C4R

Capacity for Rail

Track Design Optimization for Very High Speed

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TÉCNICO LISBOA

SEVENTH FRAMEWORK PROGRAMME

C4R
Capacity for Rail

- **Outline**

1. Objectives and framework
2. Computational model
3. Experimental tests
4. Model validation
5. Track response overview for VHS
6. Track design optimization for VHS
7. Final remarks

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Objectives and framework

Task 1.2.2 - "Track design for VHST" aims at proposing innovative **optimized track design for very high speed** on the basis of:

- numerical simulation (IST)
- real scale laboratory test CEDEX (Track box - CTB)

- Computational model **validated** based on the data provided by CEDEX (Track box ballasted track)

- Computational model used to **predict dynamic response** of the reference railway track (CTB) and evaluate **influence of train speed** increase up until 400 km/h.

- Numerical simulations made to evaluate influence of **track design variants** (mainly specific combinations of railpads and USPs - suggestions in collaboration with the other partners as CEDEX, Adif) → support CEDEX to prepare the experimental tests to be done.

- Computational model used to perform guided numerical simulations towards **VHST design optimization** aiming at reduced vibrations inside track and slower track degradation.

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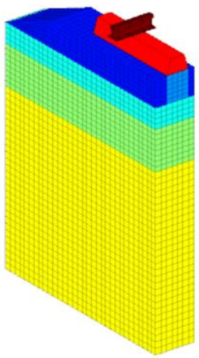
• Computational model



- Continuous media
- 3D elasticity
- Flexible body system
- Hertz contact law

▪ Track model
▪ Train model
▪ Train/Track Simulation

- Finite element method
- Substructuring
- Model reduction
- Newmark time integration

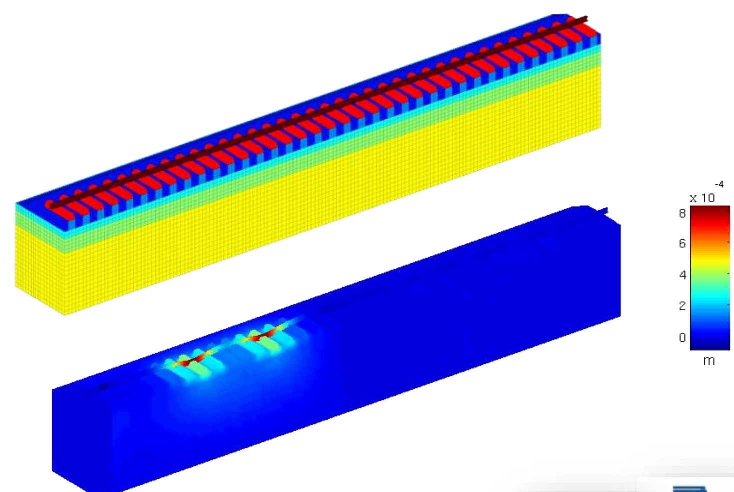
A numerical model of the train/track system has been developed with the aim of both predicting **track instantaneous dynamic** responses to train passage and **track long term** dynamic responses to multiple train passages

Approach enables very fast computing for:

- Dynamic analysis of a single HS train passage

Which makes possible to effortlessly attain:

- Simulations of millions of HS trains passages to predict track settlement progression along time



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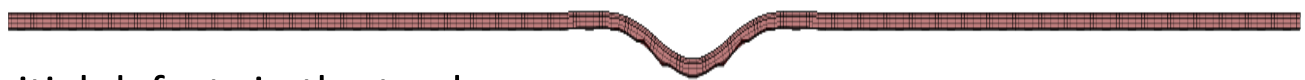
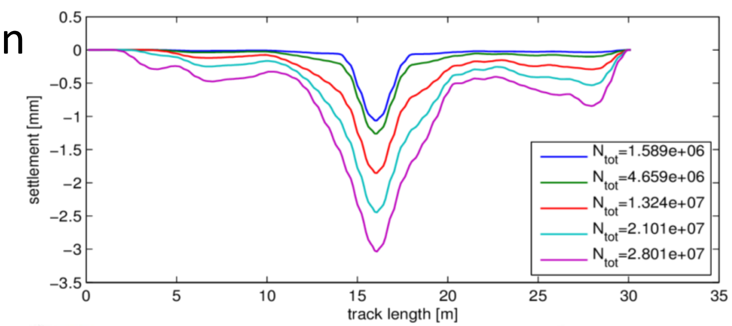
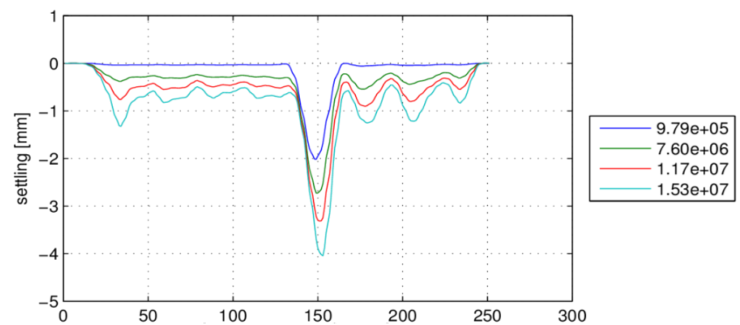
• Computational model

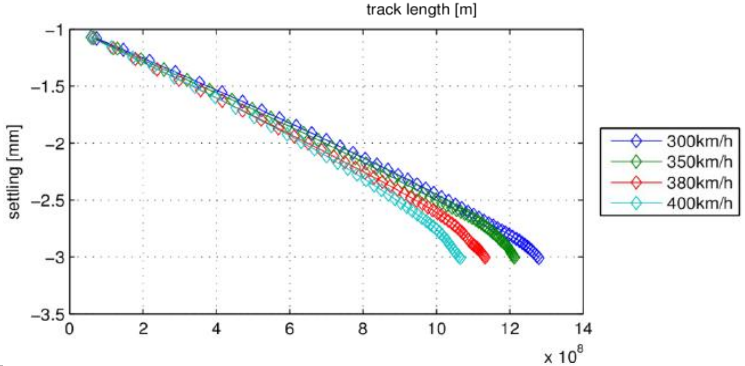
Computational developments for **long-term predictions** of track geometric deterioration

