INTERNATIONAL ASSOCIATION FOR BRIDGE MAINTENANCE AND SAFETY

Modelagem Computacional como uma Ferramenta para o Monirotamento de Estruturas de Pontes Existentes

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Organization

- Needs for advanced research in the field of assessment of bridges in Brazil
- Reasons for the safety assessment of existing bridges
- Modeling methodologies for global/local analysis of bridges
- Bridge simulation for fatigue analysis
- Methodologies of Dynamic Analysis of Bridges for High Speed Trains
- Conclusions

Needs for advanced research in the field of assessment of bridges in Brazil

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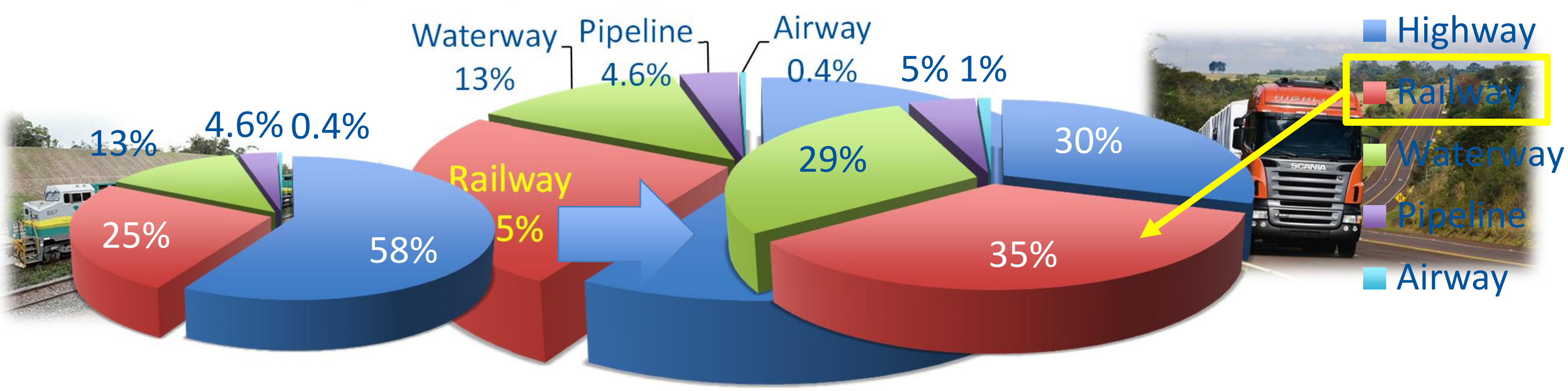
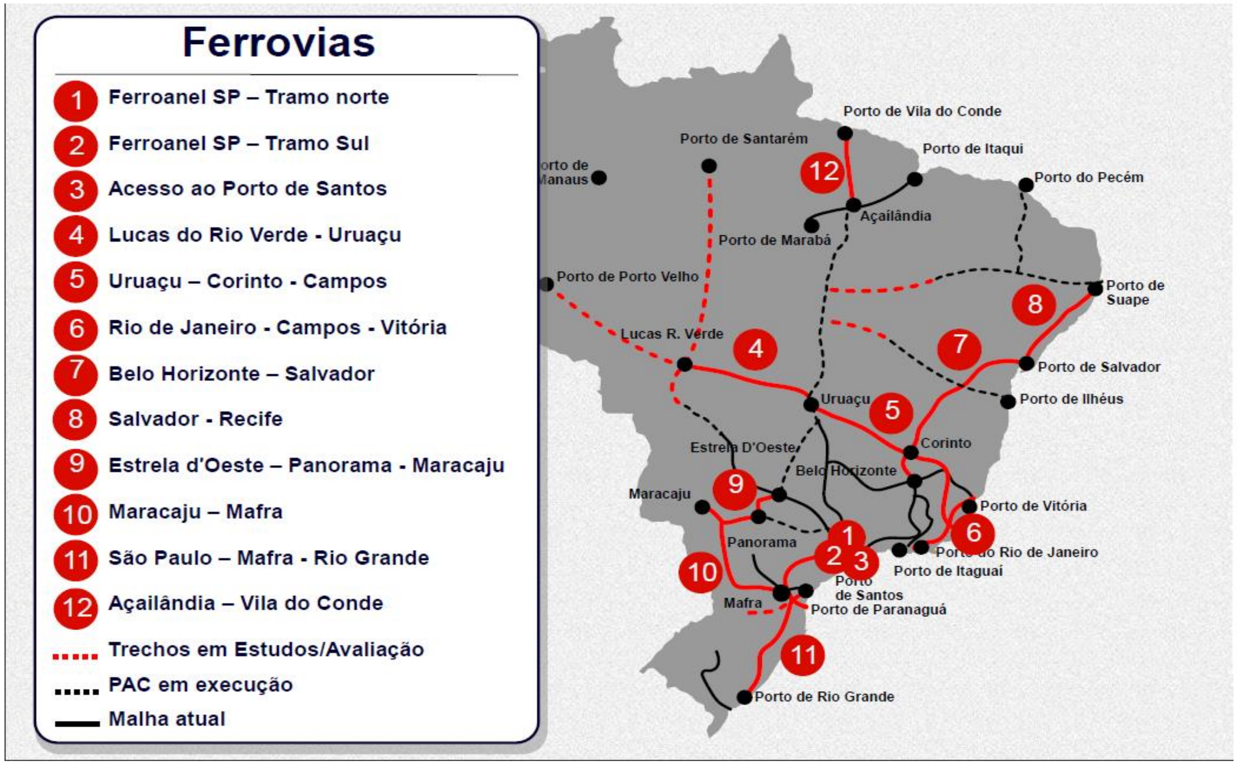
Needs for advanced research in the field of assessment of bridges in Brazil

- The Brazilian Plan for Logistics and Transportation suggests that the Transportation Mode Matrix should evolve as below:



- Brazil's Transportation Modal Matrix

Needs for advanced research in the field of assessment of bridges in Brazil



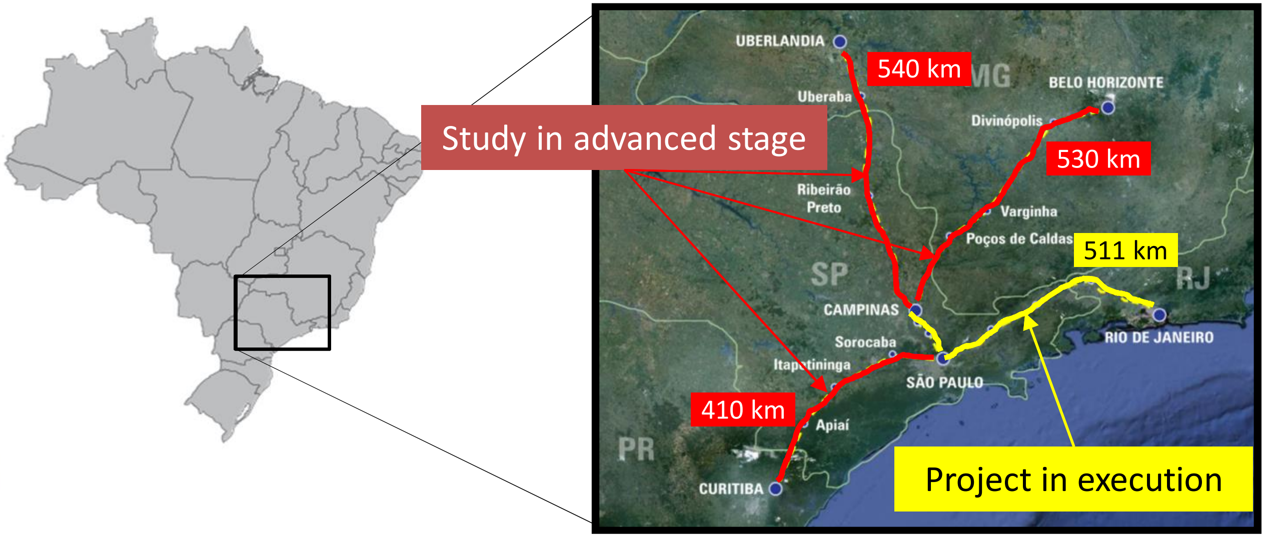
Future

Existing

This scenario poses some new challenges to the railway infrastructure in Brazil.

Needs for advanced research in the field of assessment of bridges in Brazil

- High Speed Rail Project



- The high speed tracks are supposed to link the major Brazilian cities in the southeast portion of the country.

- In total the Brazilian High Speed network will be 3,100 km long and it is supposed to be completed in the next 20 or 25 years.

Reasons for the safety assessment of existing bridges

Reasons for the safety assessment of existing bridges

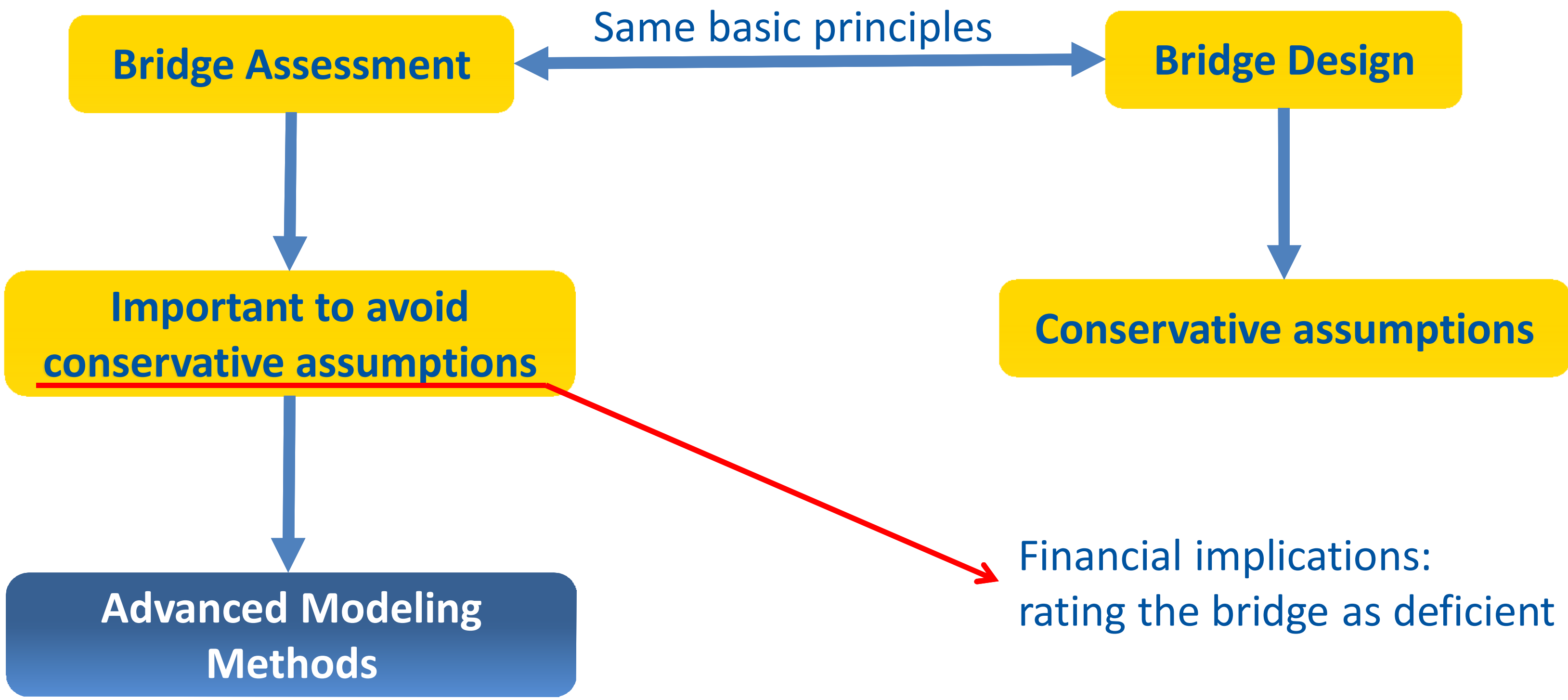
- ✓ Exceptional heavy loads and new traffic load requirements;
- ✓ Changes such as deterioration, mechanical damage, repair or change of use;
- ✓ Bridge designed according to outdated design code;
- ✓ Concern when the maximum permit load is going to be increased;

Is the bridge still sufficiently safe????

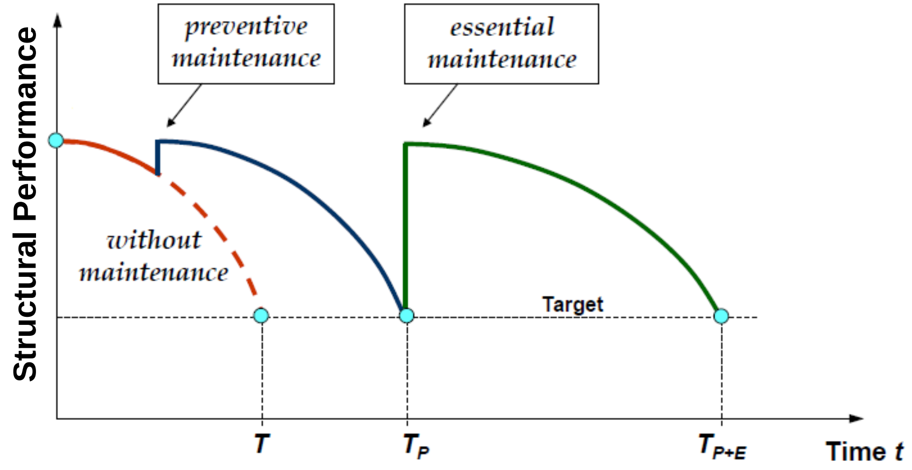
Need for Advanced Analysis Tools

Source: SB4.2, (2007). *"Guideline for Load and Resistance Assessment of Existing European Railway Bridges: Advices on the use of advanced methods".* Prepared by Sustainable Bridges- a project within EU FP6.

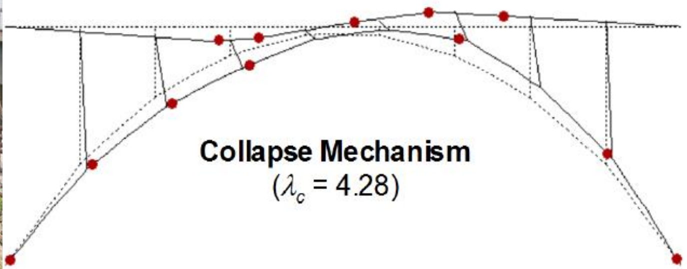
Reasons for the safety assessment of existing bridges



Reasons for the safety assessment of existing bridges



- Linear x Non-linear;
- Dynamic with/without vehicle-bridge interaction;
- Better load models;
- Better resistance parameters;
- Incorporation of the results from monitoring;
- Damage modeling: fatigue, corrosion…
- Collapse mechanisms;



Courtesy: Prof. Fábio Biondini- Politecnico di Milano

Modeling methodologies for global/local analysis of bridges

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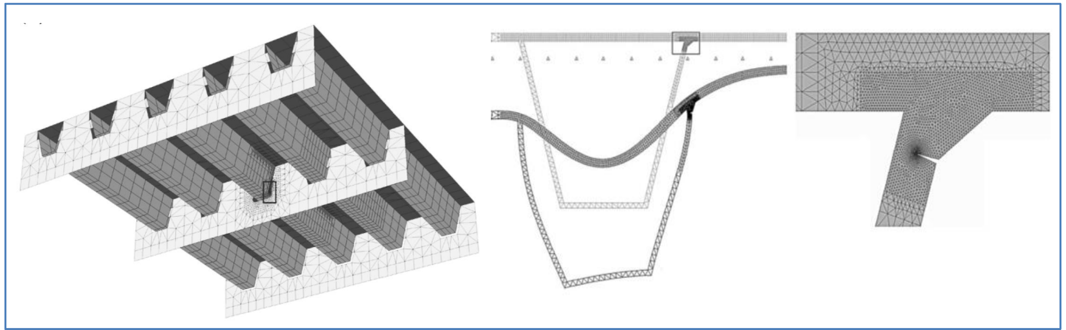
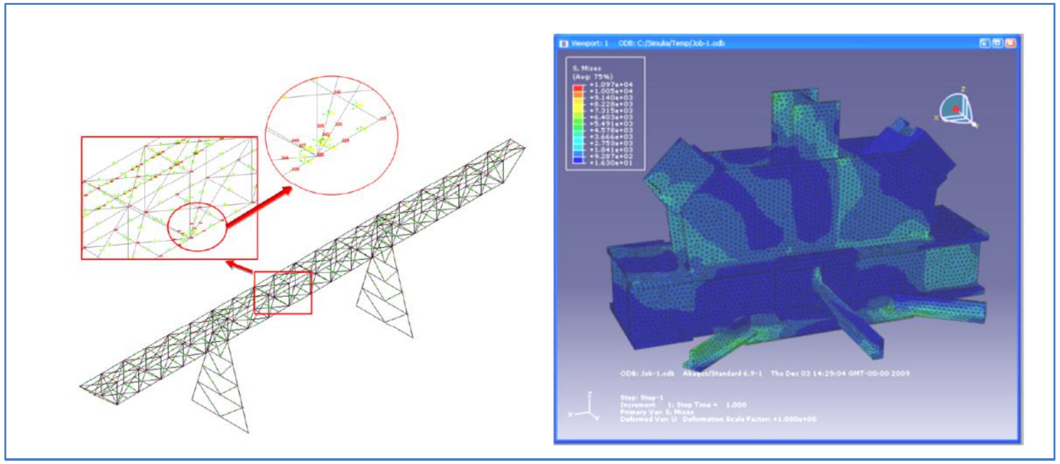
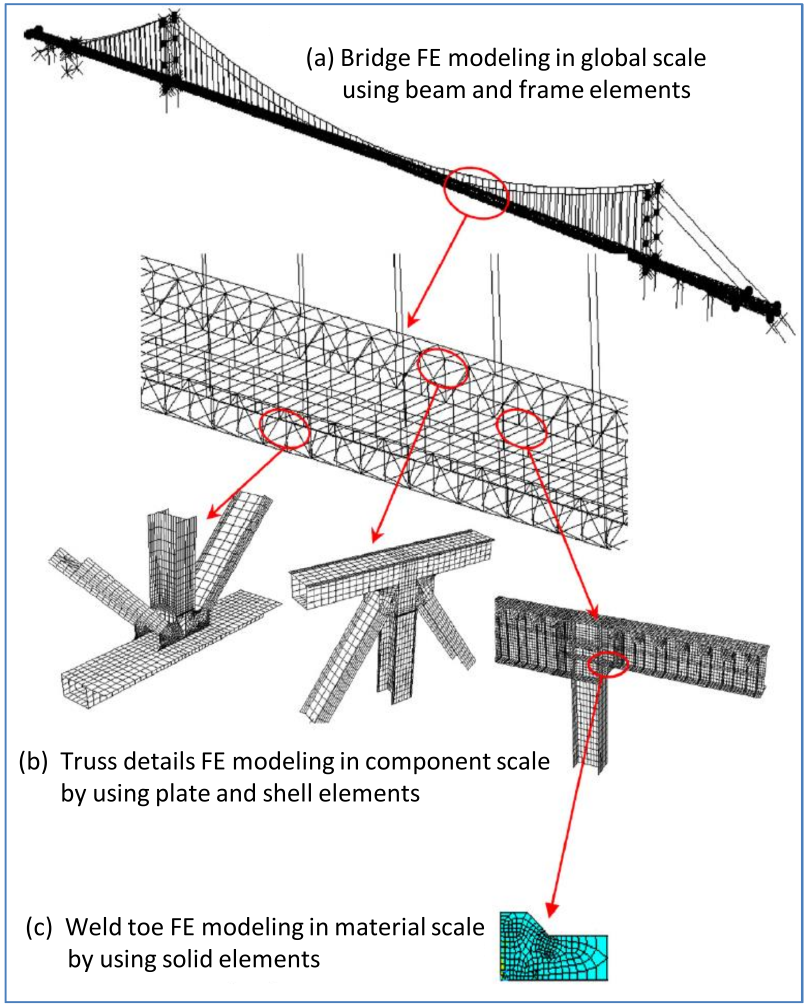
Global and local analysis

