Preparation of a proposal for a Large Scale Project in FP 7 on the mitigation of vibrations and vibration induced noise from railways

Content:

Measurement protocol for characterizing the efficiency of mitigation measures (SBB)

Objectives
The possibility to compare and characterize the efficiency of different mitigation measures by (vibration) measurements.
Mitigation measures at source (track and vehicle!), transmission way and in buildings shall be comparable by such measurements.
The efficiency of the mitigation measures shall be characterized depending on frequency spectra, ground parameters and rolling stock parameters. Based on these measurements giving the mitigation effect, it shall be possible in the future to find the appropriate mitigation measure depending on the situation (given by parameters mentioned above).

Description of work/task
- Literature study to get state of the art (e.g. future ISO standard 14837-3)
- Find relevant parameters (using measurements and models, maybe depending on lower or higher frequency spectra), e.g. quasistatic and dynamic excitation and define then influence of near-/farfield measurement points and on the other hand ground parameters are of interest.
- Outline of a protocol
- Compare with real, already done measurements =>adapt the protocol
- Calibrate and validate the protocol by measuring the efficiency of mitigation measures in anyway planned field tests.

Required input (e.g. from other tasks)
- State of the art (how is measured and analysed now): typical reports and results from RENVIB, CONVURT, LEO and standards.
- Modelling of influence parameters (other task), (Which parameters have to be taken into account?)
- Suggesting standard parameters
- Field tests of mitigation measurements (also in other task), (the same mitigation measure with different conditions or different mitigation measures with the same conditions) for calibration and validation.

Expected output/results
Calibrated and validated measurement protocol to characterize and compare different mitigation measures using frequency spectra and depending on several parameters to characterize the site and the trains.
Connected with the modelling tasks: Results of measurements with divers site parameters can be compared by transfer calculations to standard parameters.

Potential partners
(Core team: operators and modellers)
Measurements: Ziegler Consultants Zürich, …

(A minimized *budget* can be achieved by not including field tests.)

Vibration criteria for human occupancy (BAM)

Objectives:

Specific assessment of railway induced building vibration for all European countries

Description of work/task:

Compilation of European standards

Many different standards exist for different European countries (e.g. ISO 2631, 10137, VDI 2057, DIN 4150, ONS 9010, 9012, BS 6472, NF E 90-401, UNI 9614, SS 4604861, NS 8176E, PN-88/B-02171)

Comparison of European standards

All European standards have to be compared according to the following possible assessment concepts.

The assessment of vibration is usually based on measured vibration. The vibration is measured as velocity or acceleration signals. The measured quantity is not completely proportional to the sensitivity of the people in buildings. The measurement signal is therefore filtered or frequency-weighted with a certain sensitivity criterion. The sensitivity criteria are different for different axis of motion and for different positions of the person – standing, sitting or lying. To simplify this situation, there are also combined sensitivity criteria in use. Thus, different specific or general sensitivity criteria are used in different European countries.

The next difference in assessment methods arises with typical additional time-weighting or time-averaging procedures. Examples are single valued or time varying root-mean-square values.

At the end, the frequency and duration of the train induced vibration are introduced in the assessment procedure in different ways. A dose value (VDV-value) exists in the United Kingdom, characteristic values are averaged over a day or night (Germany), or the criterion has a reduced level depending of the duration of the vibration (Austria).

All European criteria have to be inspected and classified according to the specifications listed above.

Development of assessment modules for the prediction of railway vibration

The European assessment rules are very complex. They must be applied to the situation of predicted (calculated) vibrations. The calculated prediction is normally performed in frequency domain. Vibration criteria which are expressed as maximum spectra are used in some European countries and are easily applied to the vibration prediction. For other criteria, simplified assessment procedures, which are based on spectra, can be achieved. Some criteria such as the maximum particle velocity criterion have to be checked by experimentally deriving relations between the assessment quantity and spectrum based quantities.

Required input (e.g. from other tasks):

Expected output/results

Different assessment modules for different European countries

A unified approach for the assessment of *predicted* railway induced vibration.

Potential partners:

Consultants

Members of standardisation committees

Measurement protocol, Specifications (SNCF)

Reference track and soil

Objectives

The main objective of this task is to define the requirements for a reference track and soil and then their respective properties. The protocol to characterise the track and the soil must be also defined. A good practice guide to maintain the track will be also proposed.

Description of work/task

1. The use of the reference track and soil will be accurately defined. Several questions rise up : does the reference track guarantee a low emission of ground vibration? Is a single couple track+soil sufficient to be used as a reference? …
2. Then, the main properties of the soil and of the track related to the emission of ground vibration will be identified.
3. Some parametric studies will be carried out using prediction models to validate and quantify the influence of the characteristics identified in 2.
4. A definition of the reference track and soil will be proposed including a good practice guide for maintenance
5. The measurement protocol to characterise the reference track + soil will be defined, in accordance with the work carried out to characterise the mitigations measures and the soil properties.
6. The measurement protocol will be validated in several countries to select some reference tracks and soils. Their properties will be checked according to the requirements defined in 1.

