COMITÉ FRANÇAIS DE MÉCANIQUE DES SOLS ET DE GÉOTECHNIQUE

Webinaire « Doctorants en géotechnique »

Congélation artificielle des sols :

caractérisation du comportement couplé thermo-hydromécanique

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Laboratoire Énergies & Mécanique Théorique et Appliquée

BOUYGUES TRAVAUX PUBLICS

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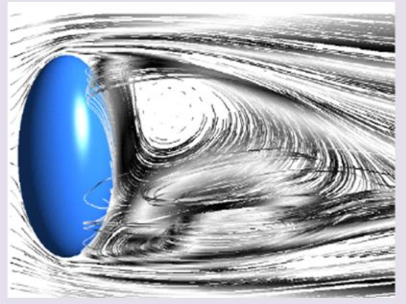
LEMTA: Joint Research Unit of the University of Lorraine and CNRS

Laboratoire Énergies & Mécanique Théorique et Appliquée

	MILIEUX FLUIDES, RHEOPHYSIQUE	
	Hydrodynamique et rhéophysique	AT IRM POUR L'INGÉNIERIE 
	Transferts dans les fluides	
	Rhéologie de matériaux nano/micro-structurés	
	ENERGIE ET TRANSFERTS	
	Transport dans les milieux complexes	
	Feux	
	Mécanique des sols, géotechnique	
	VECTEURS ENERGETIQUES	
	Hydrogène, systèmes électrochimiques	
	Gestion de la chaleur	
	Gestion de l'énergie électrique	

Mécanique des sols : thématiques de recherche

What is AGF?

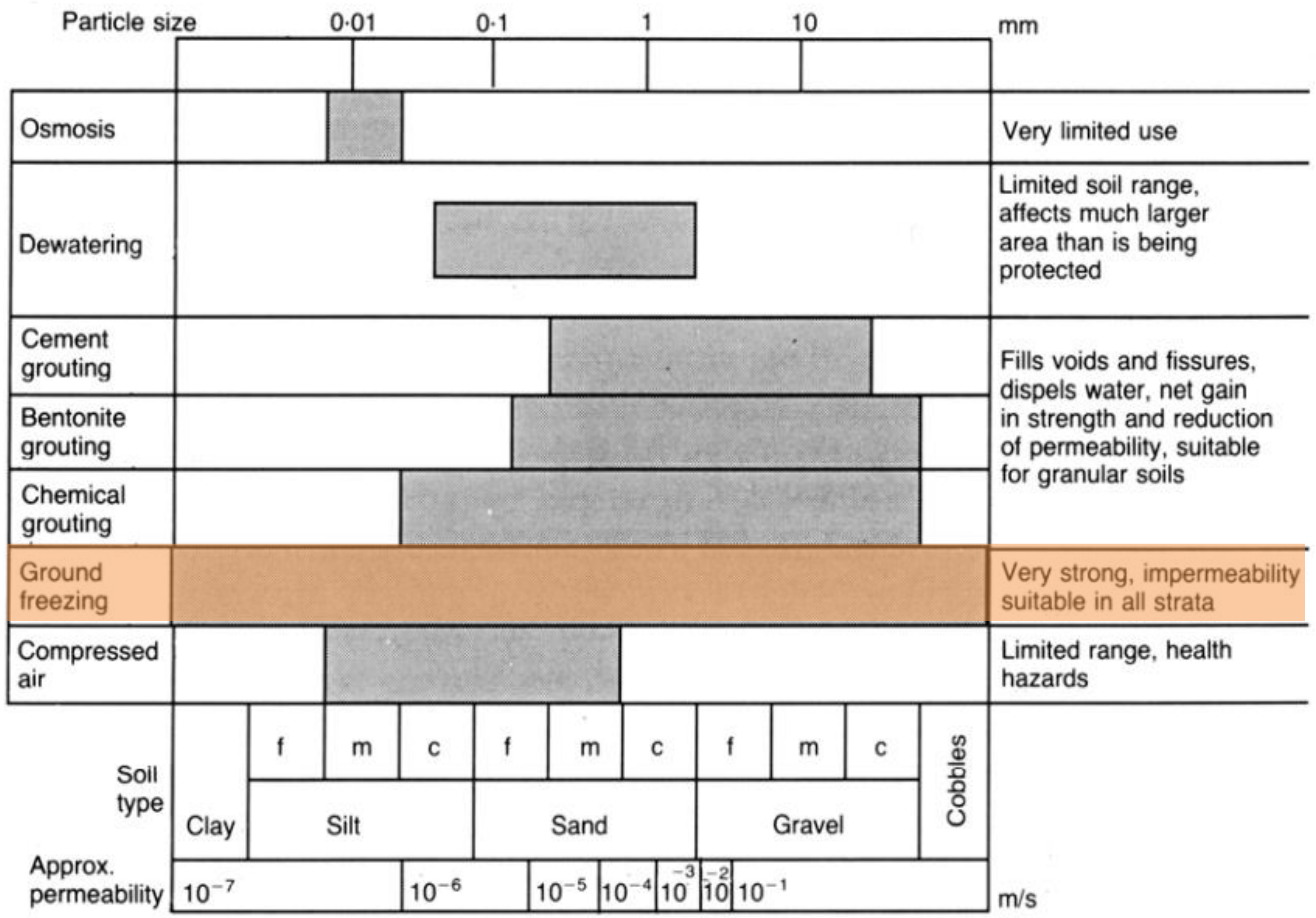
Building of cross-passages during construction of an **urban subway tunnel** by shield method

Soft saturated soil:

- rich groundwater
- low mechanical strength

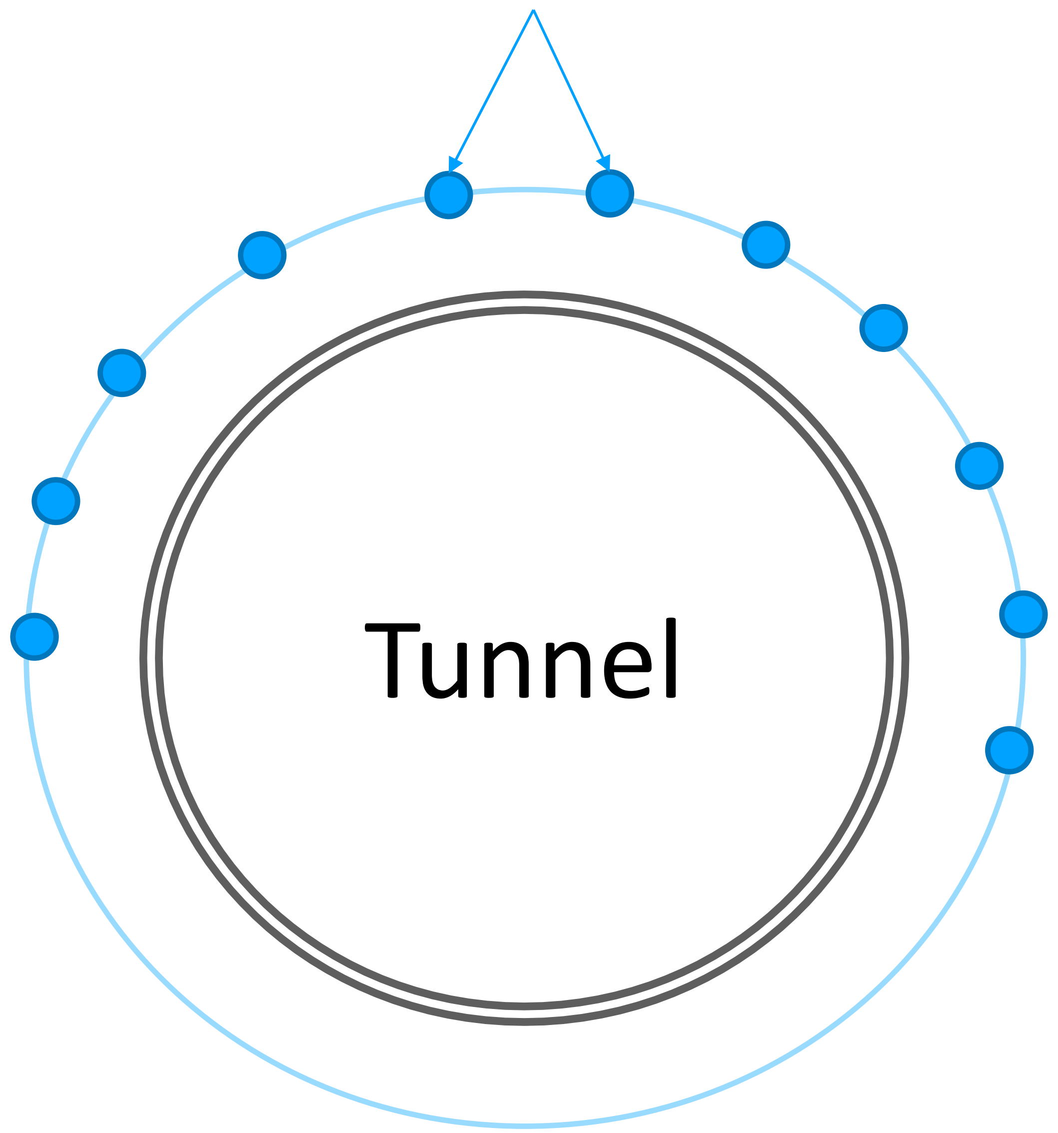
⇒ ground is prone to buckling + collapsing