KISS and DUNAI (2002)



LEITE et al. (2010)

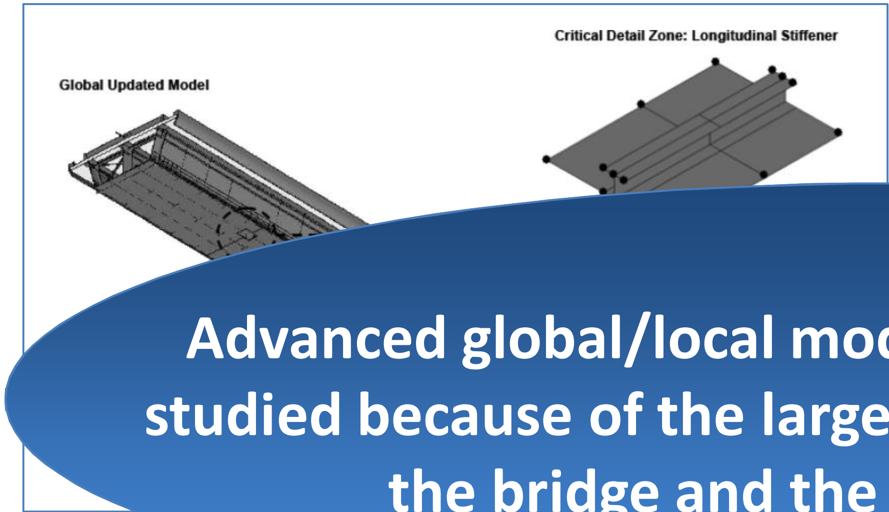




LI *et al.* (2007)

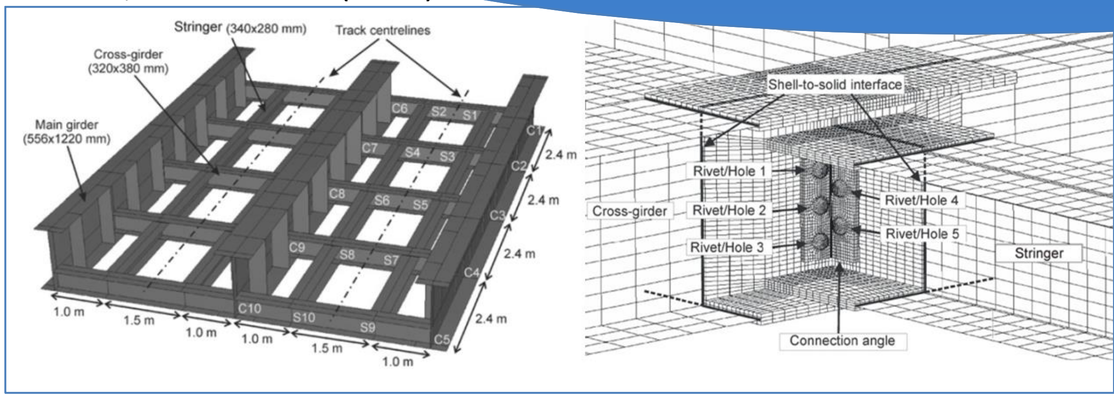
Global and local analysis

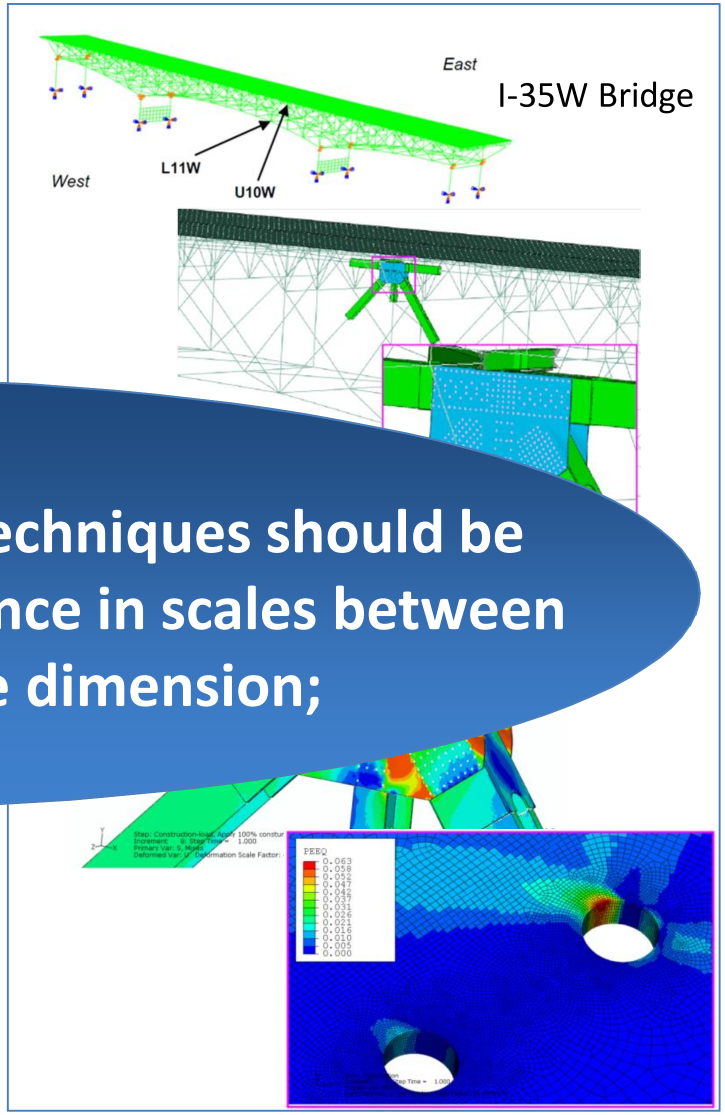
CHELLINI; LIPPI; SALVATORE (2012)



Advanced global/local modeling techniques should be studied because of the large difference in scales between the bridge and the damage dimension;

IMAM; RIGHINIOTIS (2010)





NATIONAL TRANSPORTATION SAFETY BOARD (2008)

A modeling methodology for global/local analysis

Comments:

- ABAQUS FEA software has been used because it supports programming and I/O commands;
- This approach can be automated: the tasks are programmed and performed automatically without interaction of the user while the program is executed;
- The methodology has been developed to enable the coupling between the FEA software and customized user subroutines, based on Python scripting and MatLab programming;
- The loop parameterization-simulation-parameterization is time-consuming and requires multiple calls of the physical model;

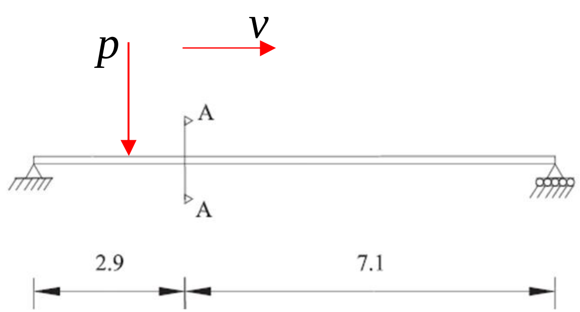
A modeling methodology for global/local analysis

- Application: fatigue crack growth analysis of bridges

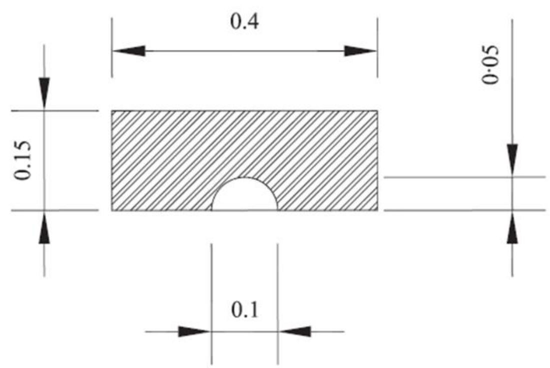
Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

- Example studied by

ALBUQUERQUE; DE CASTRO; CALÇADA (2012)



(a) Beam dimension and crack location [m]



(b) Crack dimensions (section A-A) [m]

$E = 210\ \text{GPa}$

$\nu = 0.3$

$\rho = 7850\ \text{kg/m}^3$

$p = 100\ \text{kN}$

$v = 250\ \text{m/s}\ (900\ \text{km/h})$

A modeling methodology for global/local analysis

➢ Application: fatigue crack growth analysis of bridges

Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

➢ Example studied by

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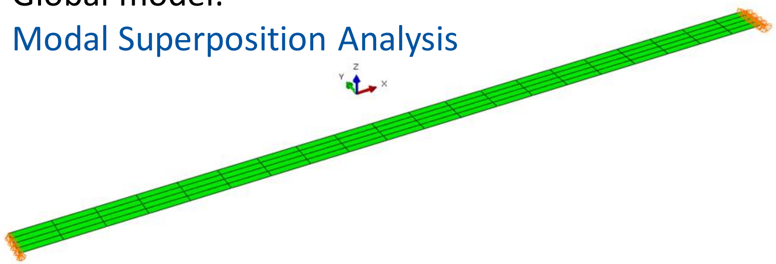
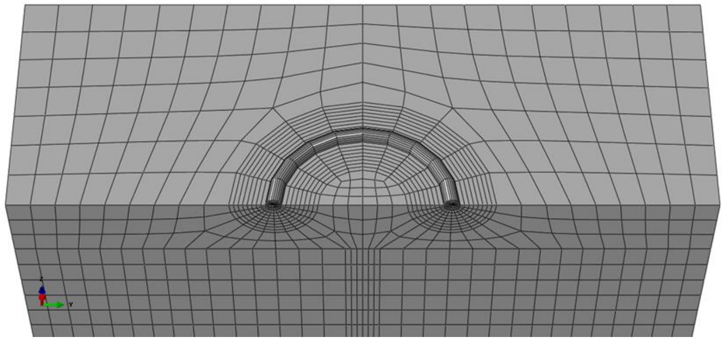
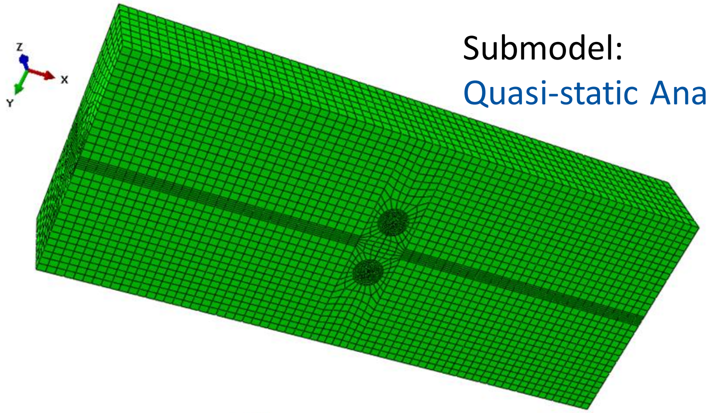
Global model:
Modal Superposition Analysis

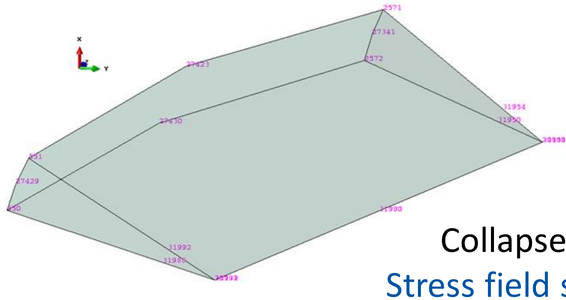




FE mesh of the crack front



Submodel:
Quasi-static Analysis



Collapsed brick element:
Stress field singularity modeling

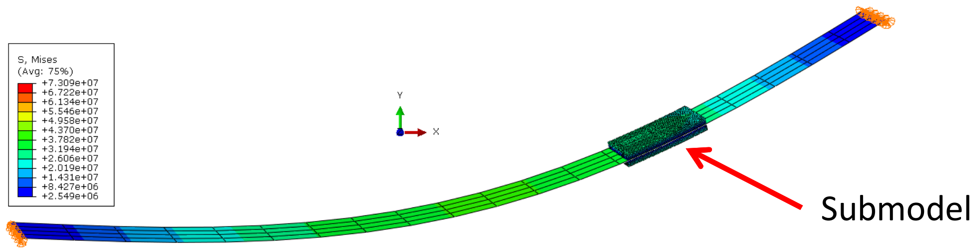
A modeling methodology for global/local analysis

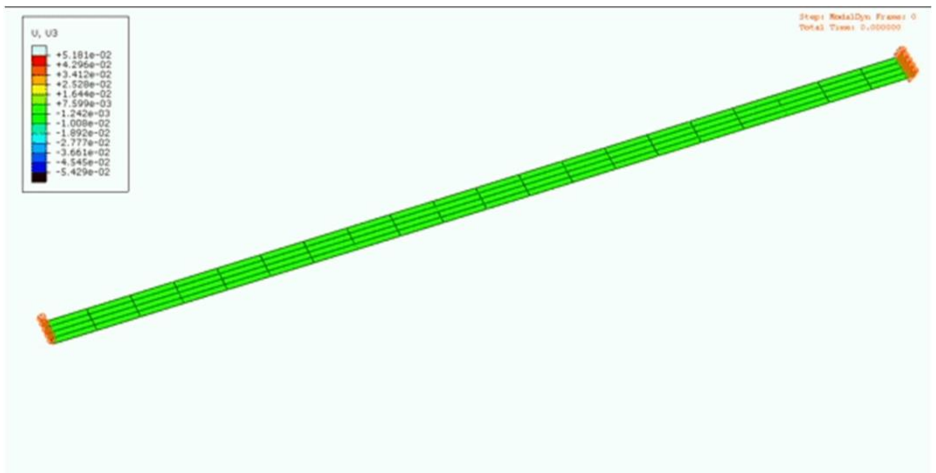
- Application: fatigue crack growth analysis of bridges

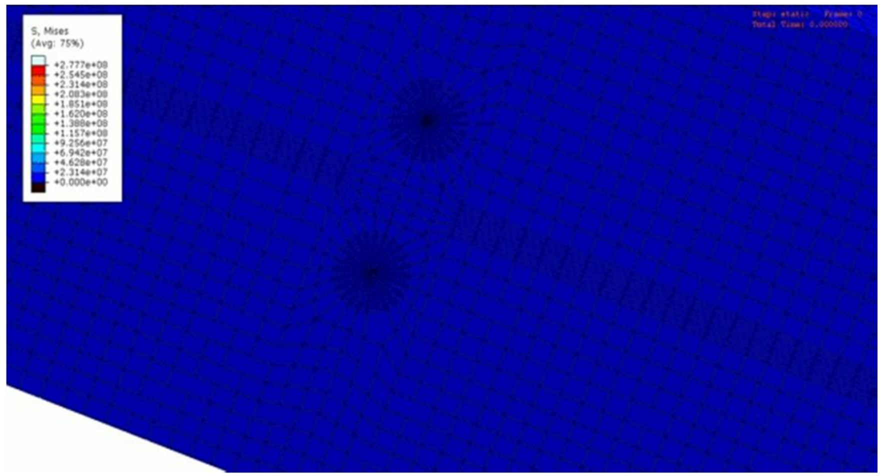
Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

- Example studied by

ALBUQUERQUE; DE CASTRO; CALÇADA (2012)







A modeling methodology for global/local analysis

- Application: fatigue crack growth analysis of bridges

Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

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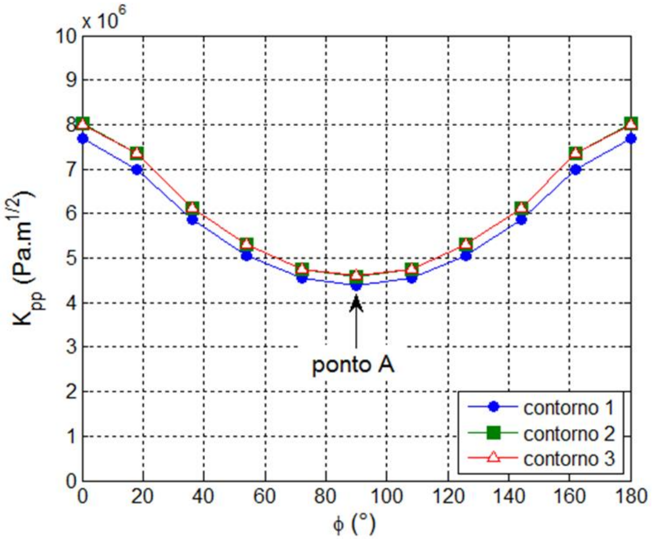
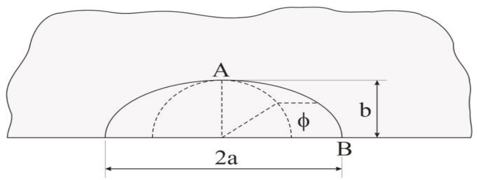


