Railway Bridges for High Speed Lines: Dynamic Behaviour and Risk

Analysis and Risk Management in Production Activities
CERUP, Porto 2007

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   - Recent Events
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3. Service Limit States: Risk to Traffic
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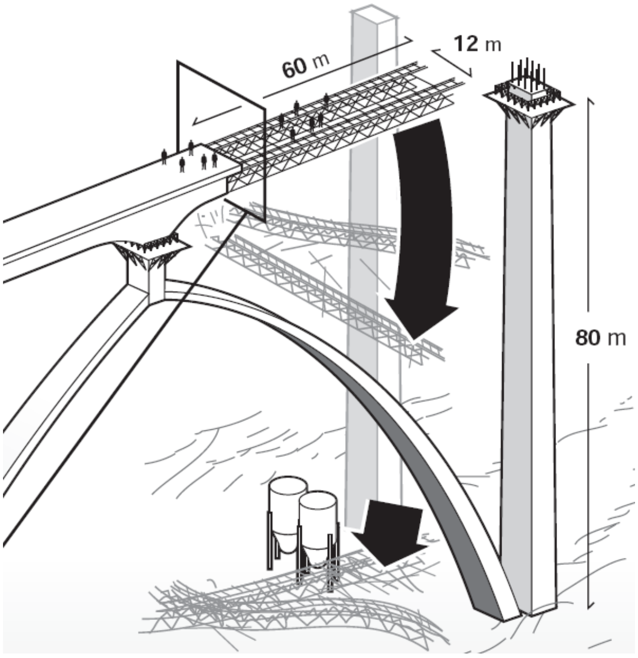
Almuñécar, Granada (Spain)

Road bridge under construction
Collapse of scaffold (7 nov 2005):
6 workers dead



O Carballiño, Orense (Spain)

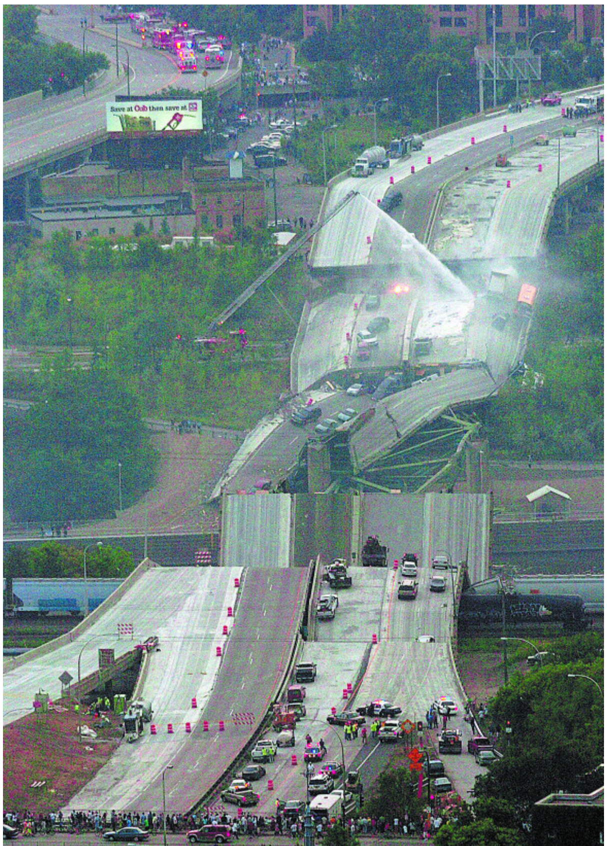
HSR bridge under construction
Incrementally launched deck
(pushing)
7 sep 2007
1 worker dead

Baghdad, Sarafiya Bridge

Main urban road bridge
Truck bomb (12 apr 2007)
$\approx$ 10 people dead

Minneapolis

Main urban road bridge
2 aug 2007: Brittle collapse;
13 people dead



Aeroelastic induced vibrations

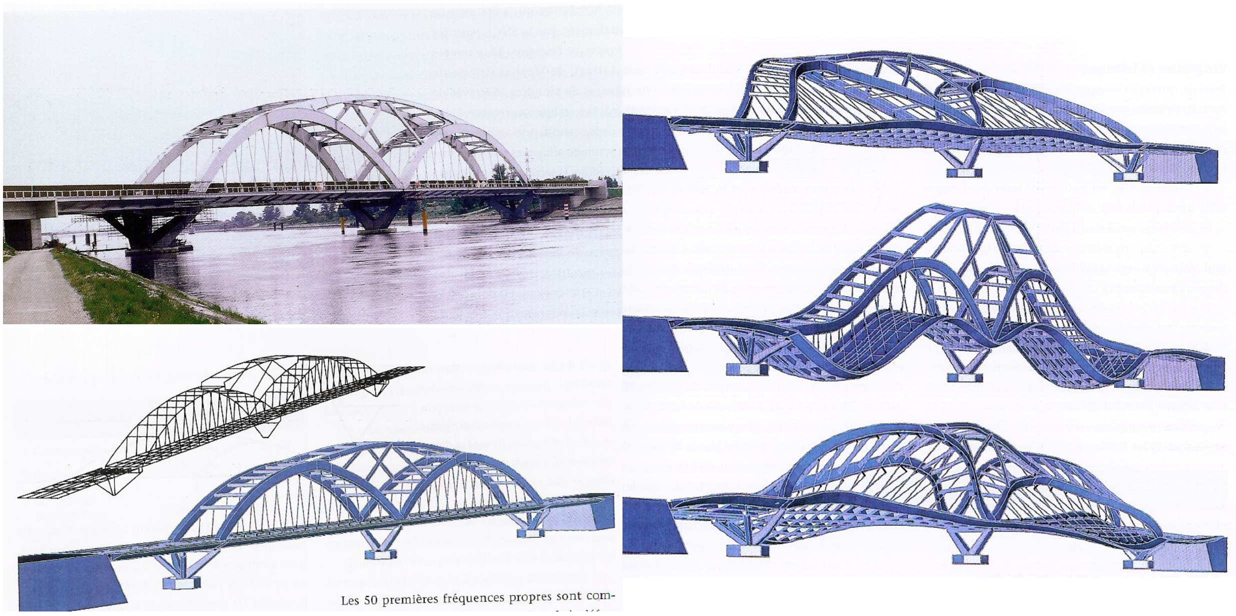
Tacoma Narrows 1940

Alconétar Arch 2006

Wind Actions (IAPF 2007)

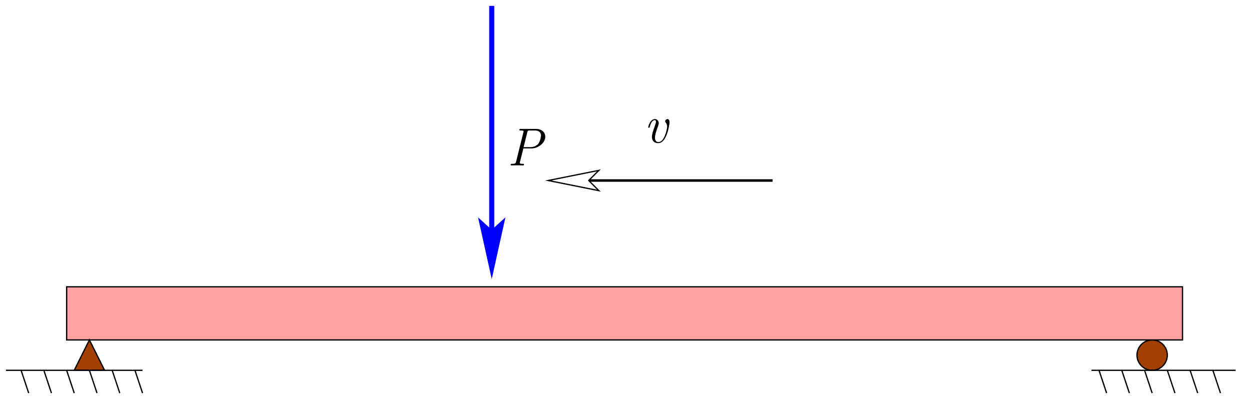
- *Normal bridges:* static wind forces
- *Singular bridges* ($L > 200$ m,...): special dynamic study

