Frost Heave Properties in Ballast Tracks

Field Observations and Laboratory Experiments

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Topics

- What is Frost Heaving
- Field Works

  Monitoring at railway tracks
- Laboratory Works

  Frost heave tests of crushed rock with different fines content

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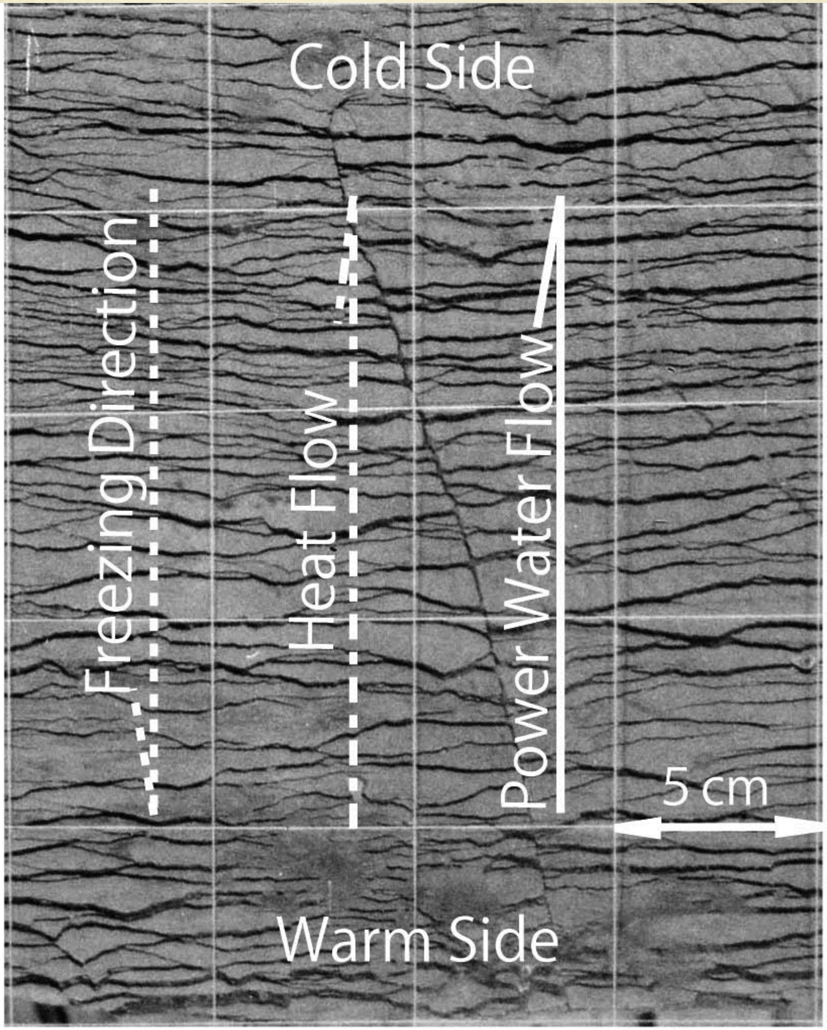
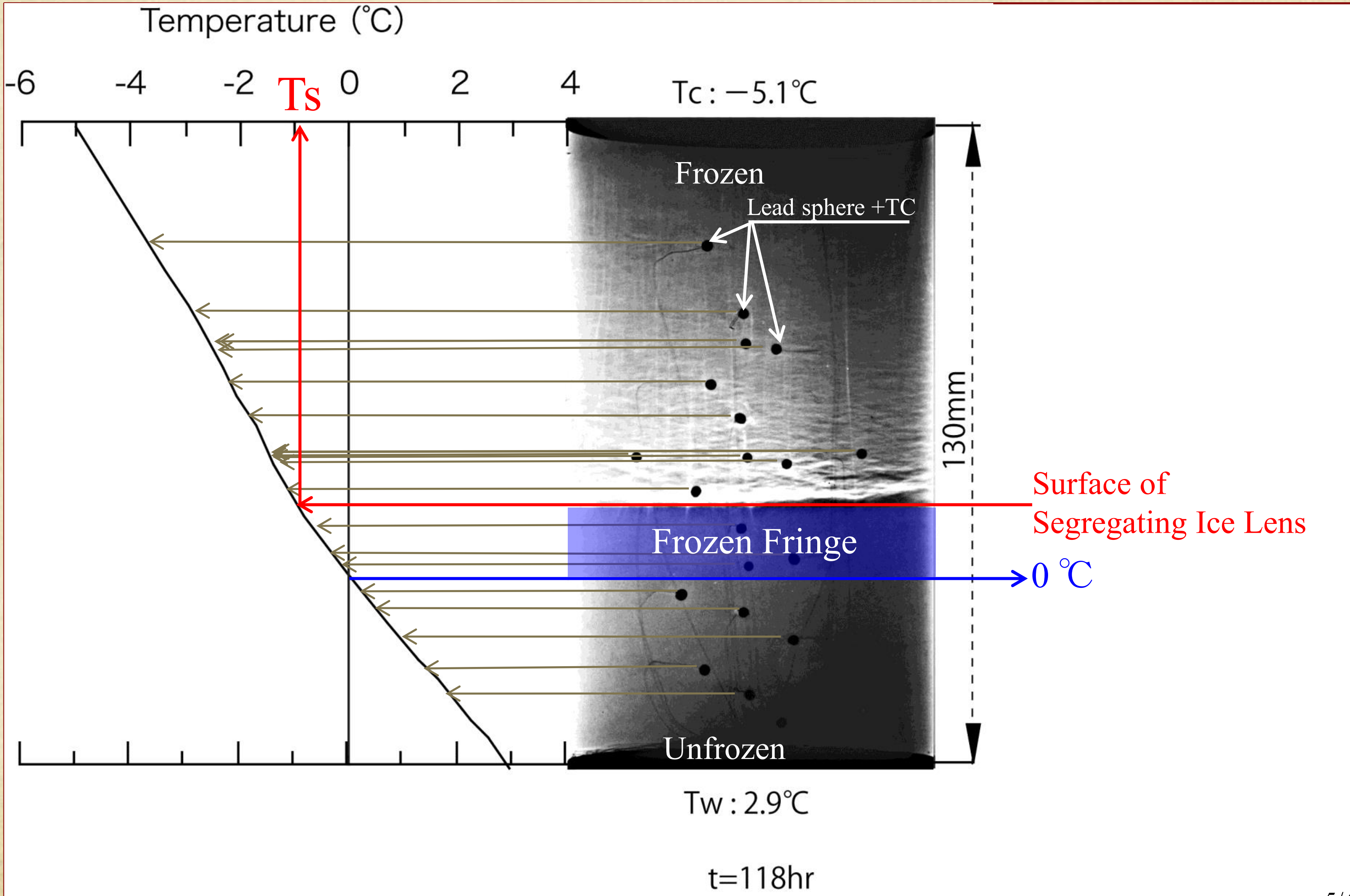
What is frost heaving.

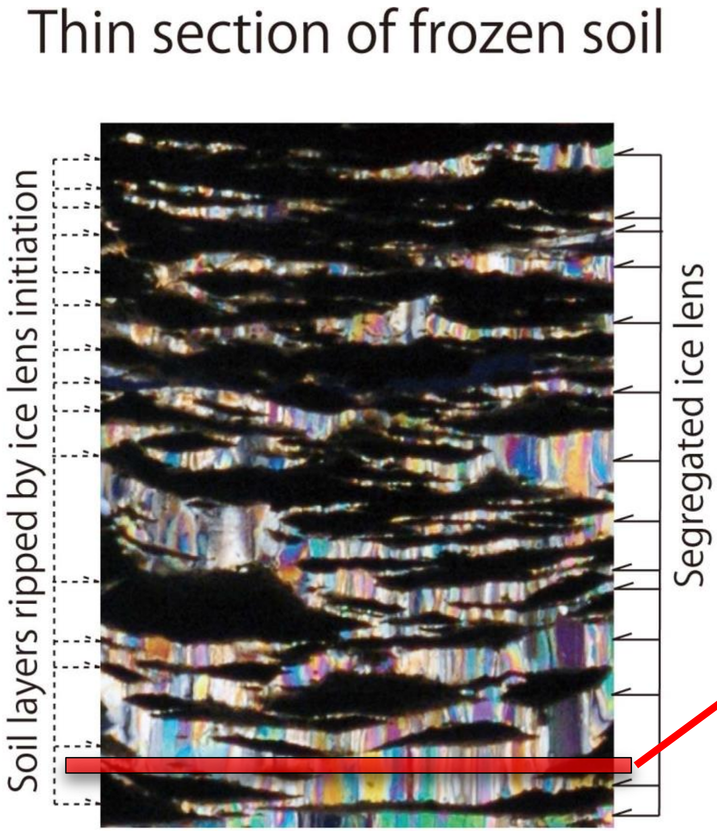


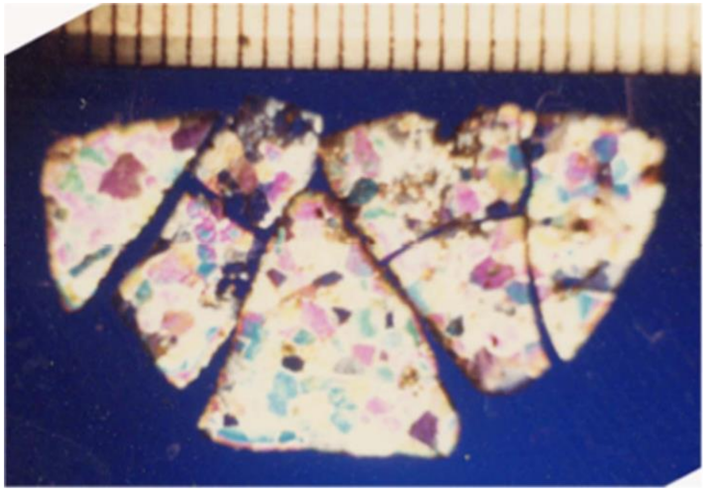
Black horizontal lines are ICE LENSes

Ice Lens Segregates at Negative Temp.

