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STRATEGIC VIBRATION MAPPING FOR RAILWAY INFRASTRUCTURES

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Abstract

The Environmental Noise Directive 2002/49/EC requires the Member States to determine the exposure to environmental noise through noise mapping for agglomerations, roads, railways and airports using common methods of assessment. These maps will be made available to the public and will allow adopting action plans to prevent and reduce environmental noise, particularly where exposure levels can induce harmful effects.

The END does not establish how to asses or reduce vibration impact caused by railway infrastructures. Within this directive, no common method of assessment or evaluation of people exposure to railway induced vibrations are defined. In this paper, Strategic Vibration Mapping concept for railway infrastructures is developed including discussion about input data, vibration harshness evaluation, quantification and action planning.

Keywords: Legislation, railway, vibration, mapping, community.

1 Introduction

The Environmental Noise Directive 2002/49/EC (END) defines a common approach to avoid, prevent and reduce harmful effects due to exposure to environmental noise. The END forces the Member States to assess the exposure through noise mapping for all major airports, agglomerations, railways and roads, to develop and adopt action plans to reduce noise impact due to these sources and to make all the information regarding noise levels public.

The END also forces the European members to designate competent authorities and bodies responsible for all the tasks to be performed. All the member states should bring into force laws, regulations and administrative provisions necessary to comply with the END. A complete schedule for data collection, noise mapping and action plan development is defined within the END until 2014.

More important that the previously described legal obligations, END defines a common framework of noise indicators, noise prediction standards and noise assessment conditions. Therefore all members could follow a coherent set of rules which guarantees all the European population to be equally protected against noise pollution. The END introduces the 24h weighted L_{den} indicator and establishes the L_{den} and the L_{night} as the future obligatory noise indicators. Standard computation methods are also established for industrial, aircraft, road and railway noise prediction. Standards related measurements are also provided.

Standardized strategic noise mapping, which should be updated every 5 years, points out as a powerful tool for noise impact assessment and for the development of action plans. The measures within the plans are at discretion of the competent authorities, but should be oriented to reduce values below relevant limits. Nevertheless, no noise limit values are given in the END and therefore the concrete figure of any limit values are to be determined by the Member States.

Railway noise impact models are based in the Netherlands national computation method (SRM II). This method comprises source models for Dutch rolling stock which can be adapted for modeling other countries typical rolling stock. Propagation model includes ground absorption and geometrical characteristics. Most commercial software also allows quantifying affected population, which is the most relevant output parameter within strategic noise mapping.

What about vibrations? Railway induced vibrations are nowadays a source of concerns for local, regional and national administrations (see Figure 1). However, no common approach exists and different national and regional legislations lead to different vibration level indicators and different vibration limits. The END does not establish any indication about recommended vibration indicators, methods of assessment or evaluation of people exposure to railway induced vibrations. Neither strategic vibration maps nor action plans are addressed. What is the problem with railway vibrations?

Figure 1 – “*No more vibrations! Solutions now!*” Neighbors complain in Spain.

2 The railway vibration problem

Most of the mechanisms related to the generation of railway vibrations, their propagation through the soil and their transmission into the building, include a large quantity of complex phenomena, complex to approach or characterize. Comparatively, noise generation, transmission and reception phenomena can be considered extremely simple: Dutch rolling stock noise models comprise a series of vertically-distributed equivalent noise sources; acoustic propagation medium is homogeneous and reflection and absorption laws are well known. Moreover, noise impact is usually calculated within the building wall and therefore building acoustic isolation properties and human response influence are completely neglected. In case predicted noise levels exceed noise limits, it is possible to reduce the impact in a cheap and efficient way, using acoustic screens. Several high quality commercial tools are available for the prediction of railway noise impact (see Figure 2).

On the other hand, railway vibration generation depends on rolling stock, wheel and rail roughness profile, rail, pad, sleeper, under-sleeper pad, fastening system, ballast, and ground vibration coupled behavior. Moreover ground vibration mechanism depends on vibration propagation characteristics, highly statistical and stochastic. Finally, most vibration legislation establishes limits inside buildings, and therefore it becomes necessary to take into account the foundation-building coupling phenomena and the building vibration behavior. In this context, several methodologies have been suggested for the prediction of vibration levels caused by rolling stock pass-by. Empirical methods[1] (some of them are used as a national reference calculation method, as in Switzerland[2], Nordic countries[3] and United States[4]) are usually based on a collection of reference values, which are modified by the most representative parameters (train speed, weight, length and others). These vibration values are usually obtained from statistical analysis of measurement campaigns[5]. Analytical methods usually require a large amount of data[6-9], thus they are not useful at first design stages. On the other hand, this kind of models allows assessing the variations due to modifications in the parameters and, consequently, are very valuable for understanding the vibrational behaviour and assessing the most contributing factors. Finally, numerical methods based on the Finite Element Method (FEM, see Figure 2), the Boundary Element Method (BEM) or in FE/BE coupled methods require geometrical and mechanical data, a long modelling period and large computational resources. Therefore, they should be the method applied in non-typical or very sensitive situations[10-12]. As a consequence of the heterogeneity in the required input data, the modelling methodology and the different accuracy levels, it becomes quite difficult to compare the results obtained with all these methods.

