25th ALERT Workshop
Aussois, 30th September 2014
Session II: Railway Geomechanics

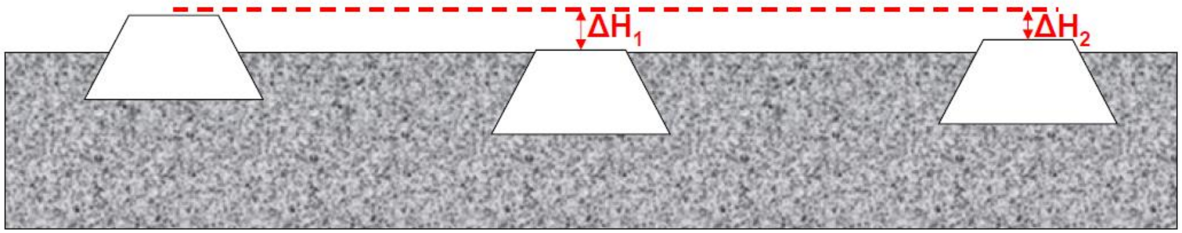
BALLAST SETTLEMENT: MECHANISMS AND ITS VARIABILITY

Juan Carlos Quezada[1], Gilles Saussine[2], Pierre Breul[3] and Farhang Radjaï[4]
[1]Laboratoire de Tribologie et Dynamique des Systèmes Ecole Centrale de Lyon, France;
[2]SNCF – Research and Innovation department, France;
[3]Pascal Institute – University of Clermont II, France;
[4]LMGC – University of Montpellier 2, France

Objectives and scope

❑ Industrial context: Train traffic induces a geometrical degradation of ballast track

(Suiker 2002)



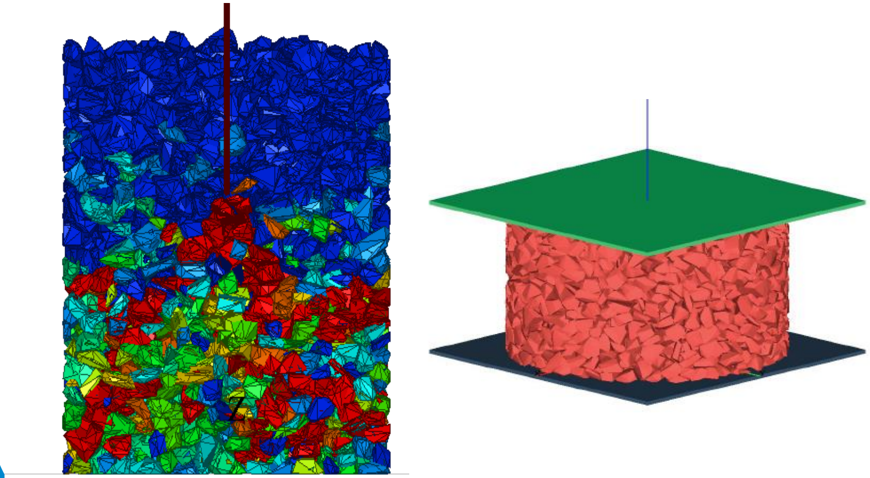
Deterioration of ballast track: Differential ballast settlement

❑ Settlement is induced by particles rearrangement under cyclic loading
❑ This degradation reduces the safety and comfort traffic levels
❑ Profile correction demands the operation of expensive equipment

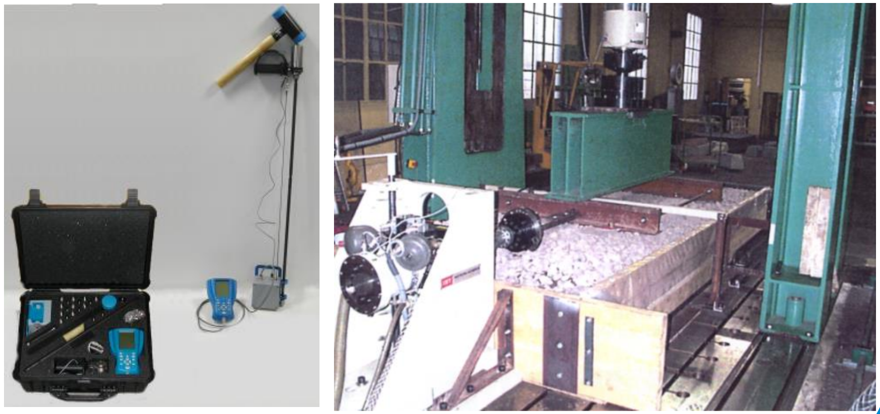
Overall objective: Create a predictive model for ballast settlement

Outlines

Numerical approach:



Experimental approach:



Modelling of ballast settlement: Development of a predictive model

Study of penetration test

Light dynamic penetrometer Panda

- Determination of cone penetration resistance q_d, by Dutch equation :

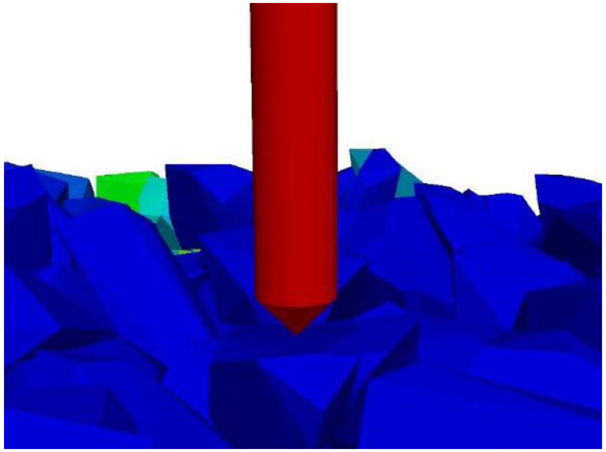
$$q_d = \frac{1}{A_C} \times \frac{E}{e} \times \frac{M}{M+P}$$

- Database links q_d and density for different kind of soils *(Chaigneau2001, Benz2009, Breul2009).*

- Used for layer recognizing in classic and high speed lines

Relevance of measure into ballast?