High Speed Railway Bridges

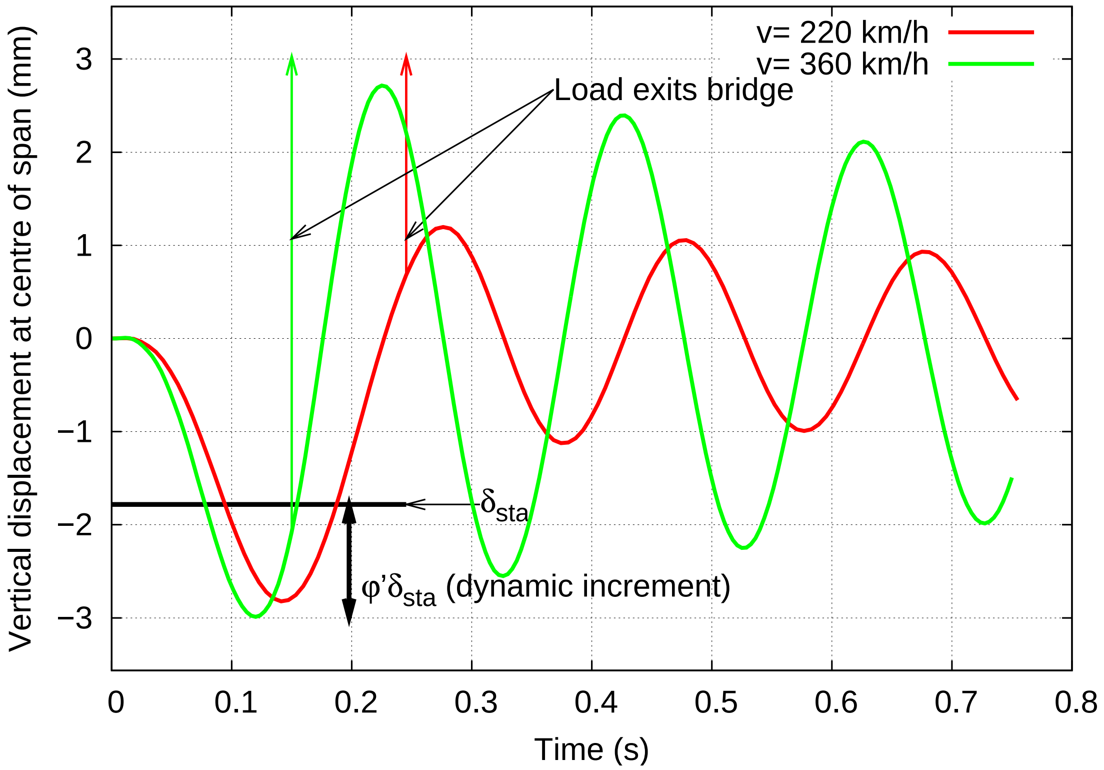


TGV Méditerranée, Donzère viaduct (arch. Marc Mimram)
Dynamic analysis: Ing. V. de Ville de Goyet

Moving load on bridge

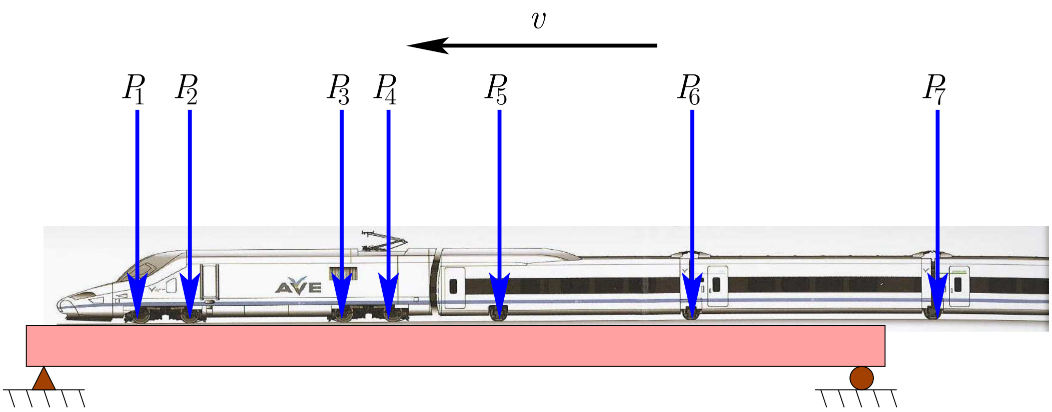


Dynamic effect of single moving load: $(1+\varphi')\delta_{\text{sta}}$



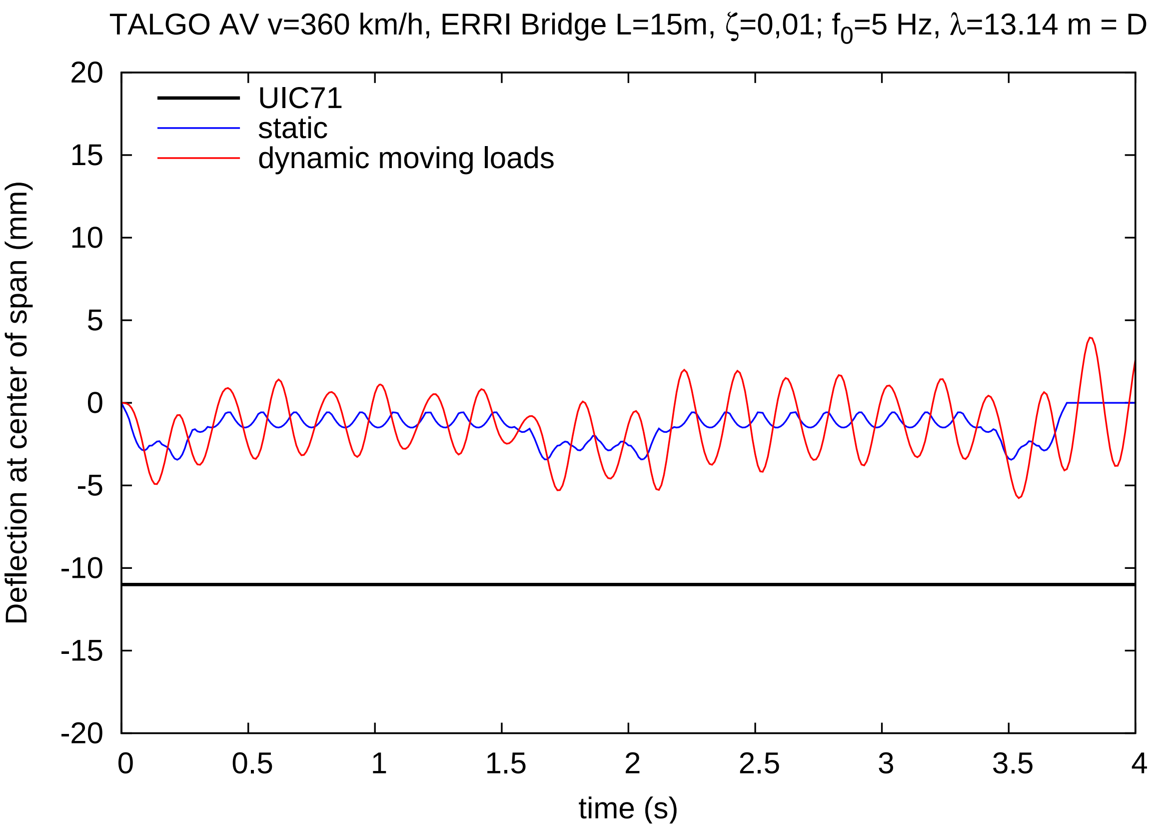
$L = 15\ m,\ \overline{m} = 15\ t/m,\ f_0 = 5\ Hz,\ P = 195\ kN,\ \zeta = 2\%.$

Dynamic effect of train

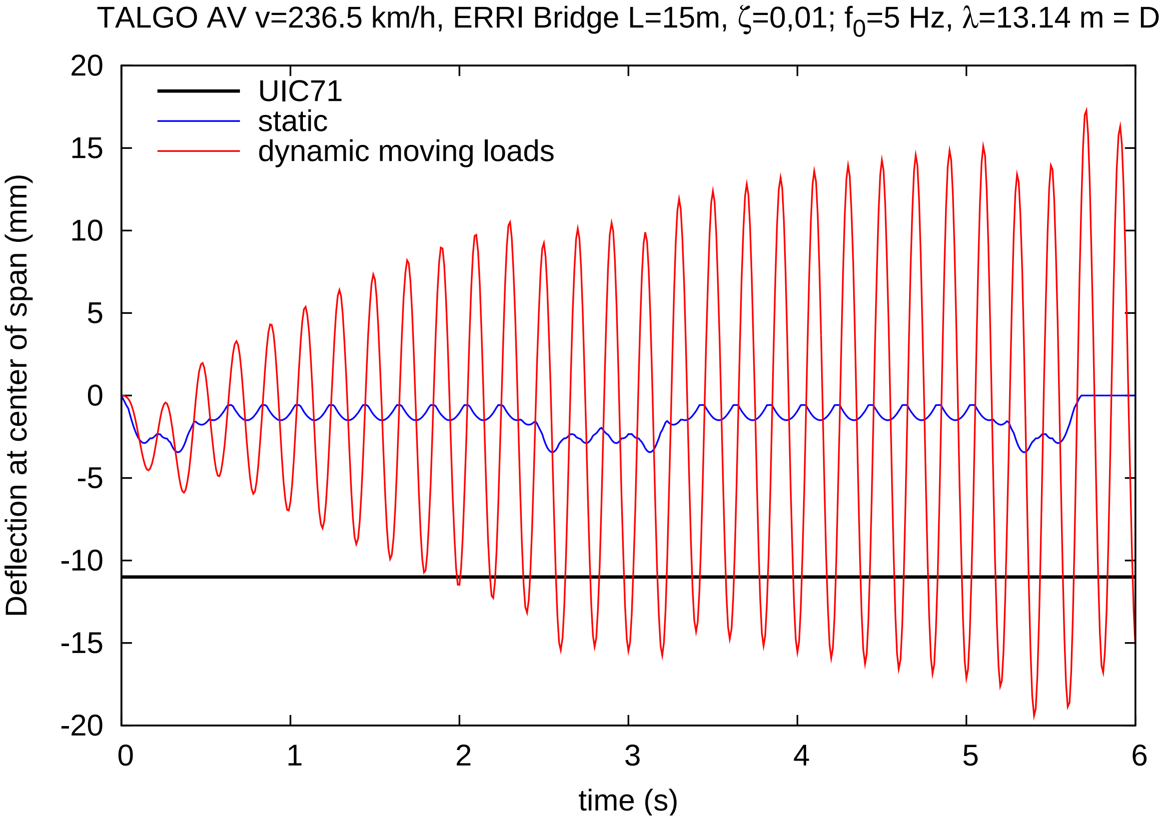


(Talgo HS train)

