Assessment of the short and long term behaviour of the track at a railway transition zone

Cristina Alves Ribeiro[1] e Rui Calçada[1]

1. *University of Porto, Faculty of Engineering, Portugal*

What is a transition zone?

Zones where variation of vertical stiffness of the track occur. Those variations can be abrupt or smoothed by transition structures. Zones that require frequent maintenance operations.

Embankment - bridge

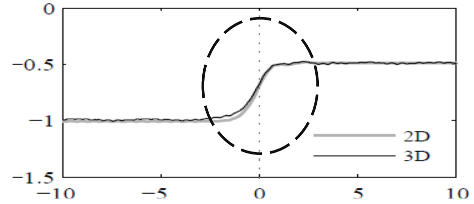
Culvert structures

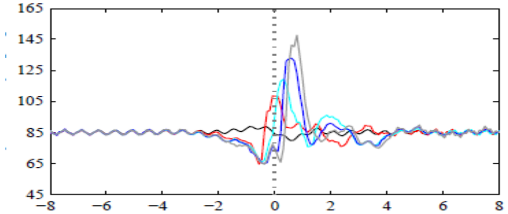
Embankment - tunnel

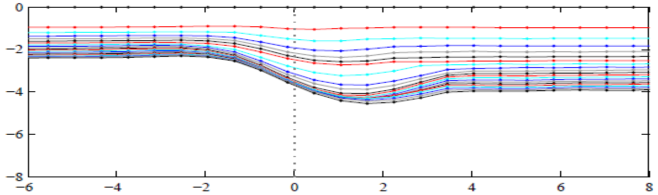
Ballast track – slab track

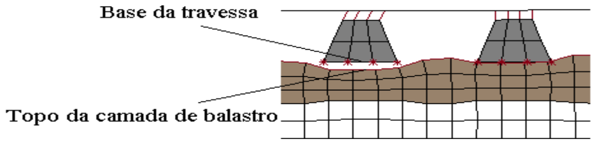
Understand the problematic

Variation of the vertical stiffness	Assess how the stiffness variation can influences the dynamic behaviour.
Variation of the wheel-rail contact forces	Asses how those forces vary in short and long term.
Differential settlements	Understand the arise of differential settlement due to railway traffic – load repeatedly applied by trains
Unsupported sleepers	Understand the arise of unsupported sleepers: the sleeper is not working properly, there is an overload of the neighbour sleepers