Numerical simulation by DEM approach



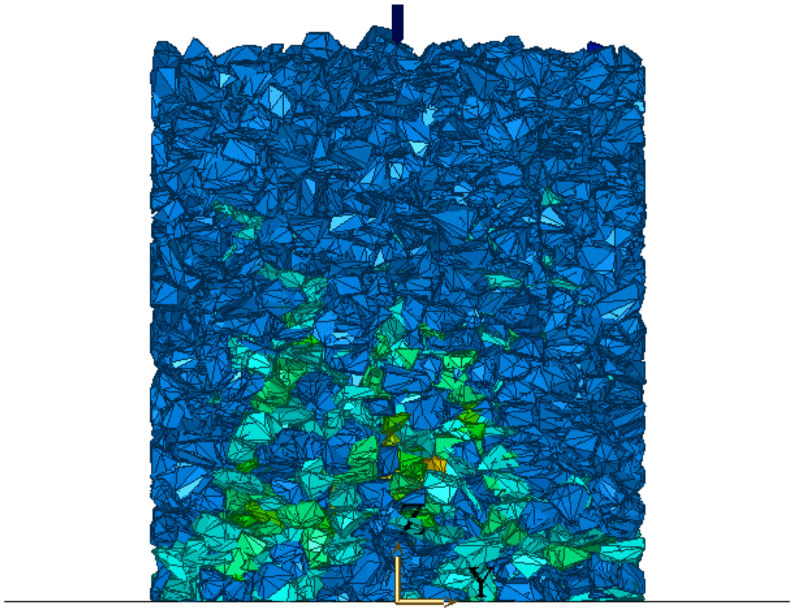
- ❑ Contacts Dynamic Method *NSCD* (*Moreau,Jean1992*), with the utilisation of LMGC90 software *(Dubois,Jean2003)*

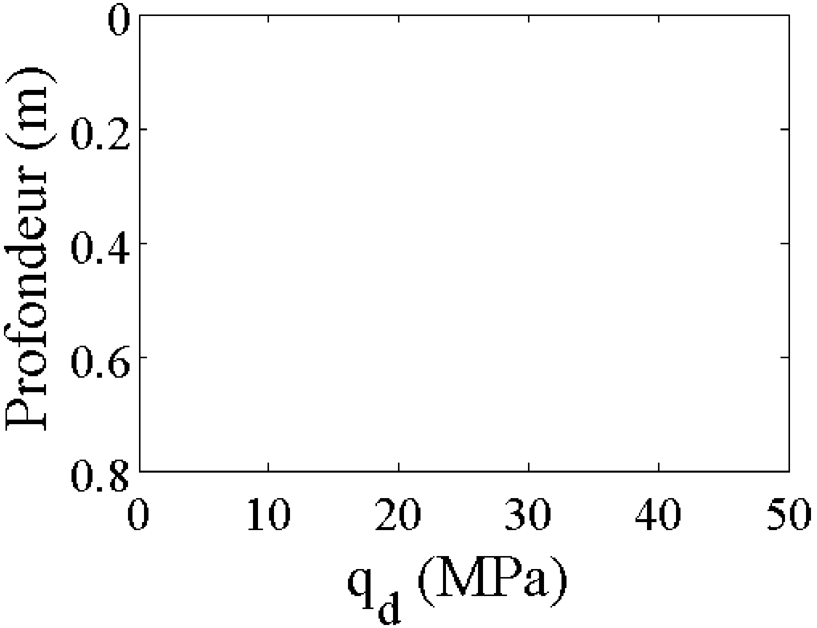
- ❑ Perfectly rigid particles with irregular polyhedral shapes.

- ❑ Parameters of granular model :
  - ❑ 5900 particles
  - ❑ Confining pressure 80 kPa
  - ❑ μ particles = 0.8
  - ❑ μ rod-particles = 0.3

