COMITÉ FRANÇAIS DE MÉCANIQUE
DES SOLS ET DE GÉOTECHNIQUE

LA CONGÉLATION _
ARTIFICIAL FREEZING OF SOILS, *IN CIVIL ENGINEERING*

GROUND FREEZING OF CAIRO SANDS TO SEAL THE CONNECTION BETWEEN A SHAFT AND A TUNNEL

CFMS SCIENTIFIC AND TECHNICAL DAY _ NOVEMBER 17TH 2023

VINCI CONSTRUCTION | GRANDS PROJETS

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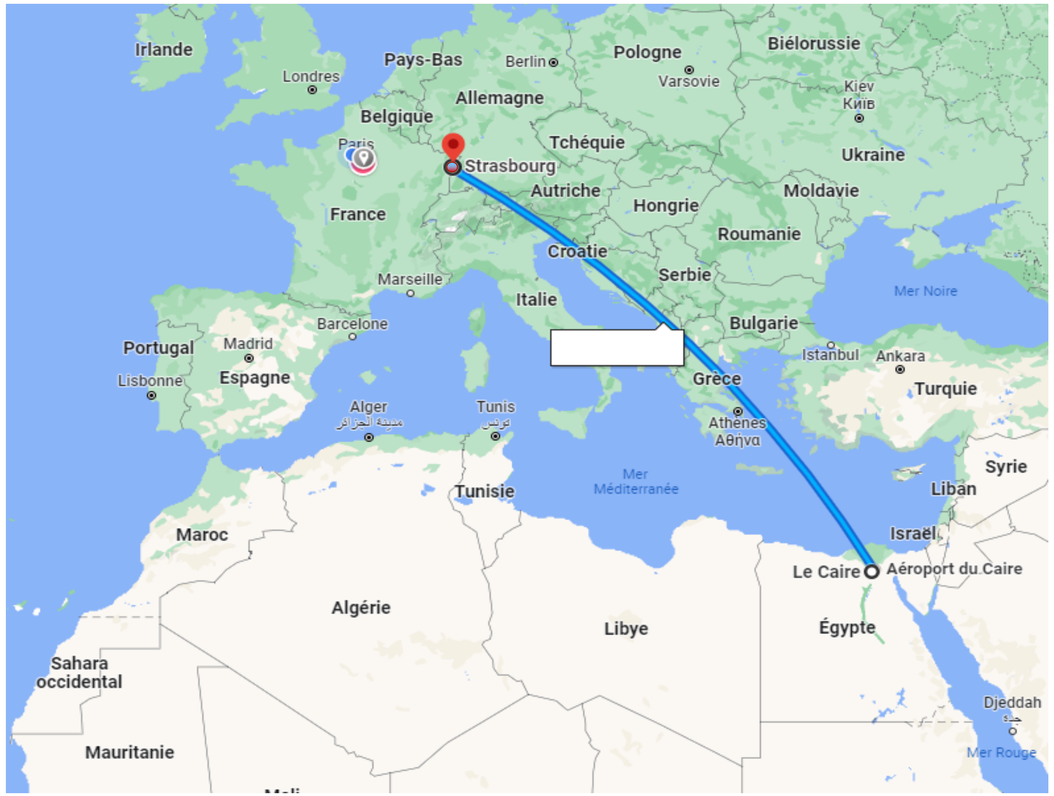
GROUND FREEZING OF CAIRO SANDS TO SEAL THE CONNECTION BETWEEN A SHAFT AND A TUNNEL

PRESENTATION OF THE PROJECT

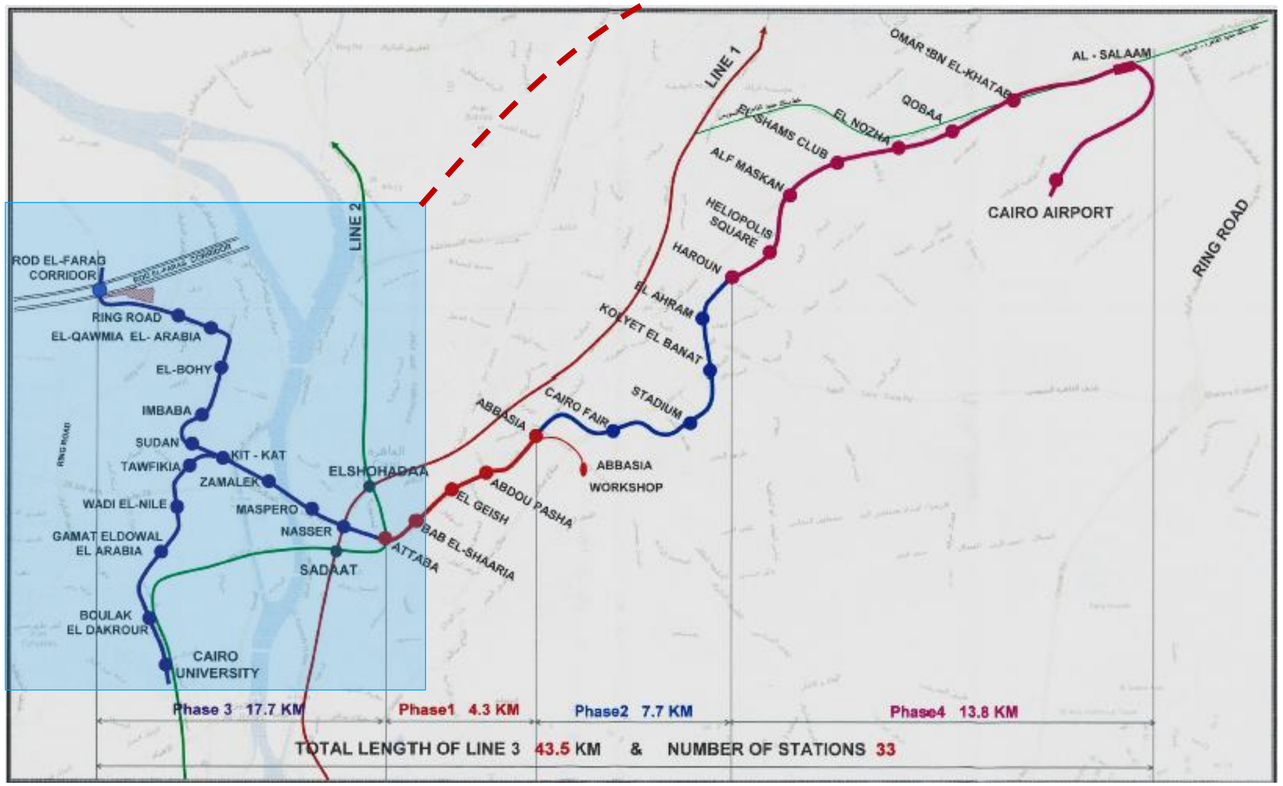
CAIRO

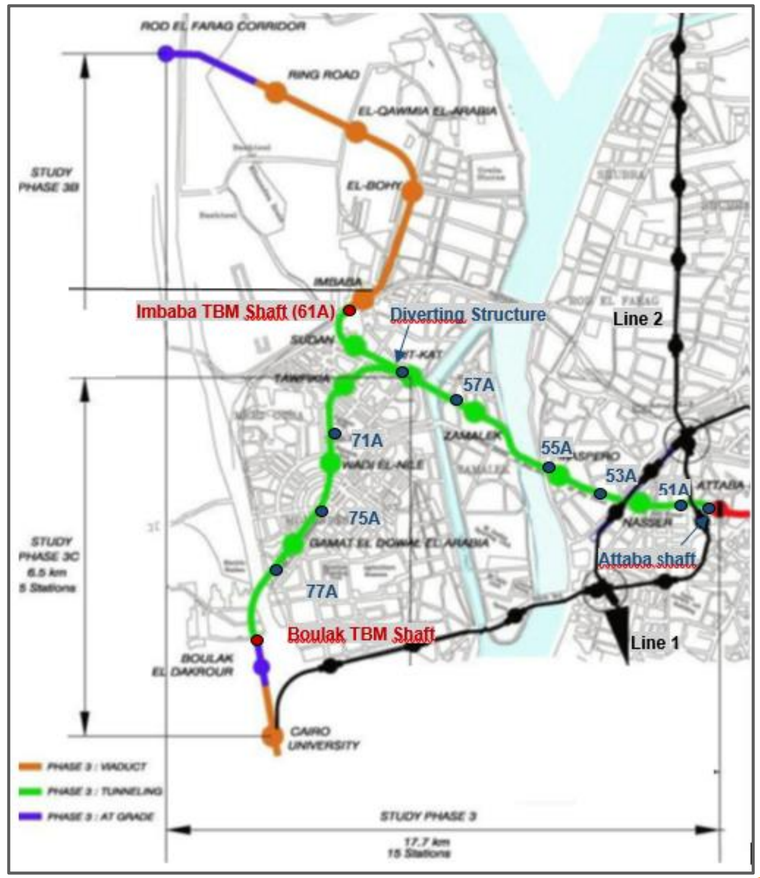


25/02/2010

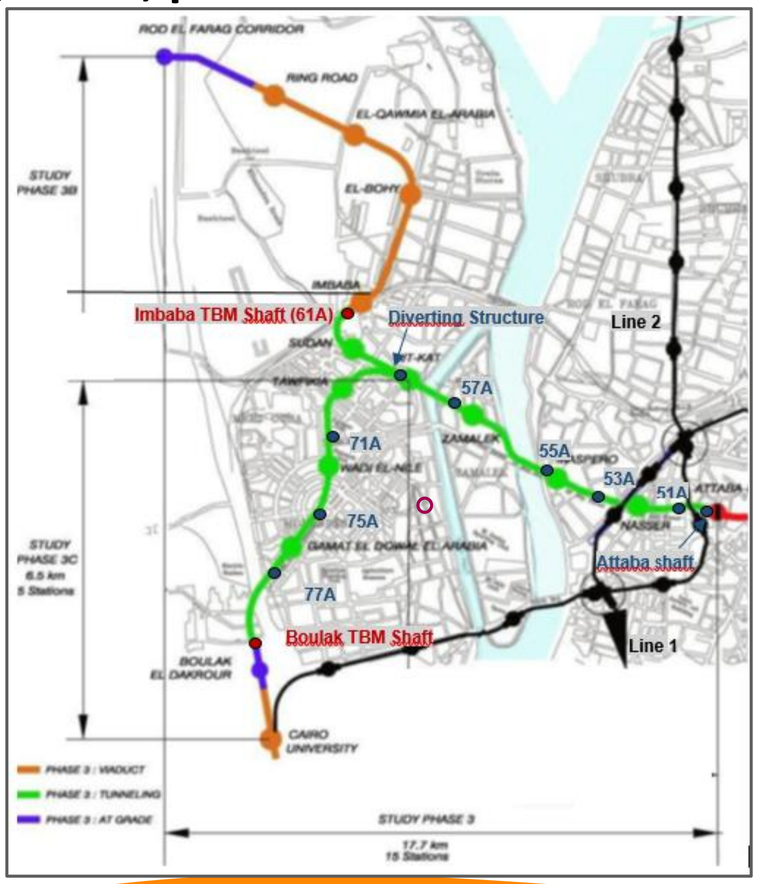
PRESENTATION OF THE PROJECT

CAIRO, line 3





CAIRO, line 3, phase 3



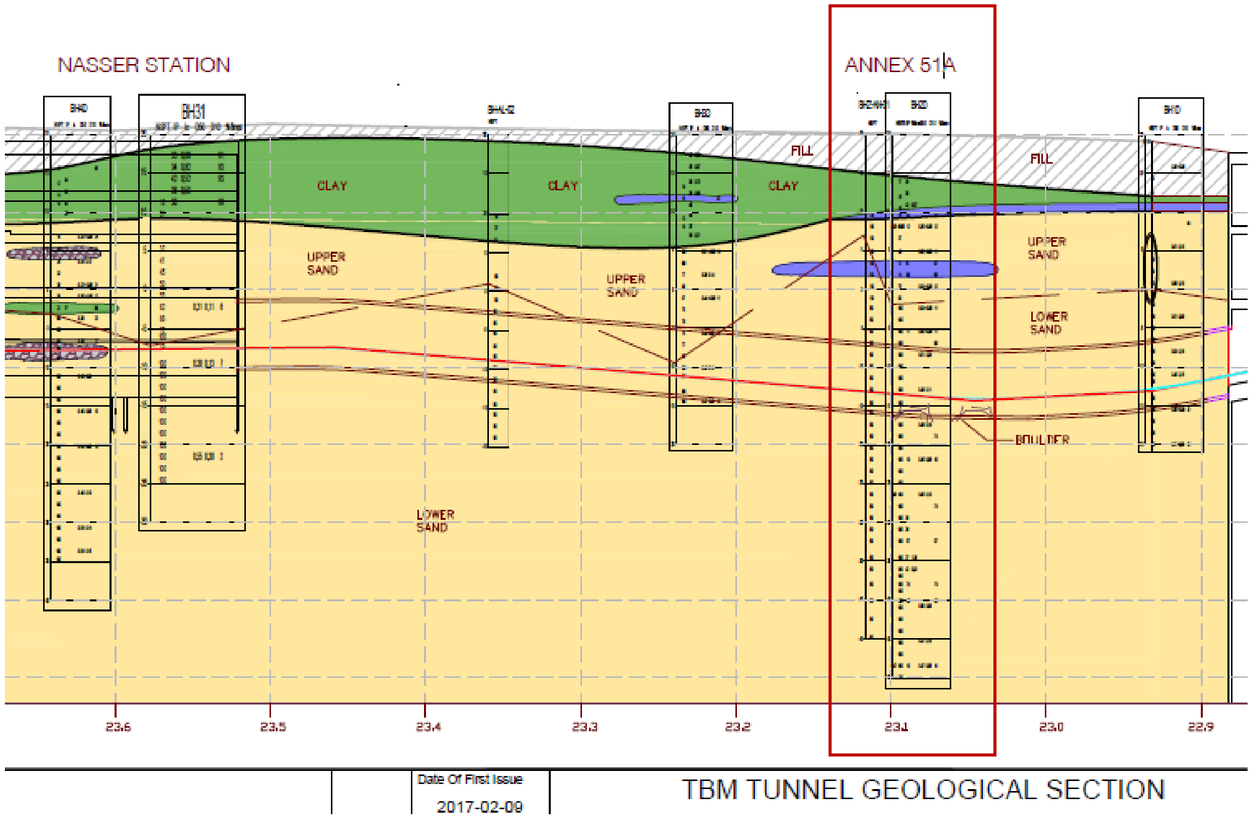
17.7 km with 10 km for the underground part bored with two slurry TBMs.