On the other hand, noise indicators for dose-values (as L_{den} specified in the END) and for instantaneous values (as L_{max}, commonly specified within Environmental Impact Assessments for new railway lines) have been defined by consensus. However, most of the vibration indicators defined in legislation include only instantaneous values (as L_{aw} and K coefficient) and, even though there is a large series of candidates, no consensus at European level has been reached regarding vibration dose-based indicators.

Finally, there is a lack of knowledge about vibration countermeasure efficiency. Anti-vibratory solution behavior depends largely on the coupled interaction between rolling stock, rail, fastening system and soil. Solutions showing high vibration isolation properties for a combination of rolling stock and soil could potentially work badly when changing some critical parameter. Unlike the noise case, it is extremely expensive to modify the vibration transmission impedance and obtained efficiency is strongly frequency dependent. Taking into account all these facts, it becomes necessary to face the problem and to address the solution for railway vibrations.

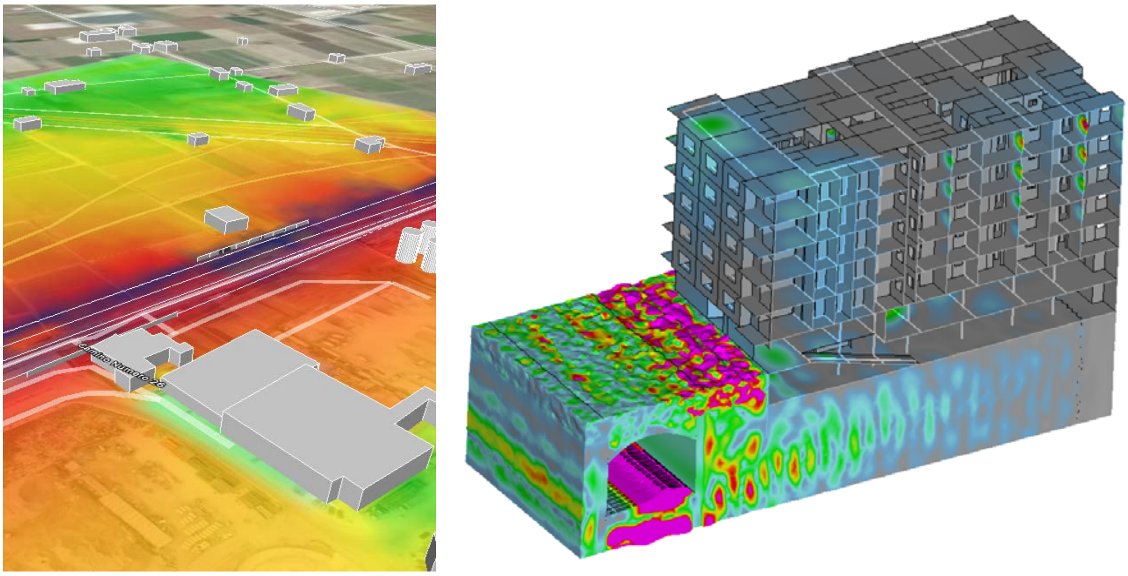

Figure 2 – Results coming from noise calculation commercial tool (left hand) and tunnel – terrain – building vibration propagation FEM model developed by SENER (right hand)

3 Strategic Vibration Maps

As in noise case, Strategic Vibration Maps would constitute a power tool for assessment, predicting and action planning. As commented before, a lot of obstacles bock the development of a consensus methodology for strategic vibration mapping for railway infrastructures. Strong differences between prediction approaches lead to use different input data and therefore results are hardly comparable. Moreover there is no consensus about the European standard vibration indicator. Action planning will require some kind of anti-vibratory toolbox which efficiency could be predicted accurately.

3.1 Input data

Input data depends strongly on the prediction model typology. Standardized noise prediction models require only a few parameters. These are, for noise source definition, train type selected from an internal and limited library and traffic for each period. For propagation and reception only atmospheric and absorption parameters are needed.