Test numerical simulation

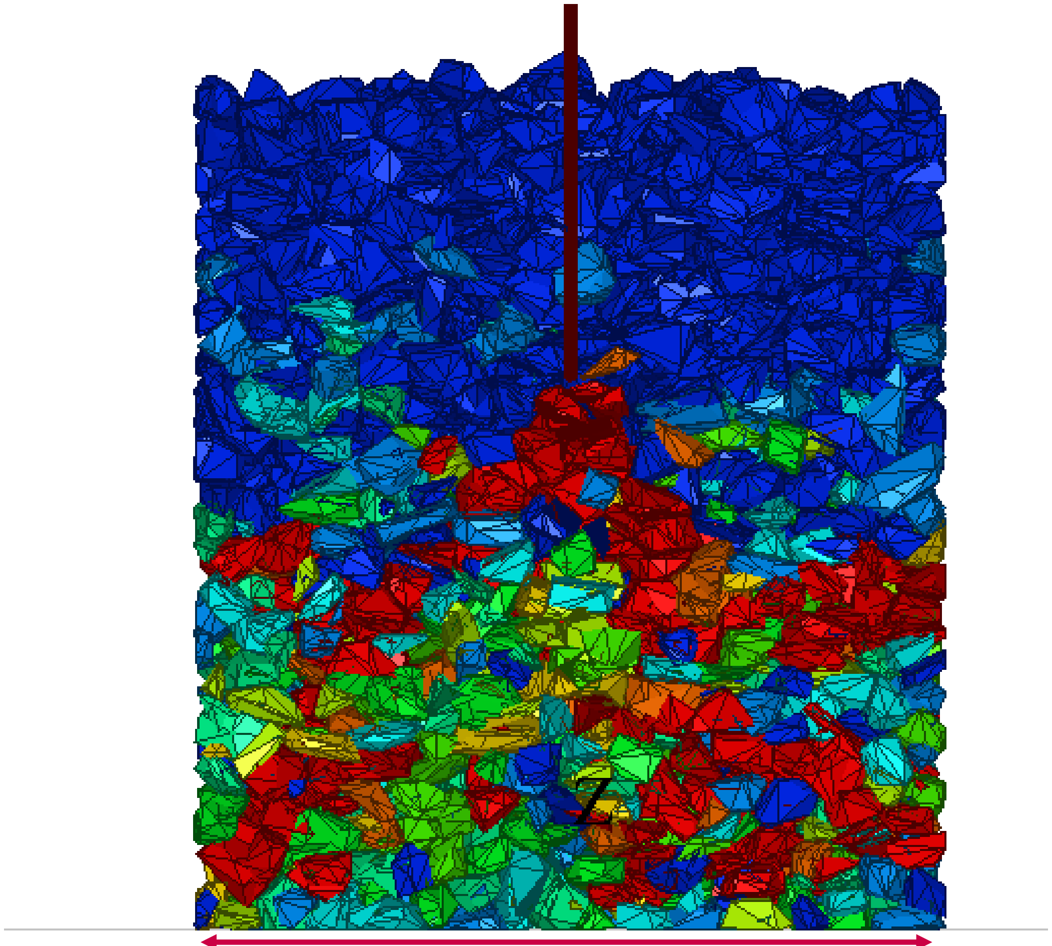
- 10 test with constant velocity, V=[0.01(m/s),10(m/s)]
- 5 dynamic test (beating), F_{peak}=[10kN,50kN]
- Measure of q_d as a function of depth





Influence zone of penetrometric measure

- ❑ Analyse of chains forces propagation



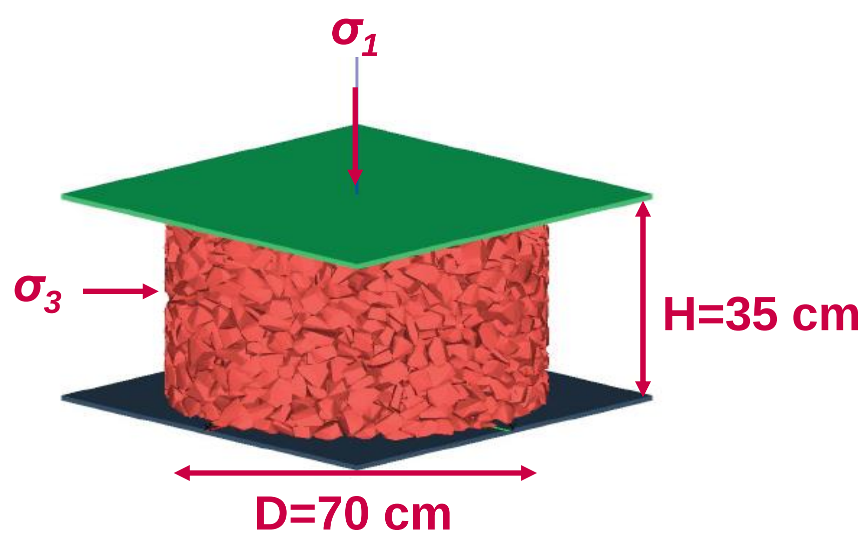
D = 70 cm

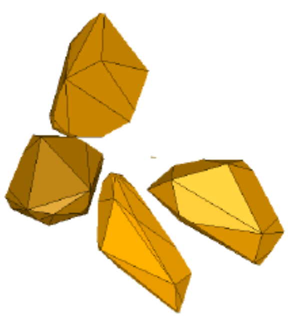
Influence zone of a Panda test allows to obtain information associated with the mechanical state under the sleeper

Mechanisms in the origin of ballast settlement

Granular model

- 32 cylindrical samples of 2700 grains between two roughs walls :
  - Initial packing fraction = 0.62
  - Height : 35 cm, diameter : 70 cm
  - Confining pressure : 80 kPa
  - Friction coefficient : 0.8
  - Time step: 5×10^{-4} seconds



