VIBRATIONS GENERATED BY RAIL INFRASTRUCTURE

Acoustic & Vibration Engineering Services

”Far better an approximate answer to the right question, which is often vague, than answer to the wrong question, which can always be made precise”.

John W. Tukey

Right questions lead to right answers

“I am not bound to swear allegiance to the dogmas of any master”.

Horace

The good thing of a problem without an obvious solution is the pleasure in finding it

“I support that symbiogenesis is the result of a long time coexistence and that is main source of evolutionary novelty in all superior non-bacterian organisms”.

Lynn Margulis

Fluent communication is the key to progress

Railway experience

Ingeniería para el Control del Ruido (ICR) is a company located in Barcelona dedicated to solving noise and vibrations problems. Founded in 1995 by professionals with more than 20 year of experience in the field of vibro-acoustics, ICR offers recent analysis methods for railways, automotive, wind power, industry and civil engineering sectors.The company's goal has always been to offer the right and most efficient solution for each vibro-acoustic problem.

ICR has taken up a relevant position in the international railway sector over the last decade thanks to the trust placed by the main European infrastructure constructors. The reason behind this success lies in the working methodology which is based on:

- Specific forecasting techniques.
- Real measurements to minimise theoretical speculations.
- The airborne and structural noise treatment of each element going to make up a coach.
- Very short response times.
- Prices in line with the market.

Most of ICR efforts have been focused on R+D, with the objective to develop new predictive and analysis methods.This company innovative profile has allowed ICR totake part in numerous highly technological projects, both national and international. In some cases, these projects were focused on a technology transfer from ICR to the main European rolling stock manufacturers. ICR compromise as vibro-acoustic expert is to propose the adequate solution for each problem of noise and vibration.

ICR provides various standardised predictive studies in the railway sector:

- Design of anti-vibrating solutions for railway infrastructures.
- Prediction of vibration levels for different railway track support types and topologies.
- Squeal noise prediction.
- Noise certification tests in accordance with the Technical Specification for Interoperability (TSI).
- Track roughness measurements (rail irregularity) and the characterisation of the dynamic behaviour of the track in accordance with ISO 3095.
- Prediction of compression wave generated by a high-speed train entering a tunnel.
- Analysis of the noise and vibration transmission paths (ATPA: Advanced Transfer Path Analysis Method). This specific ICR method allows an improvement in the interior acoustic comfort of a train.
- Environmental impact studies for railway infrastructures (train, underground and track) at the works' stage (infrastructure construction) and at the service stage (infrastructure operation):

    1. Vibration impact: study of vibrations and their propagation via the site to the sensitive areas.
    2. Acoustic impact: noise study.

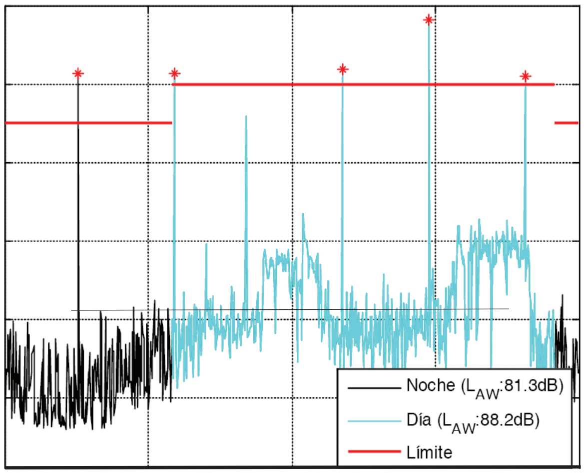
The company's goal has always been to offer the right and most efficient solution for each vibro-acoustic problem.

Background

Over the last decade the railway sector has undergone considerable growth worldwide both in terms of infrastructure investment and development. This speedy progress in the sector has resulted in an increase in the number of railways and in the urban and suburban train frequency. By contrast, new environmental contamination problems have arisen deriving from the vibrations caused during the layout works' stage and the service stage with the rolling stock in circulation.

Anticipating and predicting these vibrations in the field is one of the aims of ICR to enable the client to optimise the projected layout and apply the construction solutions required with a view to avoiding vibrations which are harmful to the neighbourhood and the integrity of the buildings near the track.

