GOBIERNO DE ESPAÑA
MINISTERIO DE FOMENTO
MINISTERIO DE AGRICULTURA Y PESCA, ALIMENTACIÓN Y MEDIO AMBIENTE
CEDEX CENTRO DE ESTUDIOS Y EXPERIMENTACIÓN DE OBRAS PÚBLICAS

C4R Capacity for Rail

Activities of the Laboratorio de Geotecnia – CEDEX in Railway Engineering

- **Fernando Pardo de Santayana**
- **José Estaire Gepp**
- **José Luis García de la Oliva**

Laboratorio de Geotecnia – CEDEX
Madrid, Spain

Madrid, 22 – September - 2017

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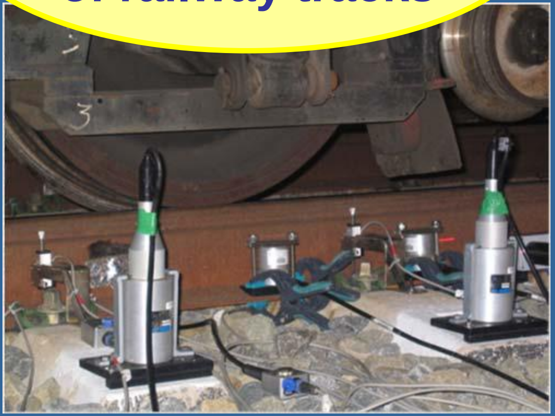
C4R Capacity for Rail

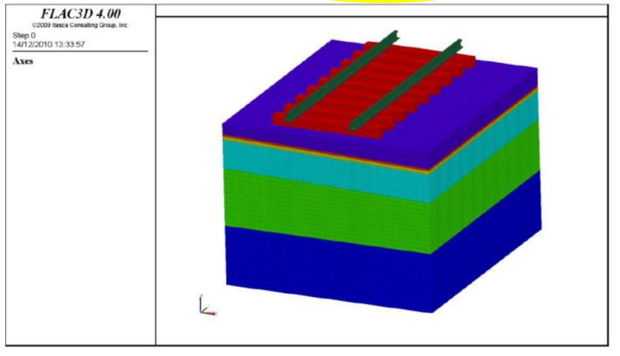
Fields of activity

1 **1:1 scale tests performed in CEDEX Track Box**

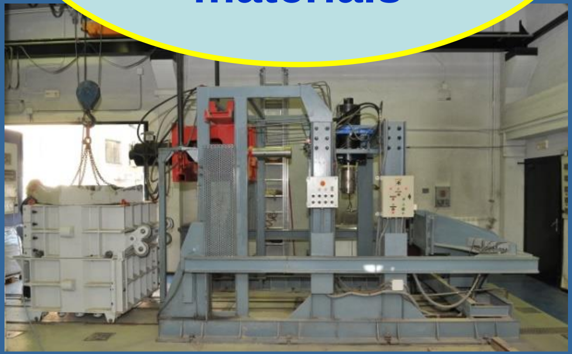
2 **In-situ instrumentation of railway tracks**



3 **Numerical analysis of railway tracks**



4 **Geotechnical laboratory tests of railway materials**



GERT
Geotechnical Engineering of Railway Tracks

Staff

Duties	1:1 scale tests performed in CEDEX Track Box	In-situ instrumentation of railway tracks	Numerical analysis of railway tracks	Geotechnical laboratory tests of railway materials
Direction	**José Estaire**	**José L. G. de la Oliva**	**Javier Moreno**	**Áurea Perucho**
Test design and interpretation	María Santana Inés Crespo Julián Valerio	Javier Moreno Ángel Tijera Rubén Ruiz	Pablo Mira Carlos de las Heras	José Estaire María Santana
Test execution	Juan L. Cámara Sagrario Merino	Pedro J. García José L. Amores	---- ---- '----	Mª Eugenia Martín Mauro Muñiz Rafael Rodríguez
Support to test execution	José M. Cerezo José L. Rocha Gema Villar	José A. Pintado Antonio Jiménez	---- --- ----	José L. Gómez Oscar Tello José L. Toledo
	1	2	3	4

CEDEX activity in Railway Geotechnical Engineering since 2002

- **Collaboration agreement between ADIF-CEDEX**
  - 2006-2009
  - 2010-2013

adif ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS

- **European Proyects in Framework Programme**
  - **5 FP: SUPERTRACK** *(2002-2005)*
  - **6 FP: INNOTRACK** *(2006-2009)*
  - **7 FP: RIVAS** *(2011-2013)*
  - **7 FM: CAPACITY 4 RAIL** *(2013-2017)*

SuperTrack

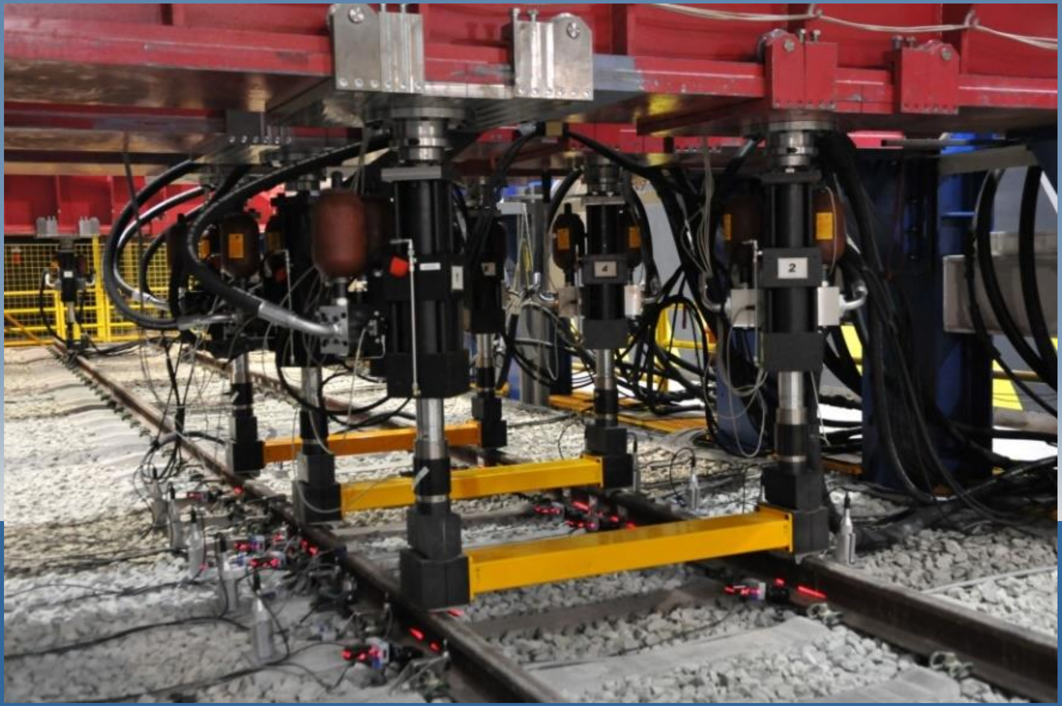
INNOTRACK Innovative Track Systems

rivas

C4R Capacity for Rail

- **Reports for other clients: UIC**; INECO; Acciona; Dragados; Sando

1. CEDEX Track Box (CTB)

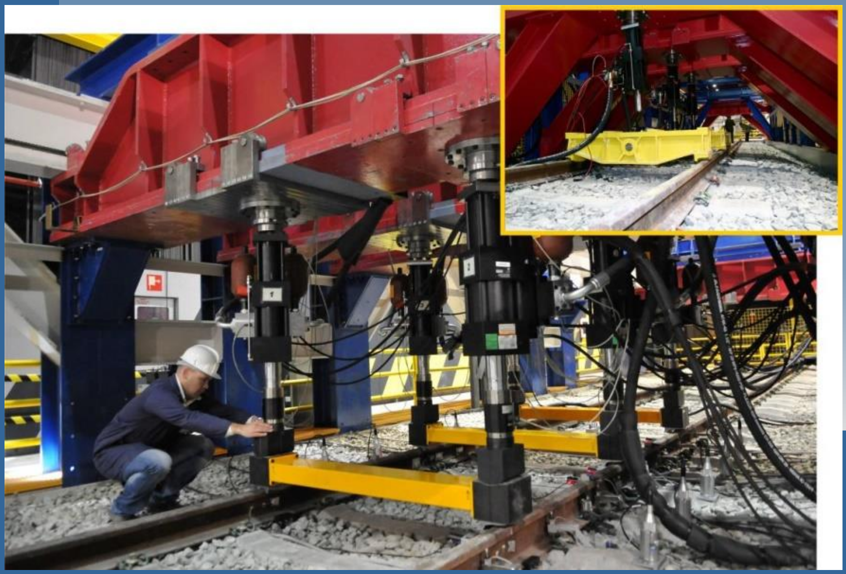


CEDEX Track Box

- Dimensions: 21 m long, 5 m wide, 4 m deep
- 3 testing zones of 7 m long
- Those dimensions makes it possible built 1:1 scale models of a complete railway track section

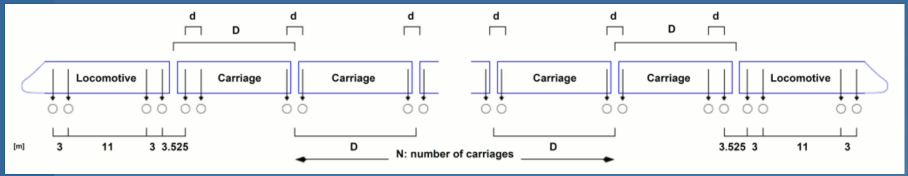
Load system

- Objective: Reproduction of the approaching, passing-by and departing of trains in a section
- Loads:
  - Applied by three pairs of servohydraulic actuators
  - 1,5 m longitudinally separated
  - Maximum load of 250 kN (frequency of 50 Hz)
  - Unphased in the three actuators
- Trains to be reproduced:
  - Conventional and High Speed Lines
  - Passenger, freight and mixed traffics
  - Speeds up to 400 km/h