Time-history of displacements: $v = 360$ km/h

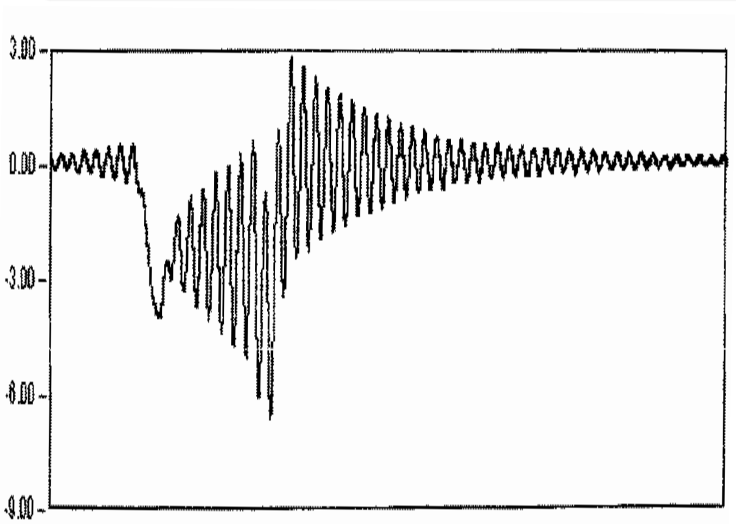


Dynamic effect of train: $v = 236.5$ km/h resonance!

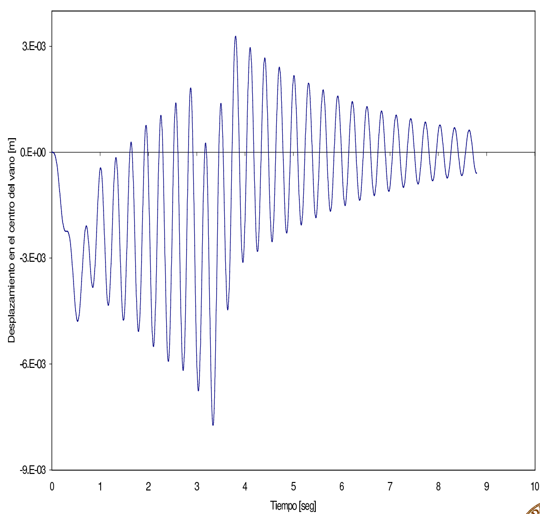


Experimental measurements: Tajo viaduct

AVE 100, simple convoy, $v = 219$ km/h

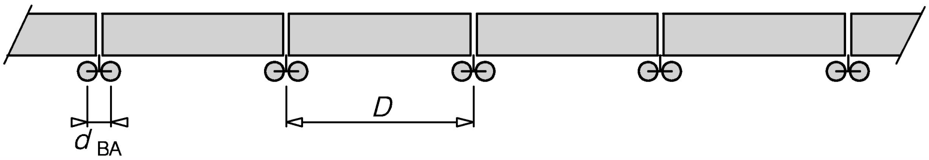


Measured displacements [mfom 96]

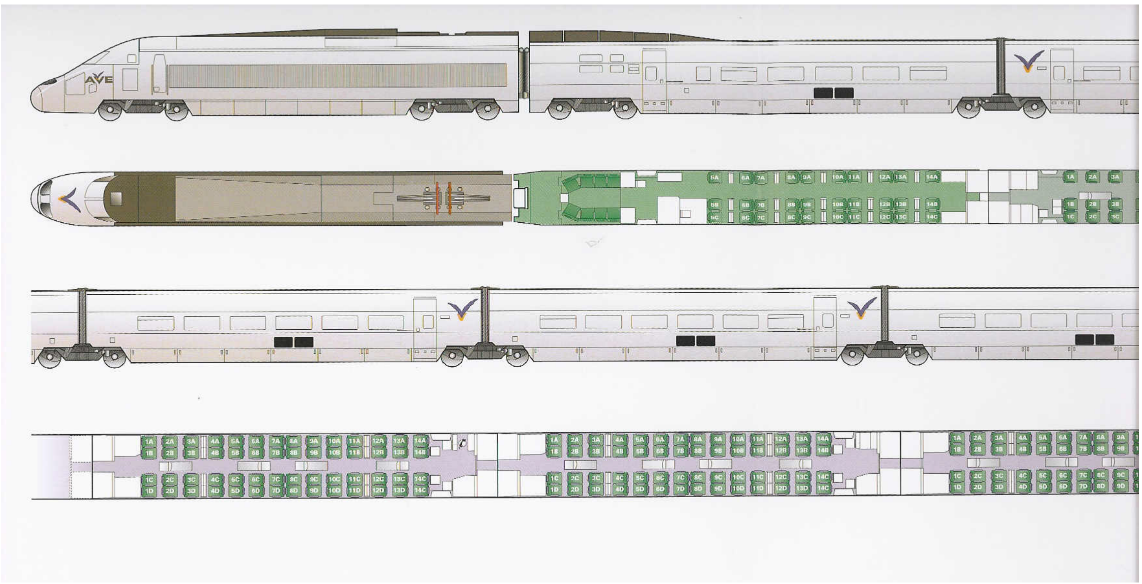


Computed displacements [Domínguez 99]

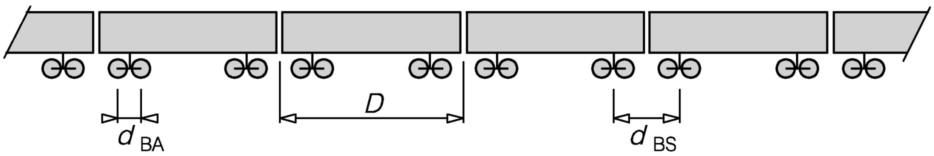
HS Trains: Articulated



Thalys, AVE-100 and Eurostar.

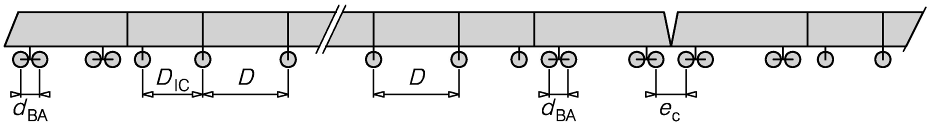


HS Trains: Conventional

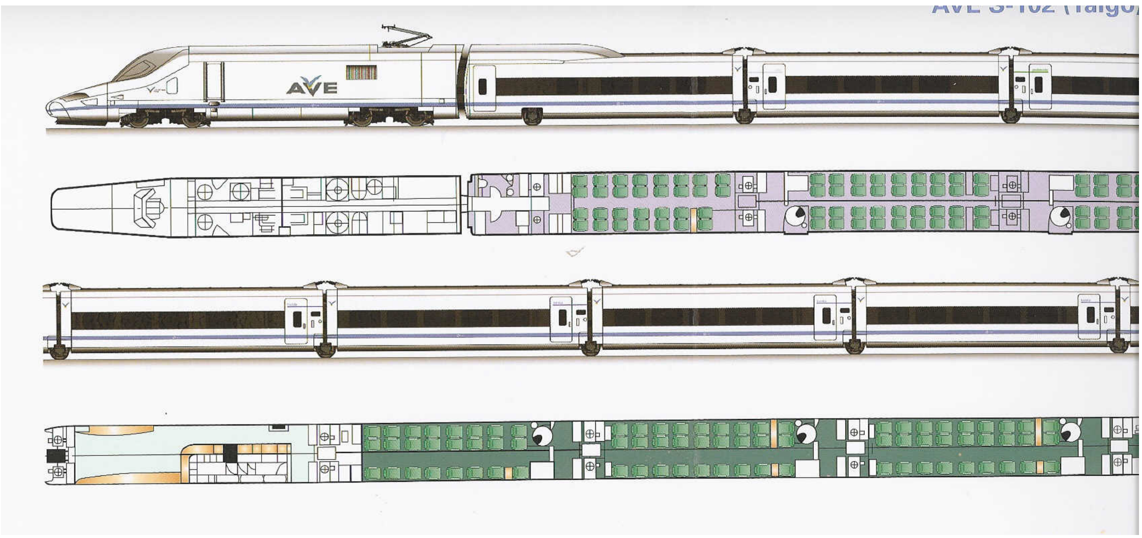


ICE2, AVE-103, Etr-y, Virgin.