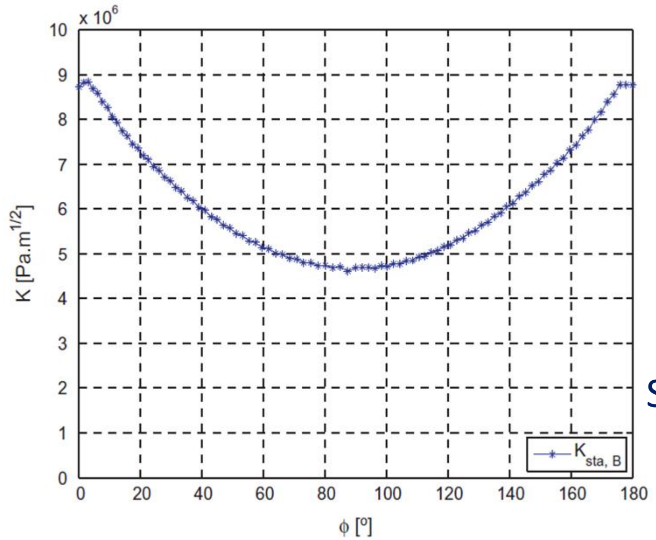
- Global/local approach used

SIF extraction method: J-integral



Dead load effect

$$K(t) = K_{static} + K_{dynamic}(t)$$



- Determined by ALBUQUERQUE; DE CASTRO; CALÇADA (2012)

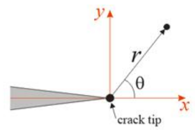
SIF extraction method: VCCT

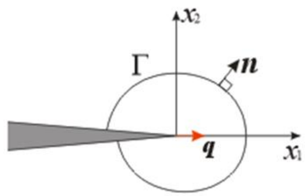
A modeling methodology for global/local analysis

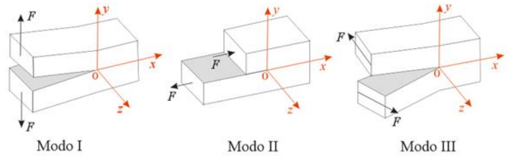
- Application: fatigue crack growth analysis of bridges

Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

$$\sigma_{ij}(t) = \frac{K_I(t)}{\sqrt{2\pi r}} f_{ij}^{I}(\theta) + \frac{K_{II}(t)}{\sqrt{2\pi r}} f_{ij}^{II}(\theta) + \frac{K_{III}(t)}{\sqrt{2\pi r}} f_{ij}^{III}(\theta)$$

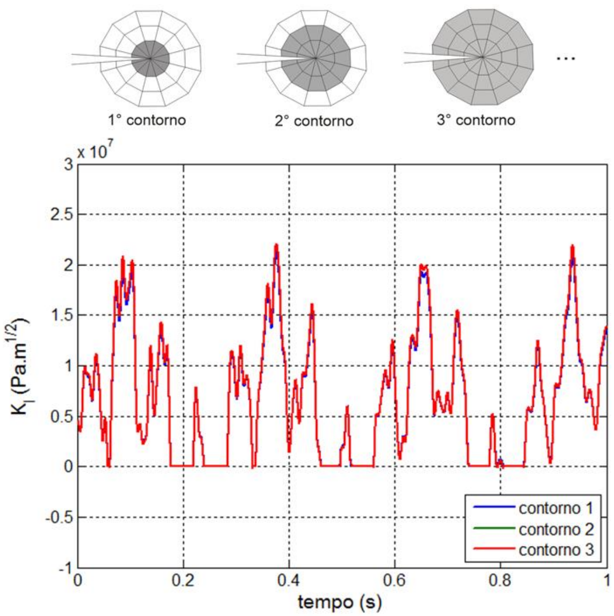






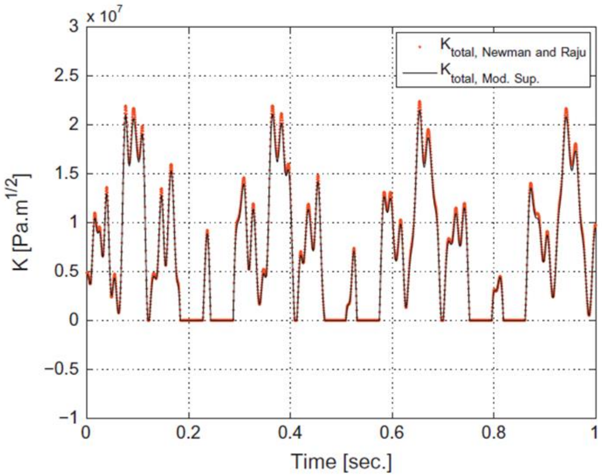
$$J = \lim_{\Gamma \to 0} \int_{\Gamma} \left[W \cdot \delta_{1j} - \left(\sigma_{ij} \cdot \boldsymbol{n}_j \right) \cdot \frac{\partial \boldsymbol{u}_i}{\partial \boldsymbol{x}_1} \right] \cdot d\Gamma$$

$$J = \frac{K_I^2}{E^*} + \frac{K_{II}^2}{E^*} + \frac{K_{III}^2}{2G^*}$$



- Global/local approach used

SIF extraction method: J-integral



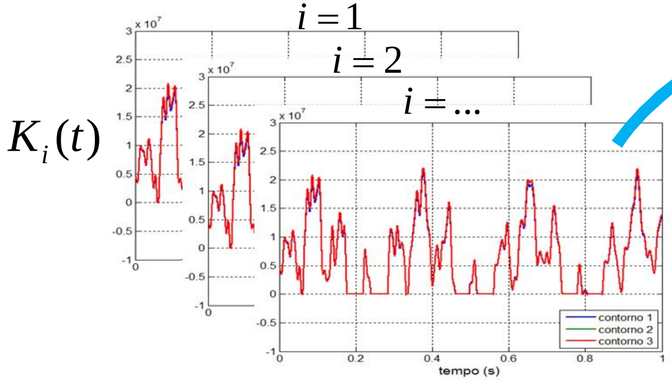
- Determined by ALBUQUERQUE; DE CASTRO; CALÇADA (2012)

SIF extraction method: VCCT

A modeling methodology for global/local analysis

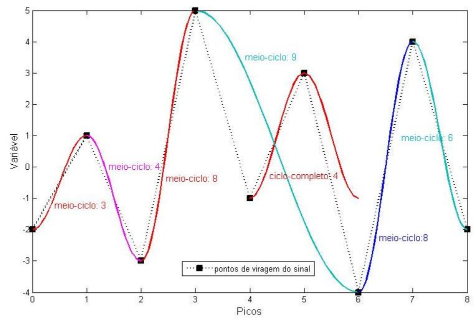
- Application: fatigue crack growth analysis of bridges

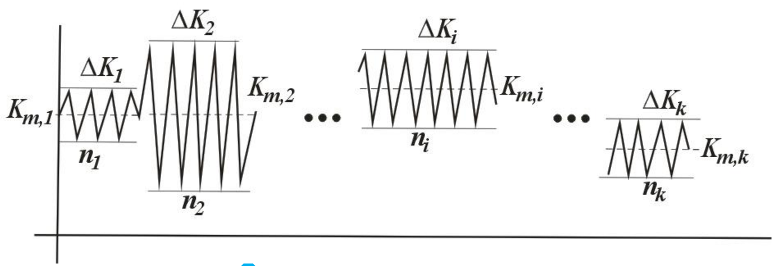
Fracture Mechanics: extraction of Dynamic Stress Intensity Factors



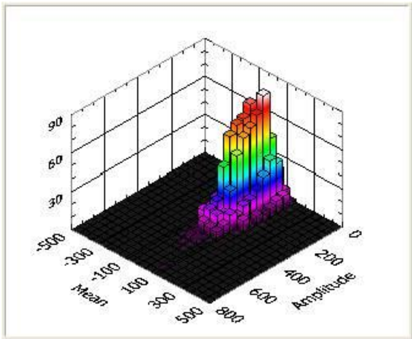
SIF histories: train sequences

Rainflow counting





SIF spectrum



$$\Delta K_{eq,i}$$

A modeling methodology for global/local analysis

➤ Application: fatigue crack growth analysis of bridges

Fracture Mechanics: extraction of Dynamic Stress Intensity Factors

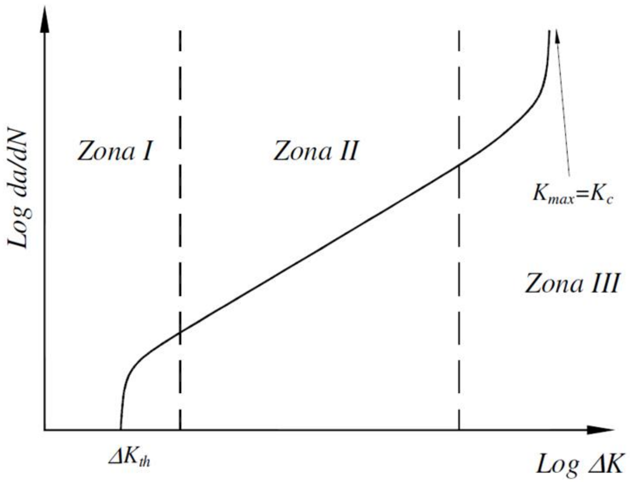
Comments:

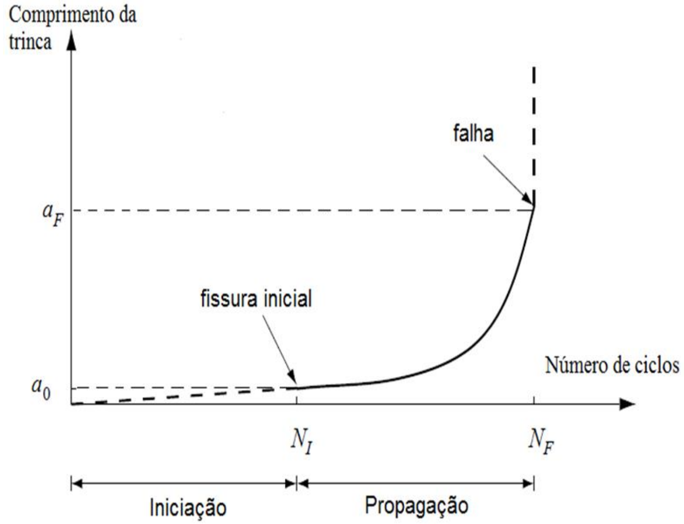
- Stress Intensity Factor Time-Histories are important for assessing the residual life of the bridge when the fatigue crack growth approach is used;
- The Paris Law can be used to predict crack growth as a function of cycles;

Paris Law

$$\left.\frac{da}{dN}\right|_i = C \cdot \Delta K_{eq,i}^{m}$$

$where\ N = number\ of\ cycles$





Bridge simulation for fatigue analysis

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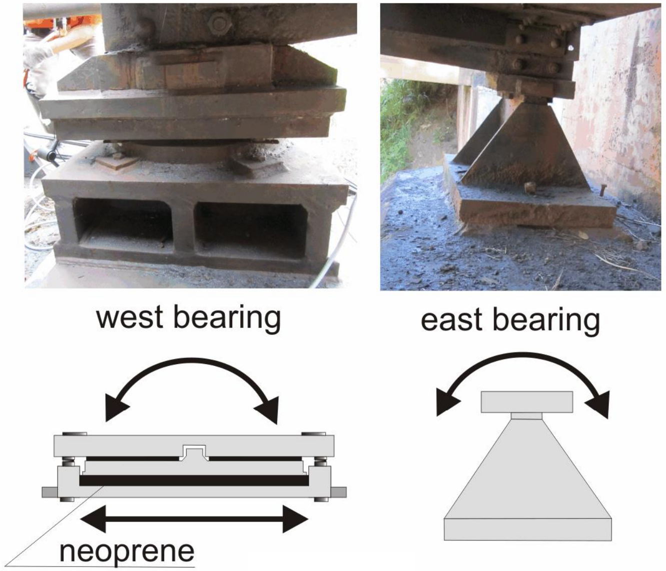
Fatigue damage analysis of an old through-truss bridge



Fundão River Bridge
Unballasted through-truss bridge : 70-year old
Span length: 41 m
The bridge is part of the Vitória-Minas Railroad

The structure was designed in 1943 according to AREMA (1941) specification

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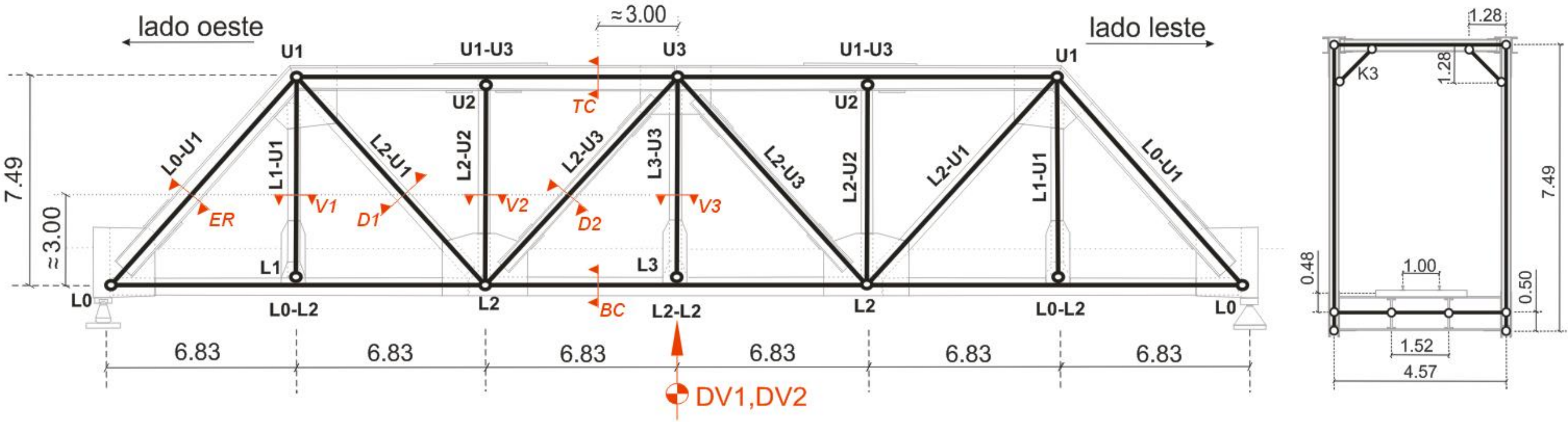
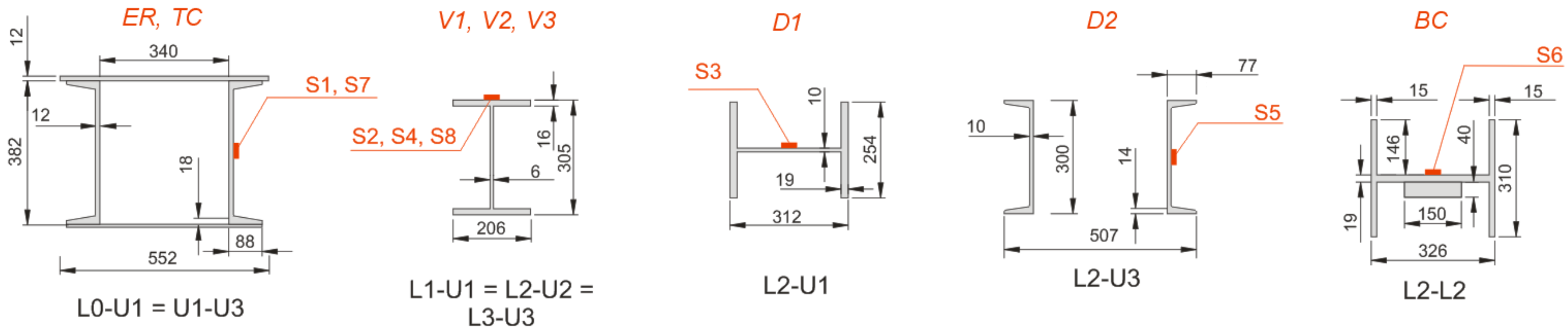


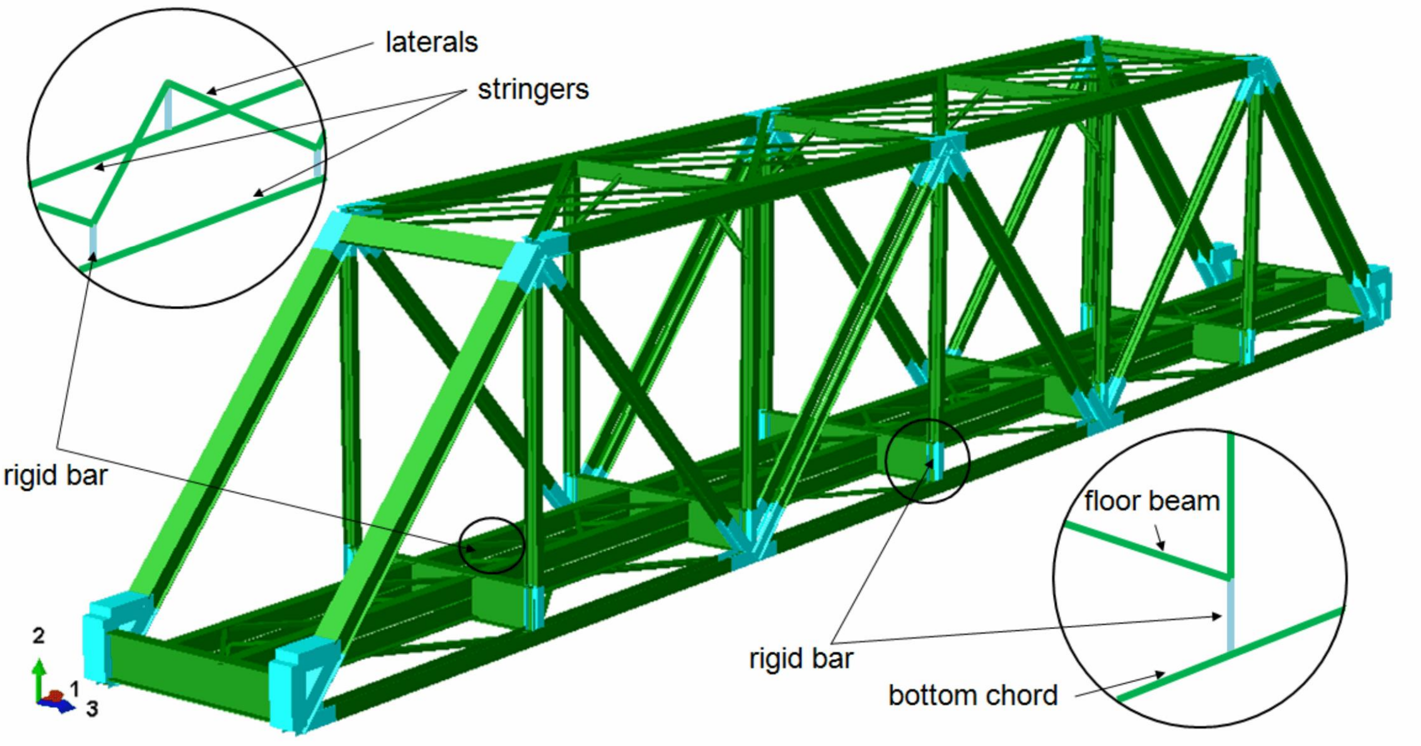
(a) dimensões em m



(b) dimensões em mm

Fatigue damage analysis of an old through-truss bridge

Global model



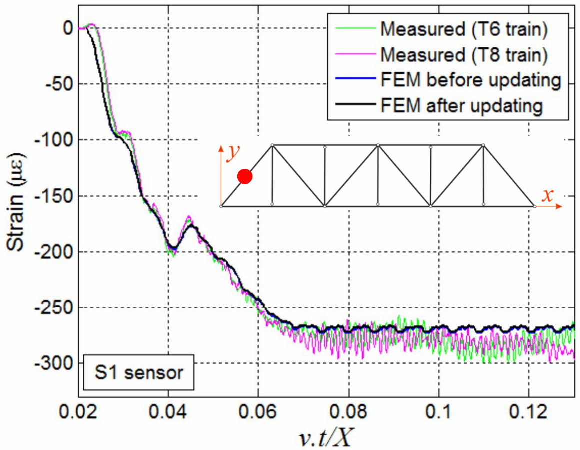
Palestra:
"Modelagem Computacional como Ferramenta para o Monitoramento de Estruturas de Pontes Existentes"