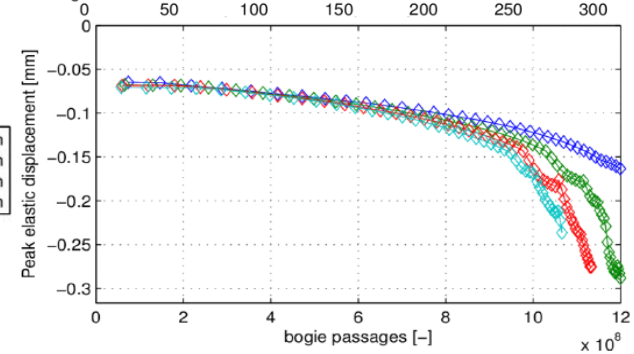


1. Introduction of initial defects in the track
2. Track settlement increases along time, after millions of running cycles
3. Model enables to know track longitudinal configuration at each cycle and its evolution









• Experimental Tests

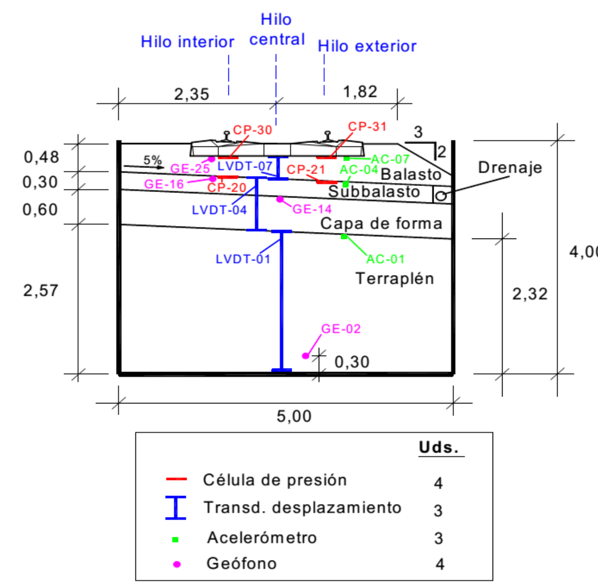
CEDEX Track Box (CTB) – Reference Track case

Trackbox section with granular subballast used for validation with results from model

Railway components

Component type	Description
Rails	UIC 60-E1
Rail pads	
Type	PAE2
Thickness	7 mm
Area	148×180 mm2
Nominal stiffness	Around 100 kN/mm
Secant stiffness	Between 20 kN/mm and 95 kN/mm
Sleepers	
Type	AI-99 (Monoblock)
Mass	344 kg (average)

source: (CEDEX, 2015)



Track box: cross-section schematic representation with sensors location

Material properties of the supporting layers

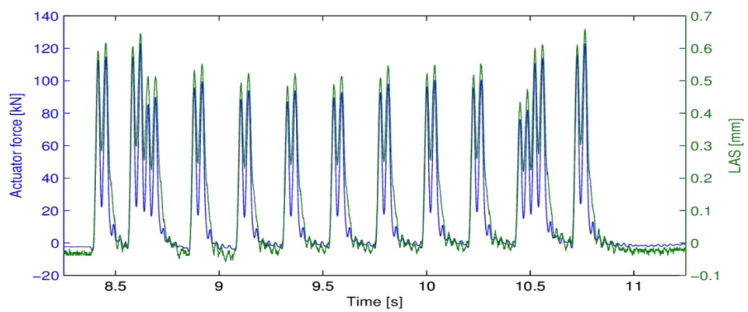
	h [m]	E [MPa]	v [-]	Density [kN/m^3]
Ballast	0,40	230	0,20	17,0
Granular sub ballast	0,30	440	0,30	22,0
Form layer	0,60	400	0,30	21,5
Embankment	2,57	385	0,40	20,2

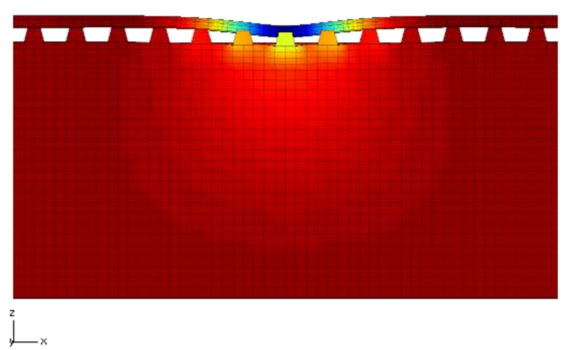
Track Design Optimization for Very High Speed

- **Model validation**

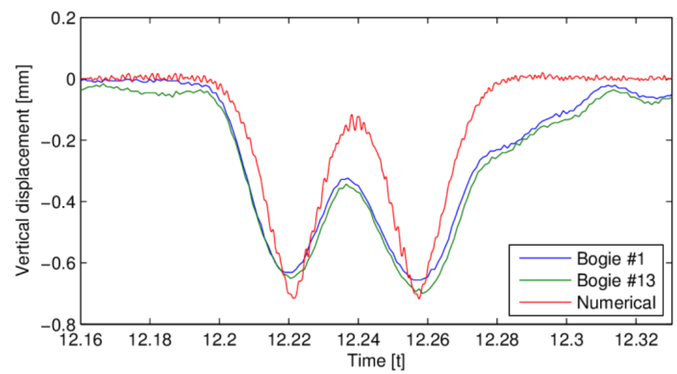
  Comparison of Experimental and Computational Results