Required input (e.g.from other tasks)

- The work must be carried out in accordance with the *properties of rolling stock*.
- Some source models and propagation tools from the *agreed models toolbox* are needed to conduct parametric studies.

Expected output/results

- A specification of the reference track and soil
- A measurement protocol to assess reference track and soil
- A good practice guide to maintain the reference track and soil

Potential partners

DB, SBB, SNCF, Vibratec, …

Measurement protocol, Specifications (SNCF)

Proposal for TSI

Objectives

The main objective of this task is to propose some recommendations that can be included in the Technical Specification for Interoperability. It concerns both, the rolling stock and the track.

Description of work/task

- Based on the *properties of rolling stocks*, the train characteristics that are already concerned by the TSI limits and influence the emission of the ground vibrations will be identified (for high speed and conventional railway).
- Some recommendations for the parameters identified in 1 and also for parameters not yet concerned by the TSI limits will be proposed.
- Based on the *reference track + soil*, the track characteristics that are already concerned by the TSI limits and influence the emission of the ground vibrations will be identified (for high speed and conventional railway).
- Some recommendations for the parameters identified in 3 and also for parameters not yet concerned by the TSI limits will be proposed.

Required input (e.g.from other tasks)

- The work must be carried out in accordance with the *reference track + soil, properties of rolling stock*.

Expected output/results

- Proposal for track and rolling stock TSI (for conventional rail and high speed)

Potential partners

DB, SBB, SNCF, …

Agreed models toolbox (SNCF)

Usable prediction tools

Objectives

The main objective of this task is to select among existing tools the most appropriate ones to predict the emission, the transmission of ground vibration and also the sound re-radiated inside buildings.
A compromise must be found between, on one side, the complexity of the inputs and the computations and, on the other side, the performances (frequency bandwidth, outputs, accuracy, …) of the predictions.

Description of work/task

1. A state of the art of the existing models must be carried out. Models proposed by the partners and also the others must be considered. Inputs / outputs / prediction methods must be clearly identified and described.
2. Some reference cases, representative of existing cases, will be defined. Field tests will be organised to characterise the reference cases.
3. According to the required inputs, the complexity of the computation, the outputs, … the usability of each approach will be evaluated before application.
4. The most usable approaches will be evaluated through the *benchmark and validation for selected cases* (reference cases).

Required input (e.g.from other tasks)

- The *characterisation of soil properties* is needed and also the *database of parameters* for simulation.

Expected output/results

- A state of the art of the existing models.
- A usable validated toolbox to predict ground vibrations.

Potential partners

BAM, Chalmers, DB, ISVR, SBB, SNCF, Vibratec, …

Optimized practice-oriented prediction tools for railway induced vibrations (BAM)

Objectives:

The aim of the research project is a complete prediction software (toolbox) which allows the prediction of train induced vibrations in buildings including all relevant aspects in a practice-oriented way.

The following three parts of the prediction of railway induced vibration have to be solved:

- the excitation by (dynamic) forces due to the vehicle and track interaction (emission),
- the propagation of vibration through the soil (transmission), and
- the response of adjacent buildings (immission).

These tools must be prepared in a comprehensive way so that each following step can use the output of the preceding step as the input. Different models of the same aspect but for different frequency ranges could be linked together if necessary.

All models will be based on physical rules. Results of detailed complex research models are approximated by simpler models. The aim is a practice-oriented, user-friendly prediction software which is able to give quick answers to the questions of a user who does not need to be a specialist. To be practice-oriented, the software also includes assessment parts for the vibration and secondary noise. For situations where the vibration level exceeds the threshold value, reduction measures can be calculated in all three prediction modules.

Description of work/task:

Comprehensive, user-friendly software has to be built to solve all problems of all three parts of the prediction. The software has to be introduced into practice and improved according to the practical experience. This includes the following seven working packages:

- Compilation of practice-oriented prediction tools
- Identification of necessary completion
- Enhancement and completion of the prediction model
- Practicability tests of the prediction software and its database

- Calibration of the prediction model and its parts
- Validation/verification of the complete prediction model
- Approval of the prediction model,

Which are described in the following sections.

Compilation of practice-oriented prediction tools

At first, the available components, tools, parts and models of the practice-oriented prediction software have to be compiled.

Identification of necessary completion

The identification of necessary completion is an iterative process which gets important input from the testing workpackage. It turns out where additional research is necessary to get complete prediction software.

Enhancement and completion of the prediction model

The practicability tests and the calibration measurements lead to necessary complementary items which must be included in the prediction software. The necessary items are derived from theory/numerical calculations and experimental results. The complementary items will be motivated and derived by true physical models as the rest of the prediction model. The completion includes the following steps:

1. research models of different research institutes and supporting measurements have to be analysed in detail,
2. general rules must be found,
3. simple models must be searched and
4. the general rules/results of the detailed analysis must be approximated.

Each research institute should be able to perform all these steps and generate a practice-oriented result.

