C4R

Capacity for Rail

Dynamic response of bridges on very high speed lines

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SEVENTH FRAMEWORK PROGRAMME

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- **Introduction**
- **Analysis of dynamic effects from HST on bridges**
- **Ways of reducing acceleration levels**
- **Verification by full scale test**
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Introduction

- **Aim of task**:

Improved knowledge on the dynamical behaviour of very high speed trains on bridges, and develop appropriate design principles

- **Project team members:**
  - ADIF
  - KTH
  - SYSTRA
  - INECO
  - CEDEX

- **Deliverables:**

D12.2 Innovative designs and methods for VHST

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Bridges on high-speed lines

- The percentage of bridges on a HSL is very high
  - Japan: ~65%
  - China: ~80-95%

- ~90% of bridges on recently opened lines are made of concrete. Steel bridges are used for the longer spans >30-50m

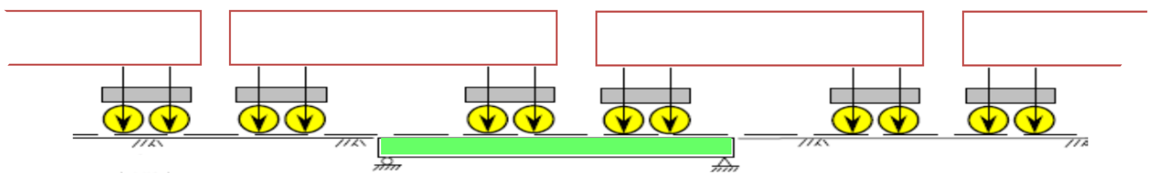
- Some new lines are unballasted due to their advantages from the maintenance point of view

- Dynamic behaviour must be carefully investigated

Requirements in the Eurocodes

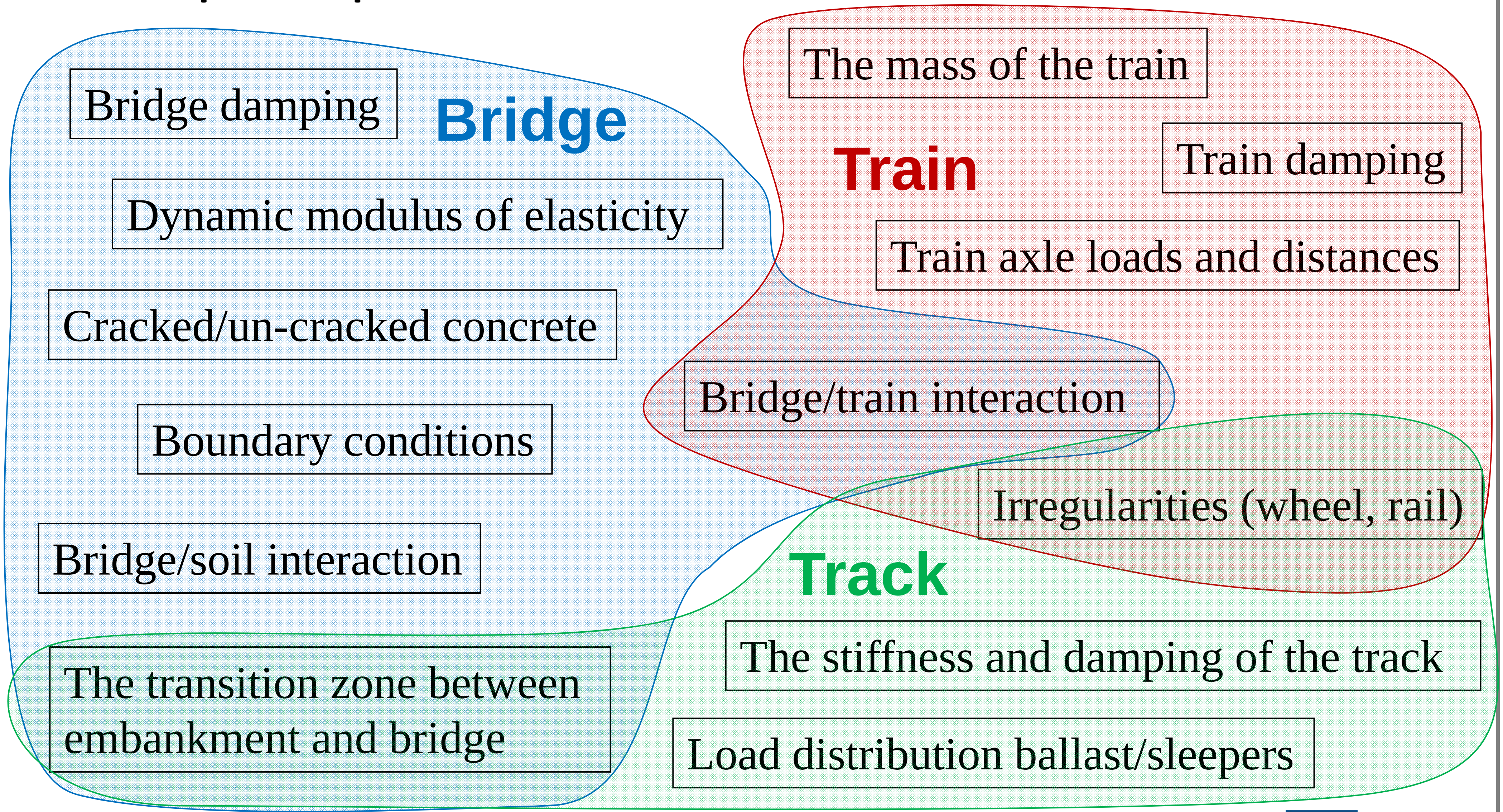
- **v > 200 km/h, consider resonance effect from high speed trains**
  - Dynamic analyses for speeds up to 1,2 x v_{max} line speed
  - High speed train models: HSLM-A and HSLM-B
  - Ballast instability: check bridge vertical acceleration
  - Deck acceleration is often the critical parameter in design