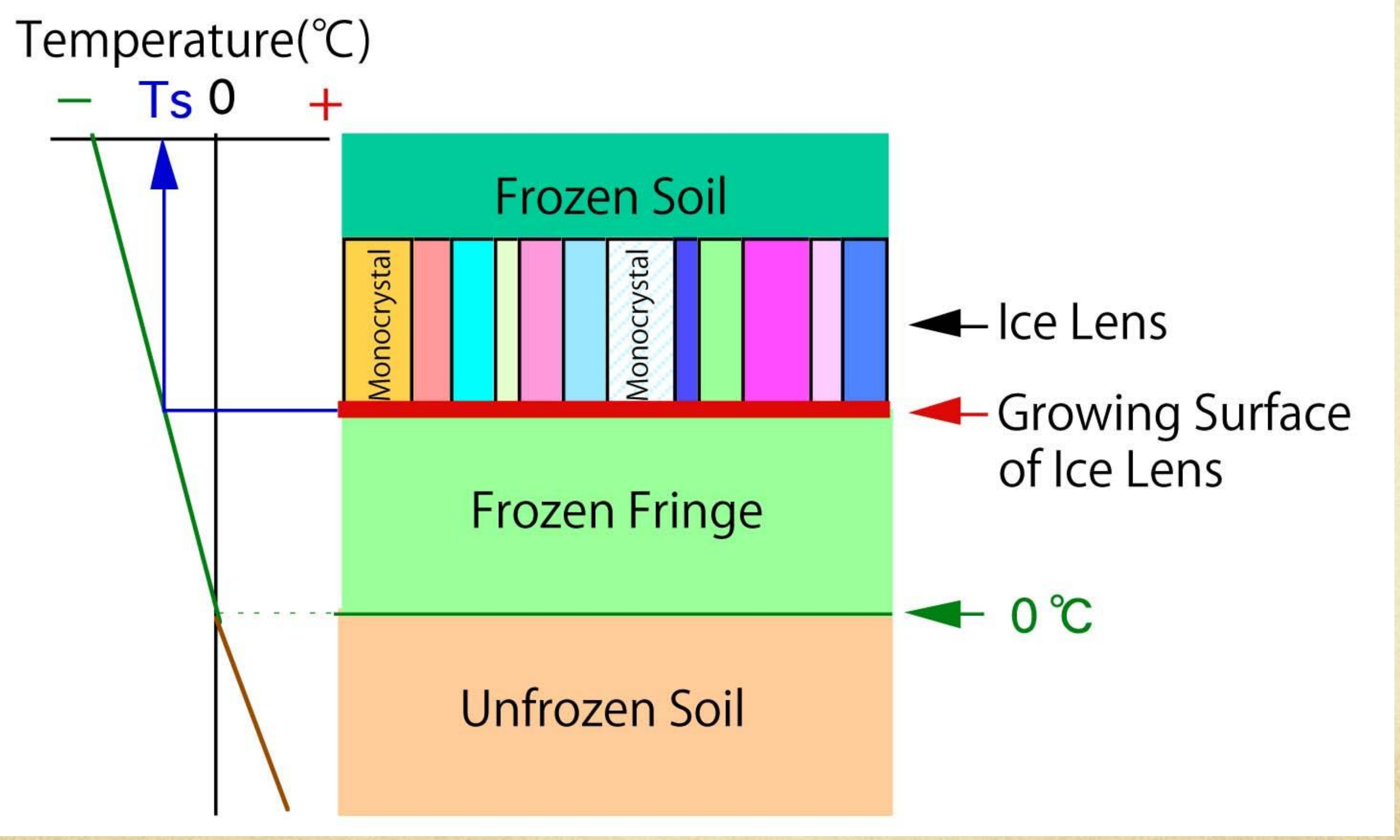


Crystal Structure of Ice Lens

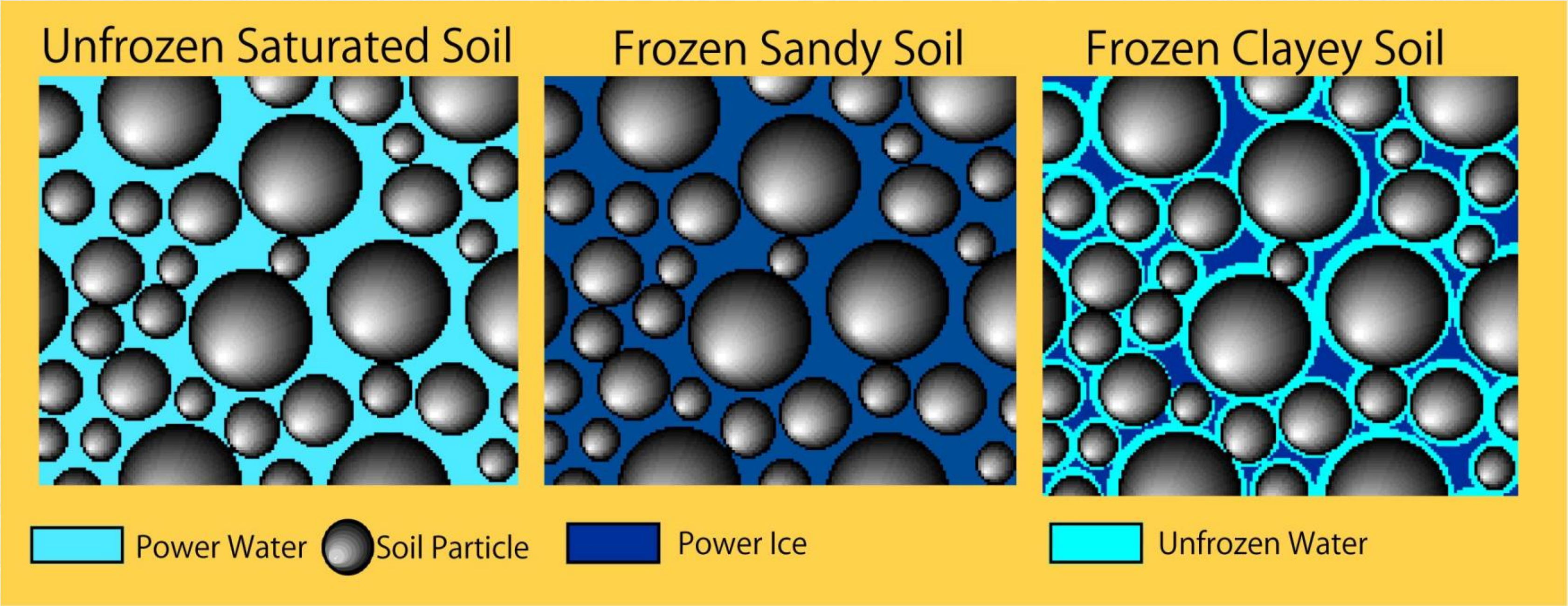




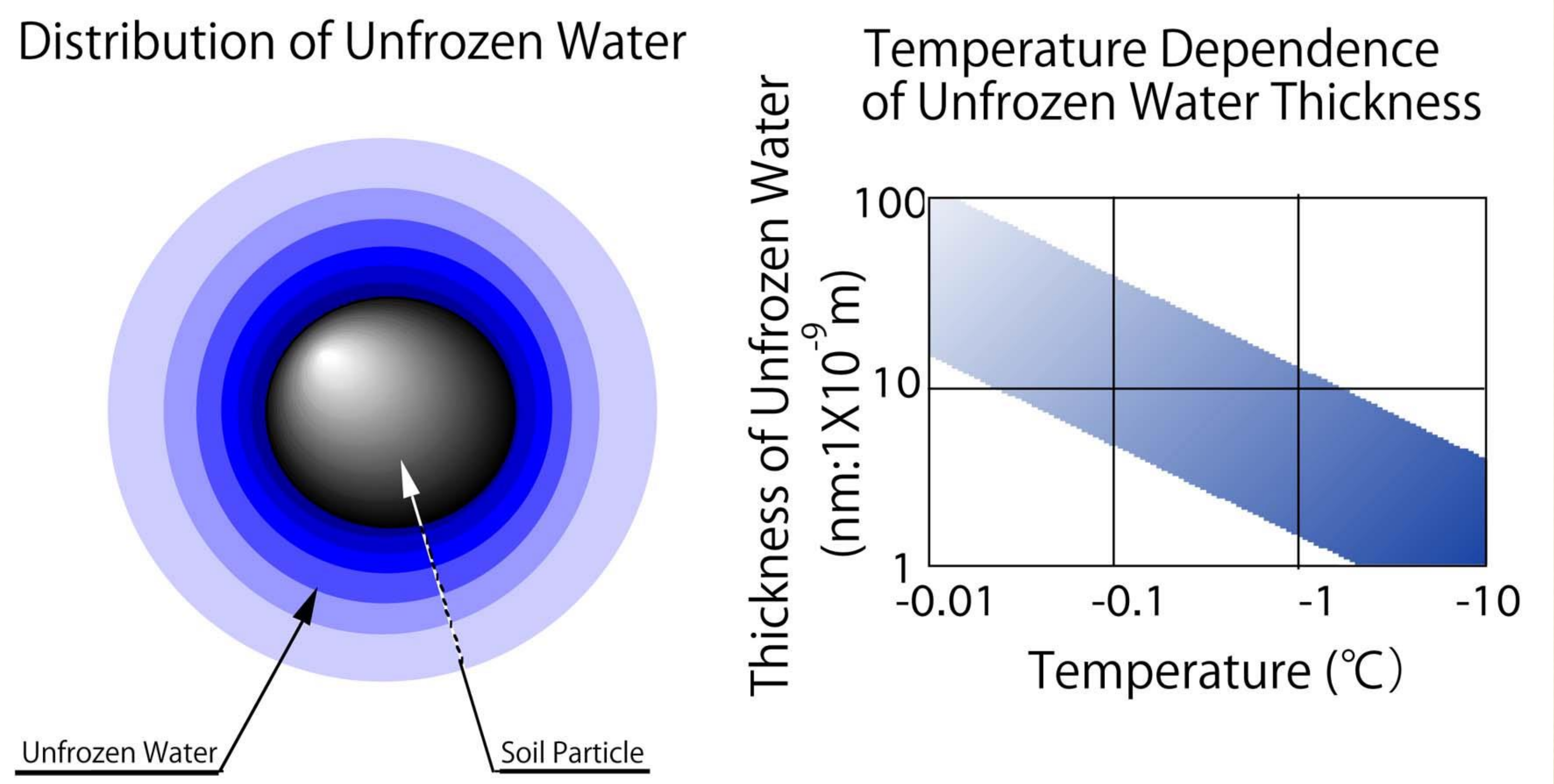
Schematic Drawing of Ice Lens



How Pore Water Freezes

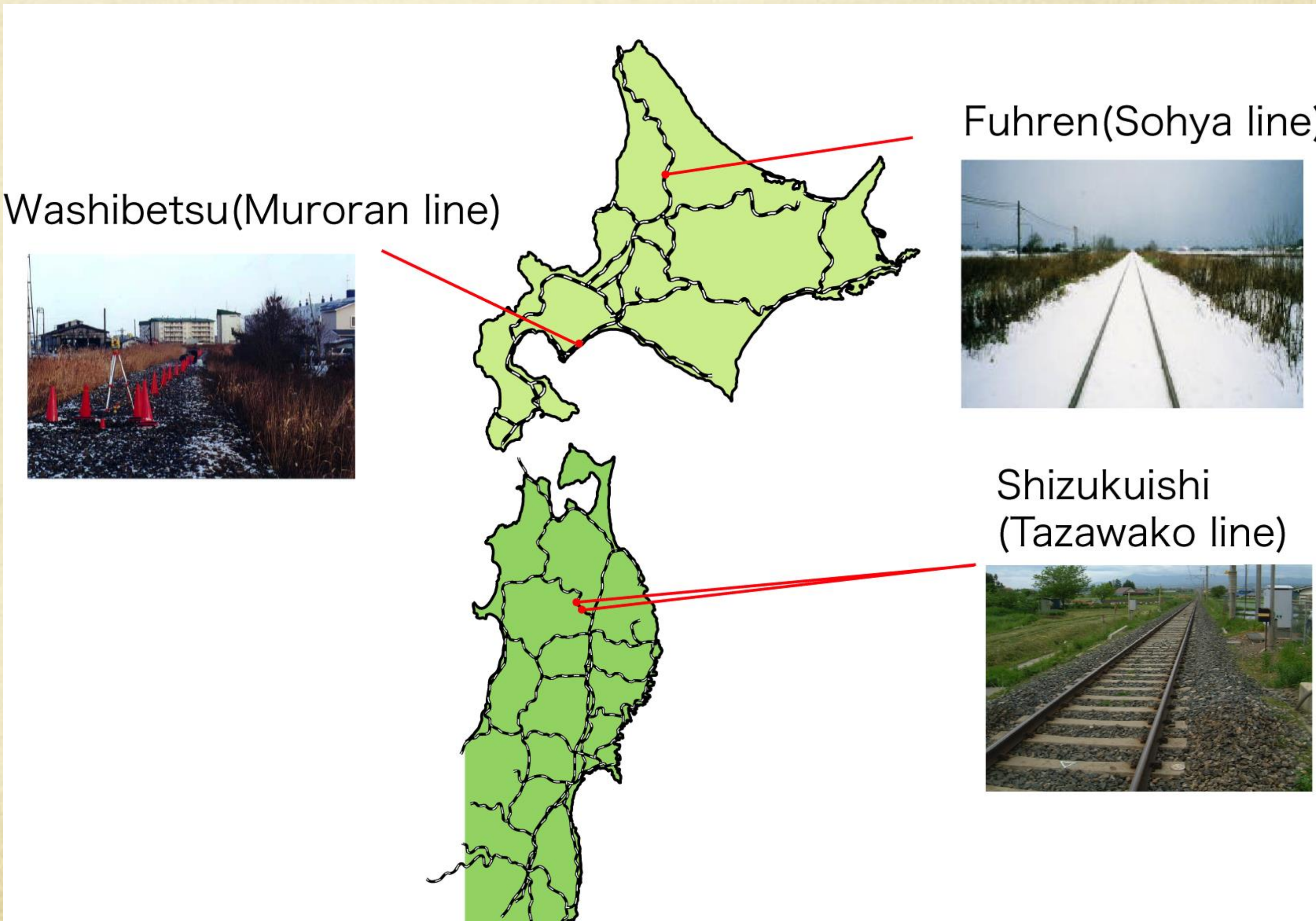


Distribution and Thickness of Unfrozen Water

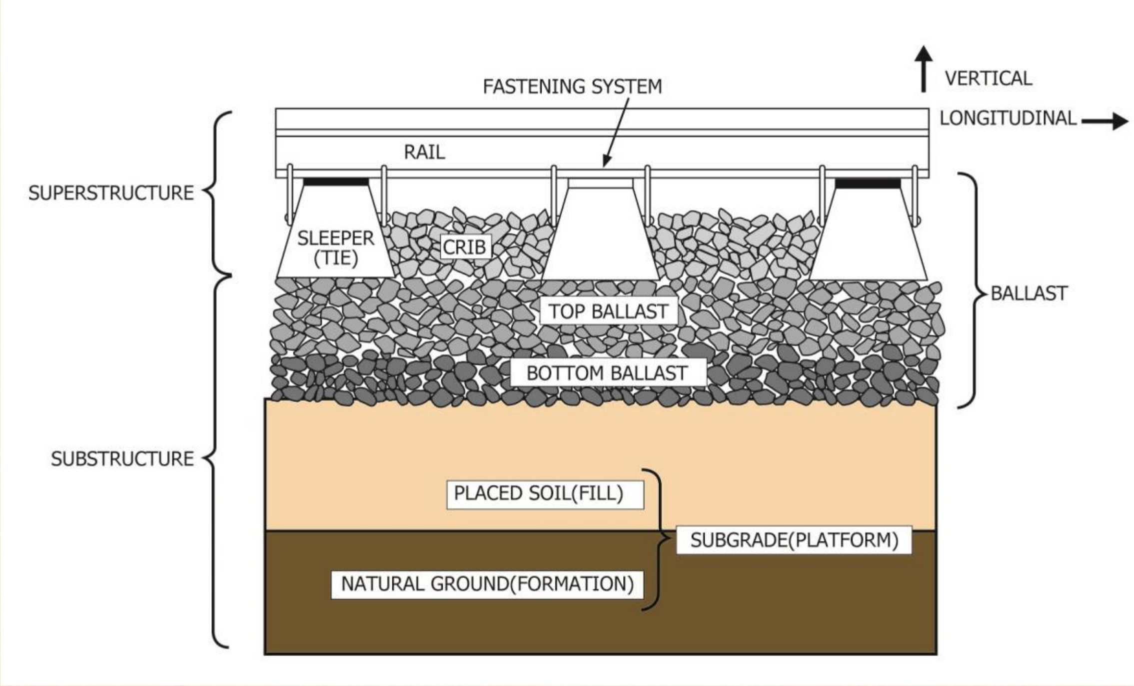