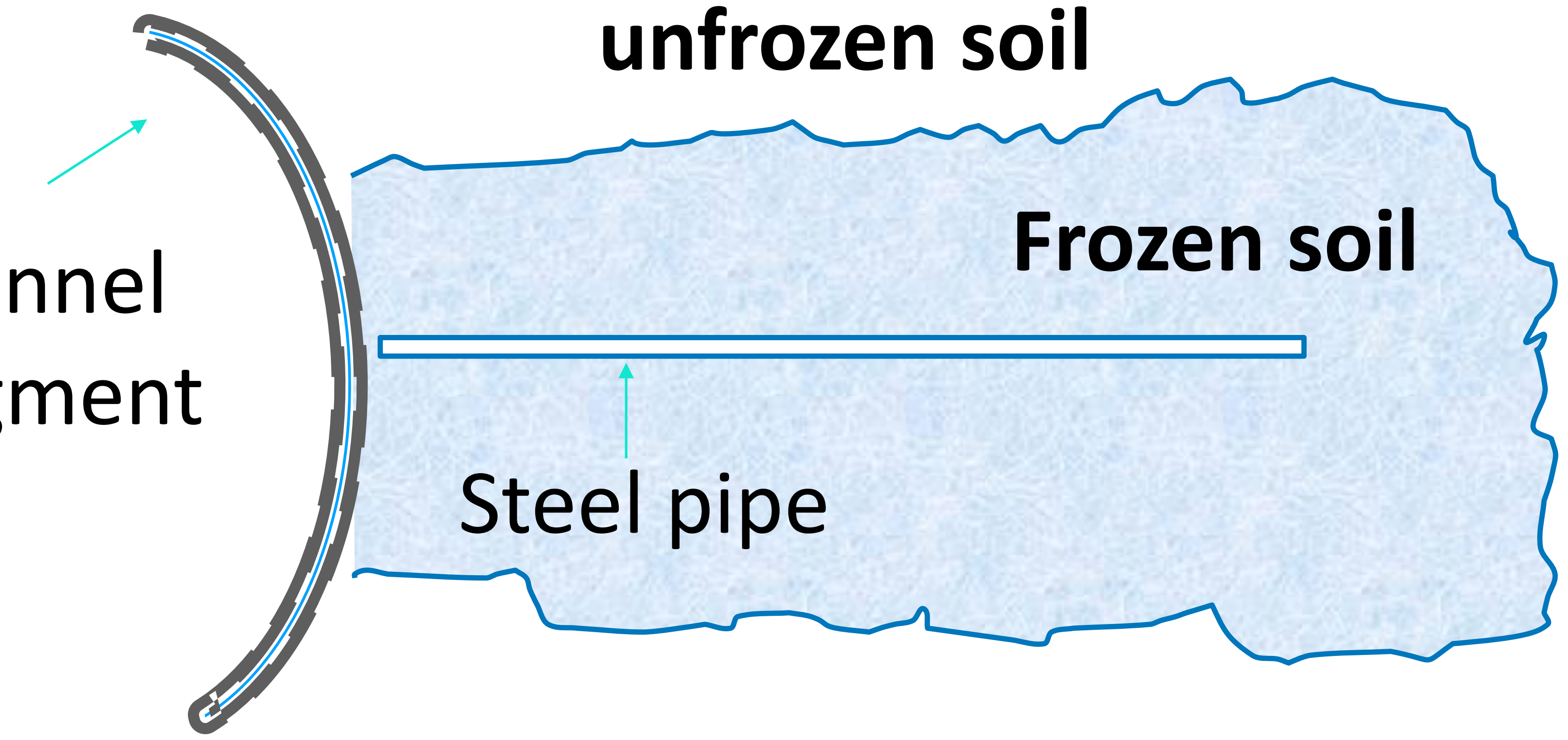
Soil treatments



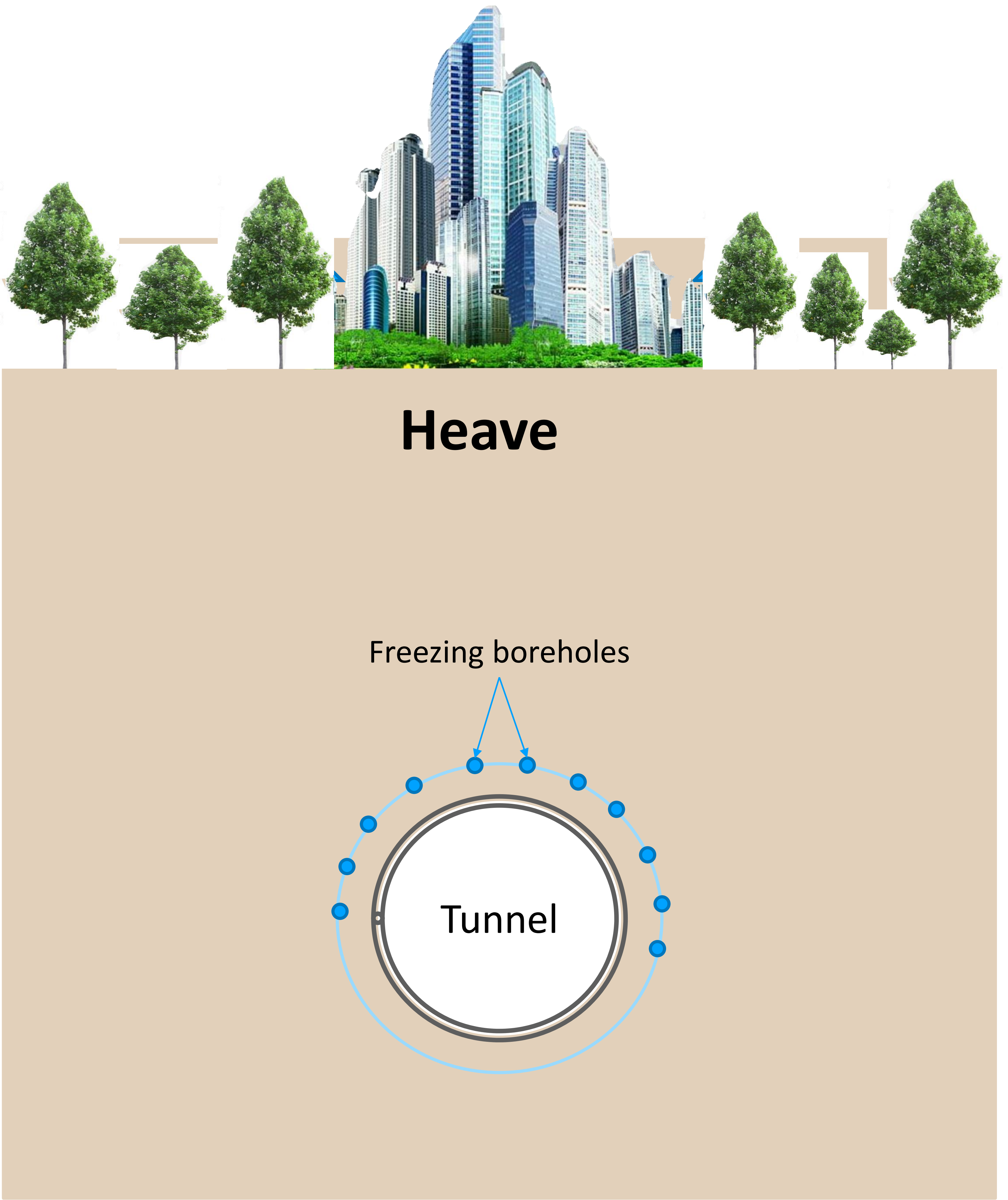
Soil stabilizing methods' utility in different soils (Harris 1995)

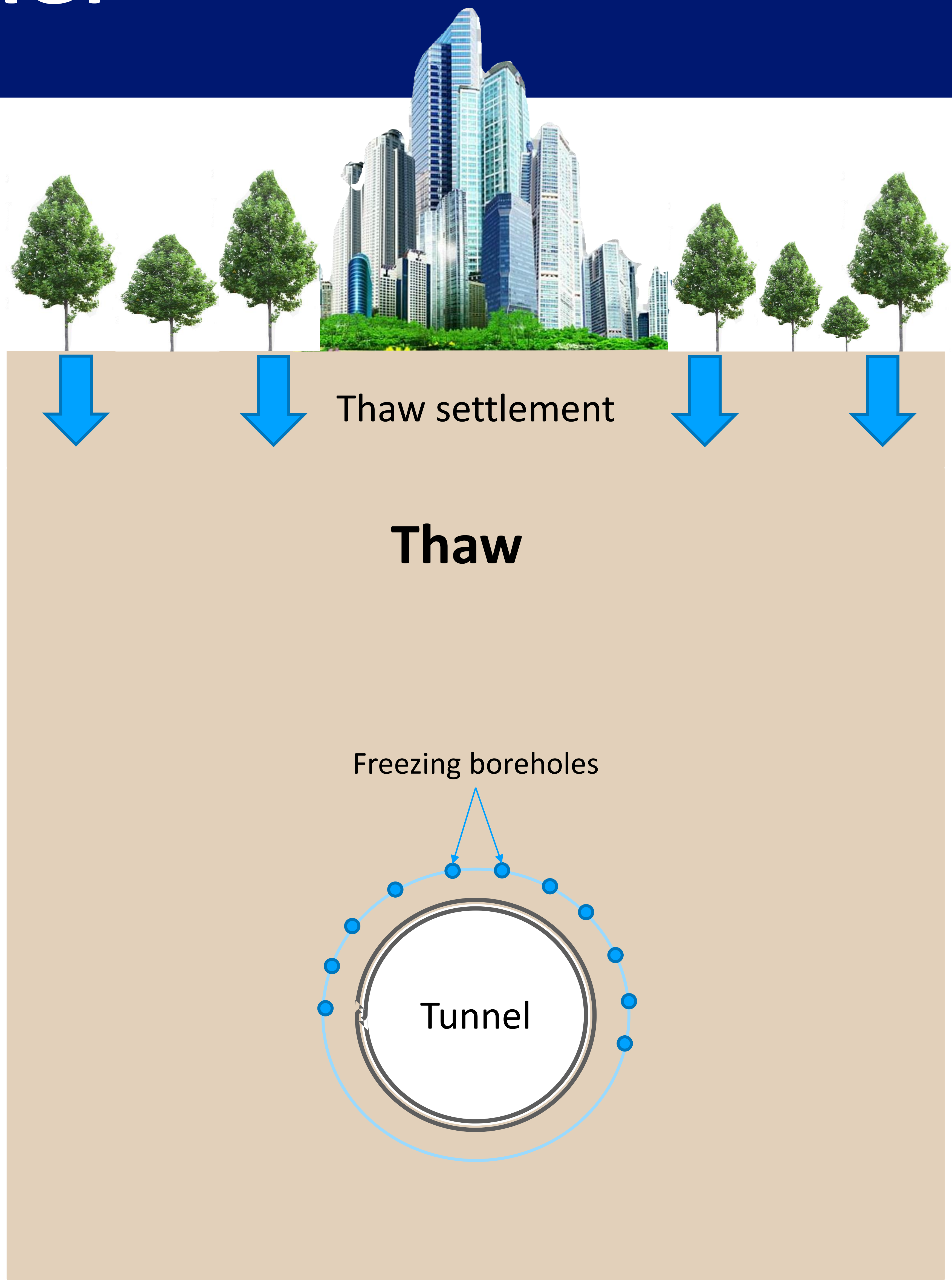
What is AGF?