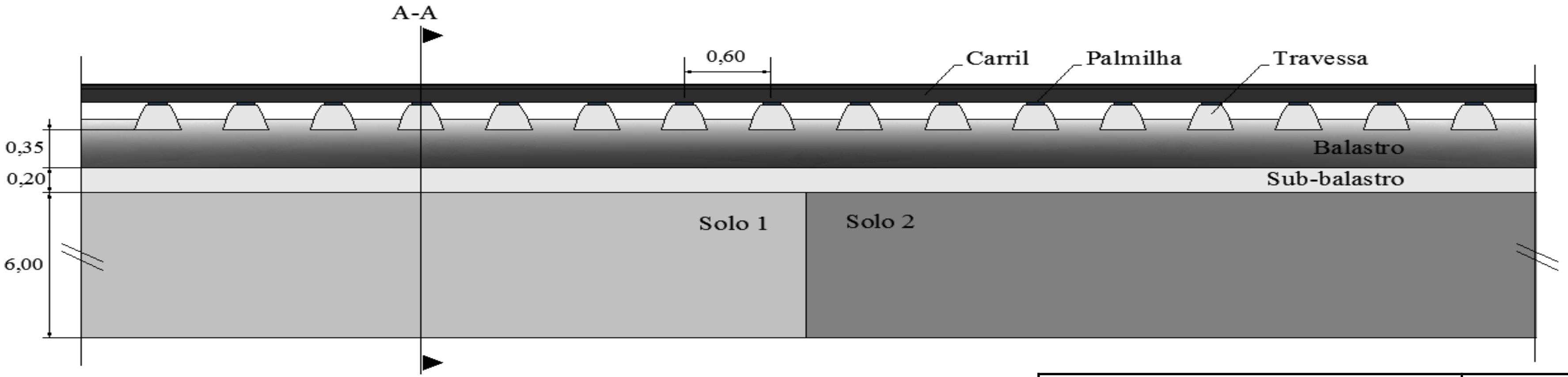




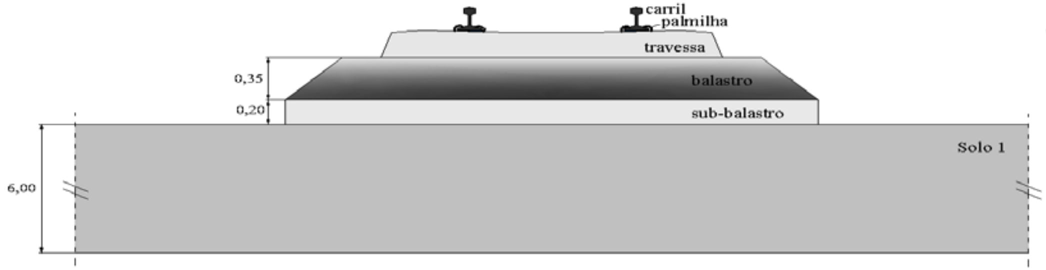
Background:

- Development of numerical models;
- Calibration and validation of the numerical models;
- Validation of the vehicle-track dynamics;

Case study

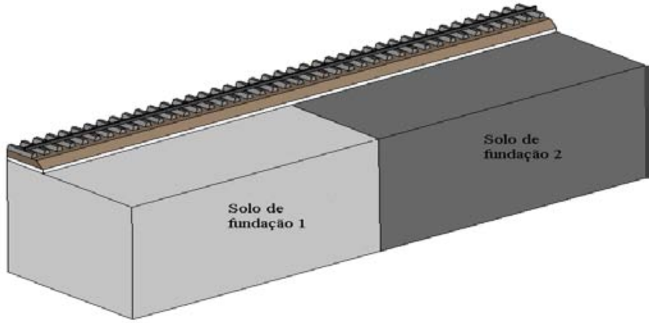


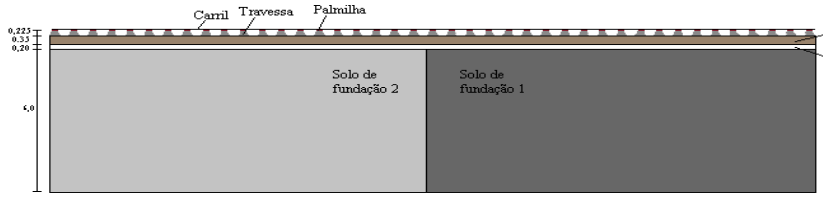
Abrupt stiffness variation:
Soil 1 → Soil 2



Track layer	E (MPa)	ρ (kg/m^3)	ν (-)
Ballast	130	1530	0,20
Sub-ballast	120	1935	0,30
Soil 1	80	2040	0,30
Soil 2	1600	2040	0,30

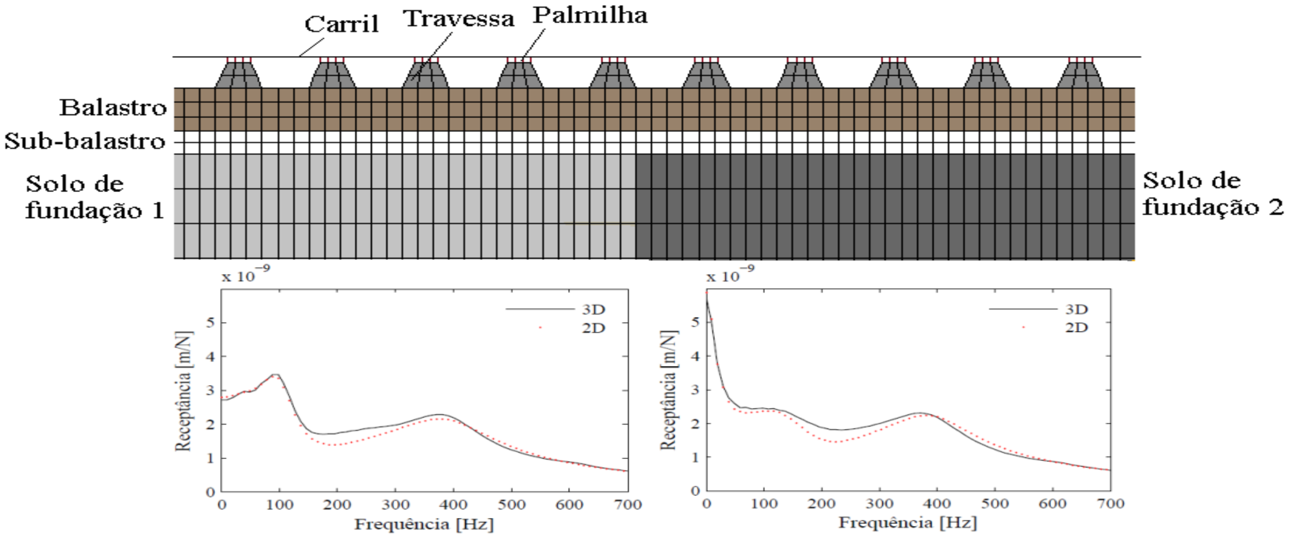
Numerical models:



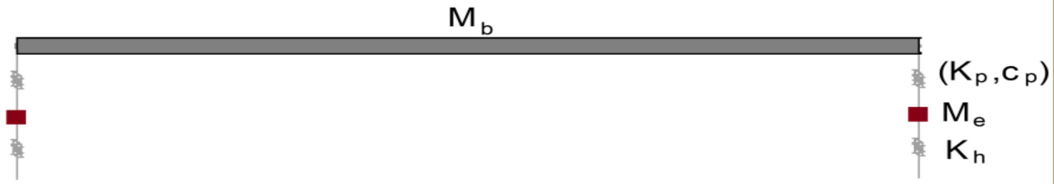


Vehicle-track model

TRACK – TRANSITION ZONE

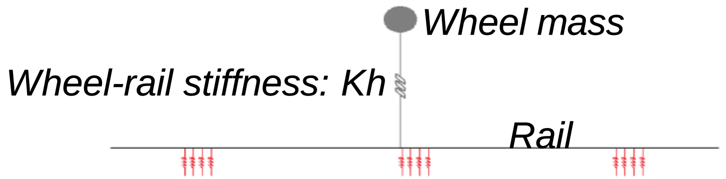


VEHICLE – 1 BOGIE



Vehicle component		Value
Bogies	Mb	2200 kg
Primary suspension	Kp	$2{,}60\times10^6$ N/m
	cp	$1{,}20\times10^4$ N/m
Wheels/axle	Me	1700 kg
Wheel – rail stiffness	Kh	$1{,}35\times10^9$ N/m