- **General limitations behind Eurocode requirements**
  - Vehicle speeds up to 350 km/h
  - Simple 2D models
  - Mainly applicable to simply supported beam-like bridges
  - Track irregularities: sinusoidal dips (loose sleepers)



Analysis of dynamic effects

- **Important parameters to consider**



Analysis of dynamic effects

- **Scope of work**
  - Typical short span beam bridges (up to 5 spans) and frame bridges (open & closed), ballasted and unballasted
  - Responses to passing HSLM, TGV, ICE2 and ICE3 trains
  - Speeds up to 480 km/h
  - Track and rail irregularities (both vertically and horizontally)
  - Passenger comfort is checked under vertical/transverse accelerations.

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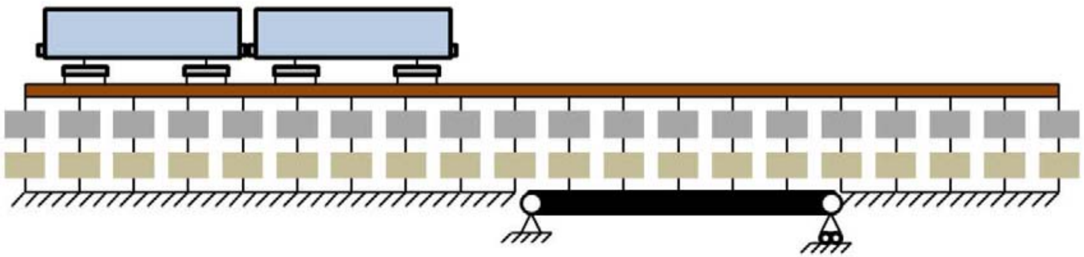
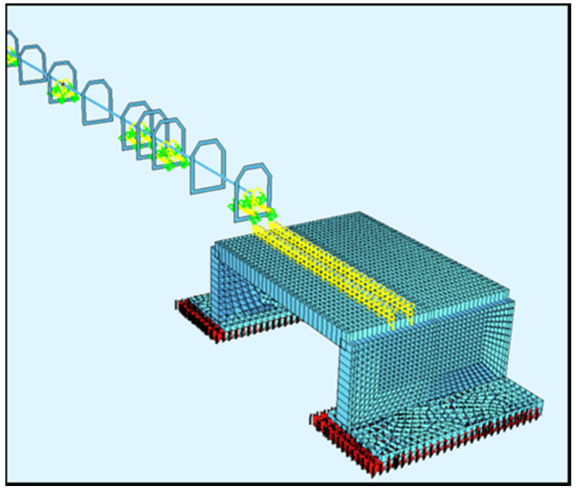
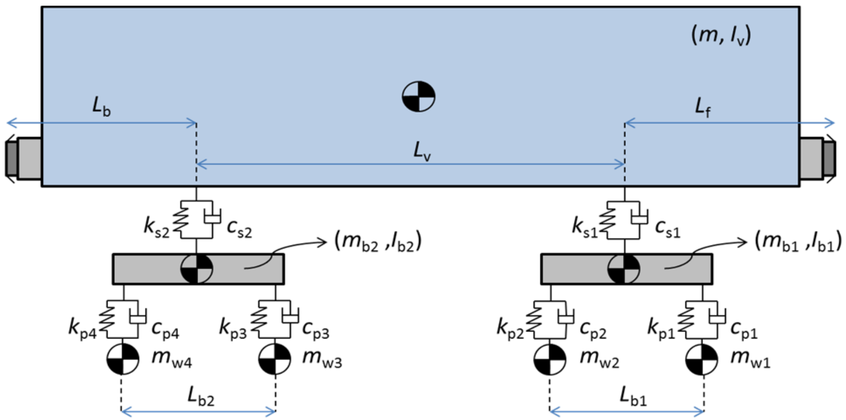
- **Train–track–bridge dynamic simulations**