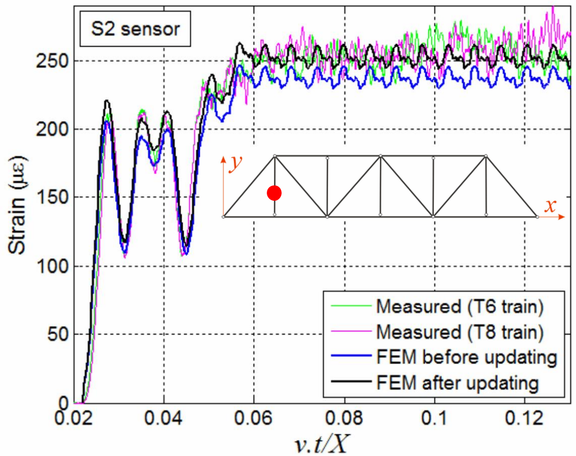
Brazil Road Expo 2015

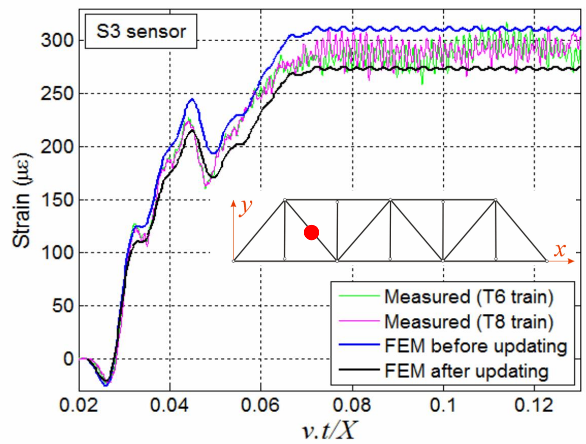
INTERNATIONAL ASSOCIATION FOR BRIDGE MAINTENANCE AND SAFETY

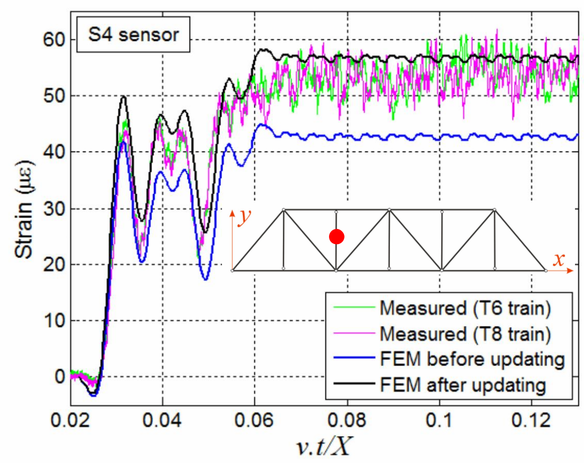
Fatigue damage analysis of an old through-truss bridge

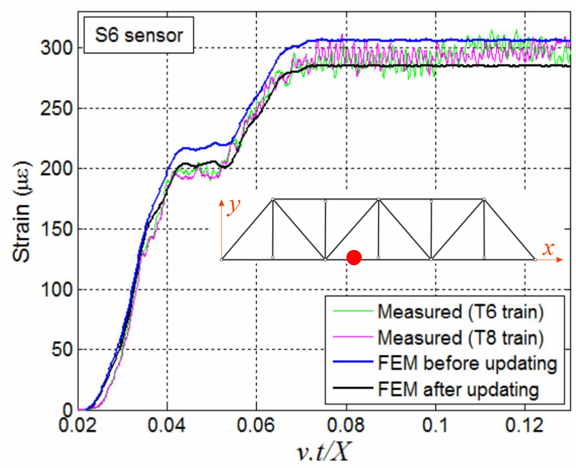
Quasi-static analysis x Experimental results

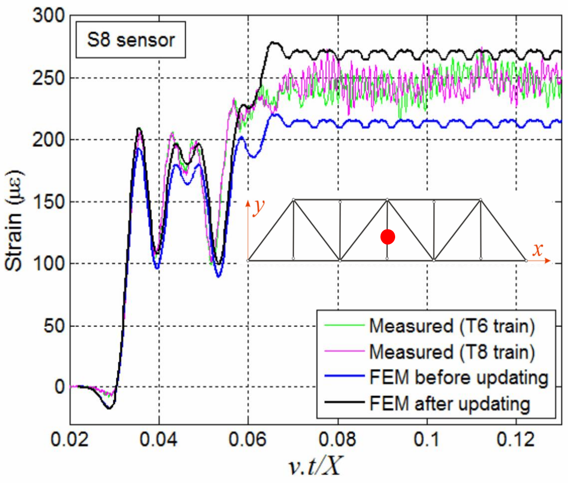








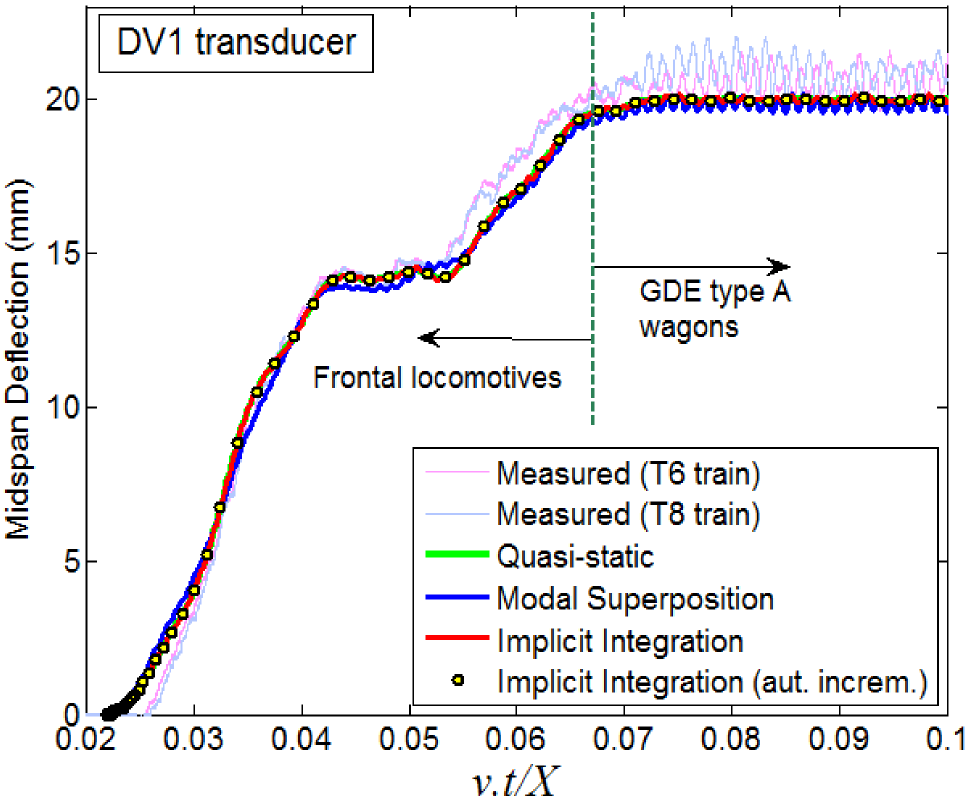




Fatigue damage analysis of an old through-truss bridge

Comparisons between analysis procedures and experimental results

Speeds between 24 km/h and 31 km/h were detected during monitoring

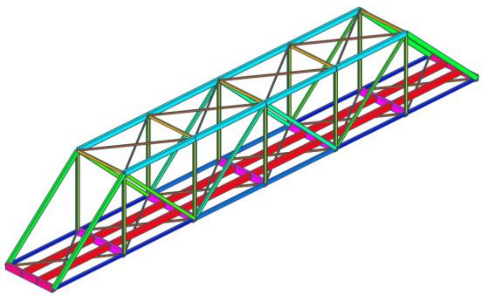


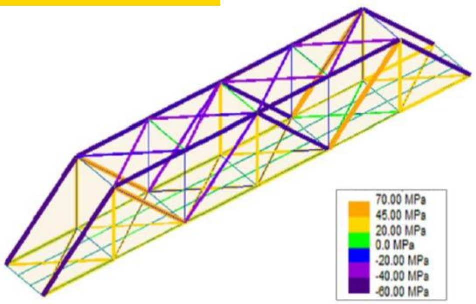
The case of the Suaçui river bridge - VM railroad

Contribution EPFL

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Structural safety





$$n = \frac{R_d}{E_d} = 1.90$$

Diagonals

$$n = \frac{R_d}{E_d} = 2.11$$

Longitudinal girders

Degree of compliance

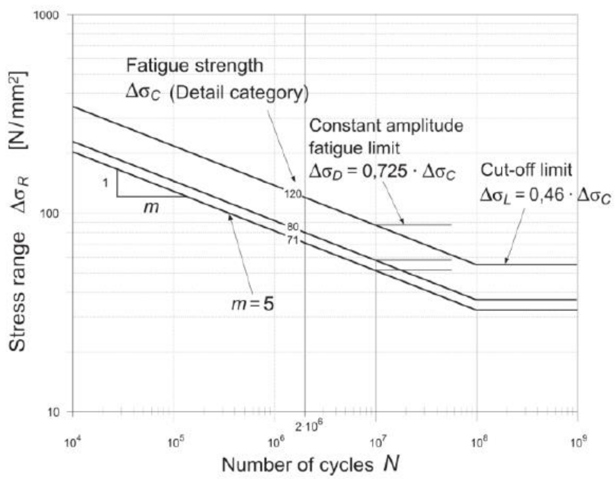
The calculation is based on 200 full GDE wagons for the full ore trains

Fatigue Analysis

Fatigue scenario with approximately 8740 trains per year.

S-N curve occurring to the fatigue category 80 and 71 for truss and deck member.

The members were found to have sufficient capacity even for another 50 years.



S-N curve used in study (SIA 269/3, 2011).

Methodologies of Dynamic Analysis of Bridges for High Speed Trains

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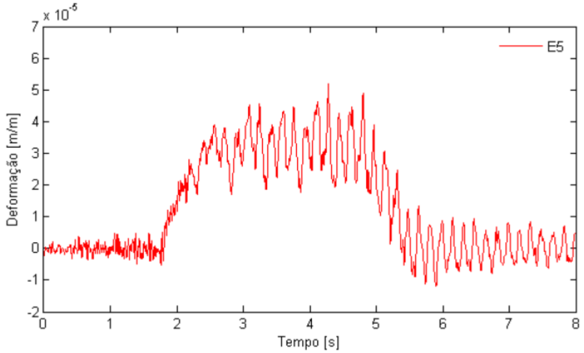
Methodologies of Dynamic Analysis of Bridges for High Speed Trains

➢ Technological developments in the rail transport sector has led to the development of new trains capable of speeds of circulation exceeding 200 km/h .

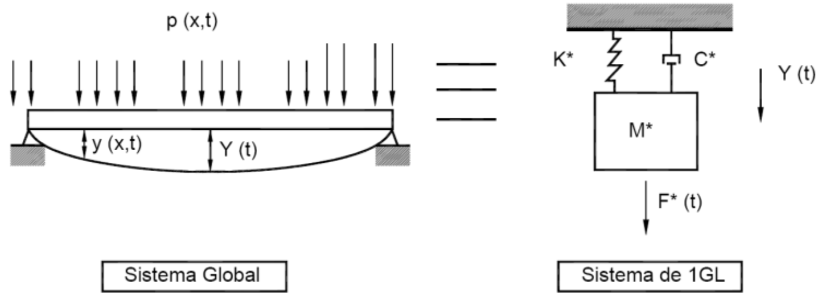
➢This increase in speed railways poses new challenges in the structural design of bridges , emphasizing the dynamic behavior, where the vibrations induced by the passage of rail traffic cause in general, displacements and internal forces in the structure significantly greater than that produced by the application of static load so as to pose in risk the structural safety of the bridge



Simplified methodologies

Easy to use and implement in commercial programs. This method is suitable for cases in which interaction does not significantly influence the dynamic response of the structure:

- ✓ Decomposition of Excitation at Resonance method (DER).
- ✓ Dynamic influence line calculation method (LIR).



$$M^* \ddot{Y}_{(t)} + C^* \dot{Y}_{(t)} + K^* Y_{(t)} = F^*_{(t)}$$

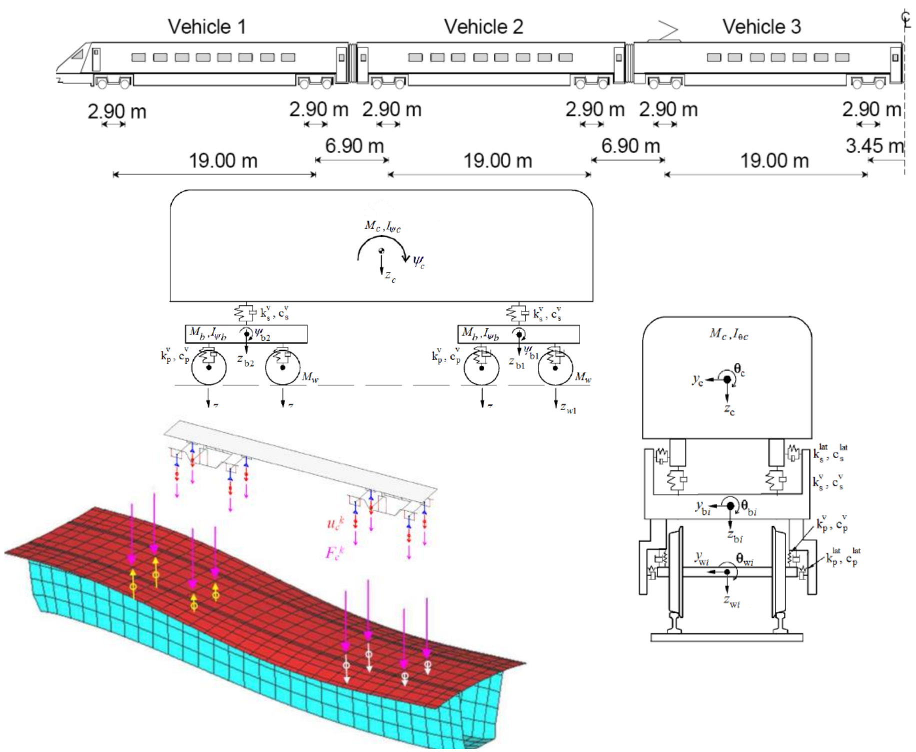
Where:
M: Mass generalized, C: Damping generalized, K: Stiffness generalized , F*: Force generalized.*

Sophisticated methodologies

More difficult to use because it involves modeling the train and the knowledge of their parameters, is not directly available in commercial calculation programs.

This methodology is very relevant in situations where one wishes to evaluate:

- ✓ The comfort of passengers.
- ✓ Analyze the stability of the wheel-rail contact.
- ✓ Evaluate the effects of track irregularities.

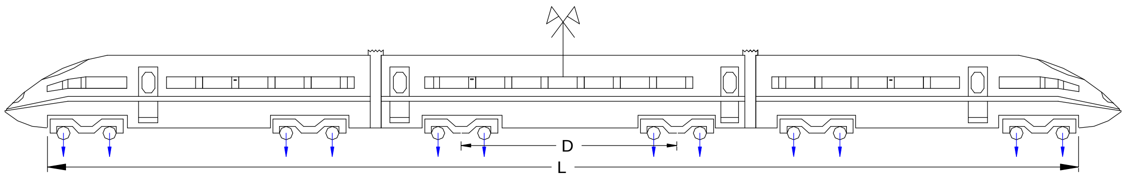


Application of simplified methodologies

The evaluation of dynamic response is applied to a bridge formed by simply supported spans with the following characteristics:

L = 15m
EI = 7694 × 103 kN.m^2
Mass: m = 15 t/m
damping ξ = 2%

Two types of trains are considered to cross the above bridge: Eurostar and TGV circulating at speeds between 140-420 km/h with increments of speed of 10 km/h.