On the underground part :

- 8 stations
- 7 annex structures

PRESENTATION OF THE PROJECT

CAIRO, line 3, phase 3



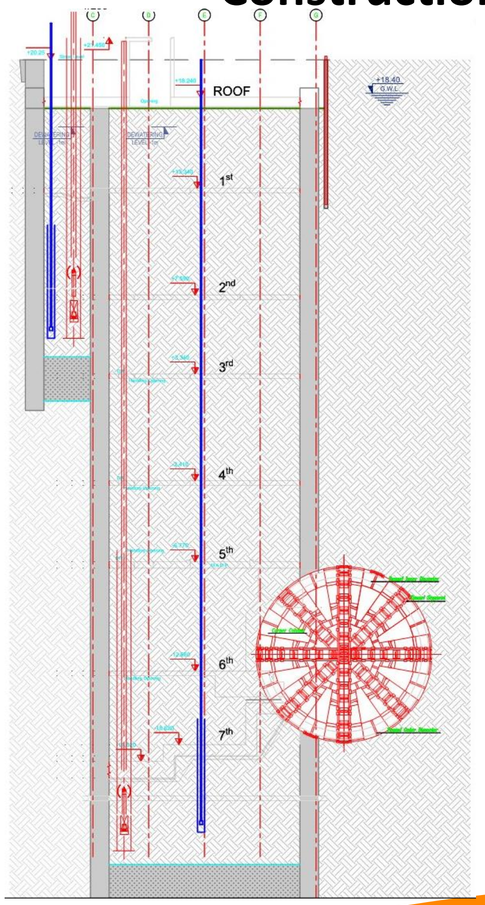
Geology :

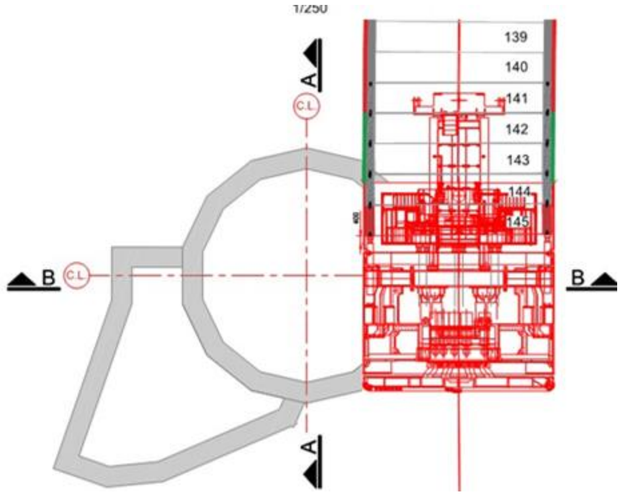
- Fill
- Clay
- Silt
- Sands with gravel horizons

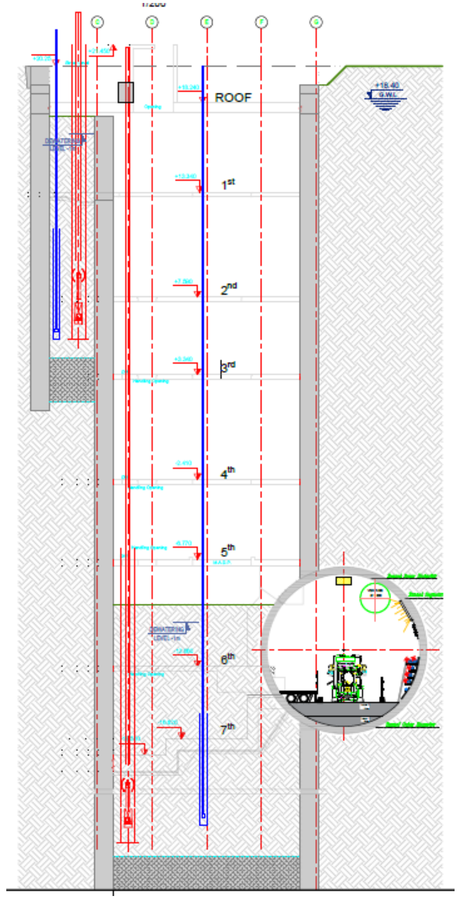
Ground cover at AS 51A : **27.5 m** at tunnel crown

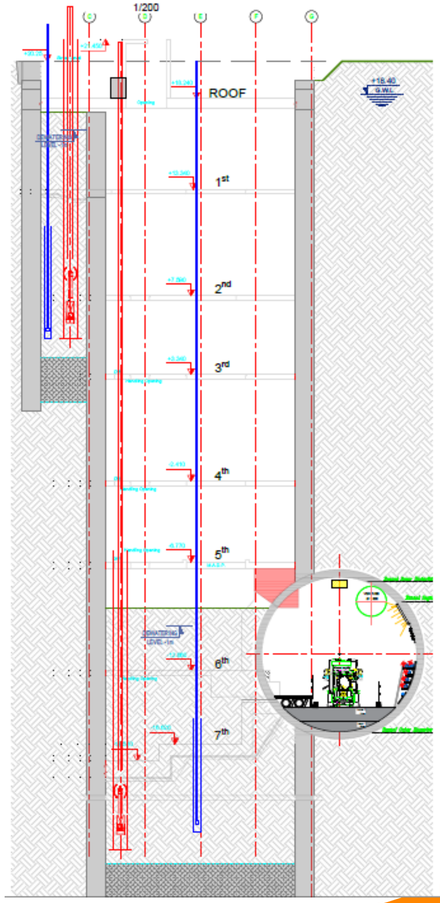
Water at 1.9m below the ground surface : **25.6 m** at tunnel crown at the AS 51A location**.**

Construction sequence of annex structures

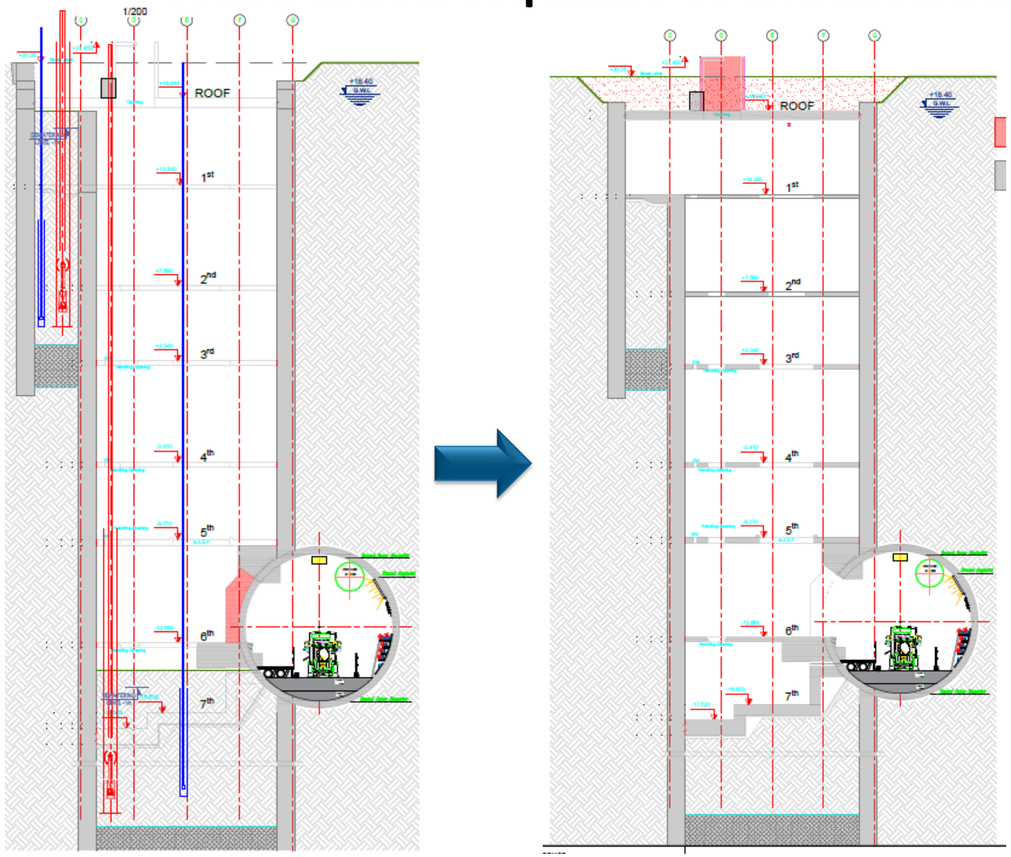


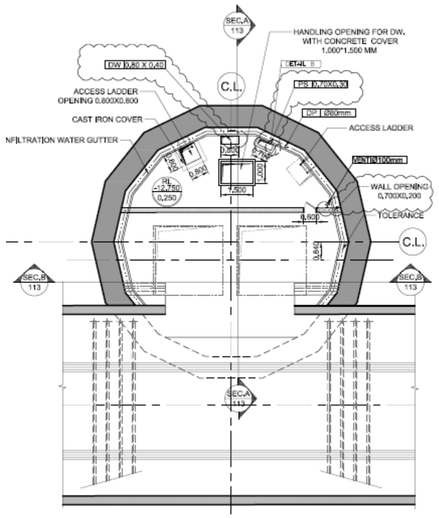




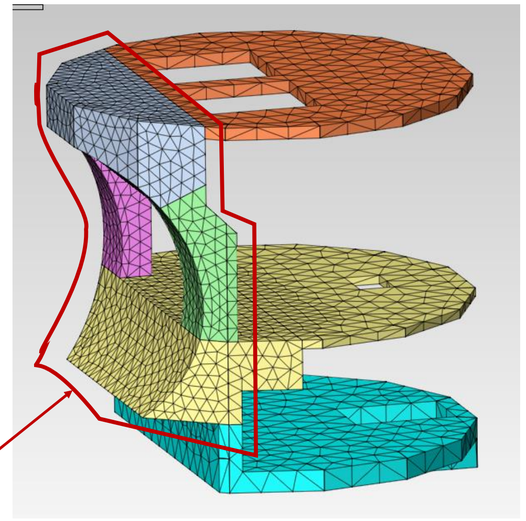


Construction sequence of annex structures



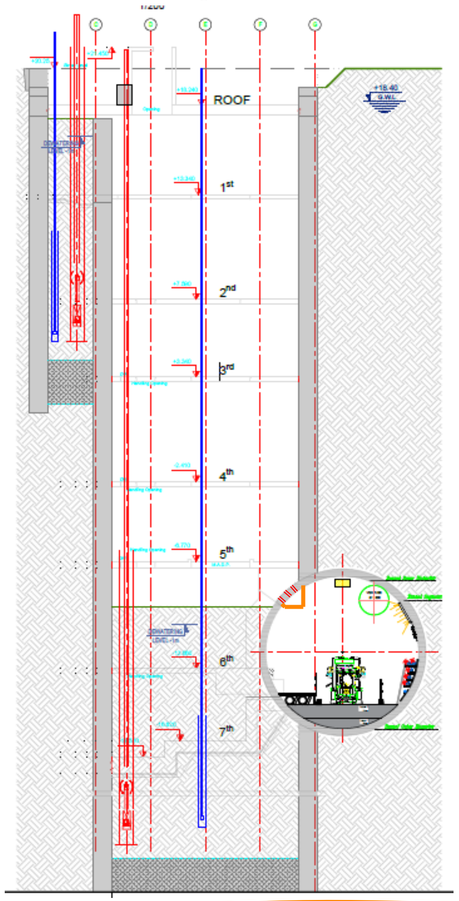


Structural elements between the shaft and the tunnel



Concrete portal

Situation in September 2019

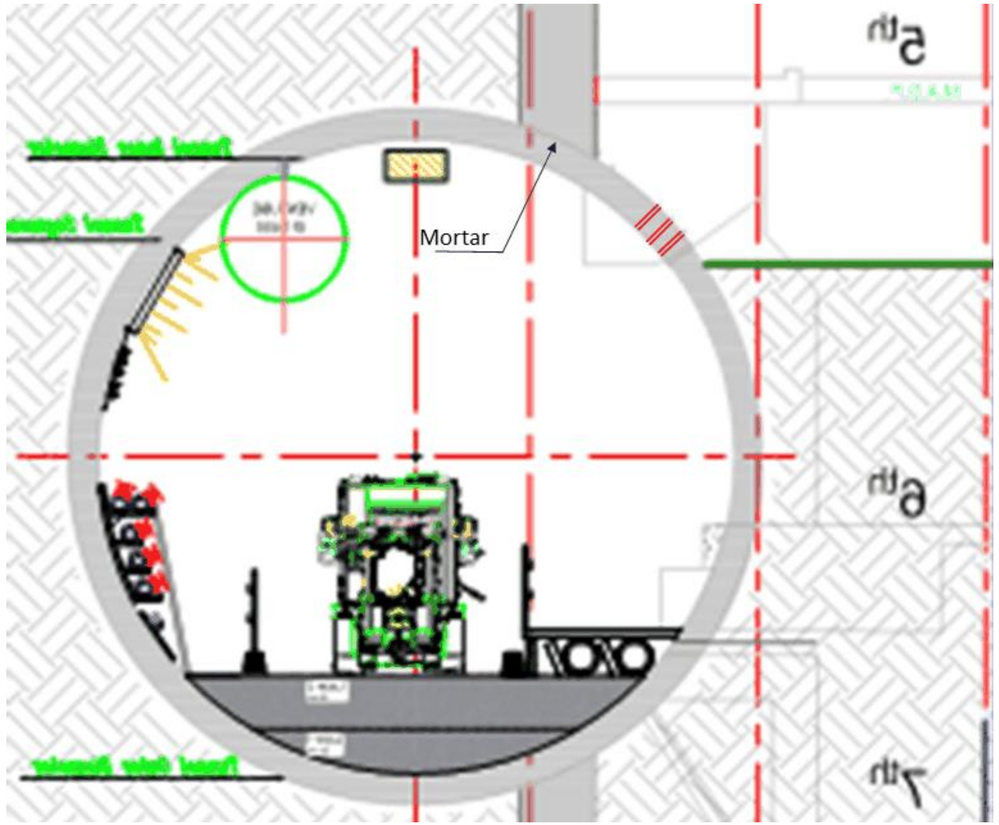


- Excavation done up to the base of the portal upper beam
- Segment coring to cast the tunnel inner beam
- Segment coring for the connection between the portal upper beam and the tunnel segments

30th of September 2019

Leakage at the interface between the tunnel and the shaft diaphragm wall

- Water inflow inside the shaft
- Water plus fines spurt in the tunnel



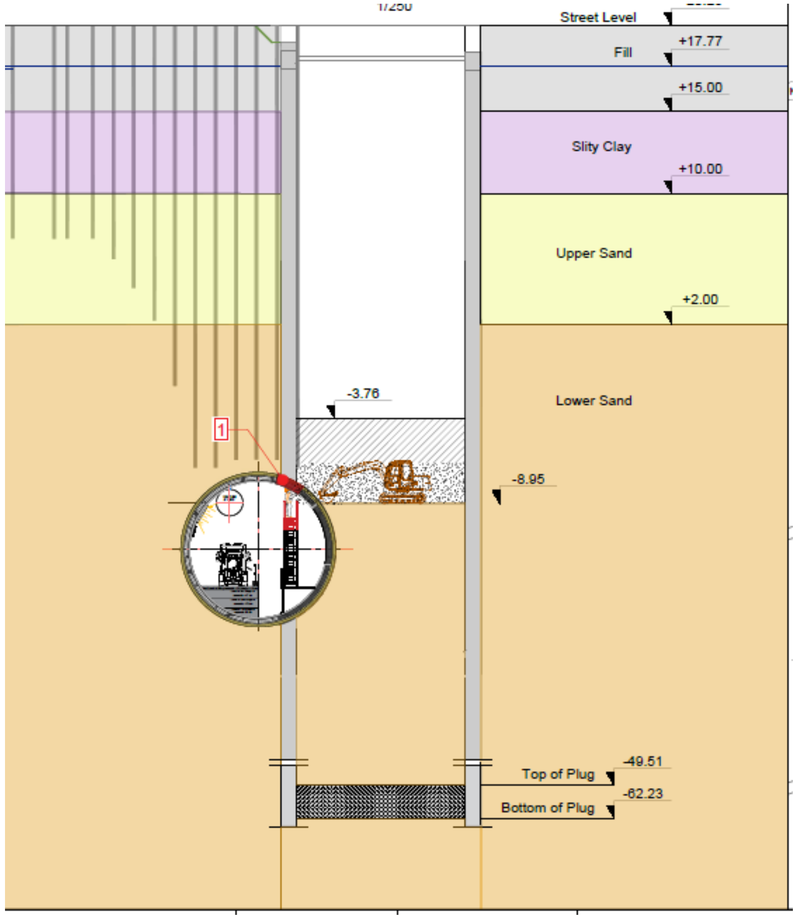
Mitigation measures

Immediate remedial mesures:

- Backfill of the shaft up to 2m above the tunnel upper ring level (40 m3 of concrete and 216 m^3 of sand/cement)
- Installation of steel plates at coring holes locations

Solution to pursue the construction works of the shaft

- **Ground Freezing**



Aim of the freezing process

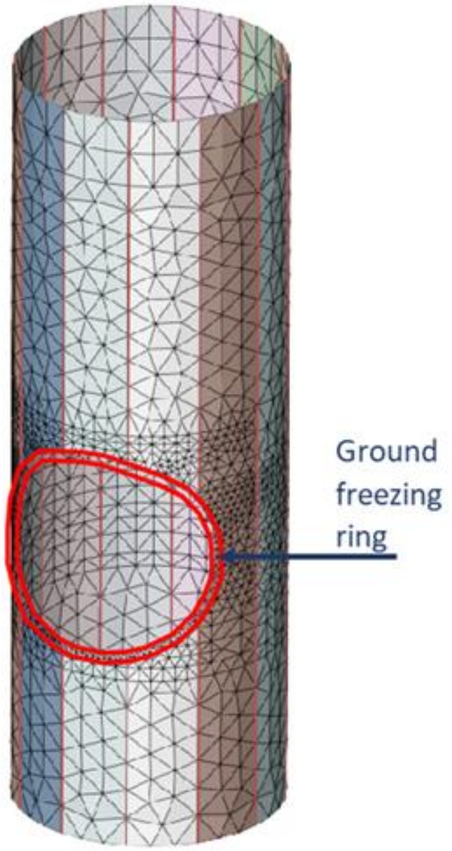
Waterproof the connection between the shaft and the tunnel.