  <u>Static and Quasi-Static Tests</u>

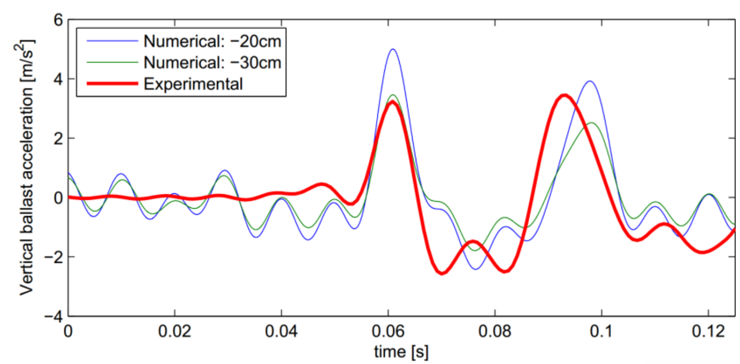




rail vertical displacement time signals

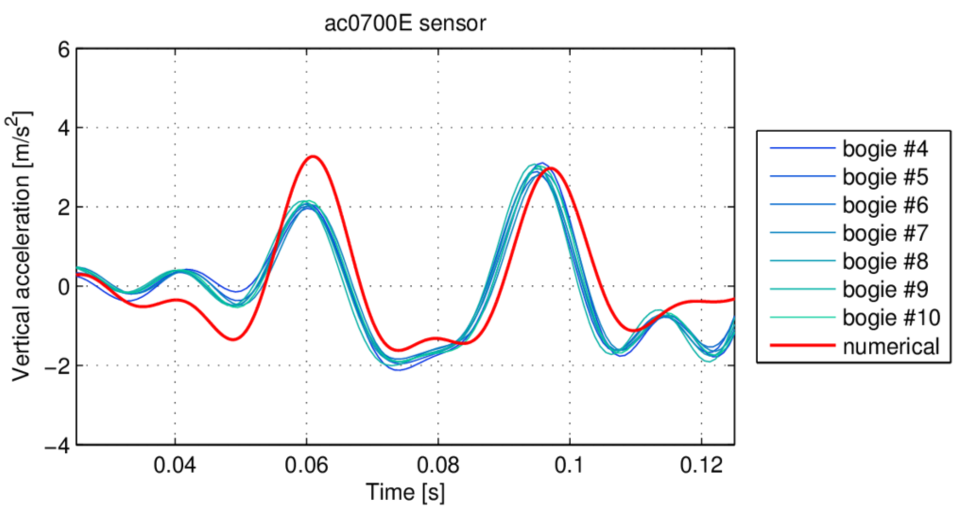


ballast vertical displacement time signals

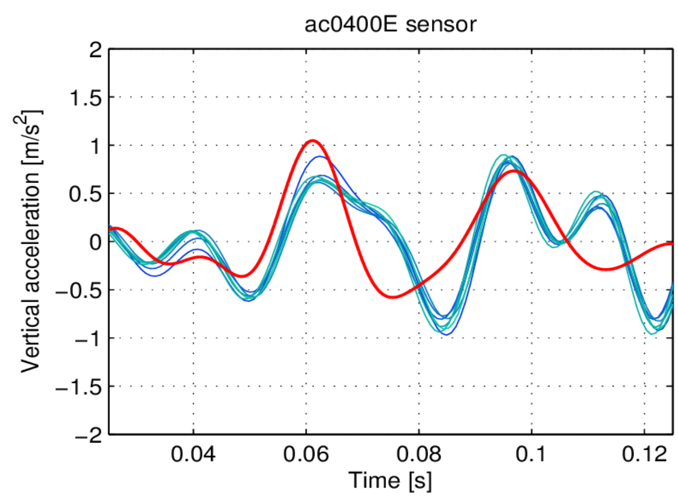


- **Model validation**

Comparison between experimental measurements CTB and dynamic calculations at 300km/h



ballast vertical acceleration time series

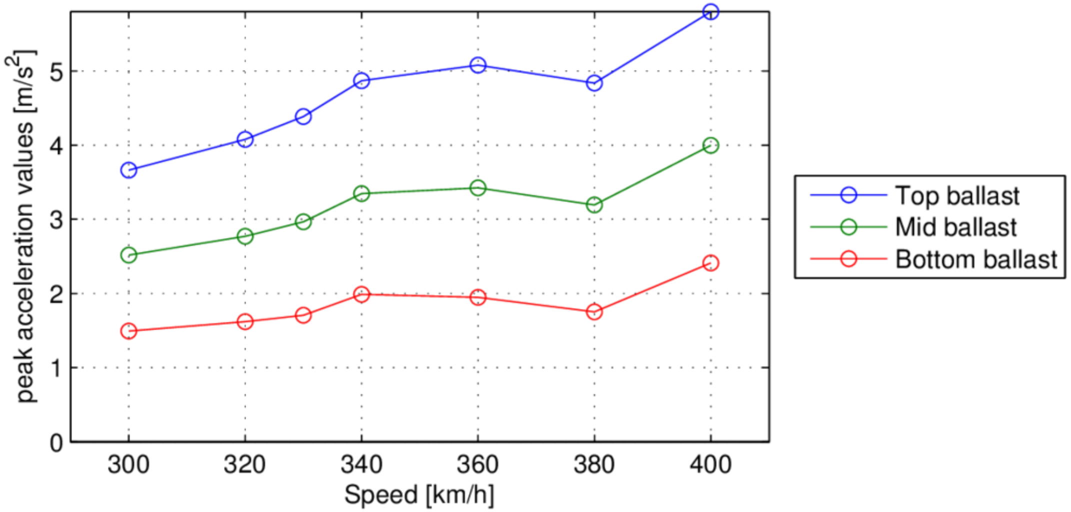


sub-ballast vertical acceleration time series

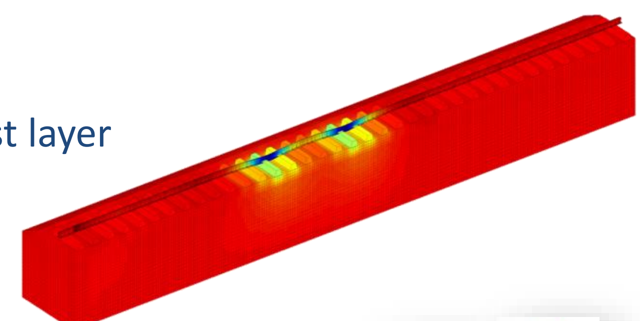
- **Track response overview for VHS**

Train speed influence on CTB track case

Dynamic calculations of CTB track reference case : influence of train speed increase from 300 to 400 km/h