HS Trains: Regular

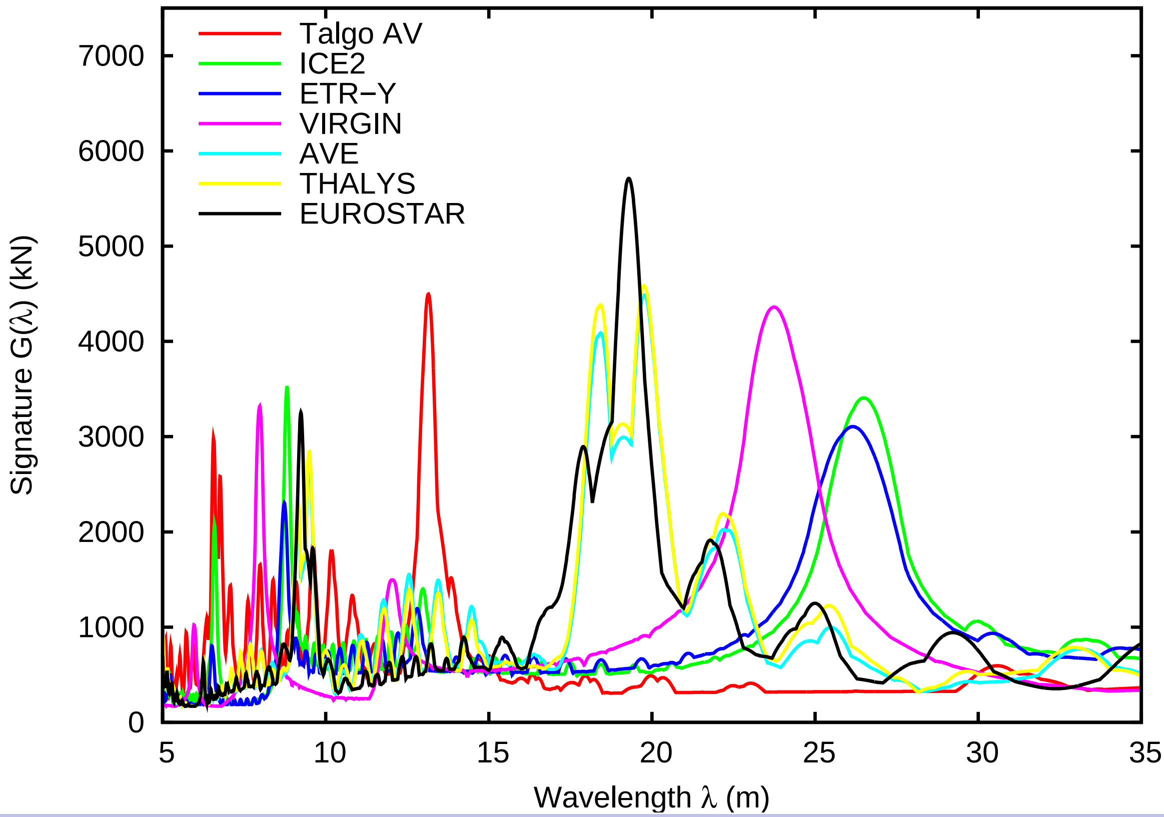


AVE-102 (TALGO).



Dynamic Signature of High Speed Trains

$G(\lambda)$ closed form expression; $\lambda = v/f_0$ wavelength



Requirements for Design

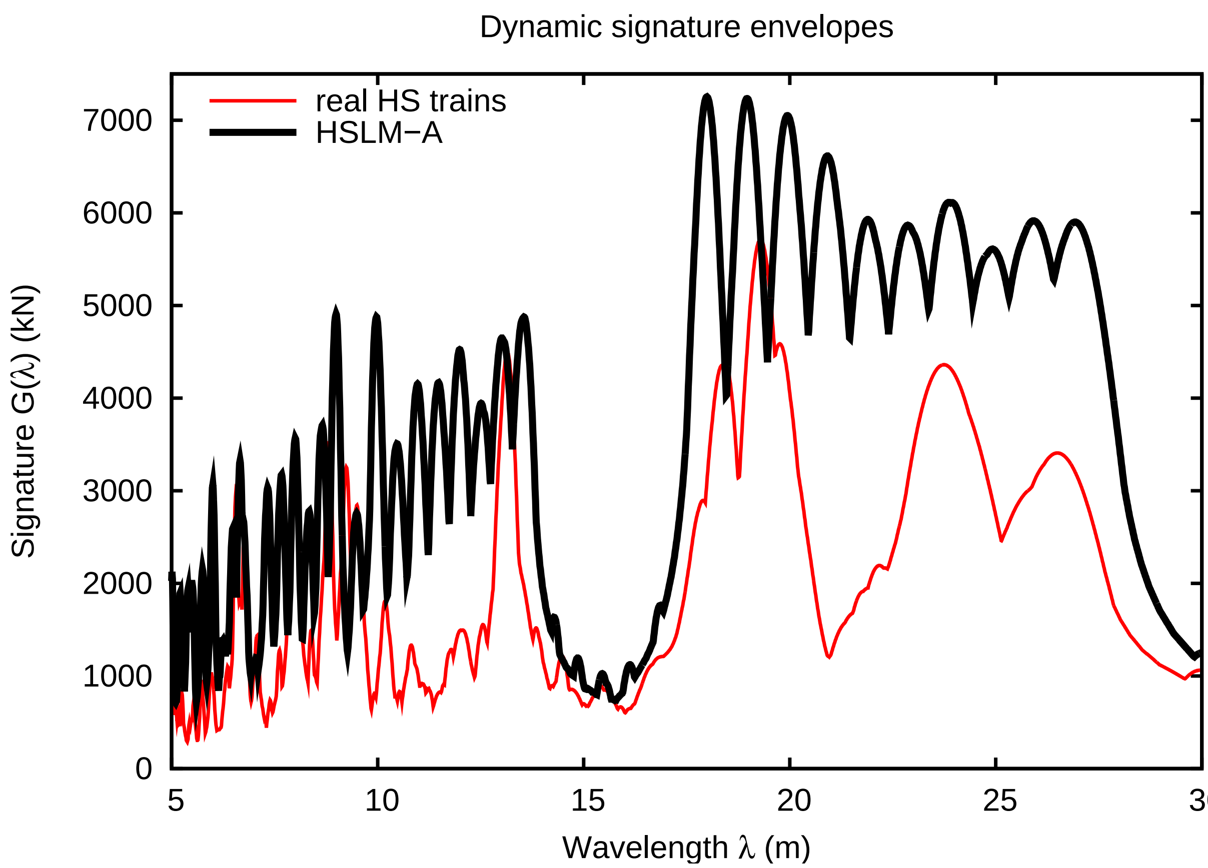
Need to consider:

- Dynamic effects
- All possible circulation speeds, with 20% margin
- All existing and foreseeable HS trains (interoperability)

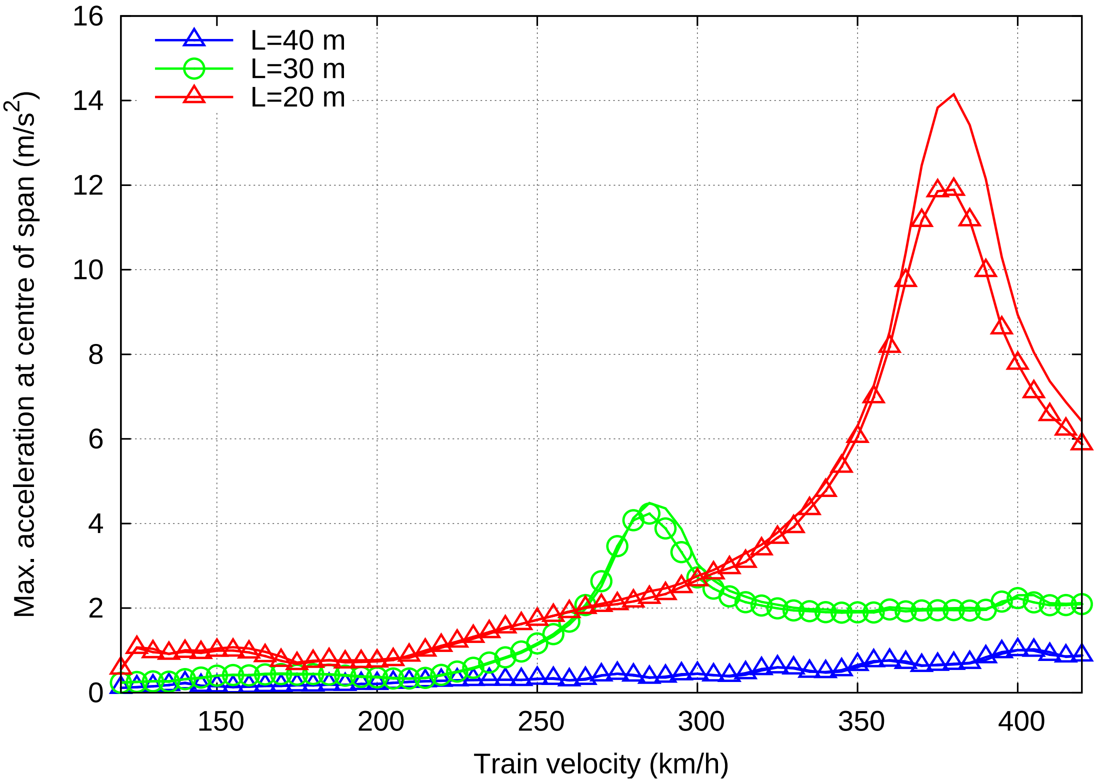
High Speed Load Model (HSLM)