Freezing boreholes
Tunnel

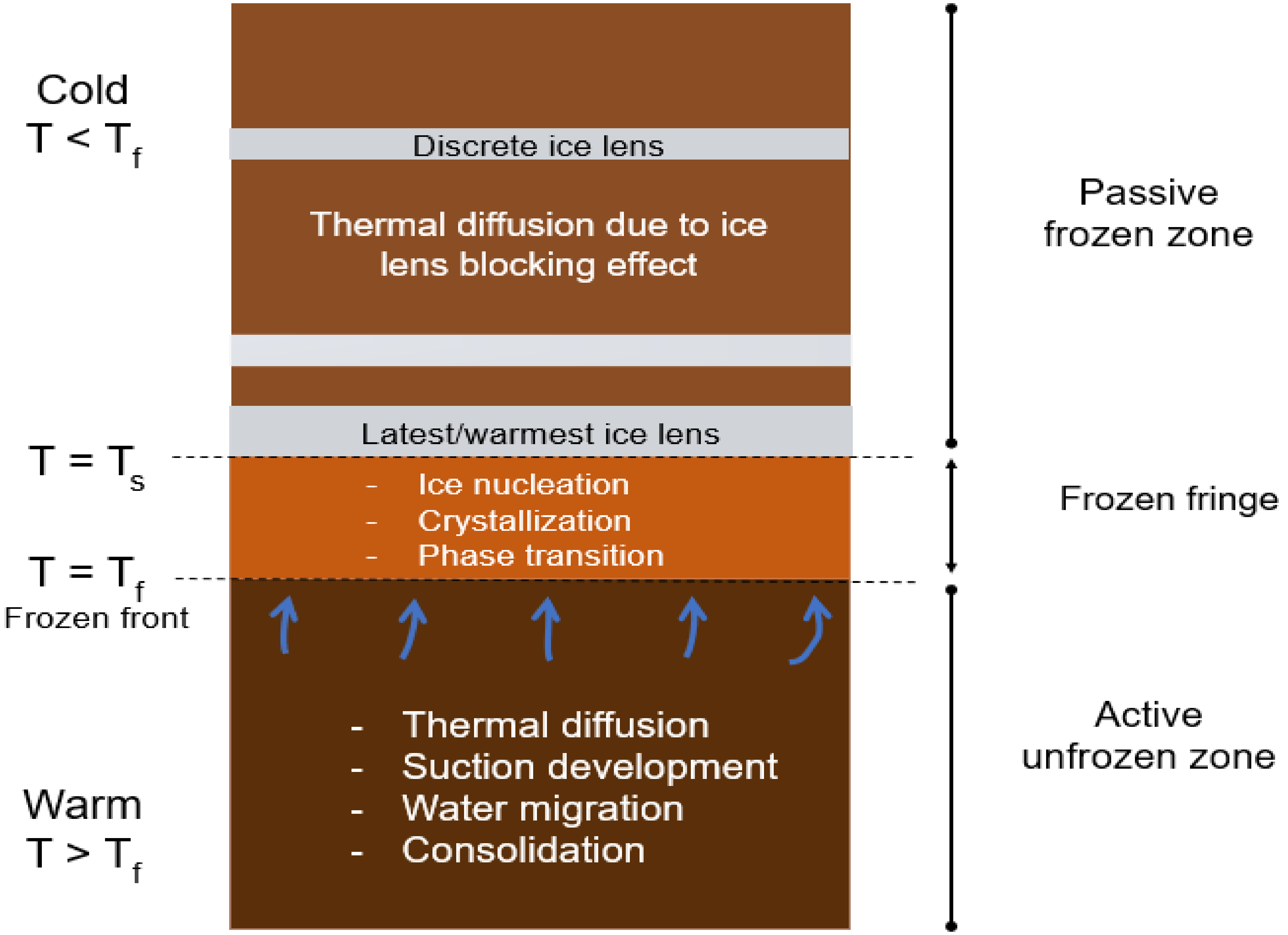

unfrozen soil
Frozen soil
Tunnel segment
Steel pipe

Deformations associated with AGF





Processes governing fine-grained soil freezing



(Joudieh 2023)

Summary of a frozen soil profile and the processes that govern freezing

Factors influencing frost heave

Factors influencing soil freezing

Condition	Factor
Site conditions	• Soil type, grain size, • Water content, water availability, • **Applied load, Overburden pressure** • Soil temperature, temperature gradient
Project settings and choices	• Freezing temperature • Distance from the injection axis, • Thickness of soil layer(s) above tunnel, • Thickness of the frozen soil

Factors influenced by overburden pressure

Factor	Reference
Water content and Water migration	Penner and Ueda 1977; Loch and Kay 1978; Ming et al. 2016; Lu et al. 2021
Suction in the frozen fringe	Konrad and Morgenstern 1982; Ji et al. 2022
Segregation temperature	Konrad 1980; Azmatch 2013; Ji et al. 2022
Thickness of the frozen fringe	Konrad and Morgenstern 1982; Xia et al. 2005; Ji et al. 2022

Effect of overburden pressure external on water intake

Effect of overburden pressure on water intake

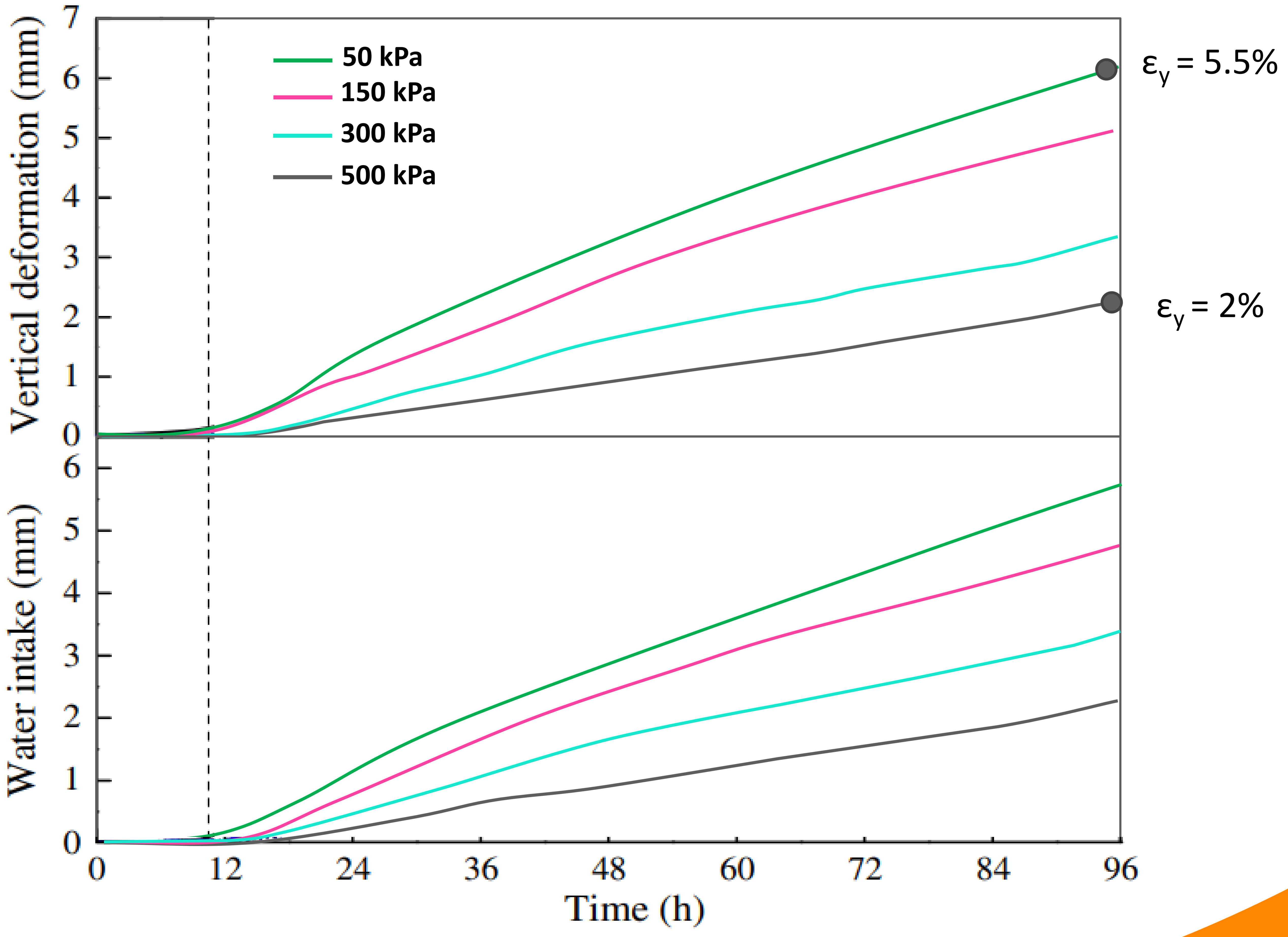
Saturated silty clay:

H = 110 mm, D = 100 mm,
w =22.3%, ρ_d = 1.75 Mg/m^3
T_{top} = -2 °C, T_{bottom} = +2 °C, freezing time = 96 h

- As stress ↗ time to absorb water ↗ → heave ↘
- Water absorption starts when the advance rate of the freezing front < critical value