VEHICLE-TRACK INTERACTION

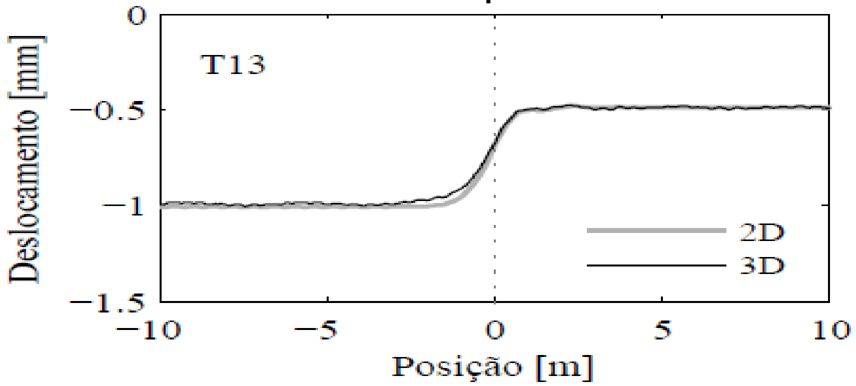


- Point-line contact
- Contact algorithms – ANSYS
- Penalty method

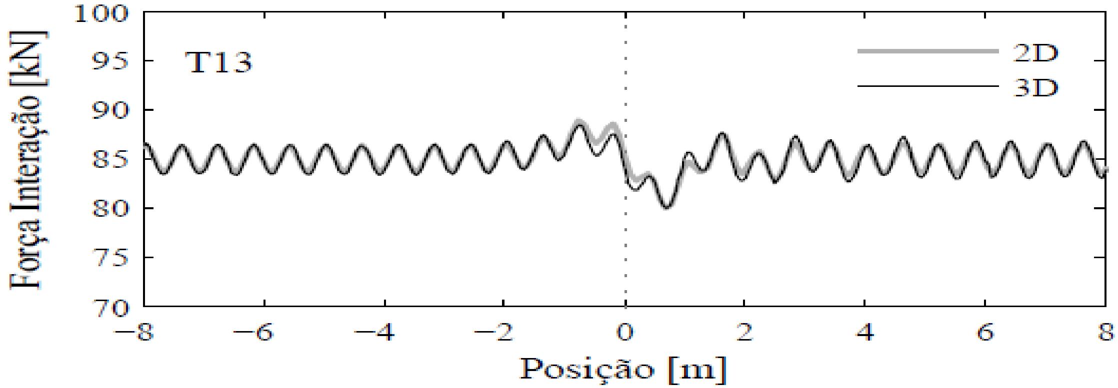
Short term dynamic behaviour

Comparison of the results obtained in both 2D and 3D models

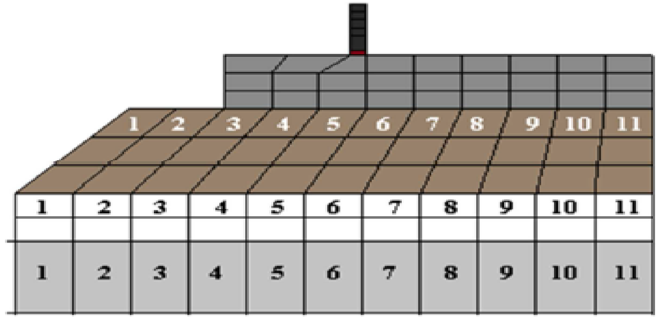
Wheel displacement

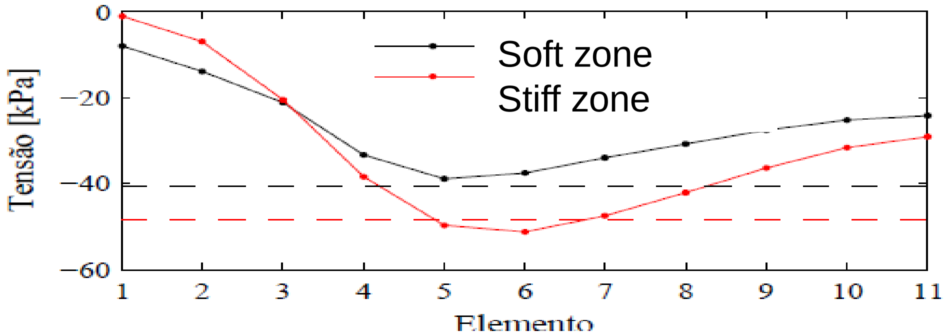


Wheel-rail contact force



Maximum vertical stress (top of sub-ballast layer)





How to simulate long term behaviour?

ANSYS

NUMERICAL MODEL OF THE VEHICLE-TRACK SYSTEM

Track geometry

Finite element model that enables to analyse the stress state induced by the vehicle passage

ANSYS

DYNAMIC ANALYSIS WITH VEHICLE-TRACK INTERACTION

Sleeper-ballast contact

Simulate the possible separation between the base of the sleeper and the top of the ballast layer

Stresses in track layers (σ)

The vertical, horizontal and tangential stresses of the finite elements of the track layers are stored in matrices

MATLAB

DEFORMATION LAW = $f(N,\sigma)$

MATLAB

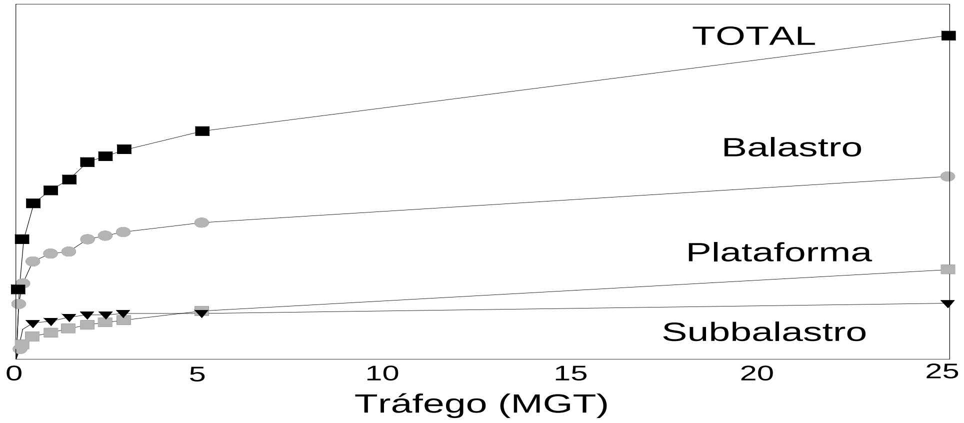
PERMANENT DEFORMATION OF ELEMENTS

$$\varepsilon = \varepsilon(N) + \varepsilon(\Delta N)$$

The simulation process is carried out considering sets of cycles (ΔN = 100 000). It is assumed that the stress is constant in each set of cycles.