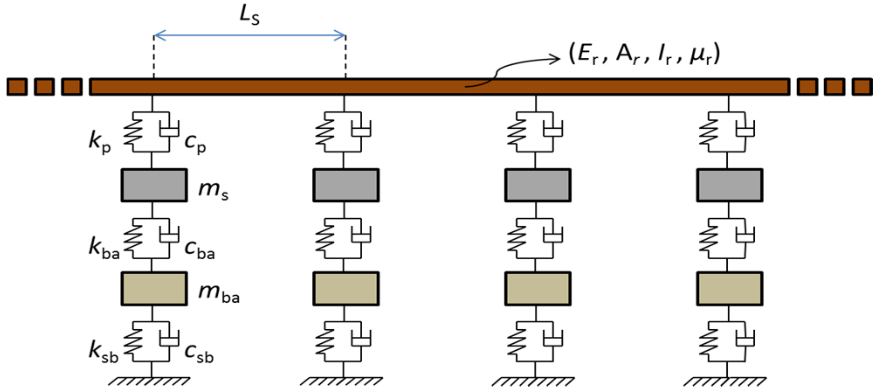
Dynamic 2D model of coupled train-bridge system including track irregularities



3D train-bridge coupled system

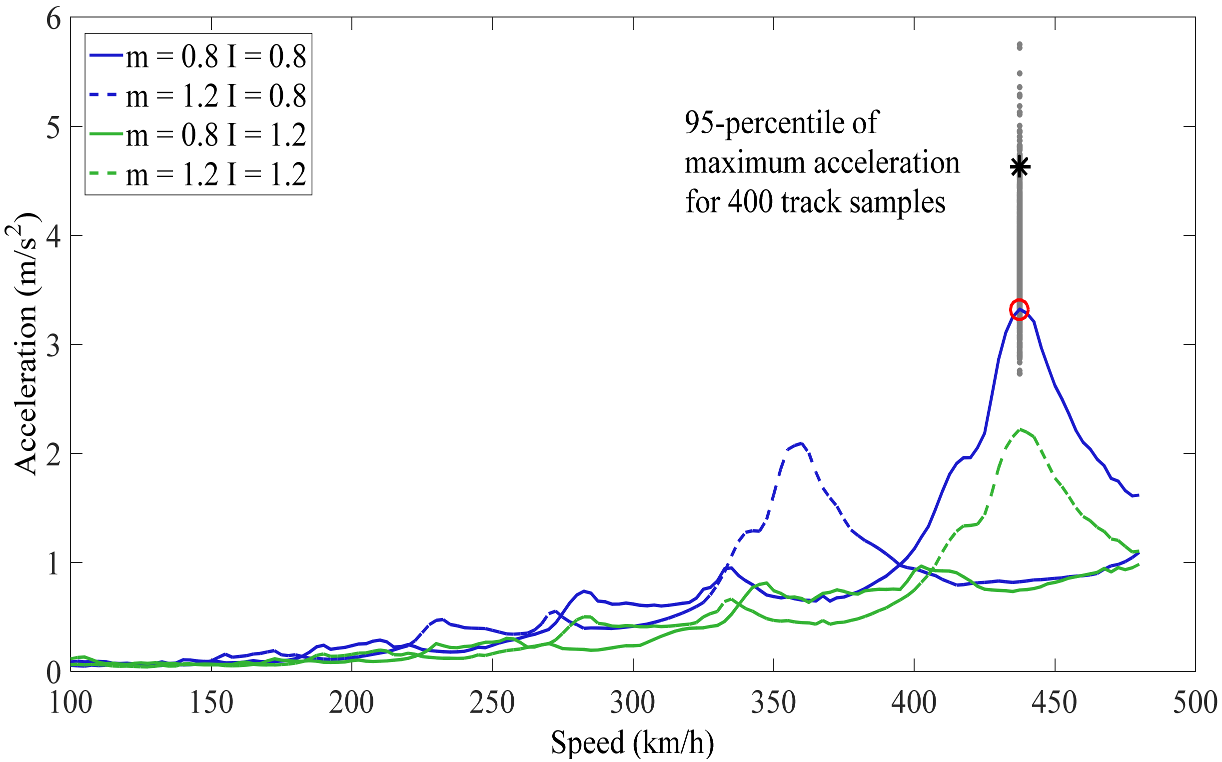


Sketch of vehicle model

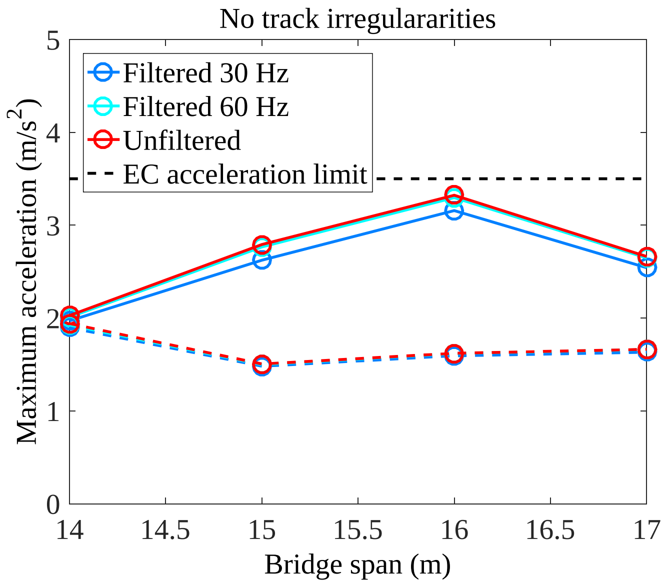


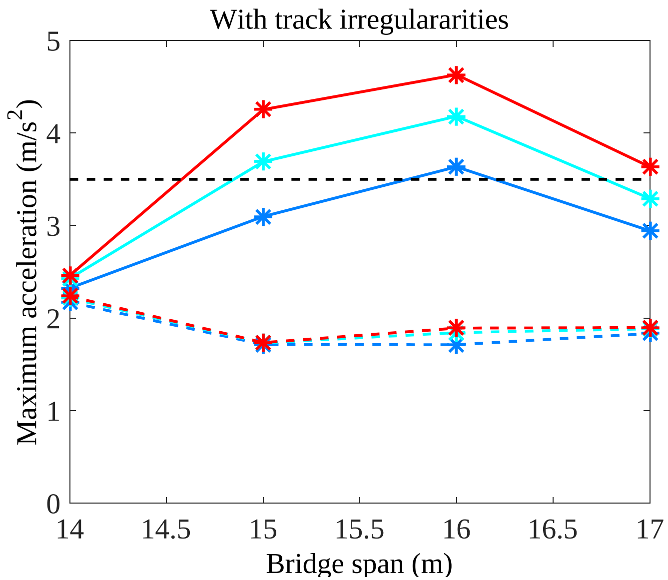
Sketch of track model

- **Some interesting results**



Maximum bridge deck acceleration for the 16+16 m span bridge. The critical speed for the critical