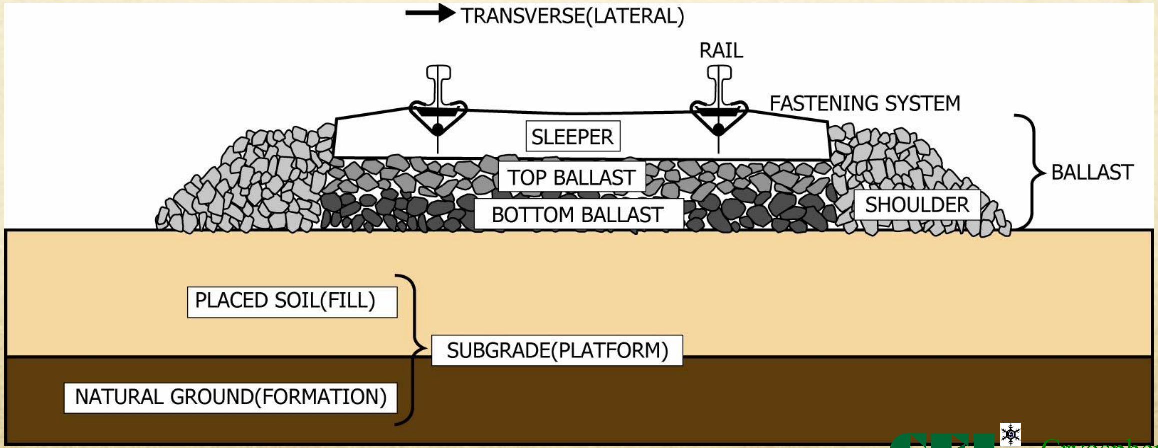
Field Observation

Our Test Fields

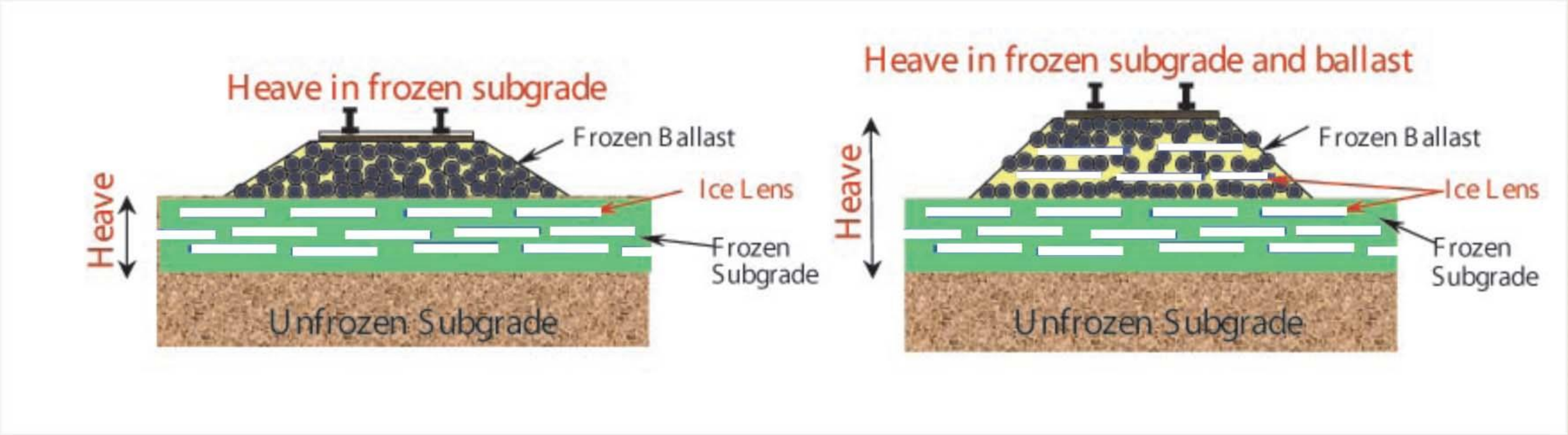


Ballast Track Structure



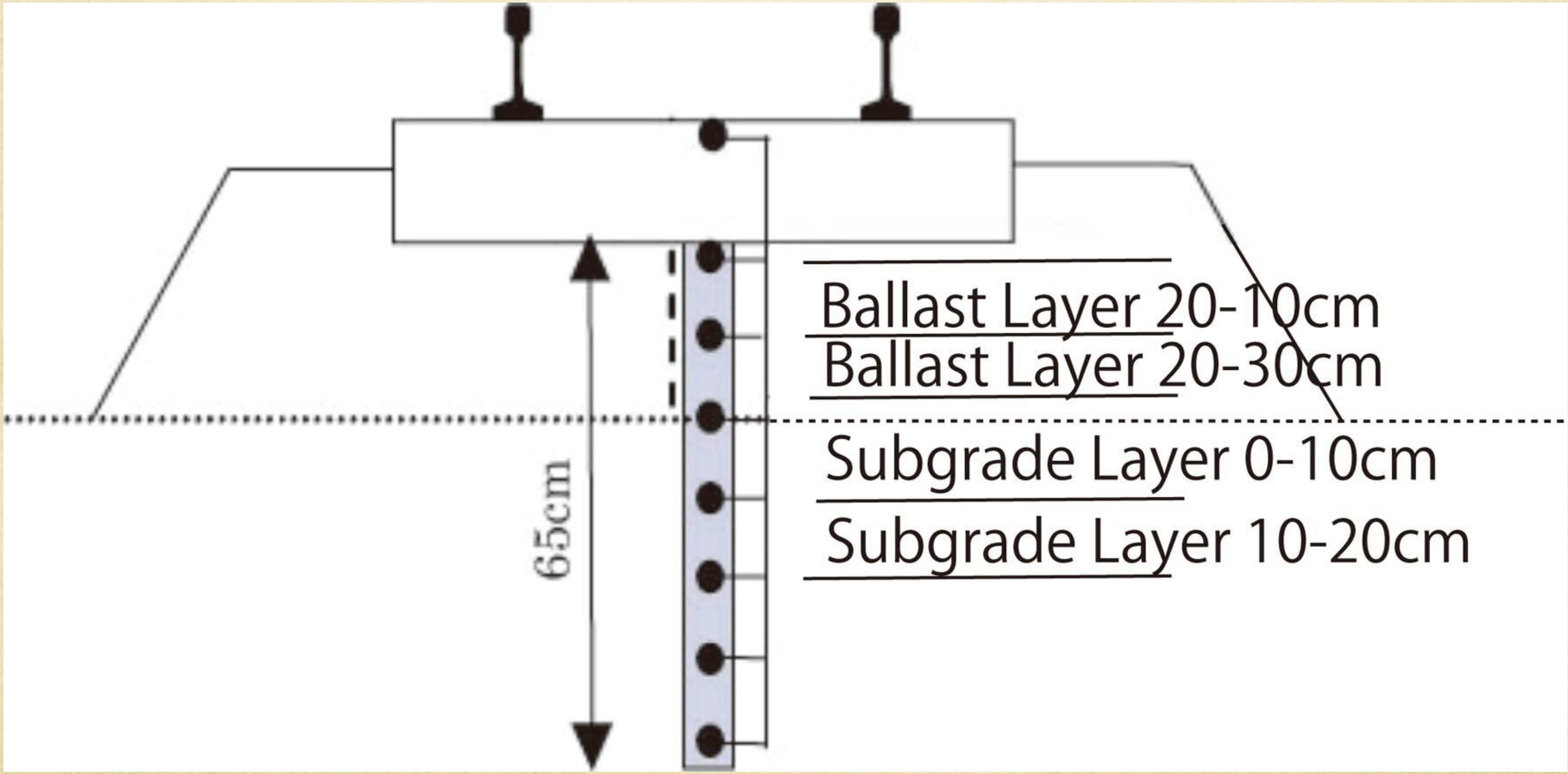


What is the uncertainty?

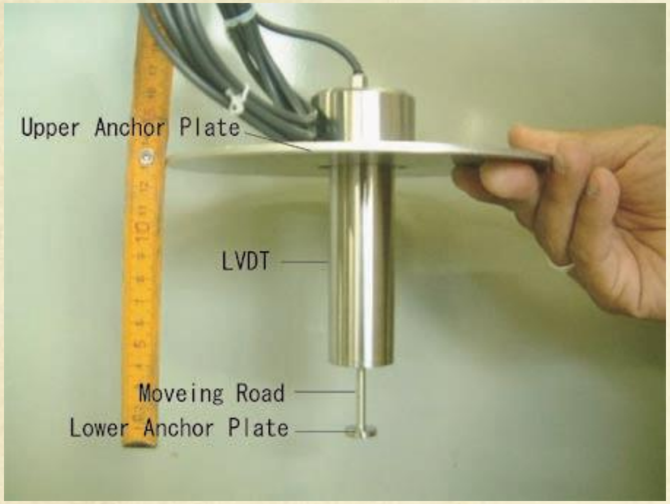


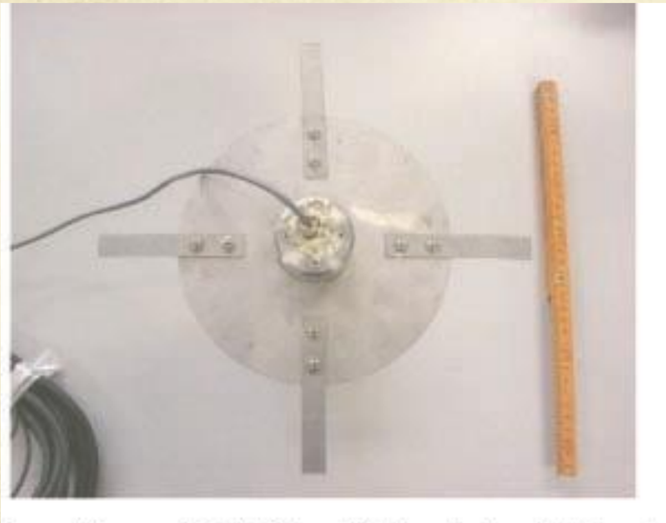
Dose ballast which contains fines frost heave?