- Family of 10 normalised, *ficticious* trains
- *Interoperability* of HS lines in Europe (TSI)

Envelope Obtained with HSLM-A Trains

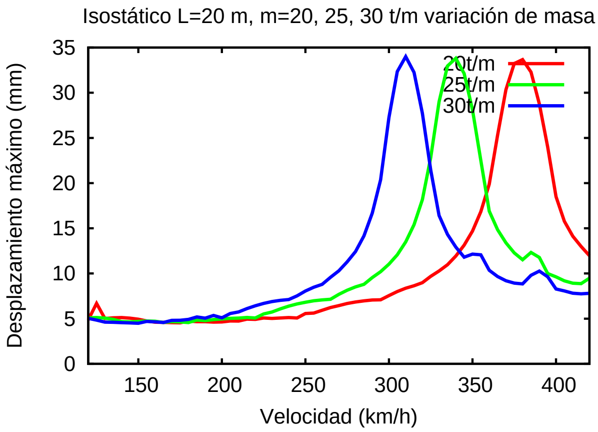


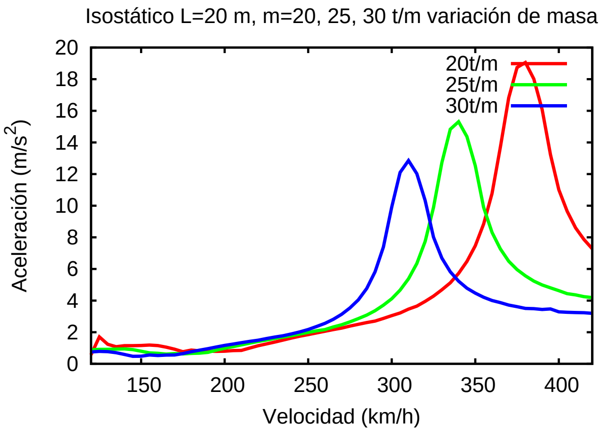
Dynamic Response for Bridges of Different Span Length



ICE2 train, acceleration at mid span

Increase Mass of Bridge

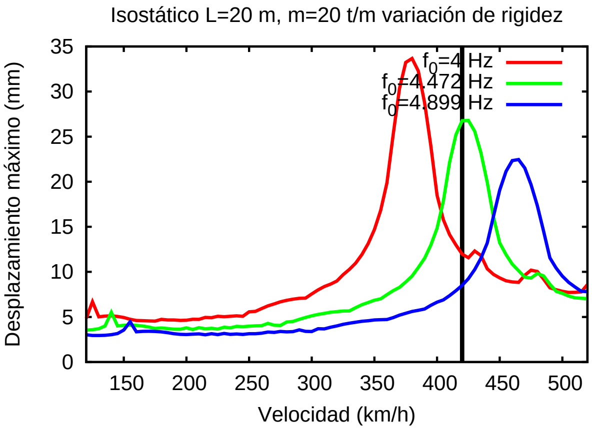


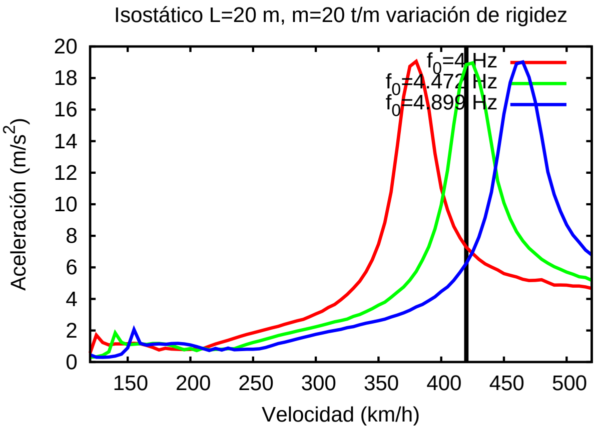


Effect on resonant response

- Frequency f_0 and critical speed v_{crit} decrease with $\sqrt{\overline{m}}$
- Maximum displacements at resonance unchanged
- Maximum accelerations at resonance decrease

Increase Stiffness of Bridge

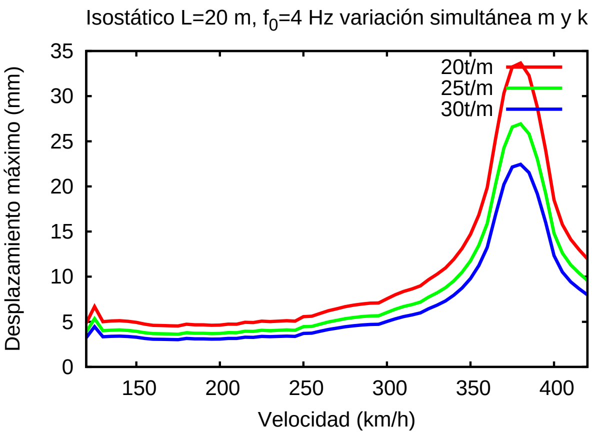


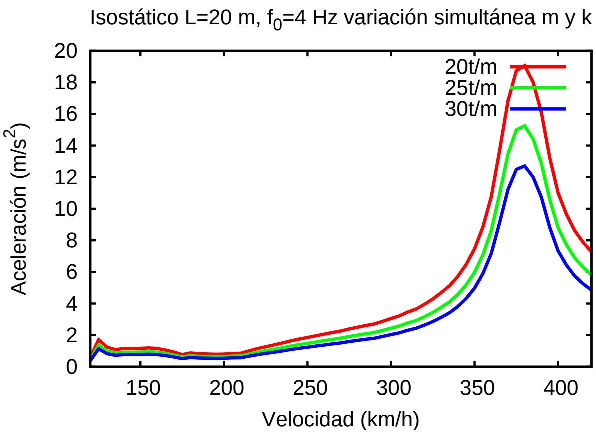


Effect on resonant response

- Frequency f_0 and critical speed v_{crit} increase with $\sqrt{k}$: "expels" resonant peaks from velocity range
- Maximum displacements at resonance decrease
- Maximum accelerations at resonance unchanged

Simultaneous Increase of Mass and Stiffness



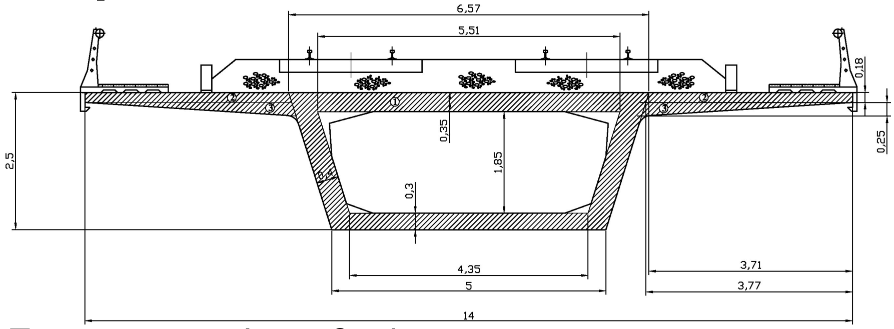


Effect on resonant response

- Frequency f_0 and critical speed v_{crit} unchanged
- Maximum displacements at resonance decrease
- Maximum accelerations at resonance decrease

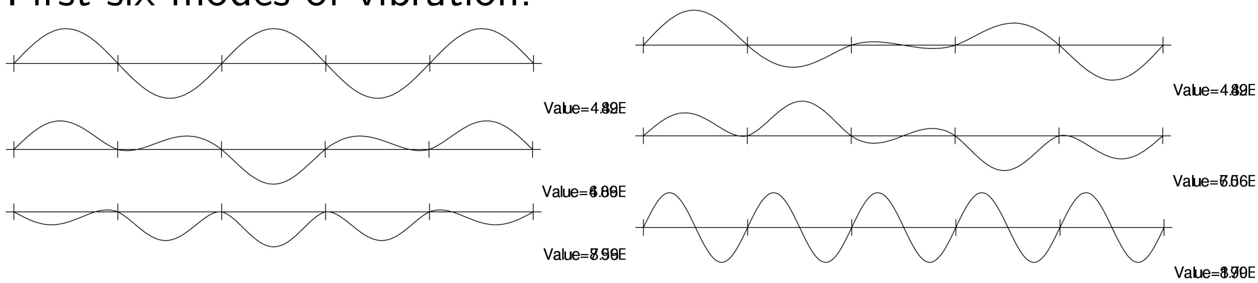
Redundant, Continuous Deck Bridges

Viaduct of *Arroyo del Salado*, continuous bridge, 30 spans of 30 m, prestressed in-situ concrete box girder [student project, B. Sanz, 2005].