combination of bridge mass and bridge stiffness is indicated by the red circle. The results from 400 track samples at this critical speed are seen in grey.





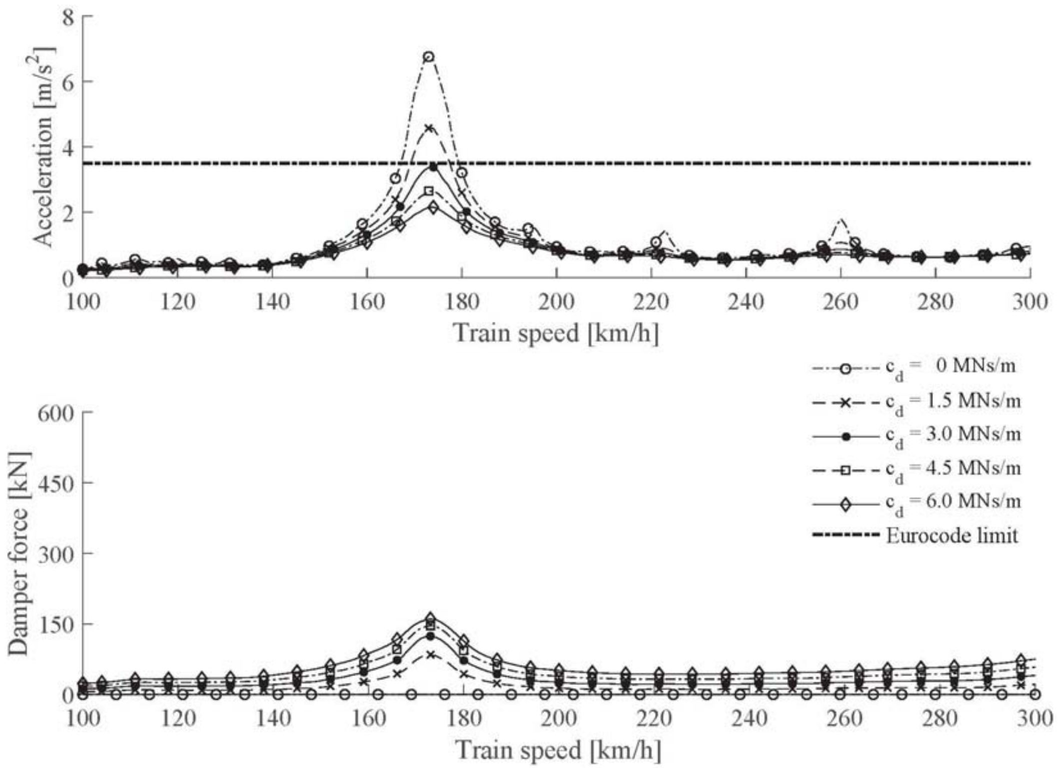
Ways of reducing acceleration levels

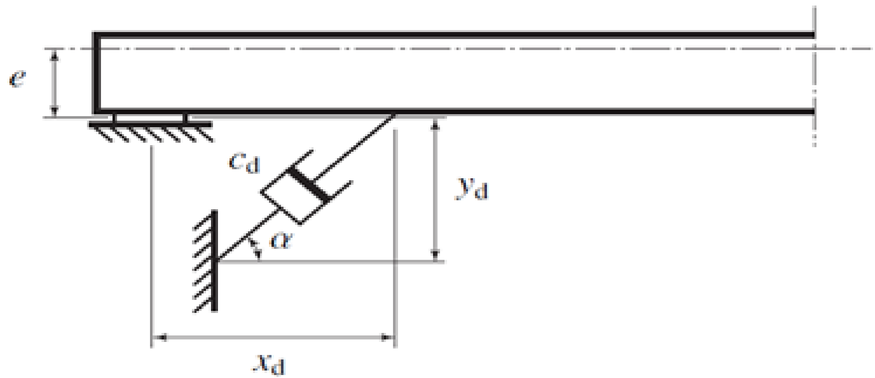
Ways of reducing acceleration levels

- **Strategies to reduce vibration levels**
  - Effect of load spreading
  - Effect of viscous dampers
  - Effect of Soil-Structure Interaction