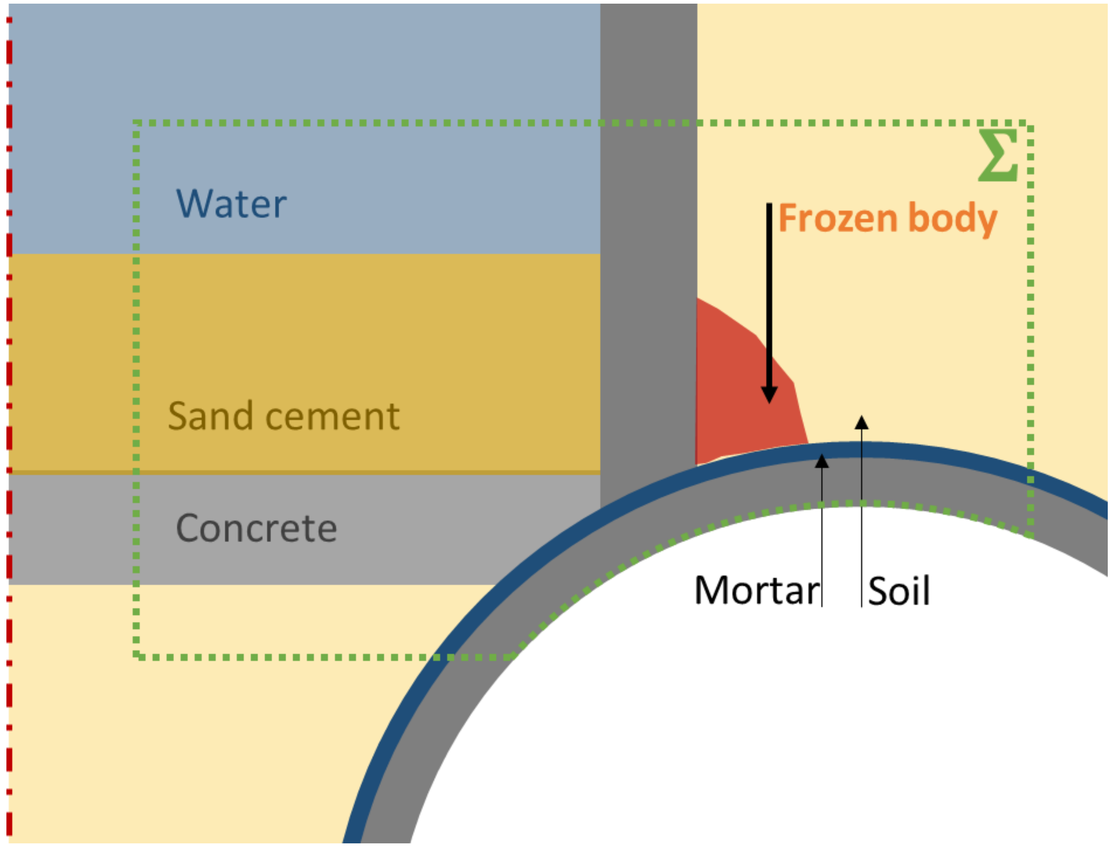
- Empty the shaft
- Build the concrete portal

Uncertainties:

- Concentration of sulfate and salt in the groundwater.
- Groundwater flows.
- Composition of the soil
- Boundary effects.

The thickness of the frozen volume at -5°C must be at least equal to $50cm$ to prevent water seepage in the shaft.

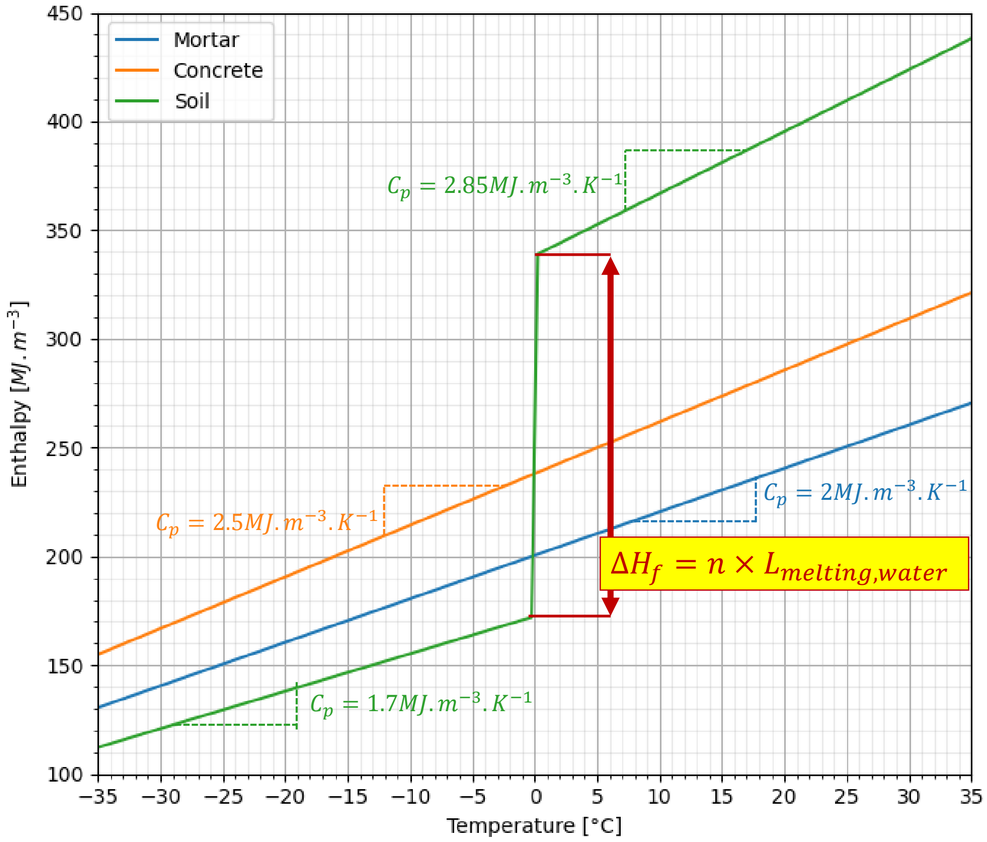


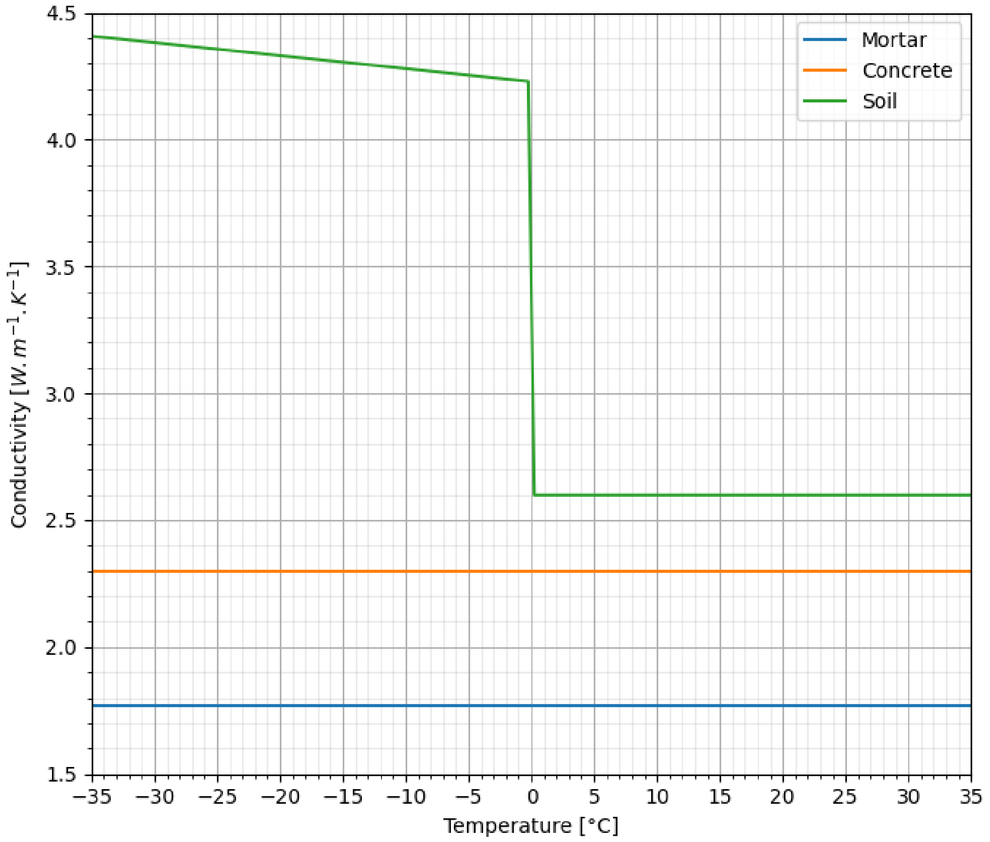


Thermal parameters

Mixing of the soil:

The porosity of the soil (n) controls the thermal parameters.

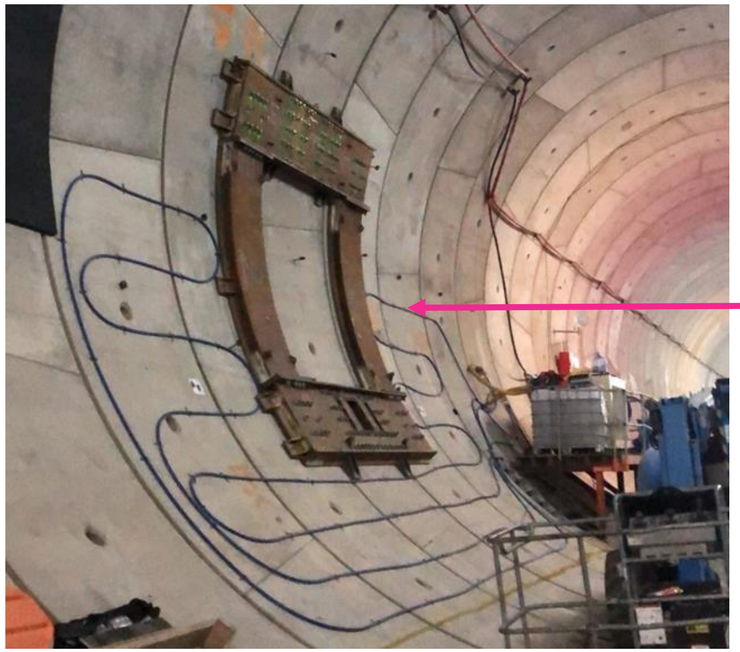


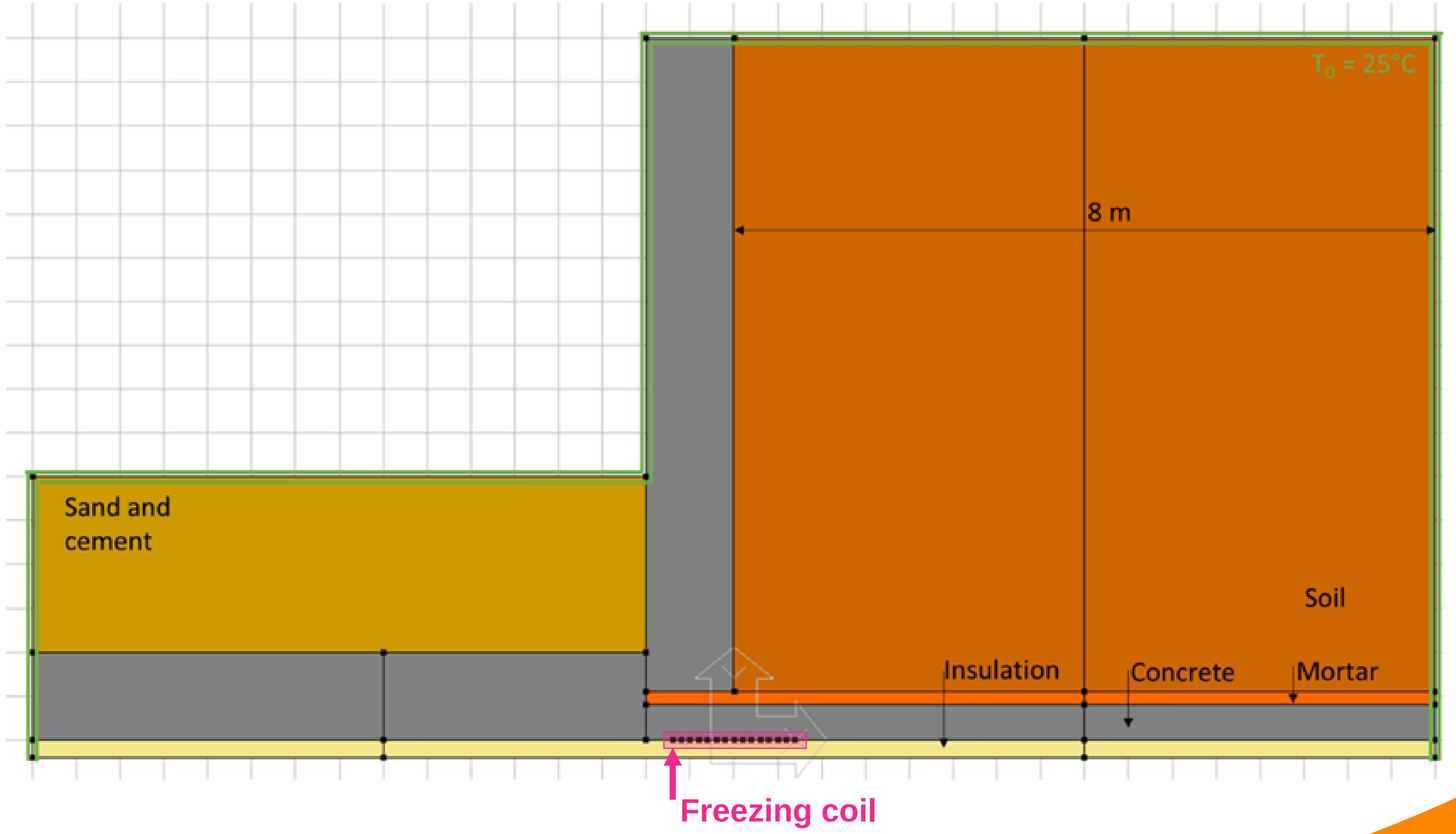


Surface cooling: Ground freezing from the inner side of the segments

Installation of **freezing coil** in the tunnel

- Thermal flux across the segment
- Freezing of the soil





Surface cooling: Ground freezing from the inner side of the segments

Installation of **freezing coil** in the tunnel

- Thermal flux across the segment
- Freezing of the soil

Use of brine at $-30°C$

Advantage:

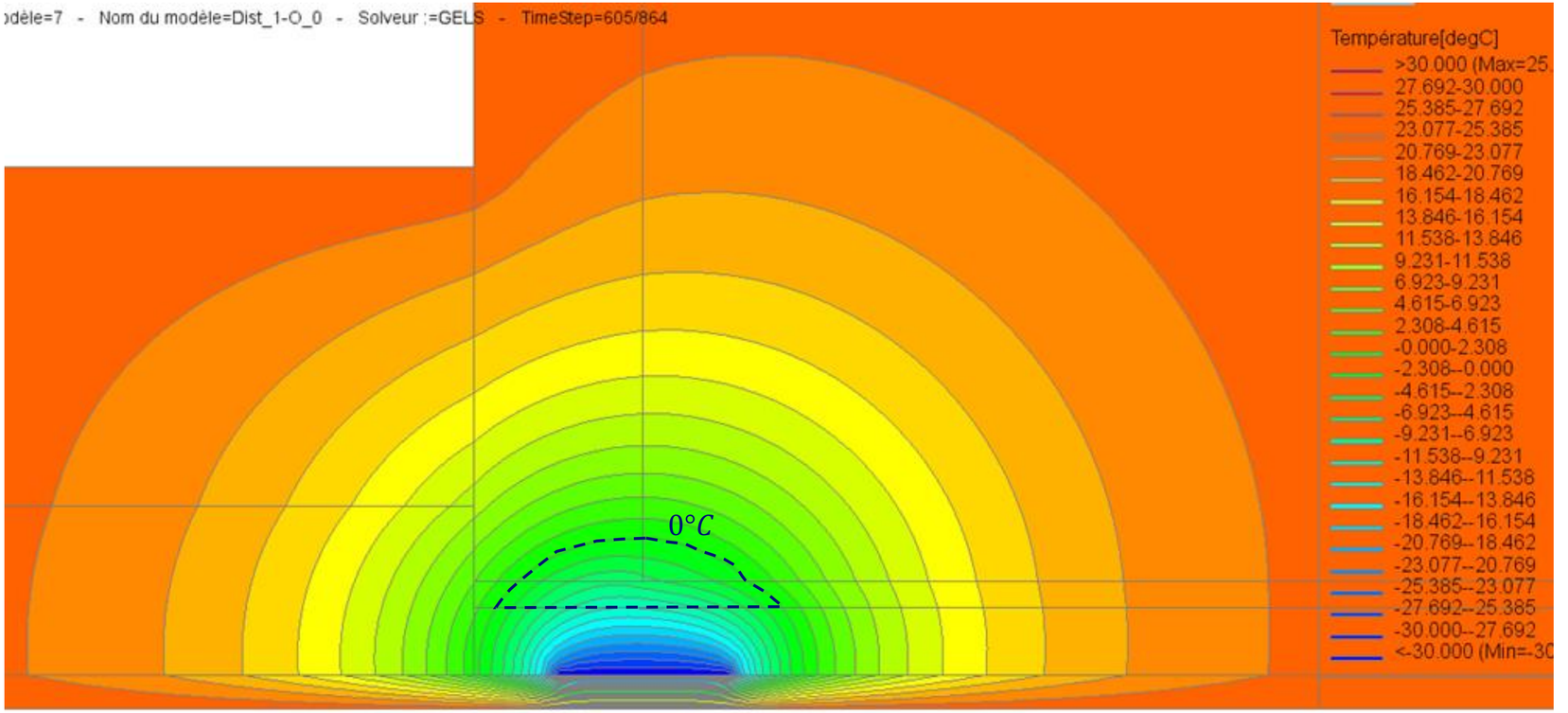
- Simple
- No drilling of the tunnel segment

Results:

- Minimal total power of $2 \times 7.5kW$
- Huge impact of the insulation in the tunnel

Issue:

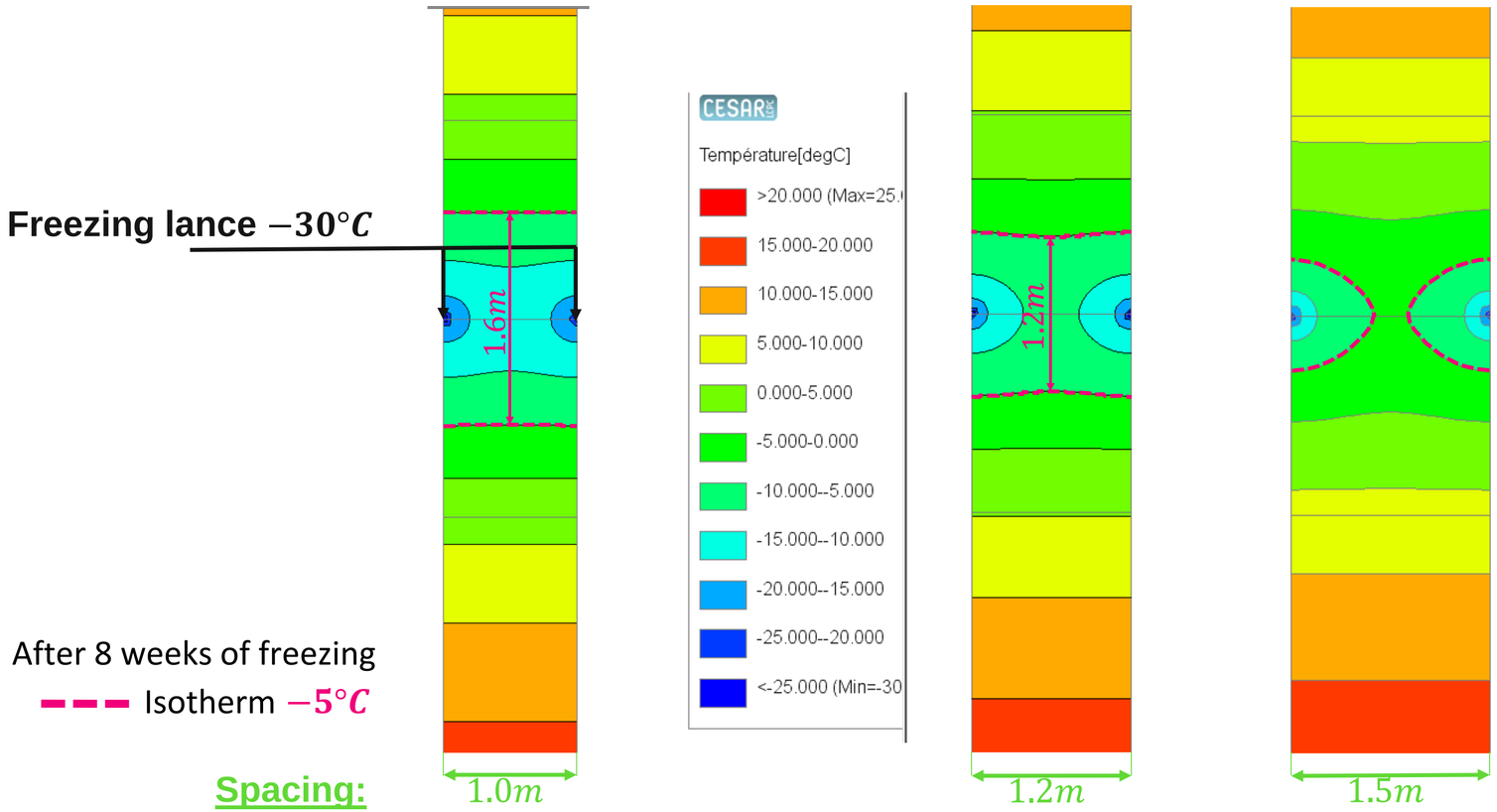
- Sensible to thermal flux in the tunnel
- No monitoring of the frozen body
- Limitation of the frozen body

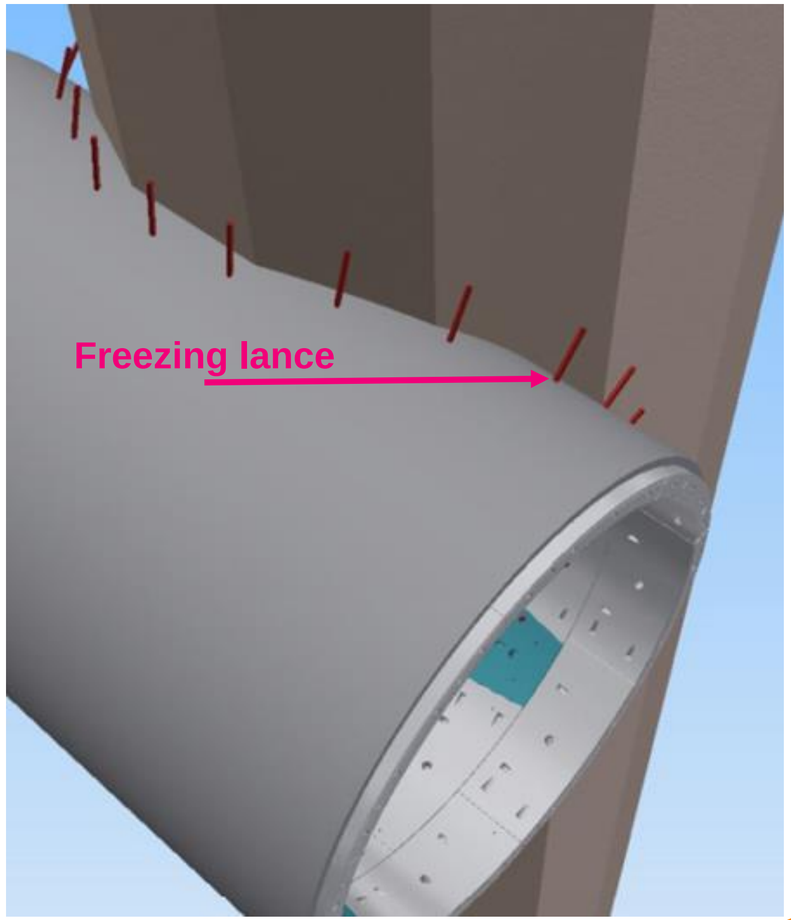


Results after 42 days (6 weeks) of freezing

DESIGN OF THE FREEZING

Conventionnal freezing



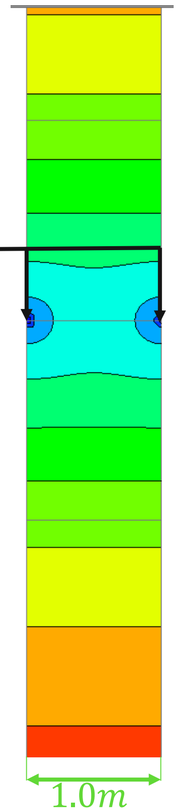


DESIGN OF THE FREEZING

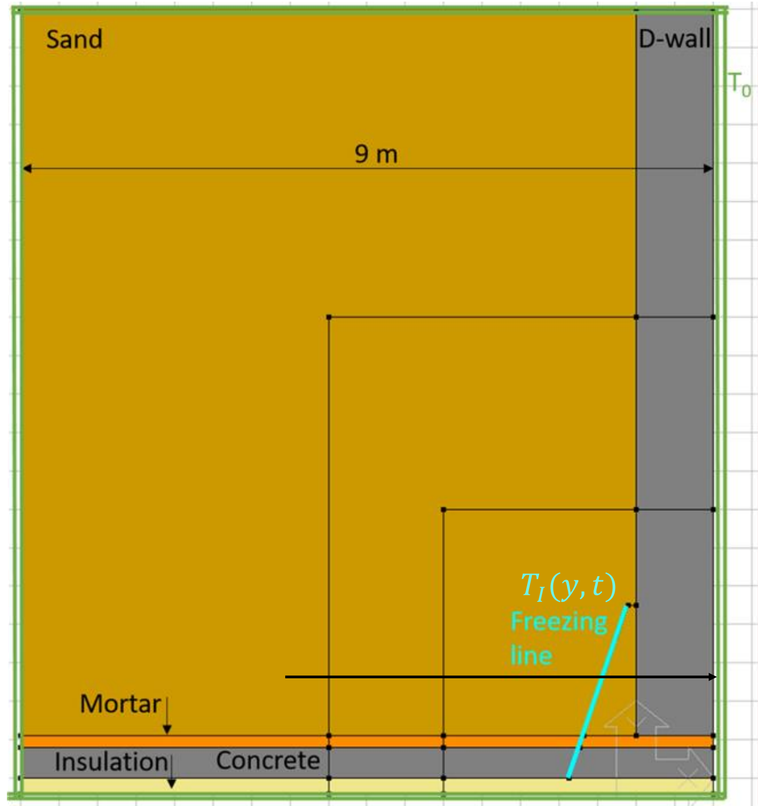
Conventionnal freezing

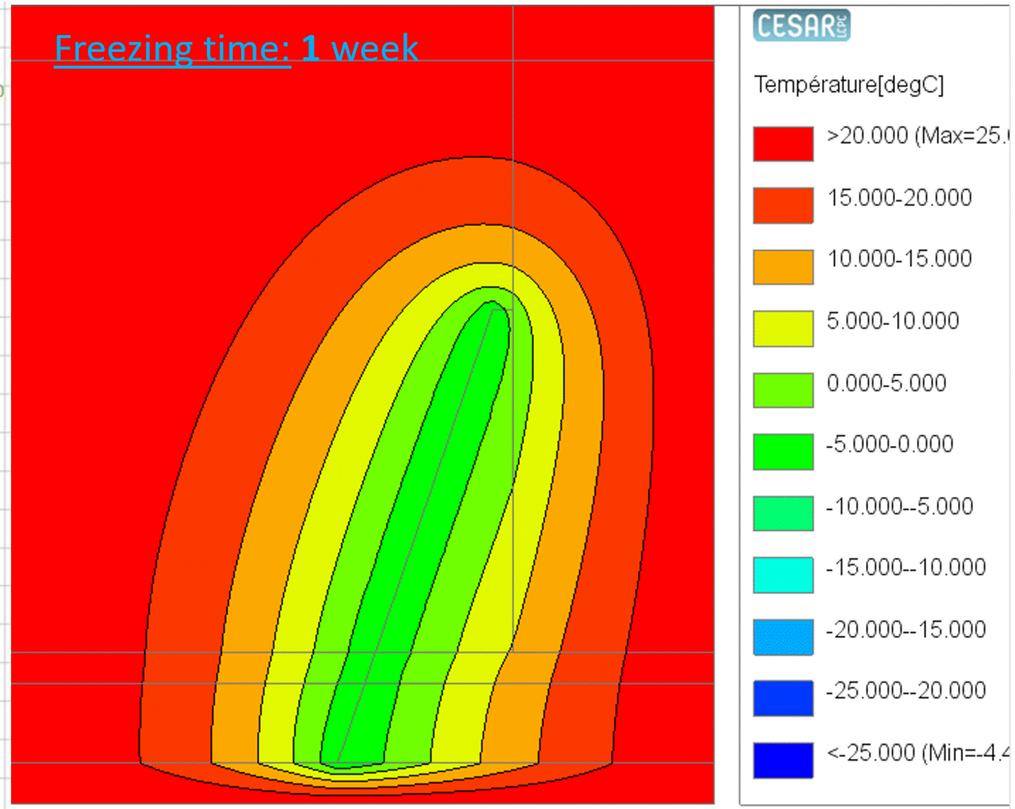
Freezing lance $-30°C$

- 6-8 weeks of freezing
- Minimal total power of $2 \times 15kW$



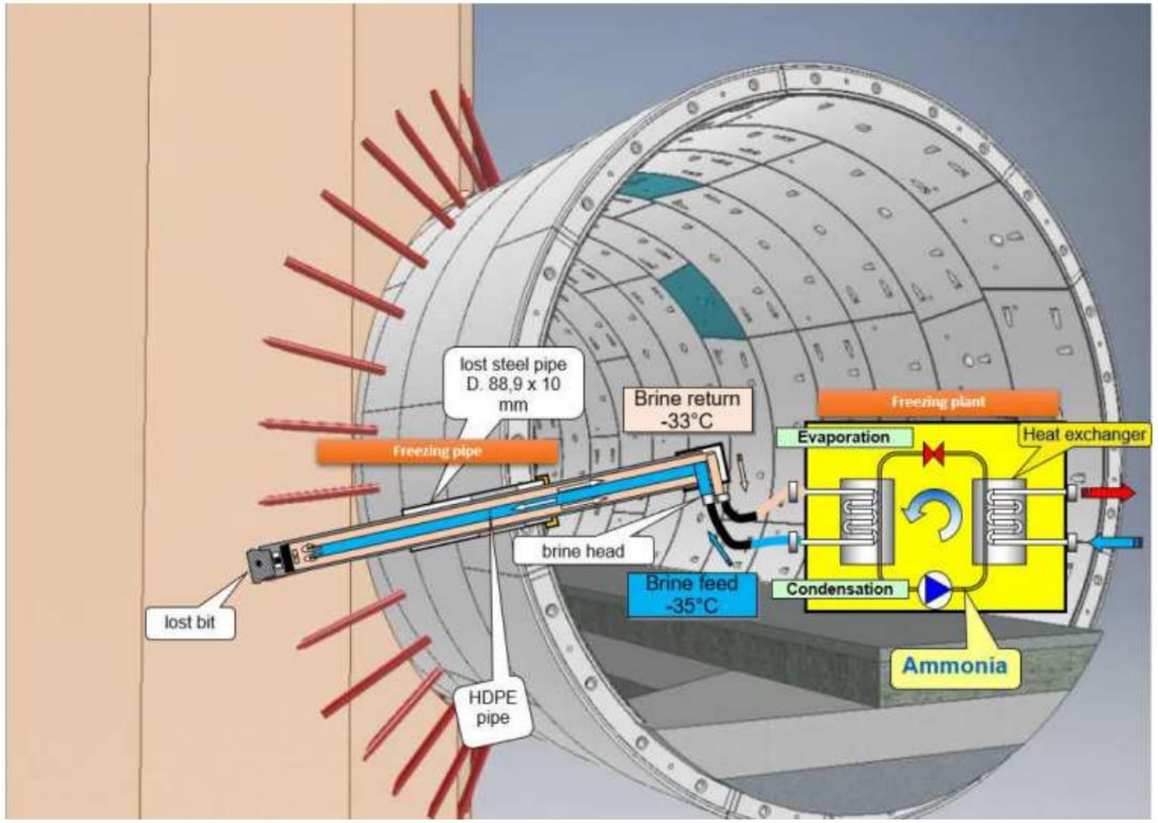
Spacing:





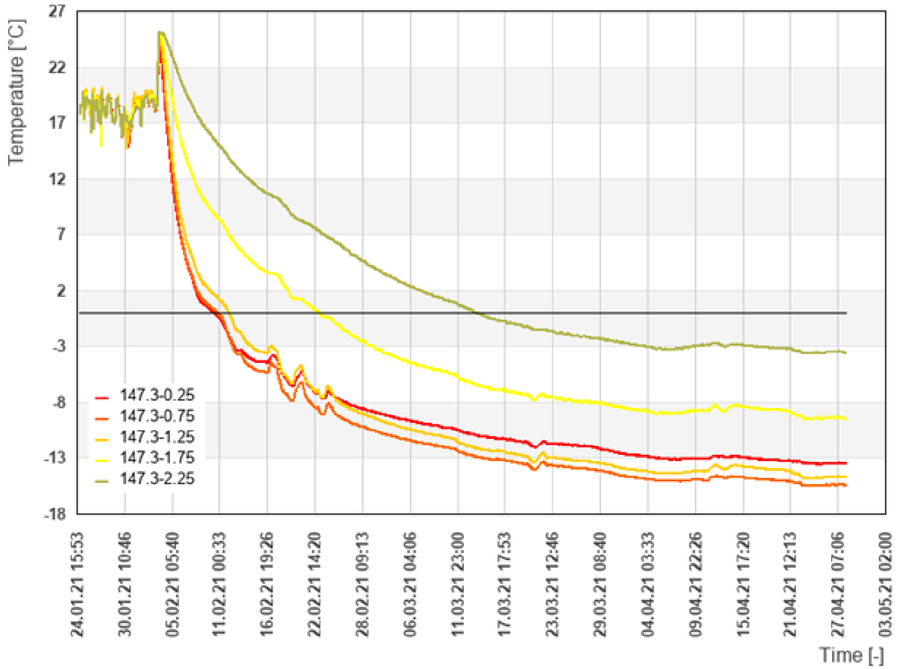
FREEZING MONITORING

Freezing process



Freezing plants:

- 7 groups
- 44 freezing lances

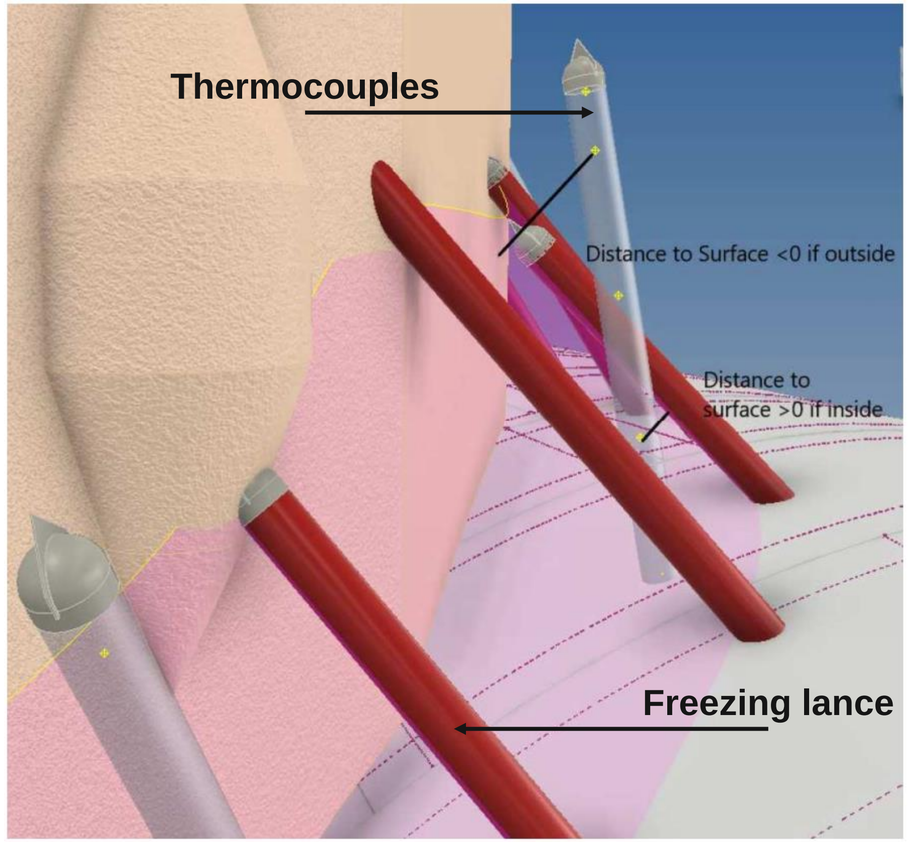


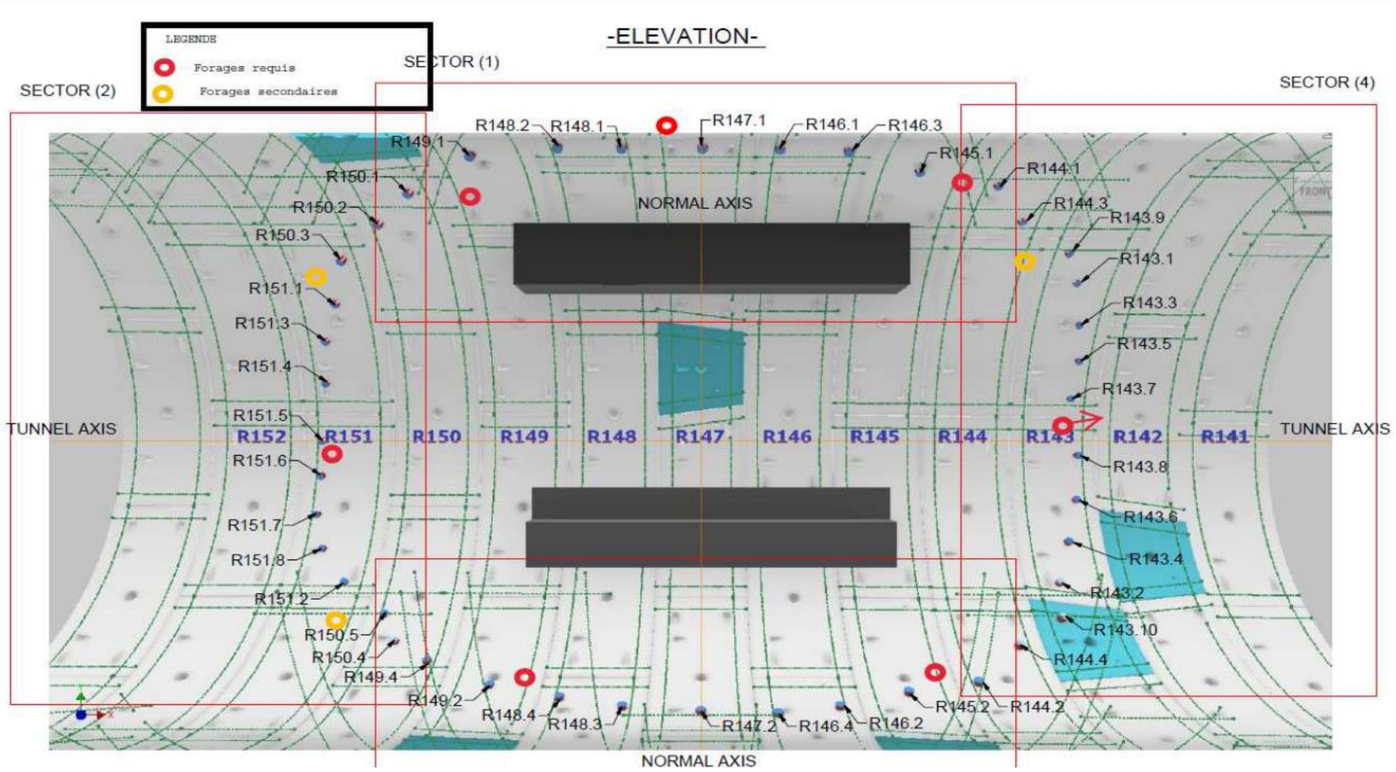
FREEZING MONITORING

Freezing process

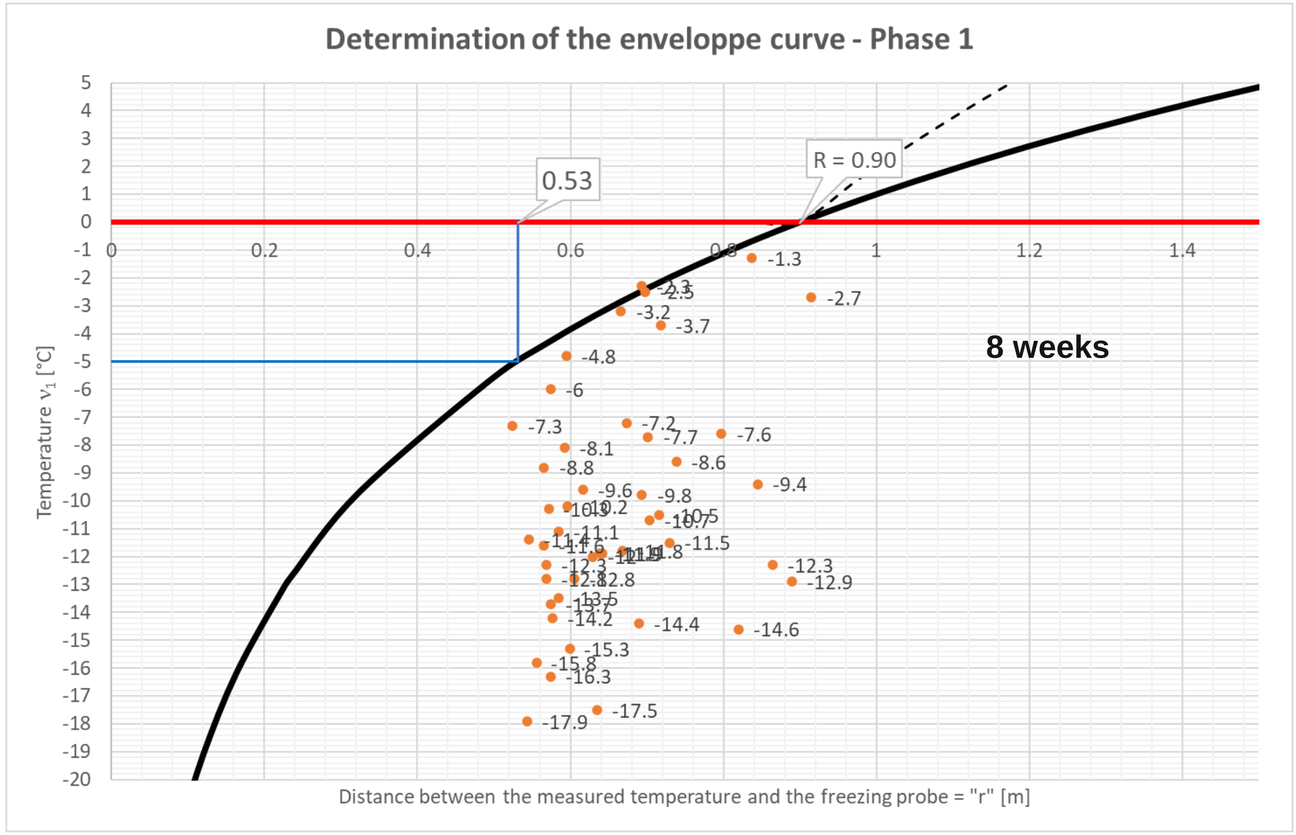
FREEZING MONITORING

Freezing monitoring

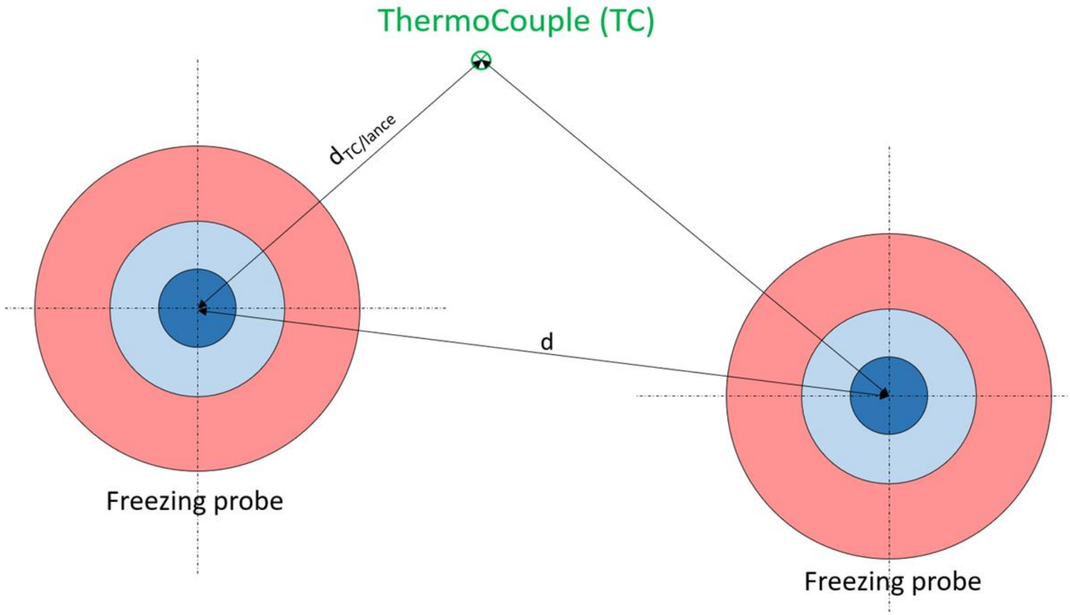




Freezing monitoring



Thickness of the frozen body using Sanger F. J. and Sayles F. M. (1979):