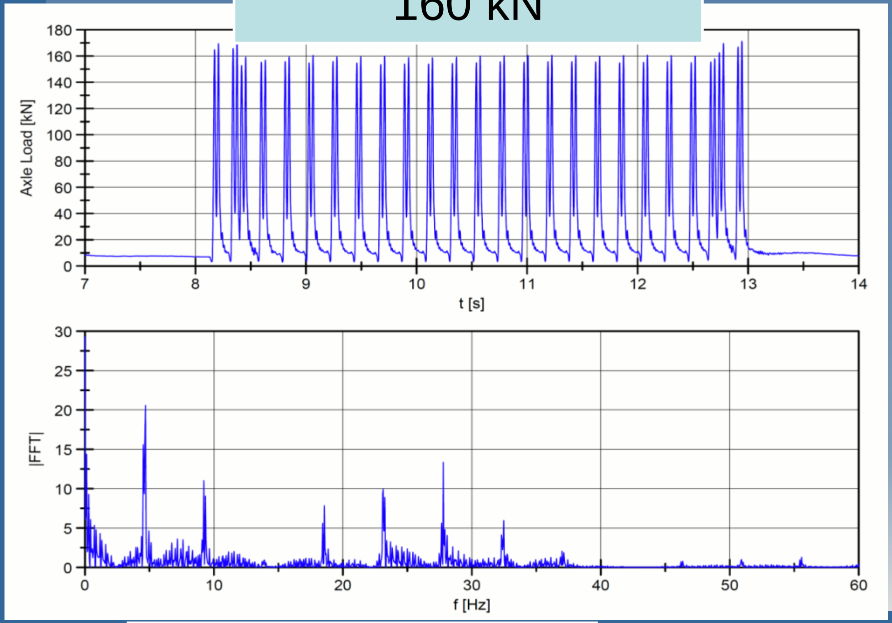


CEDEX Track Box

Eurostar passenger train with 2 locomotives and 20 bogie wagons

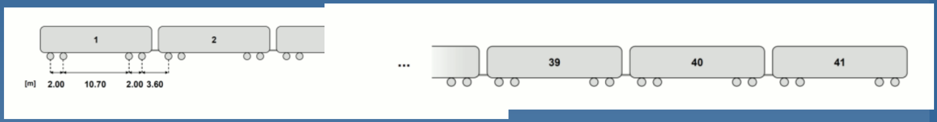


Maximum axle load:
160 kN

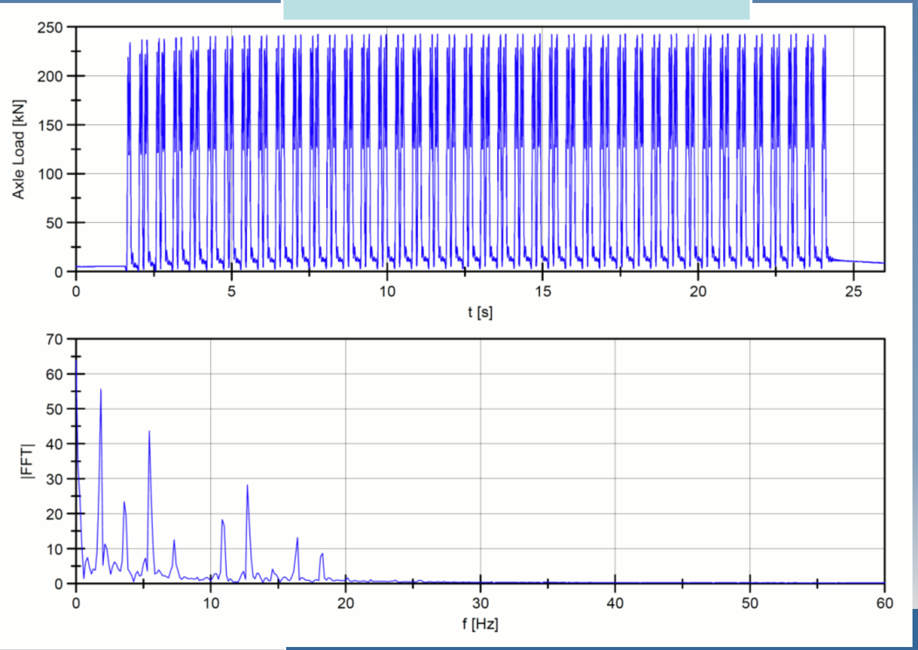


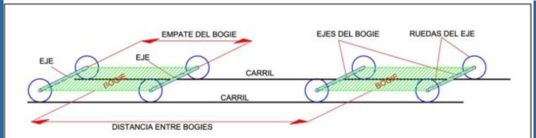
Frequencies
5 – 30 Hz

Freight vehicle with 42 bogie wagons



Maximum axle load:
225 kN



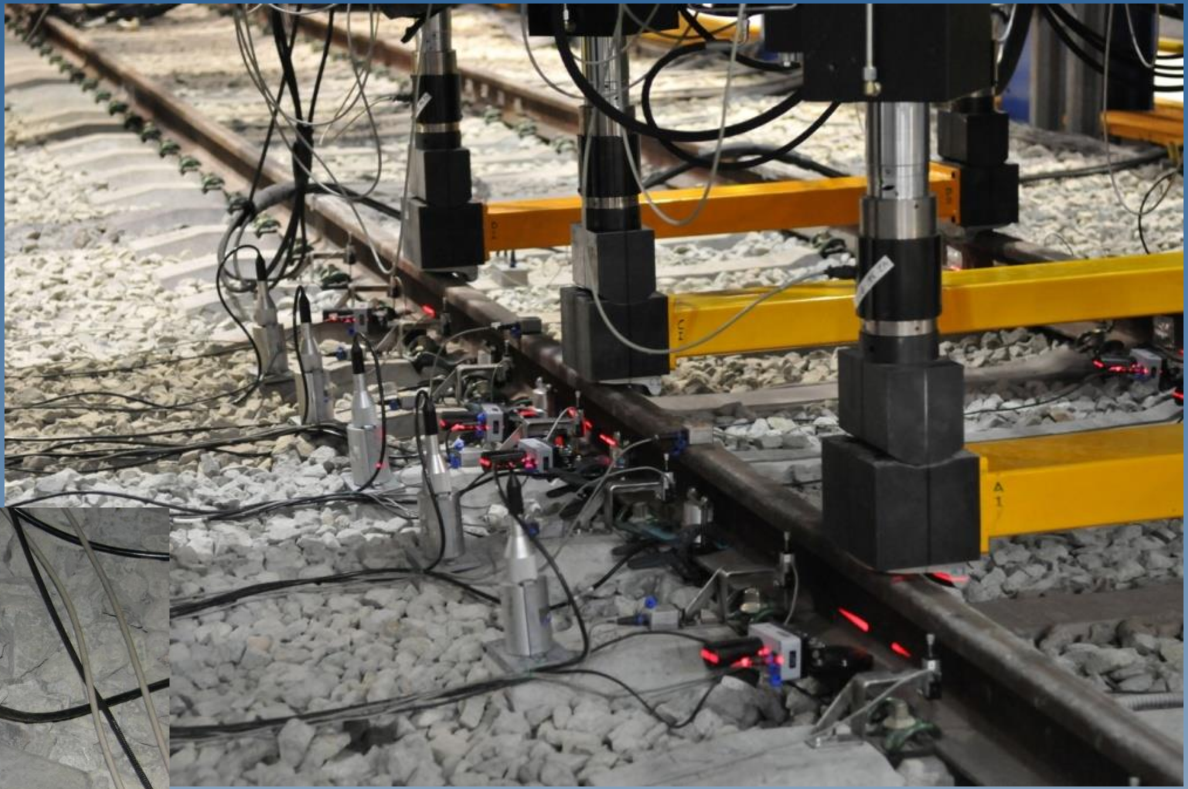


Frequencies
2- 5 – 12 Hz

Instrumentation: External sensors

For railway superstructure
- laser sensors,
- geophones and
- accelerometers

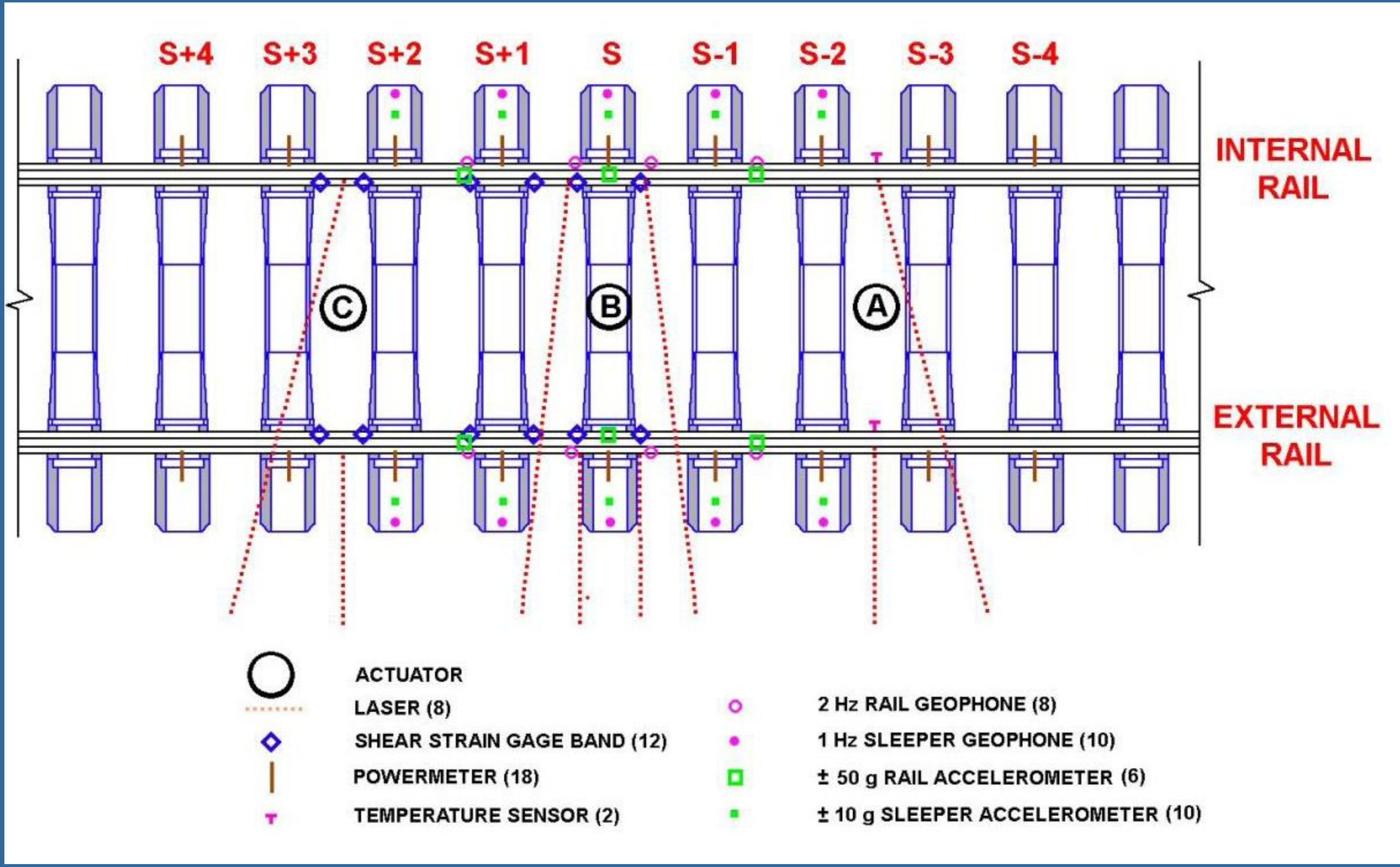
installed on the track components:
- rail,
- sleeper,
- railpad



Instrumentation: External sensors

Laser systems
Potentiometeres: rail-sleeper.
Geophones in sleepers and rails

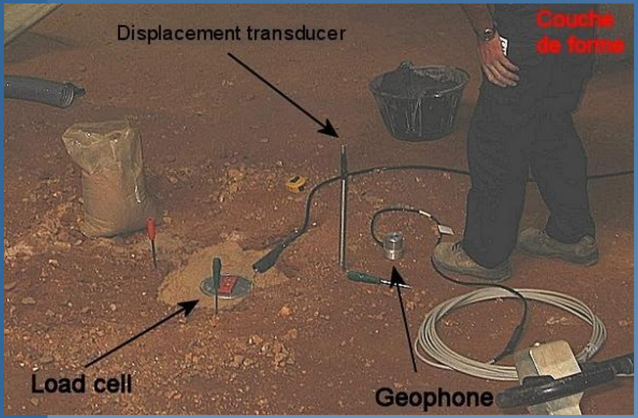
Accelerometers in sleepers and rails.
Strain gauges in rail.
Accelerometers in ballast particles

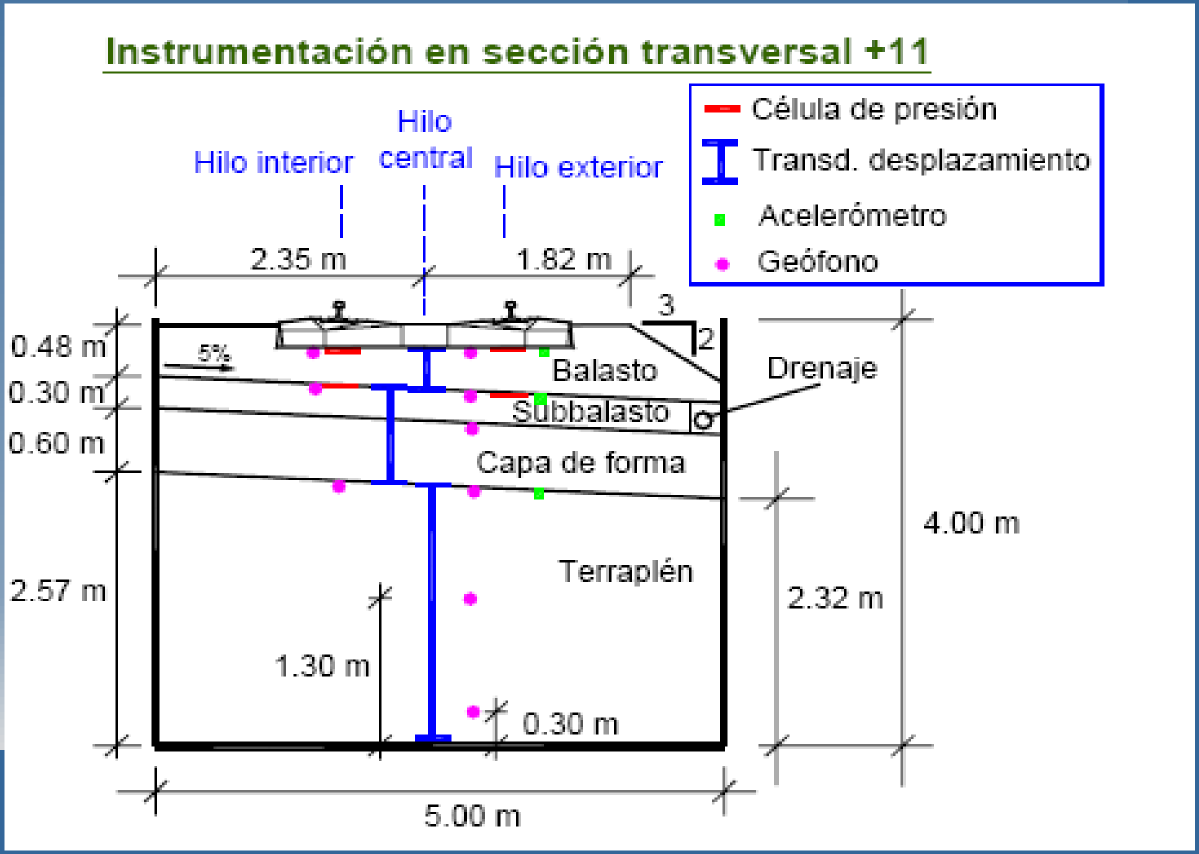


Instrumentation: Internal sensors

For track bed layers railway superstructure

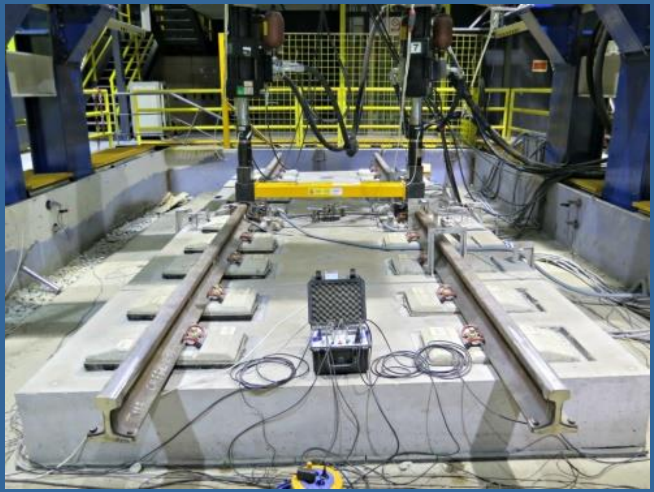
- Displacement transducers /Geophones / Accelerometers / Load cells





Applications: 1/1 scale model features

- Tests on **ballasted or slab tracks**.
- Tests on sections in **straight line or in curve**.
- Tests on **transitions zones**.
- Tests with **different kinds** of ballast, subballast, form layer or embankment.
- Tests with standard, polyvalent and three-rail **sleepers**.
- Tests with **new materials**: sleepers with USP, under ballast mats, artificial ballast, bituminous subballast, geotextiles and soils treated with lime or cement.

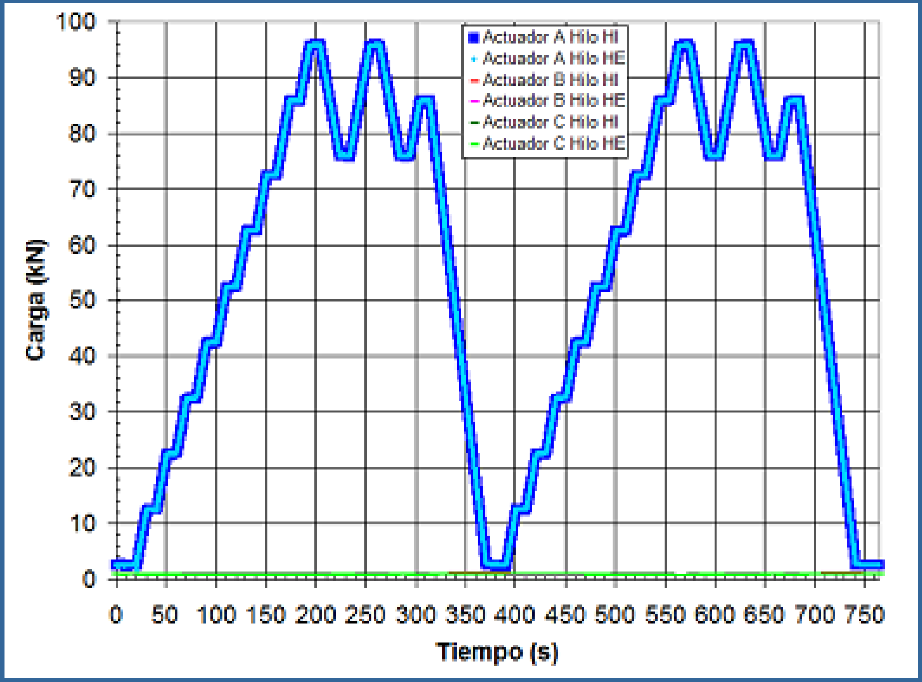


Applications: type of tests

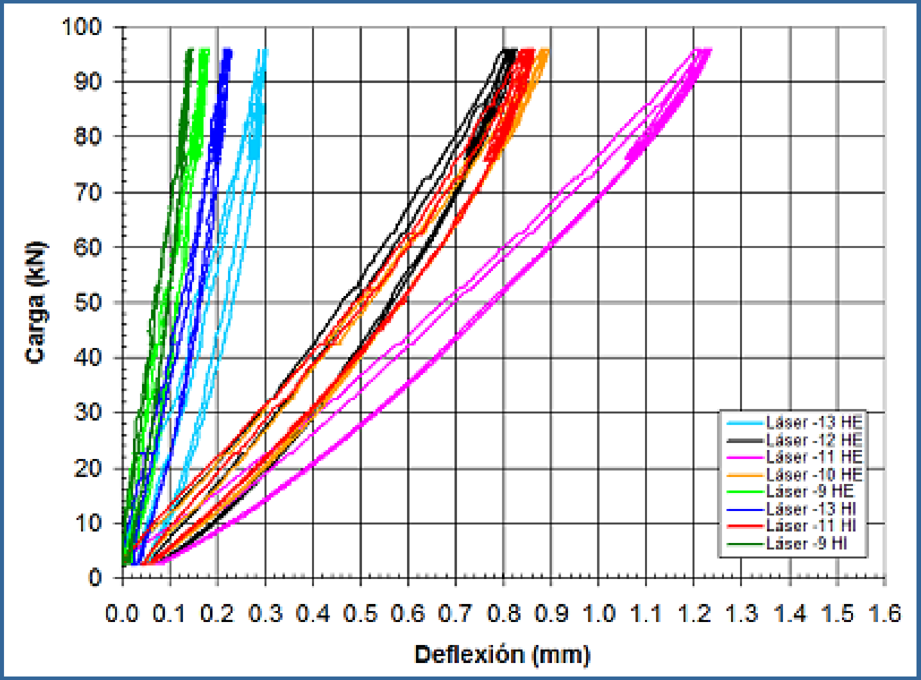
- Tests with **passenger and freight trains**.
- **Static tests** to determine track stiffness.
- **Quasi -static tests** to simulate the pass-by of trains at speeds up to 420 km/h.
- D**ynamic tests** to simulate the effects induced by track irregularities.
- **Fatigue tests** to determine the long-term behaviour of any track component by the simulation of pass-by of millions of axle trains.
- Tests on vibration propagation.
- Tests to determine the **lateral and longitudinal track resistance**.