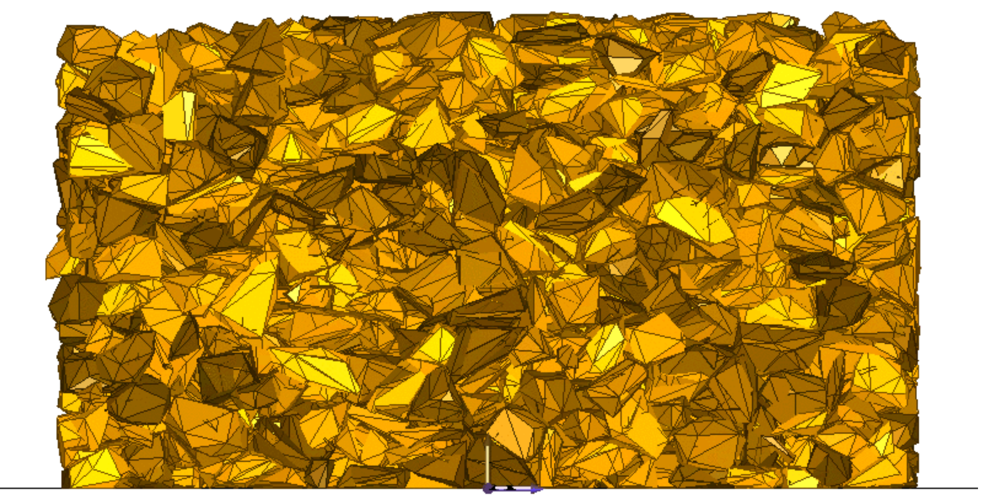


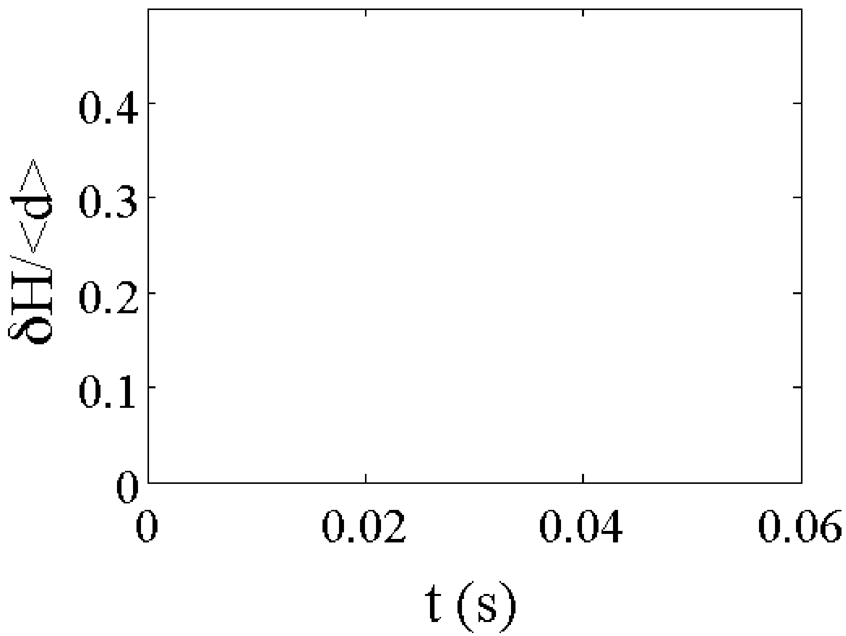
$\boxed{\alpha = H/D = 0.5}$ $\boxed{\eta = \sigma_1/\sigma_3}$

Triaxial configuration represents loading conditions under the sleeper

Creep test

- 500 different values of *F* varying from 1 to 120 kN are applied to each sample



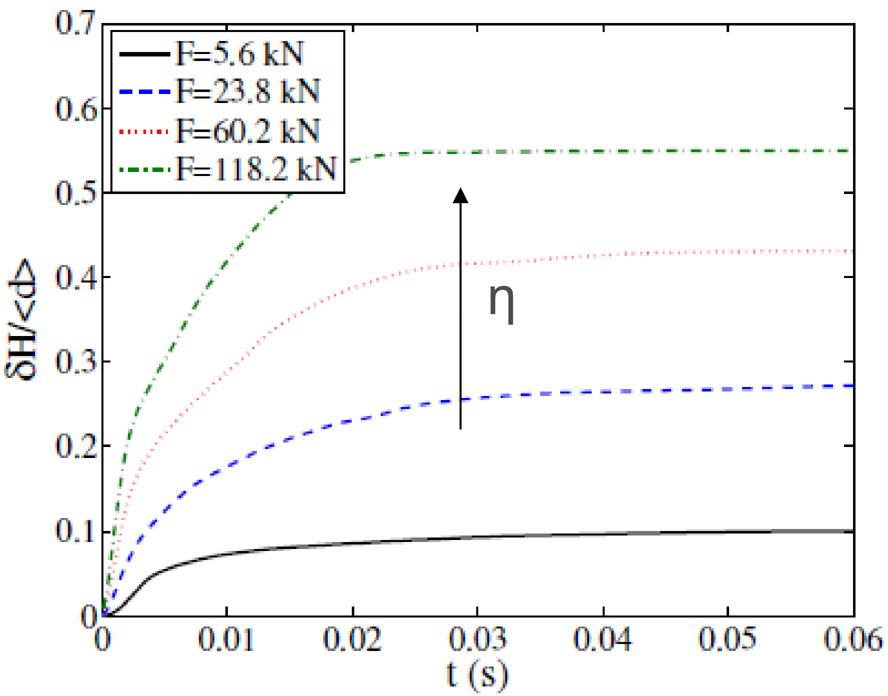


Measure of settlement as a function of time (transient deformations)
ΔH(t)

Analyse of transient deformations

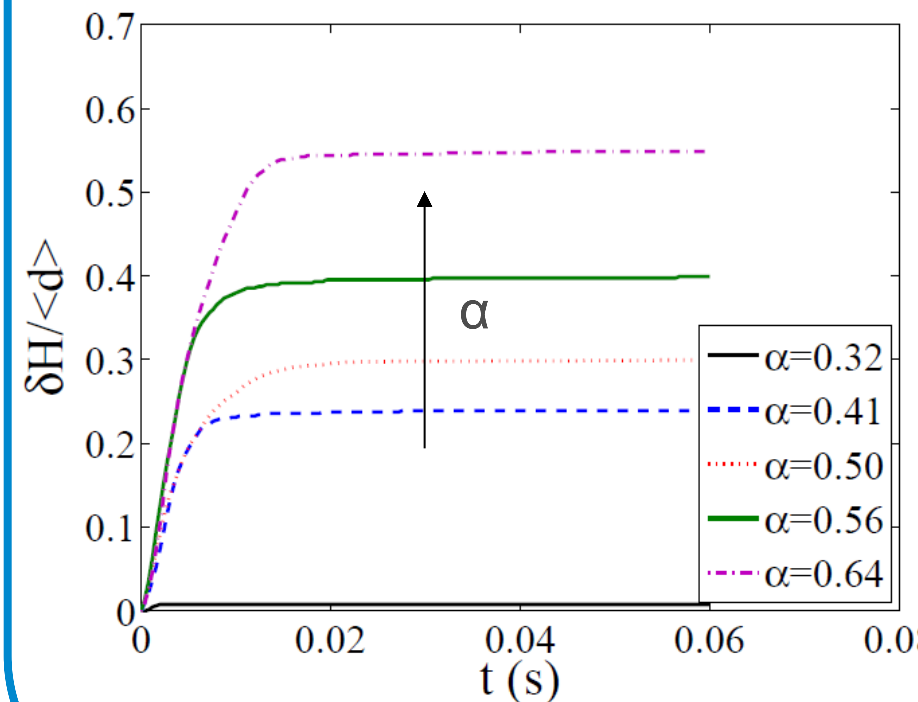
Effect of applied stress:

❑ Settlement grows as a function of applied stress



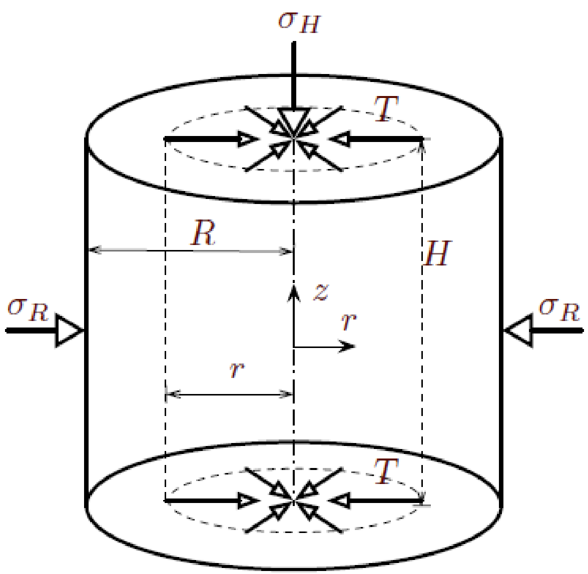
Effect of aspect ratio:

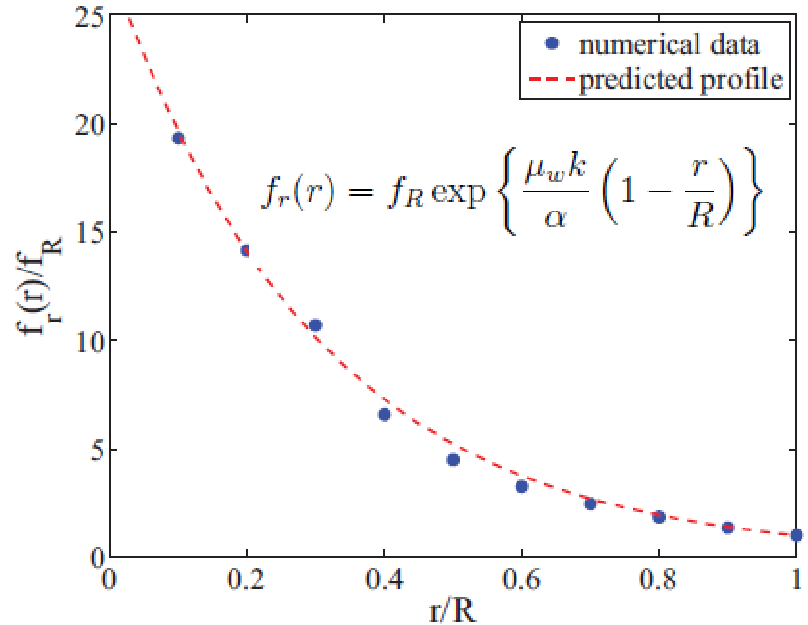
❑ Increasing values of aspect ratio induce larger values of settlement