Temperature Measurement in Railway Track Layers

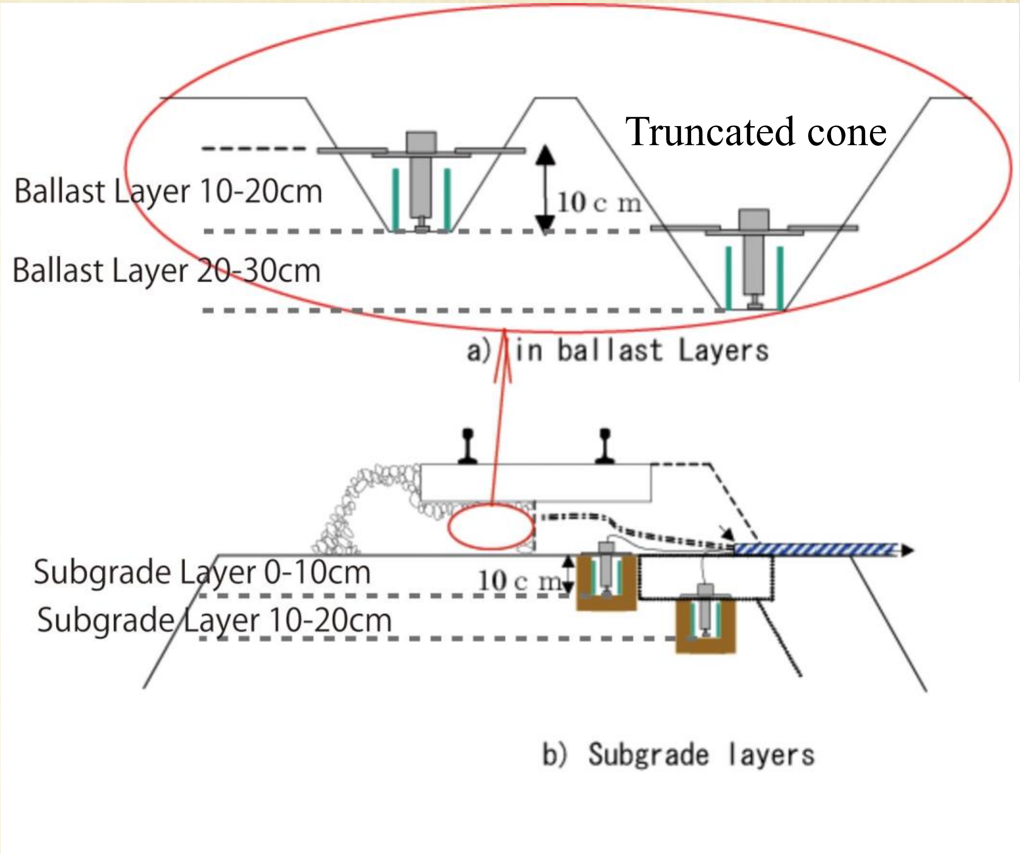


Frost Heave Measurement in Railway Track Layers





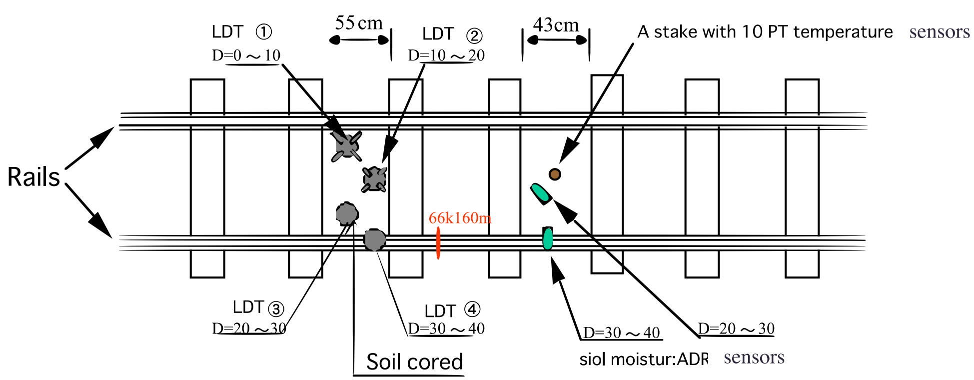
Top View of LVDT utilized in Ballast



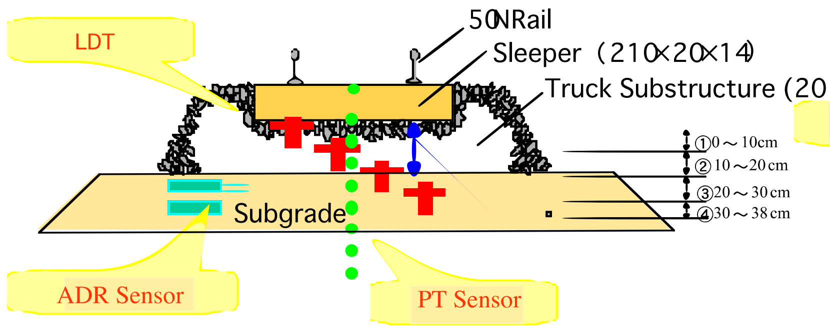
What items have monitored

Field Monitoring

Monitor items:
Temp. profile
Heave amounts,
Moisture contents

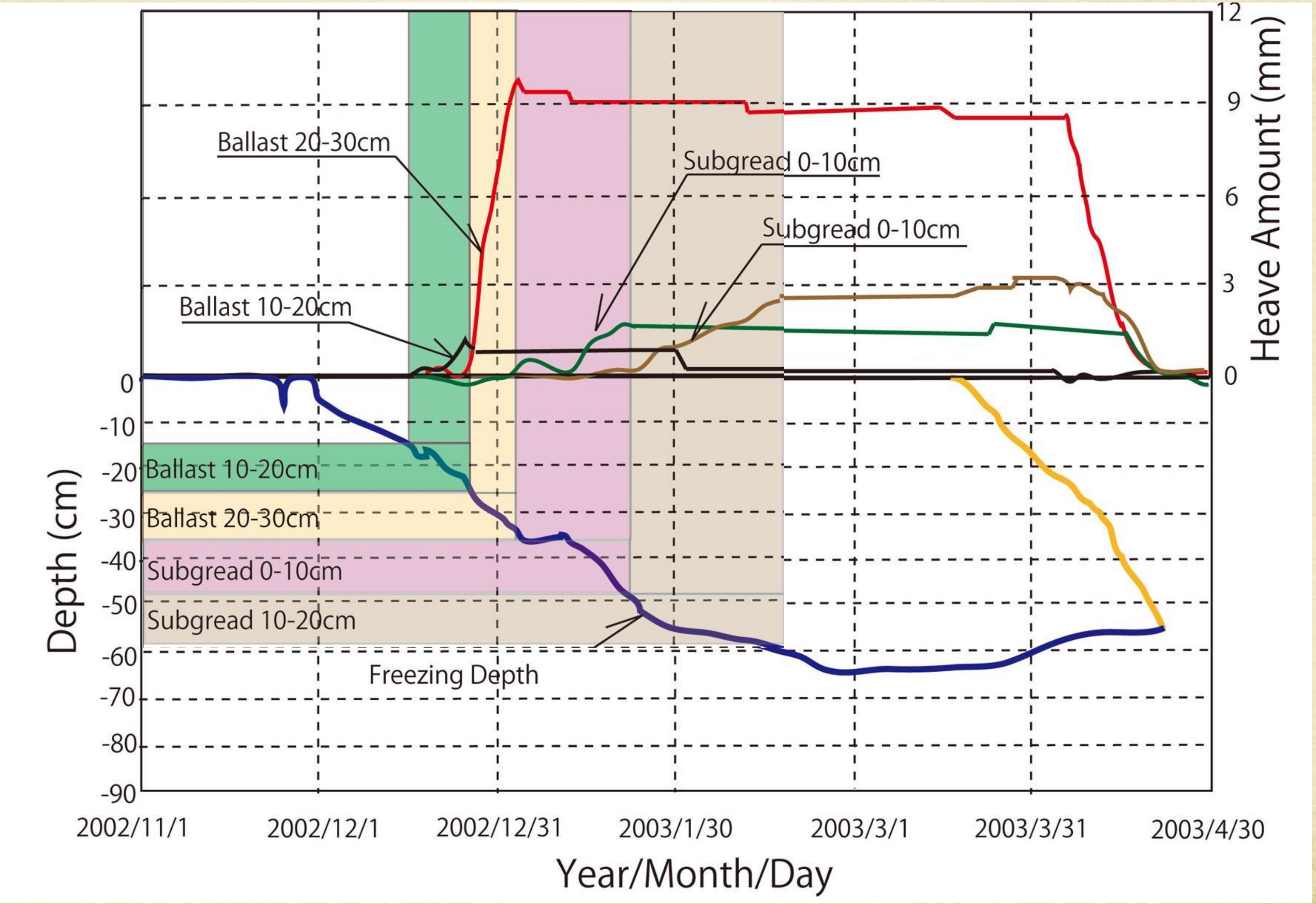


Plane View



Vertical View

Frost Heave Monitored in Ballast Track

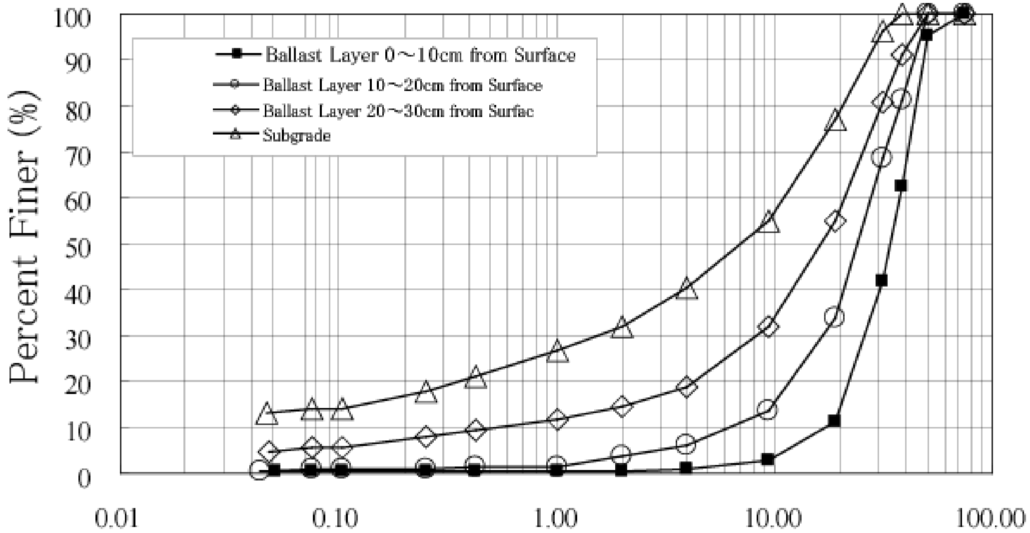


Data of Furen

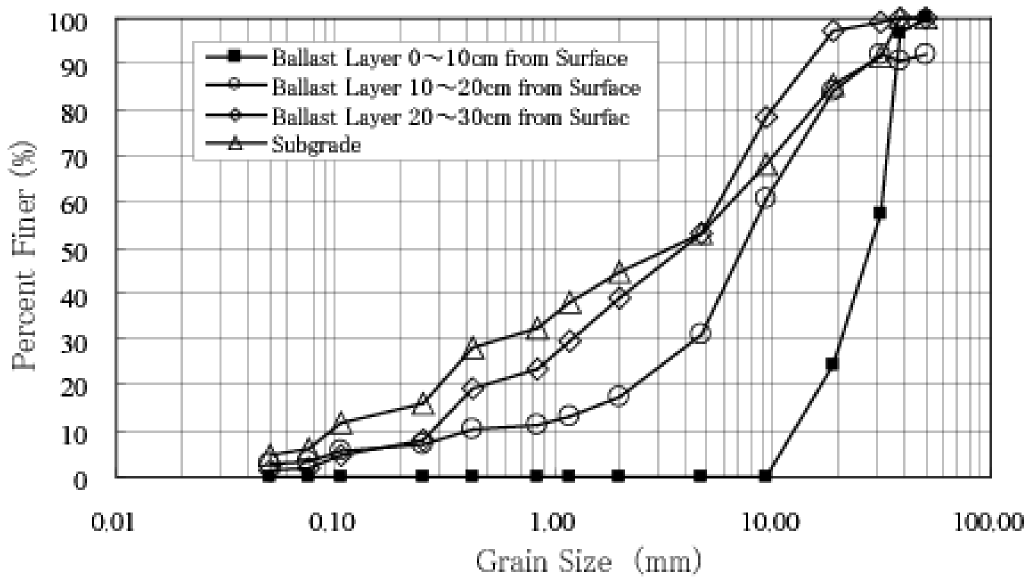
Laboratory Observation

Grain Size Distribution of Ballast Track

Fhuren



Shizukuishi



Textures of Real Ballast

Site Name	Sample Name	Specific Gravity of Soil Particle (g/cm3)	Texture Glavel (%)	Sand (%)	Fines (%)
Fhuren	Ballast Layer 0~10cm	2.465	99.5	0.2	0.3
	Ballast Layer10~20cm	2.747	98.5	1.1	0.4
	Ballast Layer20~30cm	2.744	88.4	6.7	4.9
	Subgrade	2.808	73.2	13.5	13.3
Shizukuishi	Ballast Layer 0~10cm		100.0	0.0	0.0
	Ballast Layer10~20cm	2.671	86.8	10.2	3.0
	Ballast Layer20~30cm	2.713	70.2	28.4	1.5
	Subgrade	2.676	61.8	33.7	4.5

Mineral compositions of ballast and subgrade at Fhuren and Shizukuishi

Location	Sample Name	Mineral Name									
Fhuren	Ballast Layre 0-10cm from Surface	Quartz	Anorthite	Albite	Montmorillonite	Corrensite	Biotite				
	Ballast Layre 10-20cm from Surface	Quartz	Anorthite	Albite	Montmorillonite	Corrensite					
	Ballast Layre 20-30cm from Surface	Quartz	Anorthite		Montmorillonite	Corrensite					
	Subgrade	Quartz	Anorthite	Albite		Corrensite		Kaolinite			
Shizuku -ishi	Ballast Layre 10-20cm from Surface	Quartz	Anorthite	Albite				Kaolinite	Vermiculite	Crossite	