Static tests

1.1 Measurement of track vertical stiffness: imposing static loads by the servohydraulic actuators.



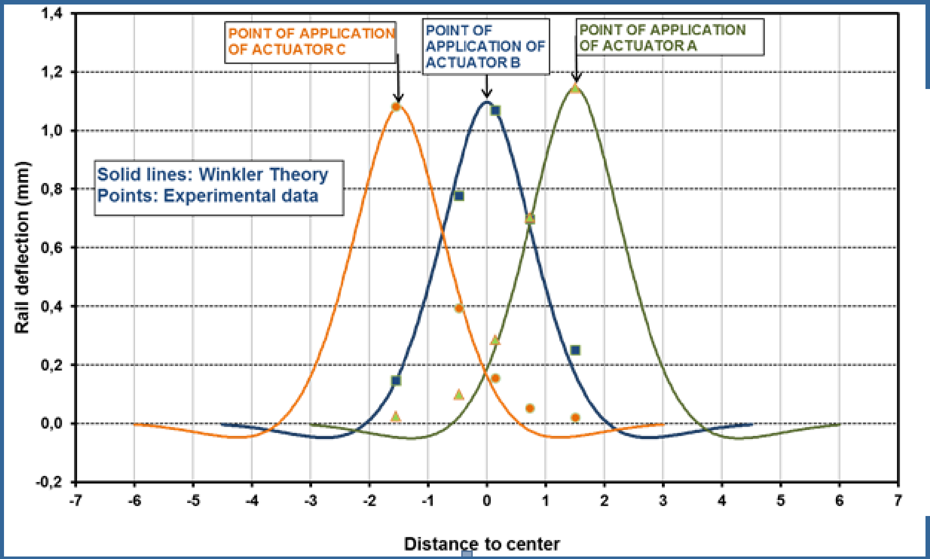
Time-load curve imposed

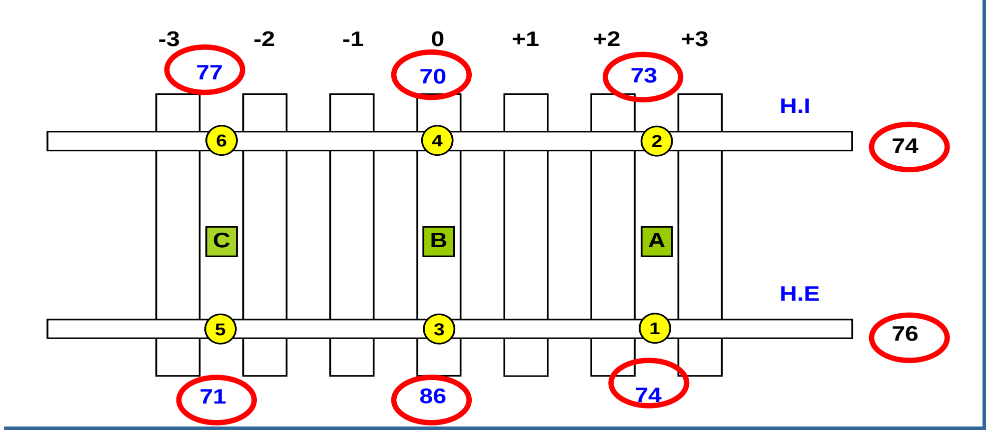


Deflection curve obtained

Static tests

1.1 Measurement of track vertical stiffness: imposing static loads by the servohydraulic actuators.





Rail deflection at different points during a set of static tests

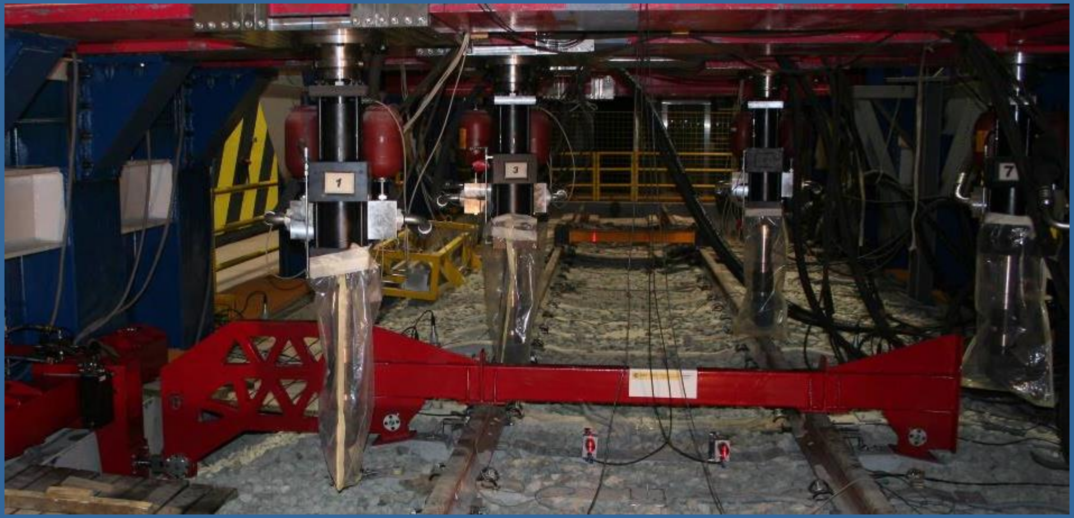
Blue values: Track stiffness (kN/mm)

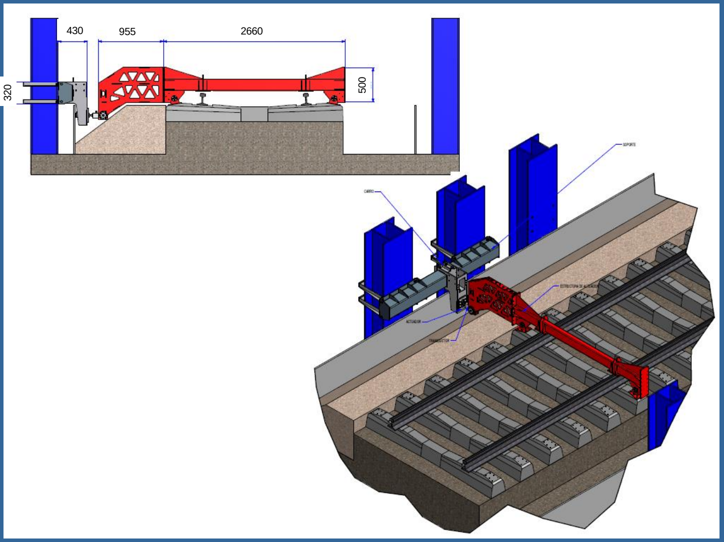
Interpretation: Winkler theory

$$\delta(x,t) = \frac{Q}{K}\, e^{-\frac{|x-vt|}{L}} \left[cos\left(\frac{|x-vt|}{L}\right) + sin\left(\frac{|x-vt|}{L}\right) \right]$$

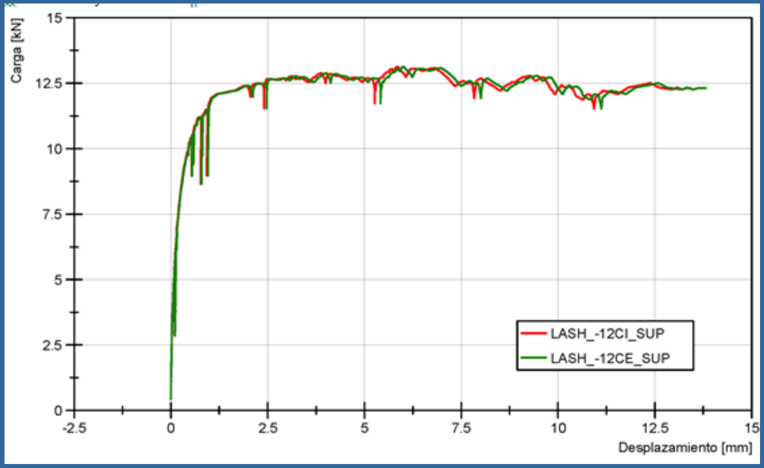
Static tests

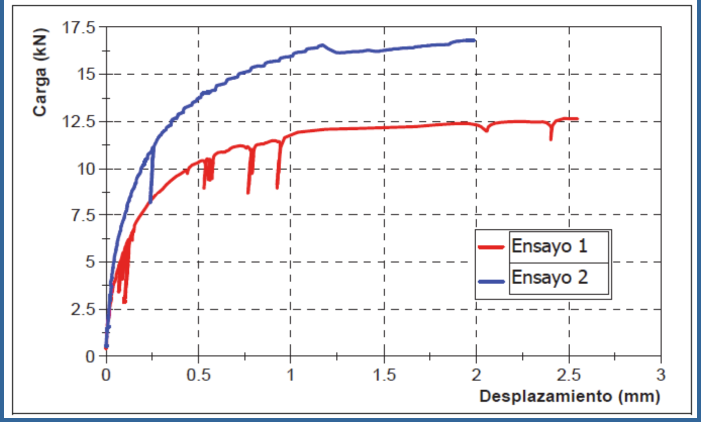
1.2 Determination of track lateral stability





Results obtained

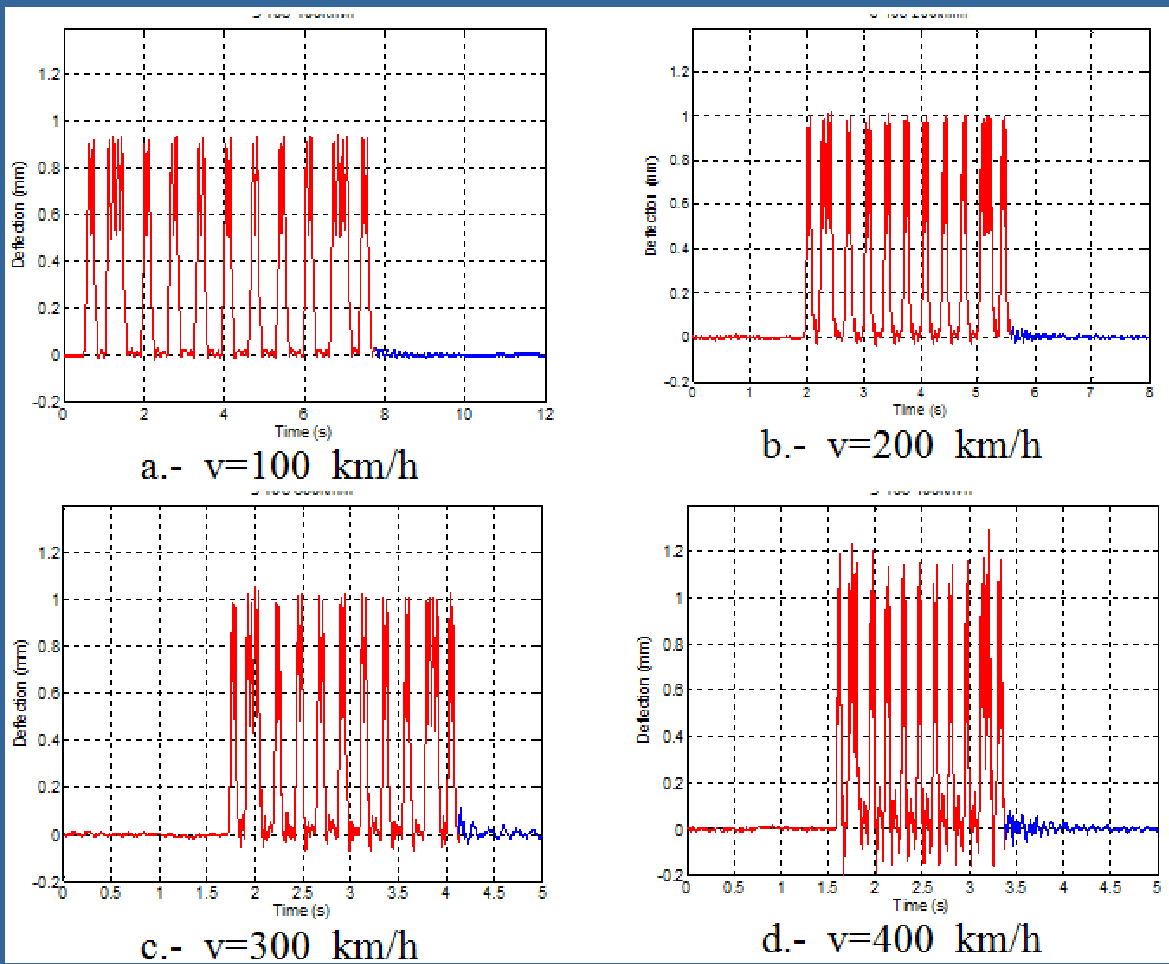




Quasi-static tests

2.1 Behaviour of the railway track for medium term:

Some tests were performed in CTB modelling the pass-by of trains at different speeds (50/ 100/ 150/ 200/ 250/ 300/ 350/ 400 km/h) to analyze the effect of speed in the global response of the track

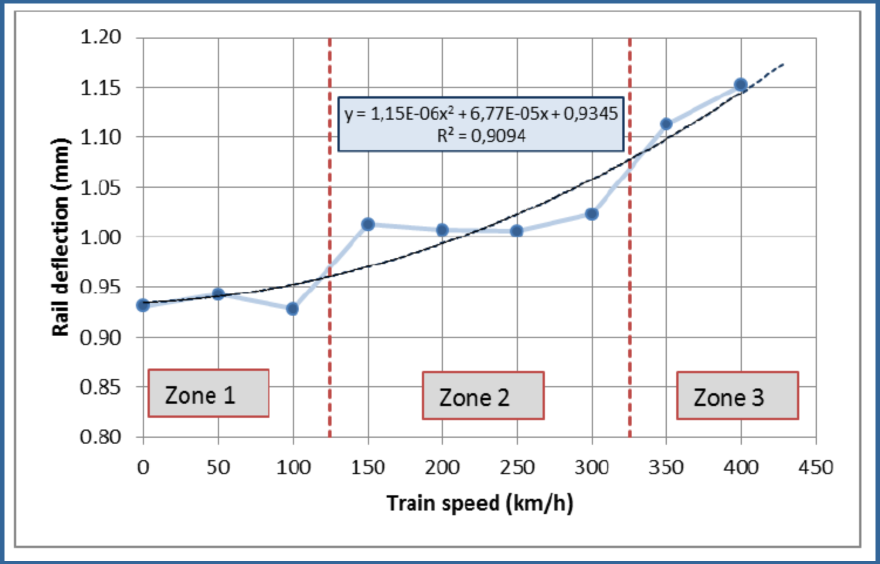


Example of rail deflections for different speeds

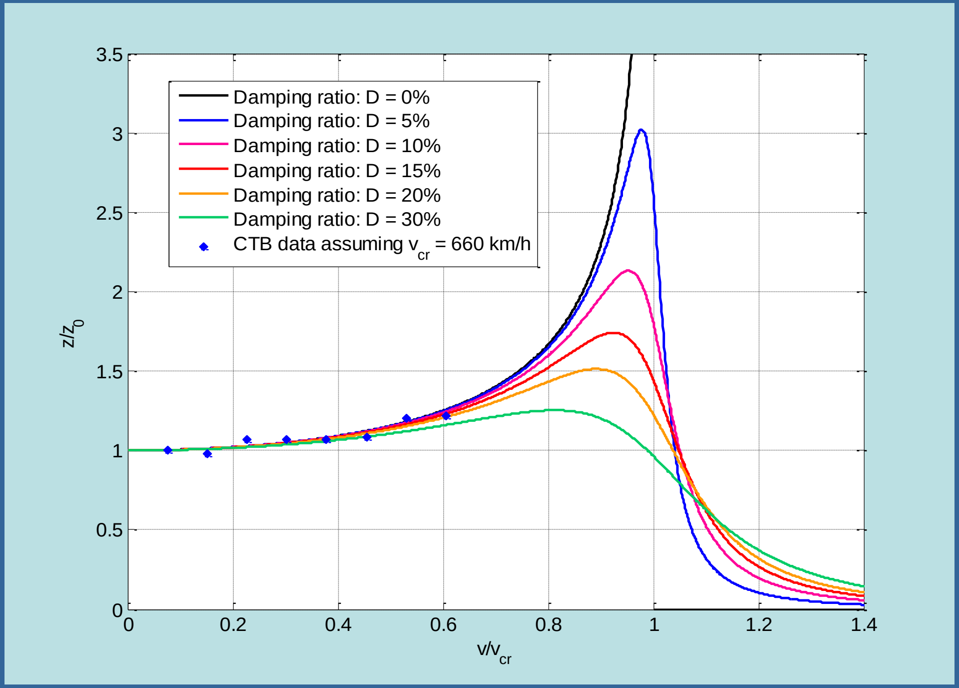
Quasi-static tests

2.1 Behaviour of the railway track for medium term:

Some tests were performed in CTB modelling the pass-by of trains at different speeds (50/ 100/ 150/ 200/ 250/ 300/ 350/ 400 km/h) to analyze the effect of speed in the global response of the track