Peak vertical acceleration values within the ballast layer



- **Track response overview for VHS**

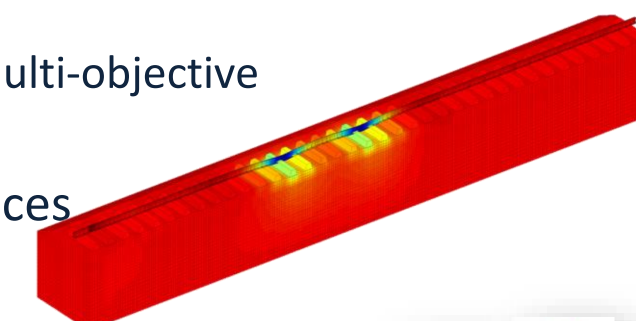
Track response overview: key aspects

- Input parameters: rail pad and USP vertical stiffness
- Design space bounds

  Rail pads: 20 kN/mm to 200 kN/mm

  USPs: 20kN/mm to 500 kN/mm
- Circulation speeds: 300, 350 and 400km/h.
- Multi-objective minimization problem

  Minimize peak vertical acceleration levels within ballast layer and sleepers
- DIRECT algorithm (IST version with support for multi-objective optimization)
- Simulation data used generate response surfaces

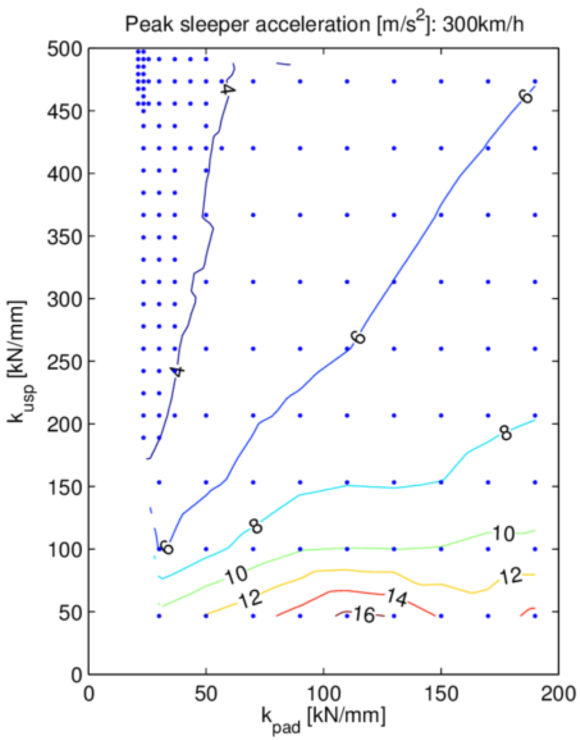


- **Track response overview for VHS**

Sleeper and ballast max accelerations: **300km/h**

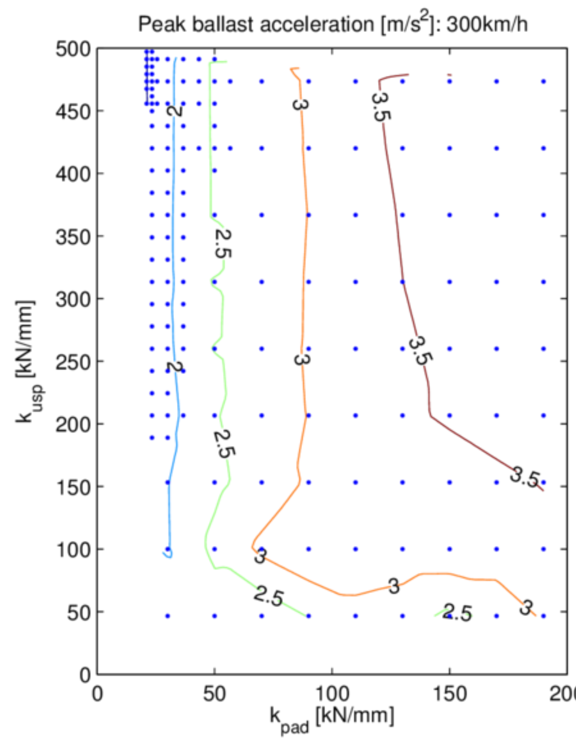
influence of **rail pad** and **USP** vertical stiffness **(k_{pad}, k_{usp})**

k_{usp}



k_{pad}

k_{usp}



k_{pad}

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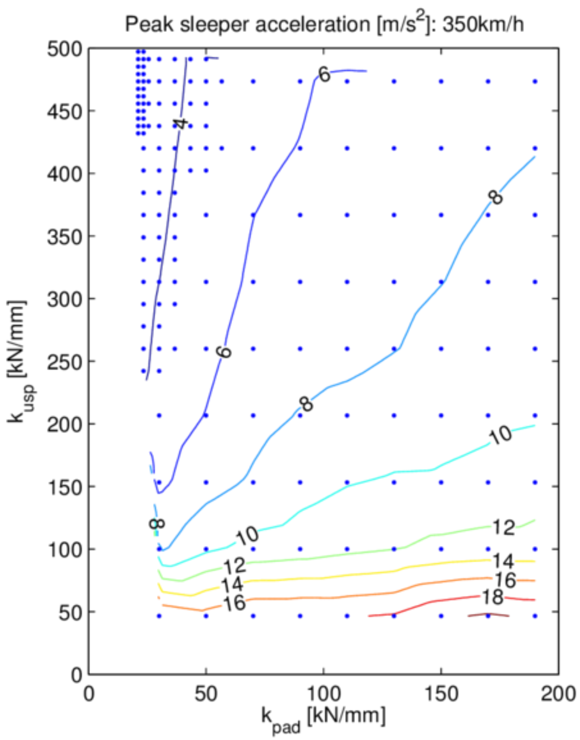
- **Track response overview for VHS**