	Ballast Layre 20-30cm from Surface	Quartz	Anorthite	Albite				Kaolinite	Vermiculite	Crossite	
	Subgrade	Quartz	Anorthite	Albite				Kaolinite	Vermiculite	Crossite	Pargasite

Frost Heave Test Results (Shizukuishi)

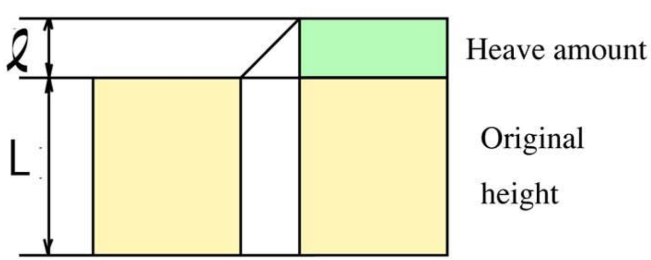
Sample Name		Fines Content (%)	Specimen Height (mm)	Heave Amount (mm)	Heave Ratio (%)
Ballast Layer	0 ～10cm	0.0	-	-	-
Ballast Layer	10～ 20cm	3.0	30.0	6.0	20.0
Ballast Layer	20～ 30cm	1.5	33.0	6.1	18.3
Subgrade		4.5	28.0	7.5	26.8
Subgrade (Undisturbed & saturated)		-	109.2	54.9	50.3
Subgrade (Undisturbed & unsaturated)		-	109.2	5.1	4.6

A Model
for Prediction
of Ballast Frost Susceptibility

An Empirical Formula has been used in Japan for Frost Heave Susceptibility Prediction

$$\xi = \xi_0 + \frac{\sigma_0}{\sigma}\left(1 + \sqrt{\frac{U_0}{U}}\right)$$

where, ξ ; heave ratio,
σ ; confining pressure,
U ; freezing speed,
ξ_0 σ_0 U_0 ; test constants

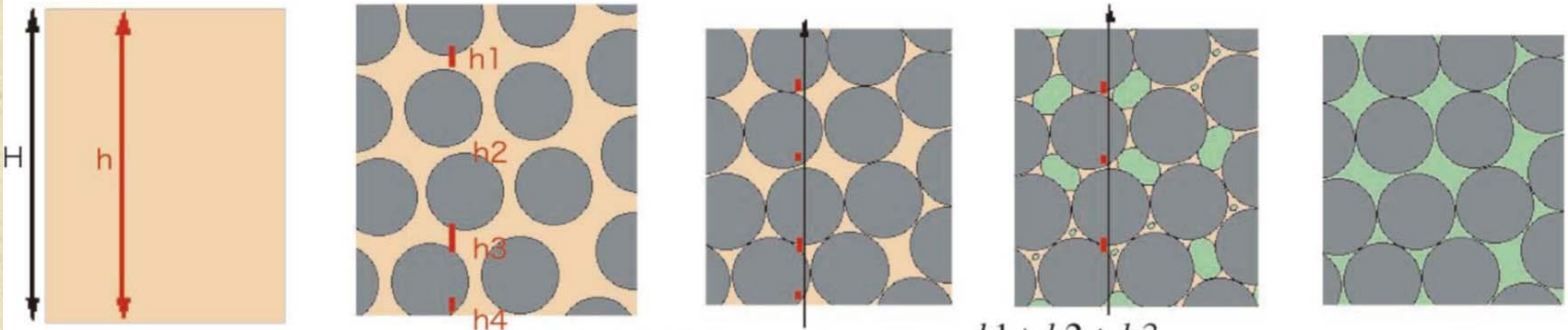


$$\xi = \ell / L$$

How the Ballast Layer Frost Heaves

CASE-1 | CASE-2 | CASE-3

Heave in fines | Heave in balast with excess fines | Heave in balast with fines saturated | Heave in balast with fines unsaturated | Heave in balast with no fines



$$\xi_B = \xi_f \times \frac{h}{H}$$

$$\xi_B = \xi_f \times \frac{h1 + h2 + h3 + h4}{H}$$

$$\xi_B = \xi_f \times \frac{h1 + h2 + h3}{H}$$

$$\xi_B = \xi_f \times \frac{h1}{H}$$

however $\rightarrow h = 0,$

then $\rightarrow \xi_B = 0.$

where, ξ_f *heave ratio of fines,*

ξ_B *heave ratio of track subgrade.*

$$\xi_B = \xi_f \times \frac{total \quad thickness \quad of \quad fines}{H}$$

Confirmation of Proposed Formula

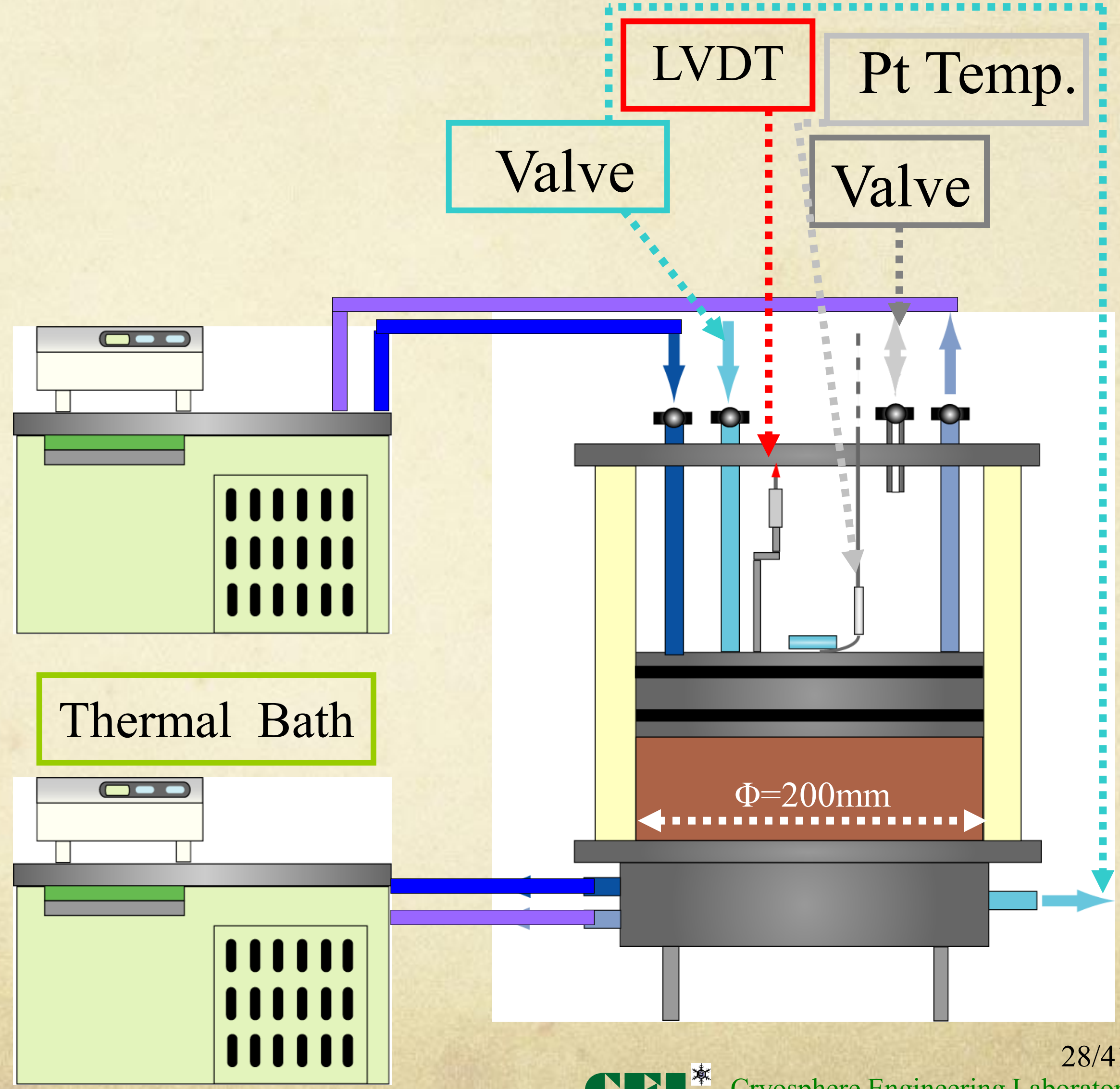
Utilized Ideal Ballast which contains Fines

