanded to reduce the values below the limits of the standard [9]. For the structure-borne noise the criteria to compare the initial and the situation after upgrading or contractual change is an increase of 3 dB(A) in the inside noise level.

Building of a new railway line: If a new line is built, initial immissions are usually not present. For the protection of the residents, mitigation measures have to be applied to ensure that the final vibration magnitude is below the guide values as defined in the standard [9] and that the criteria for the structure-borne noise as mentioned above are met. It should be emphasized that building of new railway lines rarely creates new hot-spots in Germany. This is mainly due to the fact that new lines are mostly planned in some distance to the nearest buildings in order to improve the acceptance by the residents and to avoid complaints due to noise.

In addition, in Germany mitigation measures are only applied if they have a reasonable cost-benefit ratio. This means that both, the vibration magnitude and the number of buildings affected have to be high enough. As an alternative, financial compensations can be paid depending on the value of the building as well as on the initial and the final vibration immission. The method for calculating the financial compensation is still a matter of discussion.

As an example for a typical German hotspot, the upgrade of the line from Oberhausen to Emmerich will be described. Here, an upgrade from two to three tracks is planned over a length of 73 km located partly in densely populated areas. The line consists of ballasted tracks with the typical German rail (UIC 60), concrete sleepers (B 70) and hard rail pads (Zw 678a). The traffic consists of passenger and freight trains with a maximum speed of 160 km/h. The soil type is mainly ‘Braunerde’. For the upgrading, not only a third track is added but also the existing tracks are renewed.

Before starting the construction work, potential problematic areas in terms of vibration were defined and vibration measurements of the emission, the transfer functions and the immission at some reference positions have been performed. After finishing the reconstruction, the measurements will be repeated at the same positions.

Besides the situations described above where the installation of mitigation measures is forced by law, there are also hotspot situations where a lot of inhabitants complain about vibration immissions at existing lines. These can be situations where effective noise barriers were built and the reduction of noise led to an increased perception of vibrations. In addition, lines with a lot of freight traffic (especially in the night) or with double-deck trains can be problematic.

3.2.3 French Situation

In France, the induced groundborne noise and vibration is usually assessed according to three levels:

- For very high levels of vibrations, the situation inside buildings is usually assessed according to a decree (circulaire du 23 Juillet 1986 [12]) which gives vibration velocity limits in terms of damages against structures. Limits are given in terms of rms velocity and it is distinguished between continuous or repeated vibrations.
- For annoyance due to vibrations, the standard ISO 2631 [13, 14] is used. Here the levels of vibrations are given as an rms weighted acceleration: the measured acceleration is integrated over the pass-by duration and a frequency weighting W_m (defined in ISO 2631-2:2003 [14]) is applied. The measurements are carried out in the vertical direction (optionally in the lateral direction), at the geometric centre of the floor. Acoustic consultants can use their own experience to evaluate the annoyance due to vibrations. Another common method not based on any standard consists of computing the un-weighted velocity measured on pass-by duration and analysing it in third octave band.

- For annoyance due to ground borne noise, there is neither a regulation nor a standard. By default, it is assessed according to the acoustic measurement protocol defined in the standard NF S 31-010/A1 [15]: the indicator is an emergent (A-weighted) level compared to the background noise (subtraction between the induced ground borne noise and the background noise), weighted by the duration of exposure. Again, acoustic consultants can use their own method to evaluate the annoyance. A common way consists in computing the un-weighted sound pressure level measured on pass-by duration in third octave bands and comparing it to limits based on the operator's experience.