$$N = N + \Delta N$$

Deformation laws



Permanent deformation of track layers

- Settlement growth is higher in ballast layer.
- Logarithmic laws.
- Depend on stress state and number of loading cycles

Ballast – ORE (1970) law

$$\varepsilon_N = \varepsilon_1\left(C\log\left(\frac{N+N_i}{N_i}\right)\right)$$

Do not consider the phase 1 of loading

$$\varepsilon_1 = 0.082(100n_p - 38.2)(\sigma_1 - \sigma_3)^2$$

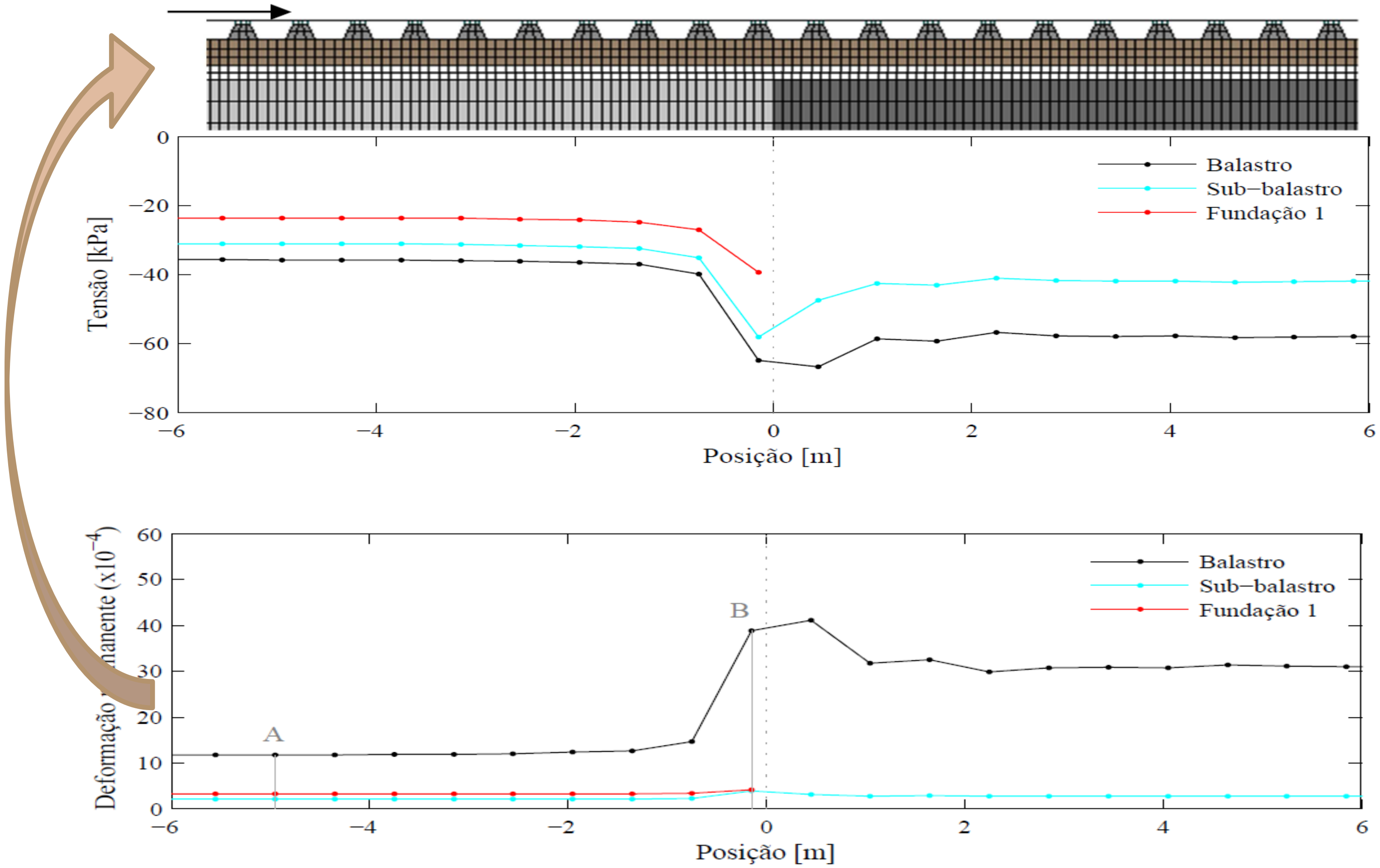
Experimental validated by Ionescu (2004)
Depends on: N, stress, porosity of layer, constants