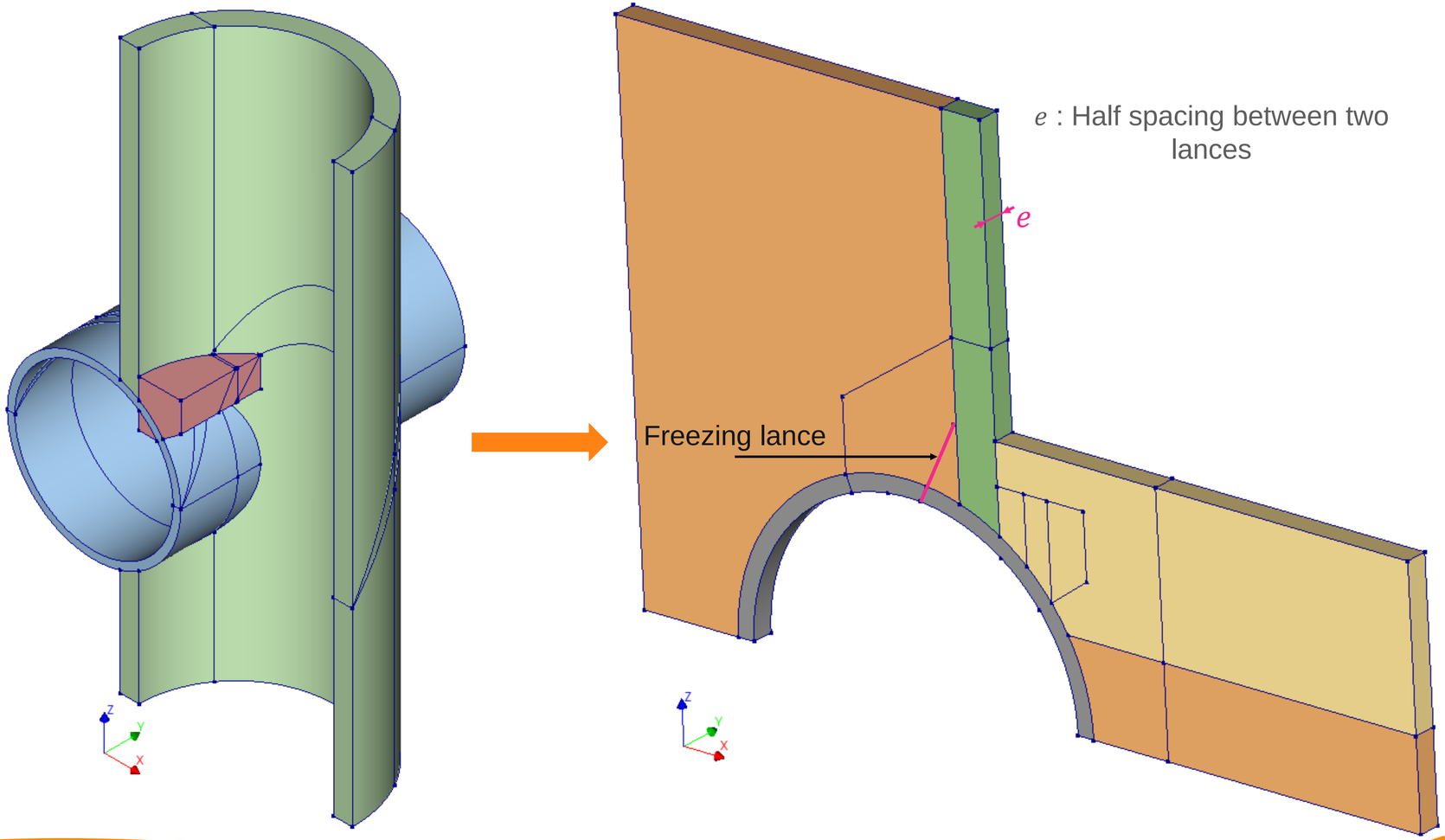


IMPACT OF THE CONCRETE HEAT OF HYDRATION ON THE FREEZING BODY

3D FEA

Study the impact of the construction of the beam

- Melting of the frozen soil
- Waterproofness of the shaft



IMPACT OF THE CONCRETE HEAT OF HYDRATION ON THE FREEZING BODY

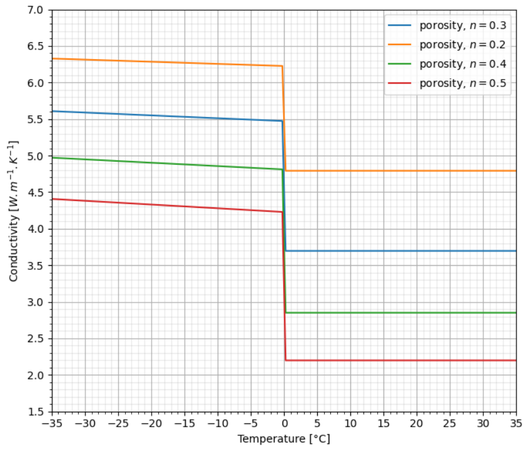
Calculation phases

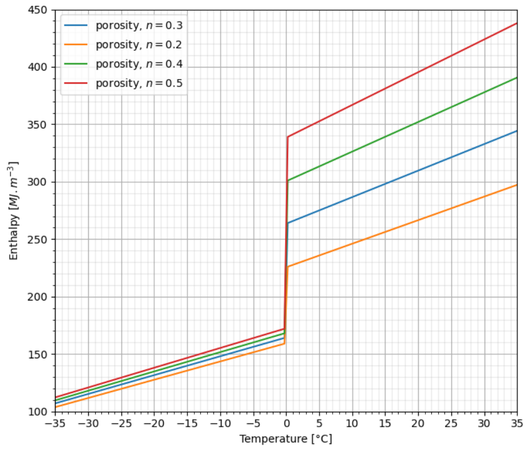
60 days

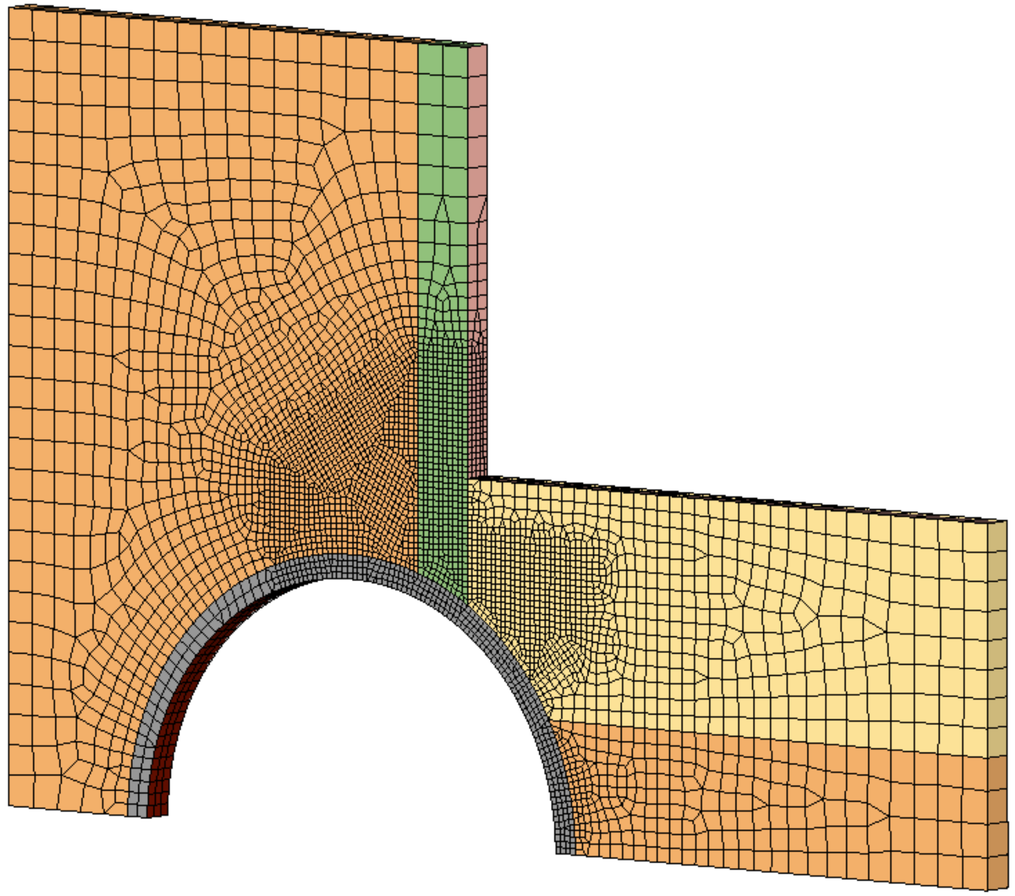
Freezing of the soil

Calibration of the thermal parameters of the soil

- Porosity
- Composition of the soil







IMPACT OF THE CONCRETE HEAT OF HYDRATION ON THE FREEZING BODY

Calculation phases

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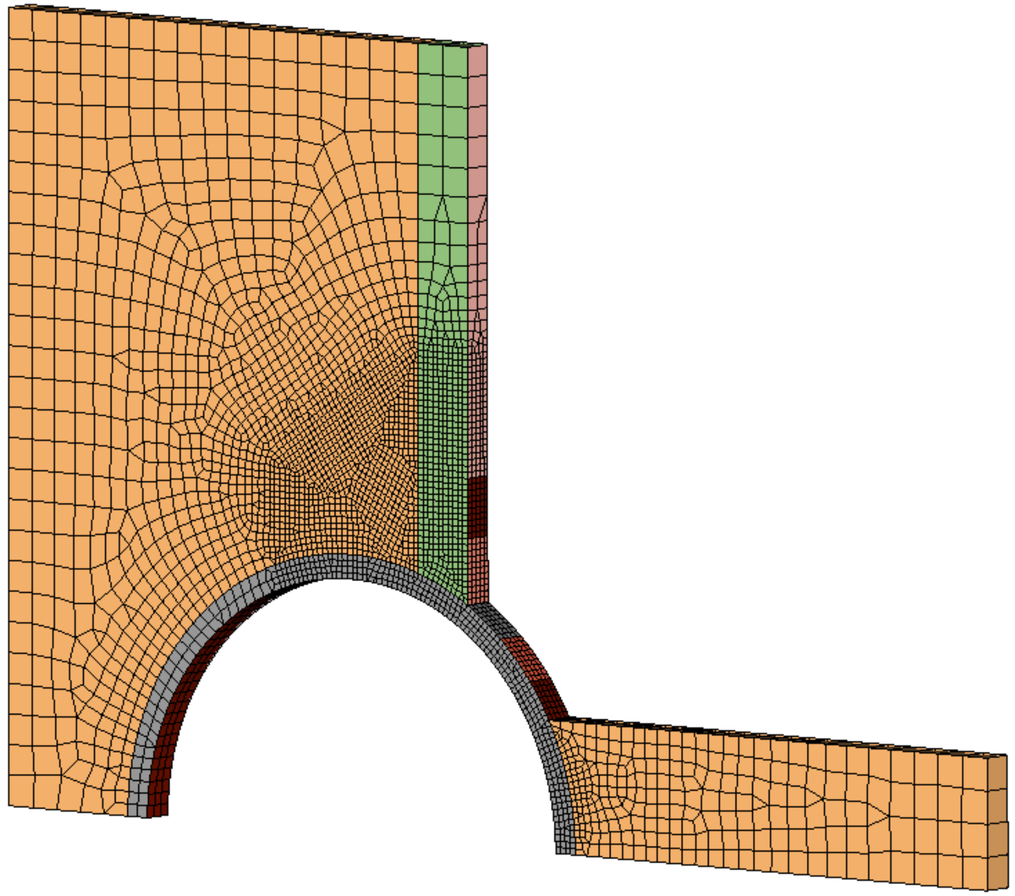
Freezing of the soil