To define a typical hotspot situation in France, several acoustic consultants, specialised in the characterisation of sites affected by railway ground borne vibration issue (where adverse comments appear), have been consulted. The databases of these consultancy offices have allowed drawing the typical hotspot configurations in terms of railway induced vibration:

- Concerning the railway infrastructure: the most critical situations appear in buildings near curved tracks or switches and crossings. Configurations where the track is in cutting often imply higher vibration levels in the surrounding buildings than embankment track configurations. No noticeable differences occur between tracks equipped with wooden sleepers and track equipped with concrete sleepers, all types of rolling stock (freight, passenger, high speed) can cause adverse comments from the neighbourhood.
- Concerning the building: the reference case is a building with concrete structure, particularly at storeys R3, R4, with one level in basement and with long strip footing. Adverse comments generally concern buildings whose distance to the track is between 10m and 40m. Another critical situation is a building with metal structure and wooden floors such as typical “Haussmanian buildings”.
- Concerning the soils, the majority of the measurement data indicates ‘alluvial soils’ or ‘gravel soil + alluvial soils’. It is therefore difficult to point out a type of ground that is particularly sensitive in terms of ground vibration.

Depending on the context, different procedures to solve ground vibration issues are considered in France:

- if the track is a new track in an urban environment, under ballast mats are most of the time installed and isolation of the building itself can be considered if the track is mainly dedicated to freight trains. In the case of lightweight trains and with high traffic this solution is not applicable because the stability of track is not guaranteed in this case.
- if the track is a new track in an area with very low density of population, the design of the track itself (its layout) is optimized to limit the annoyance in terms of noise and vibration. In case of new tracks in countryside, the ground besides the track could be bought by the infrastructure manager to avoid building houses next to the track.
- For an existing track: there is no legislation in France but most of the time, if adverse comments occur due to ground vibration causing annoyance, the infrastructure managers apply ISO-2631 [13, 14] recommendations for vibration limits and NF S 31-010 [15] for ground borne noise limits: it could end up in maintenance operations such as a change of switches or/and installation of under sleeper pads depending on the number of people annoyed.

3.2.4 Spanish Situation

In Spain, the European Directive 2002/49 related to the assessment and management of environmental noise was transposed into Spanish legislation through Noise Law of 2003 developed by two Royal Decrees:

- Royal Decree 1513/2005, focused on the development of noise strategic maps and the action plans that must be carried out [16], and
- Royal Decree 1367/2007, which establishes the criteria for noise zoning and sets the values to be achieved before 2020 on existing situations and the immission limit values that cannot be exceeded in new lines [17].

Royal Decree 1367/2007 establishes the limits for the vibration levels inside the buildings, as defined in the next table:

Building use	**Vibration Level (L_{aw})**
Residential	75
Hospital	72
Educational or cultural	72

Table 2: Limits for the vibration levels inside buildings according to [17]

Where L_{aw} is the vibration level, in dB, defined by the expression:

$$L_{aw} = 20\lg \frac{a_w}{a_0}$$

a_o= 10^{-6} m/s^2

a_w= Maximum acceleration RMS signal, with frequency weighting w_m, defined in ISO 2631-2:2003 [13].

The situations with vibration problems are considered differently in new and existing railways.

New high speed lines

The planning phase for a new high speed line includes a 'vibration study'.

This study identifies the potential hotspots, buildings or residents affected by the new infrastructure because of noise or vibrations. Before the construction of the new line the vibration immission is evaluated by 'on site' measurements. The future situation is simulated by a specific software.

In terms of mitigation measures to be undertaken in case of vibration problems, the priority is given to those measures that isolate the source (track).

Existing lines

For existing lines, the vibrations are only studied in hotspots and if a complaint is received. Each case of complaint is investigated in detail. Mitigation measures are applied if necessary.

Most of the cases with reported problems refer to tunnels, and the corrective measures are focused on track maintenance to reduce rail roughness. For removing corrugations and short wavelength roughness grinding programs are performed. Additionally ADIF installs under sleeper pads, special fastening systems or ballast mats to give more elasticity to the track.

In any case, the number of complaints received in Spain on grounds of vibrations is very low.

3.2.5 Swedish Situation

In Sweden there is a standard SS 460 48 61 Vibration and shock – Measurement and guidelines for the evaluation of comfort in buildings where the descriptor is maximum weighted running RMS value slow (acceleration or velocity) [18]. Trafikverket (Swedish Transport Administration) together with Naturvårdsverket (Swedish Environmental Protection Agency) has guidelines for noise and vibrations (Dnr.S02-4235/SA60) [19]. For structure-borne noise there is no national regulation yet.