Sub-ballast; Foundation – Gidel et al. (2001):

$$\varepsilon_P = f(N)\,.\,g(p_{\max}, q_{\max})$$

depends on: N, stress, constants that depends on the type of material

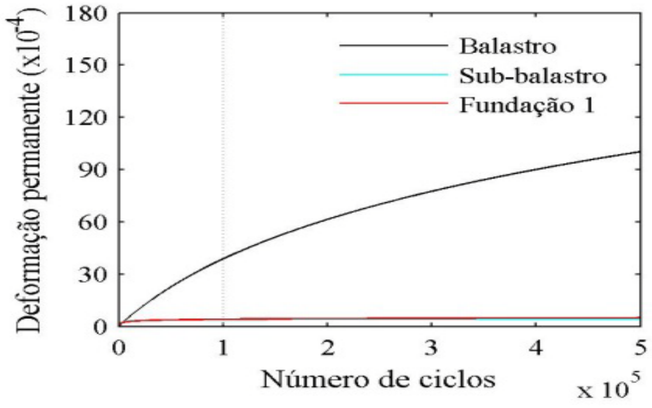
Methodology for long term simulation



Vehicle passage; dynamic analyses with wheel-rail interaction

Assess the stresses of the finite elements

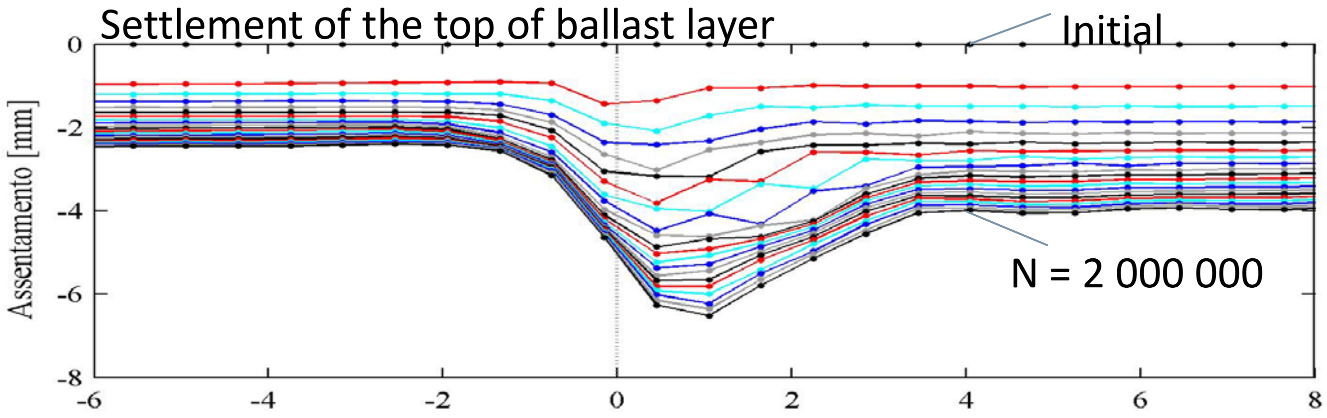
Apply the deformation law of the materials for N cycles