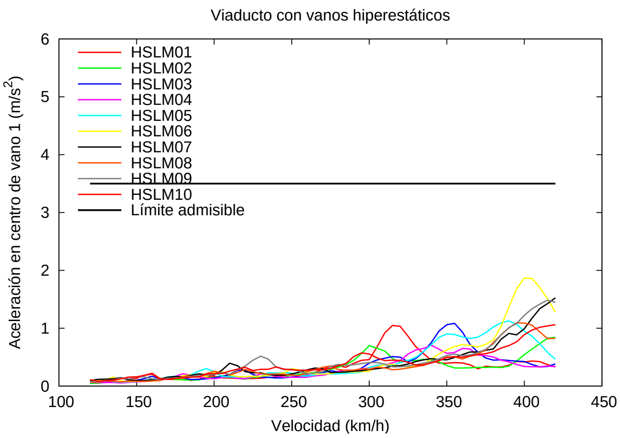
$$\frac{\text{depth}}{\text{span}} = \frac{1}{12}$$

First six modes of vibration:



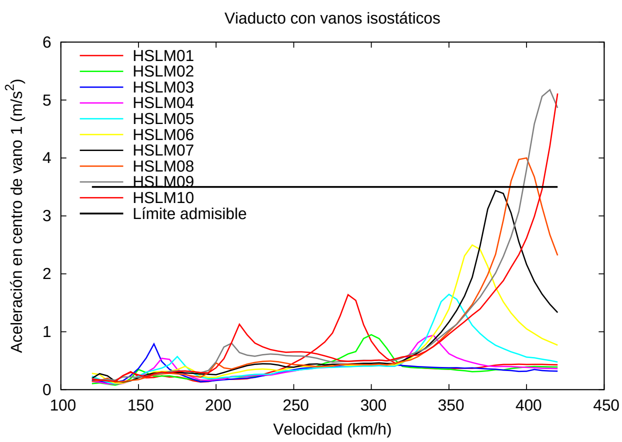
Accelerations for Continuous and Simply Supported Deck

Continuous deck



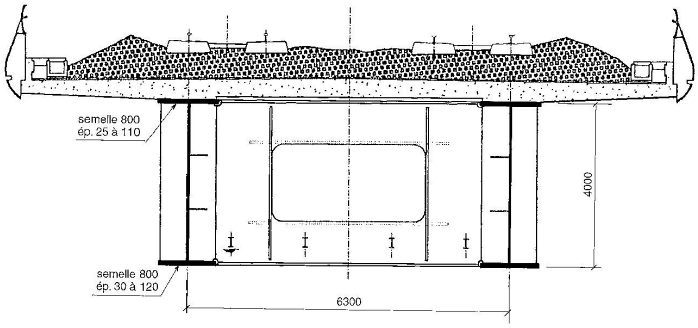
Satisfies dynamic requirements

Simply supported

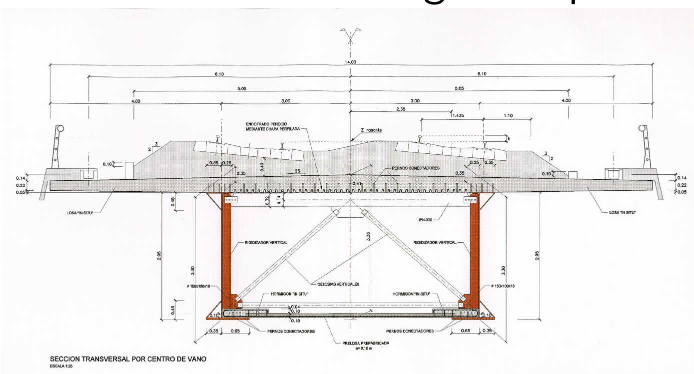


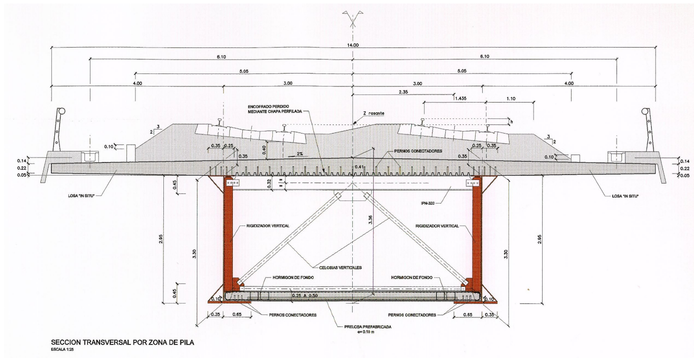
Not valid: $a_{max} > 3.5$ m/s^2

Viaduct “Las Piedras” (F. Millanes, 2004)



Twin steel girder open section, low torsional stiffness





Partially closed section, higher torsional stiffness

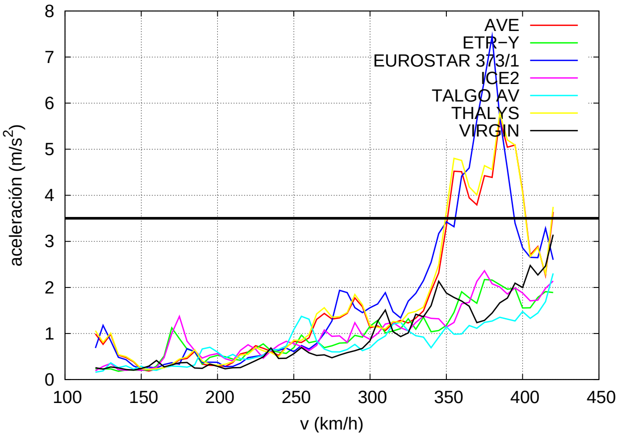
Viaduct “Las Piedras” (II)

Total length 1208.5m, spans of $L = 63.5$ m, 92 m high pier

Viaduct “Las Piedras” (III). Acceleration envelopes

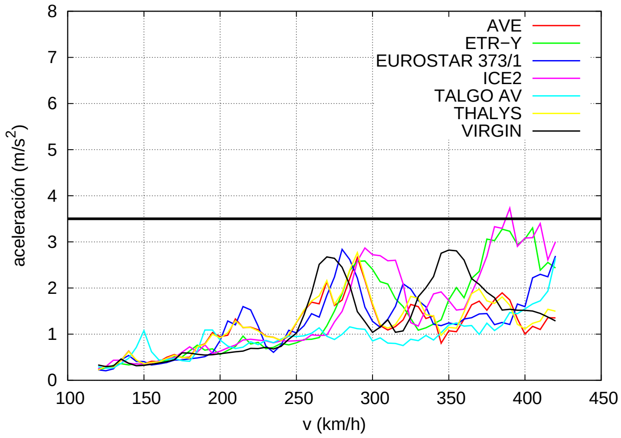
Vertical acceleration, w. bending and torsion, center of lateral span