Calibration of the thermal parameters of the soil

- Porosity
- Composition of the soil

7 days

Excavation of the shaft

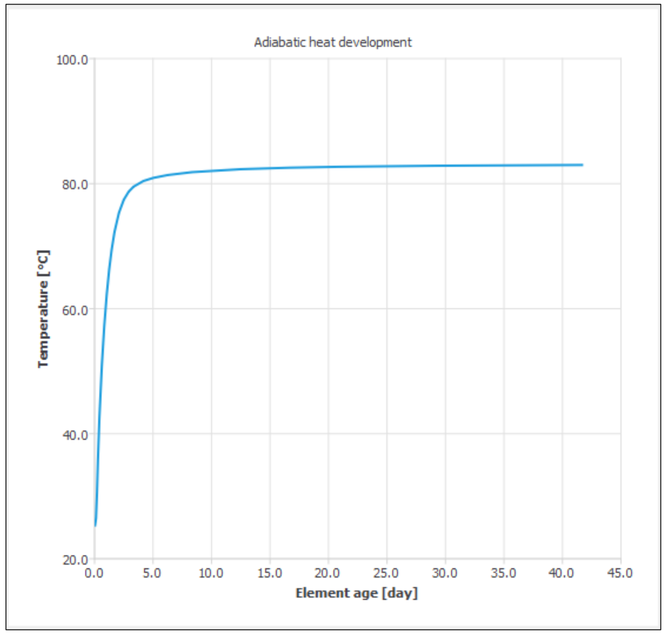


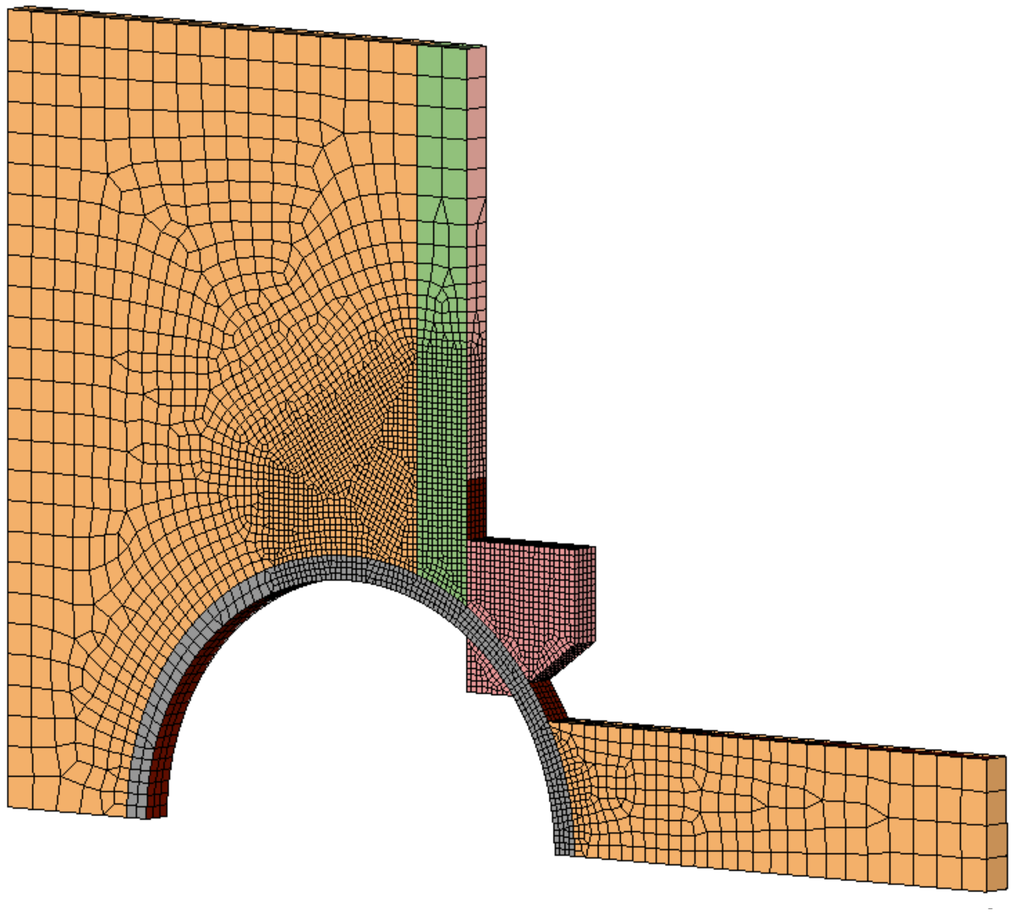
IMPACT OF THE CONCRETE HEAT OF HYDRATION ON THE FREEZING BODY

Calculation phases

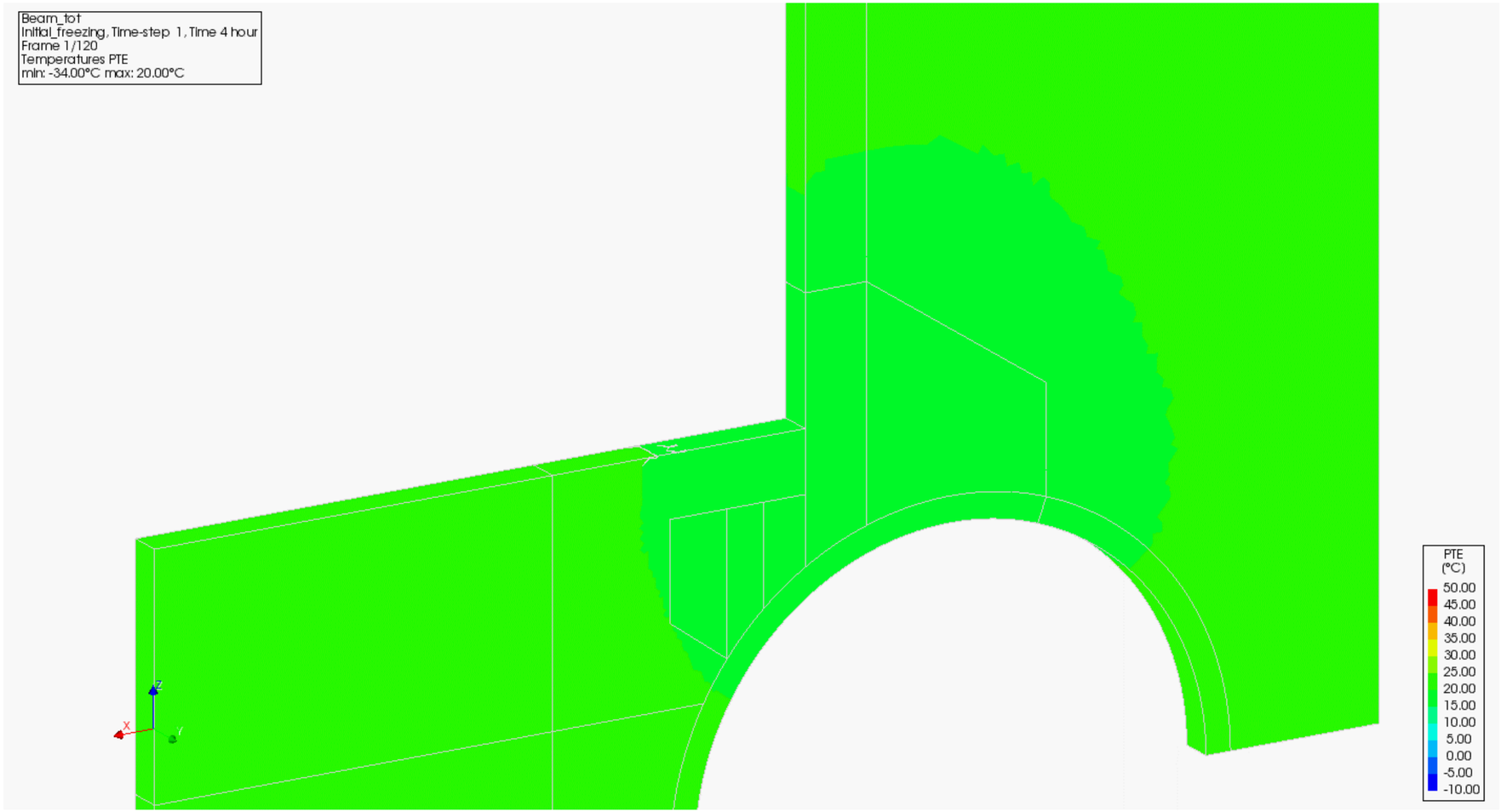
- Freezing of the soil
- Excavation of the shaft
- Construction of the beam

28 days





IMPACT OF THE CONCRETE HEAT OF HYDRATION ON THE FREEZING BODY



SUMMARY

Success of the freezing process at AS-51 of Caire Metro Line 3 phase 3

- Freezing performs well in a complex geometry
- Brine used, even with warn soils
- Freezing technique very beneficial to solve a critical situation
- Good collaboration between the design team, the production team and the subcontractor

Impact of the insulation and the external thermal flux

SUMMARY

Success of the freezing process at AS-51 of Caire Metro Line 3 phase 3

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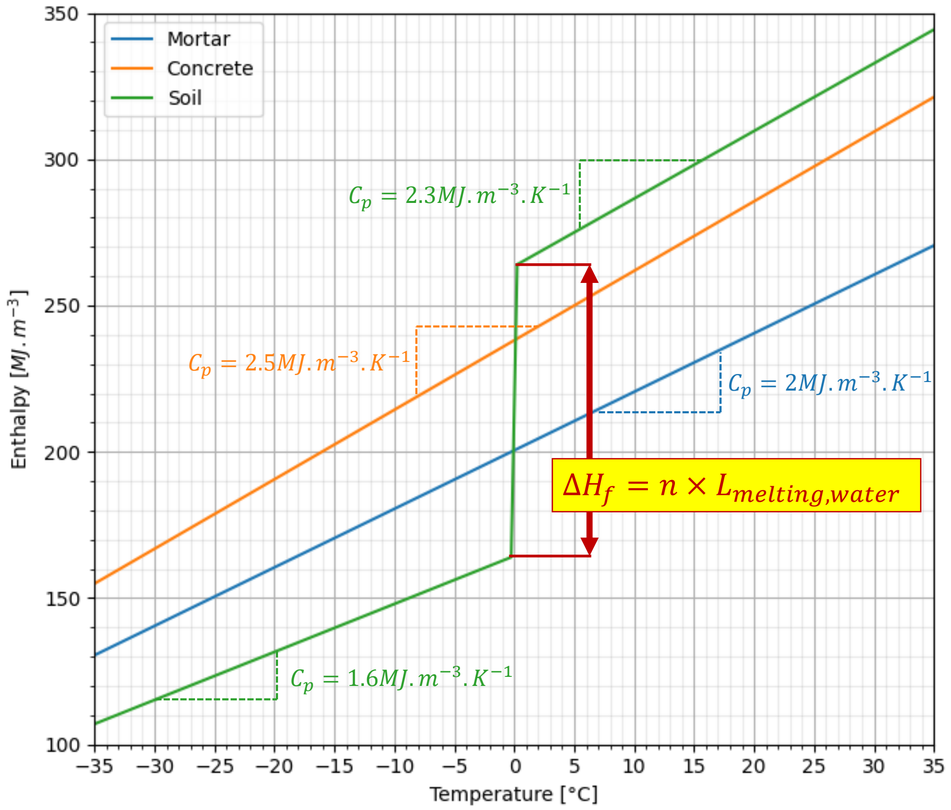
Impact of the insulation and the external thermal flux

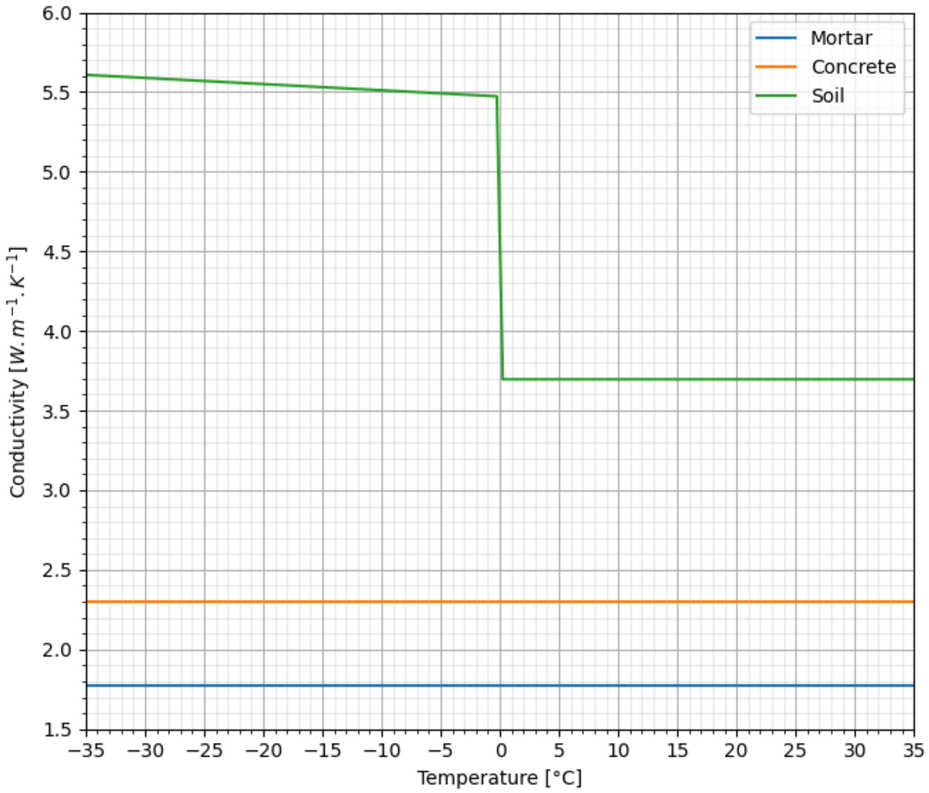
Thank You

Questions ?

