École des Ponts
ParisTech

Some unsaturated soil-related aspects in railway sub-structures

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Acknowledgements

Ecole des Ponts ParisTech (ENPC):

- Pr Pierre Delage
- Dr Anh Minh Tang
- Dr Trong Vinh Duong
- Dr Jean-Paul Karam
- Dr Viet Nam Trinh
- Dr Yang Chao
- Dr Jean-Claude Dupla
- Dr Jean Canou

The French Railway Company (SNCF):

- Mr Jean-Marc Terpereau
- Mr Gilles Marchadier
- Ms Yahel Szerman
- Mr Nicolas Calon
- Mr Alain Robinet

The French Railway network

- Most of railway structures were constructed in late XIX century
- First LGV was constructed in 1970

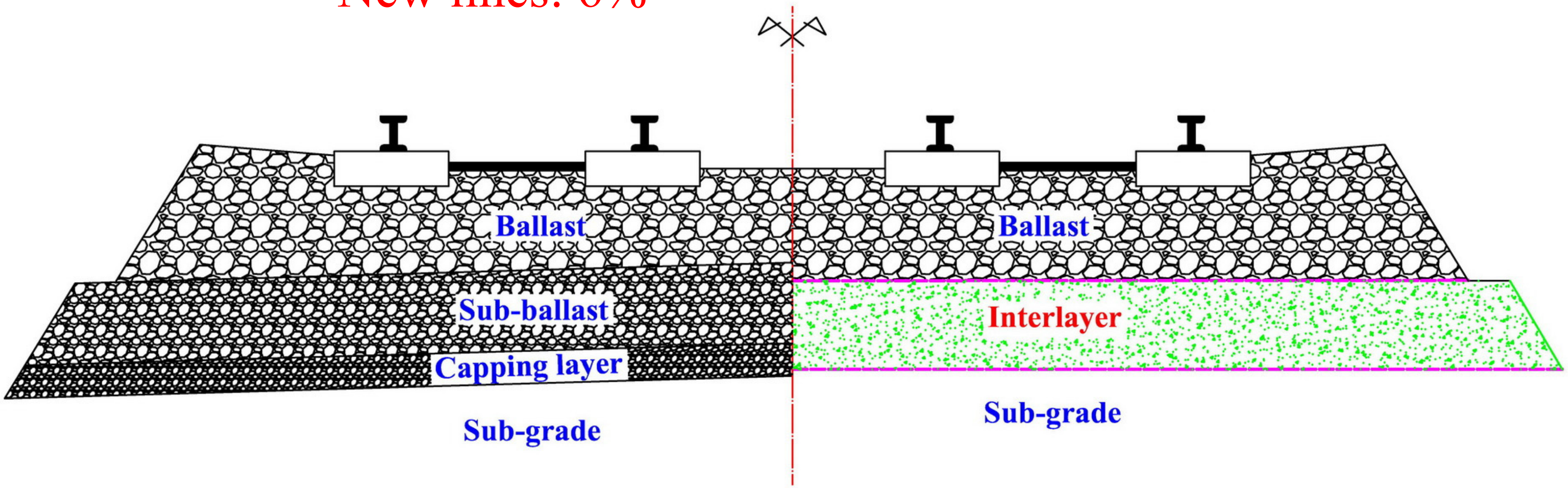
The network has not changed much since then – 94% conventional lines over 32 000 km

Railway network in late XIX century

Current railway network

New lines vs conventional lines

- New lines: 6%
- Conventional lines: 94%



Problems related to non-saturation

- New lines:
  - Special sub-grade soils such as
    - Collapsible soils
    - Swelling soils

- Conventional lines:
  - Sub-grade soils
  - Hydro-mechanical behaviour of interlayer soils

CYCLIC/DYNAMIC LOADING

Outline

- Introduction
- Case of loess along northern TGV line
- Case of marl along Mediterranean TGV line
- Interlayer soil in the sub-structure of conventional lines
- Concluding remarks