Rail deflections for different speeds

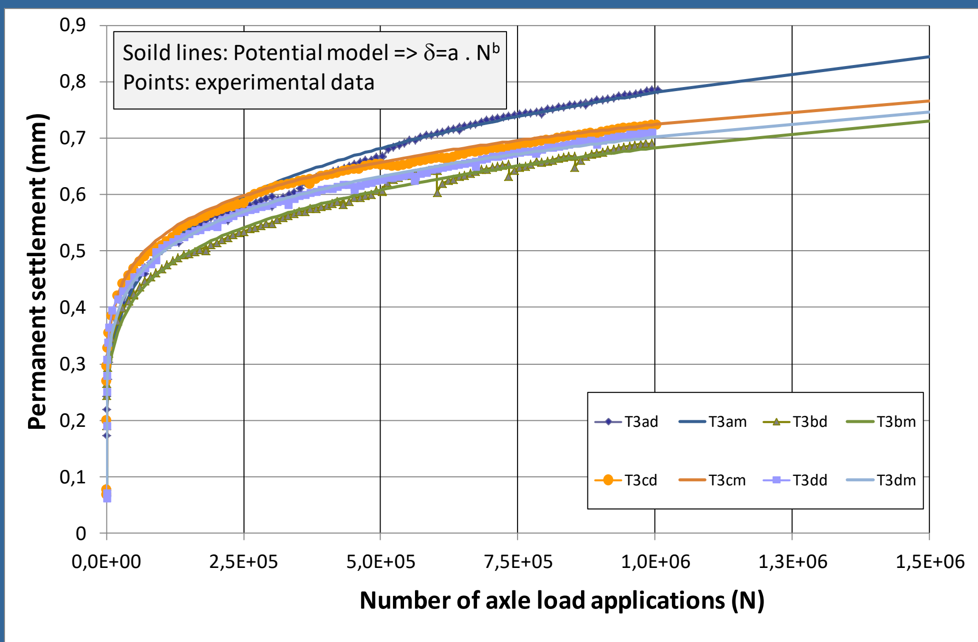


*Calculation of **critical velocity***

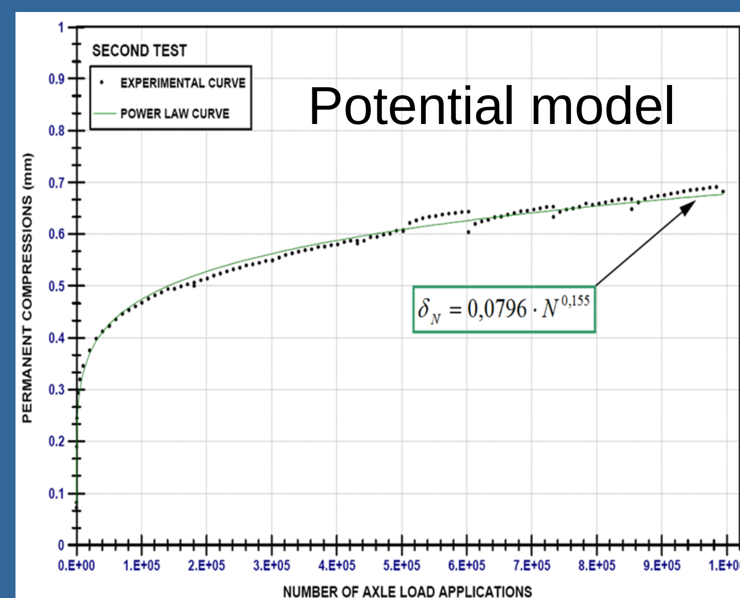
Quasi-static tests

2.2 Behaviour of the railway track for long term (Fatigue tests)

Very large number of axles are applied, under different test conditions



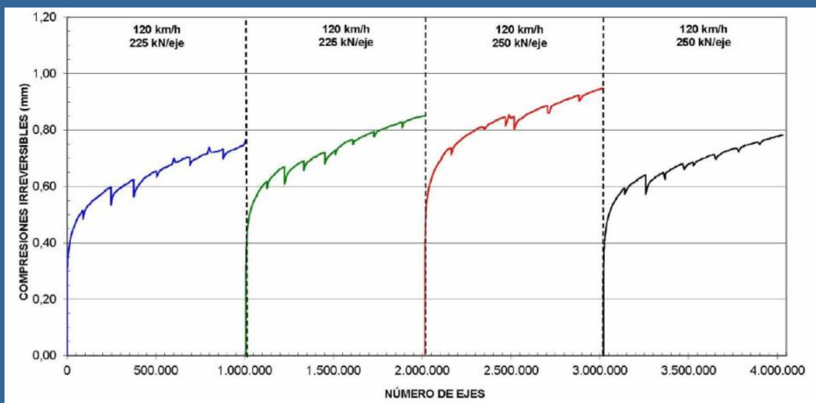
Some ballast settlement curves



Quasi-static tests

2.2 Behaviour of the railway track for long term (Fatigue tests)

Very large number of axles are applied, under different test conditions



Fatigue tests after tamping operation

Tamping machine

Quasi-static tests

2.2 Behaviour of the railway track for long term (Fatigue tests)

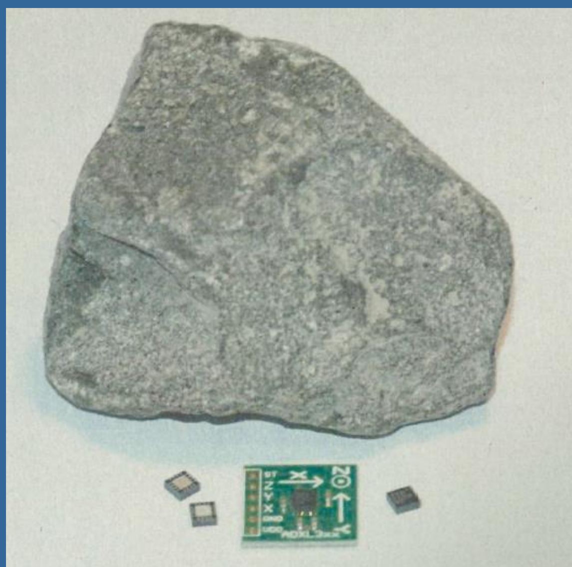
Velocities and accelerations in different track elements during the performance of fatigue tests

	Velocity peaks (mm/s)		Acceleration peaks (g)	
Train [1]	Passenger	Freight	Passenger	**Freight**
Rail	40–45	15–20	1–1.5	**0.5–0.8**
Sleeper	20–30	10–15	0.5–1	**0.15–0.3**
Ballast	15-20	7-10	< 0.5	**< 0.15**
Form layer	10–15	7-10	---	**---**
Embankment	2–6	< 4	---	**---**

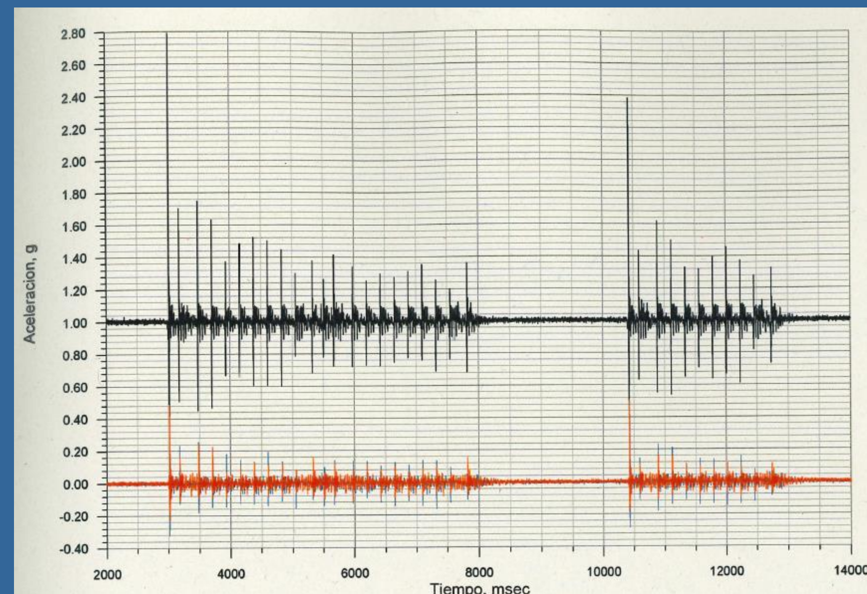
[1] **Passenger: 300 km/h;17 t/axle; Freight: 120 km/h; 22.5-25 t/axle**

Quasi-static tests

2.3 Behaviour of ballast particles in High Speed Lines



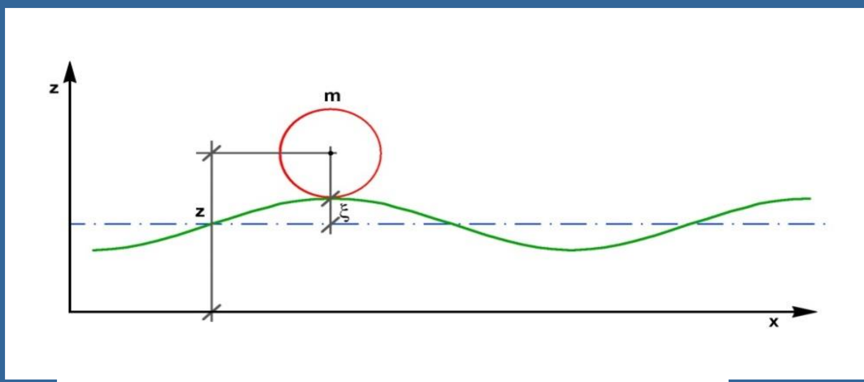
Ballast particle are monitored with a triaxial accelerometer

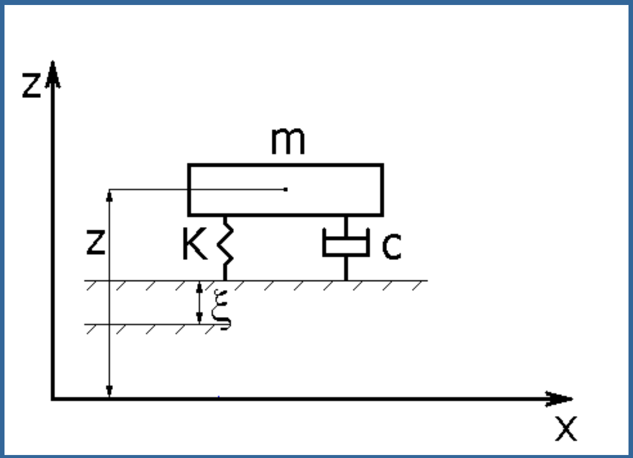


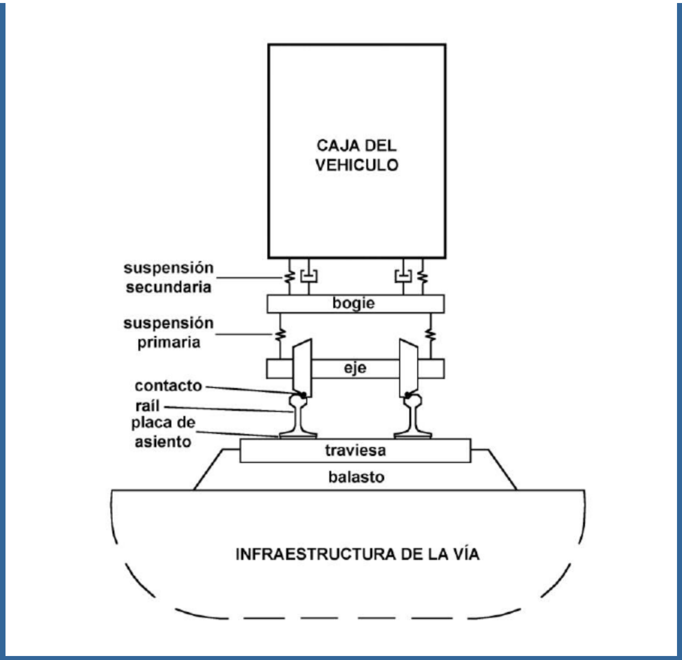
Results: Acceleration vs Time for ballast particle.
Black line: Vertical direction. Red line: Horizontal direction

Dynamic tests

Dynamic loads produced by geometric irregularities in the rail







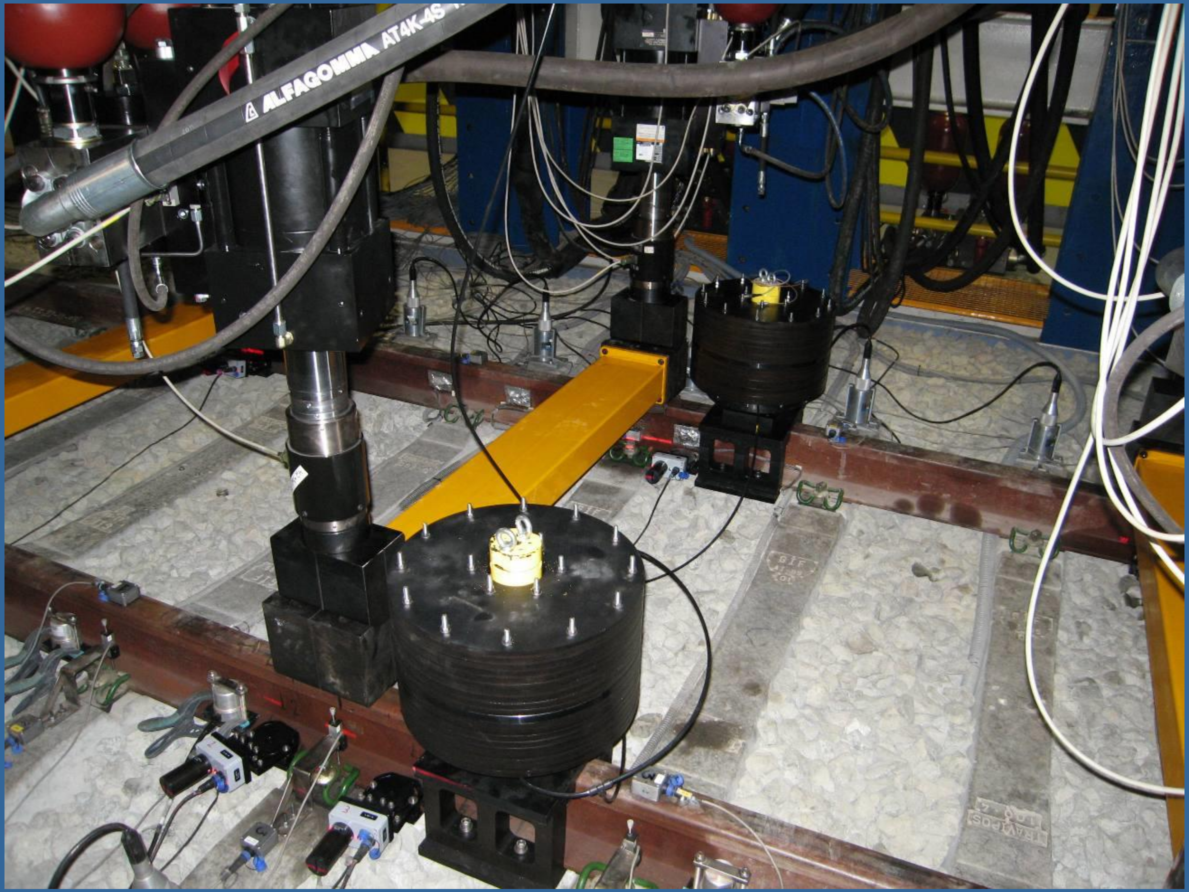
Important
- Unsprung wheel-set mass (directly associated to the vehicle horizontal axles)
- Track stiffness