Practicability tests of the prediction software and its database

The prediction software must prove its user-friendliness. This will be tested in cooperation with the future users of the software – railway societies of long distance and local traffic, consultancy firms and governmental authorities. The prototype of the prediction software will be given to a number of users within the consortium, who can get some advice and – in some cases – a prediction for a certain track or adjacent building. By that way, many comments on the practicability of the software are collected. Besides the practicability, the completeness of the database of the software is checked so that the user always finds a suitable dataset for his case of prediction, or it is possible to make a proper choice of parameters.

Calibration of the prediction models

Calibration of the prediction tool means that each step of the prediction is checked by detailed measurements. The parameters of the prediction model are fitted to the measuring and additional numerical results so that realistic results are predicted. The aim is to get correct amplitude levels for a correct assessment of the train induced vibration. The calibration measurements are usually complex measurements with a high number of measuring points at the track, in the soil and building.

For the transmission module, the wave velocity of the soil, the dispersion, and the transfer function of the soil must be measured in addition to the train induced vibration. For the immission/receiption module, the eigenfrequencies and corresponding damping values must be determined experimentally. The vibration transfer from the soil to the different storeys of the building and the propagation across the building should be measured. These calibration measurements are performed for different typical soils of different European countries and for typical buildings (typical construction, typical foundation).

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Validation/verification of the complete prediction model

The validation/verification of the prediction model consists of predictions for specific situations (train, track, soil, building) and control measurements at these places. The control measurements are simpler measurements with a few measuring points where the vibration immission is established. The comparison of the measured and predicted values indicates the quality of the prediction. A number of these control measurements shows the confidence range of the predicition method.

Approval of the prediction model

The first step to get an approval of the prediction model is good information of the users. This will be established by a good software documentation, online help functions, instruction and support. The approval of the prediction model will be effectively promoted by the cooperation in international standardisation committees, which are currently working on the field of ground vibration.

Required input (e.g. from other tasks):

- Condensed results and rules from complex research models
- Practice-oriented prediction tools and prediction models,
- Mitigation functions from Subproject IV,
- Assessment rules of all European countries from Subproject II

A prototype of prediction software has been built in the German research project "Practicable prediction method for railway vibration".

It could serve as a base for the final comprehensive prediction software.

As the prediction software does not include complex numerical models, it is possible to integrate results from different European contributors. Therefore, the progress in Europe on numerical methods for railway induced vibration can help to complete the prediction tool. At the same time, the approval in all Europe is improved by this European transfer of results.

Expected output/results

The final result of the research project is a fully developed software product, the complete programme for the prediction of railway induced vibration. That means in detail

- a calibrated software with parameters that have been fitted to detailed measurements,
- a validated software with results that have been checked by measurements at real situations and which have known confidential ranges,
- a user-friendly practice-oriented software which has been improved according to the testing results of numerous European testers,
- an international accepted software which should be introduced into the international standardization procedures.

Potential partners:

BAM, ISVR, Chalmers

DBAG, SNCF, SBB, ÖBB, Banverket,

European railway associations

Consultants of railway and building dynamics

CHARACTERISATION OF SOIL PROPERTIES (METHODS) (VIBRATEC)

Objective:

The objective of this WP is to determine methodologies to obtain some soil characteristics to fill a data base for model toolbox. Data base will be set up, organised and fill with the measurement conducted during the project.

Description of work:

The soil characteristics that need to be obtained as input data for the different models are the following: layering of the soil, density of each soil layers, dynamic soil characteristics (Shear wave velocity, Poisson Ratio, Young's modulus, Damping Ratio…).

The methodologies to obtain these data are based on in situ determination, intrusive methods and laboratory experiments.

Existing methodologies will be identified such as cone penetration tests or ground decay rate under different excitation types (shock hammer, hydraulic shaker or falling weight).

Their advantages and inconvenient will be listed. Comparison will be conducted on real site and/or in laboratory in order to define which methodology is the most appropriate for each characteristic determination.

Required input (e.g.from other tasks):
List of needed characteristics for simulation model

Output of the work package:
- List and description of methodologies
- Advantage and inconvenient of each methodology depending of the range of use
- Data base of soil characteristics

Potential partners:

ISVR, BAM

Data base of parameters for simulation (Vibratec).

Objective:

The objective of this WP is to determine data needed for the model in the toolbox.
The models will address the vibration generation, the filtering aspect as well as the ground mitigation. These aspects can be dealt as a global phenomenon or separate ones.
The data base will concern rolling stock, track and soil characteristics.

Description of work:

The data base for simulation will cover input data for the different model tools such as:
- Rolling stock characteristics: mass of rolling stock (axle, bogie, coach, wheel tread) stiffness (resilient wheel, primary and secondary suspension)…
- Excitation aspects: train speed, roughness, parametric excitation, geometric defaults…
- Track characteristics : rail (density Young modulus, vertical and lateral inertia), pads (lateral and vertical stiffness), sleepers (mass and sleepers spacing) …
- Ground characteristics : Poisson ration Young modulus …

As some models do not deal with the complete phenomenon, other data may be required:
- Ground vibration decay rate : it can be proposed to consolidate the procedure for the measurement of ground decay rate in specific context such as tramway (effect of asphalt layer, pavement edge …) or tunnel (transfer function between pipe and ground surfaces for several sites…)
- Force induce in the track depending on different rolling stock categories

This data base can be conducted through literature review, measurement campaign or information collect to the main suppliers (rolling stock manufacturers, track and component suppliers, measurement campaign…).