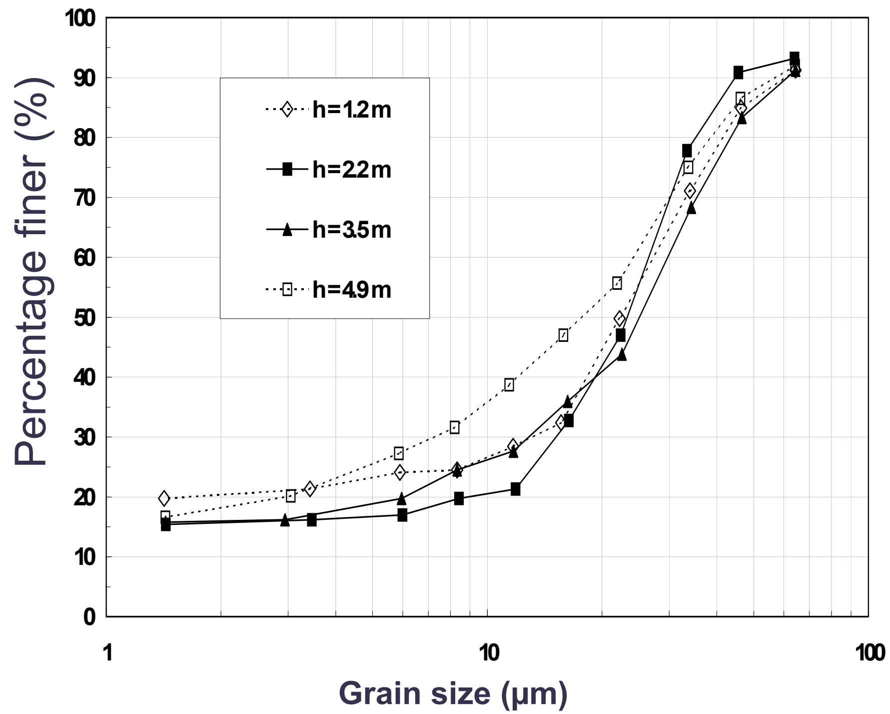
Locations of the case studies

Case of loess along northern TGV line

Sampling

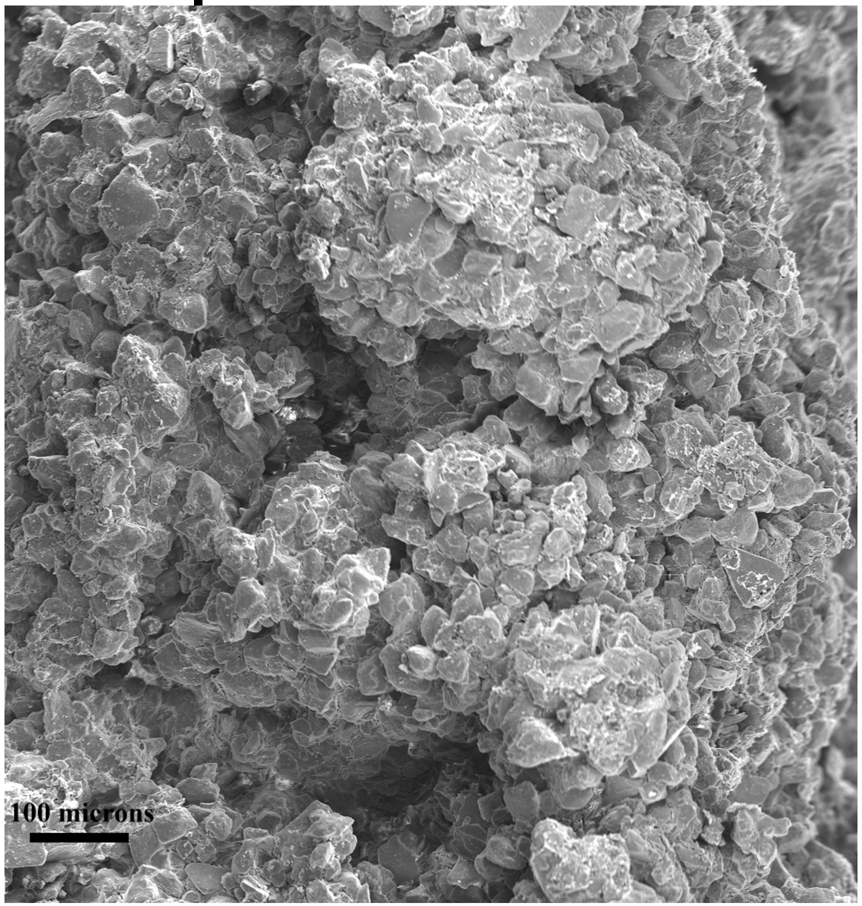
Geotechnical properties

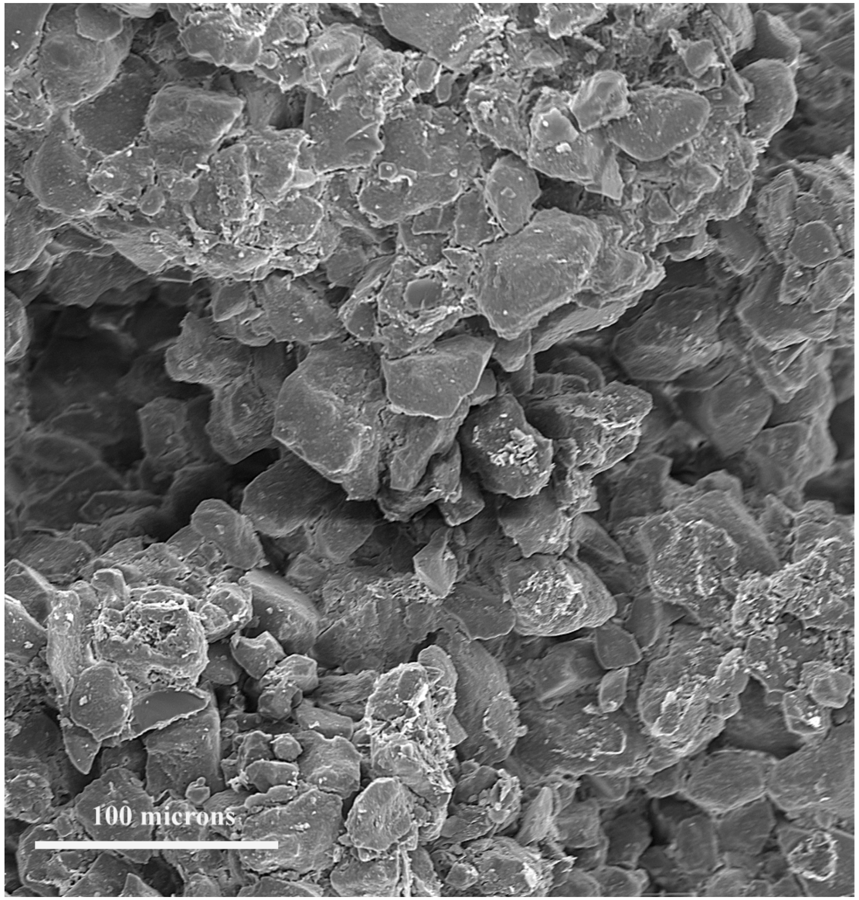
Soil	S1 (1.20m)	S2 (2.20m)	S3 (3.50m)	S4 (4.90m)
ρ_d (Mg/m³)	1.52	1.39	1.54	1.55
C_{ca} (%)	5	6	15	9
% < 2 (µm)	20	16	16	18
w_p	21	22	20	21
Ip	9	6	6	9
Suction s_0 (kPa)	20	34	28	14