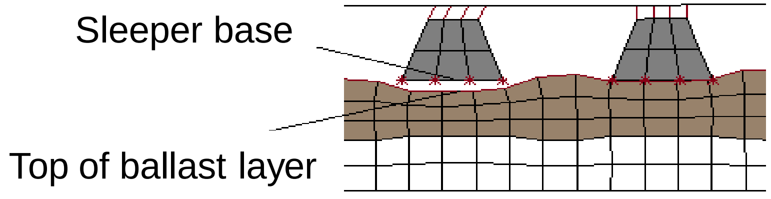


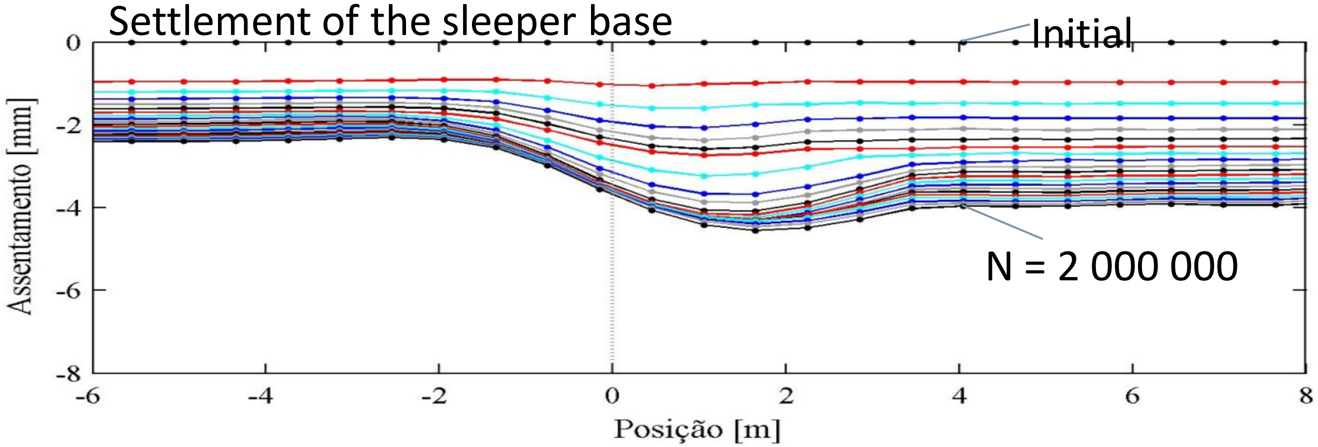
Permanent deformation of the finite elements – update track geometry