Three different situations where vibration problems could occur are:

- building new lines
- upgrading an existing line
- existing old lines

In the Trafikverket guideline these situations are treated differently:

- When building a new line mitigation measures shall always be considered when the frequency weighted rms (v_w) defined in the standard SS 460 48 61 exceeds the value of 0.4 mm/s. No residents should be exposed to vibration velocities exceeding v_w = 0.7 mm/s at night-time (22h-6h). If this cannot be accomplished with reasonable technical measures, the property owner should be offered redemption of the property.
- When a line is upgraded, mitigation measures shall be considered when $v_{w,rms}$ exceeds 0.4 mm/s at night-time (22h-6h). No residents should be exposed to vibrations exceeding v_w = 1.0 mm/s at night-time (22h-6h). If this cannot be accomplished with

reasonable technical measures, the property owner should be offered redemption of the property.

- For lines build before 1997 mitigation measures shall be considered when v_w exceeds 1.0 mm/s at night-time (22h-6h). No residents should be exposed to vibrations exceeding v_w = 2.5 mm/s at night-time (22h-6h). If this cannot be accomplished with reasonable technical measures, the property owner should be offered redemption of the property.

Technical measures should not be considered if the costs exceed half of the property value.

When a new line is built, often extensive stabilizing of the ground for the long-term stability of the track is required. As a side effect vibrations will normally not exceed the values in the guideline.

When a line is upgraded the vibration levels will usually be lower due to stabilizing of the old track or a new track beside the old one, which means that this usually not will be a hotspot situation.

The typical hotspot situation in Sweden usually occurs at old existing lines on soft soils like clay or peat. Vibrations can amplify at transition zones of bridges, switches, frost insulations and places of stiffness changes in the underground. The buildings are typically relatively old wooden single-family houses which are situated in densely populated areas. The vibration generating traffic consists of freight-trains (up to more than 60 a day). The lines consist of ballasted tracks with typical UIC 60 rail, concrete sleepers and hard rail pads.

3.2.6 Swiss Situation

Existing Regulation: A national regulation (BEKS) demands that Swiss Railways have to reduce ground-borne vibration and ground-borne noise in buildings below certain limit values (see table below) in case new lines are constructed or existing lines are altered [20]. If the increase in vibration exceeds 40%, DIN 4150-2 (only KB_{FTr}-value) has to be applied [9]. In case of an upgrade of an existing line and an increase over 40%, the vibration values are not compared directly with the DIN-Limit values, which are defined for new tracks. Instead, the use of DIN-limit values of the next higher DIN 4150-2-class (limit values differ by a factor of about 1.4) is common practice. For new lines the DIN-Limit values have to be applied directly.

A ground-borne noise limit value for the night is used and has to be compared to the highest one-hour equivalent noise level (Leq) during the night (22:00 until 6:00).

	Alteration of existing lines		New lines	
	16h-Leq, Day	Max. 1h-Leq Night	16h-Leq, Day	Max. 1h-Leq Night
Residential zone	**40**	**30**	**35**	**25**
Mixed zone, city core zone	**45**	**35**	**40**	**30**

Table 3: Ground-borne noise limit values in dB(A) for railways in Switzerland [20].

Further problems because of new regulation: Swiss authorities are preparing a new regulation (ordinance), to protect people against vibration and ground-borne noise. It is planned to put the ordinance into force in the next years. This regulation will demand mitigation measures for existing railway lines, where vibration in buildings is found to be excessive. The SBB has, in accordance with computer simulations performed in 2008, approximately 170 km conflict length over the whole network which implies mitigation costs of around 1200 million Euros if underballast mats and expensive trenches are used and installed during the regular track renewals over 35 years.