Open section



Not valid: $a_{max} > 3.5$ m/s^2

Partially closed section



Satisfies dynamic requirements

Design requirements for traffic safety

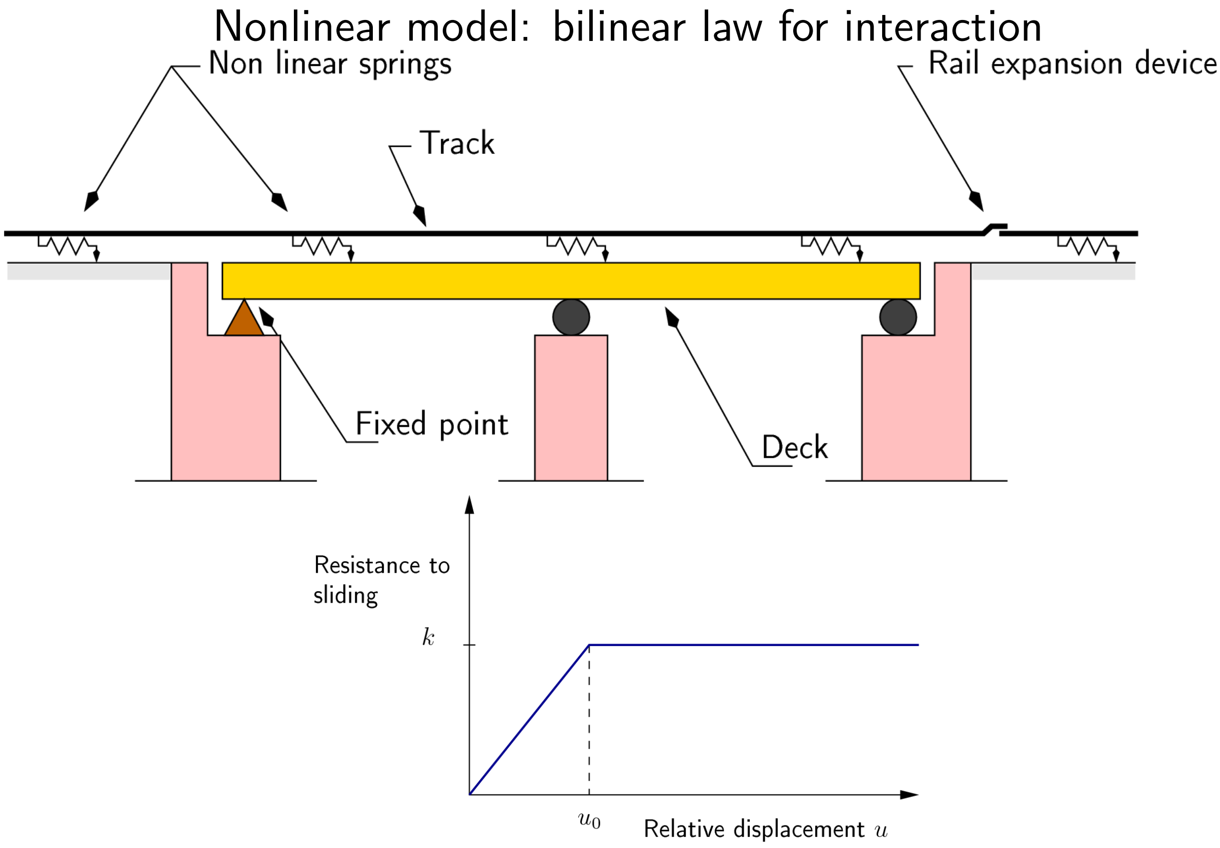
Vertical accelerations of deck

- For high levels of vibration ballast has been show to destabilize
- Requirement: $a \leq 3.5\text{m/s}^2$.

Track-Bridge Interaction

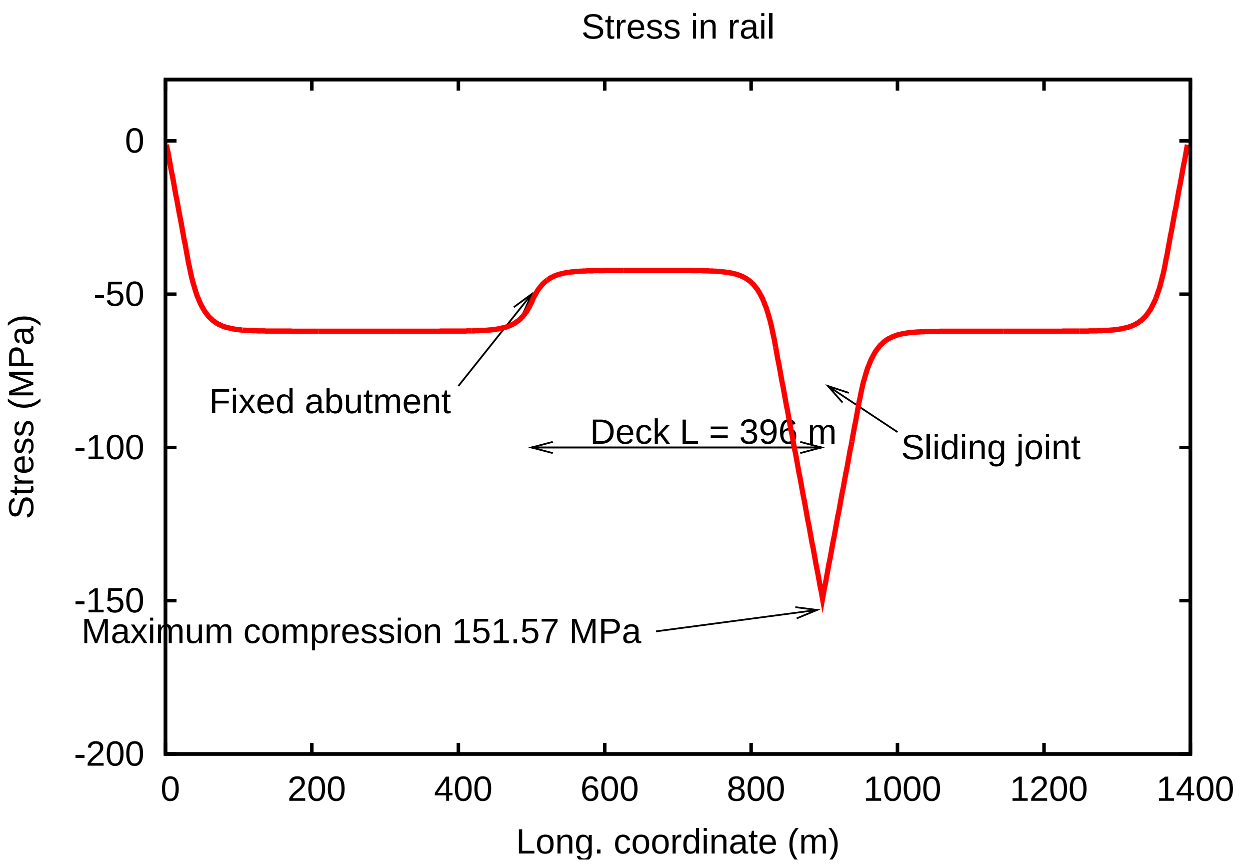
- Long welded rail in bridges: longitudinal loads from thermal actions, braking/acceleration carried by deck and rail;
- Forces transmitted to piers and abutments from combined actions of structure and track;
- Rail stresses due to thermal actions, braking and acceleration and other traffic loads;
- Relative movements and deformations at the ends of the deck due to the above variable actions.

Models to Consider for Track-Bridge Interaction



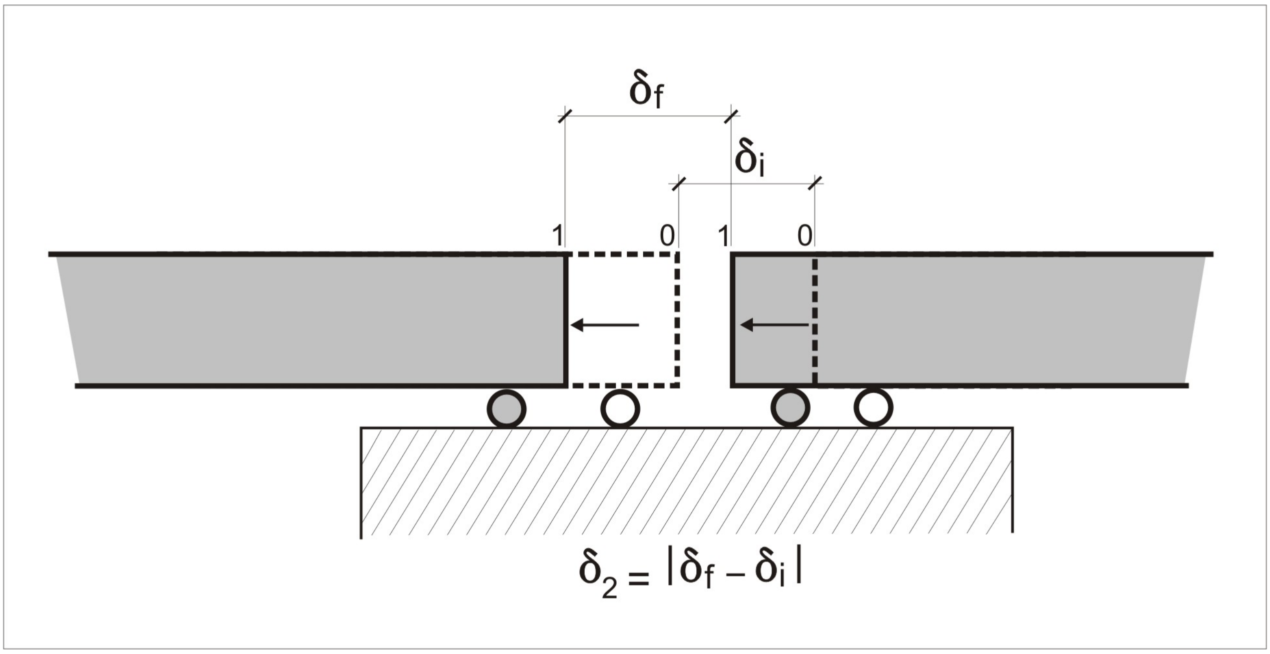
Motivation Design Considerations Service Limit States Concluding Remarks