Kaolinite Gs=2.54 g/cm3

Crushed Rock I
Grain Size Distribution;
2.5mm to 5.0mm

Crushed Rock II
Grain Size Distribution;
13mm to 20mm

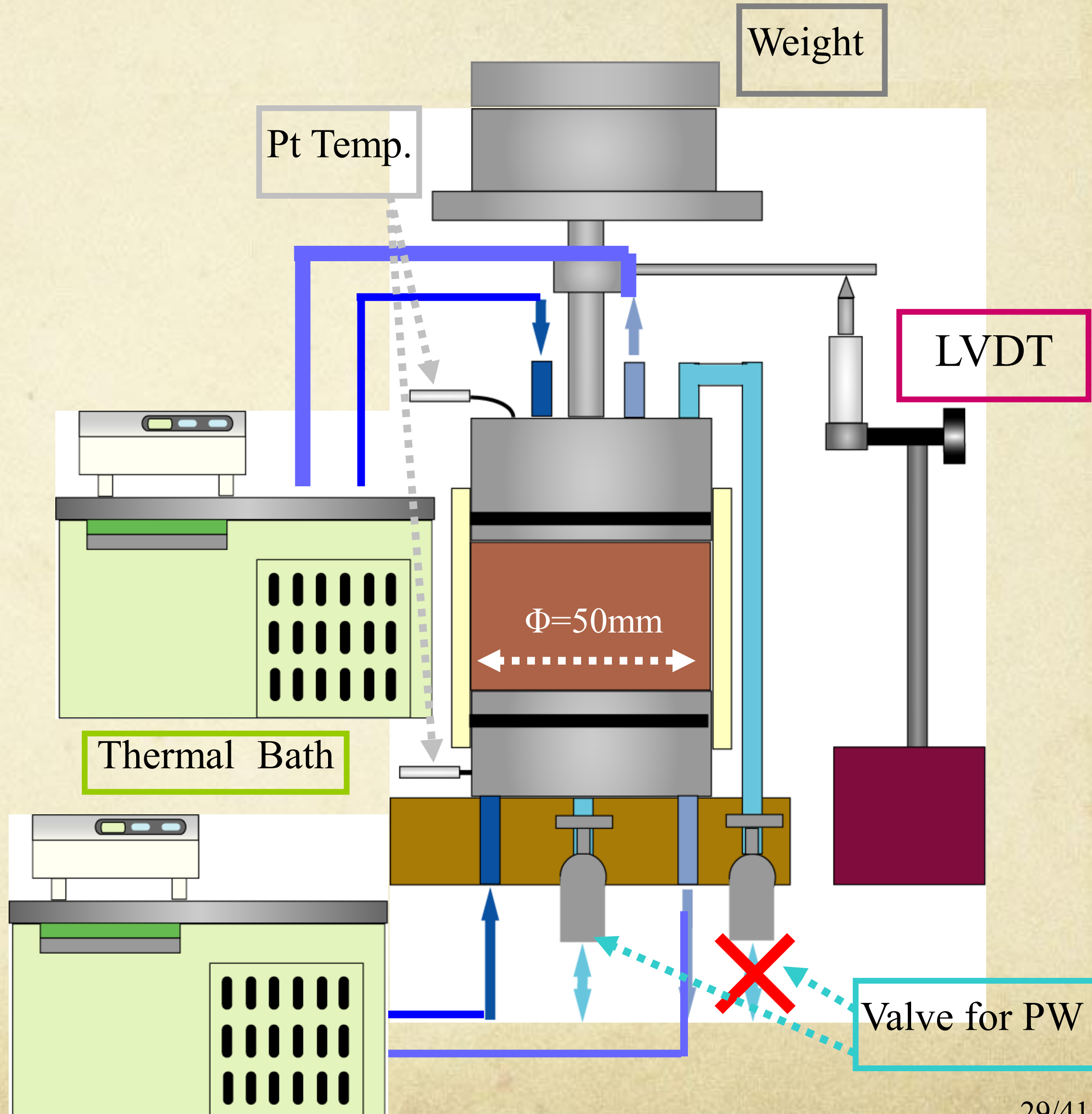
Frost Heave Test Apparatus−I



Frost Heave Test Apparatus–II

ϕ=50mm

L=20 to 100mm



Frost Heave Test Conditions

Confining Pressure

Overburden Pressure:33.9(kPa)

Pore Water Pressure：0kPa

Specimen Size

Apparatus I

Height：92～111(mm)

Diameter：200(mm)

Apparatus II

Height：38～47(mm)

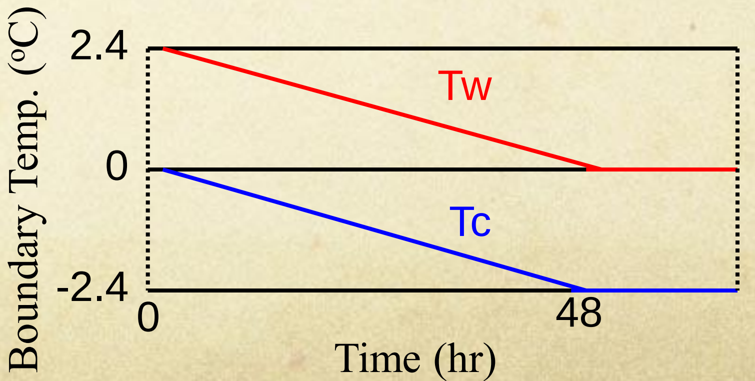
Diameter：50(mm)

Thermal Condition

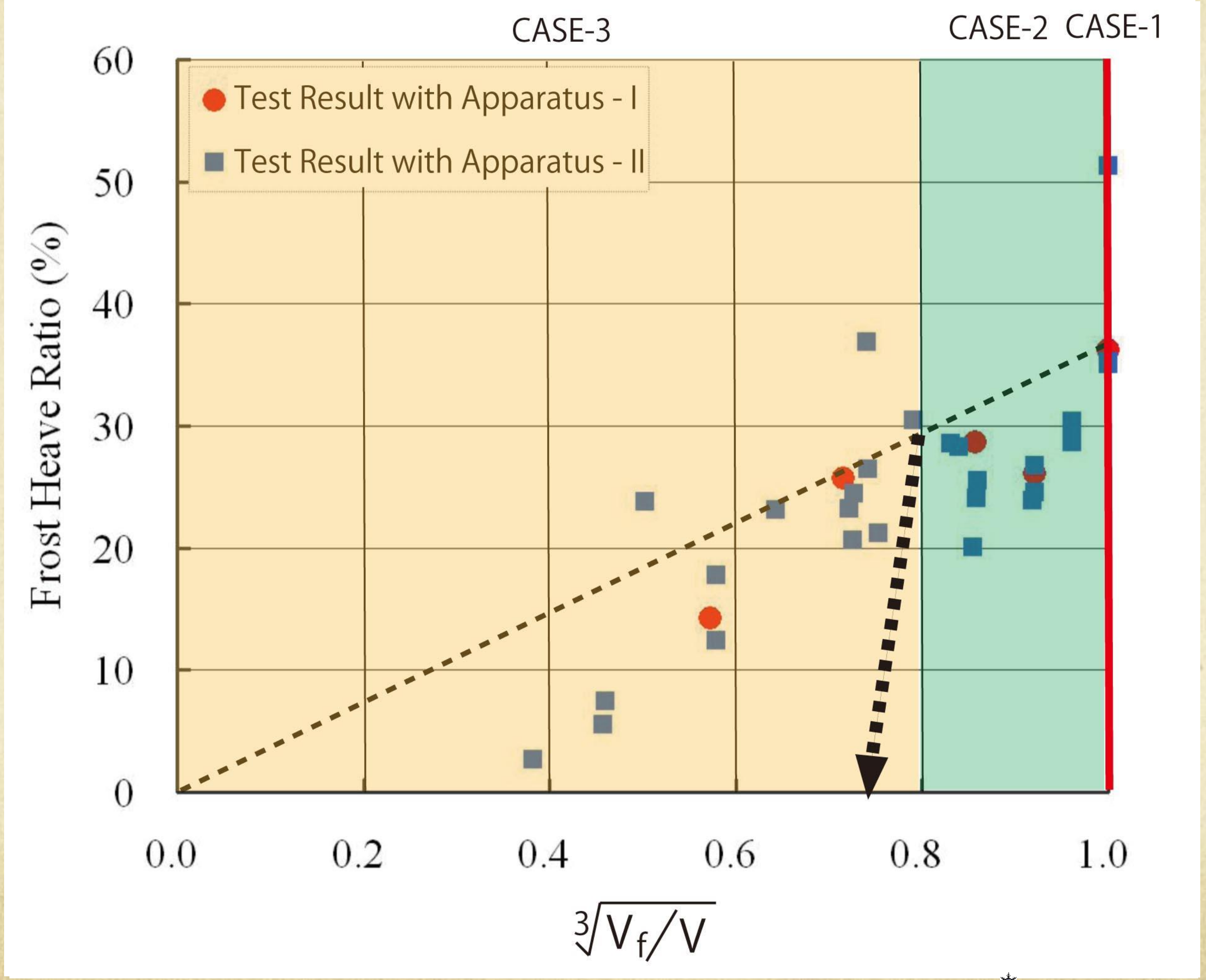
Temperature Gradient: 0.5(℃/cm)

Freezing Speed：0.10 (cm/hr)

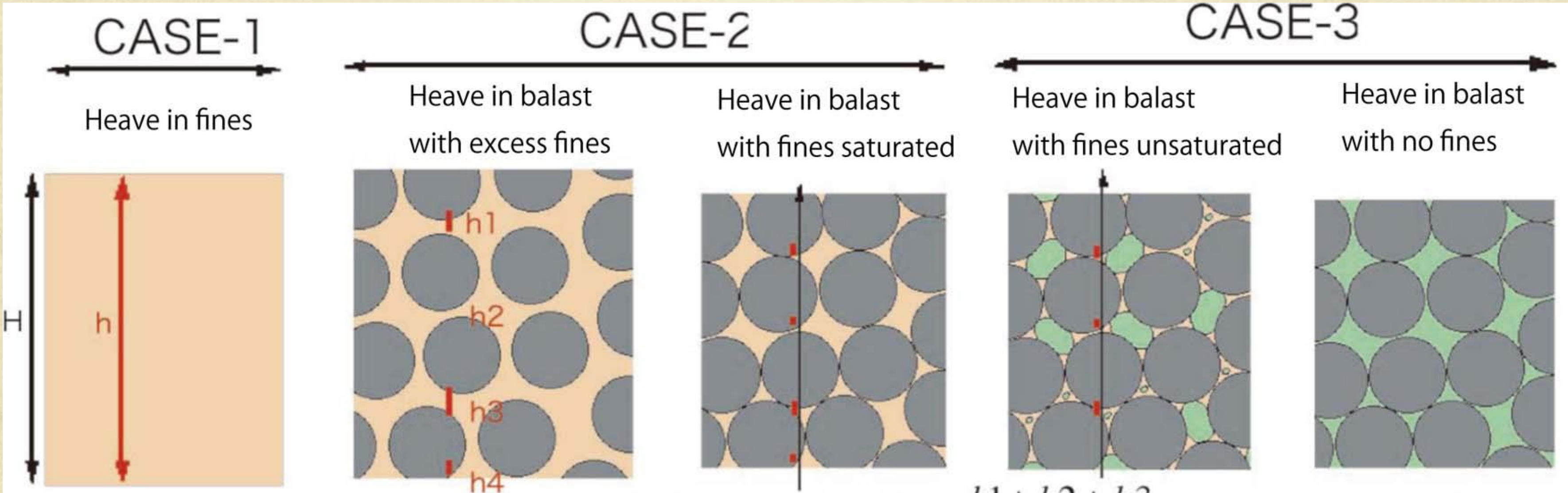
Example: Specimen Height = 48 mm



Frost Heave Tests Result



How the Ballast Layer Frost Heaves



$$\xi_B = \xi_f \times \frac{h}{H}$$

$$\xi_B = \xi_f \times \frac{h1 + h2 + h3 + h4}{H}$$

$$\xi_B = \xi_f \times \frac{h1 + h2 + h3}{H}$$

$$\xi_B = \xi_f \times \frac{h1}{H}$$

however $\rightarrow h = 0$,

then $\rightarrow \xi_B = 0$.