Less important:
- Wheel-rail contact stiffness
- Vehicle box stiffness

Dynamic tests

Dynamic loads produced by geometric irregularities in the rail

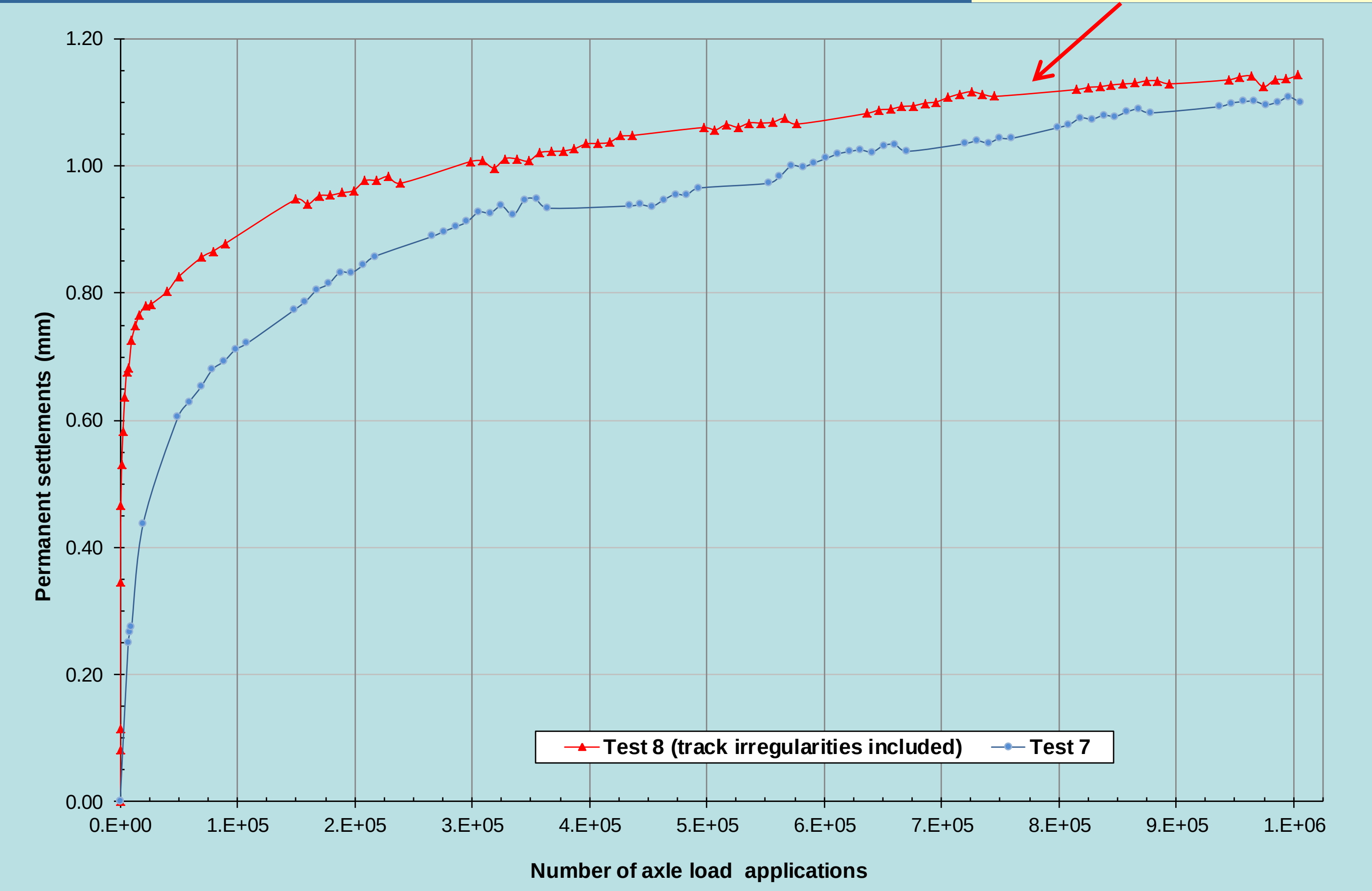
Applied by piezoelectric shakers: +/- 20 kN/axle load with f_{max}=300 Hz



CEDEX Track Box

Dynamic tests

Test with simulation of irregularities



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C4R Capacity for Rail

2. In-situ instrumentation of railway tracks

In-situ instrumentation of railway tracks

Main objectives:

- Development of measuring system and interpretation methods.
- Real railway data compilation to calibrate and validate the tests performed in CTB on 1:1 scale models.
- Analysis of problems detected in real railway sections.
- Improvement in the railway section design
- Improvement in the railway maintenance protocols.

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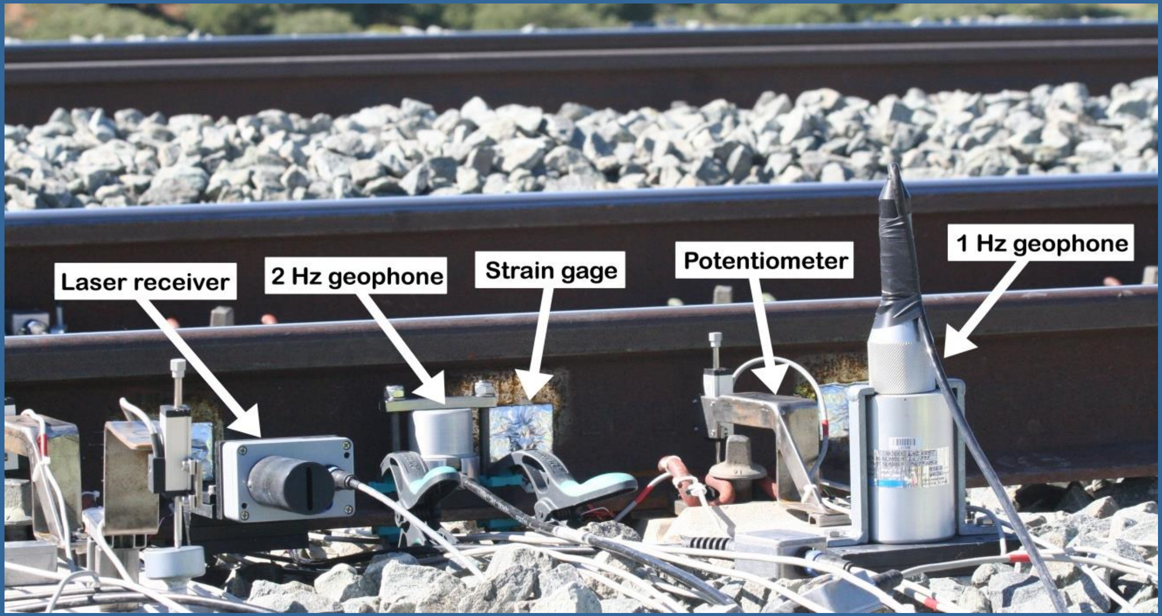
Three instrumentation equipments to analyze the railway track mechanical behaviour

1) Railway track in-situ instrumentation

- Strain gauges to measure train loads and sleeper reactions.
- Laser sensor, LVDT and potentiometers to measure displacements.
- Geophones (1 & 2 Hz) to measure velocities (and displacements by integration).
- Accelerometers (10 & 50 g) to measure acceler. (and velocities by integration)



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C4R Capacity for Rail

Three instrumentation equipments to analyze the railway track mechanical behaviour

2) Geotechnical instrumentation:

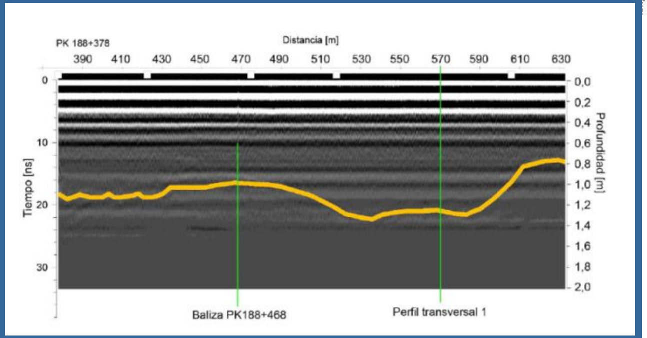
- Inclinometers
- Sliding micrometers
- Extensometers
- Pressure cells
- Dynamic plate tests

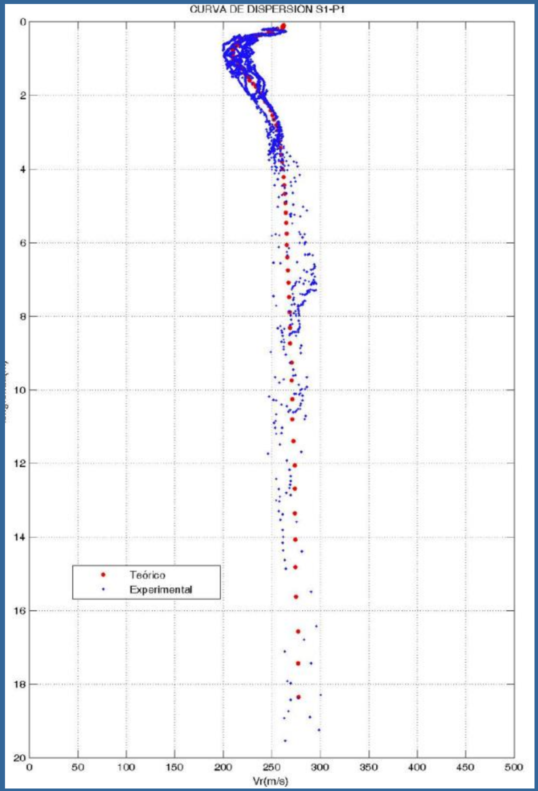


Three instrumentation equipments to analyze the railway track mechanical behaviour

3) Geophisic equipments

- Ground Penetration Radar (GPR).
- Spectral Analysis of Surfaces Waves (SASW) tests
- Instrumented impact hammer.





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C4R Capacity for Rail

Spanish HSL instrumented by CEDEX

Red de alta velocidad

In-situ instrumentation of railway tracks

Main works performed:

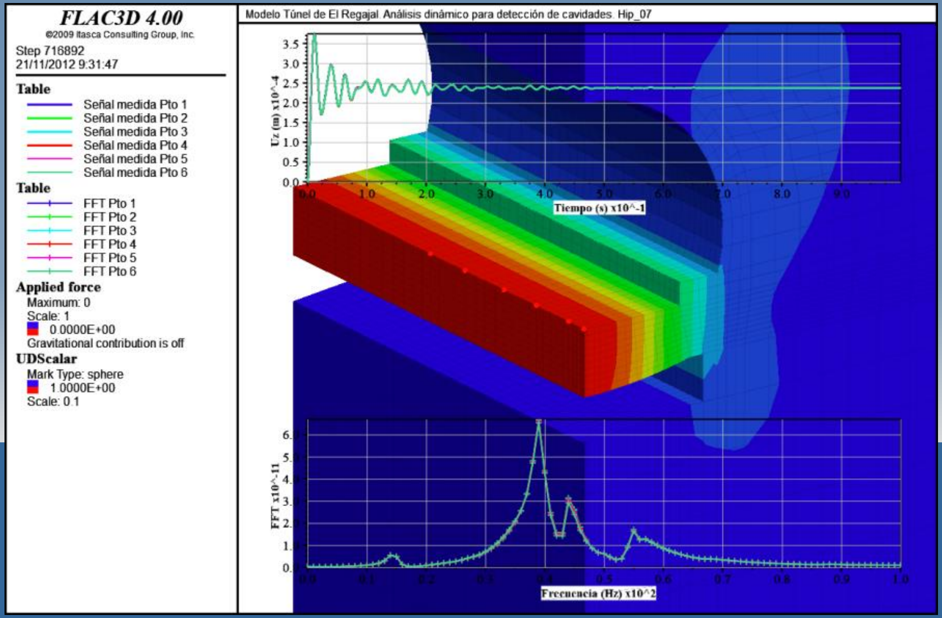
- Analysis of the mechanical behaviour of:
  - Sections with ballast layers of high thickness
  - Transition zone between ballasted track and slab track
  - Transition zone between embankment and structure
  - Transition zone between sections with granular and bituminous subballast layers
- (more in next slide)

In-situ instrumentation of railway tracks

Main works performed:

- Development of techniques to detect cavities under tunnel slabs
- Analysis of countermeasures for vibration propagation through rigid barriers

3. Numerical analysis of railway tracks



Numerical analysis of railway tracks

Software available

- Flac (2D & 3D models).
- Midas GTS NX (2D & 3D models).
- Plaxis (2D models).

Objetives

- Numerical simulation of tests performed in CTB and results obtained in real railway track monitored.
- Numerical analysis of different railway sections subjected to different load situations.

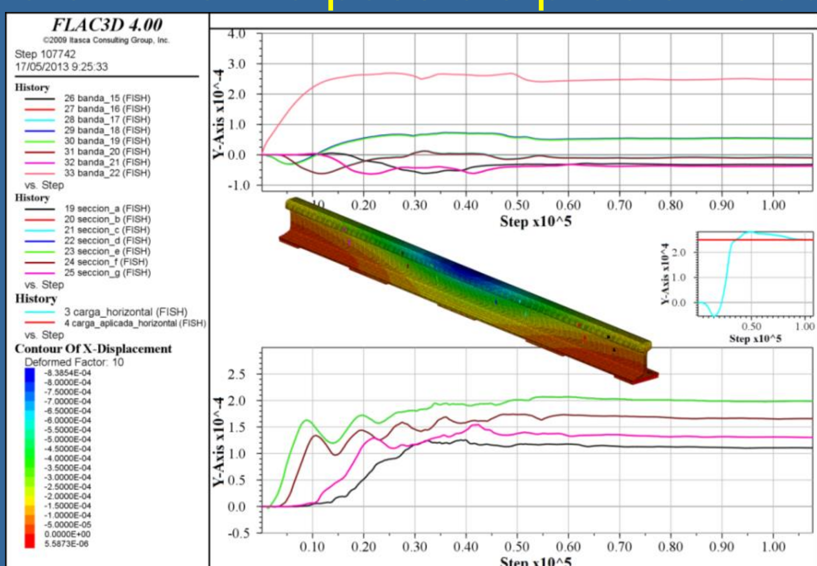
Numerical analysis of railway tracks

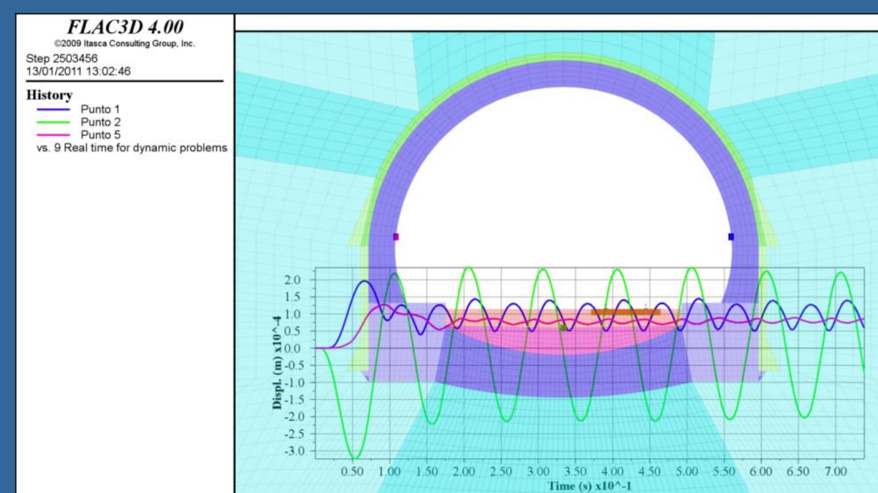
Main works perfomed:

Numerical analysys to determine the values of the mechanical parameters of the bed track layers

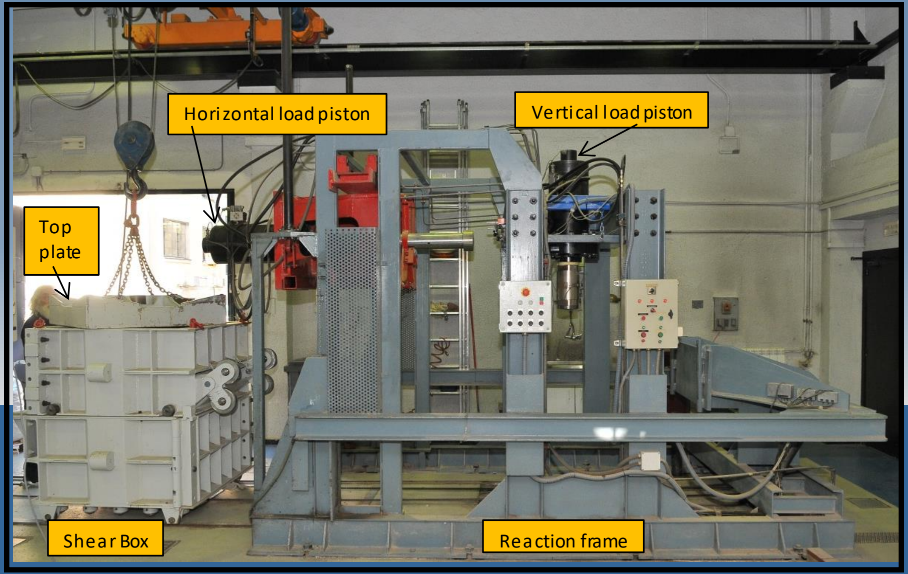
- Calculations to optimize the thickness of bituminuos subballast layer.