Sleeper and ballast max accelerations: **350km/h**

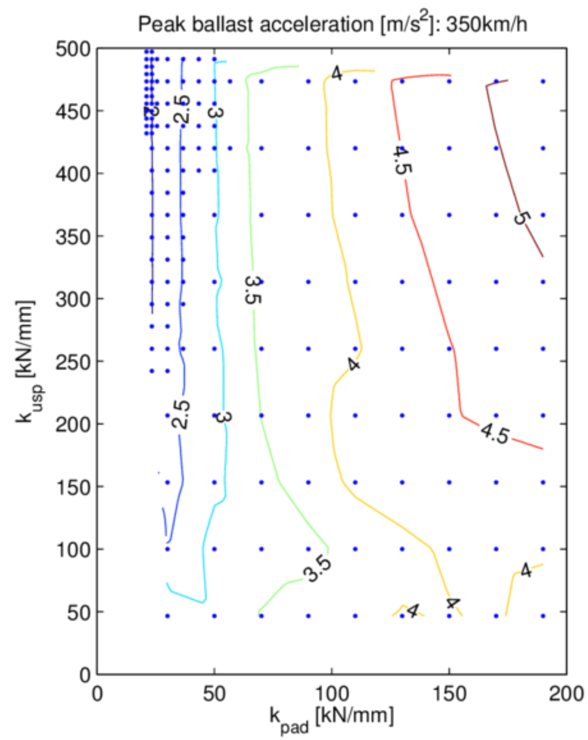
influence of **rail pad** and **USP** vertical stiffness **(k_{pad}, k_{usp})**

k_{usp}



k_{pad}

k_{usp}



k_{pad}

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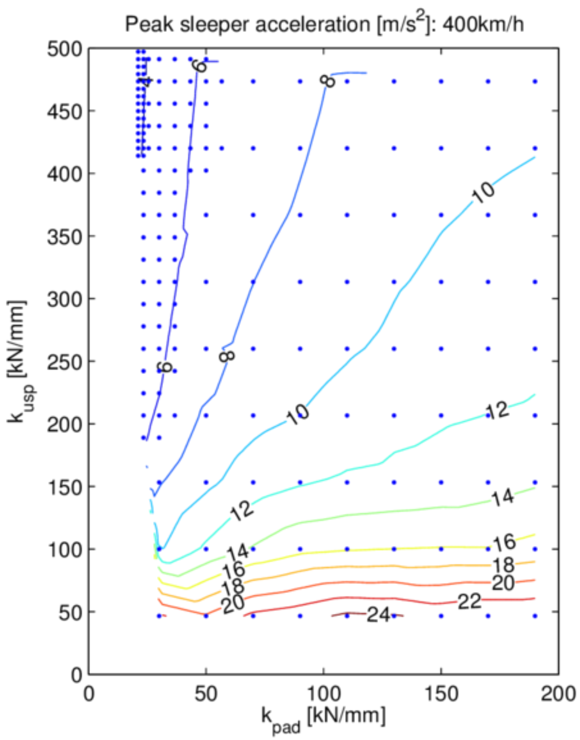
- **Track response overview for VHS**

Sleeper and ballast max accelerations: **400km/h**

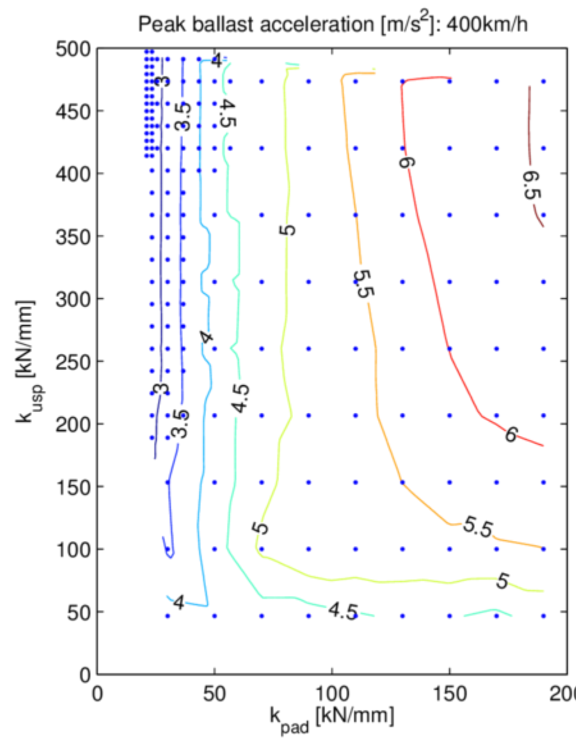
influence of **rail pad** and **USP** vertical stiffness **(k_{pad}, k_{usp})**

k_{usp}



k_{pad}

k_{usp}



k_{pad}

- **Track response overview for VHS**

Remarks

Influence of **rail pad** and **USP** vertical stiffness variations **(k_{pad}, k_{usp})**

- Peak sleeper acceleration

  Decrease with increased k_{usp}

  Sensitivity is higher when k_{usp} is low

  Peak values are very high when k_{usp} is low

  Qualitatively, the link between peak vertical vibration levels and the design parameters (vertical stiffness of rail pads and USPs) is observed on all circulation speeds.