In a case of measurement to obtain the data, procedures to obtain the data will be described

Required input (e.g.from other tasks):
List of prameters needed from simulation model

Output of the work package:
- List of parameters needed for model toolbox
- Data base of input data for the models (rolling stock, track, excitation)

Potential partners:

ISVR, BAM, Rolling stock manufacturers, infrastructure

Identification of the relevant parameters for the generation of vibrations (DB)

Objectives: To identify the relevant parameters, which influence the generation of vibrations and their emission into the track bed. This shall include track components, vehicles, maintenance procedures both for vehicles and tracks, and operation.

Description of work/task:

In general, the relevant mechanisms for vibration generation are known: Irregularities on the surfaces of rail and wheel, varying stiffness due to discrete rail support, non-uniform ballast stiffness etc. On the other hand vibration mitigation measures are mostly restricted to the introduction of additional elasticity into track/track bed (i.e. under sleeper pads, ballast mats, mass-spring systems). One or more typical scenarios (track + vehicles + operation) will be chosen, which are representative for European rail traffic. The various components influencing the vibration generation are to be identified and their influence has to be quantified. This can be done on the basis of:

- State of the art knowledge, literature
- Additional measurements
- Simulation

These parameters will be related to tracks (e.g. stiffness etc), vehicles (wheels, un-sprung masses etc…) and operation (speed, axle loads etc…). Particular attention will be paid to combinations of parameters which are (un-) favourable in terms of vibration emission.

Required input (e.g.from other tasks):

Typical scenarios with vibration problems (heavy freight, soft soil …)

Expected output/results

List of the relevant parameters/components of tracks, vehicles, and operation which are governing the vibration emission. This will provide the basis for the vibration reduction options to be developed/optimized within the project.

Potential partners: Railway operators, vehicle manufacturers, research institutes

Toolbox and Options for Vibration Mitigation measures (DB)

Objectives:

The objective of this work package is to work out a “toolbox” of existing source related vibration mitigation measures and to define the demand for further development

Description of work/task:

Existing vibration mitigation measures generally introduce additional elasticity into the track (Under sleeper pads, ballast mats, mass-spring systems) which means that only one physical parameter (i.e. track stiffness) is taken into account. Based on the results of work package “Identification of the relevant parameters for the generation of vibrations” options for the optimization of existing solutions and new developments will be worked out. These options shall include track components, vehicle components, track and vehicle maintenance and operational aspects. It is a great chance of this project to treat these aspects in an integrated fashion and not isolated from each other as it was done in the past. A prioritisation has to be done on the basis of criteria which still have to be worked out (e.g. CBA etc.)

Required input (e.g. from other tasks):

Results of work package “Identification of the relevant parameters for the generation of vibrations”
Overview over existing vibration mitigation measures

Expected output/results

Priorities for further development

Potential partners:

Railway operators, construction companies, vehicle manufacturers, track components manufactures, research institutes

Mitigation measures – Track (DB)

Objectives:

The objective of this work package is to develop, to optimize and to test track components with respect to low vibration emission and track related mitigation measures.

Description of work/task:

When vibration mitigation measures are to be installed, the usual candidates are: Under sleeper pads, ballast mats, mass-spring systems – the latter mainly for tunnels. These systems differ from each other with respect to costs by orders of magnitude. Based on the findings in work package "Toolbox and Options for Vibration Mitigation Measures" these measures will be tested and optimized. Since the real mitigation effect is unclear in some cases, a comparison according to the "Measurement Protocol" is needed.

Further development should focus on

- Mass-spring systems optimized for open lines
- Cost-Benefit Aspects
- Retrofit solutions
- Solutions for special applications like e.g. bridges

Selected solutions will be tested in field tests. Particular attention has to paid to potential conflicts with noise emission because.

Required input (e.g. from other tasks):

Results of work package ""Toolbox and Options for Vibration Mitigation Measures"

Expected output/results

Optimized track related mitigation measures.
Guidelines for the optimum choice of track related vibration mitigation measures.

Potential partners:

Railway operators, suppliers of track components, research institutes

Mitigation measures – Vehicles (DB)

Objectives:

The objective of this work package is to develop and optimize vehicle components for “Low Vibration” rolling stock.

Description of work/task:

With the implementation of TSI limits for noise considerable effort has taken place to reduce the noise emission by optimizing rail vehicles. A comparable activity is still missing with respect to vibration generation. Based on the findings in work package “Toolbox and Options for Vibration Mitigation Measures” vehicle based vibration mitigation strategies will be worked out and tested in field tests.

Further details to be worked out in cooperation with rolling stock manufacturers.

Required input (e.g. from other tasks):

Results of work package ““Toolbox and Options for Vibration Mitigation Measures”

Expected output/results

Guidelines for “Low Vibration Vehicles”

Potential partners:

Railway operators, suppliers of rolling stock, research institutes

Mitigation measures – Maintenance and Operation (DB)

Objectives:

The objective of this work package is to work out and to test optimized maintenance procedures aimed at effectively avoiding the emission of vibrations. Also the potential of optimization of operational details will be explored.