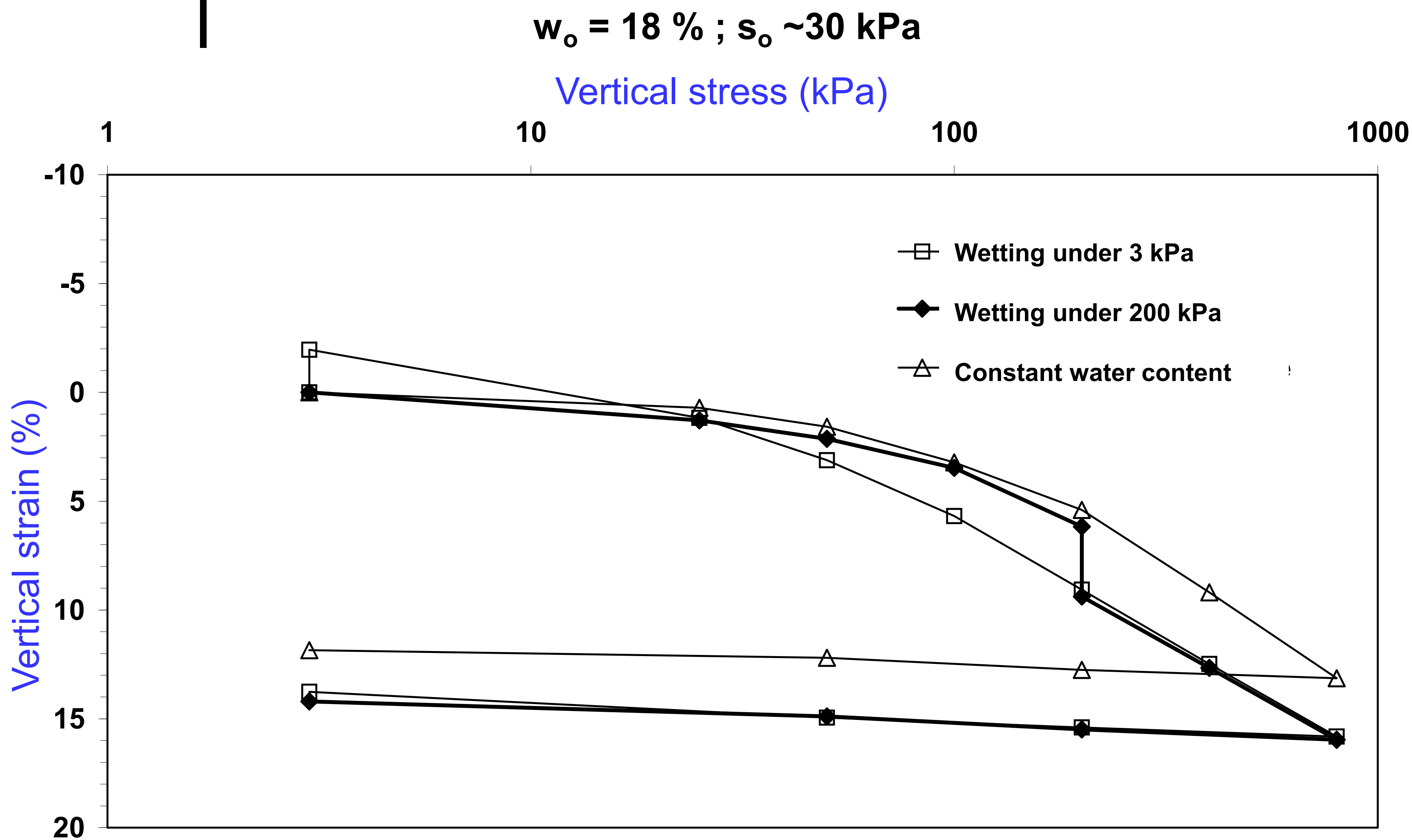
Observation at SEM

Soil 2.20 m

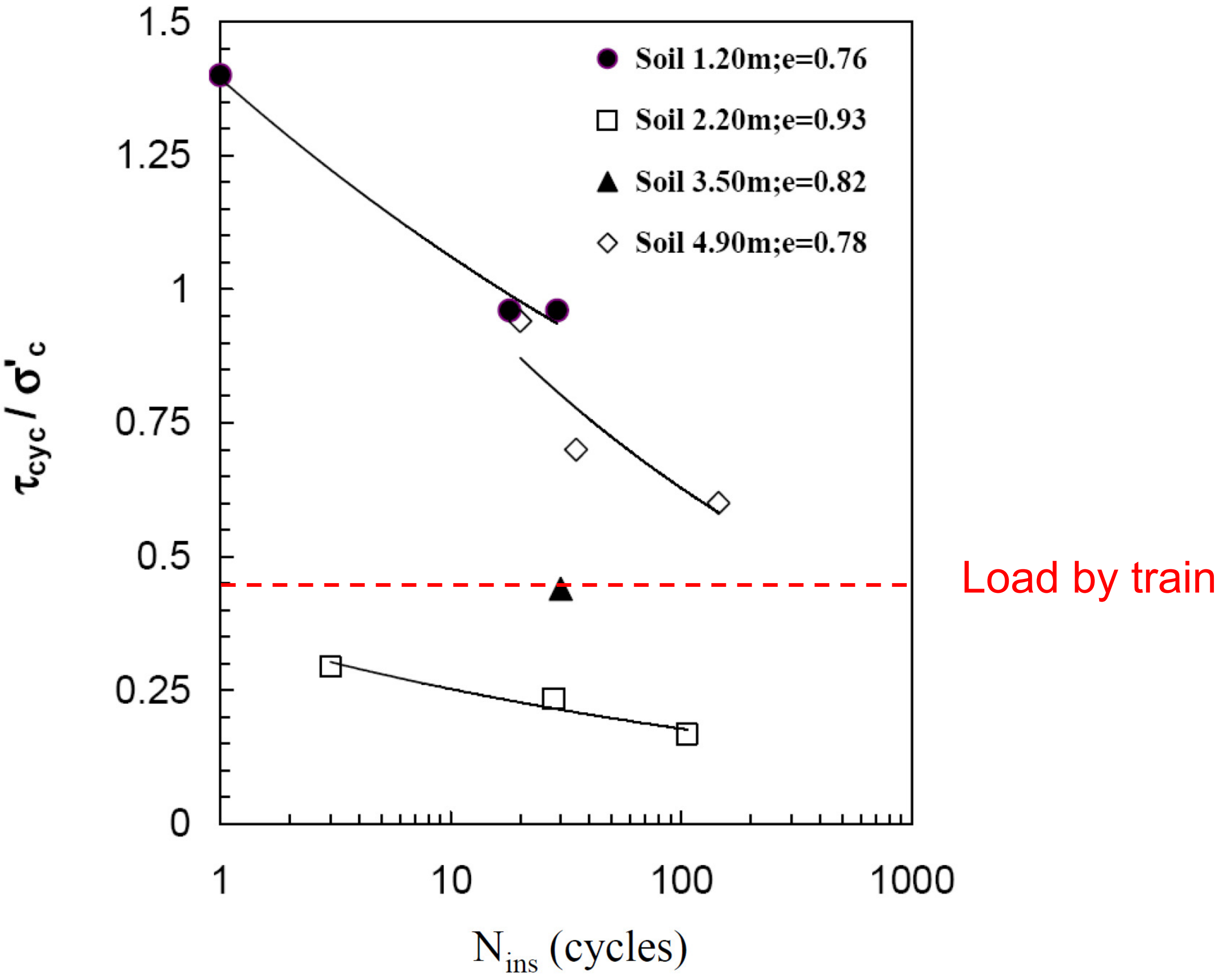




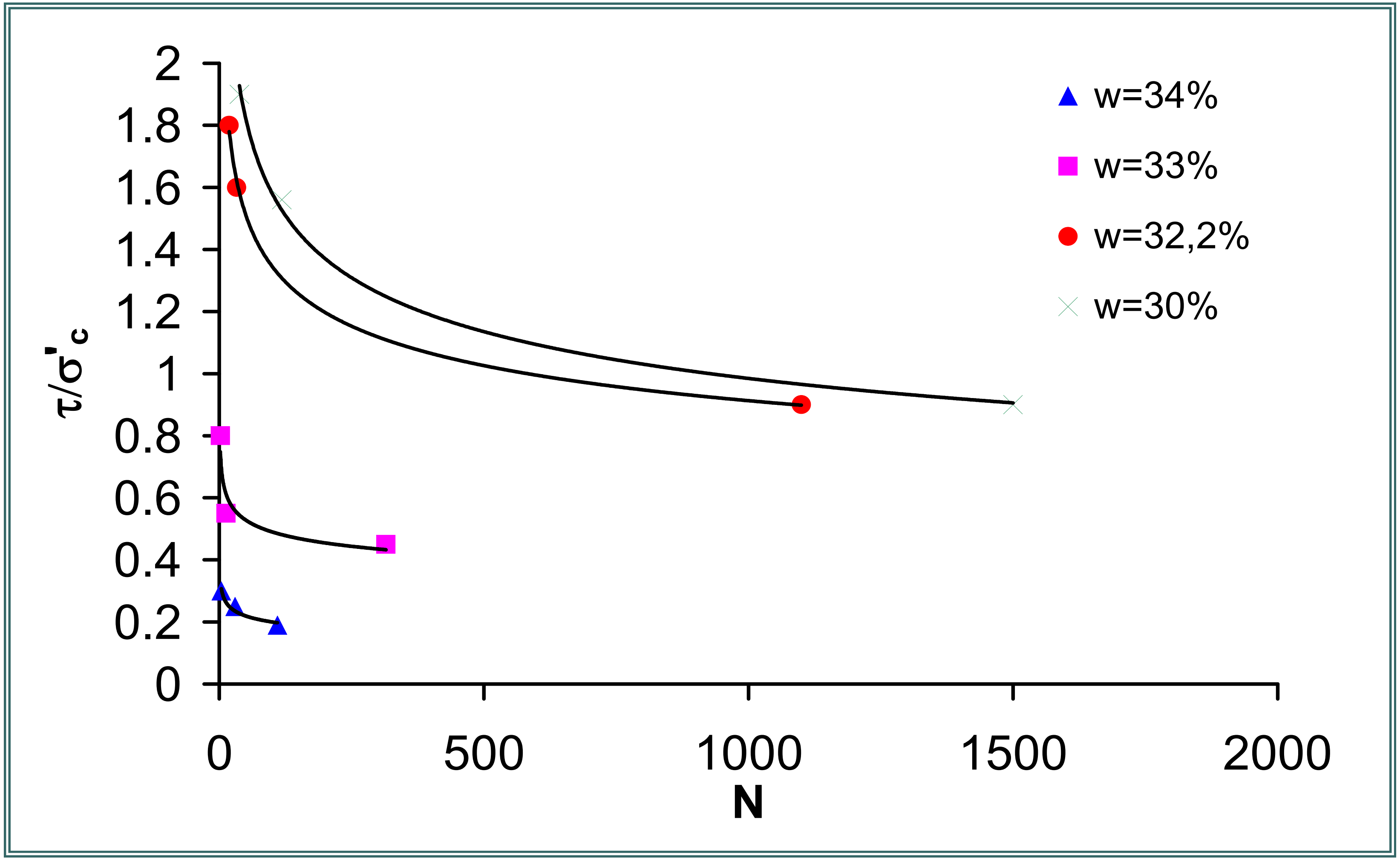
Collapse behaviour of soil-2.2 m



Liquefaction resistance



Liquefaction resistance - (soil 2.20 m)