External water intake ↘ as stress ↗ ➡ heave ↘

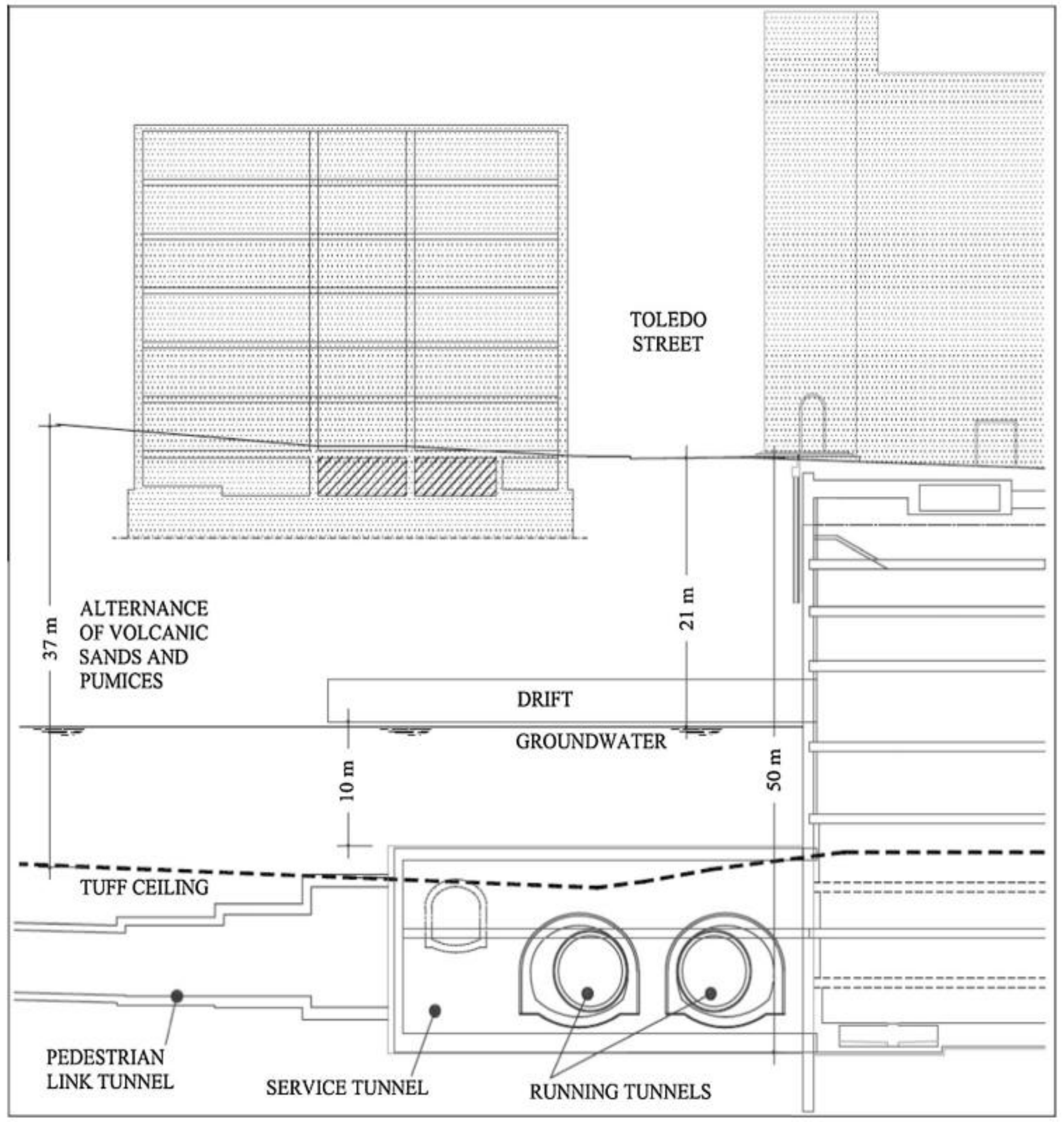
(Penner and Ueda 1977; Loch and Kay 1978; Ming et al. 2016; Lu et al. 2021)



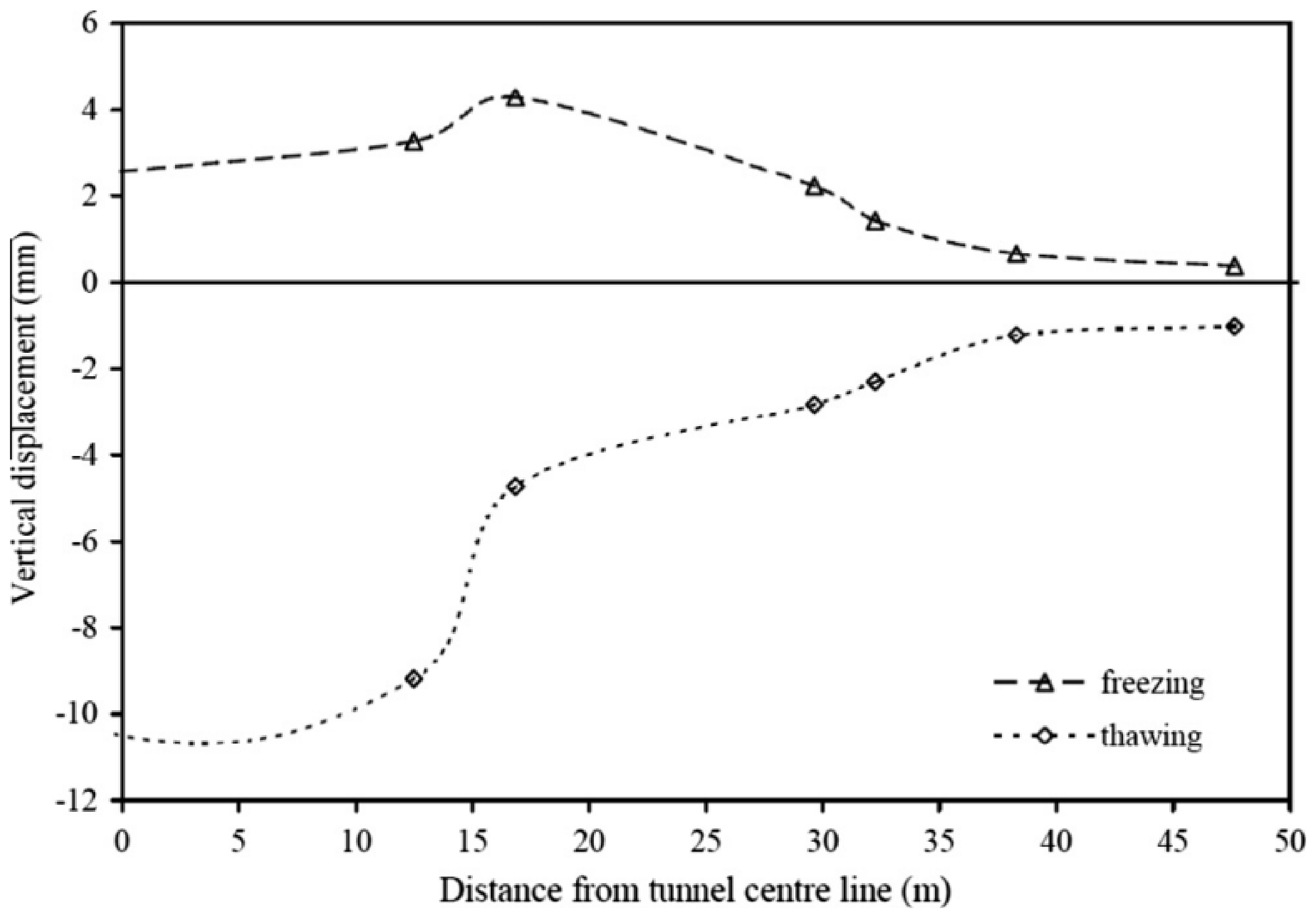
Variations of the vertical deformations and water intakes of the saturated silty clay soil samples under different applied pressures (Zhang et al. 2017)

Effect of overburden pressure?

- Develop an experimental setup
- Establish a test procedure
- Carry on tests to understand the behavior of soil during both freezing and thawing under different temperature conditions and applied pressures
- Use the acquired data to develop a model capable of predicting the F-T behavior of soil under applied pressure