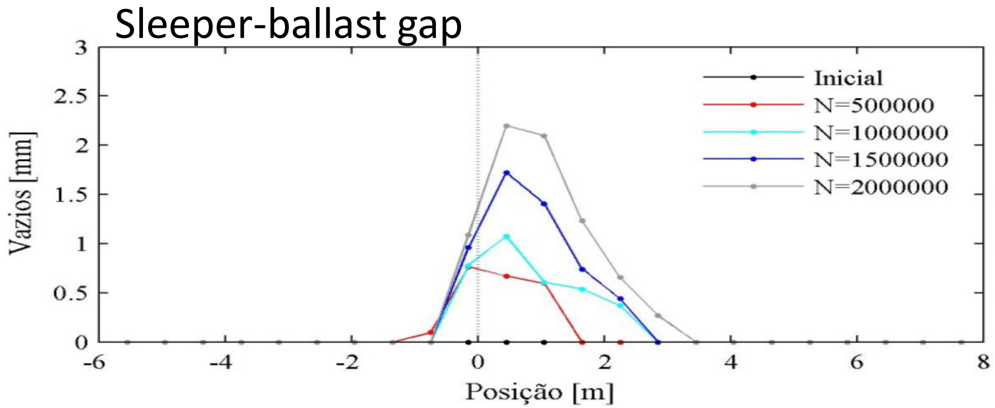
Long term dynamic behaviour

Track settlement



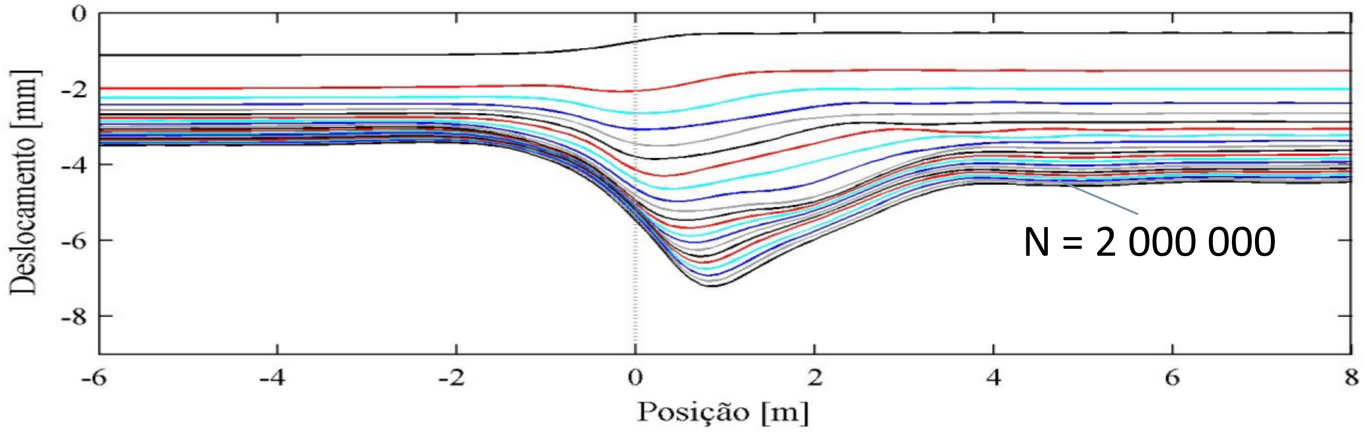




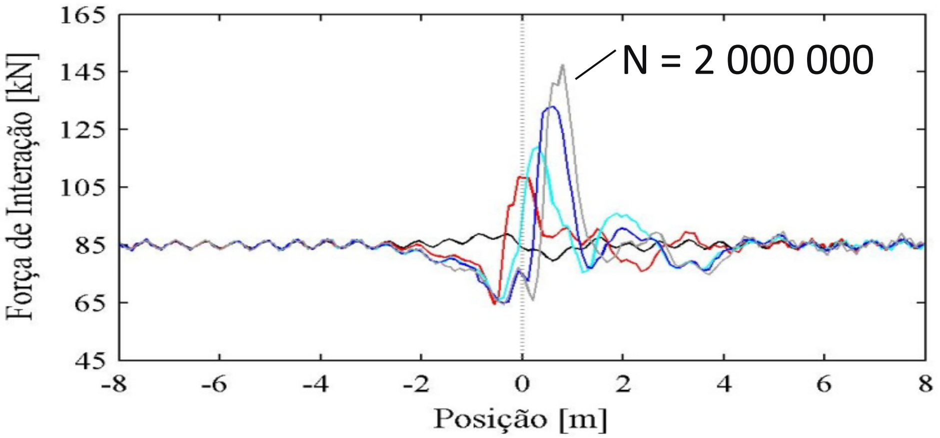


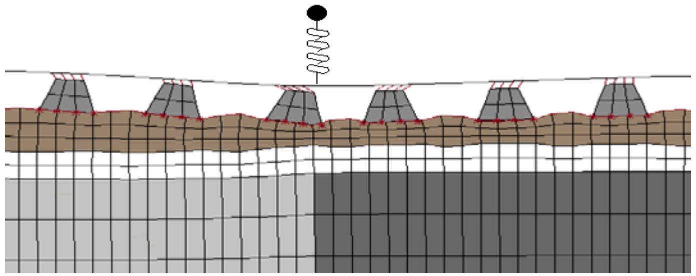
Long term dynamic behaviour

Vertical displacement of the vehicle wheel



Wheel-rail contact force





Maximum amplification: 73,6%

It is very important to consider the dynamic component of the force on the simulation process

600 000 cycles: vertical acceleration of the axle is higher than **30 m/s²**
2 million cycles: vertical acceleration reaches **70 m/s²** (immediate track correction)

Conclusions

I. Permanent deformation is higher when the deviatoric stress of the elements increase;

II. The amplification of the dynamic loads that results from the track deformation, also contributes to its increase;

III. The base of the sleepers do not follow the deformation of the track layers – gap appearance;

IV. The ballast layer permanent deformation dominates the track deformation – both due to the law considered and the stress level installed on this layer;

V. The dynamic effects obtained on the transition zone when permanent deformation is considered are higher than those obtained when there is only the stiffness variation.

VI. This methodology can be applied to predict the long term behaviour of the track in other zones.

Further developments

I. Consider the track irregularities and track defects in the assess of the long term behaviour;

II. Validate the results obtained for the long term behaviour with experimental data;

III. Perform this analysis using different deformation laws;

IV. Apply this methodology to assess the long term behaviour of other zones of the track.

Recently it was created a user-interface platform and a user manual that enables anyone to use this application in models created in ANSYS program.