Even the most simple vibration generation source model requires a large amount of input data. Most theoretical models require data about unsprung mass and equivalent mass and stiffness for rail, rail pad, sleepers and sleepers pads and in some cases, roughness profile for rail and wheel[13-15] (as seen in figure 3).

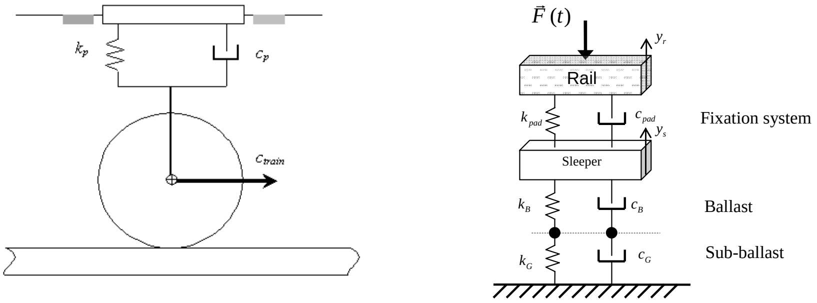

Figure 3 – Typical wheel-rail contact model which uses rail and wheel roughness profile as input (left hand) and 3 degree-of-freedom superstructure vibration model (right hand)[15]

Assembling complex propagation analytical and numerical models (as seen in Figure 4) require information regarding soil layers mechanical properties (density, elastic modulus, Poisson's ratio, damping loss factor) which are commonly available from trial excavations, or from literature in early project phases. As an alternative, empirical models can be assembled from data retrieved in test fields as SAWS (see Figure 5). Finally, reception phenomena reproduction requires performing ground-foundation-building coupled modeling. These models are feed up with information regarding dimensions and mechanical properties for foundation, structure and floors[16-19] (see Figure 6).

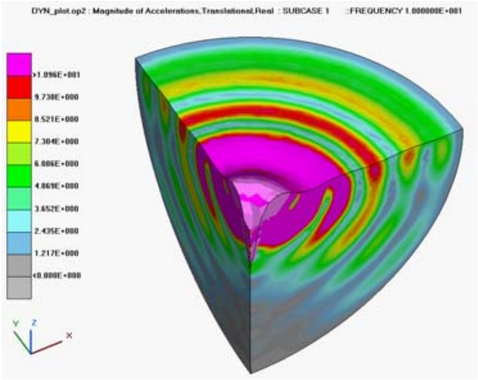

Figure 4 – FEM vibration propagation model

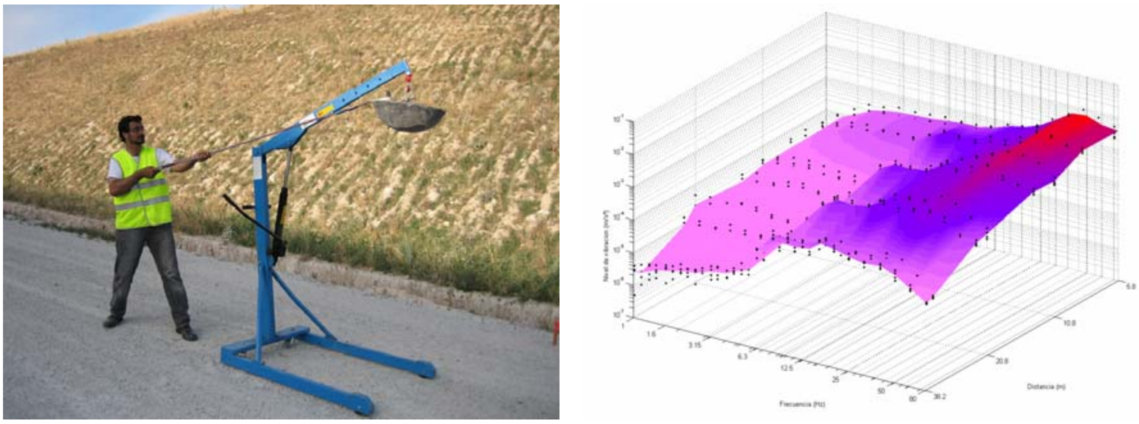

Figure 5 – Impactor developed by SENER (left hand) and ground vibration propagation results from SASW (right hand)