Train	Type of Train	Length L (m)	Distance (D) between wagons (m)	Axle Load (kN)
TGV atlantique	Articulate	468,14	18,7	170
Eurostar	Articulate	386,67	18,7	170
Talgo AV2	Regular	356,05	13,14	170

Application of simplified methodologies

- Direct Integration method and Modal Superposition method

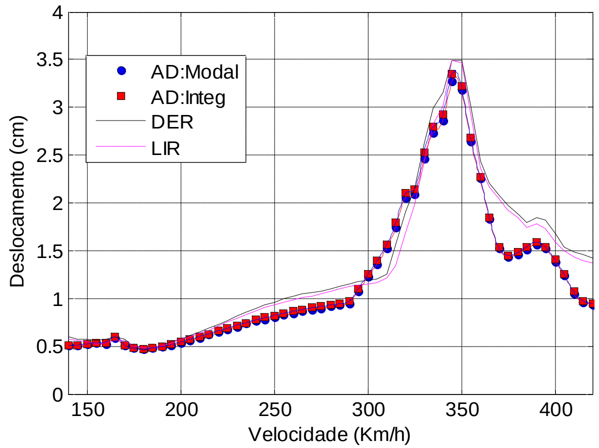
✓ The dynamic response calculation by these methods has been carried out in the SAP2000 program taking advantage of the Time-History module;

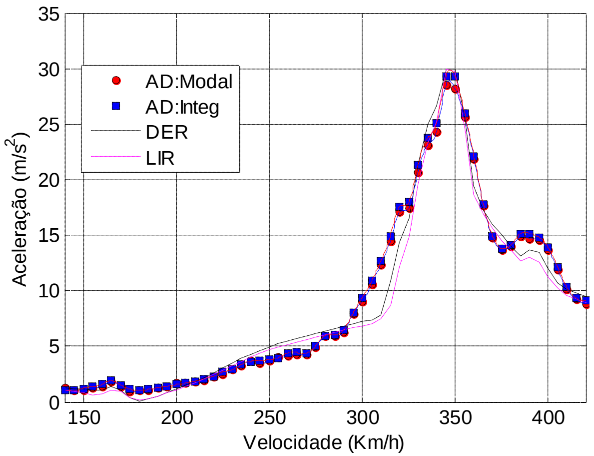
✓The iterative process has been implemented in MatLab, the management of SAP2000 files is possible through APIs, the analysis is automatic and allows an efficient data storage and manipulation;

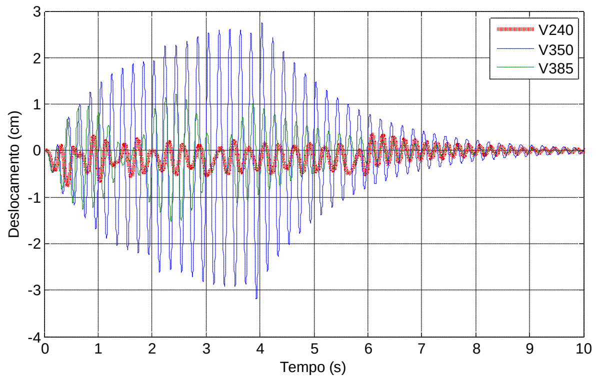
✓In the following figures, a comparison of results (deflections and accelerations) obtained by different methods for different speeds is presented.

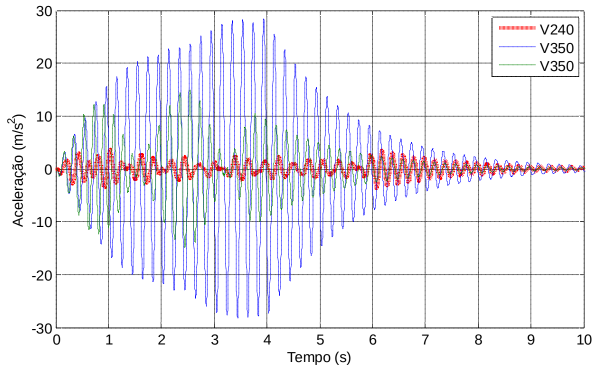
Application of simplified methodologies

- Eurostar train:



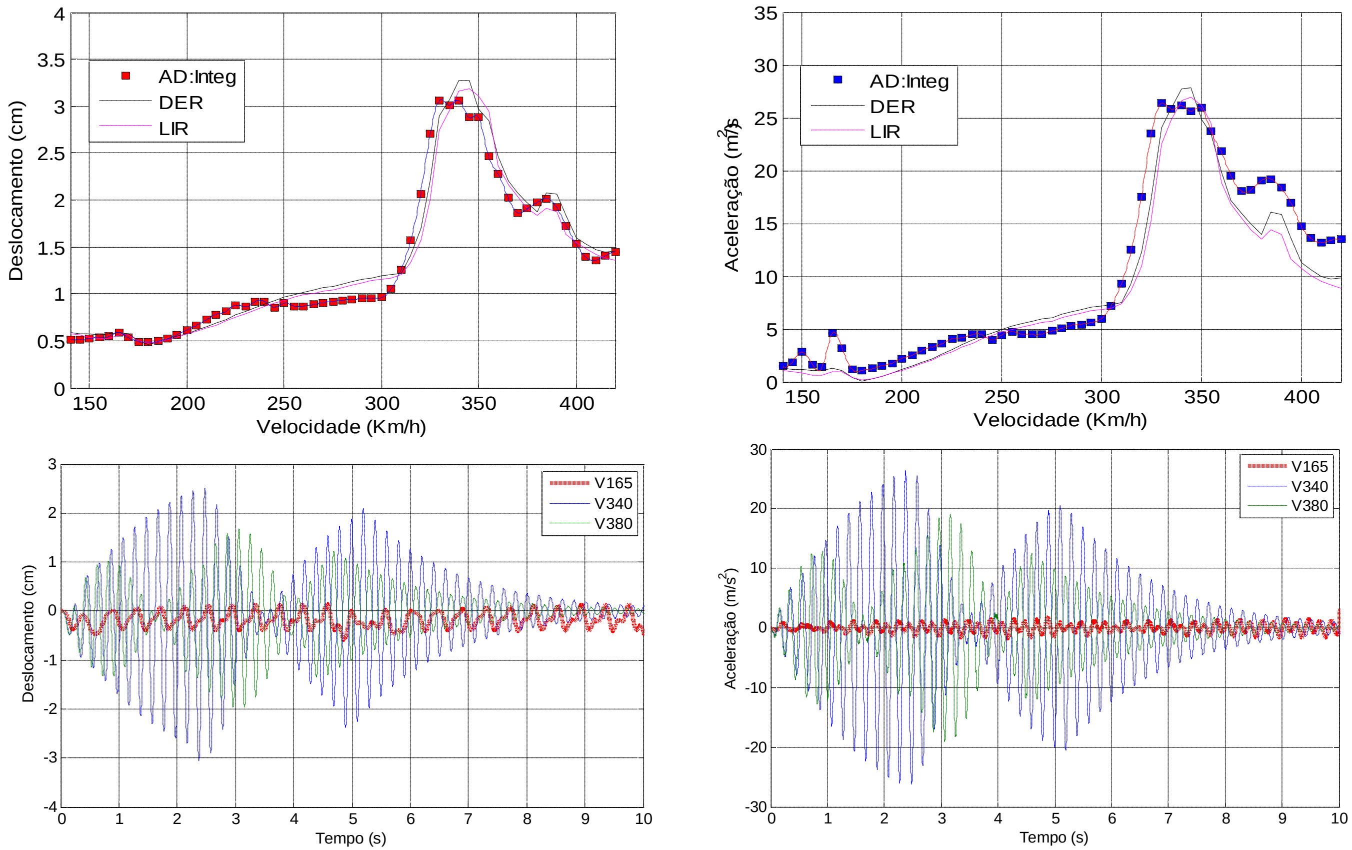






Application of simplified methodologies

- TGV train:

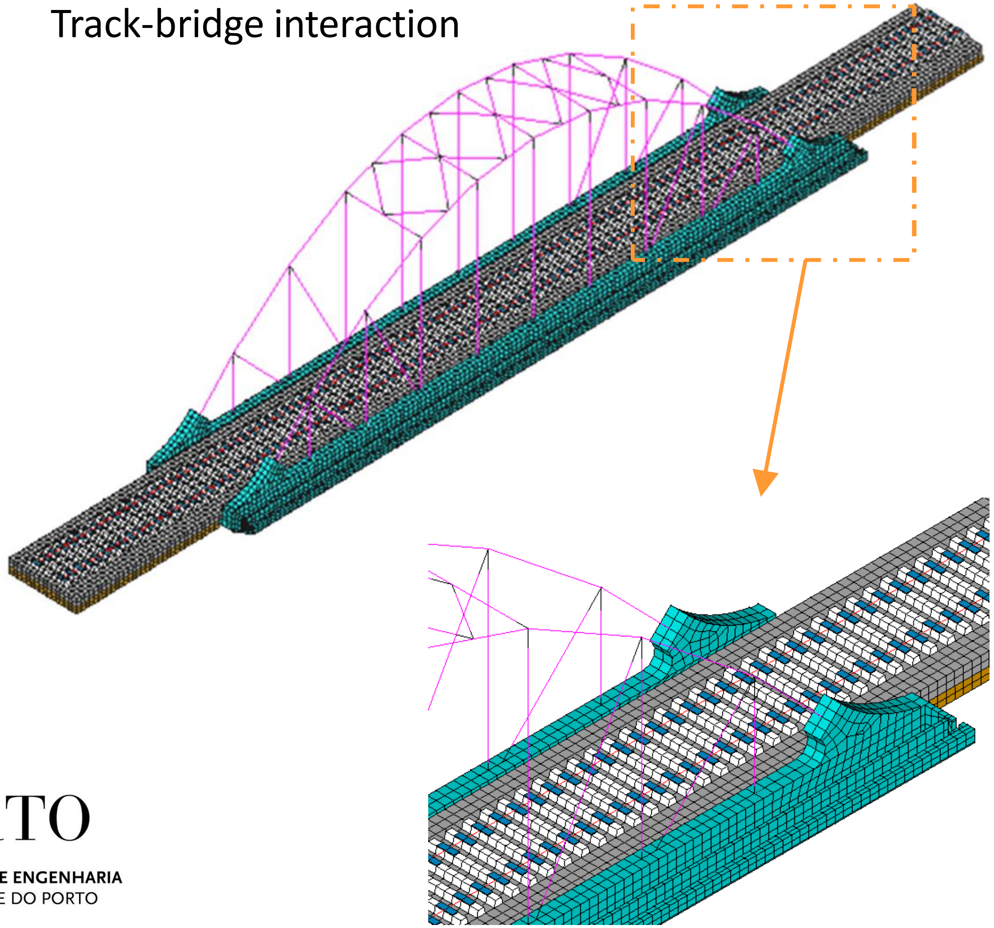


Sophisticated Dynamic modeling of railway bridges

RIBEIRO et al. (2013)

Bridge over the São Lourenço River – span of 42 m
Railway bridge of the Portuguese high speed system (220 km/h)
In operation.

Track-bridge interaction



Finite Element Model in ANSYS FEA software

Courtesy: Prof. Rui Calçada - FEUP

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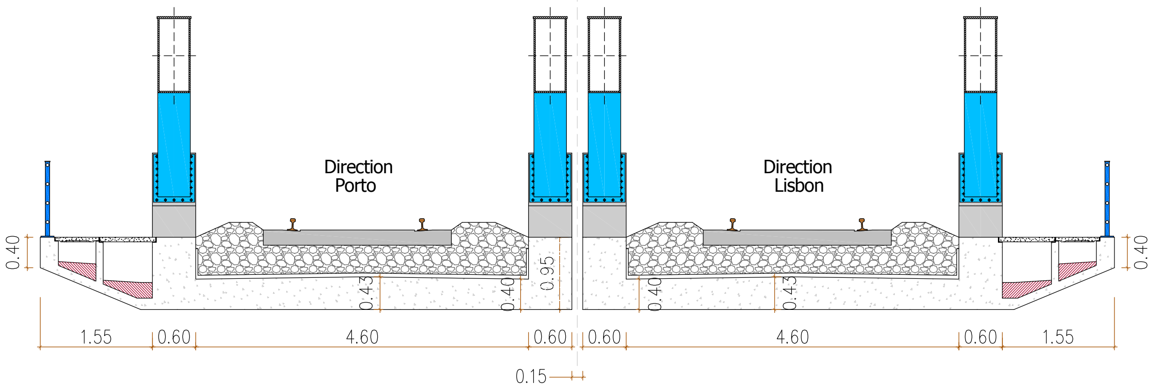
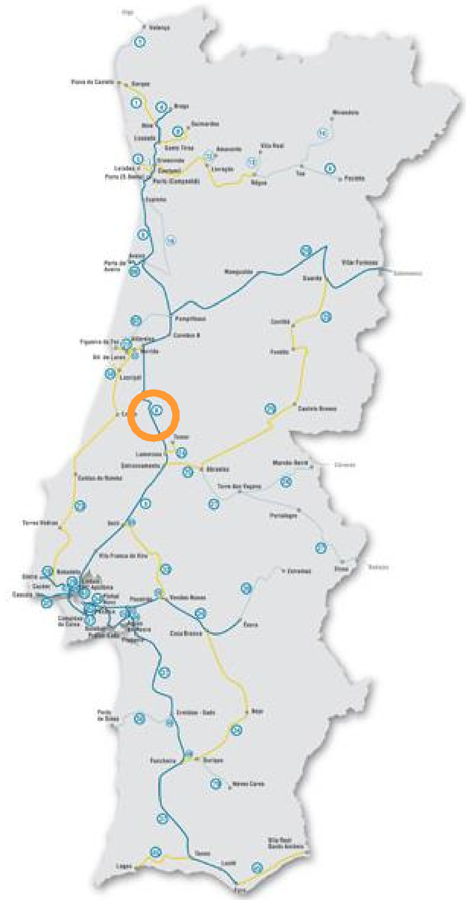
Description of the bridge





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Dynamic modeling of bridges in Portugal

Courtesy: Prof. Rui Calçada - FEUP

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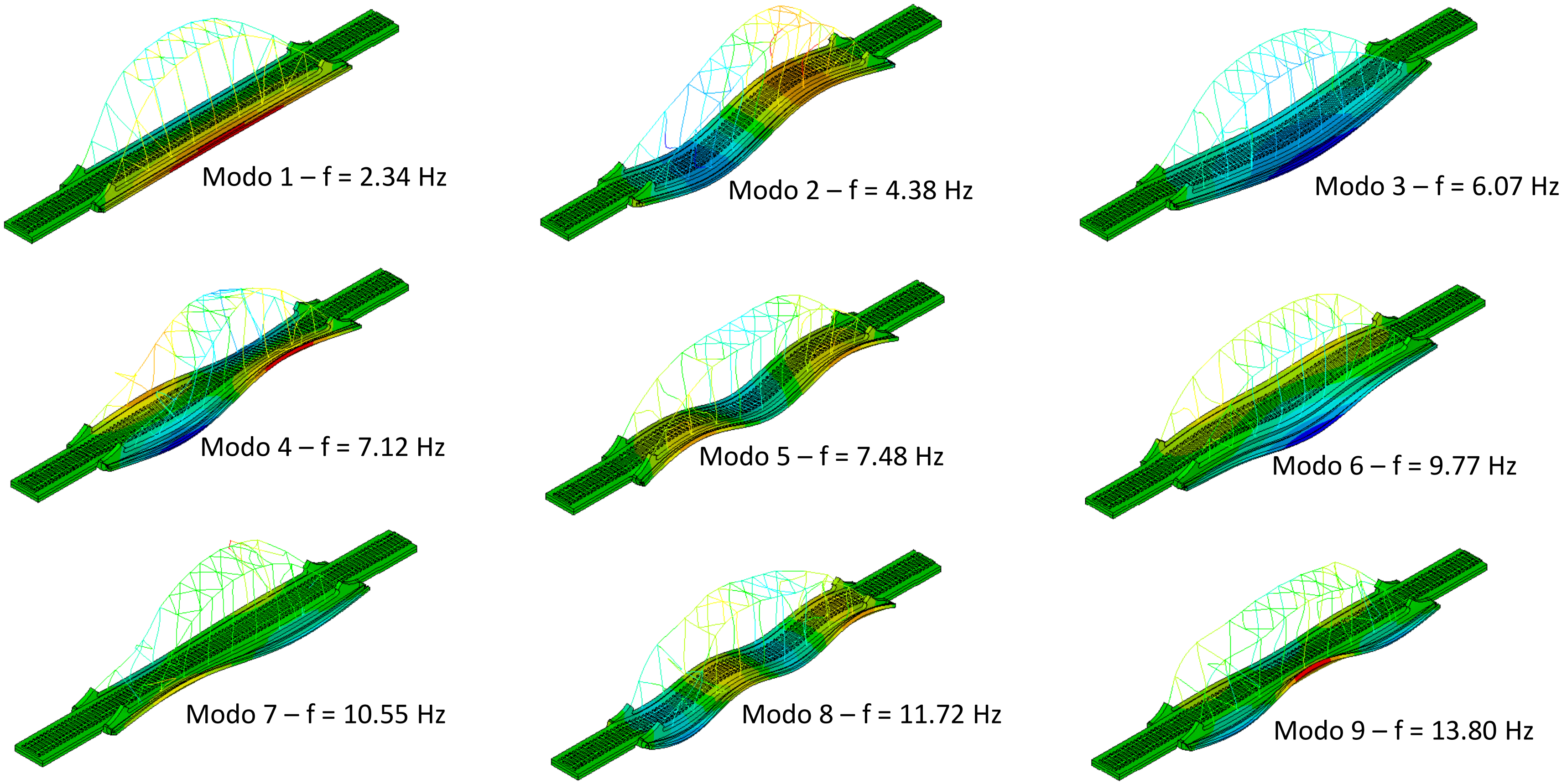
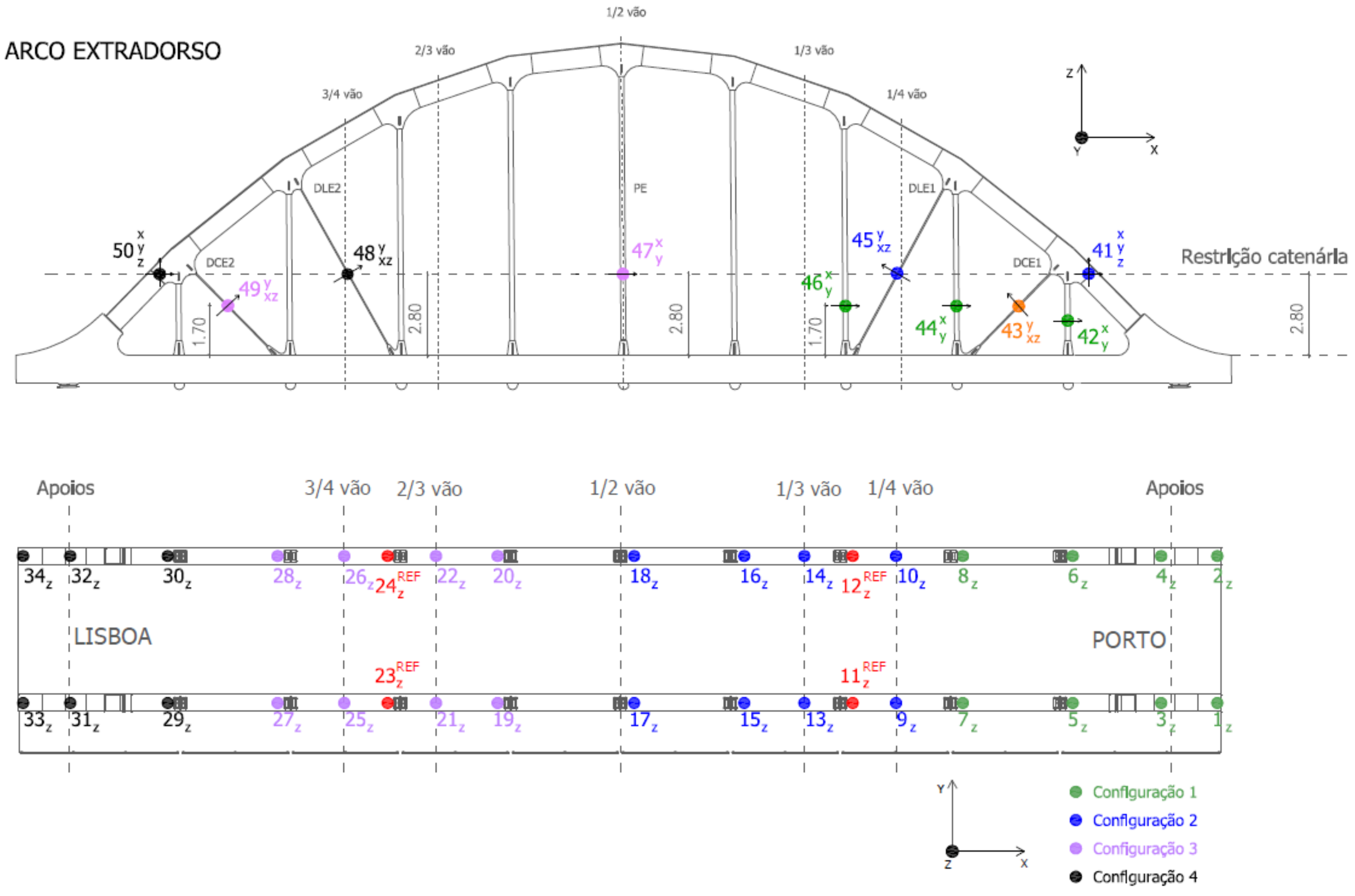
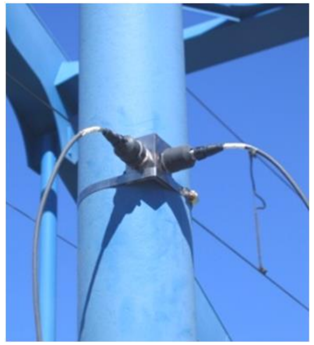