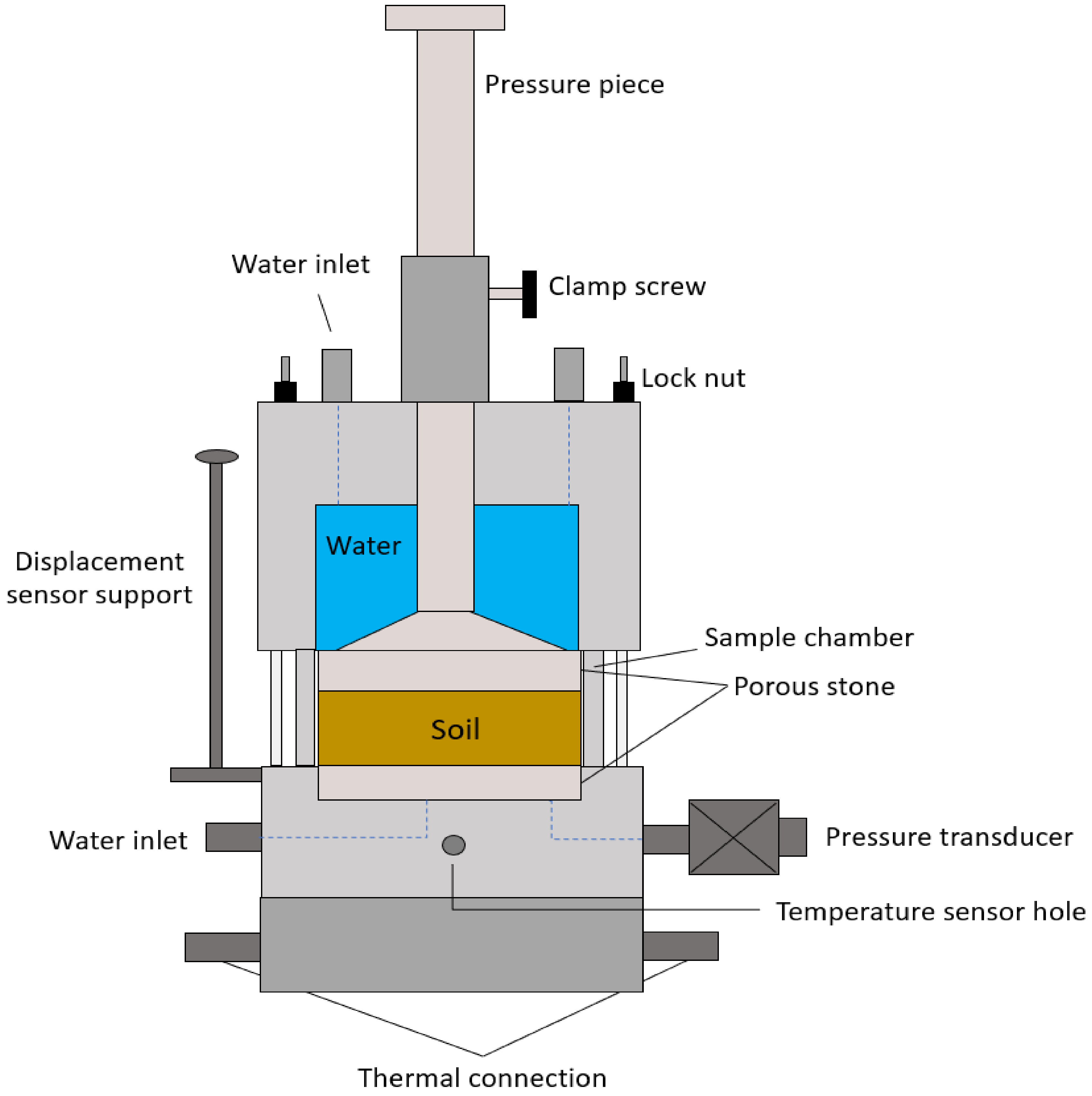


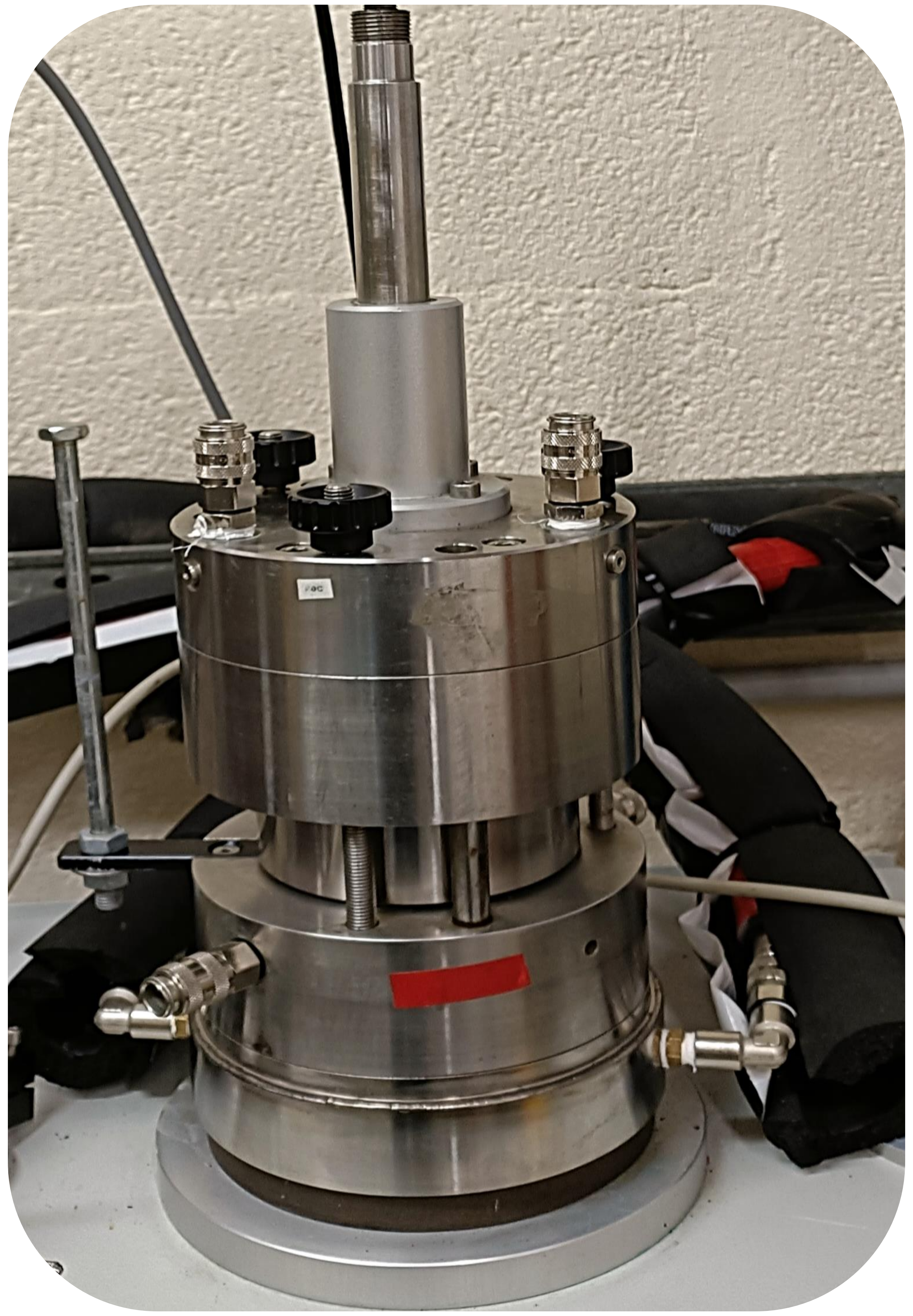
Metro line 1 – Toledo Station (Russo et al. 2015)



Displacements induced by freezing and thawing (Russo et al. 2015)

Modified temperature-controlled oedometer





Schematic diagram and a photograph of the oedometer cell

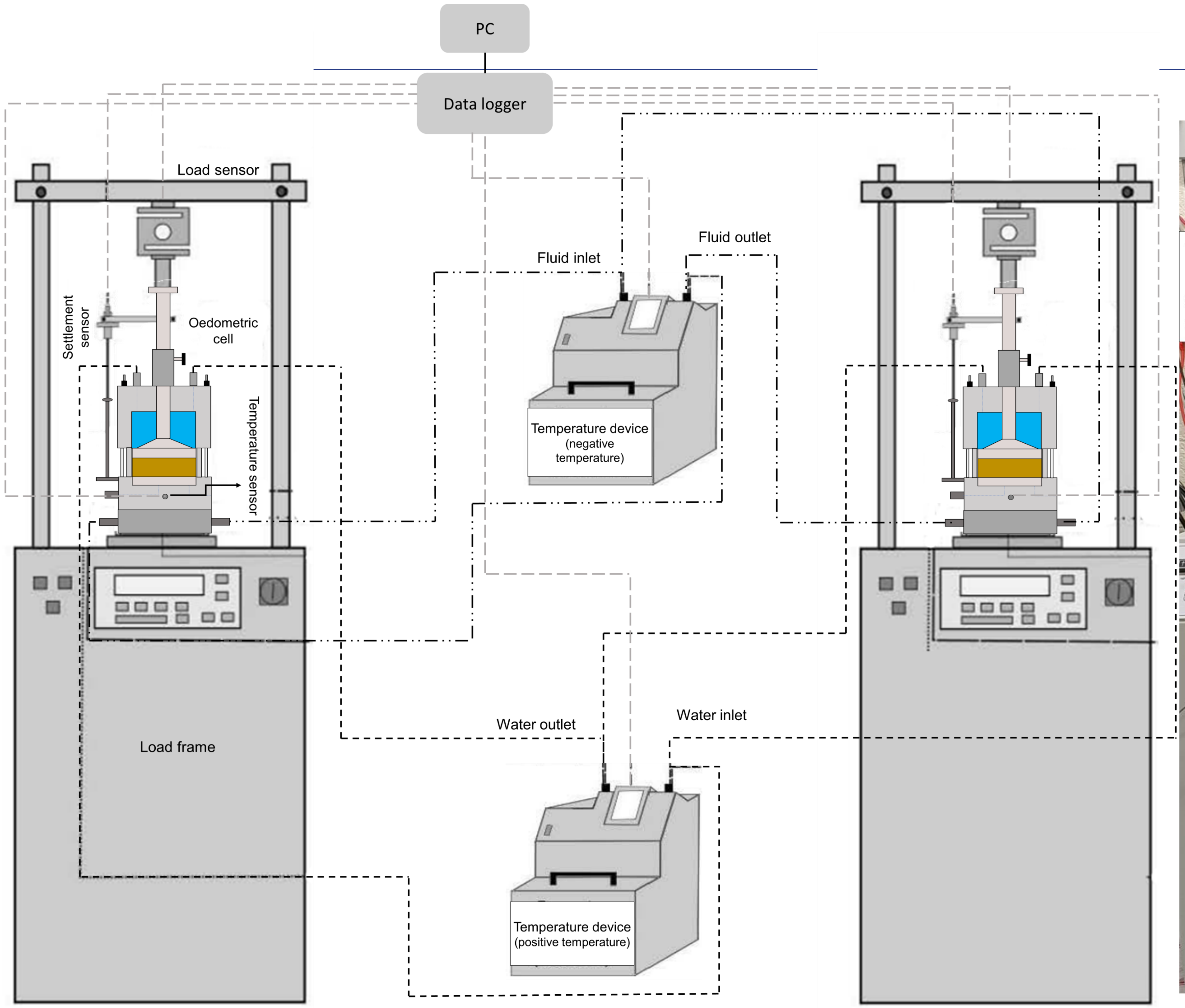
Sample size

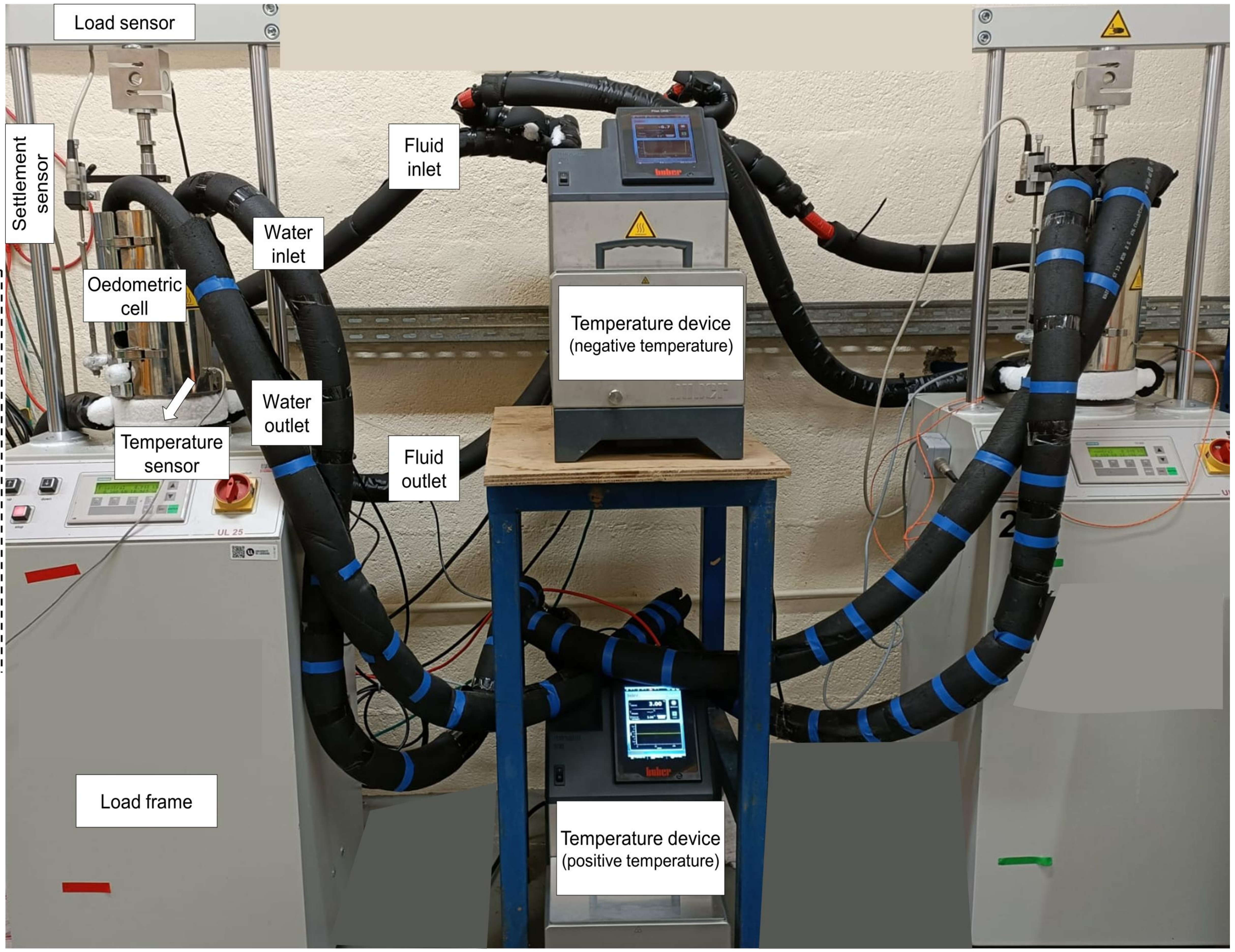
- Surface area of 40 cm^2
- Diameter of 71.4 mm
- Height of 20 or 40 mm