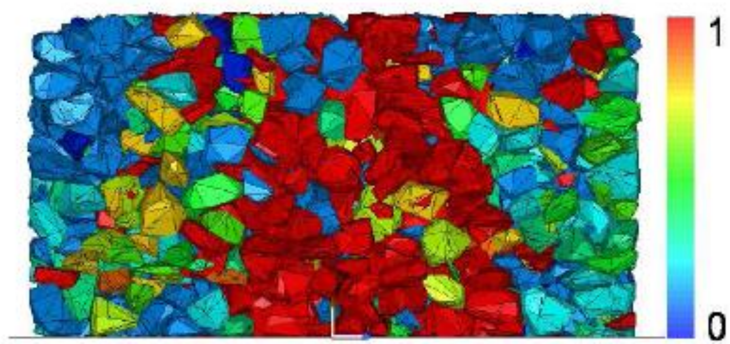


Influence of the aspect ratio

- Friction with the walls : analogy with the Janssen model

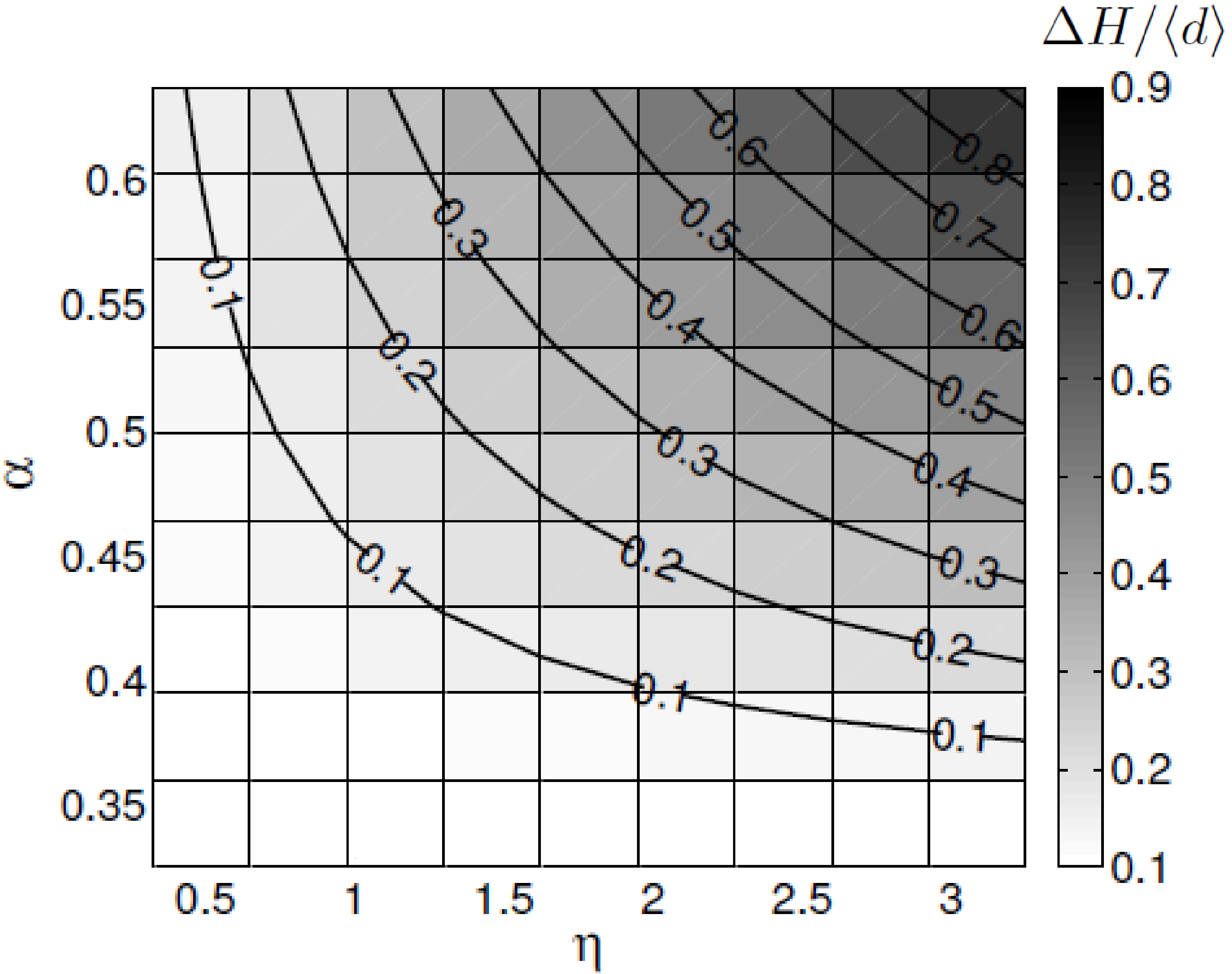






Due to friction with the top and bottom walls, the stress transmission crucially depends on the aspect ratio.

Analyse of final settlement values (ΔH)

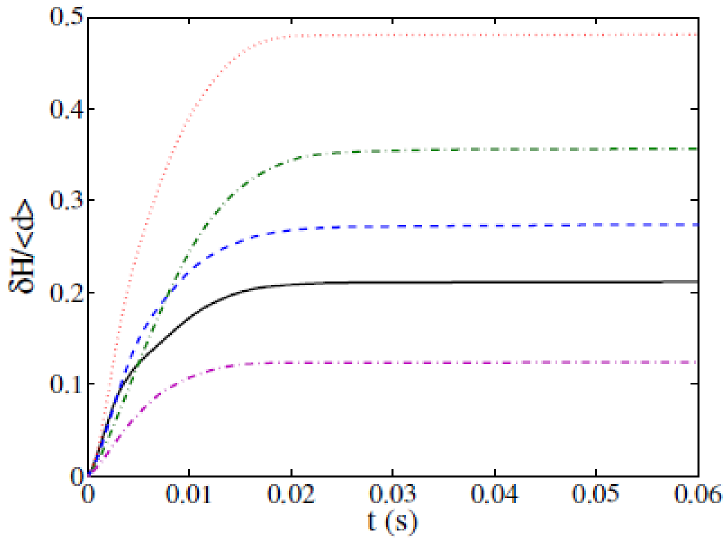


Final deformation is a function of stress ratio *η* and the aspect ratio *α*

Fluctuations of average values of settlement

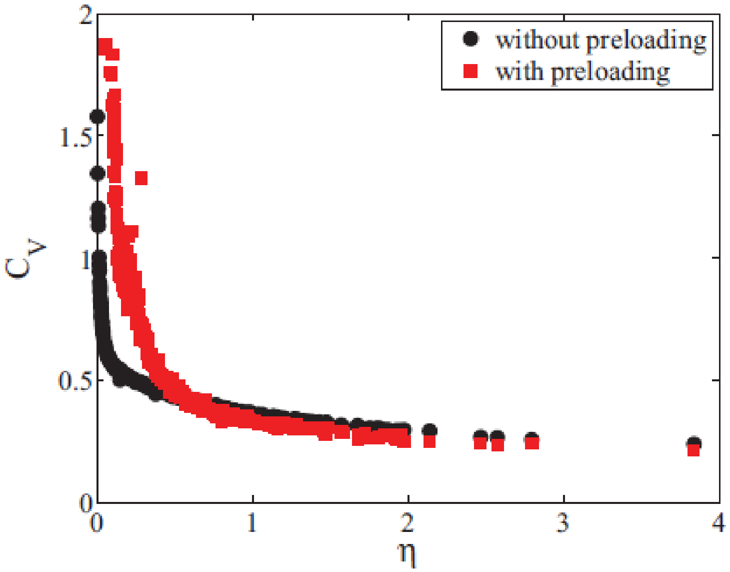
Intrinsic variability :