Modal parameters identification





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Palestra:
"Modelagem Computacional como Ferramenta para o Monitoramento de Estruturas de Pontes Existentes"

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Dynamic modeling of bridges in Portugal

Courtesy: Prof. Rui Calçada - FEUP

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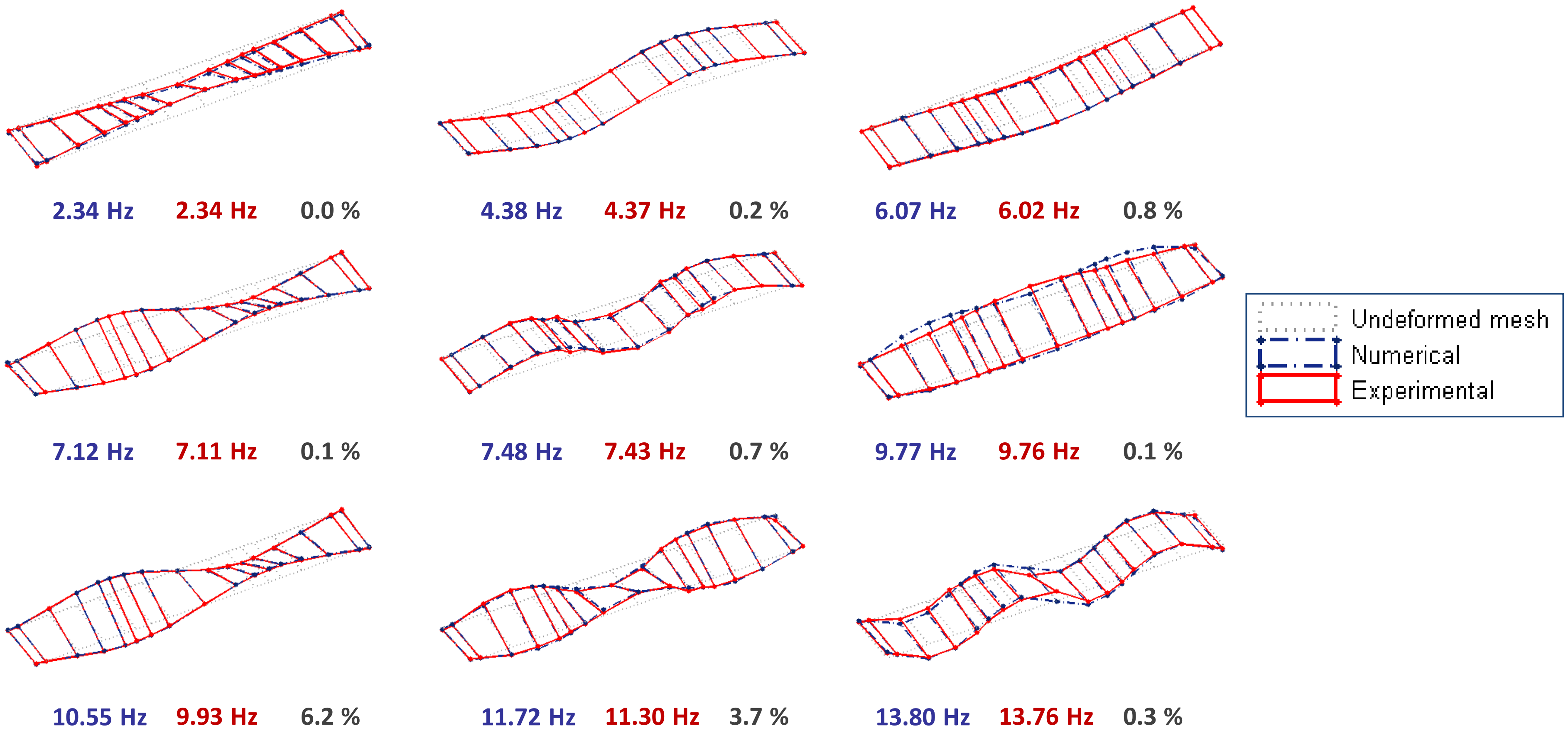

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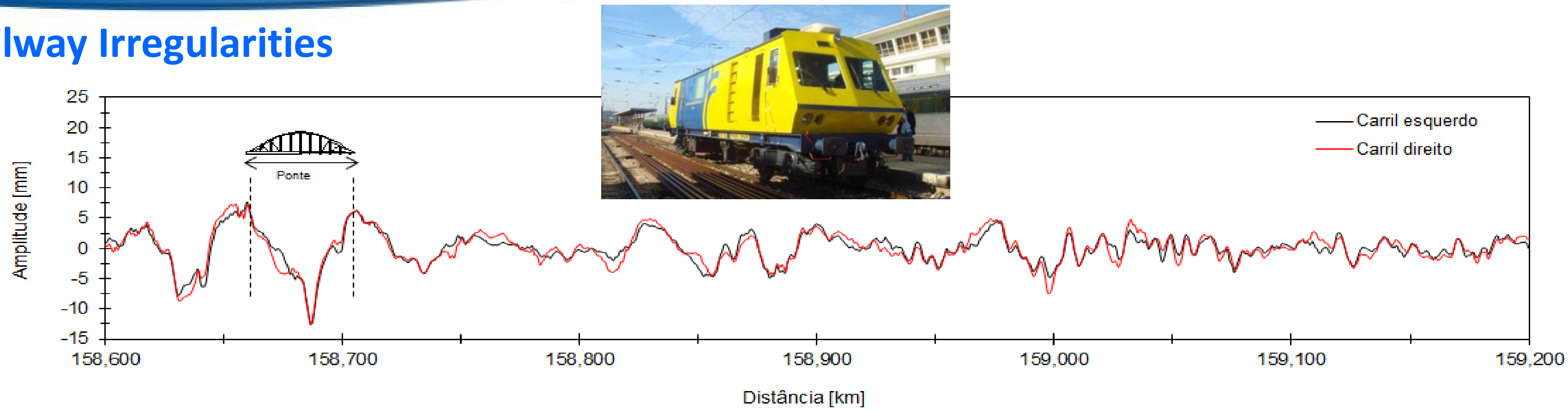
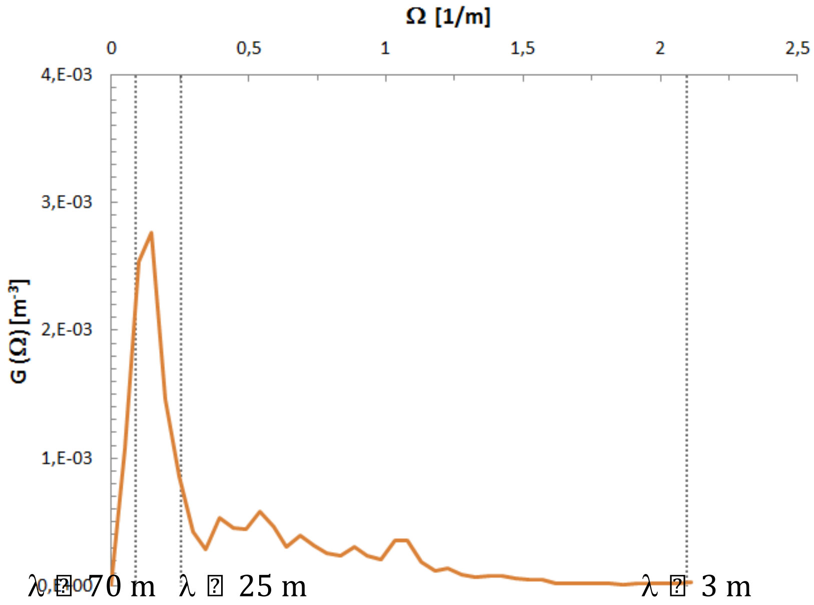
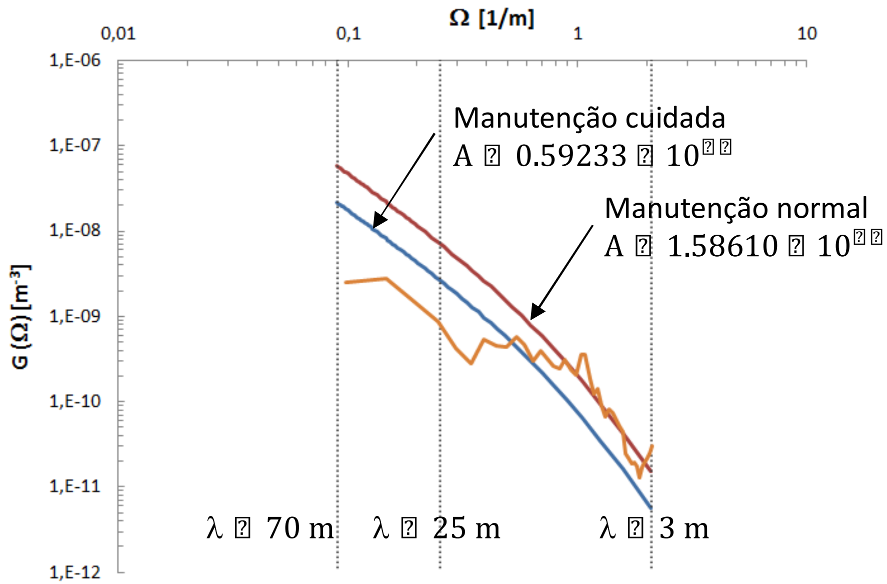
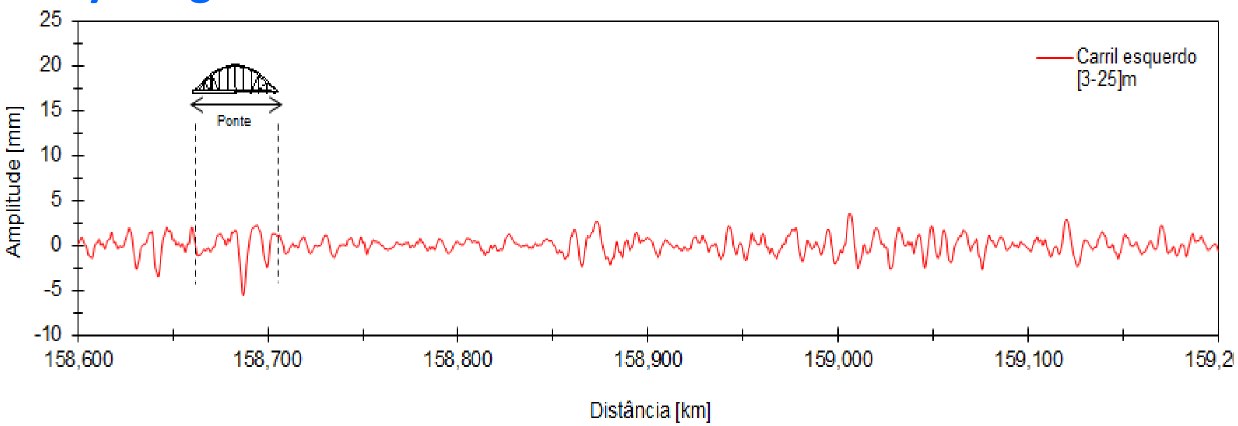
Railway Irregularities

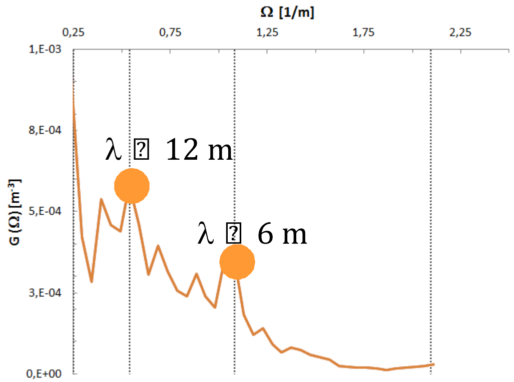


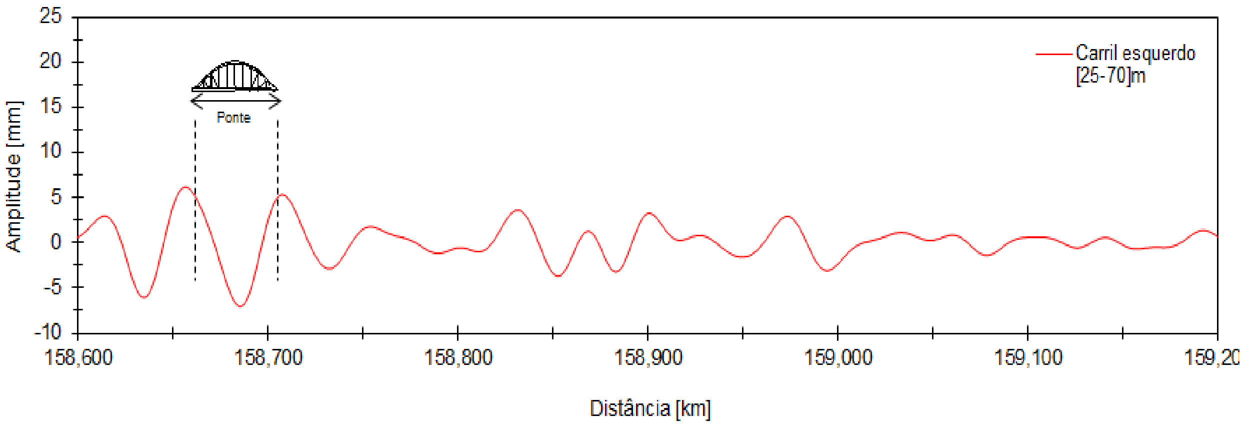


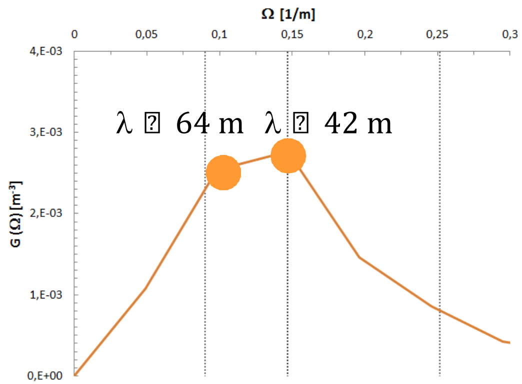


Railway Irregularities









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Dynamic Model of the Alfa pendular train