Vibration prediction at the service stage.



Graphic results of vibration measurements during the construction phase.

The environmental impact studies developed at the railway infrastructure (train, underground and tram) are divided into two differentiated stages:

- Vibration control at works' stage. The objective is to control the vibrations which the construction and the works may cause to the acoustic comfort of the neighbourhood and the integrity of the buildings nearby. The control of these vibrations is carried out bearing in mind the standards in force and the demands of the client.

- Vibration forecast at service stage. The goal is to analyze the propagation of vibrations at the site caused by the circulation of railway infrastructure on the track.

Both studies are developed considering current regulations and client demands.

Anticipating and predicting vibrations at the site is one of ICR aims in this field to allow the client to optimise the layout and apply the construction solutions required.

Vibration control at works' stage

During the vibration control phase at the works' stage (infrastructure construction) ICR pay special attention to the vibrations caused by the construction works, the earthworks or the tunnellers with a view to examining their incidence on the acoustic comfort of the neighbourhood and the integrity of the nearby buildings. These control studies are carried out according to the specifications laid down by the current standards or indicated by the client with the goal to evaluate their compliance.

The great variety of tools and study methods available at ICR, enables the company to adapt to the client's needs at any time and propose the study type which best suits each situation. This is why ICR provides control measurements uninterruptedly or control measurements on an occasional basis by sending an expert to the site.

The control measurements carried out uninterruptedly take place for a variable time period in line with the requirements of each study type (e.g.: 1 month, 2 weeks etc.). These measurements are carried out in accordance with the specific requirements or standards of the client at the pre-defined checkpoints. During this time ICR draws up results' reports as frequently as suits the characteristics of each study or client's necessities.

Concurrently, ICR generates control alarms via e-mail or SMS to provide information about vibration levels higher than those set initially. In this way the client discovers in real time whether the works undertaken fall between the limits defined.

Another study alternative is to send an expert to the site where the works are carried out. By means of the appropriate measurement equipment, are carried out personalized vibration measurements following the specifications indicated by the standards or the client. This study type allows to obtain an immediate feedback and greater flexibility when defining the checkpoints thanks to the presence of a technician on site.

ICR vast experience in this field and the availability of a multitude of vibration measurements methods and tools enables the company to offer very competitive prices adapted to the client daily reality.

ICR provides vibration control studies at the works' stage at very competitive prices adapted to the client daily reality.

Study of vibration to assess the integrity of the nearby buildings.

Vibration prediction at the service stage

In studies about the vibrational level generated by the circulation of rolling stock, ICR carries out several measurements and simulations with the objective to predict vibrations before defining the layout or once defined.

The aim is to apply the construction modifications required to comply with the standards in force. ICR thus controls the site vibrations from the track to the critical zones.

The vibration propagation studies developed on the site are divided into four main stages:

- Stage 1: preliminary site study.
- Stage 2: characterisation of the excitations.
- Stage 3: determination of the site propagation characteristics.
- Stage 4: calculation layout as a whole.

Stage 1: preliminary site study

During the preparatory stage ICR identifies the sensitive points and defines the nuisance limits in conjuction with the client.

For the identification of the sensitive track zones, ICR divides and categorises the layout into various zone types in line with the presence of sensitive buildings and dwellings near the future track.

The definition of the nuisance criteria is carried out in conjunction with the client based on a study of the risk standards for building integrity, vibration comfort or the limits of human perception.

Rolling stock at the service stage.

Stage 2: excitation characterisation

At this stage ICR is aiming to characterise the source of vibration by means of measurements on the surface, on the subsoil of the site to be studied or by means of numerical simulations.

Stage 3: determination of the site propagation characteristics

ICR offers two study alternatives:

1. SASW (Spectral Analysis of Surface Waves): measurement of the dynamic characteristics of the various site layer stages for subsequent modelling based on the numerical methods of and the infrastructure to be set up thereat.

2. The empirical method: measurement of attenuation as regards the propagation of vibrations from the railway infrastructure to the predefined sensitive points.

The first study allows defining the dynamic characteristics of the site and the second measures the propagation of waves via the site.