- Peak ballast acceleration

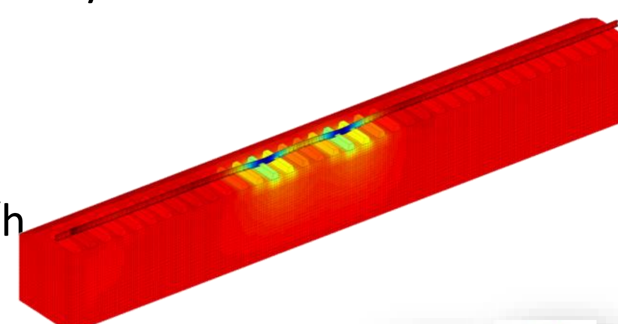
  Insensitive to k_{usp}, except when k_{usp} values are very low

  Sensitive to k_{pad}

- Caution

  No real in situ data on USP tracks

  No measurements from VHS trains at 400km/h



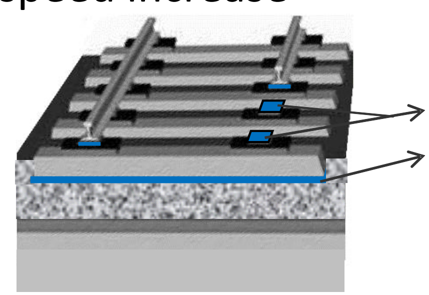
• Track design optimization for VHS

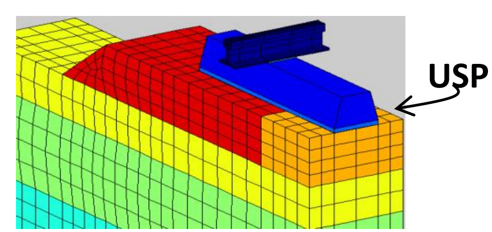
TEST plan support CEDEX to prepare tests in the CTB; coordination with other partners

- **Track design variants** to be tested: combinations of **Railpads+USPs**
  - **Compute dynamic** simulations of the passage of a train circulating at high and very-high speeds on each track variant
  - **Evaluate peak acceleration levels** observed in the track (in particular ballast layer and on the sleepers)
- **Optimized Design** to enhance track dynamic performance, **controlling and reducing** track vibrations with speed increase

Test reference	Kpad [kN/mm]	Kusp [kN/mm]	Variant description	Notes
Test 1	100	-	**M(100,-)**	Reference Track box CTB
Test 2	40	-	**M(40,-)**	
Test 3	60	-	**M(60,-)**	
Test 4	40	80	**M(40,80)**	Test 2 + USP
Test 5	60	80	**M(60,80)**	Test 3 + USP
	80	80	**M(80,80)**	Additional variant
Test 1 + USP	100	80	**M(100,80)**	Reference CTB + USP
	60	200	**M(60,200)**	Additional variant
	60	500	**M(60,500)**	Additional variant
	80	50	**M(80,50)**	Additional variant
	100	50	**M(100,50)**	Additional variant

$M(k_{pad}, k_{usp})$





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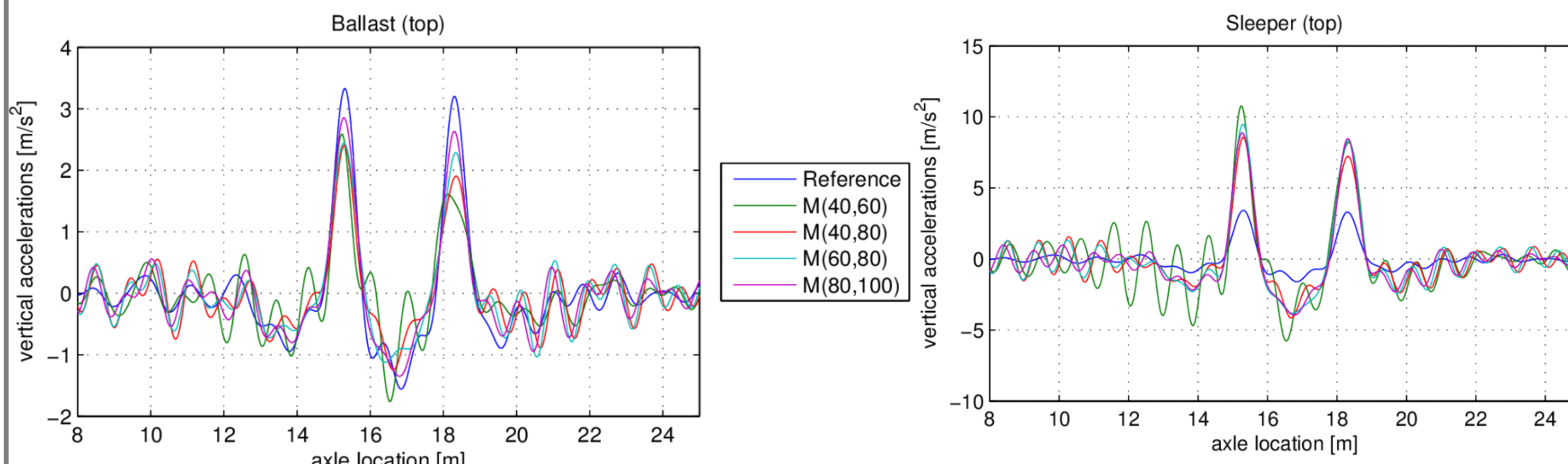
• Track design optimization for VHS

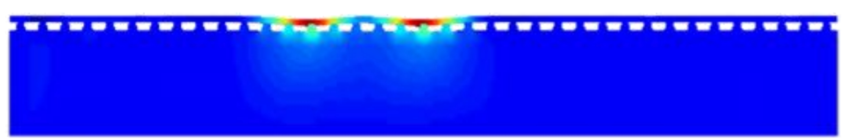
Parametric study

Railpad+USP

Rail pad stiffness k_{pad} [kN/mm]	40, 60, 80, 100
USP stiffness k_{usp} [kN/mm]	40, 60, 80, 100
Train speed v [km/h]	300, 320, 330, 350, 360, 380, 400

Comparisons of **ballast** and **sleepers** vertical acceleration time series for 300 km/h