Description of work/task:

It is well known that also the maintenance of track and rolling stock influences the emission of vibration. Based on the findings in work package "Toolbox and Options for Vibration Mitigation Measures" strategies for vibration reduction due to improved maintenance procedures will be worked out and if required tested in field tests. This may include;

- Tamping
- Rail Grinding
- Wheel reprofiling
- Others

Required input (e.g. from other tasks):

Results of work package ""Toolbox and Options for Vibration Mitigation Measures"
Typical maintenance strategies for rolling stack and track.

Expected output/results

Guidelines for maintenance of track and rolling stock with respect to low vibration generation

Potential partners:

Railway operators, track construction companies, research institutes

Influence of superstructure design and stiffness of layers and components on vibration mitigation measures (Railone)

Objectives:
Identification of influence of superstructure design with their stiff layers and components and their resilient ones on the vibration damping and frequency modulation

Description of work/task:

Various superstructure designs exist nowadays. From conventional ballasted track to ballasted track with under sleeper pads, over ballasted track on subballast mats and various slab track systems up to mass spring systems exists for railway application. The number and level of resilient components (subgrade, sleeper soffits, rail fastening) is different in the various systems. Apart of their different investments and LCC costs is the efficiency of the different superstructures in respect of their effectiveness related to vibration abatement of great interest. Not at last the different designs have different requirements in terms of the geometrical height and therefore have their restricted utilisation related to the provided construction heights in case of existing lines. The effectiveness should be quantified in relation to each other to be able to detect and choose the right economical superstructure system for each practical application and requirement.

Required input (e.g. from other tasks):
Suspended and not suspended wheel set mass
Specified superstructure designs
Particular rail and fastening system and their geometries and properties
Geometry and stiffness of track component (solid and resilient ones)
Bedding modulus and compaction grade of the subsoil and the frost protection layers
Damping value of resilient components

Expected output/results
Determination of the effective natural frequency
Evaluation of vibration damping and insulation degree
Evaluation of insertion loss

Potential partners:
- Calenberg Ingenieure
- Getzner Werkstoffe
- Saargummi
- Gerb
- Vossloh
- Pandrol

Mitigation measures – transmission (ISVR)

This work package tests a number of ideas for reduction of vibration along its transmission path. These include, trenches, structural barriers (buried walls), wave impeding blocks (WIBS), resonant reflectors made with masses placed on the ground next to the track and the effects of stiffening the subgrade.

While some of these ideas have been studied before generally, the particular nature of surface vibration propagation from railways and the layered structure of the soil should be taken into account. In the frequency range of interest the very top layer of soil causes a steep rise in the vibration transmission spectrum as propagating modes of vibration, 'cuts on'. The significance of this layer is often dismissed in general vibration studies. However, in these studies a key approach is to use or alter the effect of the layered ground structure to form barriers to propagation in this frequency range. It is hoped that taking advantage of a detailed knowledge of railway vibration propagation and its mechanism may lead to more productive designs of transmission mitigation measure.

A number of case examples exist in the literature of barriers to vibration transmission, however, these tend to be specific, and therefore not systematic, studies and for vibration from tunnels which propagates via body waves rather than surface propagating modes as from open line.

In other developments in recent years advanced models for vibration transmission have been developed. Amongst these are advanced boundary element and finite element techniques that have been specifically developed by the project partners to address railway problems. These are briefly described below. <<*???*>>

<<Should we put in something here about the models we have or would this go elsewhere??? – each modelling partner to write a few lines about the models they will be using?? >>

One advantage of transmission measures is that they could be implement on railway land close to the track but not require major disturbance or rebuilding of the track itself. This may also apply to

Sub packages:

Mitigation measures – transmission – trench and buried wall barriers (ISVR)

Objectives:

1. Test the idea of using trenches and buried as barriers to surface vibration using numerical models.

2. Produce design rules and examples from the study to indicate what can be achieved depending on the ground properties.

3. If a barrier solution is to be tested by the project, the models will be used to optimise the design for the particular site.

Description of work/task:

The idea of using trenches to make a barrier to propagating ground vibration generally has been around for a long time. It is well known that analyses that idealise the ground as a half-space indicate that significant reductions only occur when the depth of the trench is of the same order of magnitude as the Rayleigh wavelengths. Past studies have either relied on such idealisations of the ground or two-dimensional models. For the low frequencies of interest in surface railway vibration, this is impractical. However, the importance of the first weather layer of soil, often about 2 m deep, in railway vibration propagation offers the hope of making a more significant difference if this layer is cut. These can now be studied using three-dimensional models of vibration propagation from trains.

The effectiveness of a barrier depends on the degree to which the impedance in the medium changes causing a reflection of the wave. Such a change in impedance can be brought about either by an interruption in the medium (trench filled with air) or by a material much stiffer (and denser) than the soil (buried wall). It is likely that a feasible barrier construction would use elements of both since walls, or sheet piling would have to be used to retain a narrow, deep trench.