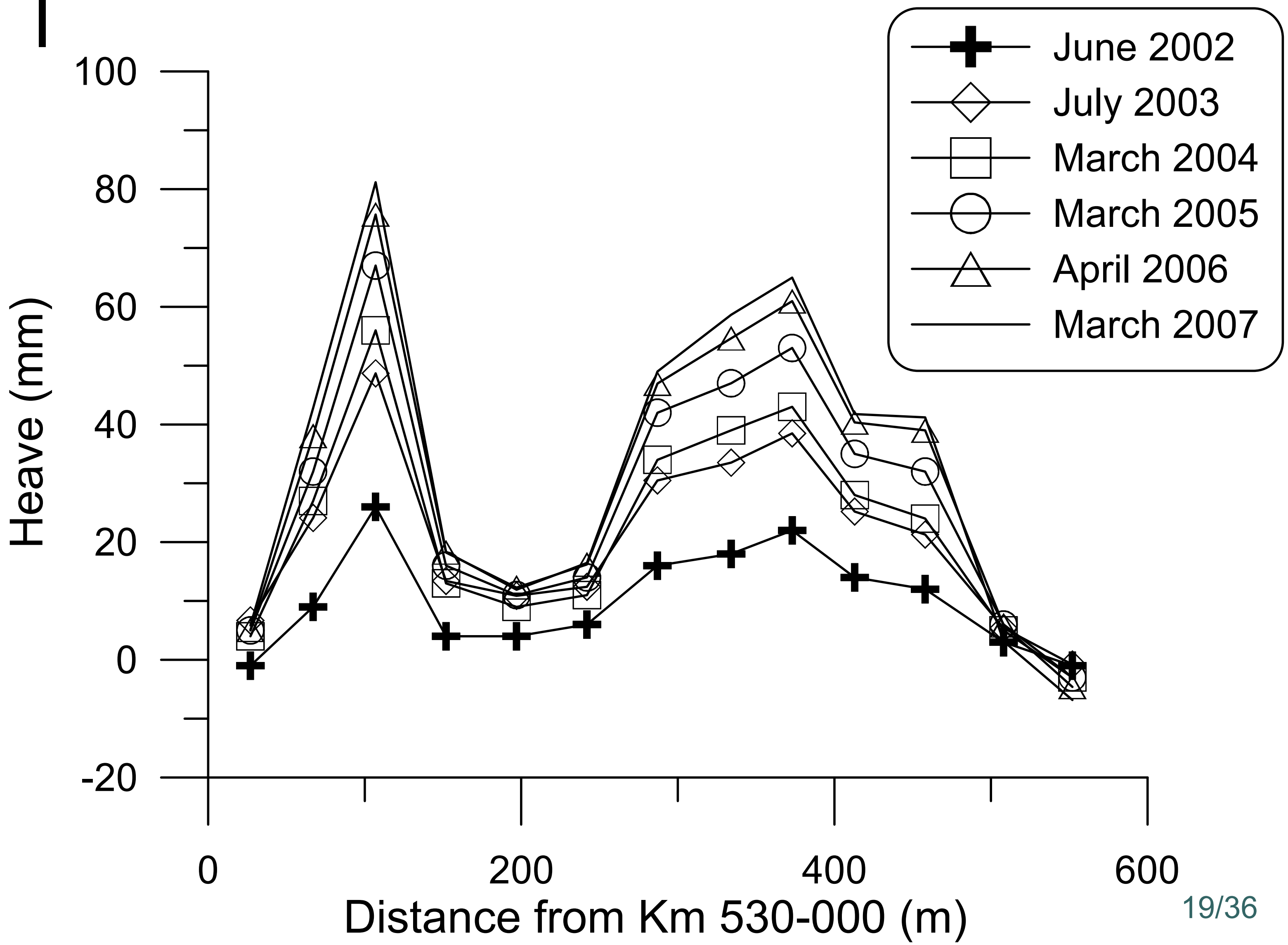


Case of marl along Mediterranean TGV line

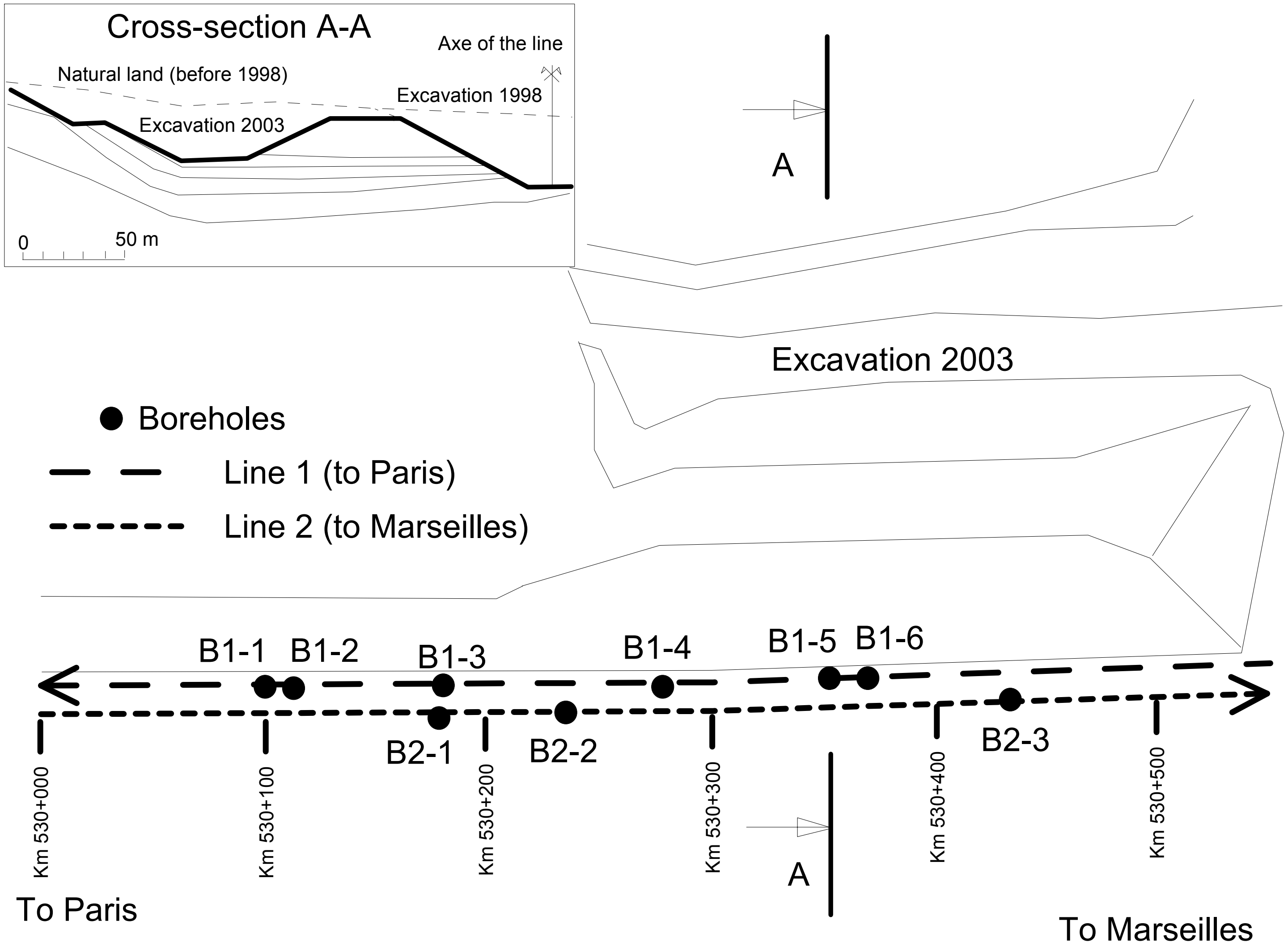
Damage to the drainage system

Chabrillan site; line constructed in 1998; damage observed in 2001

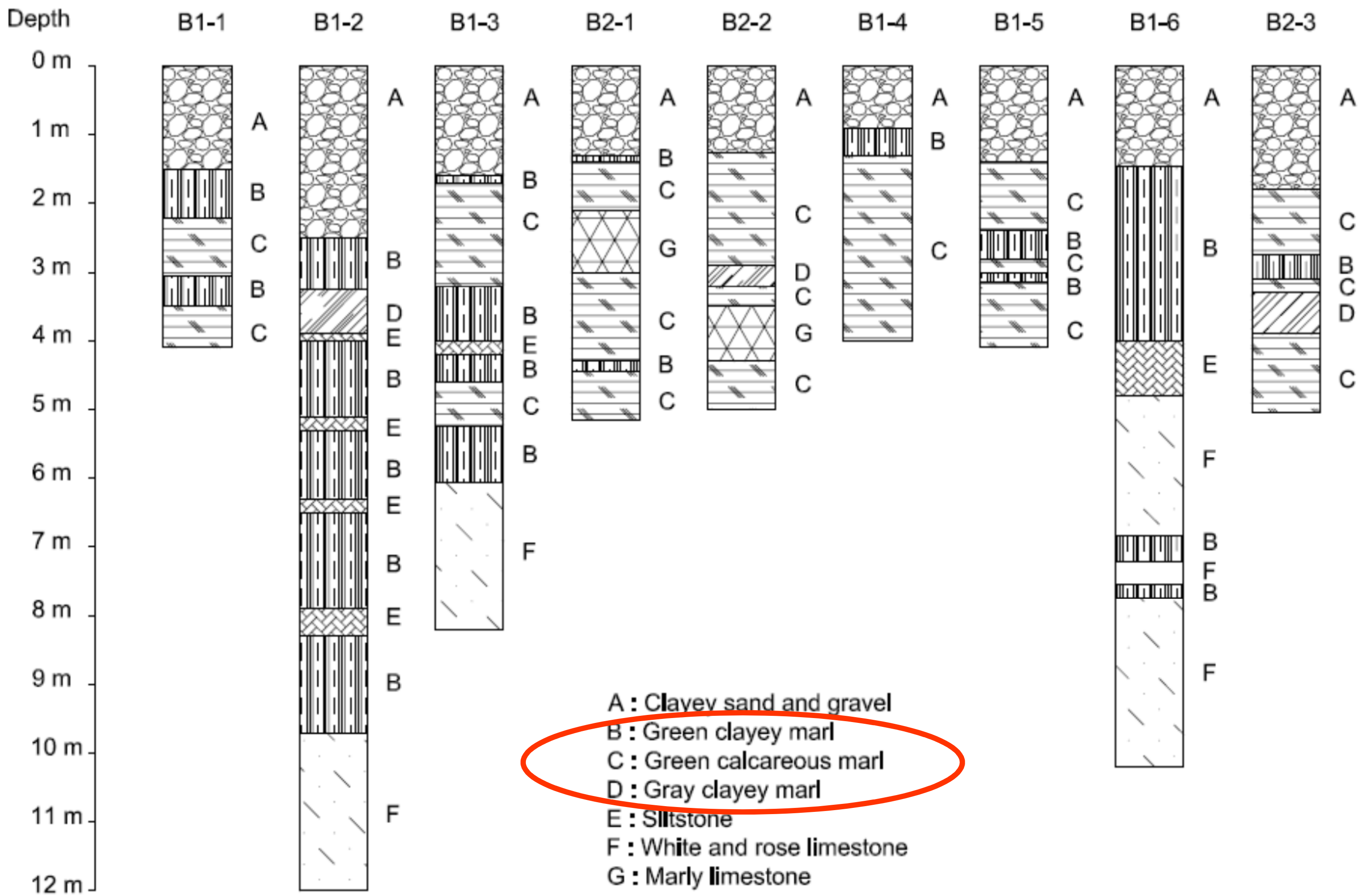
Profiles of heave of Line 1 (to Paris)



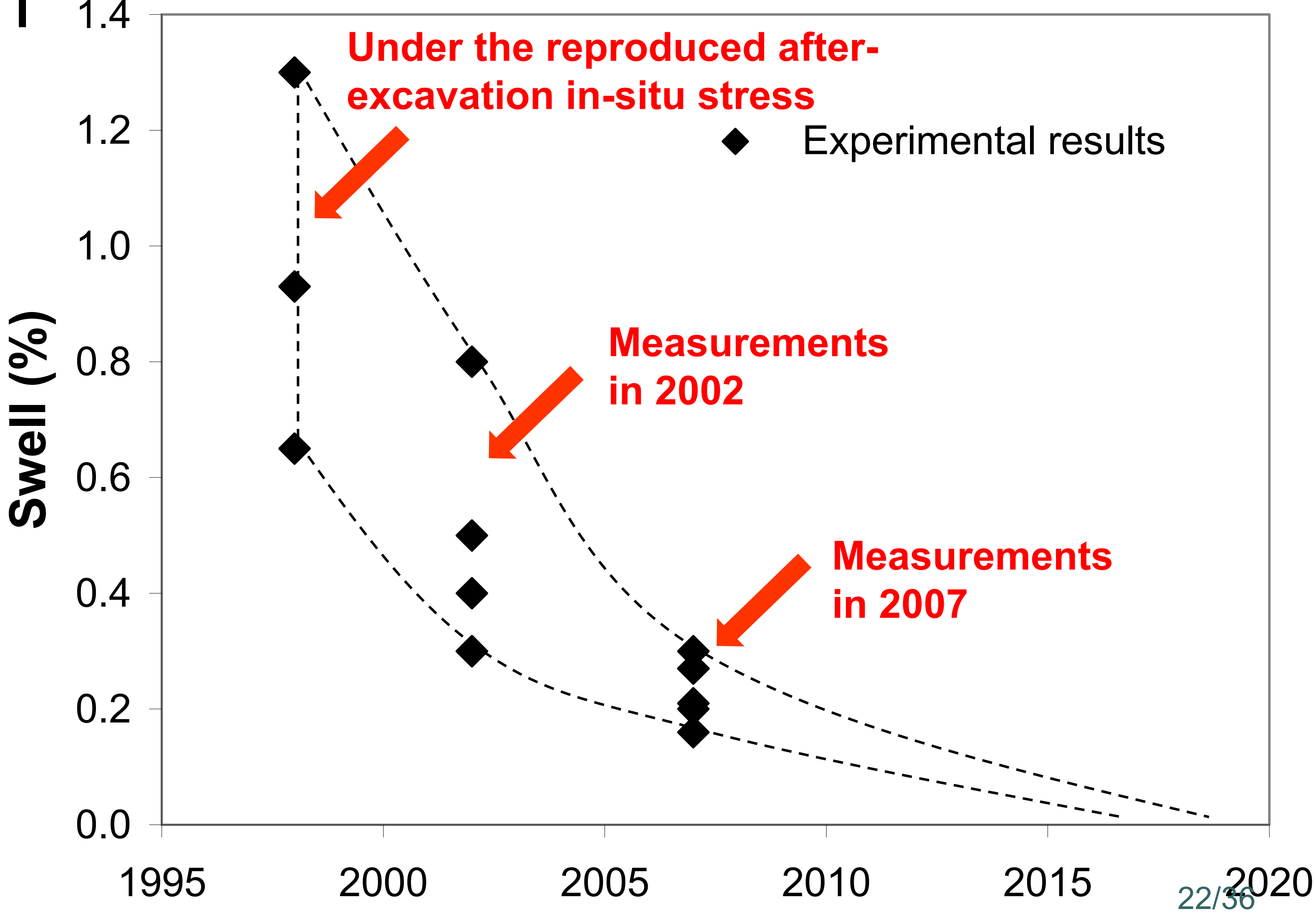
Plan of investigation boreholes and the excavation in 2003