Distance between axles D = 25.9 m

Axle Load P = 129-137 kN

Total Lenght L = 158.9 m

Maximum Speed v = 220 km/h

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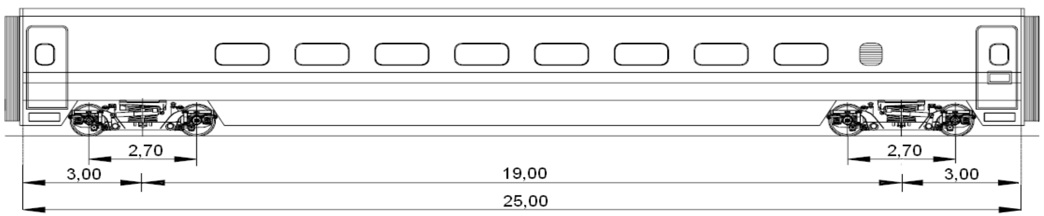
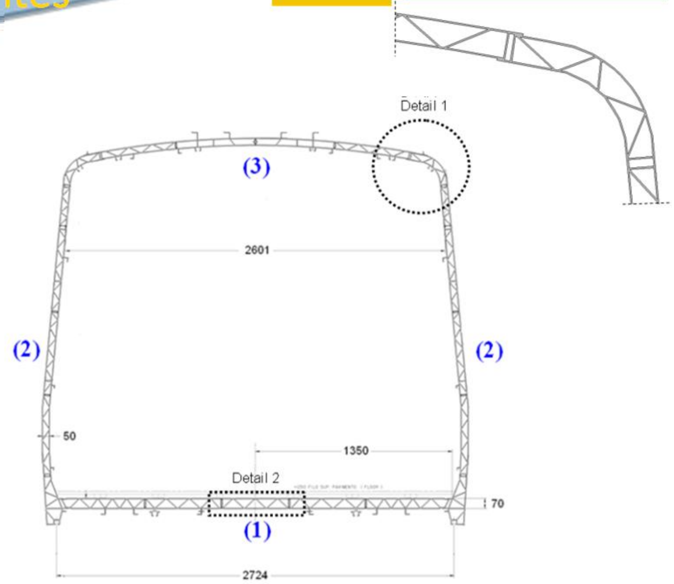
Finite Element Model

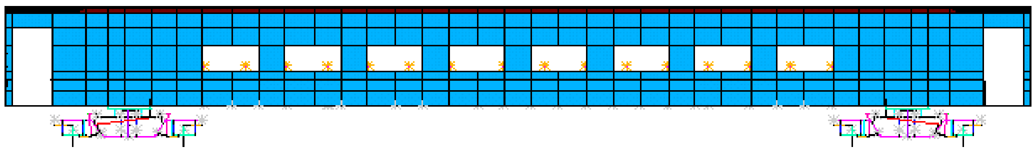


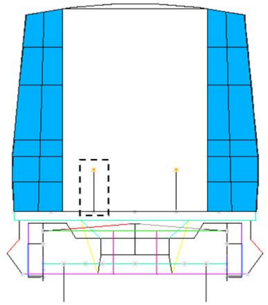


(1) Base

(2) Painéis laterais

(3) Cobertura





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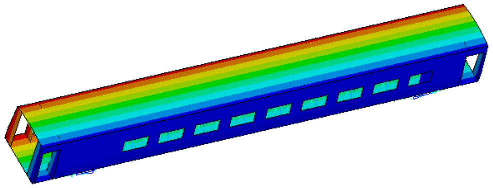
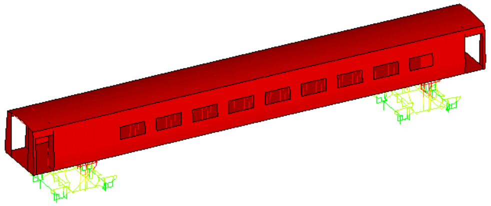
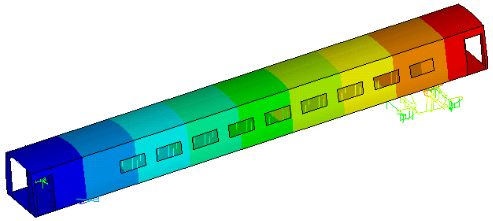
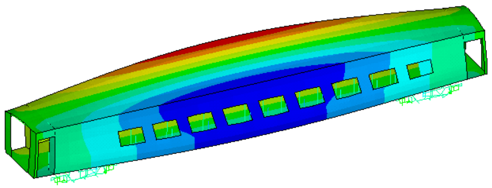
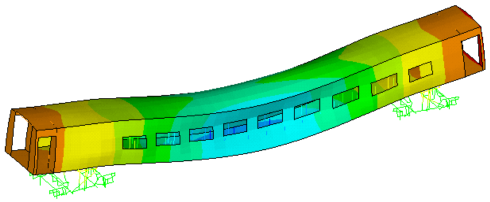
Computed Modal Parameters

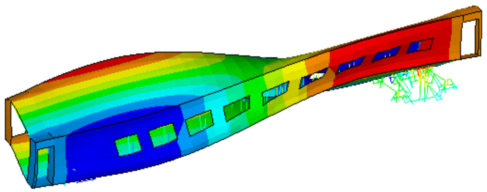

1C - f_D = 1.01 Hz


2C - f_D = 1.24 Hz


3C - f_D = 1.70 Hz

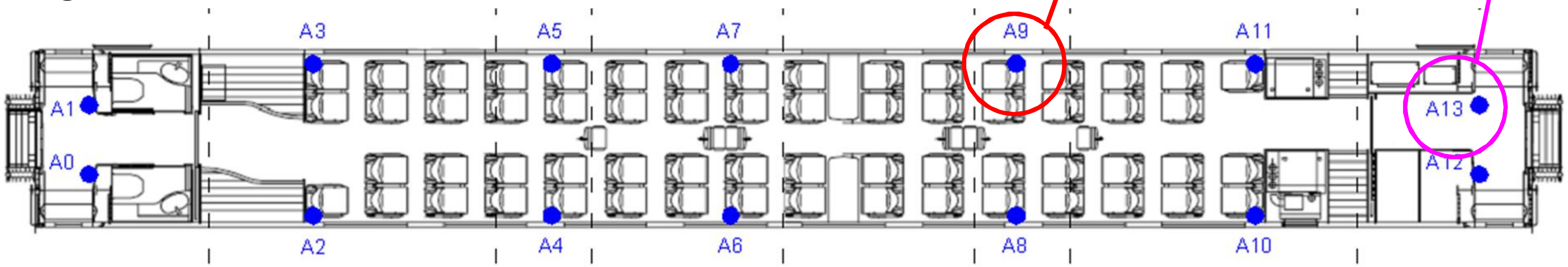

4C - f_D = 8.39 Hz


5C - f_D = 12.16 Hz

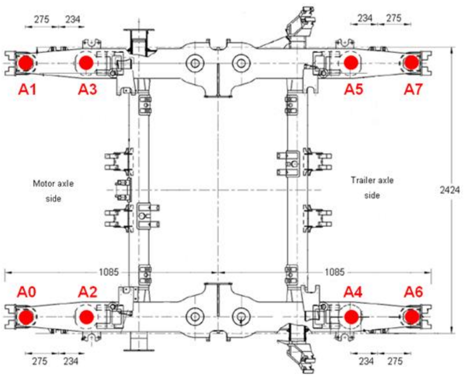

6C - f_D = 17.73 Hz

Modal Parameters Identification


Wagon Instrumentation



Truck Instrumentation

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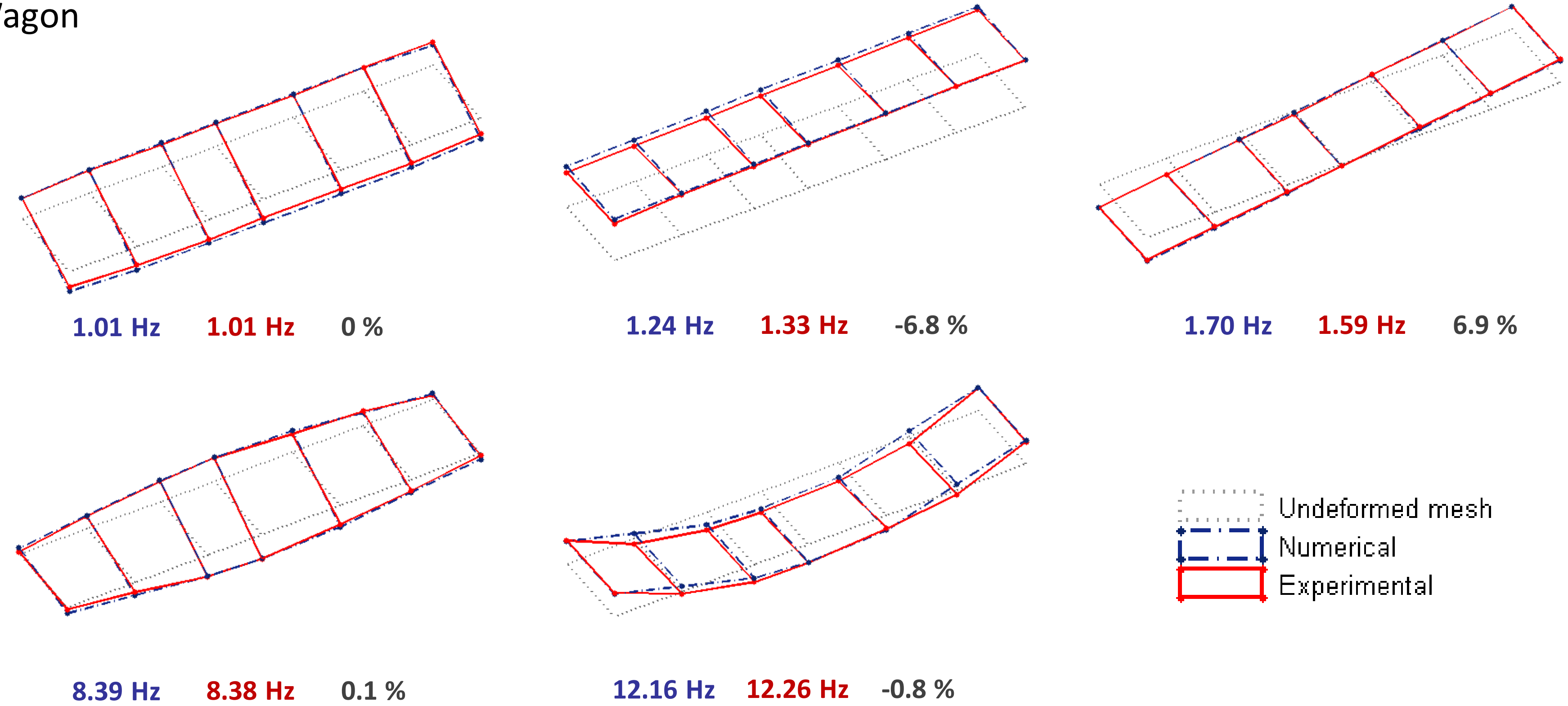
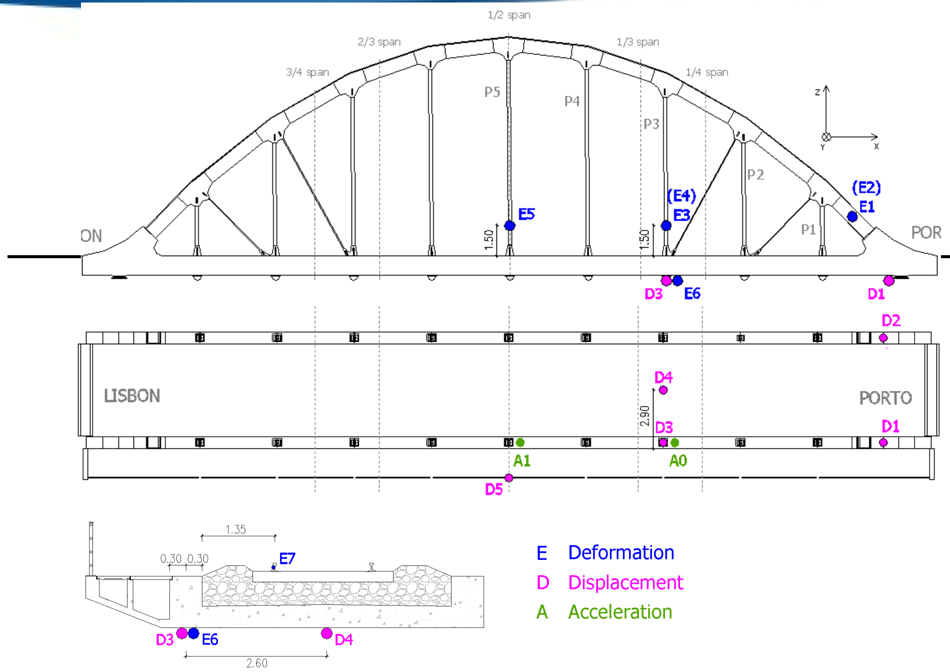
Numerical vs Experimental Modal Parameters

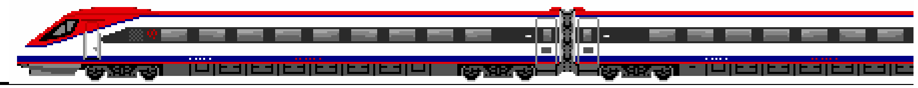
Wagon

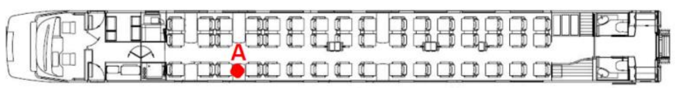


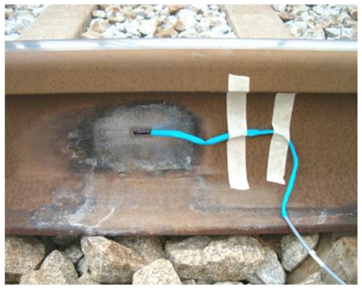
D. Ribeiro, R. Calçada, R. Delgado, M. Brehm and V. Zabel. Finite element model calibration of a railway vehicle based on experimental modal parameters, Vehicle System Dynamics, Volume 51, Issue 6, 2013

Dynamic Test under real traffic









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Dynamic modeling of bridges in Portugal

Courtesy: Prof. Rui Calçada - FEUP

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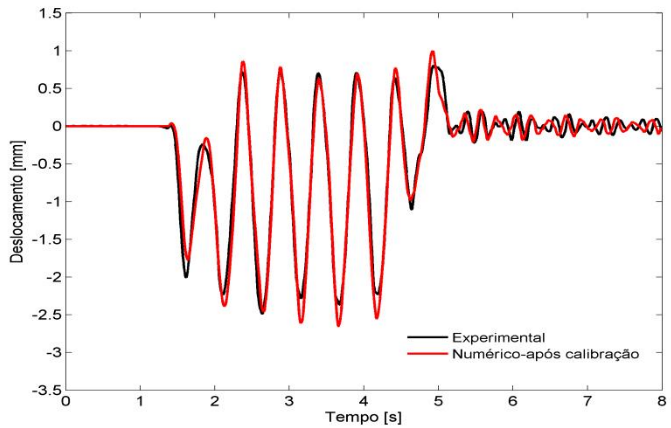
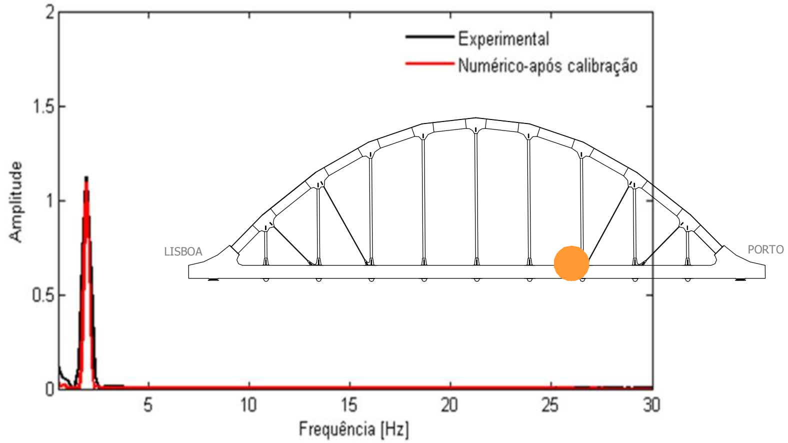
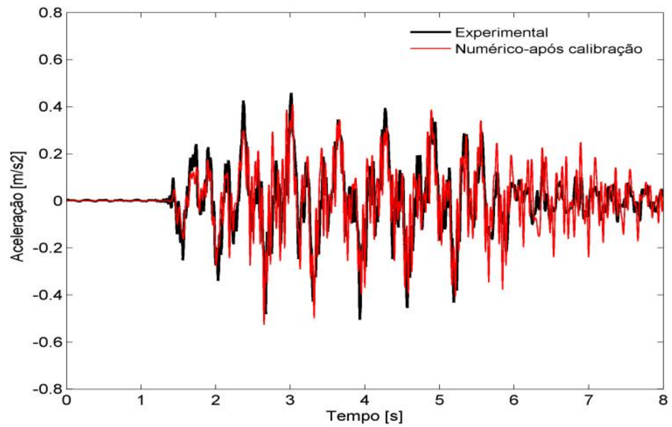
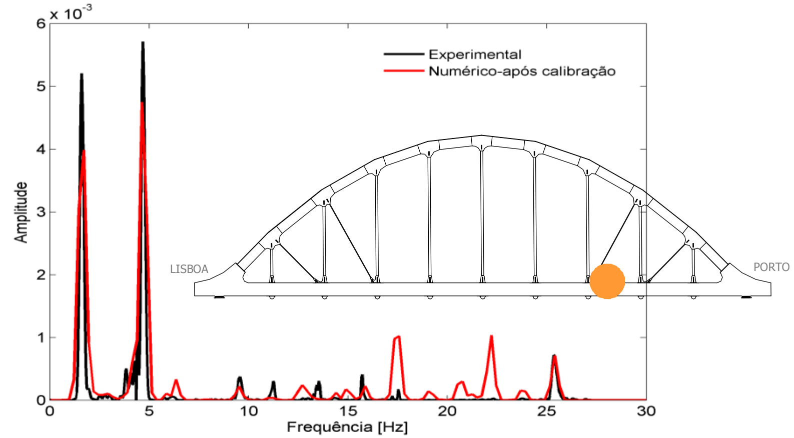




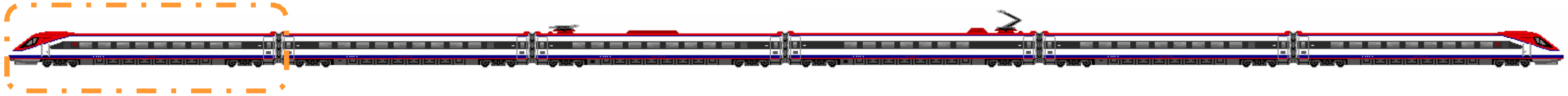


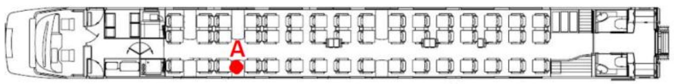


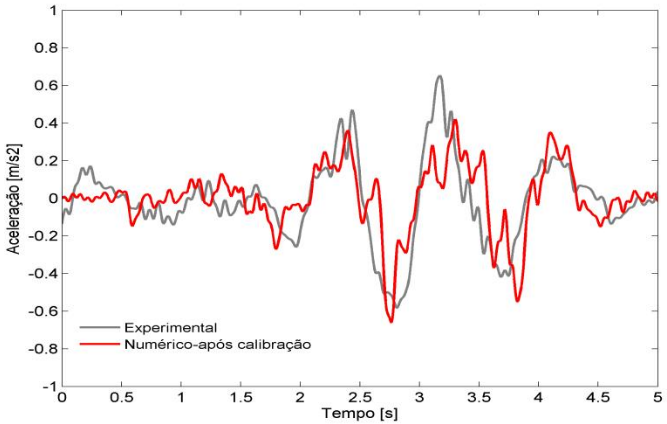
Alfa pendular train
(v = 180 km/h)