The work will start by presenting options to railway civil engineers and consulting them on the feasibility of construction of different possible configurations. A number of systematic studies will then be carried out using the numerical models. These would consider:

- a number of different real ground site parameters (‘lithologies’) : material properties, layer depths, track formation engineering
- different designs of barrier, open trench, walled trench, solid wall
- the effect of depth in each soil lithology
- effects of width and distance from the source
- in addition the effects of some line-side engineering such as noise barrier foundations would be assessed.

Each case would be assessed in terms of the attenuation achieved and the extent of the ‘shadow zone’.

<< Jens would Chalmers time-domain models be good at looking at transient effects at the ends?>>

Required input (e.g. from other tasks):

- Measured and validated ground parameters including material properties (i.e. P-wave and S-wave speeds in each layer), damping and layer depths.
- These would be supplemented by other known site parameters where necessary to make up a complete study
- Input from railway civil engineers on design and feasibility. SNCF, Banverket, DBAG, <<NR have offered this informally>>

Expected output/results

- Systematic studies resulting in design rules for trench and wall barriers
- Identification of site conditions where barriers are most likely to be beneficial
- Potential site-optimised design for installation and testing in another work-package

Potential partners:

ISVR, BAM, Chalmers

Mitigation measures – transmission – wave impeding blocks (WIBs) (ISVR)

Objectives:

1. Test the idea of using WIBs to reduce low frequency surface vibration using numerical models.

2. Produce design rules and examples from the study to indicate what can be achieved depending on the ground properties.

3. If a WIB solution is chosen to be tested by the project, the models will be used to optimise the design for the particular site.

Description of work/task:

Wave impeding blocks (WIBS) have been proposed by a small number of researchers for use under or next to railways. These start from the understanding that the propagation of vibration along the ground surface is to large extent controlled by the layer depth and soil structure of the top layer in the frequency range of interest because of the cut on of vibration modes in that soil layer. The method therefore seeks to stiffen soil or replace it with concrete in order to change the modal propagation regime, i.e. to move the cut on of propagation in the top layer to higher frequencies. Thus the method uniquely offers vibration reduction at very low frequencies rather than above a particular frequency as wavelengths get shorter (e.g. with the barrier methods).

The required soil stiffening might be achieved through soil treatment methods such as lime injection, jet grouting or in-situ lime mixing. Although the primary design to investigate would require treatment of the soil under the track, it is not necessarily the case that the track would need to be disturbed to do so, e.g. with injection techniques. Furthermore, the effectiveness of these measures placed in the ground only to the side of the track shall be investigated.

As with the work of barrier methods, the work will start by presenting the technology idea to railway civil engineers and consulting them on the feasibility of construction of different possible configurations. A number of systematic studies will then be carried out using the numerical models. A large variety of block configurations are possible. The studies consider different configurations with regard to a number of different real ground site parameters (‘lithologies’) as in the case of the barrier methods.

Again, each case would be assessed in terms of the attenuation achieved and the extent of the ‘shadow zone’. Although some literature on the theoretical analysis of WIBS exists, there have been no practical tests on railways.

Required input (e.g. from other tasks):

- Measured and validated ground parameters including material properties (i.e. P-wave and S-wave speeds in each layer), damping and layer depths.

- These would be supplemented by other known site parameters where necessary to make up a complete study
- Input from railway civil engineers on design and feasibility. SNCF, Banverket, DBAG, <<NR have offered this informally>>
- Input from external sources such (e.g. Keller Colcrete <<*not a partner*>> on dynamic properties of jet grouting, or in-situ lime mixing)

Expected output/results

- Reports on the effectiveness of possible practical implementations of WIBS in real soils.
- Potential site-optimised design for installation and testing in another work-package

Potential partners:

ISVR, BAM, Chalmers

Mitigation measures – transmission – masses on the ground (ISVR)

Objectives:

1. Test the idea of using resonant reflectors to reduce low frequency surface vibration using numerical models.

2. Produce design rules and examples from the study to indicate what can be achieved depending on the ground properties.

3. If a resonant reflector solution is chosen to be tested by the project, the models will be used to optimise the design for the particular site.

Description of work/task:

Wave propagation in linear structures can be efficiently reflected by an impedance change introduced by the placing of discrete resonator tuned to the frequency of the wave to be reflected. A good example of the electrical analogue of this is provided in railway signalling by 'jointless' track circuits. In these the high frequency track circuit signal is reflected a signal block boundaries by a tuned circuit rather than by an insulated joint.

The idea to exploit this to reflect surface ground wave propagation has been proposed a number of times previously and was tested by BR in the late 1980s. The tests consisted of placing concrete masses on the ground surface and using the natural foundation stiffness to provide the resonant system.

The tests were unfortunately inconclusive due to the choice of site for the experiment and the lack of capability in the modelling analysis available at the time. With the improved modelling capabilities available in this project and the availability of known parameters for a number of real track sites, this idea shall be re-examined. As with the other transmission mitigation methods, a large range of configurations is possible with resonances possible via 'bouncing', and 'rocking' modes of the masses. A further dimension that will be studied is the possible treatment by multiple tuning frequencies. Again, therefore a systematic study of the possible effectiveness of the measure is required for different ground parameters.