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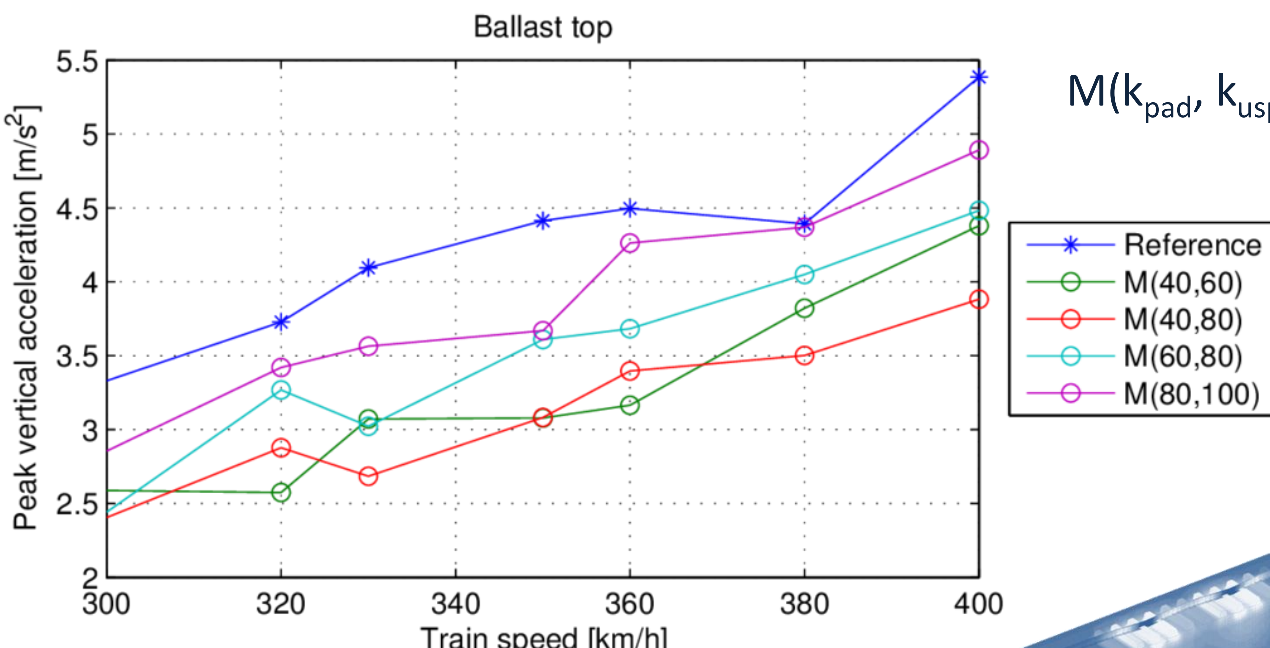
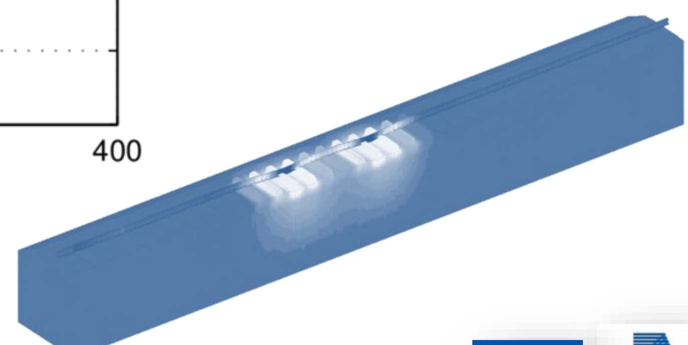
• Track design optimization for VHS