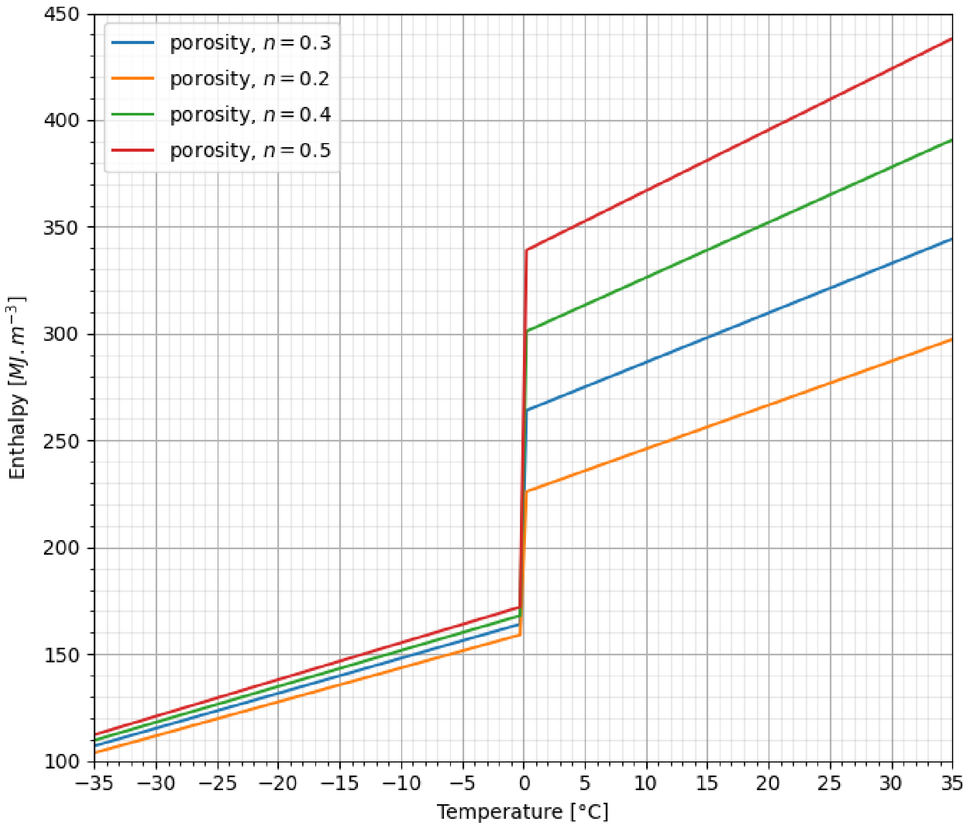
Thermal parameters

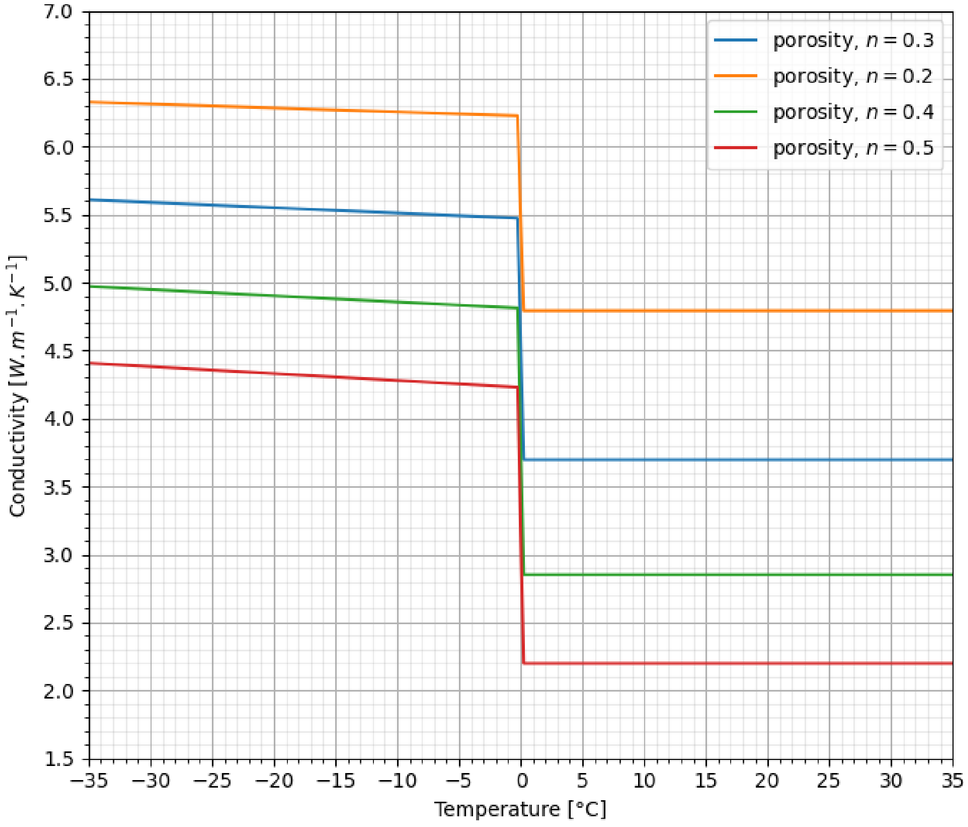
$n = 0.3$



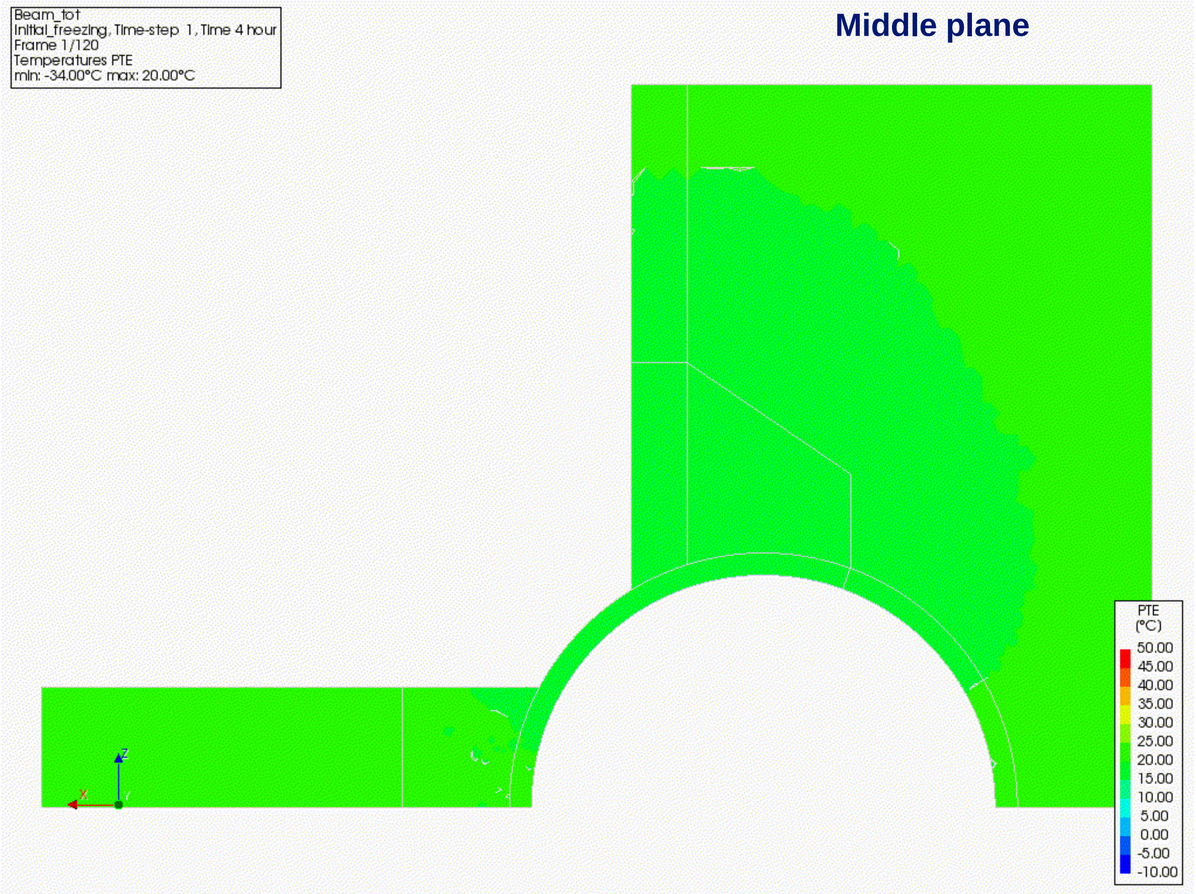


Thermal parameters



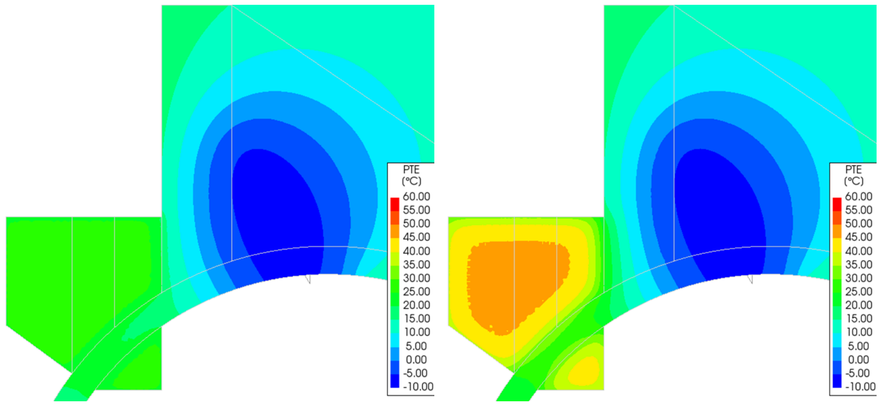


ANNEX


Middle plane
Beam_tot
Initial_freezing, Time-step 1, Time 4 hour
Frame 1/120
Temperatures PTE
min: -34.00°C max: 20.00°C
PTE
(°C)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00

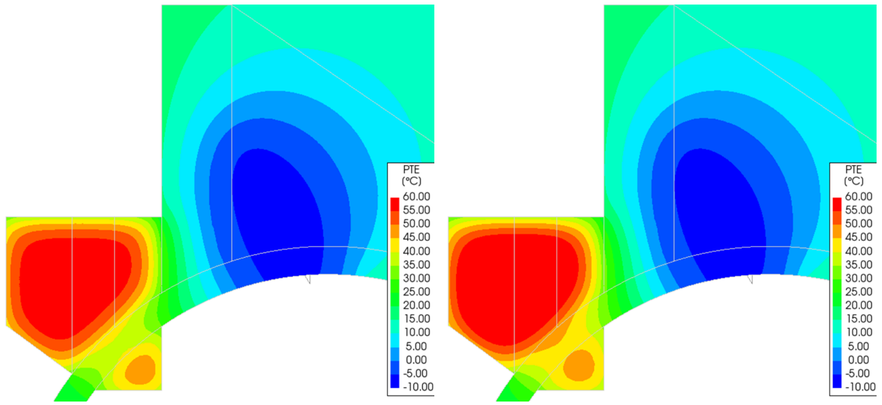

Plane of the freezing pipe
Beam_tot
Initial_freezing, Time-step 1, Time 4 hour
Frame 1/120
Temperatures PTE
min: -34.00°C max: 20.00°C
PTE
(°C)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00

ANNEX



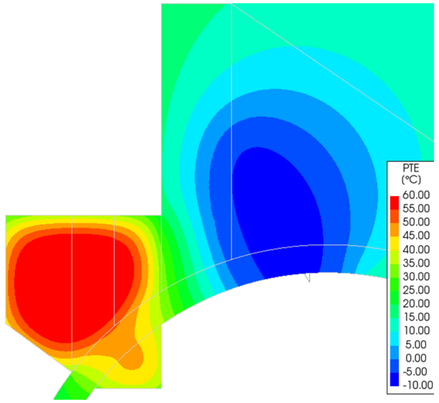
67 days + 1 hour

67 days + 12 hours

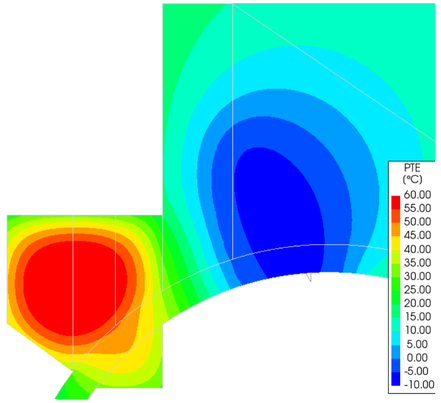


67 days + 24 hours

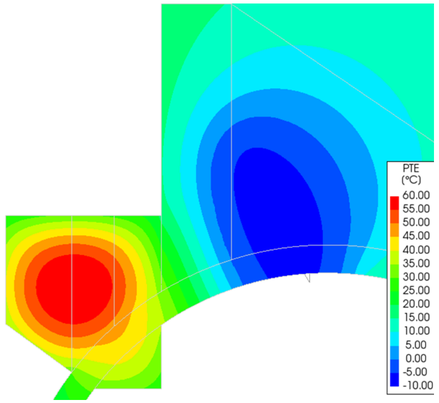
67 days + 36 hours



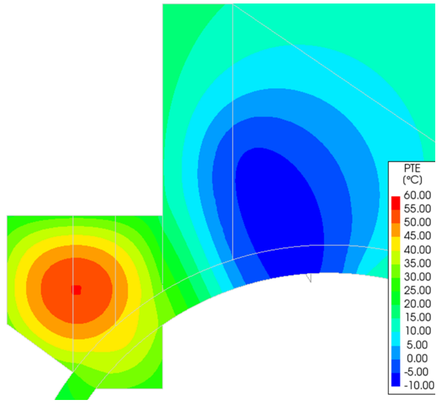
67 + 2 days



67 + 3 days

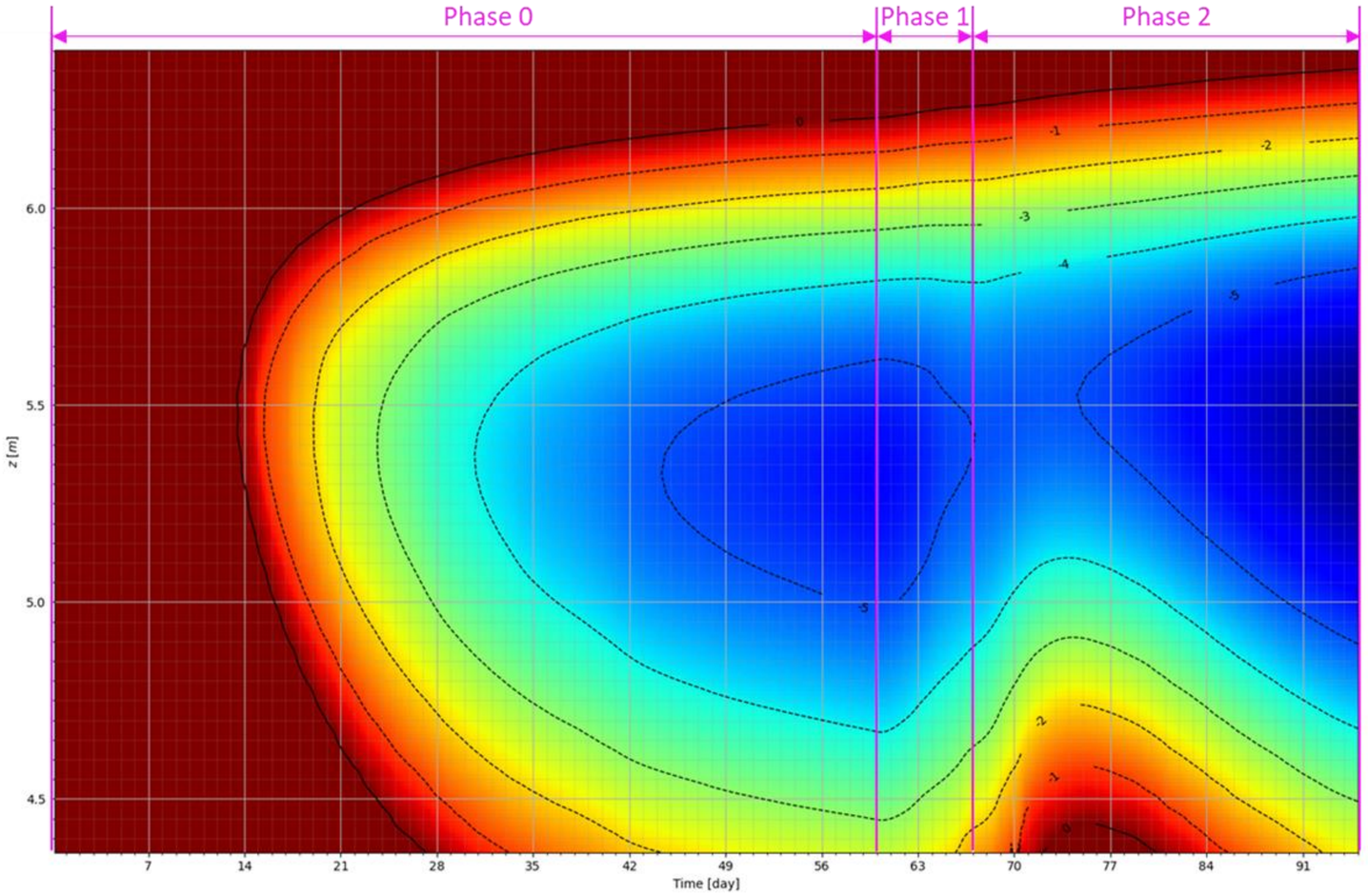


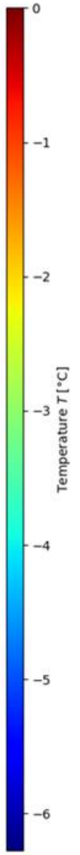
67 + 4 days

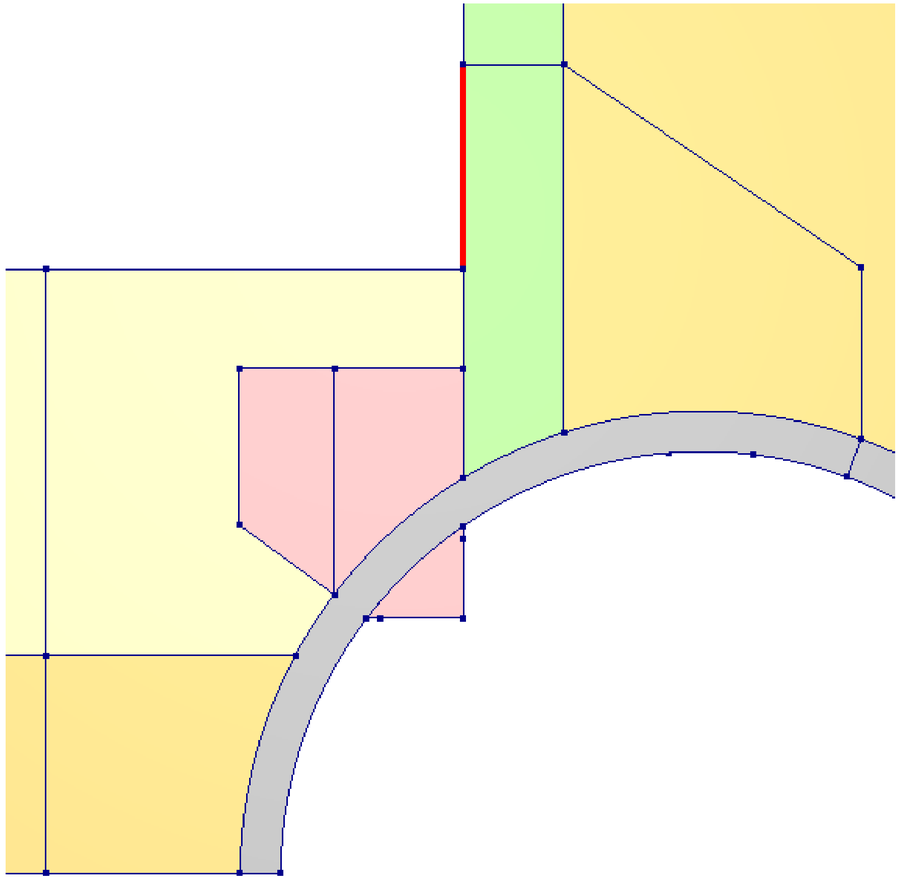


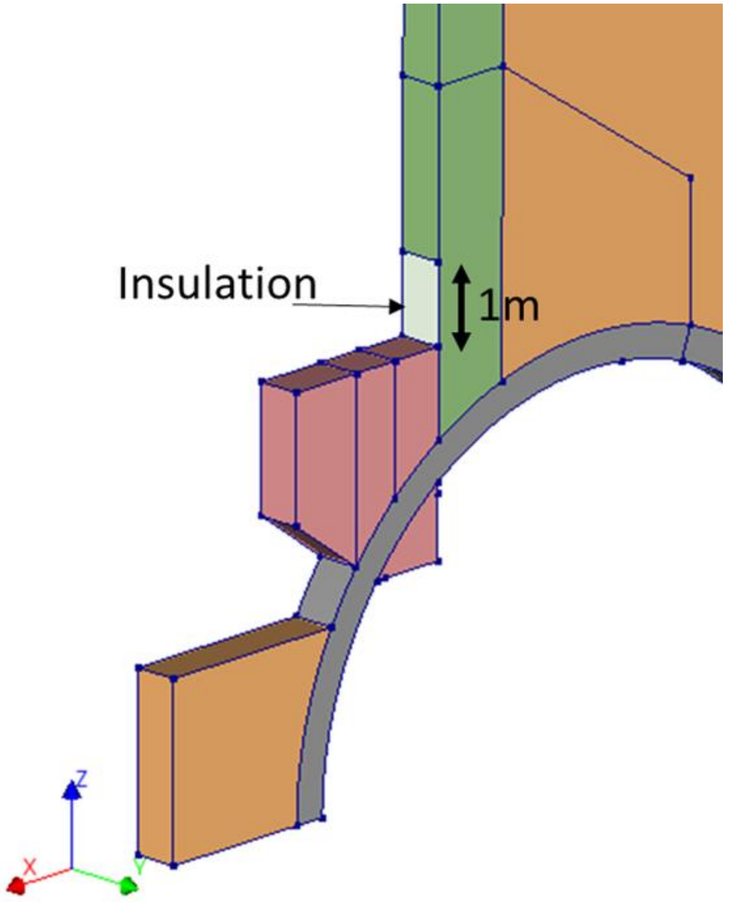
67 + 5 days

ANNEX


Phase 0
Phase 1
Phase 2
z [m]
6.0
5.5
5.0
4.5
7
14
21
28
35
42
49
56
63
70
77
84
91
Time [day]


0
−1
−2
−3
−4
−5
−6
Temperature T [°C]




Insulation
1m
Z
X
Y