If the method is shown to be successful it could be the cheapest and simplest of the transmission mitigation options to implement since it would not interfere with the track and would only require the placing of masses on the ground surface.

If chosen for testing within the project, the models would be used to optimise this method for the implementation site.

Required input (e.g. from other tasks):

- Measured and validated ground parameters including material properties (i.e. P-wave and S-wave speeds in each layer), damping and layer depths.
- These would be supplemented by other known site parameters where necessary to make up a complete study

- Input from railway civil engineers on design and feasibility. SNCF, Banverket, DBAG, <<NR have offered this informally>>

Expected output/results

- Reports on the effectiveness of possible practical implementations of resonant reflectors in real soils.
- Potential site-optimised design for installation and testing in another work-package

Potential partners:

ISVR, BAM, Chalmers

Mitigation measures – transmission – subgrade stiffening (ISVR)

Objectives:

1. Test the idea of using various track formation engineering methods to reduce the dynamic track deflection and consequently reduce the vibration propagated into the surrounding ground.

2. Produce design rules and examples from the study to indicate what can be achieved depending on the ground properties.

3. If a foundation stiffening solution is chosen to be tested by the project, the models will be used to optimise the design for the particular site.

Description of work/task:

Theoretical analysis linked with realistic ground site parameters carried out during the last few years with the advanced models that have been developed, has shown that surface vibration from trains may be generated either by dynamic forces from the irregular vertical profile of the track or by the convection of the moving quasi-static displacement pattern under the axles of the train. The models encompass both mechanisms of generation. Although the dynamic generation mechanism is most commonly the important one, in very soft soils, and for close distances, the quasi-static generation mechanism has been shown to be of importance. In particular this may be important a locations most likely to have severe vibration problems. While improvement of the vertical alignment is expected to have a significant effect where the dynamic mechanism dominates, it will have no effect where the quasi-static mechanism dominates.

For these situations increasing the beam stiffness in the track-axial direction by incorporating a stiff beam into the embankment or formation is proposed. This kind of engineering has been implemented in new tracks for high speed lines to avoid high displacements when trains travel at speeds close to the ground wave speeds. The vertical support stiffness of the track has also been increased in these conditions in some case by the use of lime columns, mini-piles or even large-scale piling. Existing examples to reduce track deflections include sites at Ledsgård (Banverket), Rainham Marshes (NR), Kungsbacka (NS) and Gardermoen (NSB).

The effect on reducing environmental vibration in conventional circumstances will be studied in this task. The work will start with a survey of possible engineering measures and study the effectiveness of a practical range of options. This task is different from the forgoing transmission path mitigation options in that it is envisaged more specific examples will be studied rather than a systematic parametric study. The project is less likely to test this engineering because of the costs of implementation. Nevertheless, the potential benefits of such engineering for environmental vibration should be studied for when foundation stiffening is carried out either in new railway projects or for track deflection reasons.

Required input (e.g. from other tasks):

- Measured and validated ground parameters including material properties (i.e. P-wave and S-wave speeds in each layer), damping and layer depths.
- Case example data on design together with possible design parameters.
- Input from railway civil engineers on design and feasibility of piles, lime columns, high bending stiffness track slabs and other measures. SNCF, Banverket, DBAG, <<NR have offered this informally>>

Expected output/results

- Reports on the effectiveness of possible practical implementations of resonant reflectors in real soils.
- Potential site-optimised design for installation and testing in another work-package

Potential partners:
ISVR, BAM, Chalmers
<<Jens, Alexander Smekal of Banverket may have something to add/comment on here from his experience of Ledsgård and elsewhere(?). Could you contact him?>>

Supplement of BAM to the proposal from ISVR

Available numerical methods at BAM that are related to transmission of railway induced vibration are

- A 2-dimensional finite-element programme with thin layer boundary (SESAB),
- A 3-dimensional coupled finite-element boundary-element programme for tracks or buildings on the ground (AUFEBEM),
- A wave-number domain method for calculation of stationary or moving loads on the ground and on tracks.

All methods work in frequency domain, but they have also been combined with Fourier- and Laplace transformation to generate time histories. The frequency range is usually from 0 to 80 Hz, the tracks are calculated with the FEBEM up to 150 Hz (according to the sleeper distance excitation at high-speed traffic. The soil can be homogeneous or layered, in the finite-element region it can also be irregularly inhomogeneous.

Typical systems/mitigation measures that have been analysed with these programmes and which could be a topic/subpackage of this work package:

- Different lines such as open line, tunnel line, line on a dam, line in a cut,
- A plate, a wall and a block as a mitigation measure,
- Stiffer soil areas under and near the track,
- Plates under a surface line.

The two last ideas could also be treated as mitigation measures of the emission.