Technical Specifications

- Temperature: - 40 -> + 90 ^{o}C
- Maximum axial stress up to 5000 kPa

Modified temperature-controlled oedometer



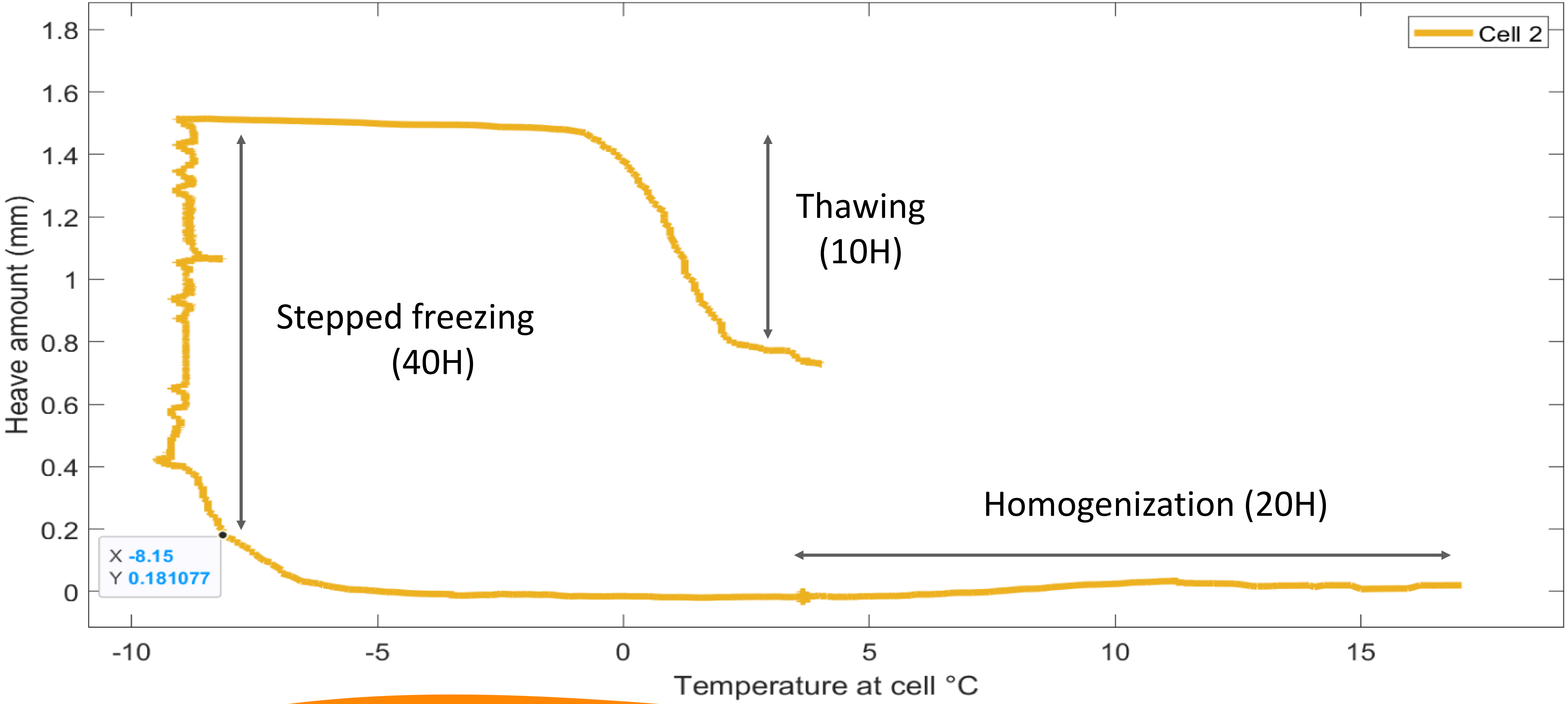


Schematic diagram and photograph of the modified TC oedometric system

Modified temperature-controlled oedometer

Repeatability

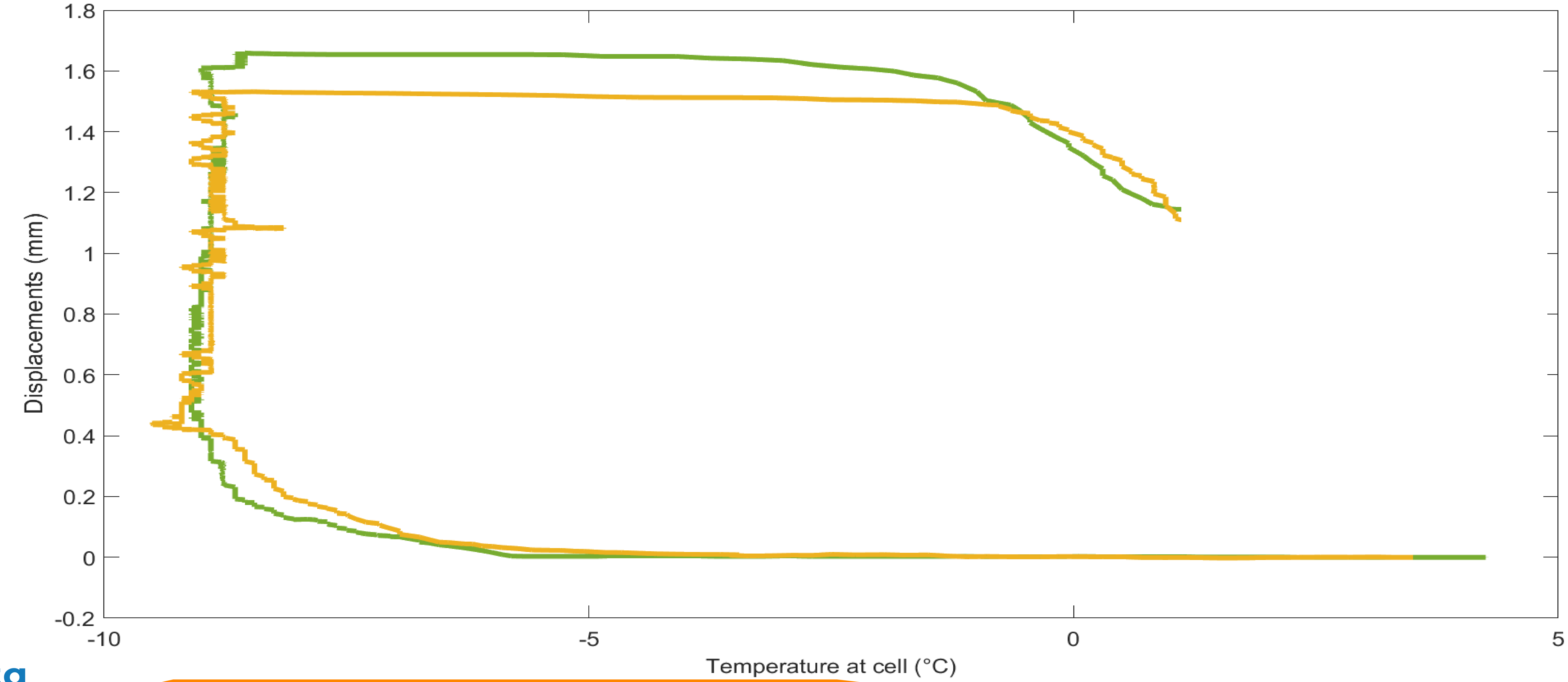
Silty soil: H = 20 mm, water content = 17.2%, dry density = 1.75 Mg/m^3