1. SASW method

The SASW method (Spectral Analysis of Surface Waves) is a vibrational analysis technique which allows the dynamic characteristics of the site to be identified in line with measurements at the surface and the static physical parameters (taken from the site geotechnical study). The parameters obtained by this method determine the dynamic behaviour of the ground and thus enable to predict the propagation of the vibrations on the site and their incidence on the nearby structures.

By quantifying all these parameters it can be draw up a numerical model to predict the propagation of the vibrations at the site:

- Finite Element Modelling (FEM).
- Boundary Element Modelling (BEM).
- Rayleigh's analytical propagation models.

> The SASW method allows the identification of the dynamic characteristics of the site.

What does it calculates?

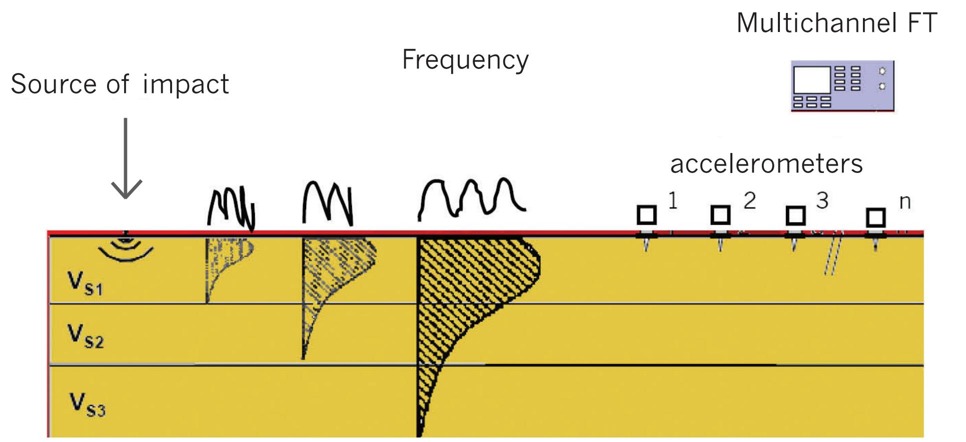
Originally, the method was designed to determine only the elastic modulus of the different site layers but the separate damping evaluation was subsequently added. Consequently, the SASW allows the simultaneous determination of the elastic modulus and the coupled damping.

SASW technology determines the shear wave propagation speed and the associated damping for each of the layers impacting propagation. Concurrently, is used the Nakamura method, which allows the determination of the depth required for the numerical model. The number of layers to be studied, in other words, the site depth, will depend on the frequency range to be borne in mind in the future model.

How does it works?

Vibration studies using the SASW method are carried out by measuring the accelerations in a vertical direction at various points distributed along a straight line.

The excitation source is sited on the same line. Finally, the propagation speed profile is obtained in line with the site depth.



Excitation at one point and vibration response measurements at various points (surface wave).

2. Empirical method

The empirical method, based on the FTA manual (US Federal Transit Administration) about the noise and vibration environmental impact study is a vibrational analysis methodology which allows a site to be characterised in purely experimental way. In other words, it allows to know propagation of the direct and indirect vibrations on the site when a force is applied at a given checkpoint.

The empirical method is based on carrying out mobility measurements to predict vibration propagation from the point where the future vibration source will be located (the railway infrastructure) to the checkpoint. The force is applied at the same point where the railway is expected to pass.

This work procedure allows:

- Data to be obtained about the vibration propagation from the track to the sensitive points.
- When the number of sensitive points to be studied is low and the sitings are easily identifiable, this is an economical solution.

How does it work?