- Interpretation of the results obtained during El Regajal tunnel monitoring to determine the possible problems due to salt dissolution.





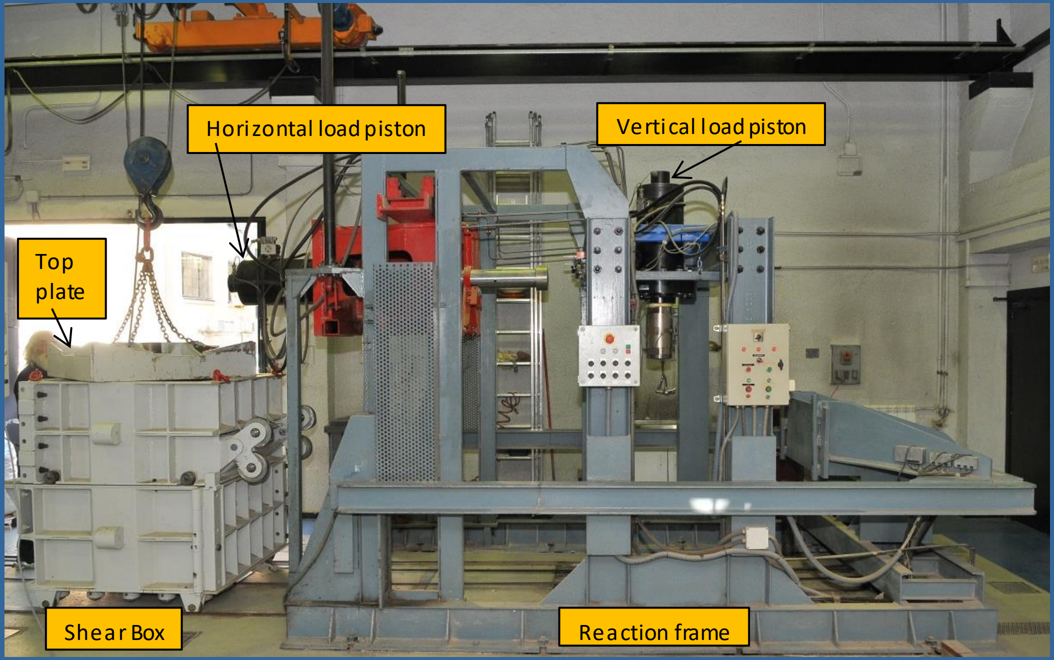
4. Geotechnical laboratory tests of railway materials



Geotechnical laboratory tests of railway materials

Materials tested: Ballast / Bed layer materials / Elastomeric materials

Test devices



1x1 m shear box

30 x 30 cm shear box

Geotechnical laboratory tests of railway materials

Test devices

30 cm diameter cell for permeability tests

9” diameter cells for static and dynamic triaxial tests

Ballast

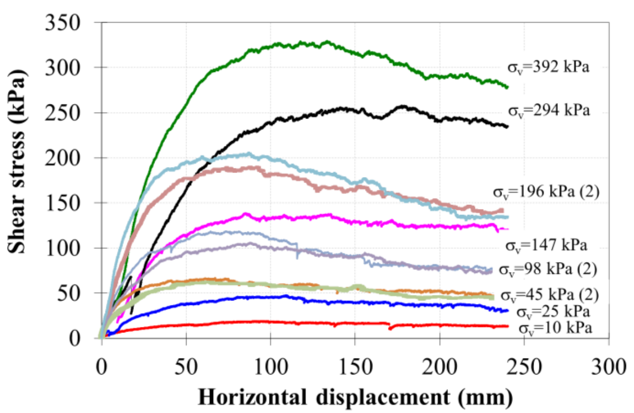
1x1 m shear box

It fulfills standard dimenssion requirements

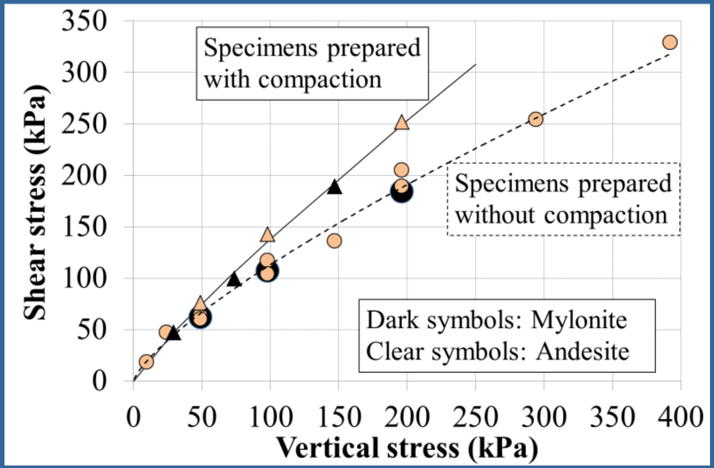
30x30 cm shear box

It does not fulfill standard dimenssion requirements

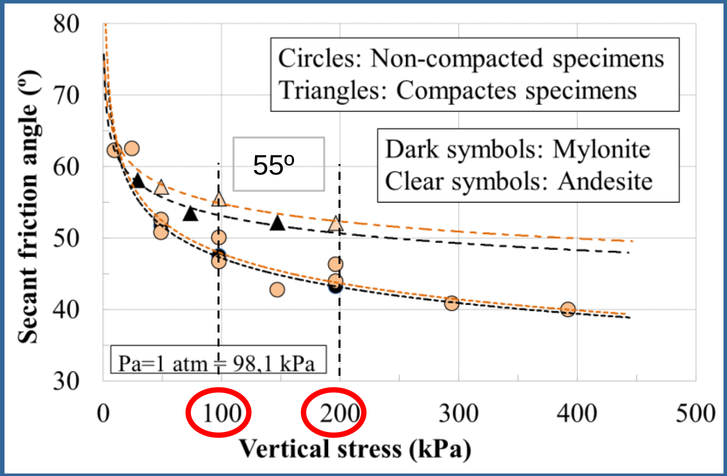
Ballast – Direct shear strength



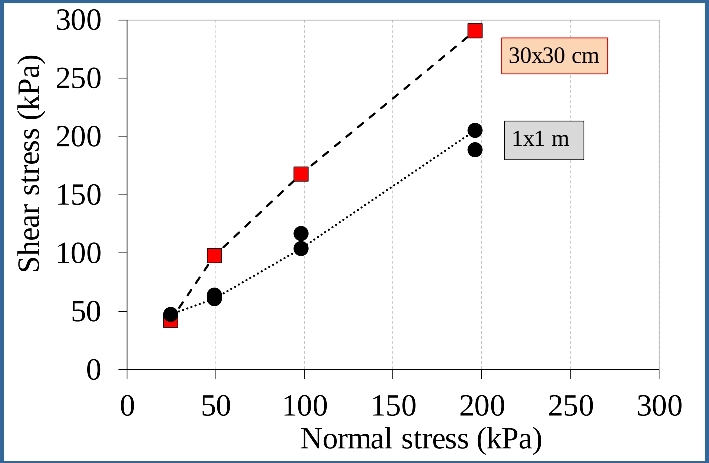
Direct shear curves for Test 2 (Normal stress= 10-400 kPa)



Direct shear test results for all the specimen (parabolic model)

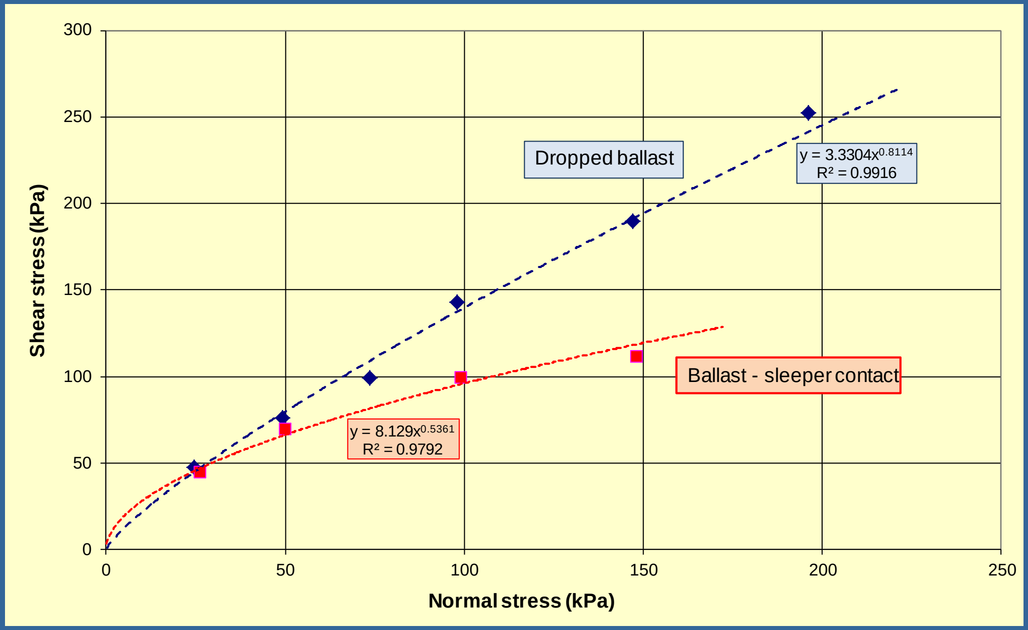


Secant friction angles (60-80º)



Scale effect: (1x1 m) v (30x30 cm)

Direct shear strength in the Ballast – Sleeper contact



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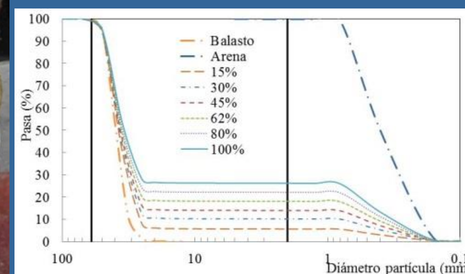
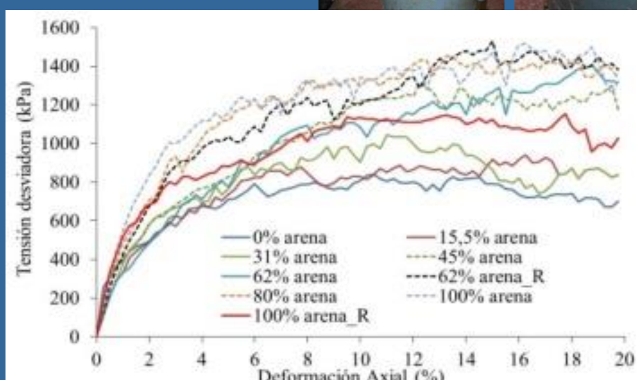
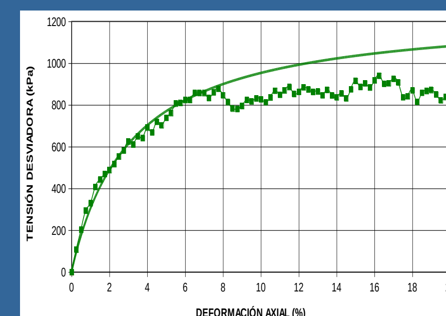
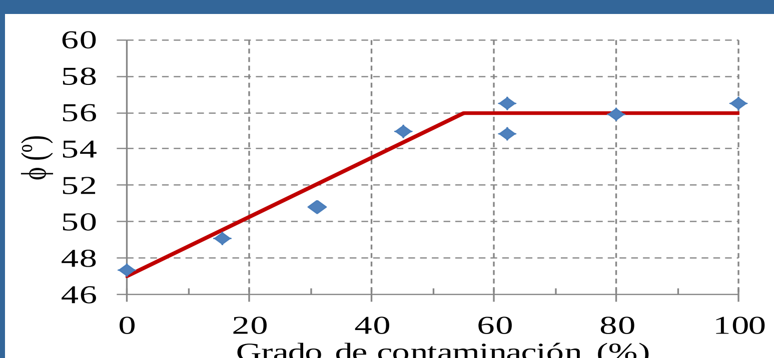
Ballast – Triaxial strength

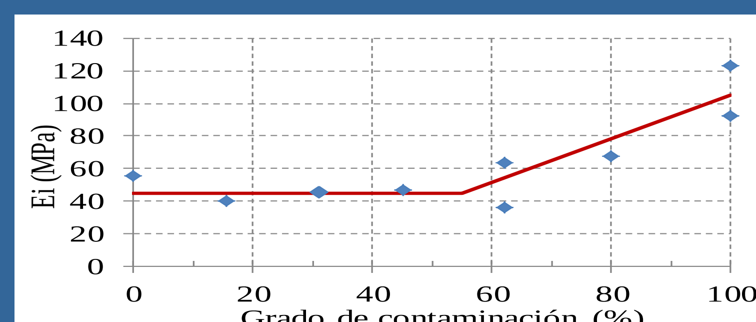
Ballast fouled with desert sand











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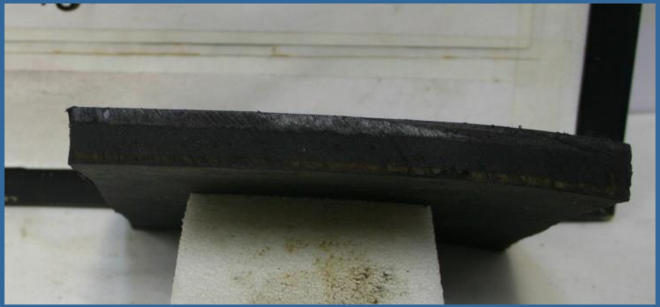
Geotechnical laboratory tests of railway materials
Elastomeric materials

Rigid plates

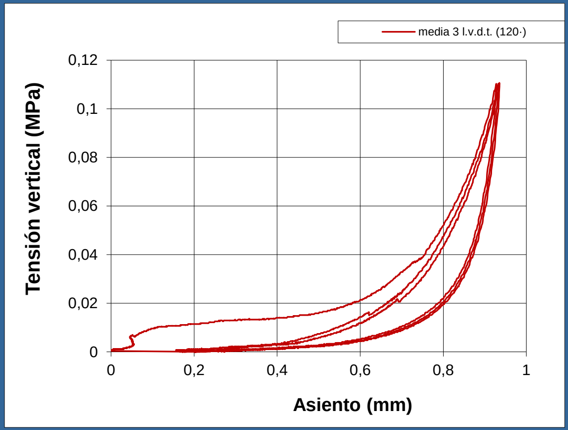
LVDT sensor to measure relative displacements

Test equipment in load system

Elastomeric materials

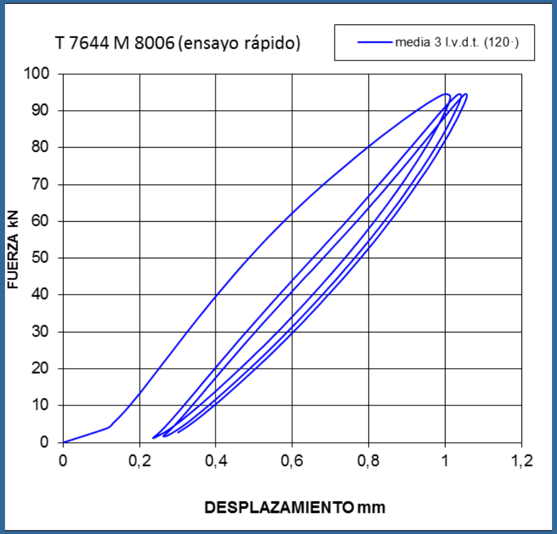


USP with two layers



Result: Secant modulus= 0,94 Mpa/mm

Rail Pad



Result: Vertical stiffness=116 kN/mm

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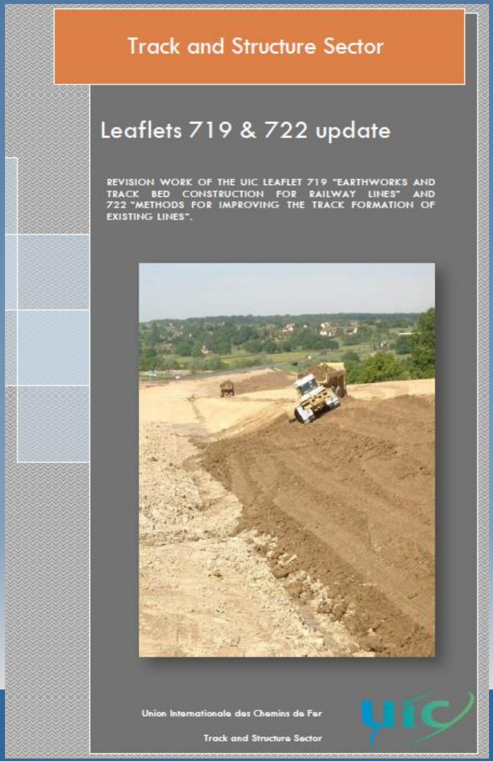
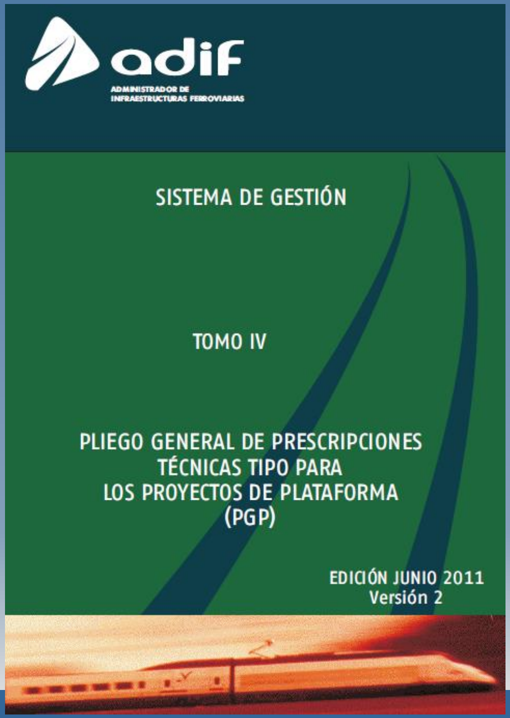
5. Others activities related with Railway Geotechnical Engineering: Standard drafting