where, ξ_f *heave ratio of fines*,

ξ_B *heave ratio of track subgrade*.

$$\xi_B = \xi_f \times \frac{\textit{total thickness of fines}}{H}$$

$$\xi_B = \xi_f \times \sqrt[3]{V_f / V}$$

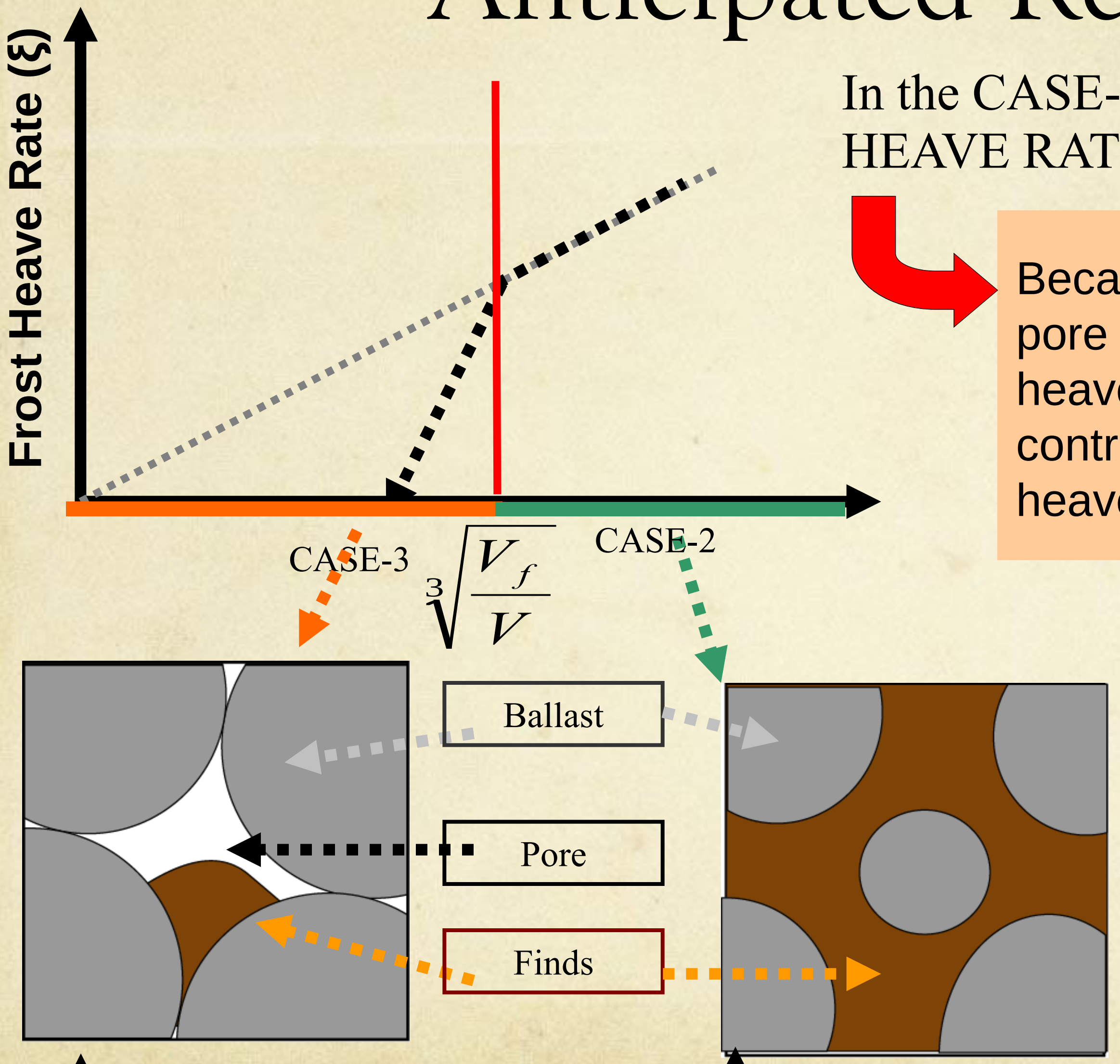
where, V_f : volum of fines in an unit volume of track substructure

V : an unit volume of track substructure

Anticipated Result

In the CASE-3, steeper reduction of HEAVE RATE was expected.

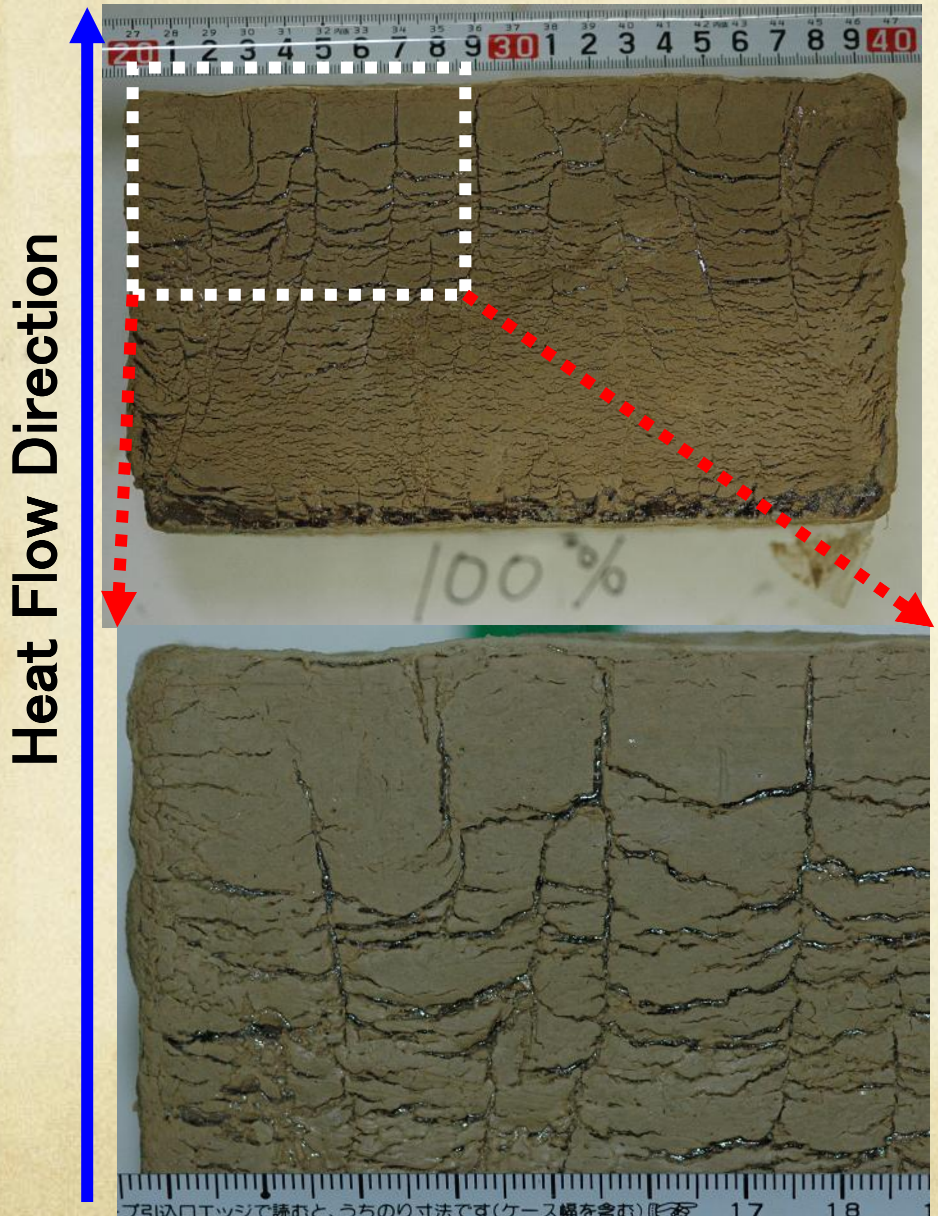
Because of the unsaturated pore condition with fines, frost heave of the fines may not contribute the macroscopic frost heave in CASE-3.



Pores are not saturated with fines

Piece of ballasts are floating in the pore fines

Vertical Section of frozen Fines (CASE-1)

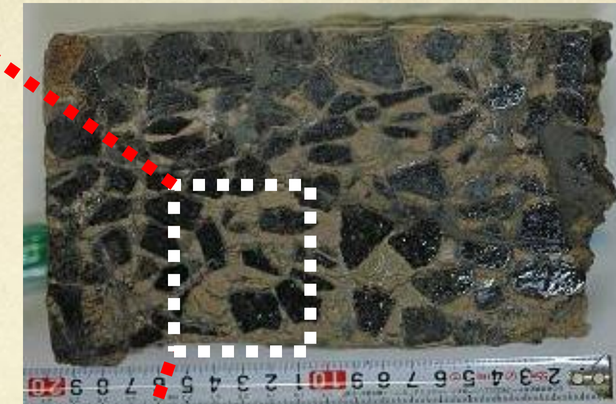


Horizontally elongated ice lenses which are normal to the heat flow are observed. Vertical ice veins which are developed by the shrinkage due to pore water pressure depression in frozen fringe is also observed.

Normal frost heaving has happend

Vertical section of frozen Ballast (CASE-3)

Macroscopic Heat Flow Direction



$$\sqrt[3]{\frac{V_f}{V}} = 0.57 \qquad \left(\frac{V_f}{V}\right) = 0.19$$

⇒Even in the CASE-3, pores are filled with fines and ice lenses but no frozen balk water.

Fines between Piece of Ballasts may Segregate Thick Ice Lenses

Macroscopic Heat Flow Direction

Thick ice lenses have developed at the upper part of piece of ballasts (=cold side of piece of ballasts)

Thermal conductivity of rock is higher than soil.

↓

0 isotherm in rock advances faster.

↓

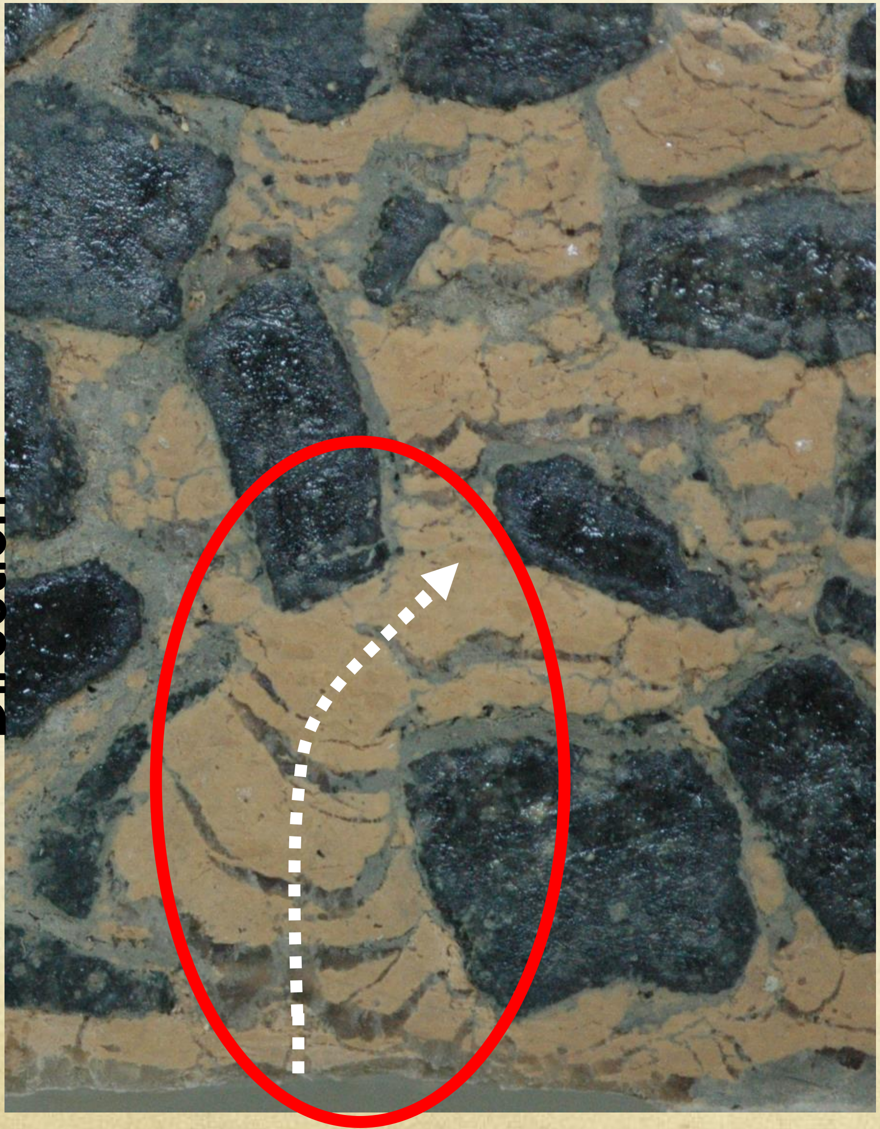
Heave at the rock-fines boundary last longer.