Profiles of boreholes



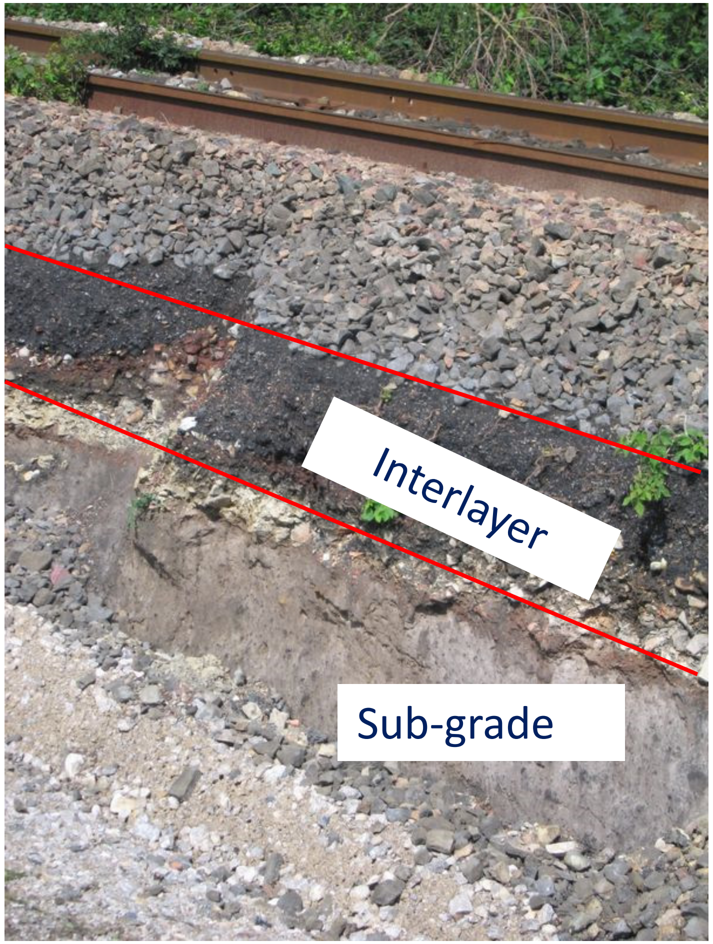
Evolution of swell potential



Interlayer soils

Conventional railway substructures

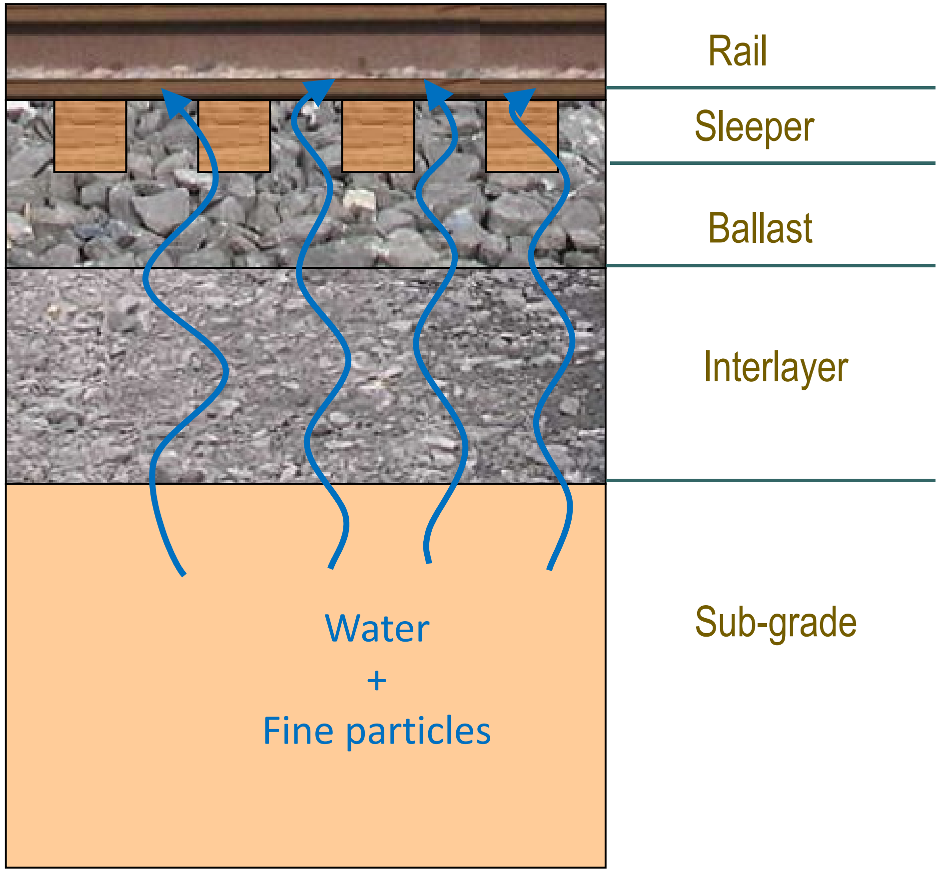
- Were initially built with ballast and sub-grade without separation layer
- Complex substructure :
  - The interlayer was created mainly by naturally mixing ballast and sub-grade
  - Variability of interlayer soils depending on the nature of sub-grade
- Three functions expected for the interlayer when innovating the lines :
  - Separation
  - Support
  - Drainage



Function of interlayer

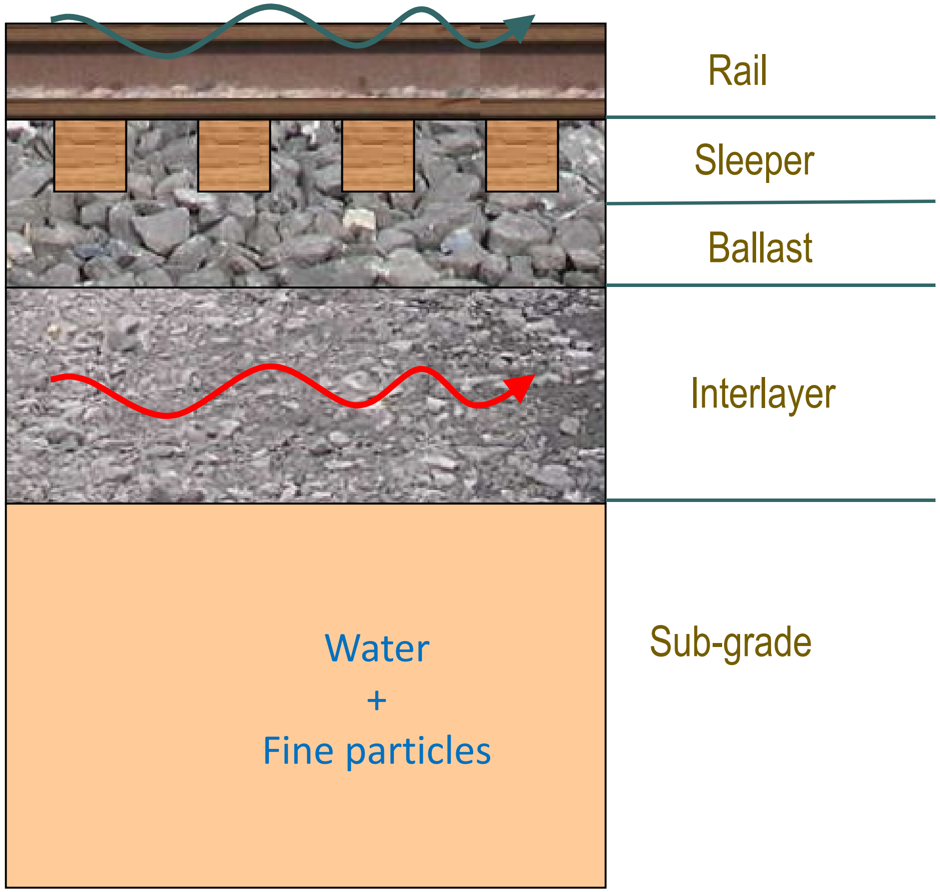
- Separation
- Support
- Track-bed drainage