Update of leaflets 719 & 722 UIC (2008 & 2017-2018)

(Earthworks and track bed construction for railway lines)



Update of ADIF Technical Prescriptions (2011-13)

(Earthworks , bed track layers, treatment with binding materials)

GOBIERNO DE ESPAÑA

MINISTERIO DE FOMENTO

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CEDEX

CENTRO DE ESTUDIOS Y EXPERIMENTACIÓN DE OBRAS PÚBLICAS

C4R

Capacity for Rail

Activities of the Laboratorio de Geotecnia – CEDEX in Railway Engineering

Madrid, 22 – September - 2017

Contact: jose.estaire@cedex.es

CEDEX TRACK BOX (CTB)

GENERAL DESCRIPTION

CEDEX Track Box (CFC) is a 21 m long, 5 m wide and 4 m deep facility whose main objective is to test, at 1:1 scale, complete railway track sections of conventional and high speed lines for passenger and freight trains, at speeds up to 400 km/h.

The testing facility was designed, built and developed as part of SUPERTRACK ("Sustained Performance of Railway Tracks", 2001-05) and INNOTRACK ("Innovative Track Systems", 2005-2009) projects funded by the European Union Fifth and Sixth Framework Programs, respectively. Figure 1 shows a general view of the testing facility.

Its principal advantage is the possibility of performing fatigue tests in a fast way as in one working week, the effect of the passing-by of trains during a year in a real section can be modelled.

The reproduction of the effect of an approaching, passing-by and departing train in a test cross-section, as it occurs in a real track section, is performed by application of loads, adequately unphased as a function of the velocity of the train which is being simulated, produced by three pairs of servo-hydraulic actuators. These actuators can apply a maximum load of 250 kN at a frequency of 50 Hz and are placed on each rail separated 1,5 m longitudinally, as seen in Figure 2.

Furthermore, the reproduction of wheel and track imperfection effects that produces low amplitude high frequency dynamic loads can also be carried out by the use of two piezoelectric actuators that can apply loads up to 20 kN at 300 Hz.

The railway track response, in terms of displacements, velocities, accelerations and pressures, is collected from a great number of linear variable differential transformers (LVDTs), geophones, accelerometers and pressure cells installed inside both the embankment and the bed layers (ballast, sub-ballast and form layer) of the track.

On the other hand, the railway superstructure response is recorded with mechanical displacement transducers, laser sensors, geophones and accelerometers installed on the different track components (rail, sleeper and railpad). The acquisition data unit can receive information from 150 sensors at the same time.

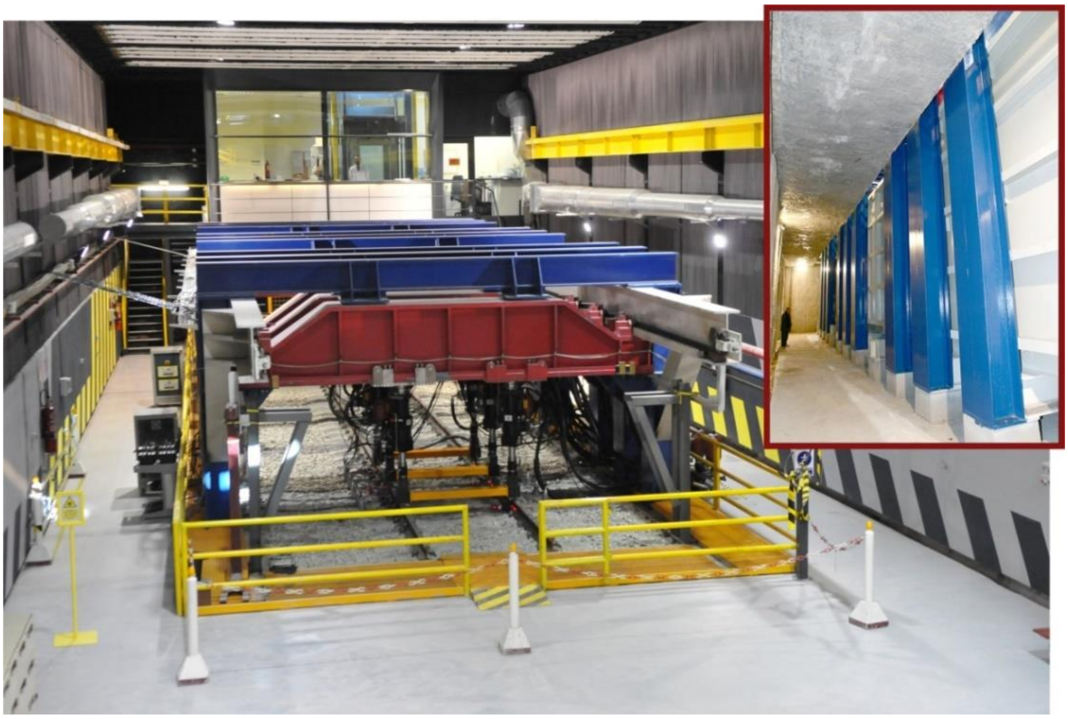

Figure 1: General view of the testing facility

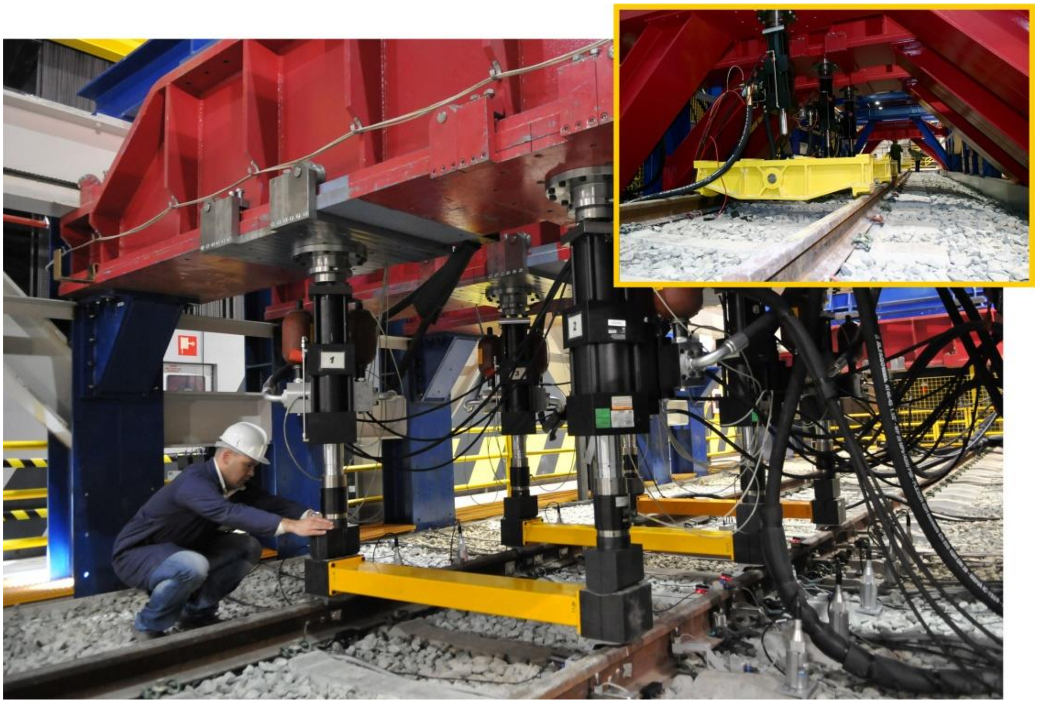

Figure 2: Loading system formed by three pairs of hydraulic actuators

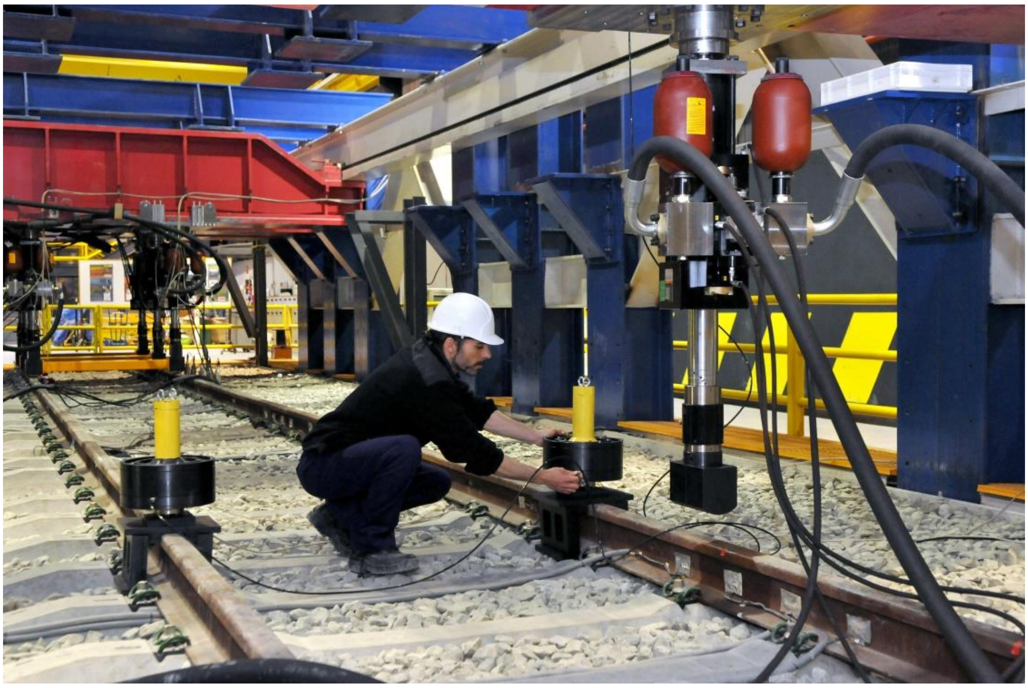

Figure 3: Piezoelectric actuators to simulate the effect of track imperfection

Figure 4: Surface instrumentation installed in one test

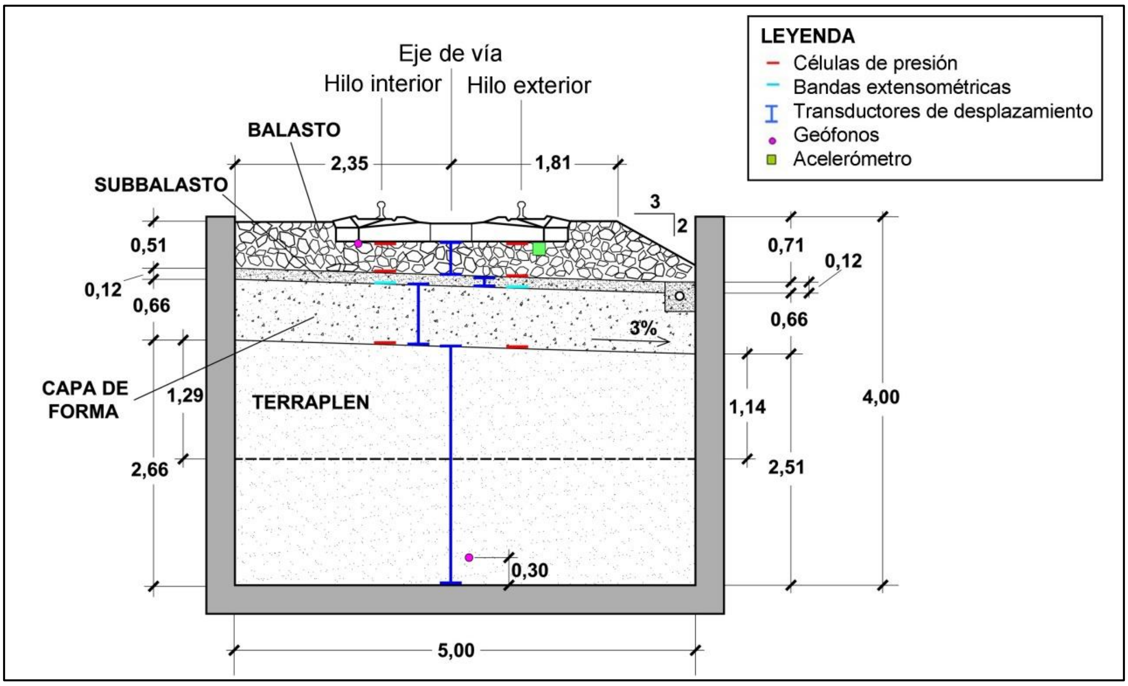

Figure 5: CTB cross-section with some of the internal sensors installed for one of the tests

Figure 6: Motors of the hydraulic system with a power of 350 CV each to generate a pressure of 210 bars and a flow of 1800 l/min

Figure 7: Tamping machine adapted to be used in CTB

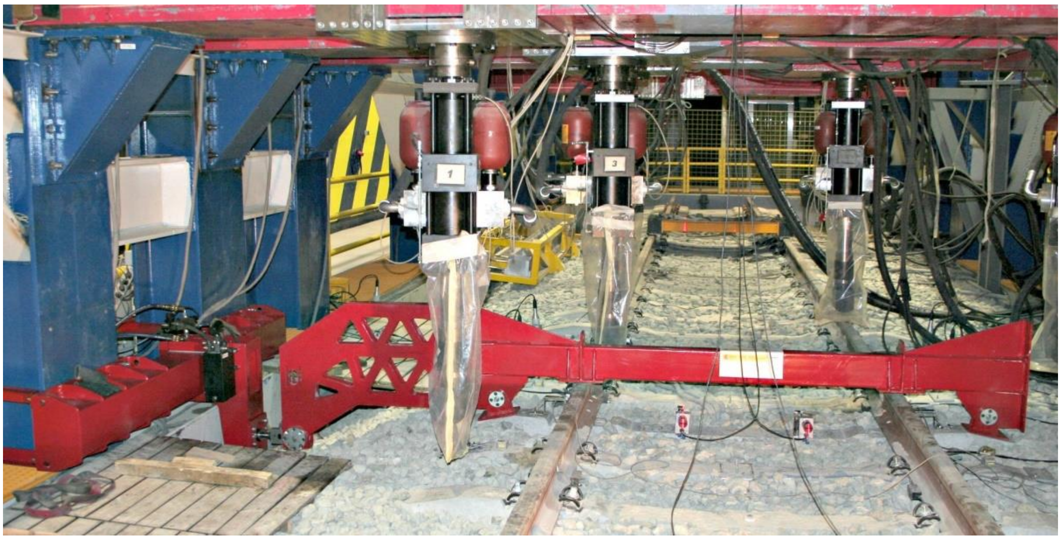

Figure 8: Tool to perform lateral resistance tests mounted on a sleeper

APLICATIONS

CEDEX Track Box, as testing facility, allows the performance of different kinds of tests on 1:1 scale models of track sections with different characteristics.