↓

Thick ice lens may segregate.

Fins in pores frost heave higher than total heave

Macroscopic Heat Flow Direction

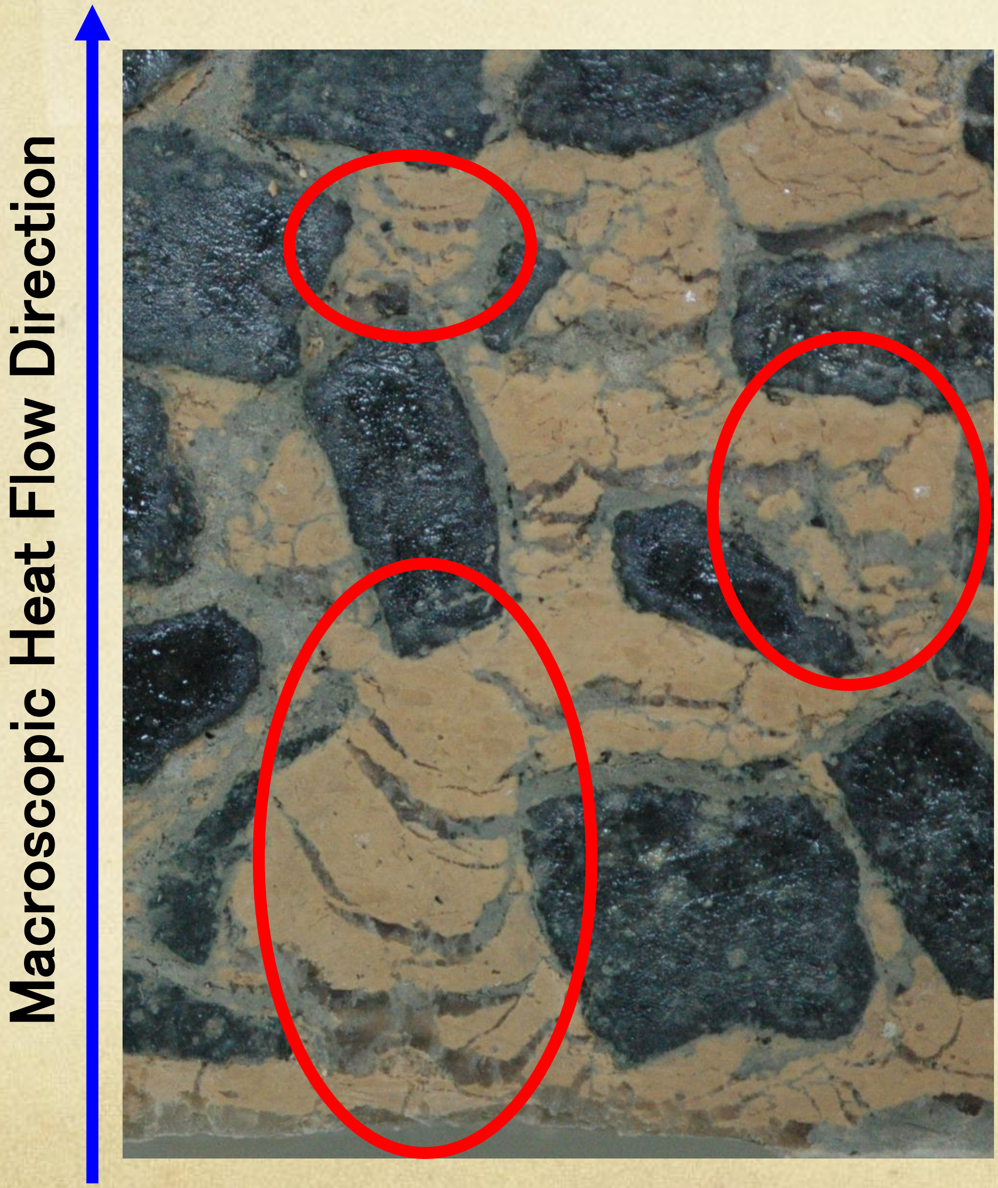


Microscopic frost heave ratio along the white dotted line was 32%, whereas average was 14%.

Fines in pores show higher frost heave ratio.

Microscopic heat flow may meander due to inhomogeneity of thermal conductivity

Cause of Thick Ice Lenses in Pore in CASE-3

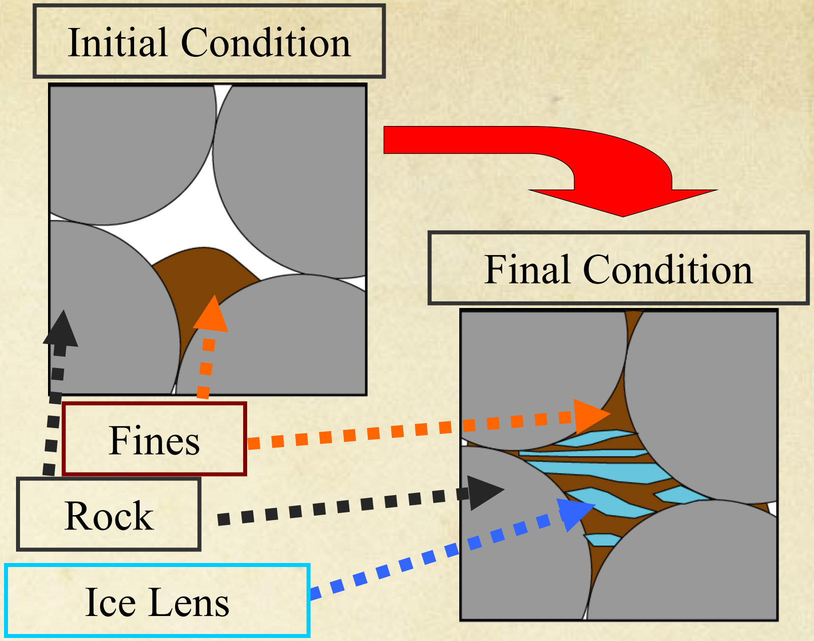


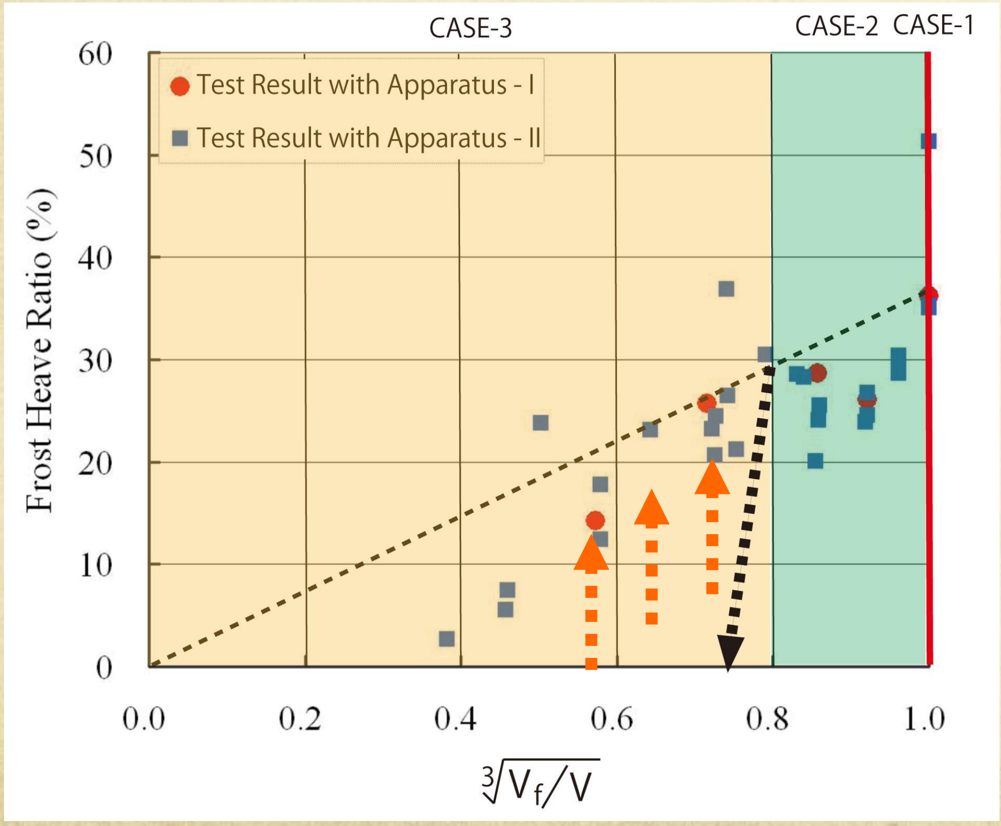
Initially total stress was supported by rock skeleton.

Then fins suffer almost no confinement.

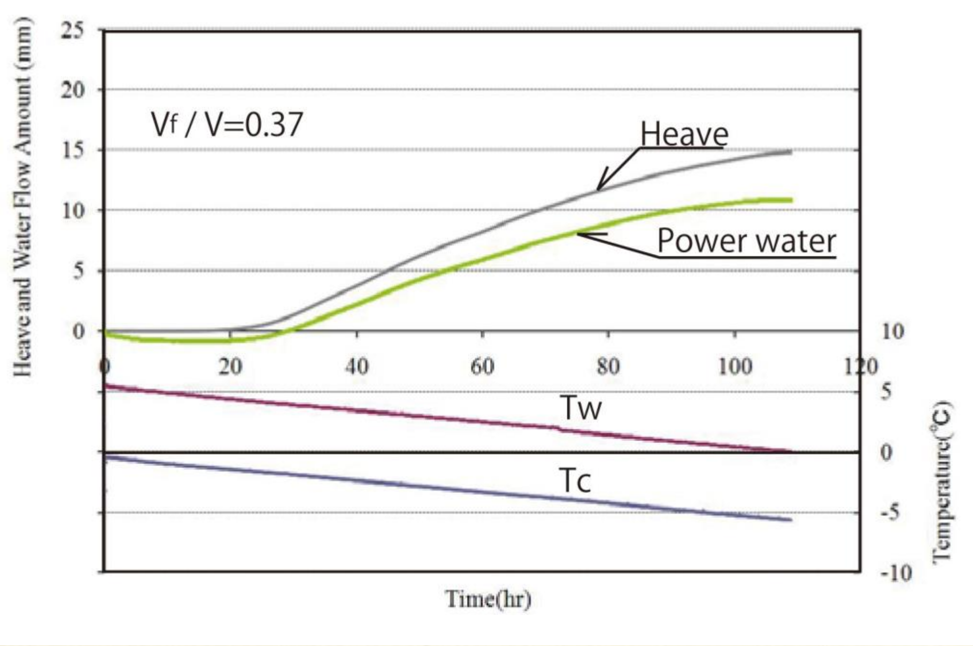
Heave rate of fines under very low confinement is very high.

Again what was happened





One Evidence



Conclusions

- Ballast which contains fines may frost heave.
- Proposed empirical formula provides frost heave susceptibility of ballast which contains fines.
- However farther researches will be required to refine the reliability of the proposed formula.

Thank you for your attention