Ways of reducing acceleration levels

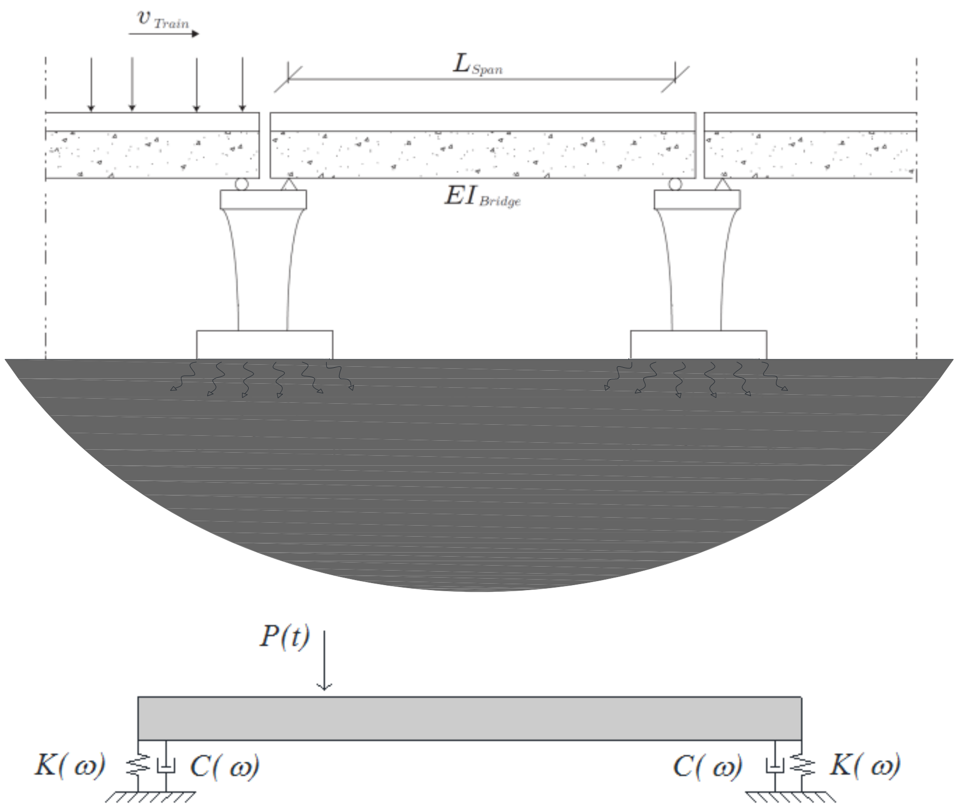
- Investigate effects of viscous damper
  - Gaps in joints
  - Elasticity in abutments
  - Uncertainties → probabilistic analysis



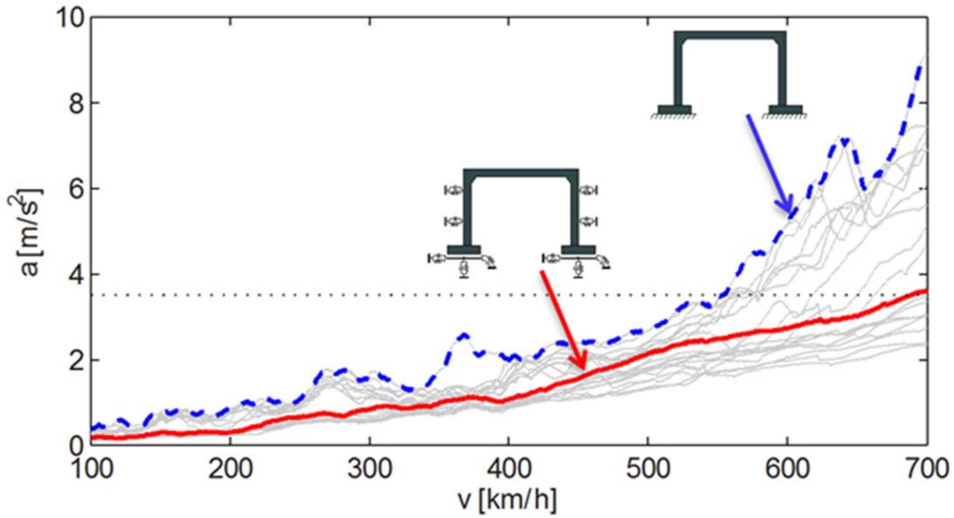


Ways of reducing acceleration levels

- Investigate effect of Soil-Structure Interaction (SSI)
  - Flexibility of foundation and backwalls
  - Additional energy dissipation



2- Soil/foundation is replaced by freq. dependent spring/dashpot at the interface



Calculated maximum acceleration at bridge's mid-span; Envelope of all HSLM trains.