Characteristics of the 1:1 scale models

The 1:1 scale models that can be built in CTB can have the following features:

- Tests on ballasted or slab tracks.
- Tests on sections in straight line or in curve.
- Tests on switches and crossings.
- Tests on transitions zones.
- Tests with different kinds of ballast, subballast, form layer or embankment.
- Tests with standard, polyvalent and three-rail sleepers.
- Tests with new materials: sleepers with USP, under ballast mats, artificial ballast, bituminous subballast, geotextiles and soils treated with lime or cement.

Kind of tests to be performed

The tests that can be performed in CTB can have the following features:

- Tests with passenger and freight trains.
- Tests with static loads to determine track stiffness.
- Tests with quasi -static loads to simulate the pass-by of trains at speeds up to 400 km/h.
- Tests with dynamic loads to simulate the effects induced by track irregularities.
- Test to determine the fatigue behaviour of any track component (mainly, fastening system, ballast, subballast) by the simulation of pass-by of millions of axle trains.
- Tests on vibration propagation.
- Tests to determine the lateral and longitudinal track resistance.

Analysis of results

The test results can be used to:

- Analyze the short and long term behaviour of railway track sections submitted to any kind of train traffic and
- Calibrate 3D numerical models to be used in other type of studies or to widen the aim of the tests.

Other tests

Additionally, in the Laboratorio de Geotecnia – CEDEX, a Soil and Rock Mechanic Laboratory fully equipped with large test devices, situated in the same location, the following tests can be performed:

- Geomechanical tests on ballast, subballast and other ground materials.
- Test of the sleeper-ballast contact.
- Mechanical tests on elastomeric materials.

EUROPEAN PROJECTS

- **SUPERTRACK (2001-05) "Sustained performance of Railway Tracks" in the frame of 5th European Framework Program.**
  http://cordis.europa.eu/project/rcn/63386_en.html

  Experience with high-speed train in recent years has demonstrated unexpected settlement problems at certain sections of railway lines. This has caused railway companies expensive maintenance work and has become a concern in expanding high speed services which provide effective and environment-friendly transportation. The objectives of the project are: i) improving performance of railway ballasted tracks and reducing maintenance costs by understanding the dynamic and long-term behaviour of ballast using large-scale laboratory tests, ii) identifying weak portions of the railway network for retrofitting these locations by innovative, cost effective methods without interrupting train operation, iii) devising a global numerical model accounting for train-track interaction and non-linear behaviour of track components for a more reliable and cost effective design.

- **INNOTRACK (2005-09) "Innovative Track Systems" in the frame of 6th European Framework Program**
  http://cordis.europa.eu/result/rcn/47369_en.html

  The INNOTRACK project concentrated on research issues that contribute to the reduction of rail infrastructure life cycle cost (LCC). The main objective of INNOTRACK has been to reduce the LCC, while improving the reliability, availability, maintainability and safety (RAMS) characteristics. INNOTRACK has been a unique opportunity bringing together rail infrastructure managers (IM) and industry suppliers, the two major players in the rail industry. One of the biggest challenges for railways in Europe is that track costs, the major cost component for infrastructure managers (IMs), have not significantly decreased in the last 30 years. Therefore, the main objective for INNOTRACK is to reduce costs, decrease disturbances and increase availability. In addition to the issues of cost and availability, also noise pollution has become a crucial issue for railway operations.

- **RIVAS (2009-13) "Railway Induced Vibration Abatement Solutions" in the frame of 7th European Framework Program**
  http://www.rivas-project.eu/

  RIVAS aims at reducing the environmental impact of ground-borne vibration from rail traffic while safeguarding the commercial competitiveness of the railway sector. For several areas of concern, vibration should be reduced to the threshold of annoyance or even below. The project's goal is therefore to provide tools to solve vibration problems for surface lines by 2013.

  It therefore aims to contribute to the development of relevant and leading technologies for efficient control of people's exposure to vibration and vibration-induced noise caused by rail traffic.

- **FASTRACK (2013-2014) "Nuevo sistema de vía en placa para alta velocidad sostenible y respetuoso con el medio ambiente" in the frame of Spanish CDTI Research Programs.**
  (http://www.fastrack.es/)

  El objetivo principal del proyecto FASTRACK es el desarrollo de un nuevo sistema de vía en placa, focalizado para ser utilizado en líneas ferroviarias de Alta Velocidad (velocidades por encima de los 250 km/h), sostenible tanto económica como medioambientalmente. Para ello, el proyecto propondrá innovaciones en diseño y materiales que le permitirá al nuevo sistema de vía en placa:

- Abordar una fabricación asequible y medioambientalmente sostenible.
- Lograr una rápida puesta en obra, alcanzando mayores rendimientos en su construcción.
- Conseguir una máxima eficiencia de recursos, tanto en su fabricación como puesta en obra.
- Disponer de elementos que minimicen al máximo la afección social que tiene la producción de ruido y vibraciones del tránsito ferroviario.
- Necesitar de un bajo mantenimiento, aumentando las horas de disponibilidad de explotación de la infraestructura.
- Requerir de una fácil y rápida reparación en el caso de ser necesario, evitando largos cortes de vía.
- Alcanzar una considerable reducción del coste del ciclo de vida.

- **CAPACITY4RAILS (2013-2017) "Increasing Capacity 4 Rail networks through enhanced infrastructure and optimized operations" in the frame of 7th European Framework Program**
  http://www.capacity4rail.eu/

  CAPACITY4RAIL aims at paving the way for the future railway system, delivering coherent, demonstrated, innovative and sustainable solutions for:

  - *Track design*: transversal approach for infrastructure solutions for conventional mixed traffic and very high speed, integrated monitoring and power supply, reduced maintenance, new concept for highly reliable switches and crossings.
  - *Freight*: longer trains, lower tare loads, automatic coupling, enhanced braking, modern, automated, intelligent, fully integrated system for efficient, reliable and profitable freight operations
  - *Operation and capacity*: traffic capacity computation for freight and passenger, models and simulators for planners: capacity generation, traffic flow, resilience to perturbations, ability to recover from disturbance, computerized real time information to customers and operators at any time
  - *Advanced monitoring*: Integration of Advanced Monitoring Technologies in the design and building process, for an easier-to-monitor (self-monitoring) infrastructure with low cost and low impact inspection.

  The full sustainability of the developed solutions and innovations will be assessed and scenarios for a smooth migration of the system from its current to its future state will be evaluated

TESTS PERFORMED

The following tests have been performed at CEDEX Track Box:

- Determination of fatigue curve of ballast and sub-ballast material.
- Analysis of the optimum thickness of bituminous sub-ballast.
- Study of the propagation of vibration through the track bed and embankment.
- Study of the effect of fouling with sand in the behaviour of the ballast layer.
- Homologation tests of prototypes of slab tracks.
- Study of the effects of very high speed (up to 400 km/h) in the mechanical behaviour of track beds.

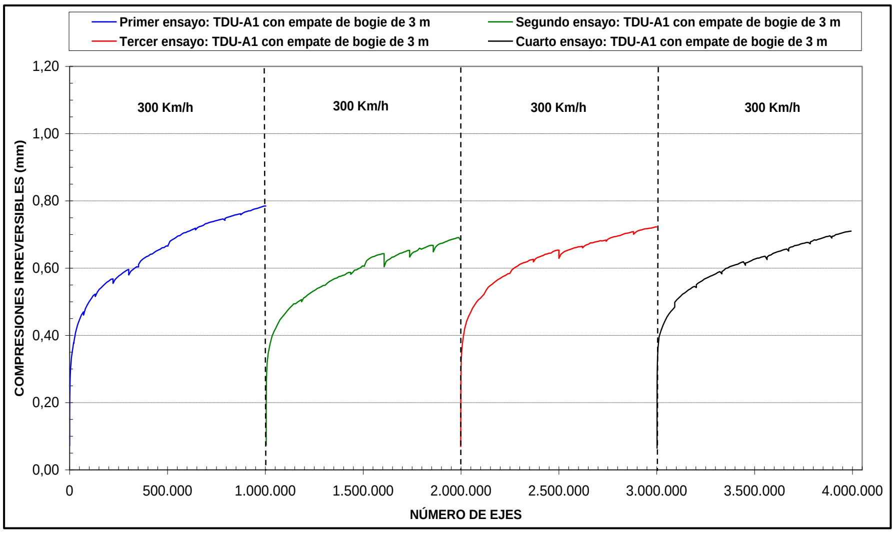

Figure 9: Ballast fatigue curves obtained for different track conditions

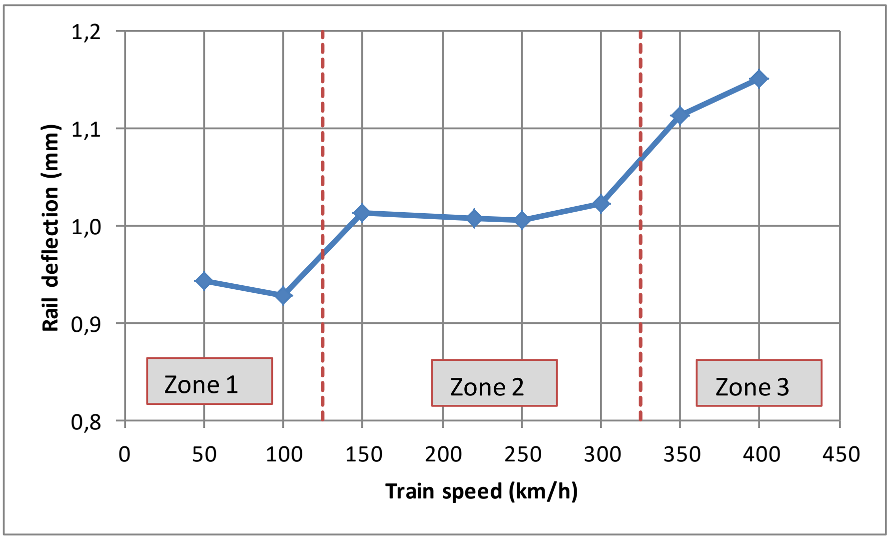

Figure 10: Rail deflection obtained in CTB tests as a function of train speed

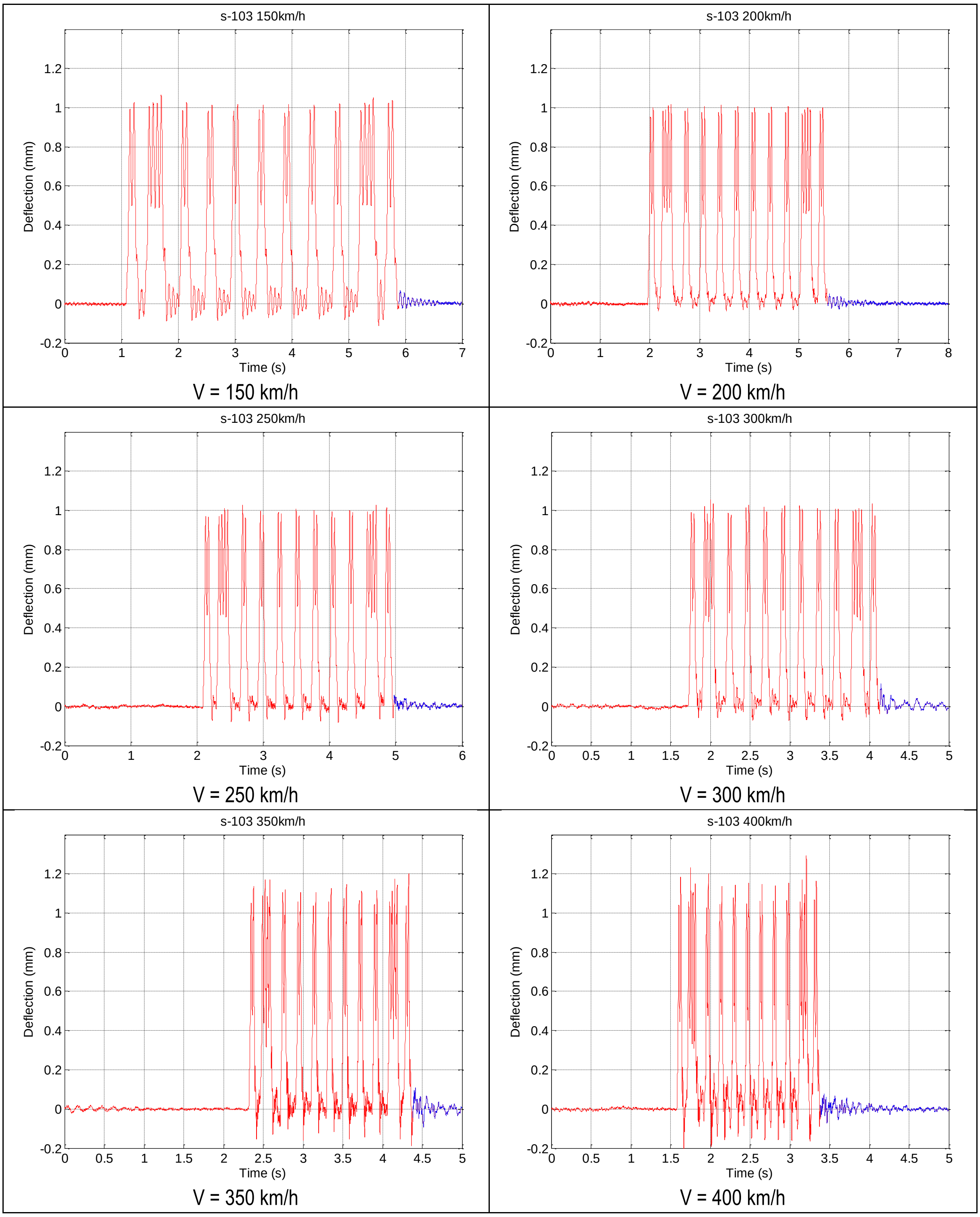

Figure 11: Time histories of rail deflections obtained in CTB tests as a function of train velocity

STAFF

GERT
Geotechnical Engineering of Railways Tracks

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STAFF

Duties	1:1 scale tests performed in CEDEX Track Box	In-situ instrumentation of railway tracks	Numerical analysis of railway tracks	Geotechnical laboratory tests of railway materials
Direction	**José Estaire**	**José L. G. de la Oliva**	**Javier Moreno**	**Áurea Perucho**
Test design and interpretation	María Santana Inés Crespo Julián Valerio	Javier Moreno Ángel Tijera Rubén Ruiz	Pablo Mira Carlos de las Heras	José Estaire María Santana
Test execution	Juan L. Cámara Sagrario Merino	Pedro J. García José L. Amores	---- ---- '----	Mª Eugenia Martín Mauro Muñiz Rafael Rodríguez
Support to test execution	José M. Cerezo José L. Rocha Gema Villar	José A. Pintado Antonio Jiménez	---- --- ----	José L. Gómez Oscar Tello José L. Toledo

CEDEX c/ Alfonso XII, 3-5 28014 Madrid (Spain)	**Contact: José Estaire** Telephone.: +34 91 335 73 62 email: jose.estaire@cedex.es

PAPERS RELATED WITH THE TESTS PERFORMED IN CEDEX TRACK BOX

Settlement laws of bed layers of a ballast track as determined in 1:1 scale models performed in CEDEX Track Box José Estaire, Vicente Cuéllar, María Santana, Juan L. Cámara. In preparation

Determination of the critical speed of railway tracks based on static FEM calculations. José Estaire, María Santana & Inés Crespo. In preparation for NUMGE 2018, Porto (Portugal)

Track stiffness in a ballast track fouled with desert sand. Estaire José, Cuéllar Vicente, Santana María. To be submitted to Symposium International GEORAIL 2017 International Symposium

Large direct shear tests performed with fresh ballast. J. Estaire; M. Santana. Geotechnical Testing Journal. Submitted, 2017

Ensayos de resistencia lateral de vía realizados en el Cajón Ferroviario del CEDEX y su modelización. J. Estaire; V. Cuéllar; M. Santana; J.L. Cámara. Revista Geotecnia. Submitted, 2017

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Short and long term behaviour of high speed lines as determined in 1:1 scale laboratory test. V. Cuéllar, F. Navarro, M.A. Andreu, J.L. Cámara, F. González, M. Rodríguez, A. Núñez, P. González, R. Díaz, J. Navarro, R. Rodríguez. In XV World Congress Railway Research, May 22-26, 2011.

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