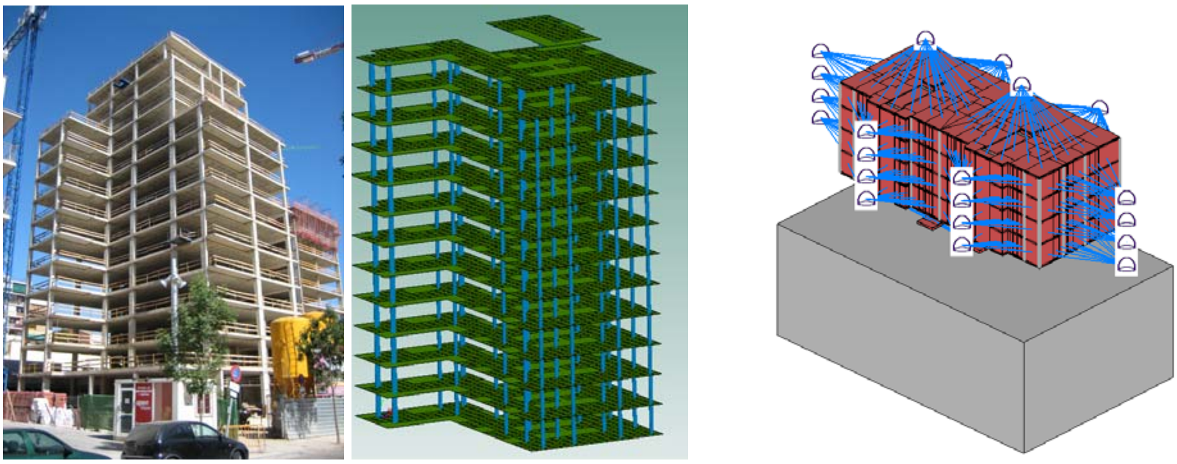

Figure 6 – FEM-SEA hybrid vibration model[19] (left hand) SEA predicting model (right hand)

As in noise case, it should be possible to develop some simplified standard calculation method and define some kind of library of equivalent train sources and a series of standardized ground typologies which could provide with average accuracy predictions. These kinds of results would allow performing both strategic vibration mapping and action planning and could constitute a really useful first iteration in the evaluation of the affected areas for new railway lines.

3.2 Vibration evaluation

As stated before, main noise impact indicators and corresponding legislation takes into account dose influence. Vibration impact indicators usually focus only in maximum values and therefore traffic influence is neglected. Many vibration indicators, such as root-mean-square acceleration, Vibration Dose Value (VDV) and maximum transient vibration value (MTVV)[20] consider exposure time defined as "duration of the measurement". Additionally vibration effects on health are analyzed commonly only for high-intensity long-term (workday) vibration exposure for labor protection purposes. As in noise case it should be necessary to define some equivalent day-evening-night dose-value indicator which could help to define assessment vibration maps for long-term (whole year) affected people quantification. An equivalent $L_{aw\ den}$ including period weighting would do the work but a large consensus has to be reached before getting a definition.

Moreover since vibration spreads much less than noise, it is possibly not valid to consider all the population living in all floors of a building as affected from the same vibration impact level. Consequently it would be necessary to define a criterion for vibration level assign. Standardized floor vibration attenuation could constitute a way to perform the calculation in a simple but realistic way.

3.3 Action planning

Vibration reduction solutions are commonly extremely costly. Most common actuations over source include wheel and rail maintenance procedures but actual vibration generation reduction requires taking into account the complete train-superstructure coupled behavior. In noise it is possible to reduce transmitted noise by means of screens. Vibration transmission reduction is not straightforward since vibration barriers behavior is strongly frequency-dependent. Realistic action planning would require strong collaboration between national and local authorities and railway managers.

4 The CATdBTren project

The CATdBTren project deal with the problematic related to vibrations generated by railway infrastructures and affecting its surroundings. The project is aimed to reduce the vibrational impact due to train pass-by by means of expanding the current know-how, which will include, among others, to perform measurement campaigns, the development of prediction models and the design of new anti-vibration fastening systems. Members of the CATdBTren consortium provide with the infrastructure required for carrying out the project including facilities, laboratories, test benches (see Figure 1), rail tracks and a high qualified group of researchers from R+D departments.

The first stage of the project comprises the creation of models to reproduce the three steps of the vibration phenomenon: generation in the railway track, transmission through the ground and propagation in buildings. Analytical, semi-empirical and numerical models (see Figure 6) are performed in order to enhance the understanding of the vibration behaviour of each individual element. Finally these sub-models will allow to assemble a complete model to estimate the influence of all the involved parameters (rolling stock, rail and wheel roughness, fastening system, substructure, soil propagation properties and building characteristics) in the final vibration impact.