- **Challenges in dynamic analysis**
  - Choice of computational model (complex models need more input)
  - Estimation of frequencies & mode shapes
    - Mass and stiffness
    - Boundary conditions
  - Estimation of damping (magnitude and sources of damping, SSI)
  - Influence of environmental conditions
  - …

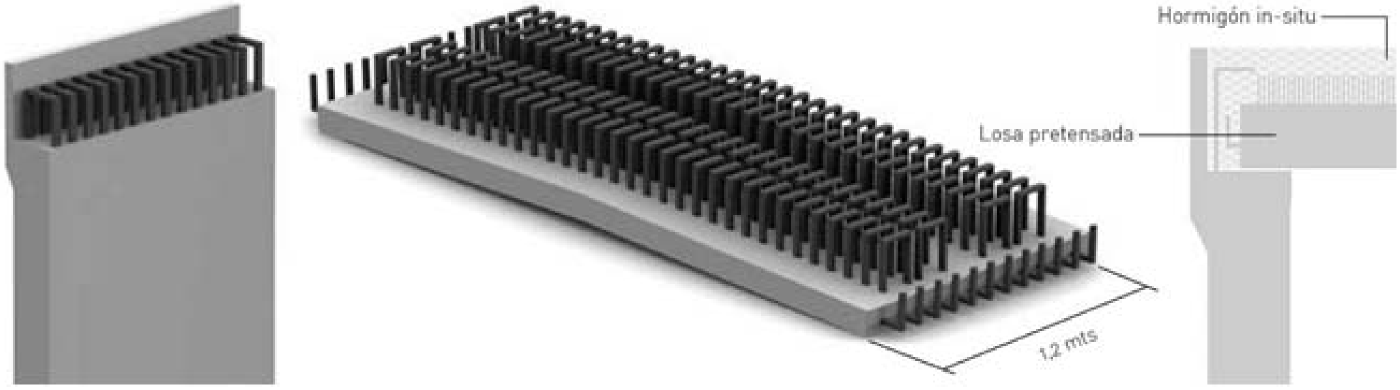
→ We need monitoring & field tests
to measure true dynamic behaviour
and to update our models

Verification by full scale test

- **Summary of full scale tests**
  - ADIF, NECO & CEDEX performed full-scale tests in November 2015.
  - The bridge is designed as a portal frame bridge 8 m span and is located on the high-speed line between Madrid and Barcelona.
  - The instrumentation consisted of accelerometers, geophones, strain gauges and displacement transducers.
  - KTH made dynamic analyses using 3D models.
  - Aim: measure with trains near resonance speed & verify models.

The bridge during passage of a CAF Alvia S-120 train.

Verification by full scale test

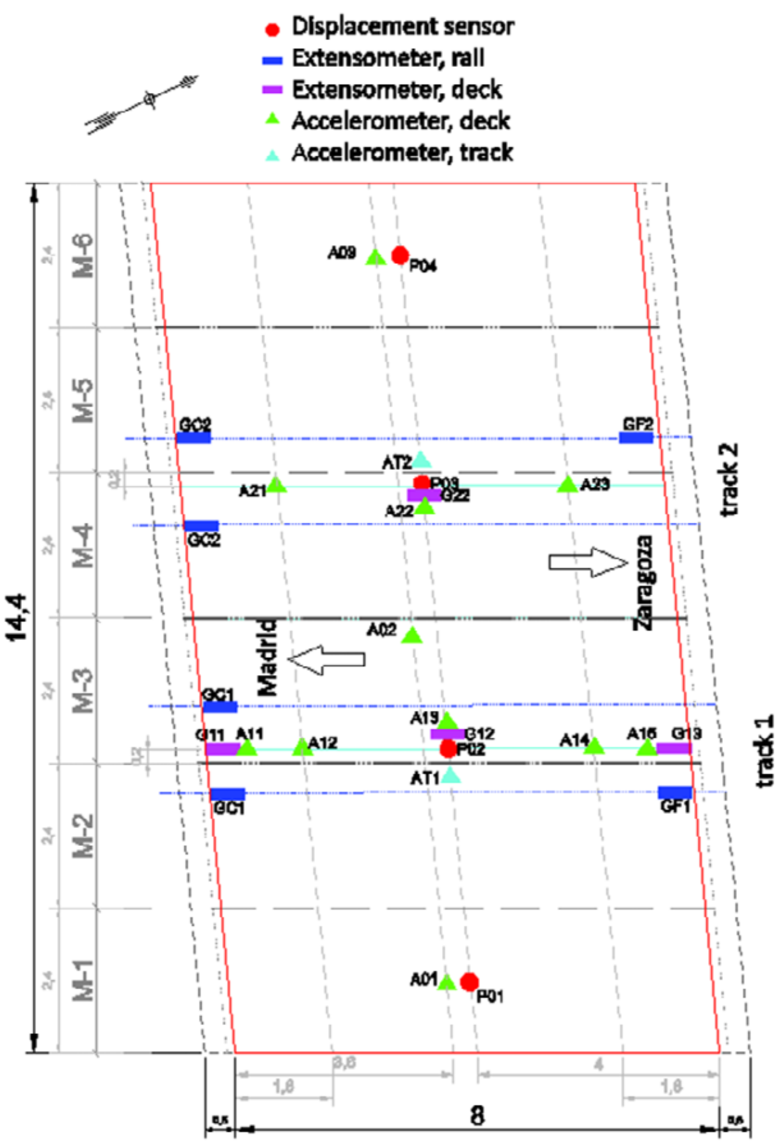


a) b) c)

Pre-fabricated bridge elements, a) upper part of the wall, b) the deck, c) the wall-to-deck connection.