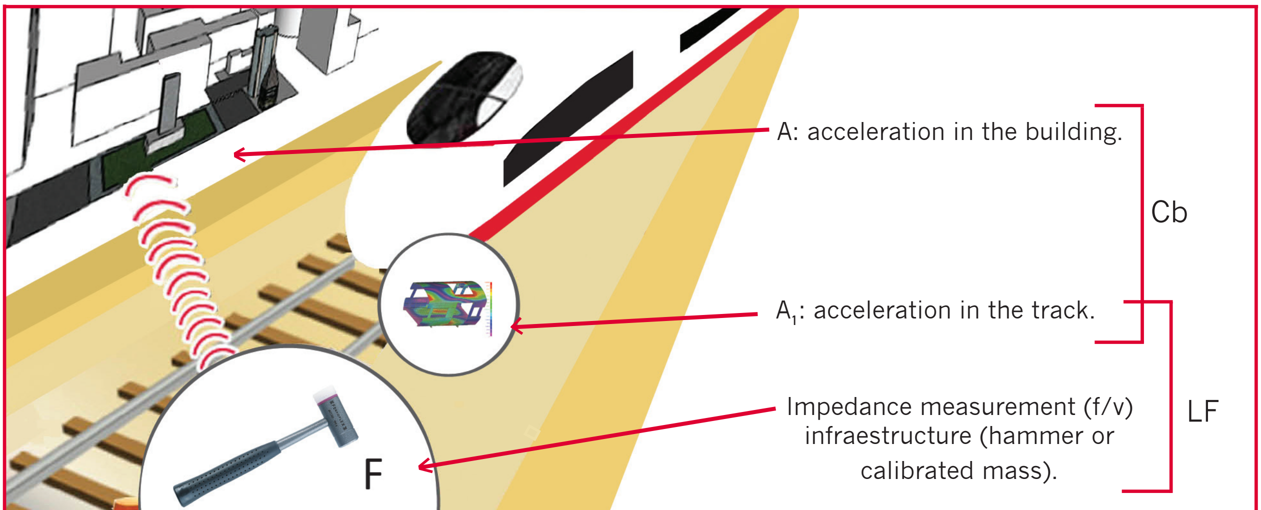
Method operation is expressed by means of the following formula:

$$\boxed{Lv = LF + TM + Cb}$$

where:
Lv: vibration level at a sensitive point.
LF: force applied by the train at a crossing point.
TM: mobility transfer function of the linear source from the tracks to the sensitive point. This function expresses the ratio between the entry force at the site and the vibration at the sensitive point.
Cb: adjustments to take into account the interaction between the site and the buildings and the attenuation or amplification of the vibration amplitudes propagated through the buildings.

To obtain the real force applied by the circulation of the train, ICR provides two possible study methods:

- Simulations with a model of the train and using the ICR data base on rolling stock.
- Measurements with rolling stock with the same or similar characteristics.



Study of vibration by empirical method.