Mud pumping zone



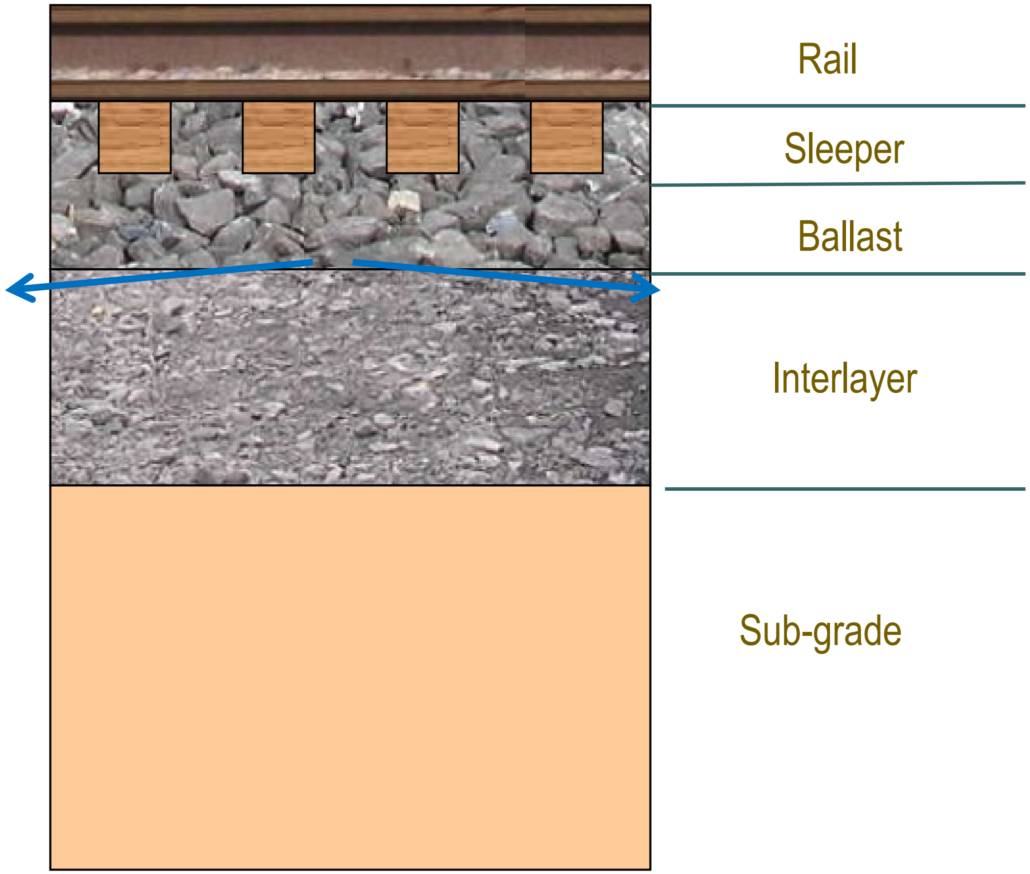
Function of interlayer

- Separation
- Support
- Track-bed drainage



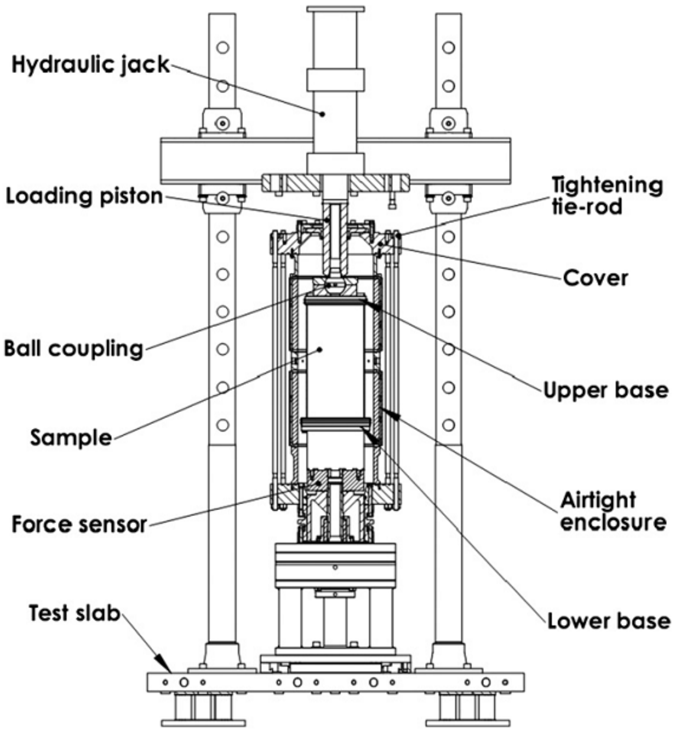
Function of interlayer

- Separation
- Support
- Track-bed drainage



Experimental devices

- Large-scale triaxial cell



Soil specimen:

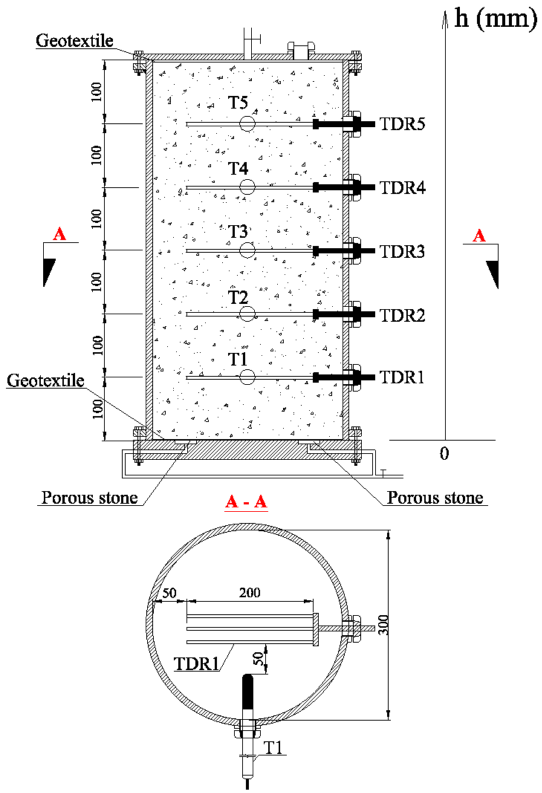
D = 300 mm

H = 600 mm

Loading frequency: < 20 Hz

Experimental devices

- Large-scale infiltration column



Soil specimen:

D = 300 mm

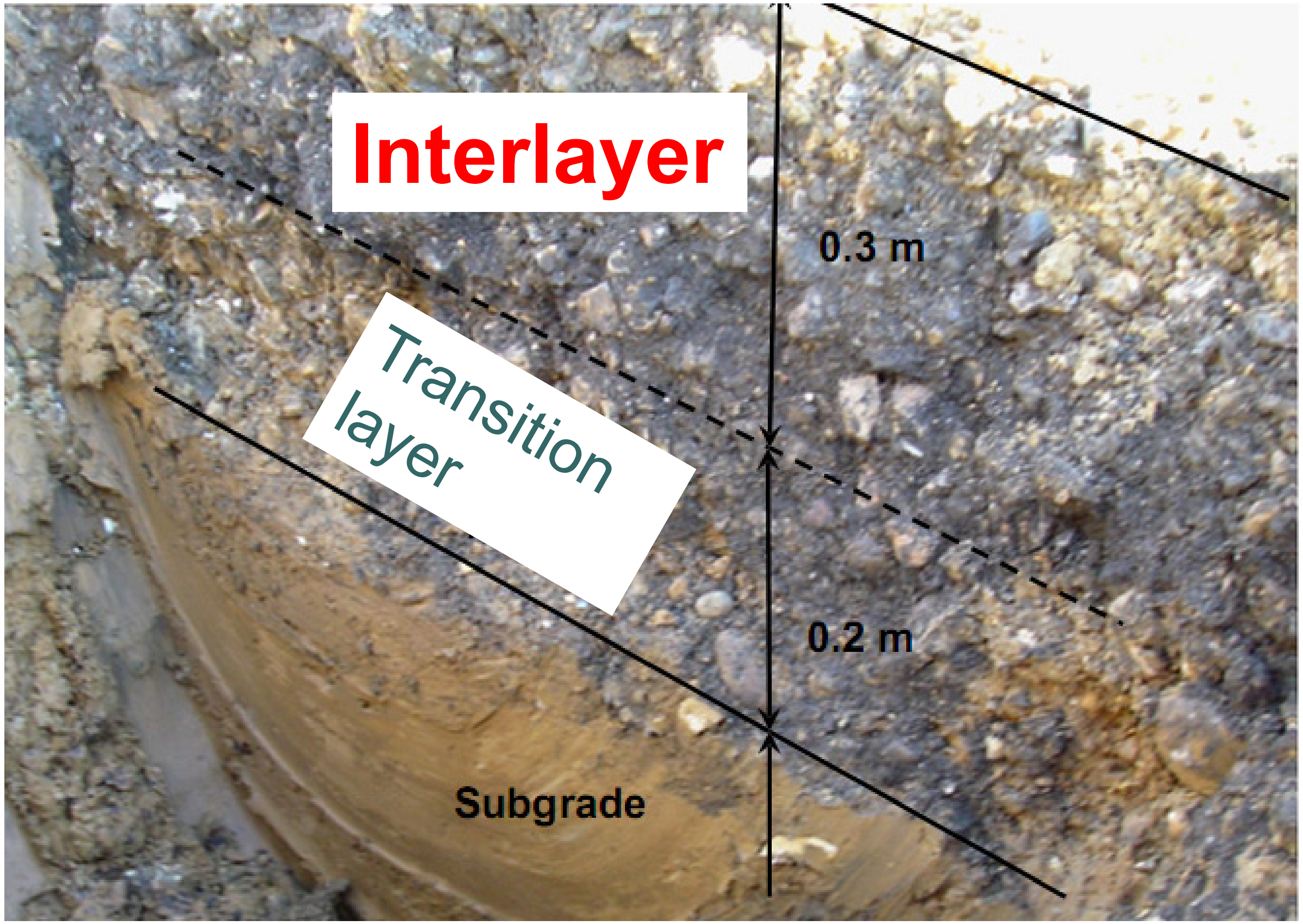
H = 600 mm

Instrumentation:

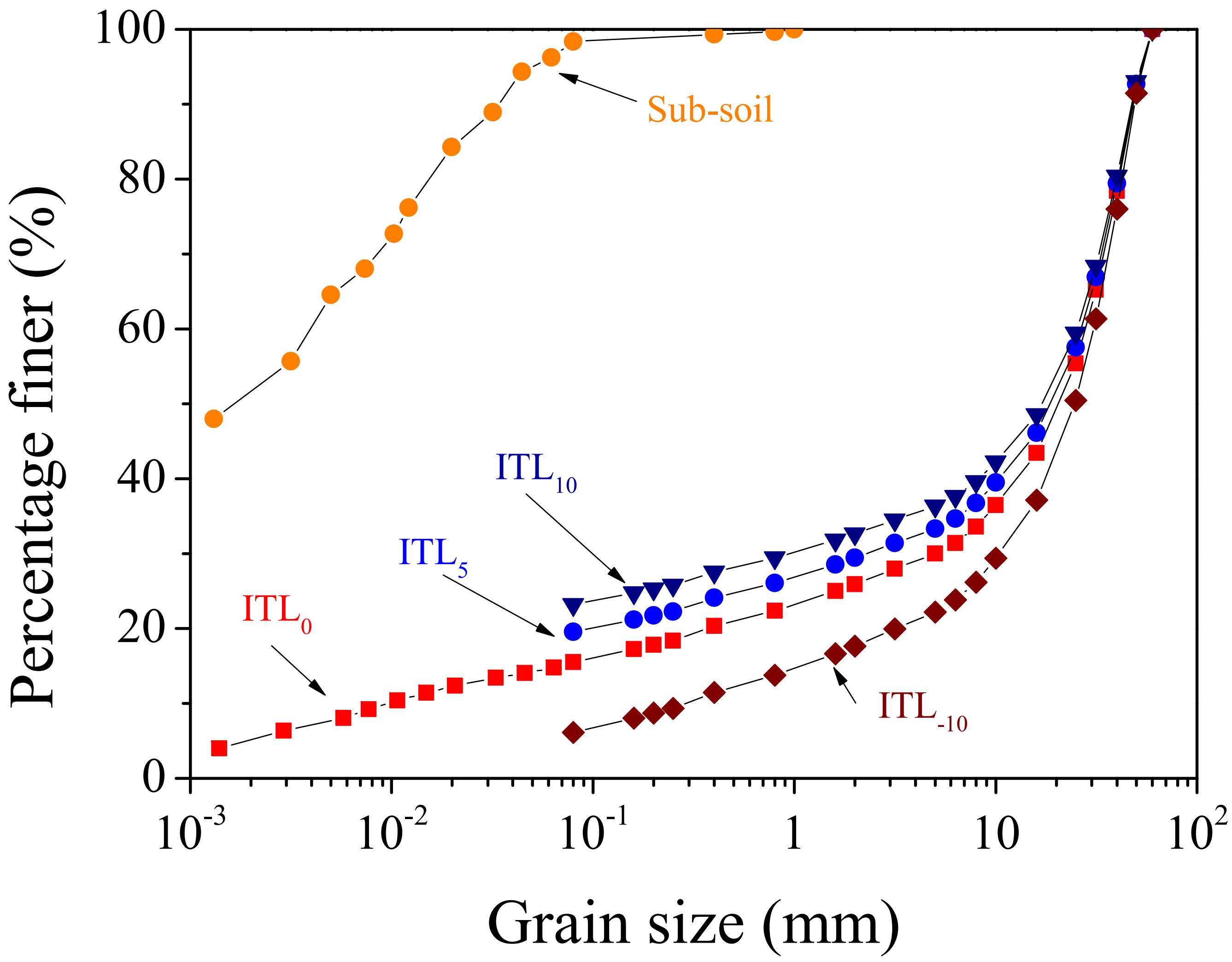
- 5 TDR for volumetric water content

- 5 tensiometers for soil suction

Soils' sampling



Soils studied



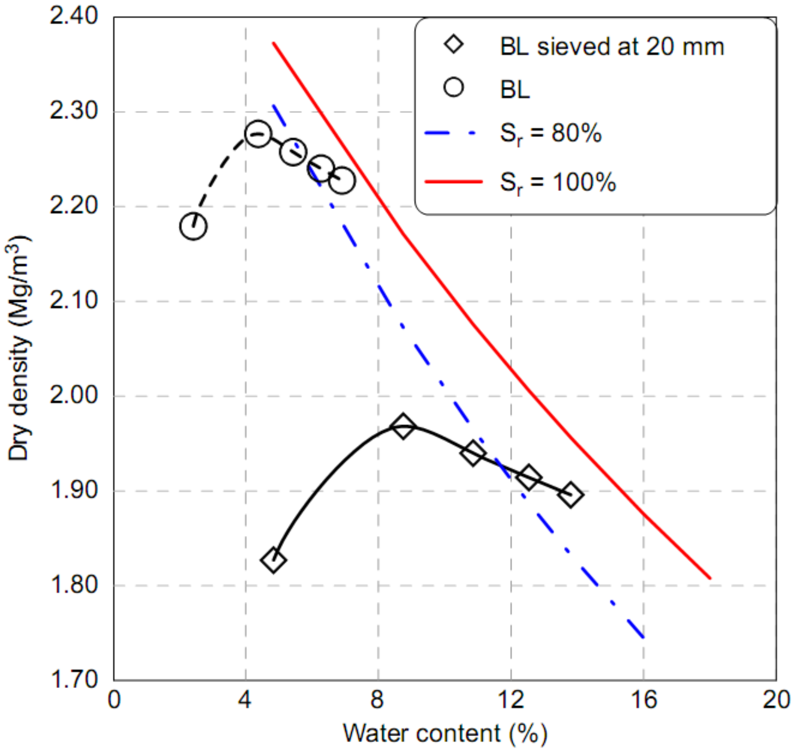
ITL_0: Natural interlayer soil

+5 % sub soil → ITL_5

→ *+10 % sub soil → ITL_{10}*

-10 % sub soil → ITL_{-10}

Sample preparation in laboratory



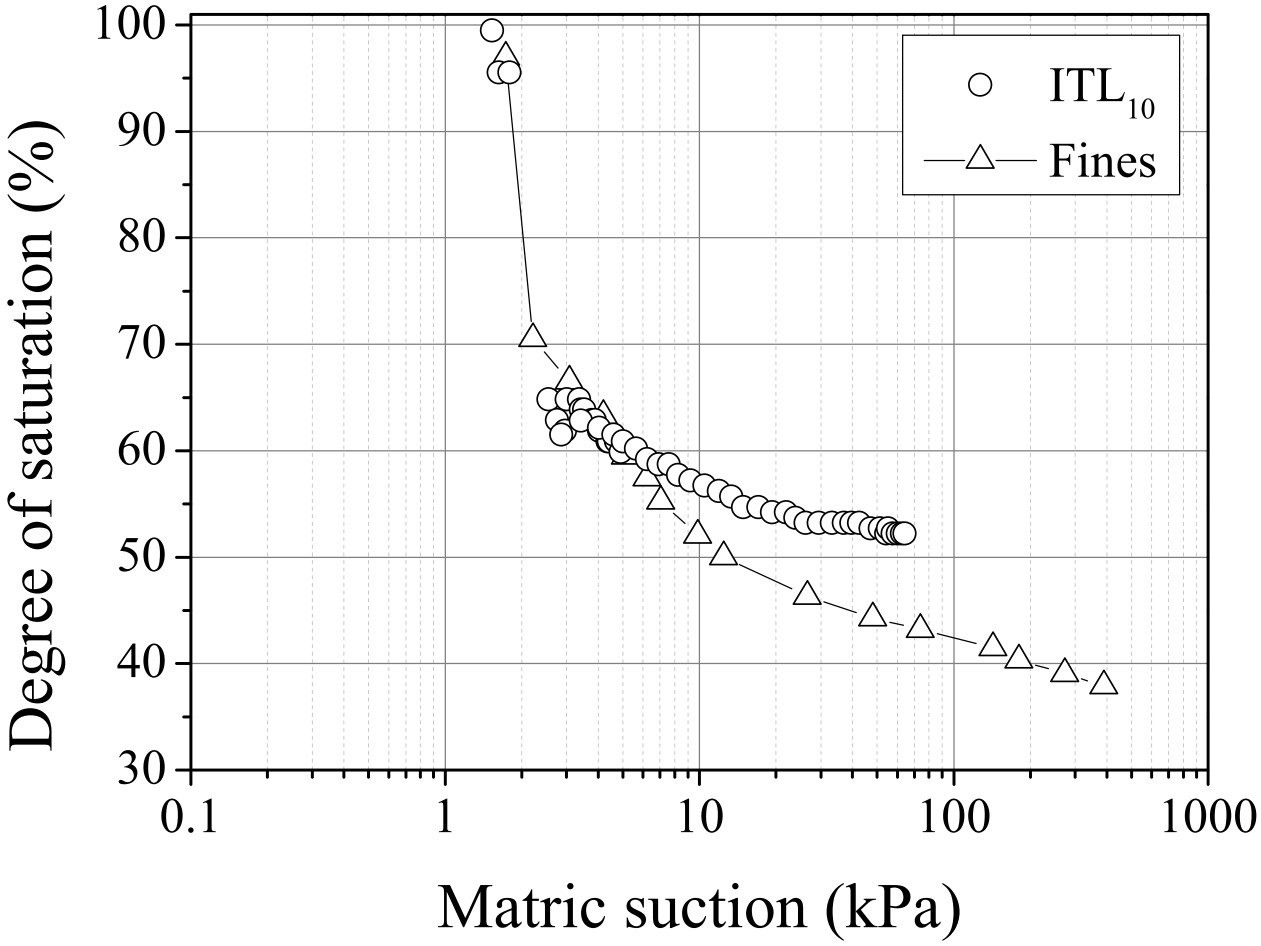
Soil dry density:

- In situ: 2.40 Mg/m^3

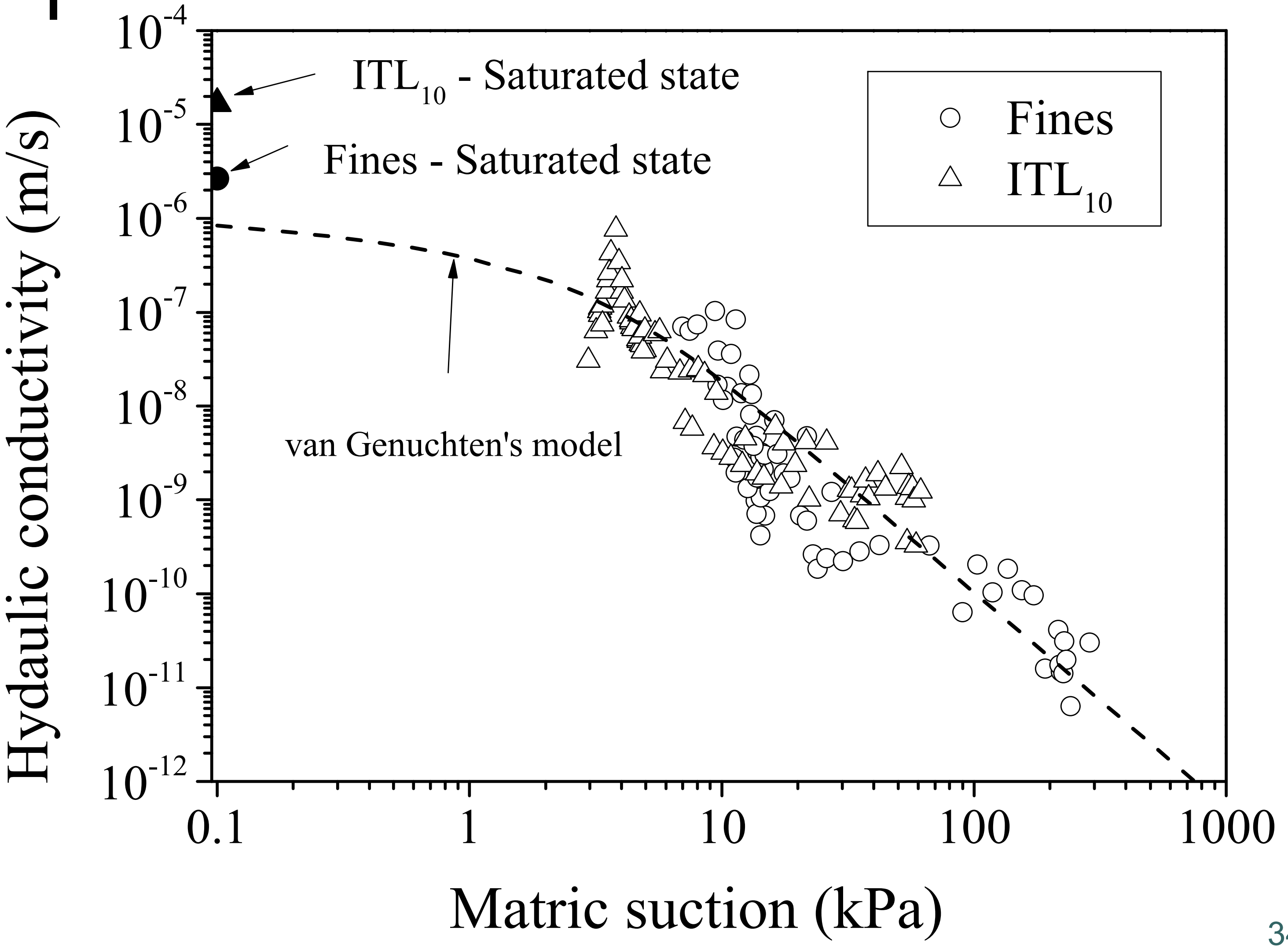
- Laboratory: 2. 00 Mg/m^3

(compaction in layers)

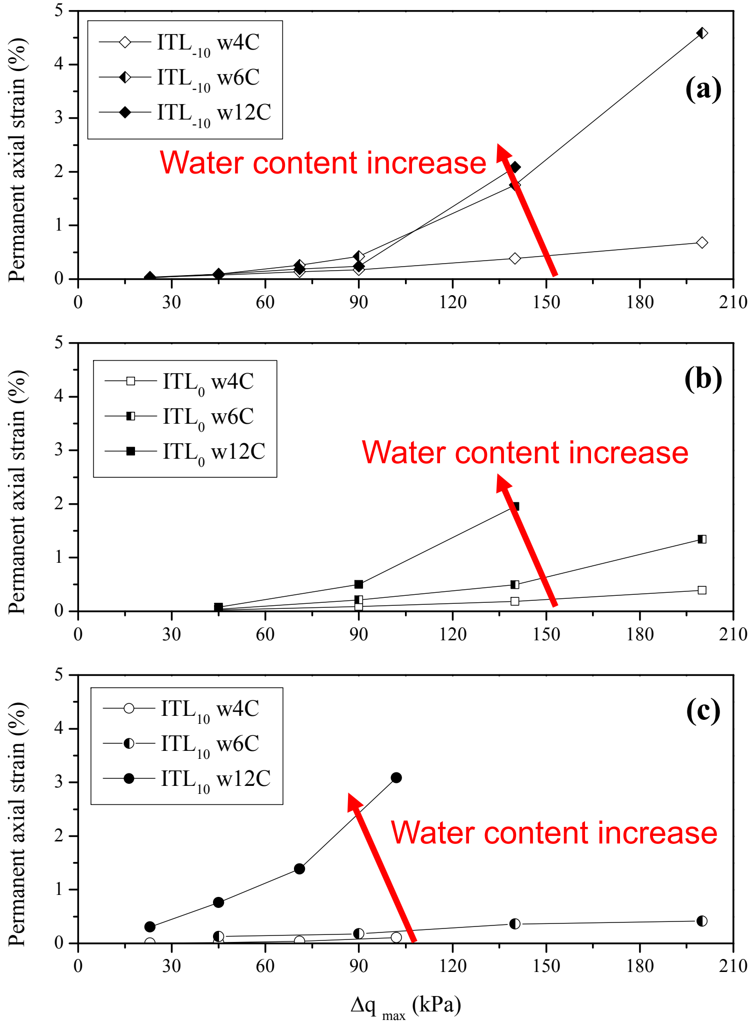
Water retention property

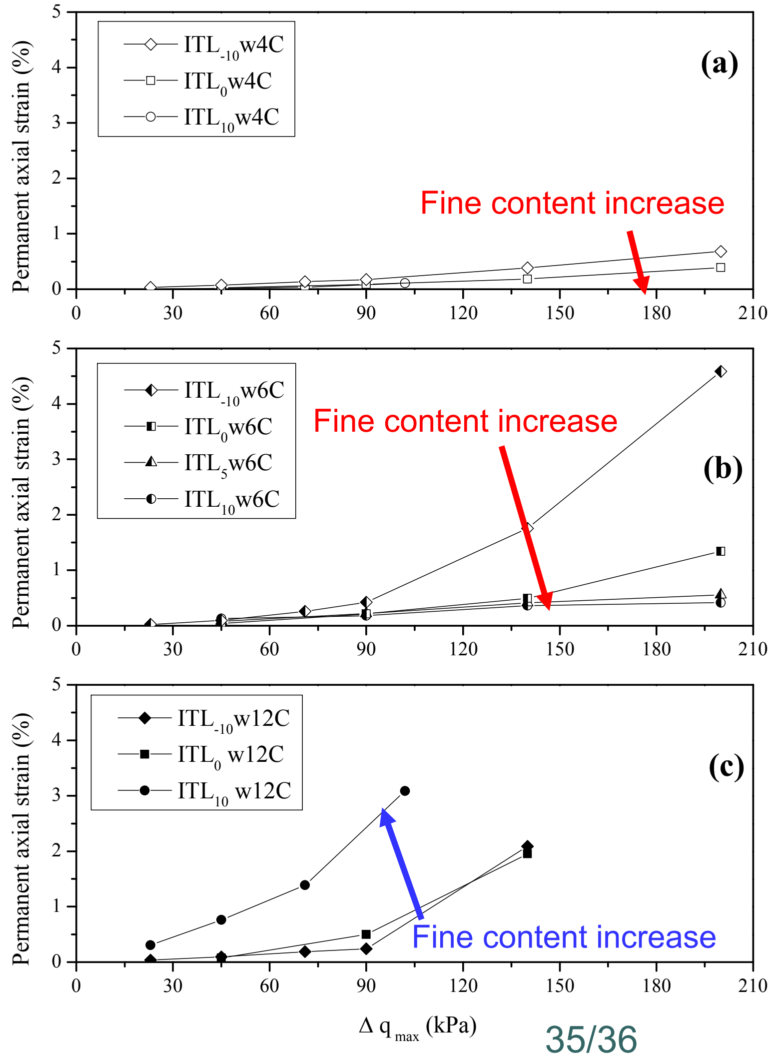


Hydraulic conductivity *vs* suction, fines, macropores



Permanant strain *vs* water content and fine fraction





Concluding remarks

- Unsaturated soil mechanics is involved in both new and conventional lines
- New lines - Special sub-soils
  - Loess: collapse upon wetting; liquefaction in saturated state, and the liquefaction resistance can be increased significantly with a slight decrease of water content
  - Marl: swelling upon water infiltration; excavation or unloading is the origin of swelling; possibility to estimate the time needed to reach a new equilibrium
- Conventional lines – Interlayer soils
  - Governing role of fine fraction for the hydraulic conductivity of interlayer soils
  - Effects of water content and fine content to be accounted for together when analyzing the mechanical behavior