View of a similar bridge during construction.

Verification by full scale test

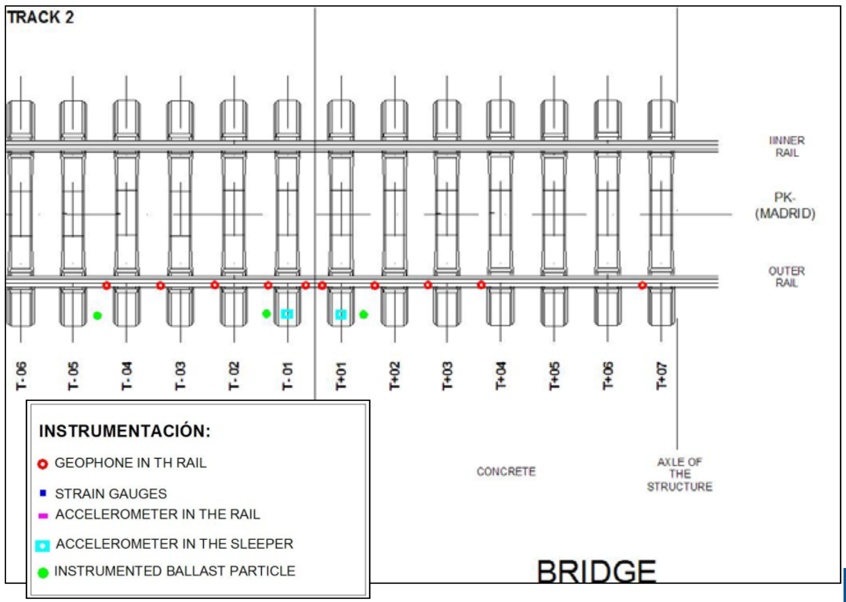


Instrumentation of the bridge by INECO

Estimated natural frequencies and damping ratios, based on free vibrations.

	f_1 (Hz)	ζ_1 (%)	f_2 (Hz)	ζ_2 (%)	f_3 (Hz)	ζ_3 (%)	f_4 (Hz)	ζ_4 (%)
TP01	18.2	4.9	22.7	4.3	31.0	2.3	42.1	2.2
TP02	18.4	5.3	23.2	3.4	30.7	2.3	41.3	2.1
TP03	18.6	5.1	23.2	4.2	30.6	2.8	41.2	2.3
TP04	18.6	4.1	22.7	2.0	30.6	2.1	41.3	2.3