Modified temperature-controlled oedometer

Repeatability

Silty soil: H = 20 mm, water content = 17.2%, dry density = 1.75 Mg/m^3

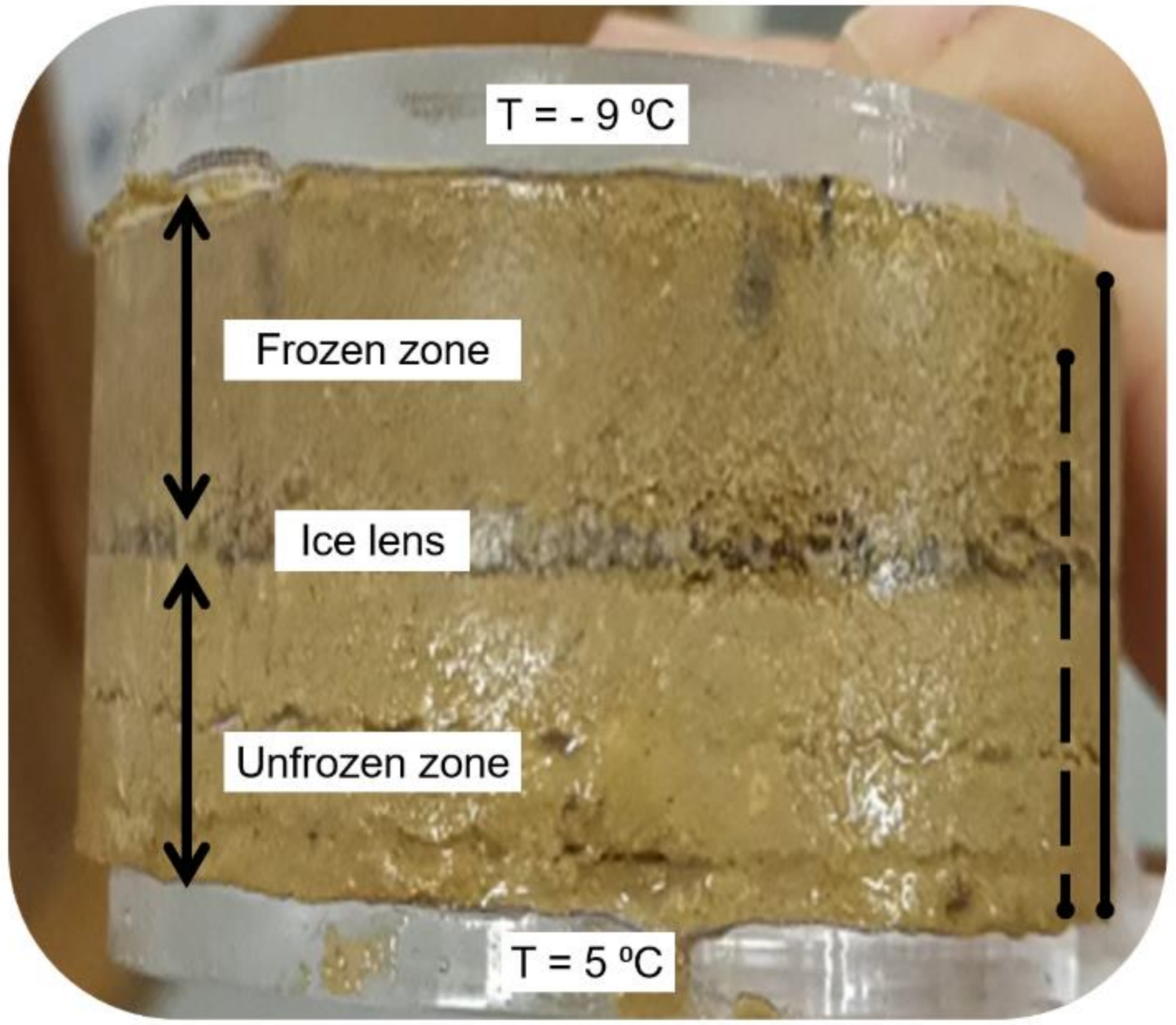


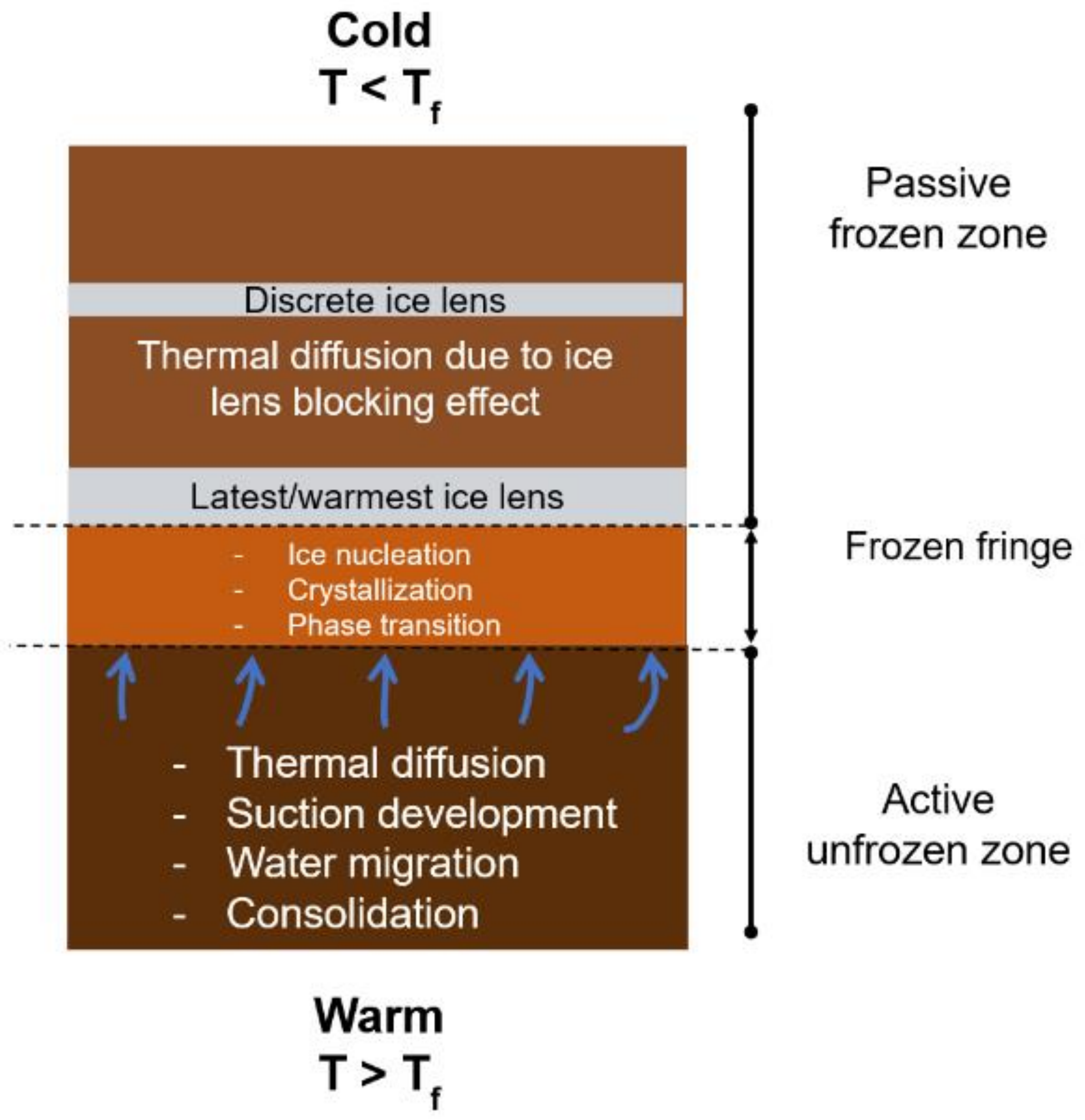
Modified temperature-controlled oedometer

Silty soil: H = 40 mm, water content = 17.2%, dry density = 1.75 Mg/m^3

6 months of a heavy experimental plan to:

- Develop a prototype: a miniature heave test
- Check the repeatability of the results
- Check saturation inside the TC oedometer
- Validate the experimental protocol





$\%W_{Initial} = 17.2$ → $\%W_{Frozen} = 29.4$ → + 12.3 %

Freeze-thaw tests on silty sand under applied pressures

Test protocol

1. Sample preparation → **2. Sample saturation + temperature homogenization** → **3. Load application** → **4. Freezing** → **5. Thawing**

1. Sample preparation

Retained value:

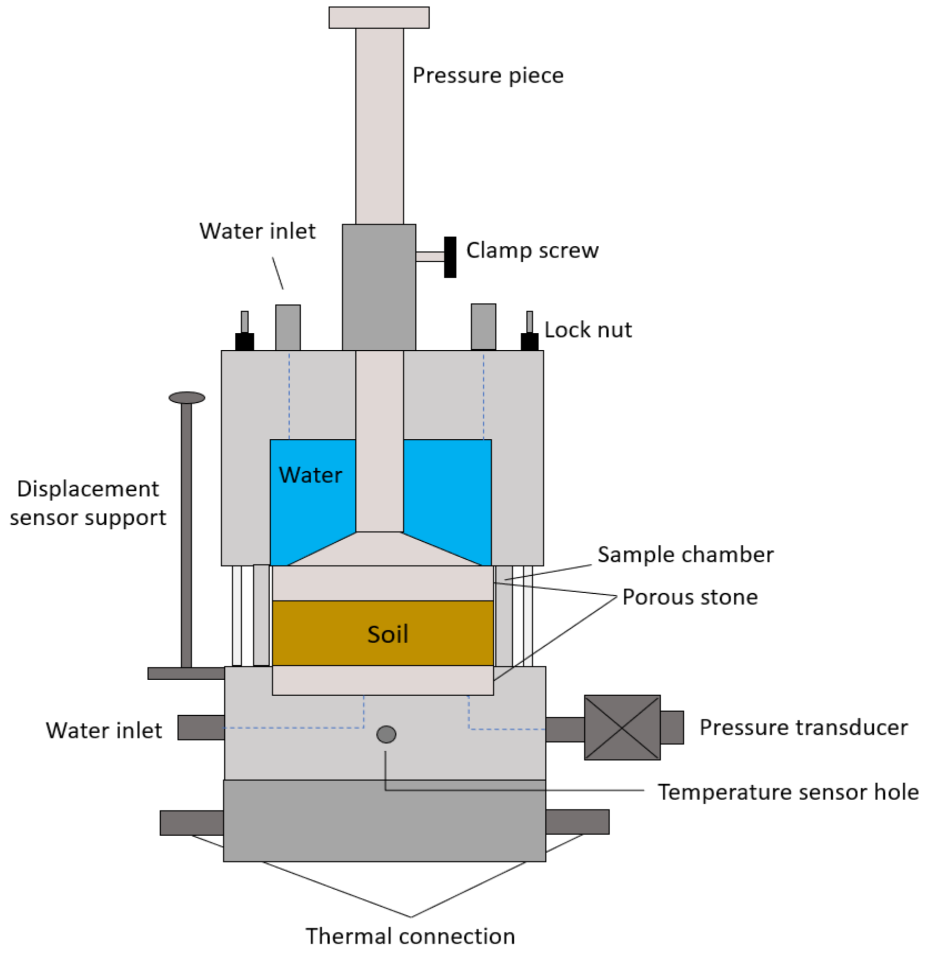
H = 20 mm
D = 71 mm
Water content = 16.5 %
Dry density= 1.7 Mg/m^3

2. Sample saturation + temperature homogenization

Applied pressure = 100 kPa for 10 mins to ensure contact
Applied pressure = 10 kPa
T_{cell} = + 4 ~ 5 ^oC
Saturation time = 65 hours