Figure 6: Test rig (left hand) and floating slab system FEM model (right hand)

Empirical tests within controlled environments (test rig) and real on-site testing (railway infrastructure, see Figure 7) are carried out in order to validate theoretical results. A wide scope of data is achieved by means of measurements in rail, ground and building in a large set of locations including underground, conventional and high-speed lines. Finally, a predictive software will be achieved. This tool will allow public administrators and companies the prediction of vibration impact produced by any type of railway construction work in early project stages and analyze expected results when modifying already existing ones.

The CATdBTren project is aimed to develop a prediction tool allowing the evaluation of the vibration impact for new railway infrastructures. This software will include models of contact forces caused by high-speed, conventional and underground rolling stock. It will be able to reproduce infrastructure vibration transmission behaviour, ground vibration propagation, terrain-foundation coupling and building vibration behaviour. Thus, the CATdBTren prediction tool will estimate the influence of the rolling stock, rail and wheel roughness, fastening system, substructure, soil propagation properties and building characteristics, all in the final vibration impact. This tool is intended to be user-friendly and to produce results with average accuracy, so detailed studies of problematic areas will still be required.

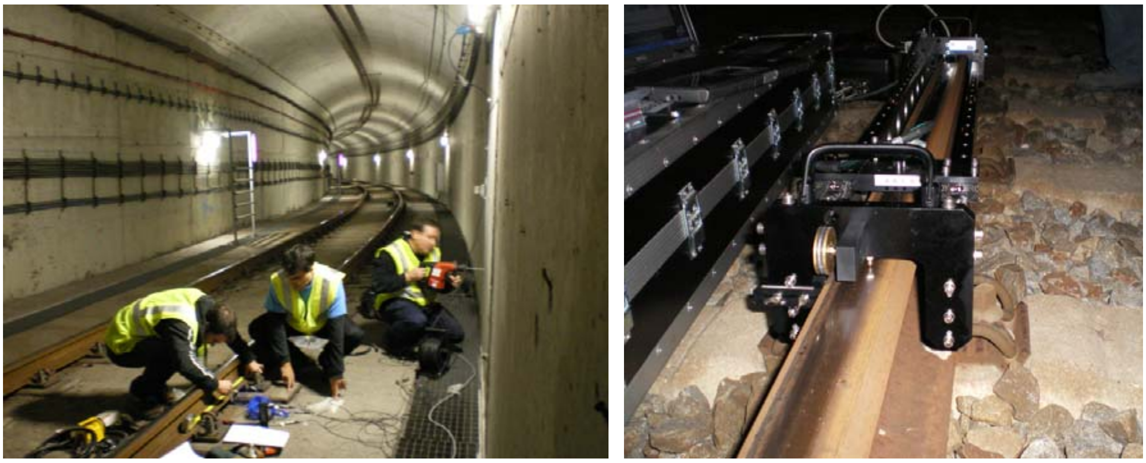

Figure 7: On-site acceleration measurements (left hand), roughness rail measurements (right hand)

The CATdBTren project is carried out in the 2008-2010 period. The word CATdBTren is composed by three concepts: “Catalonia”, “vibrations (in dB)” and “Train” in Catalan language. Three prestigious companies, SENER, Railtech and Quantech, used to work together in several noise and vibration projects and the Spanish Railway Cluster compose the CATdBTren consortium. SENER, the largest multidisciplinary private engineering company in Spain with workplaces around the world is the main member of the project and the leader member. Their Noise & Vibration Technical Department is a well-known reference in automotive, aeronautics, marine, energy, civil, and railway fields. Railtech is an expert European company for design and manufacture of track and anti-vibratory solutions. Quantech is a spin-off company from the UPC (Universitat Politècnica de Catalunya). Its area of expertise is the development of CAE software. Railgrup is the Spanish Railway Cluster. It counts with over 90 member companies including public administrators, universities and research centres, operators, rolling stock and track manufacturers and logistic, transport, civil engineering and consulting companies. Its main objectives are to coordinate certification, commercial and research activities and promote the technological innovation. The two main Catalonian Railway operators, TMB and FGC, collaborate actively in the CATdBTren project. The Acoustic and Mechanical Engineering Laboratory (LEAM) of the UPC and the Technological Centre of Manresa (CTM) collaborate also as research centres. CDM, Gerb, Getzner and Rockdelta and others anti-vibratory solutions manufacturers have also provided with their expertise in the field and with a large amount of valuable technical data.

5 Conclusions

The railway vibration problem has been addressed in the past in a series of different complementary approaches. A lack of common framework and the different solution development methodologies difficult standardization and at this point it remains impossible to see a clear convergence between them. Some consensus has to be reached before all European Members can claim for some kind of European Vibration Directive which could guarantee a common protection frame against railway vibration pollution.

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