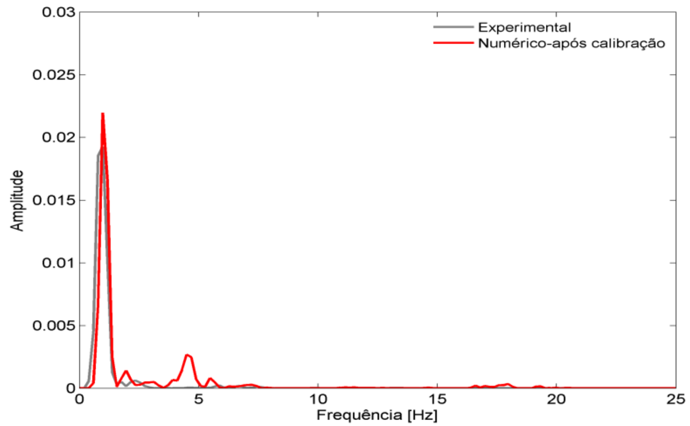
Dynamic Response under real traffic

Alfa pendular train (v = 180 km/h)









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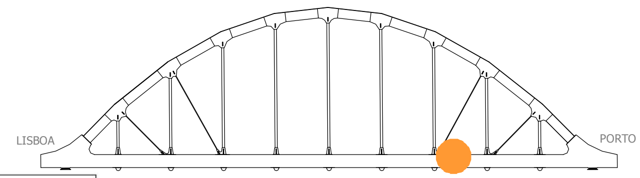
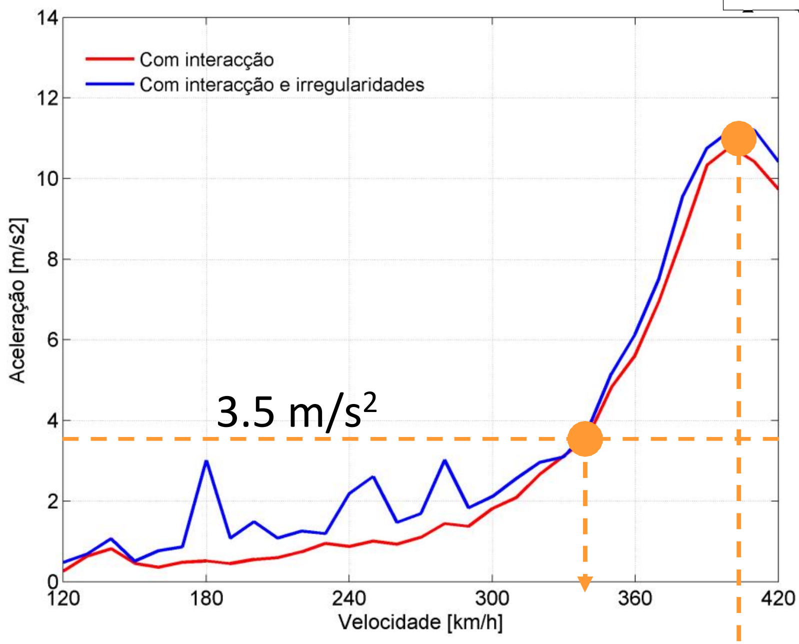
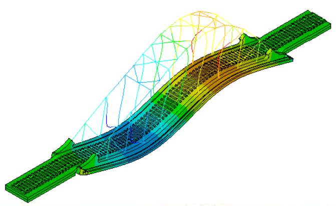
Railway Stability







$f_2 = 4.38$ Hz

$v_{res} = f_2 \times D = 4.38 \times 25.9 = 113.4\ m/s \approx 405\ km/h$

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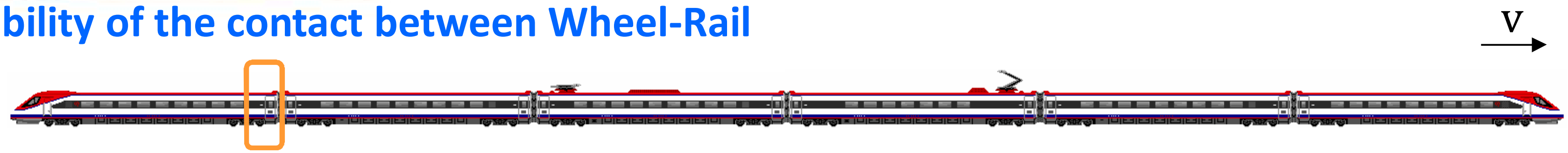
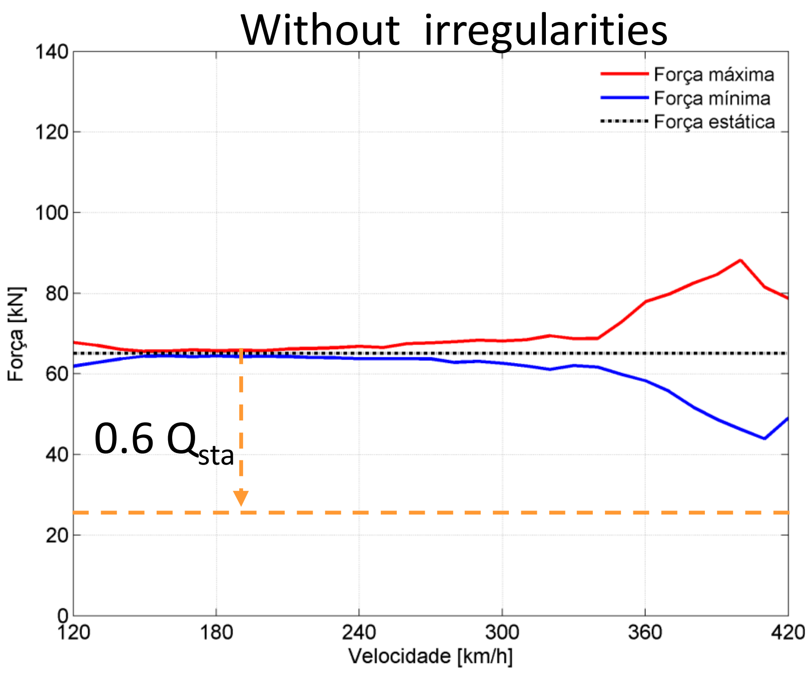
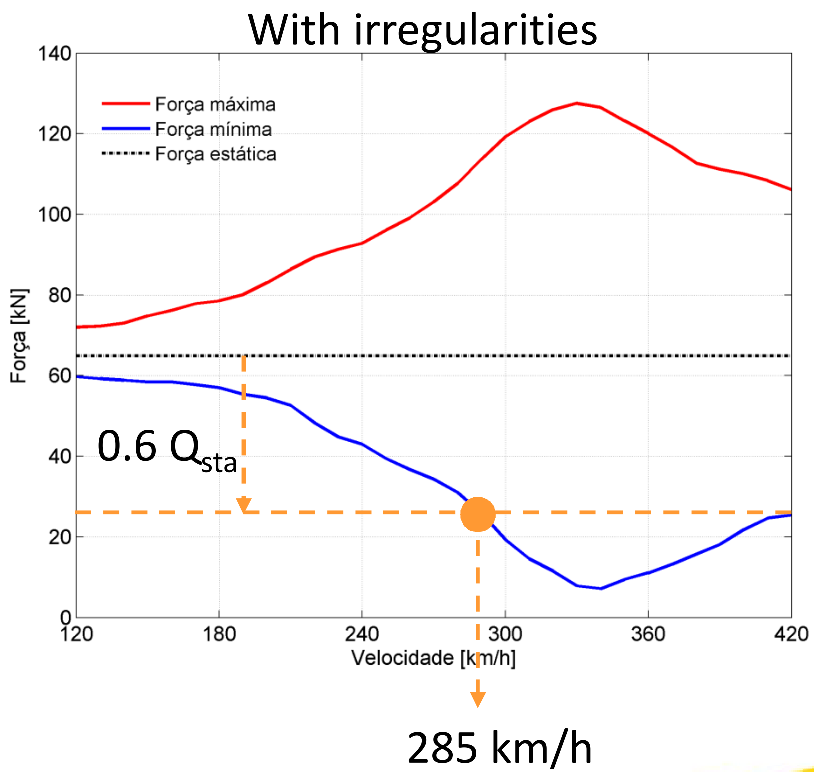
Stability of the contact between Wheel-Rail







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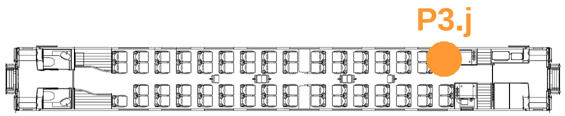
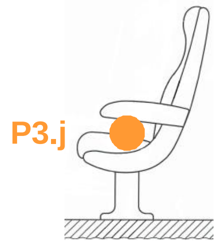
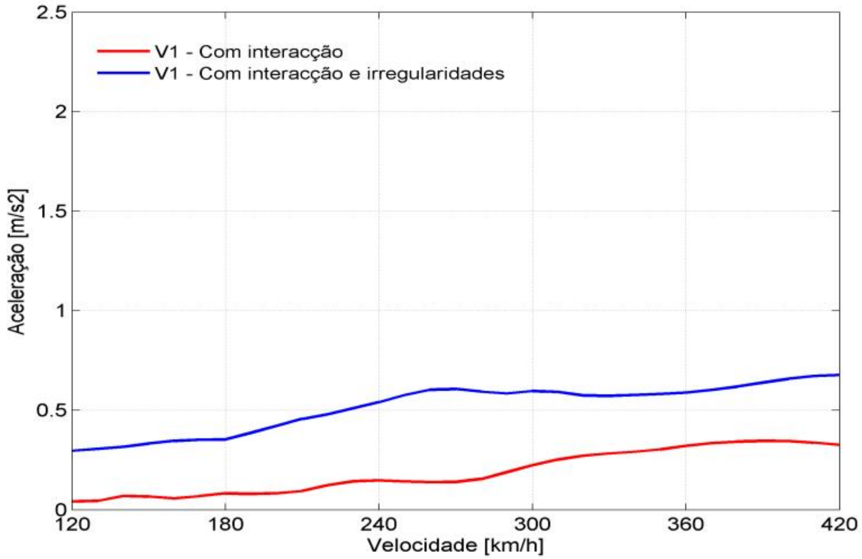
Passengers Confort

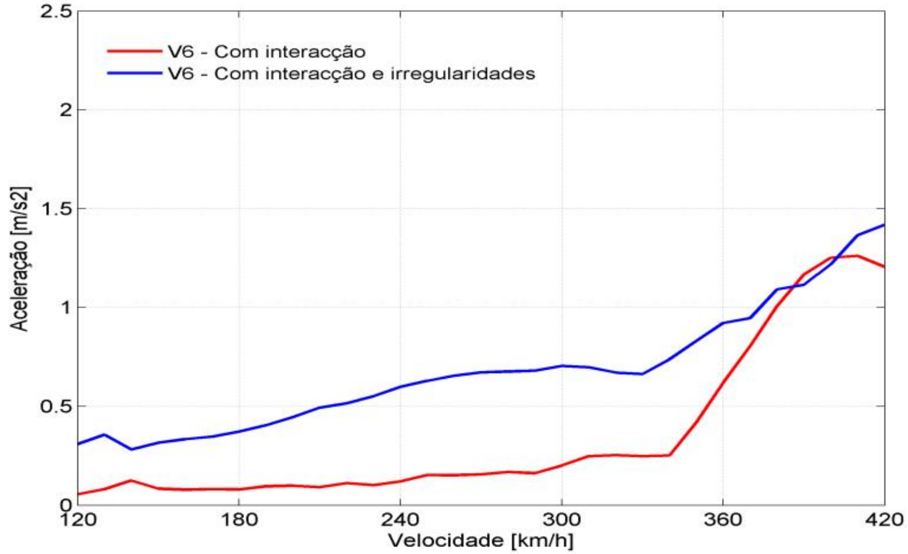




Wagon 1



Wagon 6



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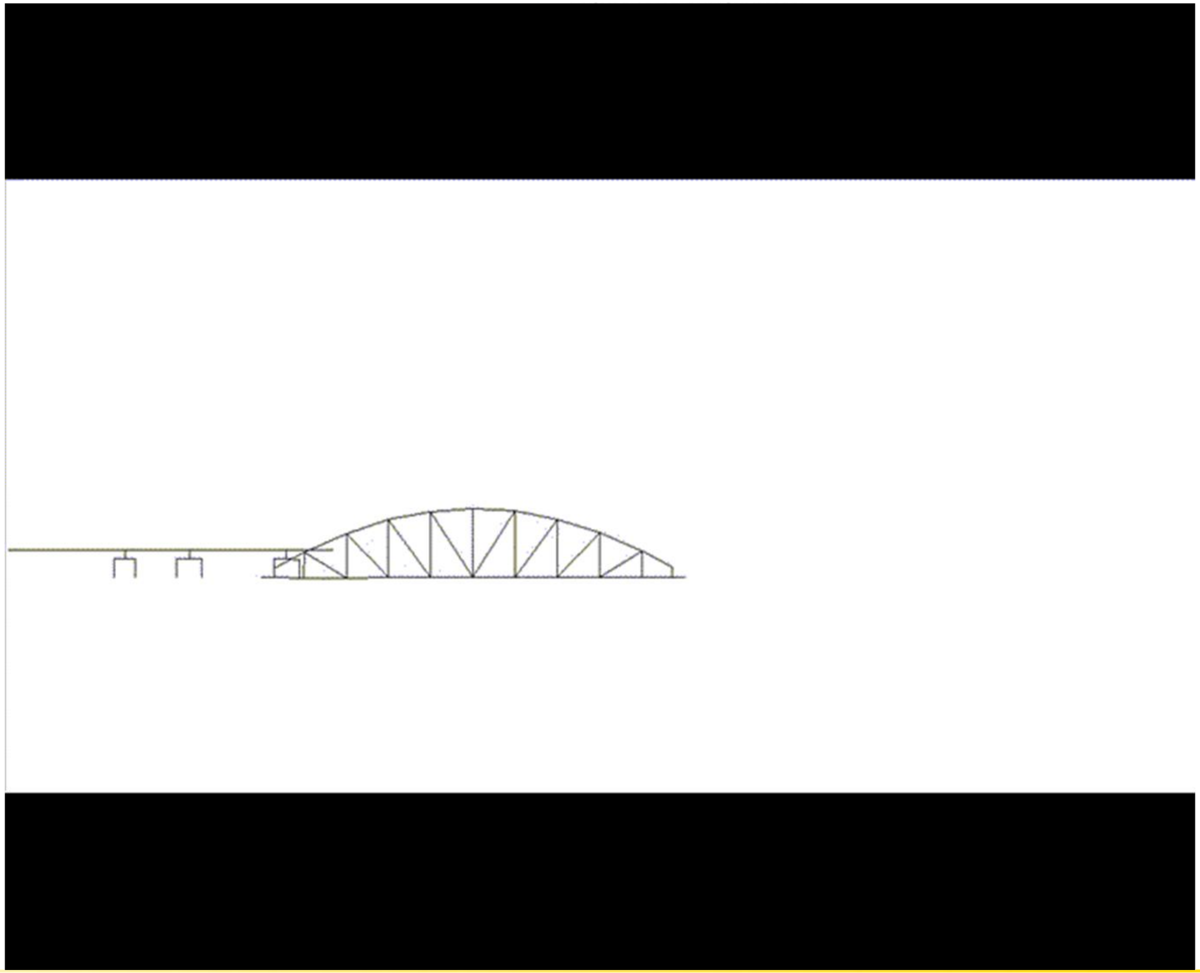
Dynamic modeling of bridges in Portugal

Courtesy: Prof. Rui Calçada - FEUP U.PORTO

Alcácer do Sal Bridge

(RIBEIRO, 2004)

Train-bridge interaction



Track-bridge interaction

Courtesy: Prof. Rui Calçada - FEUP

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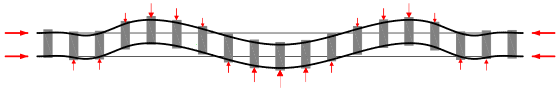

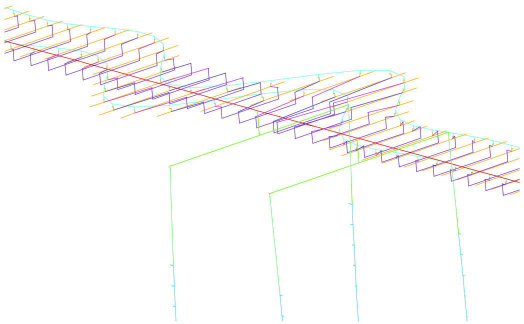

Conclusions

- ✓ The overview presented here shows the need to develop efficient modeling methodologies as supporting tools for the assessment of bridges;

- ✓ Technological developments in the rail transport sector has led to considerable requirements for the increase in the wagon load capacity (with associated heavy axle loads) and for high speeds (in the case of high speed railroads), posing new challenges in the field of structural evaluation of bridges;

- ✓ Advanced analysis techniques based on finite element methods have been successfully employed and are getting notorious development due to an increasing availability of computational resources, allowing a better level of model exploration;

- ✓ Such techniques should also have the ability to represent damage mechanisms and deterioration processes along time, such as fatigue damage and corrosion;

Conclusions

✓ An efficient methodology is under development to enable a continuous integration between different analysis types, including static and dynamic procedures, necessary for fatigue assessment through iterative processes. Preliminary results have been shown here;

✓ FE models for fatigue assessment of steel railway bridges have been developed taking as a reference some existing bridges. The models are updated based on short-term monitoring and can present responses adjusted to the field measures;

✓The dynamic behavior of bridges in high-speed lines is an important issue and has been briefly addressed, highlighting sophisticated tools of analysis that include track-bridge interaction and train-bridge interaction;

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Obrigado pela sua atenção!