Additional Stress in Rail from Braking



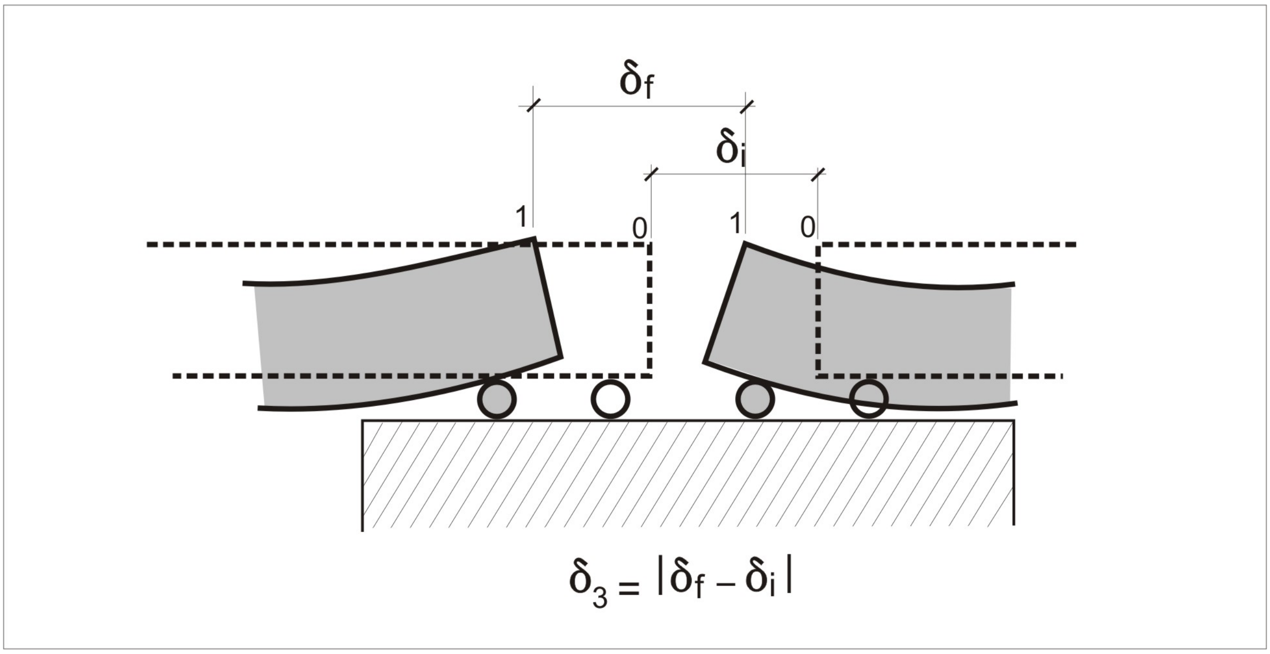
Horizontal Displacement from Braking/Acceleration

Relative displacement at deck joint: $\delta_2 \leq 5mm$



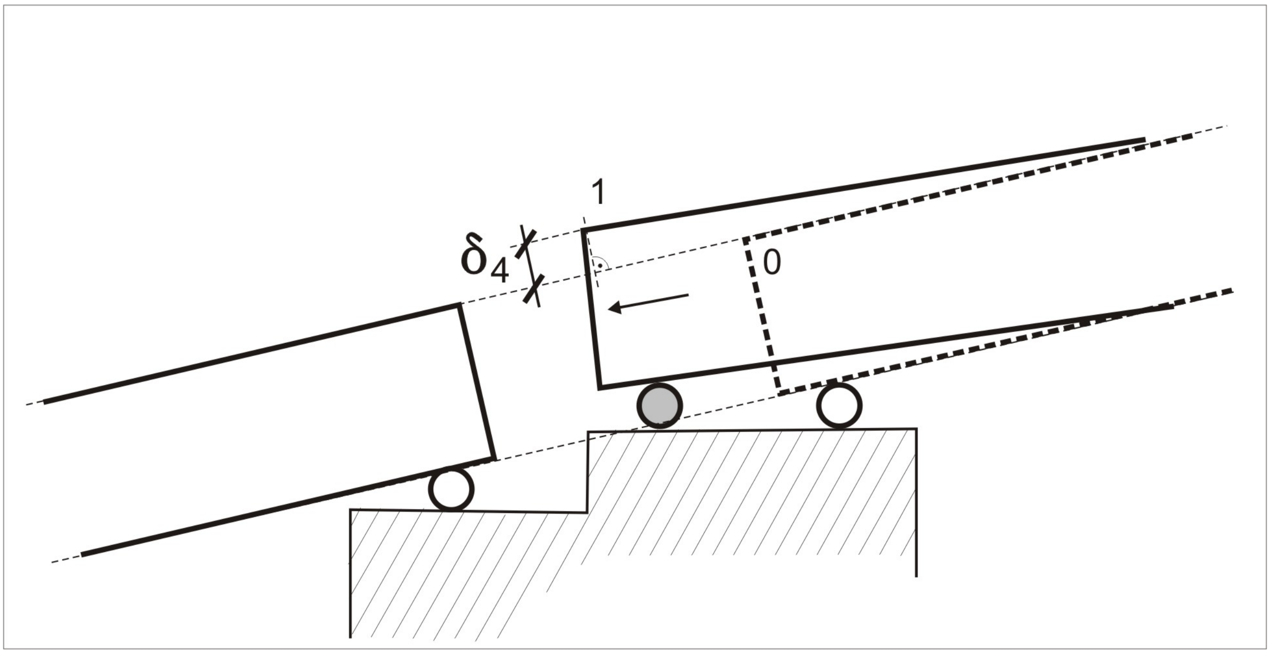
Horizontal Displacement from Bending due to Traffic Loads

Relative displacement at edge of deck joint: $\delta_3 \leq 5mm$

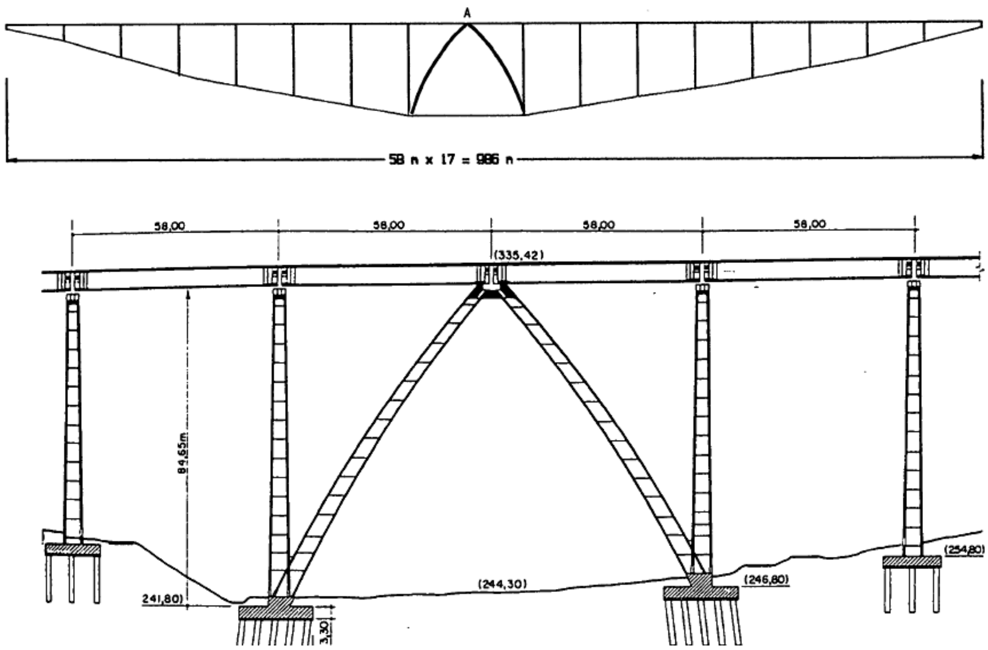


Vertical (Normal) Displacement at Edge from Variable Actions

Relative displacement at deck joint: $\delta_4 \leq 2mm$



Solution (example) for long viaduct: fixed point at center



Concluding Remarks

- High Speed Railway (HSR) bridges are a new and important type of infrastructure.
- New phenomena whose risk must be adequately considered: construction, dynamic effects, Track–Bridge interaction.
- Dynamic analysis is necessary for HS bridges to consider resonance
- Serviceability Limit States (SLS) for the structure are of utmost importance, as they become Ultimate Limit States for the safety of traffic
- New codes for actions in HSR bridges: EN 1991-2 2003, EN 1990-A1 2005, IAPF 2007

The End

THANKS FOR YOUR ATTENTION

Recognition

- **Coworkers/researchers:** J. Domínguez, J.A. Navarro, F. Gabaldón,
- **Master students:** F. Ruano, B. Sanz, A. Cámara, I. Barrios, R. Dias
- **Motivation:** J. Nasarre, E. Alarcón; Dir. General Ferrocarriles (J. Santos, I. Alonso, A. Corral)