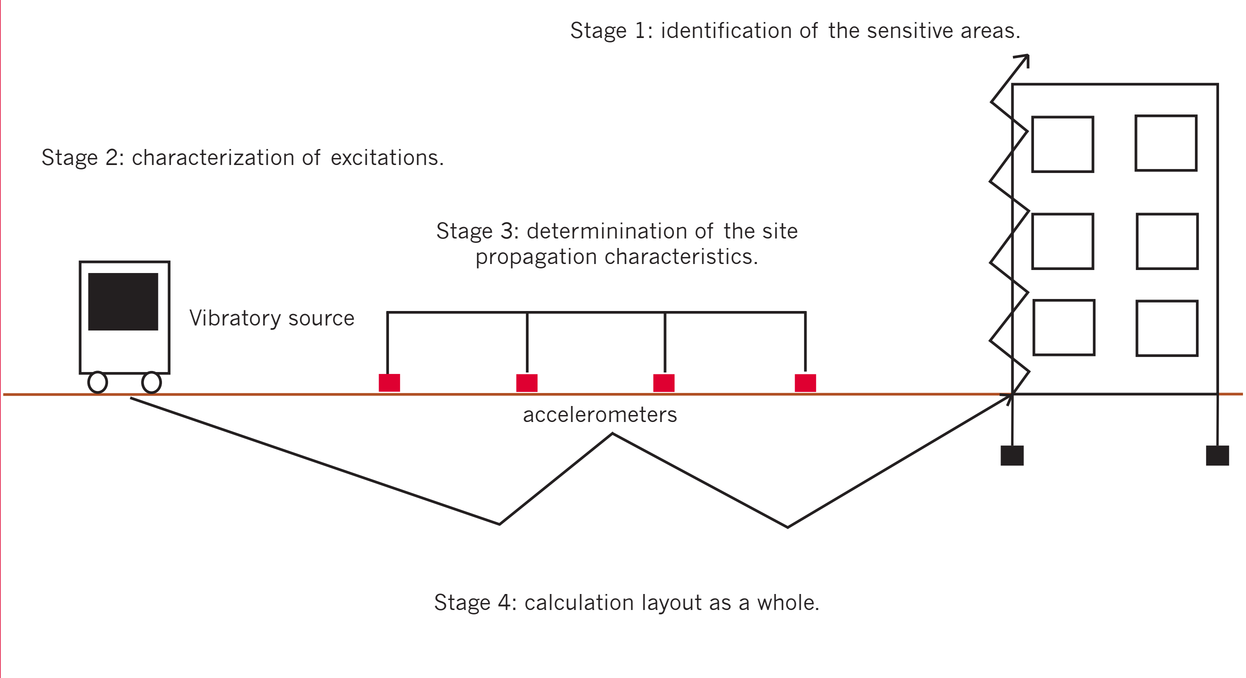
Stage 4: calculation layout as a whole

At the final stage of the study it is desired:

- To estimate, through calculation, the vibrational levels on the layout as a whole.
- To provide recommendations about the anti-vibrating support system to be installed at the critical areas.
- To minimise the length of the anti-vibrating supports' installations in the layout as a whole, respecting the nuisance levels defined at stage 1.

To this end the vibrational levels will be estimated at the base of the buildings and in their interior based on:

- The source of vibration (rolling stock) characterized at stage 2.
- The type of supports on the track assembly.
- The characteristics of the vibration propagation on the layout.



Study of vibration during the service stage.

EXPERIENCE

Control and prediction of vibrations in rail infrastructure projects

- Vibration control generated by the works at Sagrera on the AVE (high-speed train) stretch. Acciona Infraestructuras.
- Vibration control produced inside Farmahispania, S.A. factory because of Ferrovial Agroman, S.A. works on the AVE stretch in Montmeló.
- Control and monitoring of the vibrational levels inside an industry generated by the AVE works at the industrial estate Pla sota el Molí in Barcelona. Confidential client.
- Vibrational levels control at line 9 of Barcelona underground works. GEOCAT, Gestió de Projectes S.A.
- Study of vibration on a stretch of the AVE (high-speed train) line Valladolid - Burgos in Contreras (Burgos). Ineco Tifsa.
- Study of vibration during the works on line 9 of the Barcelona underground. Entorn S.A., Enginyeria i Serveis.
- Study of vibration on line 9 of the Barcelona underground. UTE Gorg.
- Weekly control of the vibrations generated by a tunneller on stretch 3 of line 9 of the Barcelona underground. Entorn S.A., Enginyeria i Serveis.
- Acoustic impact study caused by the passing of the high-speed train (AVE) through the Guadarrama mountain range (Segovia - Soto del Real stretch). Forecast noise levels, pressure pulse at tunnel entry, acoustic impact of the tunnel and track construction works and proposal of solutions. Inimasa.
- Acoustic impact study due to the vibrations generated by the circulation of the train near NorControl industrial plant premises in Tarragona.
- Environmental impact study due to a new tram system in the Camp de Tarragona. Auding Intraesa.
- Analysis of vibration generated by the circulation of AVE in the vicinity of the future Borges thermosolar plant and development of a predictive model by Finite Element Modelling (FEM). Abantia and Comsa Emte.

Other projects of control and prediction of vibrations

- Vibration measurements at the base of the facade of a dwelling near the client works for a 5-day period. Barcelona. ACSA Sorigué

- Occasional control of the vibrational level caused by site drilling at a works located in front of Industria Indukern in Prat de Llobregat, Barcelona. Paymacotas.

- Vibration measurements in the subsoil and forecast environmental impact by means of vibration propagation model and calculation of the vibrating environmental impact at the Montflorite airport works. Project ZIMA-041189-ES with award no.041190. Ineco.

- ALBA del Vallès synchrotron project: tests and vibration prediction at the site using the SASW method and Finite Elements Modelling (FEM) to determine the structure required to install the Critical Slab and comply with the vibrational specifications. Determination of the site constants for drawing up a numerical model capable of foreseeing the behaviour of the critical zone compared with the site vibrations. ALBA del Vallès synchrotron Project, Máster Ingeniería S.A.

ICR

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