Parametric study: Influence of train speed

Peak **ballast** responses for the different selected variants



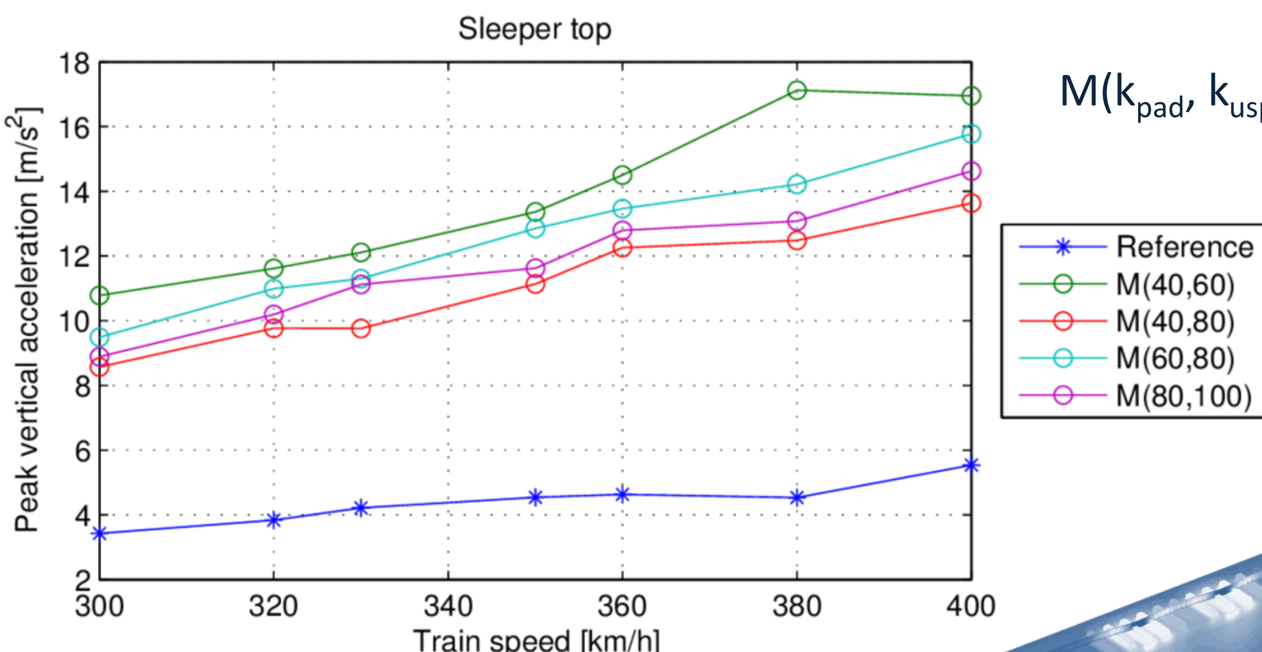
$M(k_{pad}, k_{usp})$



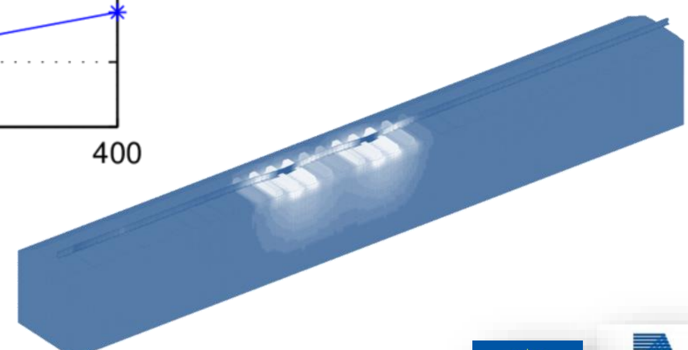
Track design optimization for VHS

Parametric study: Influence of train speed

Peak **sleeper** responses for the different selected variants



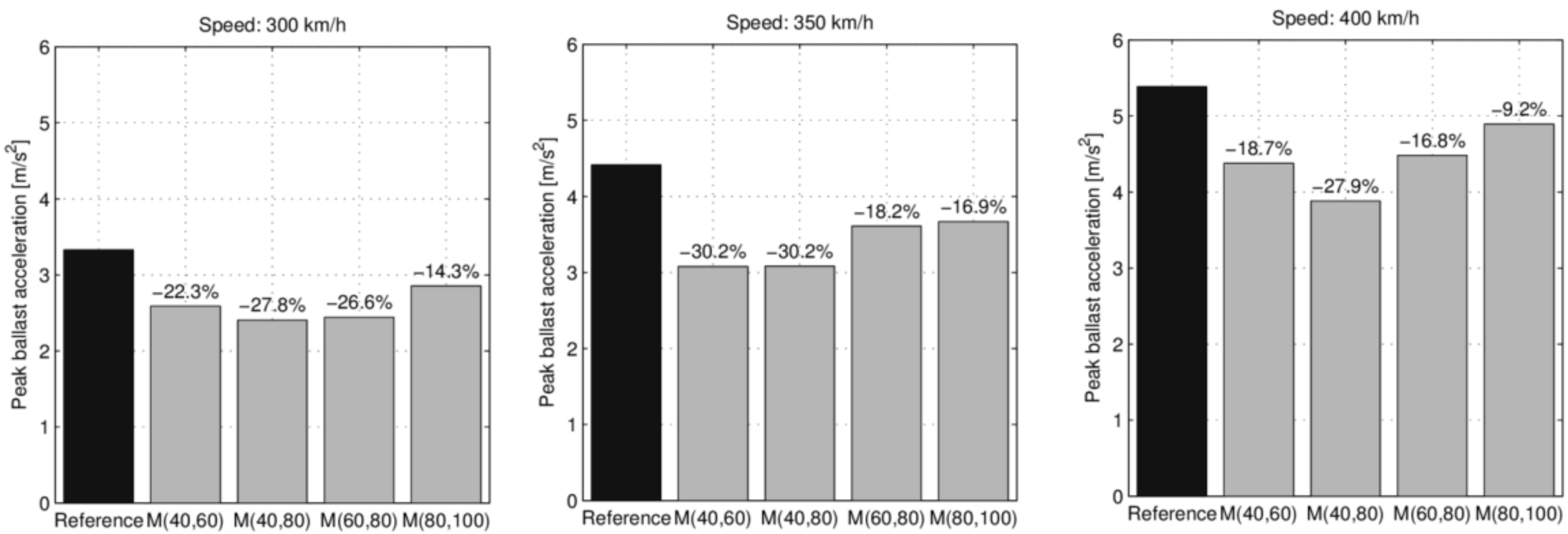
$M(k_{pad}, k_{usp})$

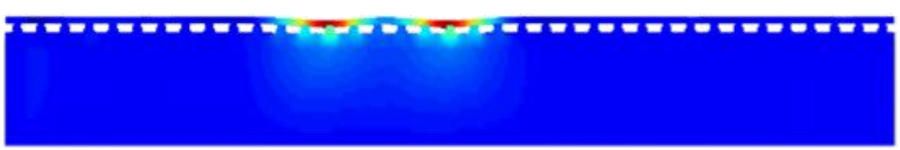


- **Track design optimization for VHS**

Parametric study

Relative reductions in peak **ballast** accelerations with regards to the reference model





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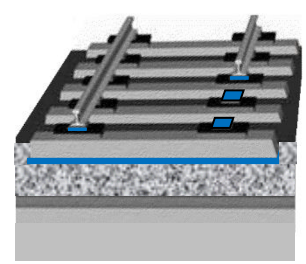
• Final Remarks

- ✓ The introduction of USPs results in a significant reduction in peak vertical displacement and acceleration levels within the track supporting layers, ballast layer included, for all the track design solutions tested.
- ✓ However, it must be highlighted that these improvements are accompanied by increases in peak vertical displacement and acceleration levels on track components supported by the USPs, as the rails and the sleepers.
- ✓ Notwithstanding, the results also suggest that incorporating stiffer USPs may reduce peak acceleration levels within the ballast layer while preserving peak sleeper acceleration levels.



• Final Remarks

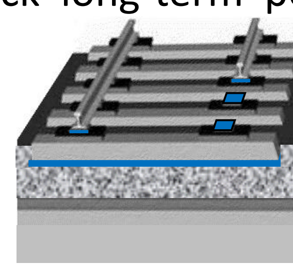
Along the interpretation and critical analysis of the results attention must be paid to the following:

✓ The numerical model is not able to consider the following positive effects known already to be provided by USPs:

- increase in the interface and load-distributing area between sleepers and ballast
- embedding effect of the ballast stones by the USP elastic layer

✓ Any results obtained for trains speeds of 400km/h must be taken with care as no validation with real measurements was made at these speeds;

✓ The numerical results here analysed are provided exclusively from short term computations, that is, only track instantaneous responses are obtained, so, conclusions cannot be directly extrapolated to track long-term performance nor within a life cycle analysis perspective;



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Thank you for your kind attention

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