Instrumentation of the track by CEDEX

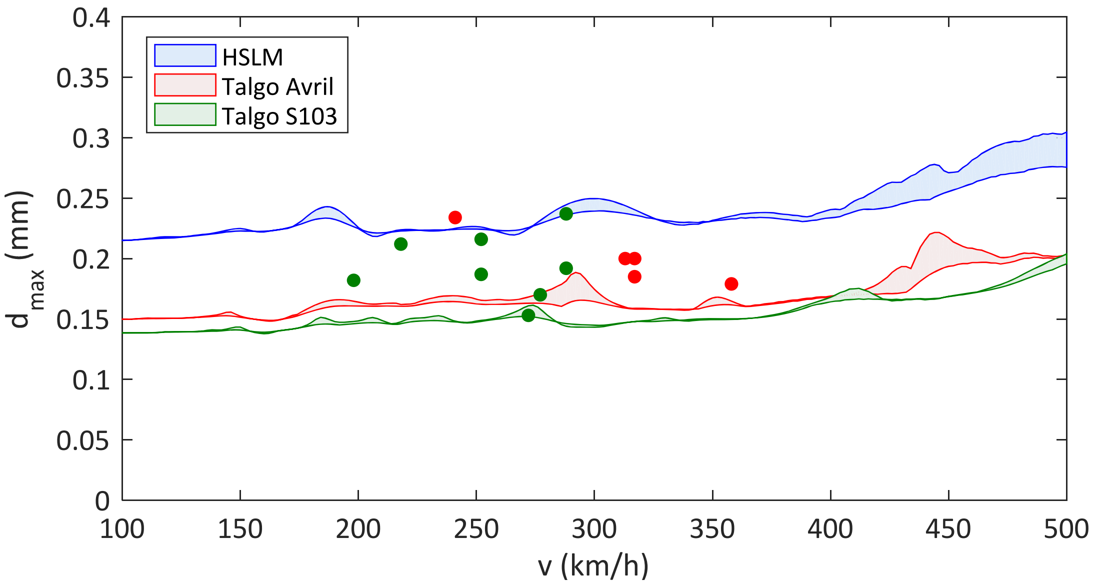


Verification by full scale test

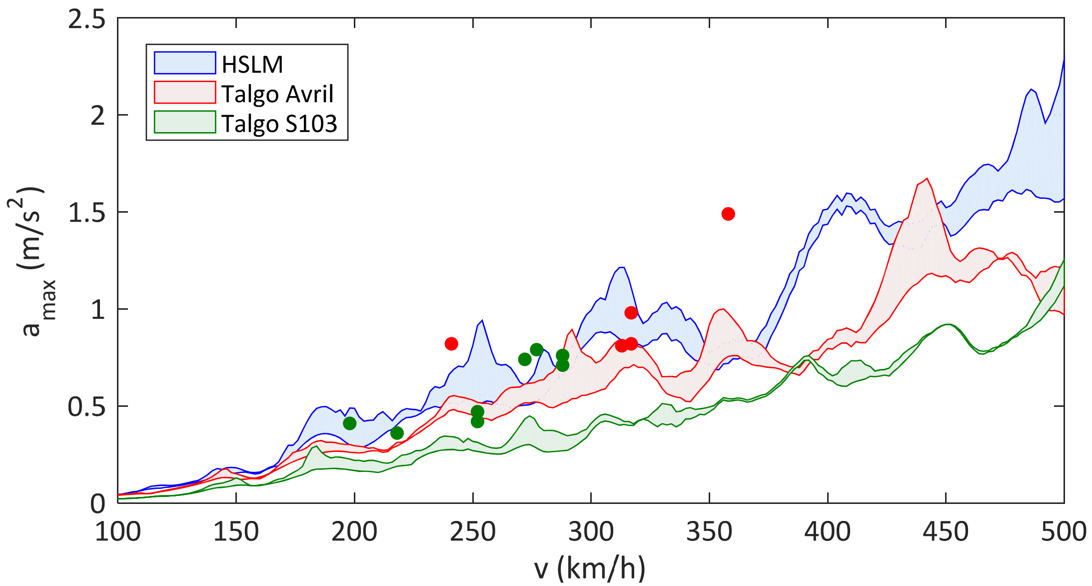
Measured train passages and peak deck acceleration and deck displacement, LP-filtered at 40 Hz.

Train	Direction	v (km/h)	track	amax (m/s2)	dmax (mm)
Talgo Avril	Madrid - Barcelona	317	1	0.98	0.19
Talgo Avril	Barcelona - Madrid	358	1	1.49	0.18
Talgo Avril	Madrid - Barcelona	313	2	0.81	0.20
Talgo Avril	Barcelona - Madrid	317	2	0.82	0.20
Velaro S103	Madrid - Barcelona	277	1	0.79	0.17
Velaro S103	Madrid - Barcelona	252	1	0.42	0.19
Velaro S103	Barcelona - Madrid	198	2	0.41	0.18
Velaro S103	Madrid - Barcelona	252	1	0.47	0.22
unknown	Barcelona - Madrid	-	2	1.11	0.35
Velaro S103	Madrid - Barcelona	218	1	0.36	0.21
unknown	Madrid - Barcelona	-	1	0.34	0.32
unknown	Barcelona - Madrid	-	2	0.55	0.38
Velaro S103	Madrid - Barcelona	288	1	0.71	0.24
Talgo S102	Barcelona - Madrid	241	2	0.82	0.23
Velaro S103	Barcelona - Madrid	272	2	0.74	0.15
Velaro S103	Madrid - Barcelona	288	1	0.76	0.19

Verification by full scale test



Peak deck displacement as function of the train speed. Shaded areas from FE-results (low/high damping), circles from experiment.



Peak deck acceleration as function of the train speed. Shaded areas from FE-results (low/high damping), circles from experiment.

- **Summary of test results**

➢ Measured response from passing trains show a peak deck acceleration of 0.5 – 1.5 m/s^2 and a peak deck displacement of merely 0.2 mm.

➢ The first four modes can be obtained from the free vibration response, consisting of one bending mode and three plate modes.

➢ Based on the free vibrations, the modal damping is estimated to 5% for the first mode, 4% for the second mode and about 2.5% for the third and fourth mode.

➢ A 3D FE-model is updated based on the experimental modal properties. The model proposes that the stiffness in the transverse direction is very low, likely due to the prefabricated elements.

➢ The simulated response from passing trains is generally in good agreement with the experimental results.

Concluding remarks

Concluding remarks

- **Some of the main conclusions drawn from this study are:**
  - The analyses on short span beam and frame bridges show that their dynamic behaviour need to be studied carefully for VHST. These bridges may have acceleration levels above or close to the Eurocode acceleration limit 3.5 m/s^2 or 5 m/s^2 for track without ballast.
  - At the presence of track irregularities, significant high-frequency content was observed in the bridge deck acceleration for some of the case study bridges. There is a need for further research on the behaviour of ballast at different frequencies of vibration in order to give thorough recommendations on the choice of cut-off frequency.
  - Field tests show that there is a risk that our train-bridge models underestimate the response.
  - Many structures have complex 3D behaviour which can be difficult to capture in simple models. (be careful with the support modelling, SSI . ..)
  - Update code requirements so future new bridges can be designed to cope with dynamic effects from VHST.

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Thank you for your kind attention

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