When do problems arise (complaints): In Switzerland a first study of SBB around the year 2000 showed: About one third of the complaints are because of rolling stock alterations, another one third is because of switches (see Fig. 2). Switches can lead to a 100% increase of vibration (KB_{FTr}) if they are placed close to a building, and the vibration magnitude can increase if an existing switch is badly maintained. From Swiss experience it can be concluded that a typical hot spot situation is a new/existing tunnel below a city (many people concerned) or a new/existing switch (because of high vibration, but normally only few people are concerned). An analysis of the Swiss Federal Office of Railways/Environment and SBB showed so far no other hotspots for open lines. It happened in some cases that underground improvement of existing lines gave problems. Otherwise a gas-tube or similar can be a conductor of vibration. Critical for being over the limit is distance to the line and/or sensitive floors in the building.

For tunnels mitigation measures exist but so far not for the switch on open lines because of the very low frequencies which have to be reduced. The maintenance state of the wheels of the rolling stock can be important and therefore complaints arose when the maintenance state was weakened.

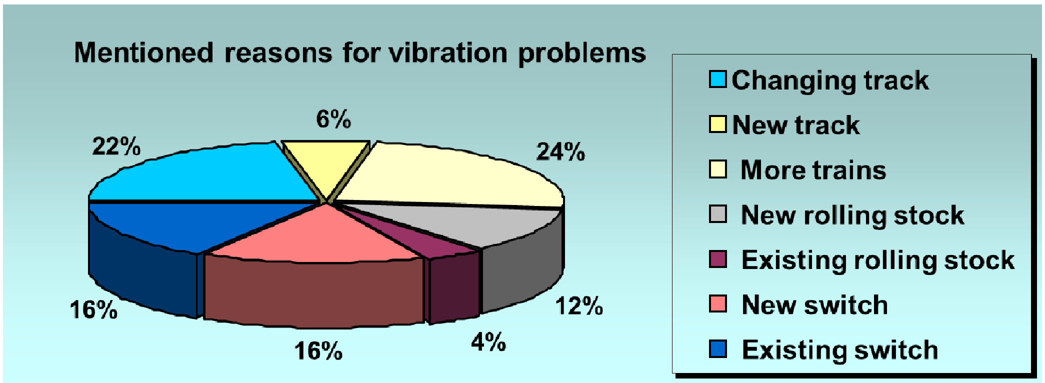

Fig 2: SBB-Swiss study "complaints"

Costs of mitigation measures: The Swiss environmental law states that protection measures must in general be proportionate in terms of costs and protection target. The responsible Swiss authorities intend in the new regulation (not yet in force) to define proportionality dependent on:

a. effectiveness of the measures

b. number of protected people

c. costs of the measures.

In the case of noise abatement, such an instrument developed by SBB has become the legally approved basis for deciding on mitigation measures. At the moment for vibration the Swiss authority decides in each case individually, which mitigation measure is proportionate. No rules have been published so far.

3.2.7 Summary

The previous section shows that typical reference conditions are different from country to country. In Germany, problems arise typically during the upgrade of an existing line in densely populated areas. In the other countries, vibration problems at existing and newly built lines can also become problematic. In addition, the main reasons for applying mitigation measures are different. Thus rolling stock replacement (Swiss), problems arising due to curves, switches and crossings (France and Swiss), corrugations in tunnels (Spain) and soft soils (Sweden) are mentioned by the partners. But all countries agree on distinguishing between existing lines, upgrade of lines and building new lines. Vibration limits for new lines tend to be much lower than for existing lines. In addition, normally mitigation measures are only used if the cost-benefit ratio is low enough. Alternatively, financial compensations are offered to the residents.

3.2.8 Definition of reference cases

From the previous analysis of the situation in Europe three typical scenarios with vibration problems can be defined:

1) Upgrade of an existing line (additional track)
2) Existing freight line
3) A track with vibration problems due to soft soil

Deliverable D1.12 'Vibration reduction for reference cases', which is due at month 36 will build on these three scenarios. D1.12 will define reference cases on the basis of the scenarios including building configurations and building-track distances typical for the countries involved. At least one reference case shall also include switches. For these reference scenarios it will be demonstrated how the RIVAS results can be used to efficiently solve the vibration problems.

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