❑ Settlement under the same overload for different samples: strong variability



❑ The coefficient of variation (Cv) is high at low values of η but declines as a function of η

$$C_v = S/\langle \Delta H \rangle$$



Fluctuations are an intrinsic part of the deformation process and controlled by the granular disorder for all levels of loading

Experimental study

Experimental setup (CEV) :

❑ Parameters to analyse:

- Vertical load: 194, 238 et 272 KN
- Loading frequency: 3.3, 4.5 , 5.4 et 6 Hz
- Stiffness of subgrade: rigid

❑ Experimental tests carried out on a full-scale track model at *Centre d'Essais et d'Expertises SNCF* (June 2010 – March 2011):

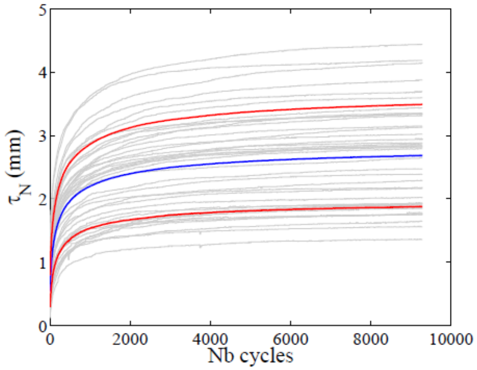
- 12 loading combination
- 6 repetition for each loading combination
- 288 obtained settlement curves

Development of loading test:

Evaluation of the mechanical state

Cyclic loading

Measure of settlement



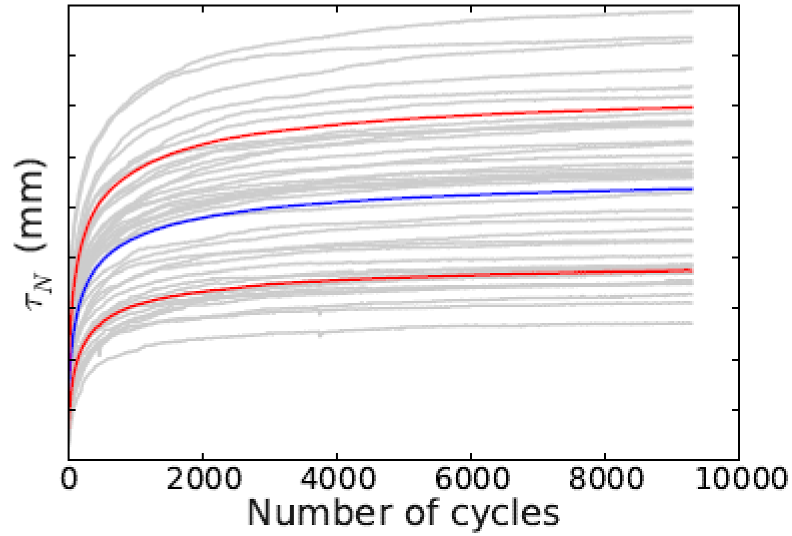
Construction of a predictive model

$$\tau_N \Leftrightarrow f(N,Q,F,q_d)$$

Analysis of experimental results

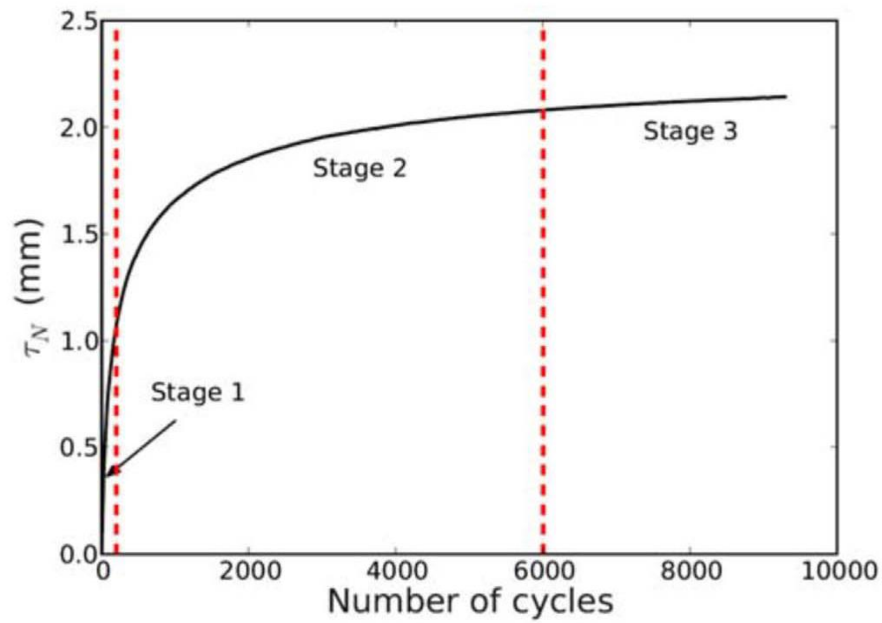
- ❑ Variability in the response for a given combination of loading factors (30%)

- ❑ The shape of the curves is similar to that usually observed in laboratory and simulation tests



Curve shape:

- ❑ Stage I : Initial compaction of ballast
- ❑ Stage II : Medium term behaviour
- ❑ Stage III : Long-term behaviour



Classical settlement models do not allow to describe the shape of our curves

Density relaxation law

❑ Analogy with the density relaxation in vibrated granular materials *(Knight1995,Nowak1998).*

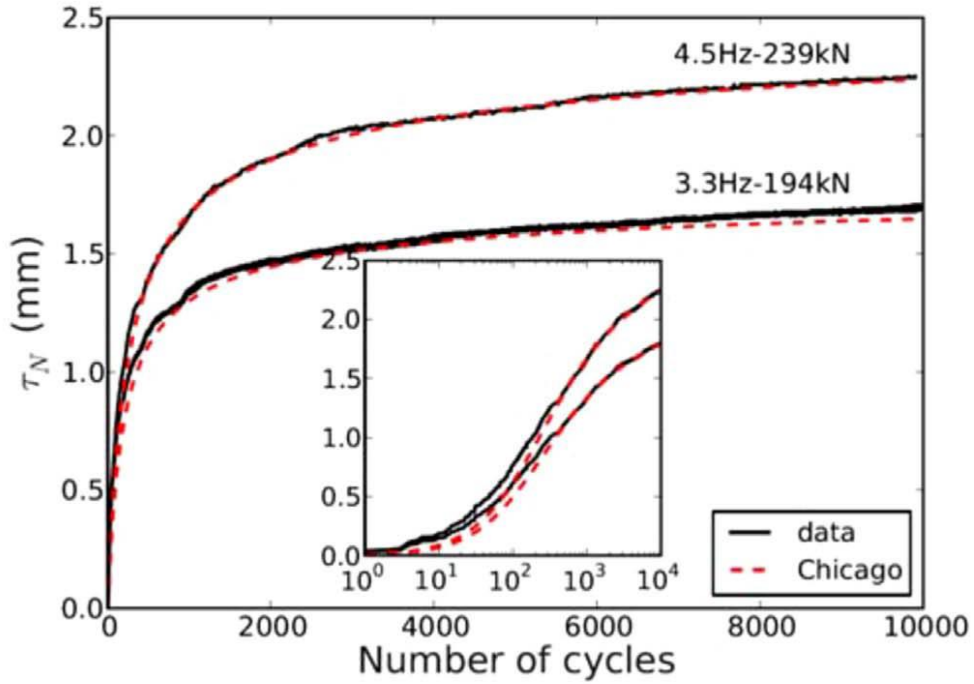
$$\tau_N = \tau_\infty \left(1 - \frac{1}{1 + B \ln\left(1 + \frac{N}{N_0}\right)} \right)$$

❑ This model predict with a good agreement the settlement evolution and the shape of the settlement curve (3 stages)

$N_0 = f(q_d)$ → **Stage 1**

$B = f(\Gamma)$ → **Stage 2**

$\tau_\infty = f(\Gamma)$ → **Stage 3**



Model validation

1) Parameters identification:

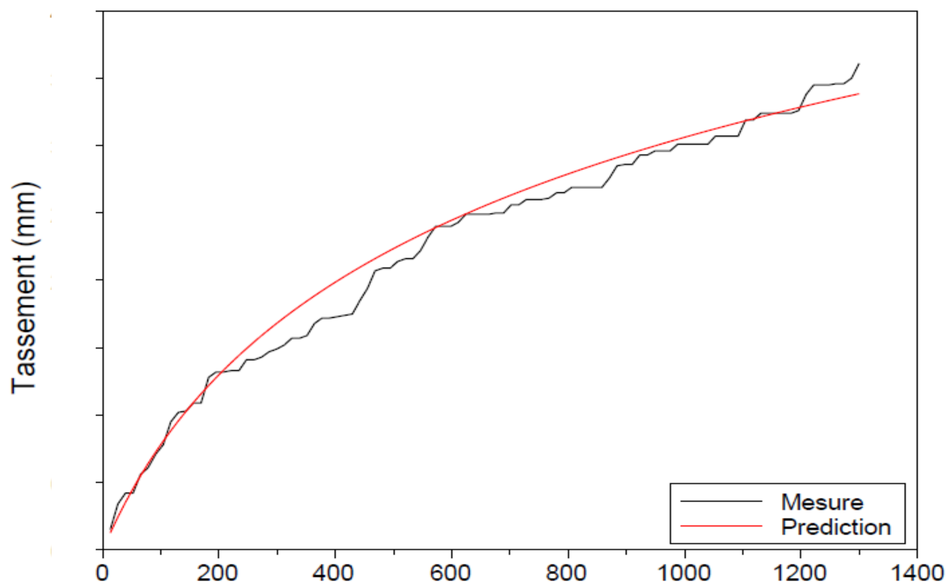
$q_d \rightarrow N_0$

Train speed + axle load $\rightarrow \begin{cases} \tau_\infty \\ B \end{cases}$

2) Model application:

$$\tau_N = \tau_\infty \left(1 - \frac{1}{1 + B \ln\left(1 + \frac{N}{N_0}\right)} \right)$$

3) Prediction:



Concluding remarks

Concluding remarks

- ❑ Using the penetrometer test allows the characterization of the mechanical state of ballast, which is linked to the density of the material,

- ❑ Settlement due to creep deformation depends on various parameters (stress ratio, aspect ratio, loading history). Creep deformation shows intrinsic fluctuations, which can be considering as resulting from a stochastic process.

- ❑ By developing a model based on a logarithmic relaxation law, we are able to estimate the evolution of settlement from measurable parameters in situ.

Perspectives:

- ❑ Improving the phenomenological model by taking into count the global stiffness and its influence on global response

Thanks for your attention