3. Load application

Stepped loading of 24 hours each

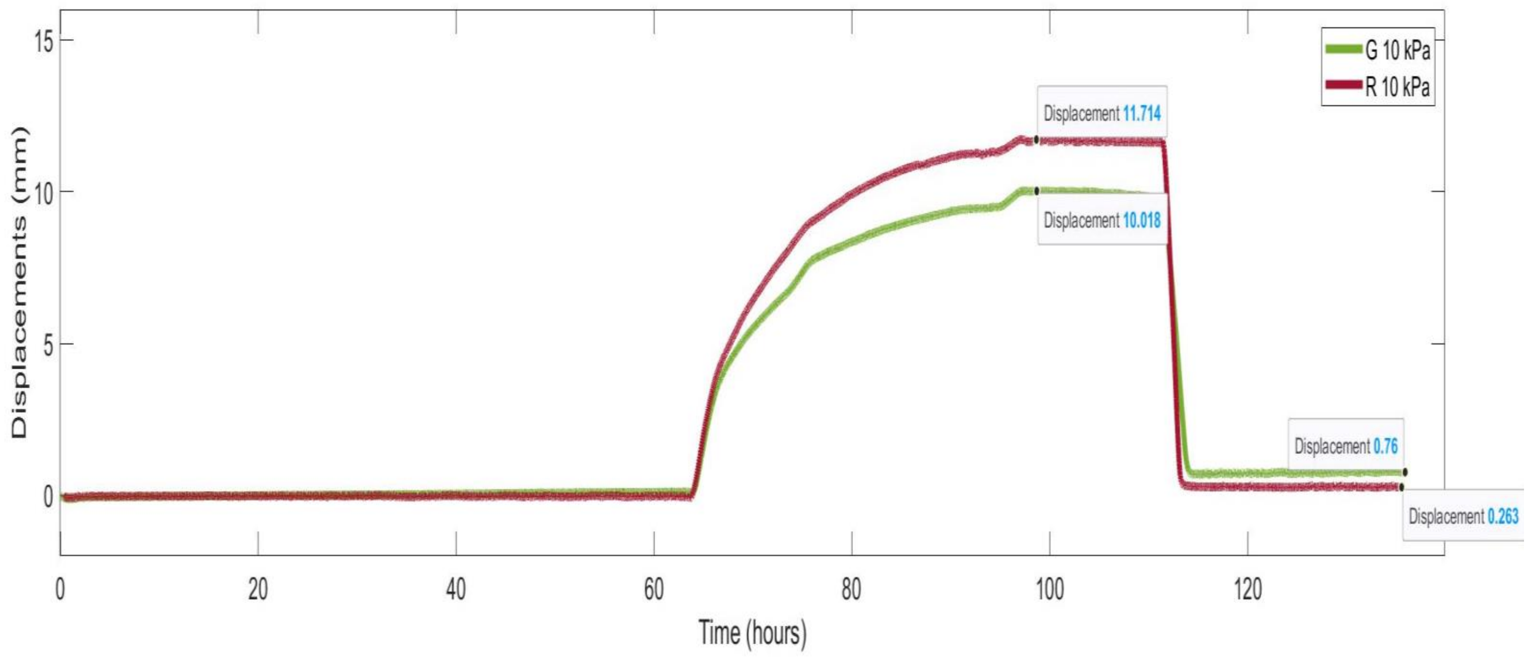


4. Freezing

For 48 hours

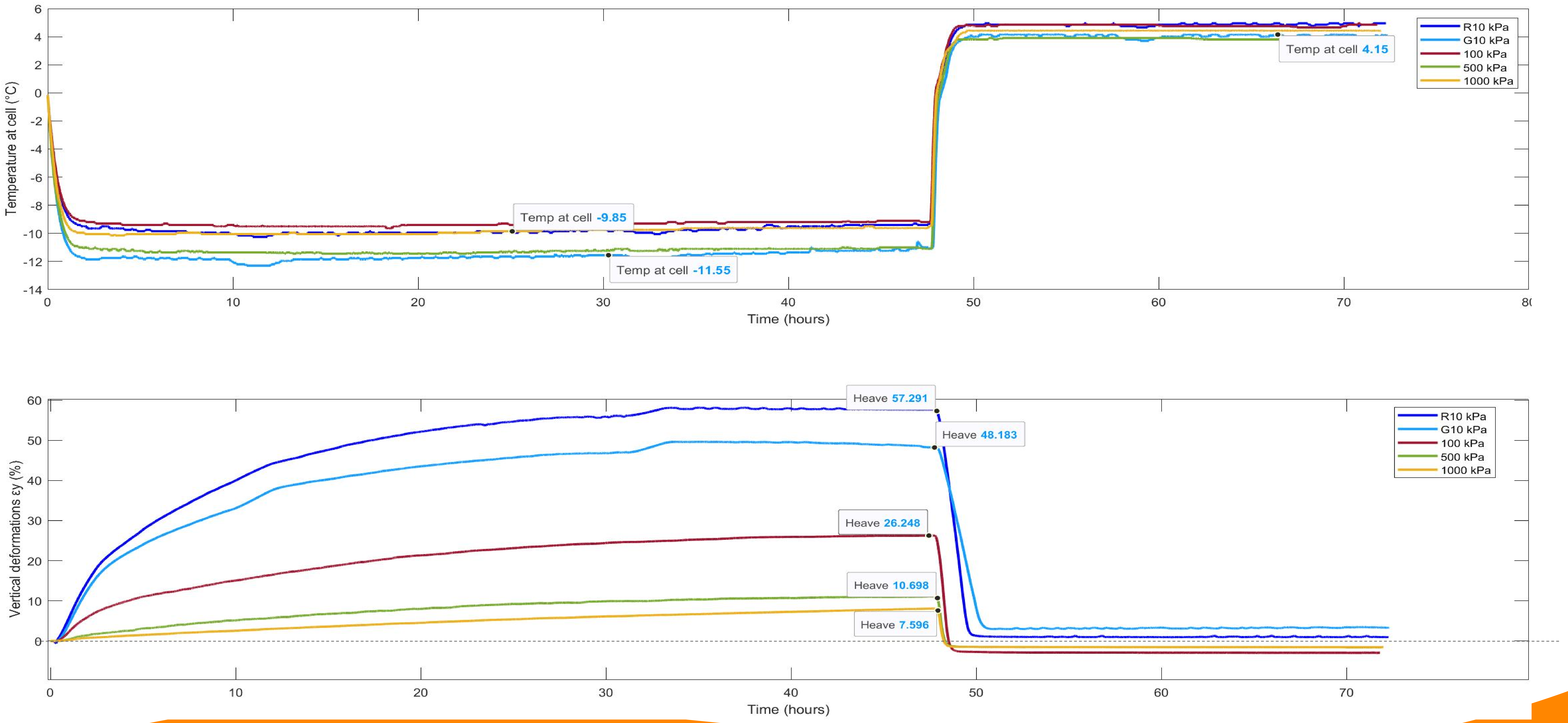
5. Thawing

For 24 hours



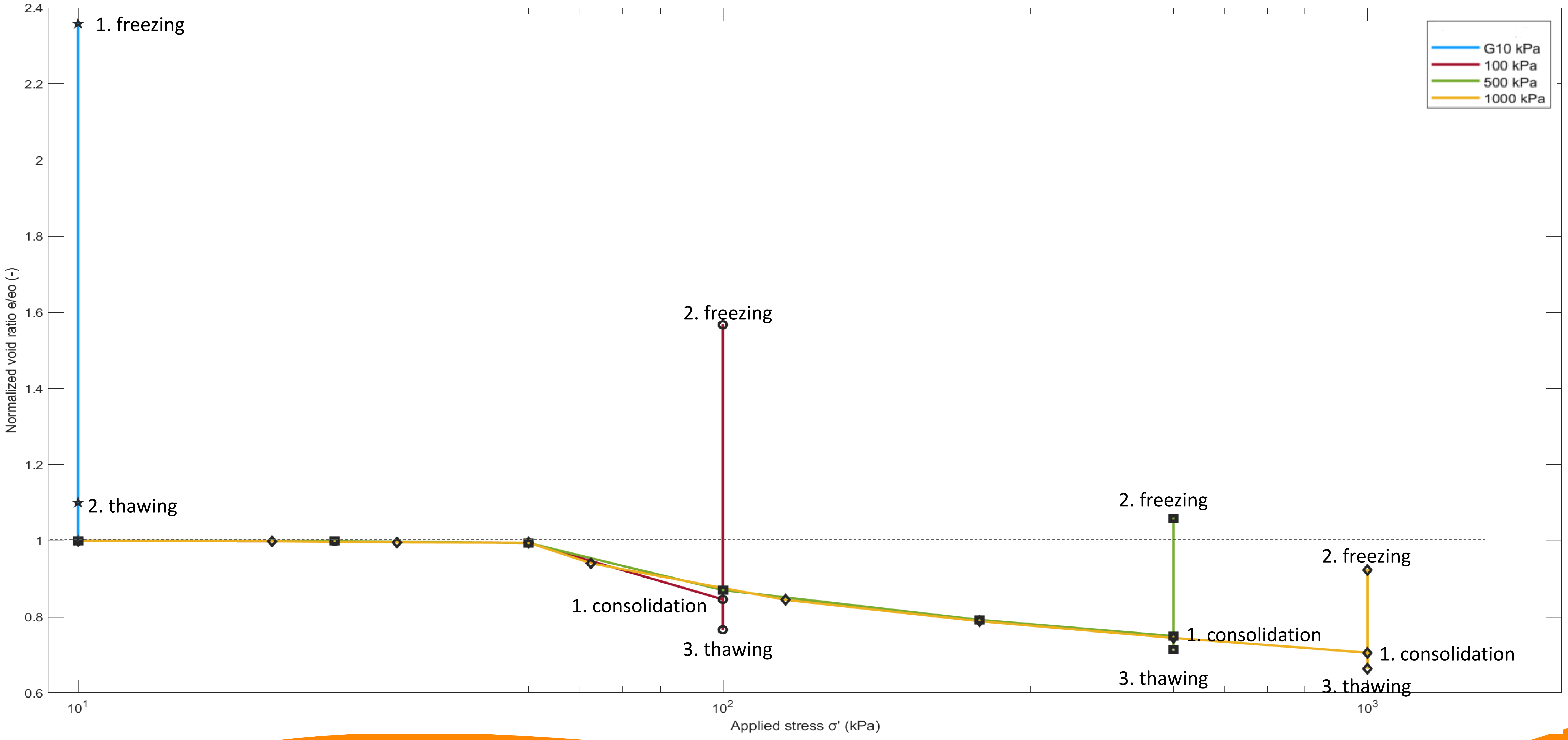
Freeze-thaw tests on silty sand under applied pressures

Freeze-thaw tests of silty soil under different applied stresses
a) Variation of temperature at cell (°C) in function of time (hours). b) Variation of displacements (mm) in function of time (hours)



Freeze-thaw tests on silty sand under applied pressures

Evolution of the normalized void ratio (-) in function of applied stress (kPa)



Conclusions

- AGF = ft (Soil type, grain size, water content, water availability, **applied load**…)
- Overburden pressure affects water content, water migration, suction in the frozen fringe segregation temperature, the thickness of the frozen fringe, permeability (partially frozen soil)
- Heave ↘ as applied pressure ↗
- Further research on higher applied pressure is in perspective

Thank you
for your attention

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