Available experimental methods at BAM that are related to transmission of railway induced vibration are

Evaluation of the important ground parameters by

- Measuring the Rayleigh wave velocity to get information of the ground stiffness,
- The dispersion of the Rayleigh wave in case of a layered ground situation,
- The transfer function/transfer admittance of the soil in the frequency range of 4 to 200 Hz and distances of 4 to 128 m or even more

The ground can be excited by
impulse hammer,
drop weight and
harmonic electro-dynamic or unbalanced vibrator.

Measurement of train induced vibration at up to 100 (and more) measuring points simultaneously, for example two measuring axes for a track with and without mitigation measure and extensive ground and track measurements are possible.

Mitigation measures at the receiver (BAM)

Objectives:

The objective of this work package is to establish different simple and complex mitigation measures at the receiver of railway induced vibration and their frequency-dependent reduction effects for different situations. Mitigation measures for vibration as well as for secondary noise in buildings are searched.

Description of work/task:

Compilation and categorization of possible mitigation measures

A literature survey on existing mitigation measures as well as on normal reduction effects is performed. All ideas of reducing building, floor and wall vibrations have to be collected. They have to be categorized concerning the necessary effort and complexity of the measure and the expected efficiency.

Analysis of buildings with and without mitigation measures

Mitigation measures for building and floor vibrations can be developed on the base of a better knowledge of the dynamic behaviour of normal buildings without mitigation measures. The following effects should at least be analysed:

- The influence of the compliance and damping of the soil on the reduction of the building vibration with increasing frequencies,
- Wave passage effects for stiff or stiffened foundations,
- The influence of the floor eigenfrequency on the resonance amplification of the floor compared to the free-field soil amplitudes,
- The vibration transfer into the different storeys. There is an amplification or reduction with increasing storey number which depends on the frequency.

The reducing effects of standard building elements such as floating floors (at high frequency and for the secondary noise), or non-bearing walls and their capacity of damping floor vibrations should be analysed.

The analysis is done by complex finite-element-models. If it is necessary, the complete building-soil interaction must be included. A high number of examples must be calculated and the general amplification and namely reduction rules must be established from the analysis results.

The calculations are performed at two stages:

- The first study is for normal buildings without mitigation measures
- The second stage is for buildings with mitigation measures. These calculation must also be performed for a high number of different buildings to show the efficiency of the mitigation measure under different circumstances.

Choice of appropriate mitigation measures

The choice of the appropriate mitigation measure is based on the established efficiency and the cost-benefit relation.

Demonstration

A few mitigation measures have to be realised within the project and their efficiency has to be checked by measurements.

Required input (e.g.from other tasks):

Prediction of train induced building vibration by prediction tool (from Subproject III)

Expected output/results

Optimized mitigation measures for noise and vibration
Mitigation measures for the retrofit of buildings

Potential partners:

BAM, ISVR, Chalmers, DBAG, SNCF
Construction firms for the realisation of special solutions
Specialists for structure borne noise

Field demonstration (SNCF)

Objectives
The main objective of this task is to prove the applicability of the results of the project. Some solutions to reduce the ground vibration will be installed and characterized. The field demonstration will be used for dissemination.

Description of work/task

- Some test sites will be selected to be used on one side as reference cases, and on the other side as demonstration sites. These test sites must cover the complete scheme of the ground vibration problem, from the emission (rolling stock and track) to the reception inside a building.
- The measurement protocols developed to characterise the soil, the emission, the propagation, the efficiency of the mitigation measures, will be applied on theses demonstration sites.
- The most efficient solutions to reduce the ground vibrations will be installed and characterised on these test sites.

Required input (e.g. from other tasks)

- The field demonstration concerns the *results*, the *mitigation measures*, … all the results of the project.

Expected output/results

- Some demonstration sites where the efficiency of the solutions (rolling stock and track) is validated.

Potential partners
DB, RailOne, SBB, SNCF, …

Additional Information:

FEM90 – Chalmers computer program for simulation of ground vibrations

FEM90 is a computer program for simulation of three-dimensional ground vibrations in the time domain that has been developed by Chalmers Department of Applied Mechanics. Vehicle, track and layered ground are modelled as one compound system using the finite element (FE) method combined with rigid body dynamics. The model features adaptive finite element technology, a moving mesh technique that allows for analysis of three-dimensional motion with the train constantly at “the same” position in the mesh, and a tuned visco-elastic layer surrounding the FE mesh to reduce the spurious reflections from the boundaries of the model. Solid three-dimensional elements are used for all parts of the track structure (rail, rail pads, sleepers, ballast and sub-ballast) and soil (crust, organic clay and marine clay). The material characteristics of the various regions in the layered structure can vary along the track. The analysis can be extended to changing geometries, material nonlinearities, material inhomogeneities and irregularities in vertical track alignment.

Simulation results display the dynamic behaviour of the separate components of the system. Wave propagation in rails, embankment and surrounding ground e.g. the combinations of high train speed and soft clay in the subgrade, can be studied. Moreover, the effect of vibration counter-measures can be investigated. Mainly due to limitations in computational resources and numerical problems with a short time increment, it has been found that high frequency variations can not be accurately resolved by the program. The range of problems suitable for analysis is restricted to phenomena below 20 Hz.