

# MORETRENCH

Lateral and Vertical Pressures on  
Structures During Artificial Ground  
Freezing

Lessons Learned from  
First Street Tunnel, Washington, D.C.

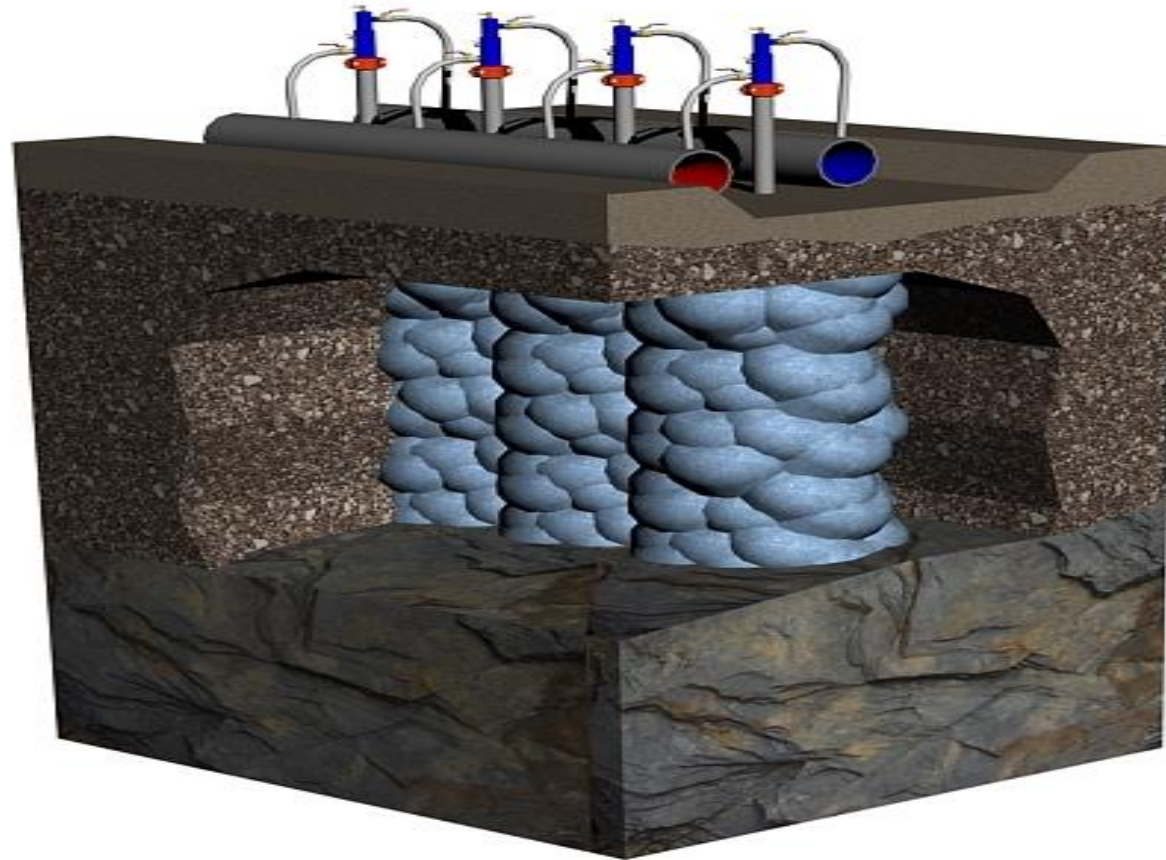
And

Access Shaft No. 3, Buenos Aires,  
Argentina

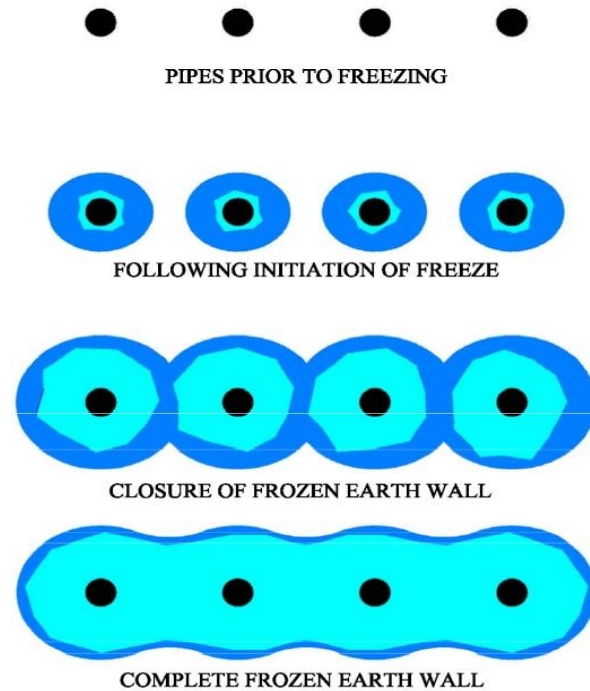
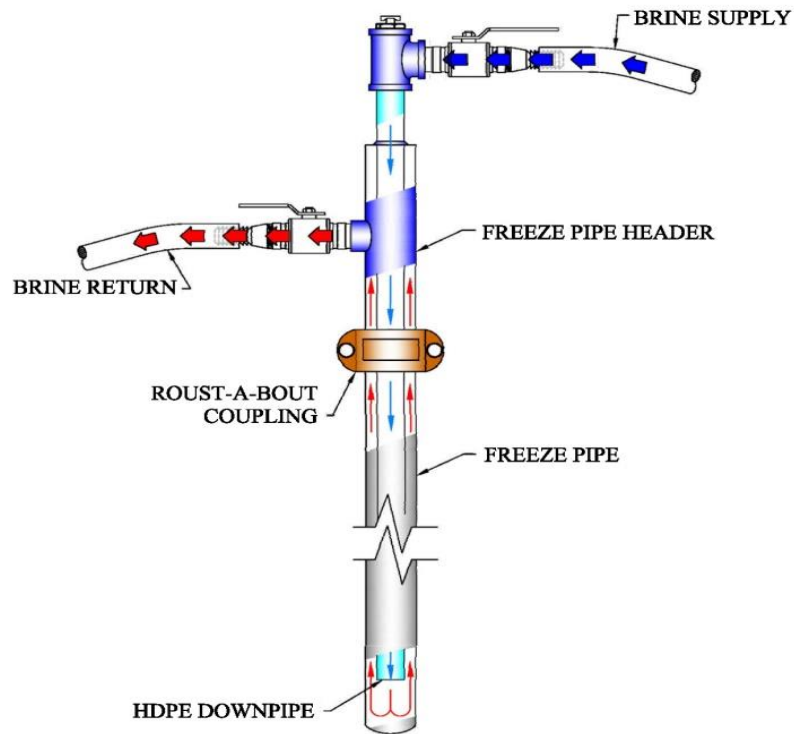
**MORETRENCH**

# BASIC GROUND FREEZING

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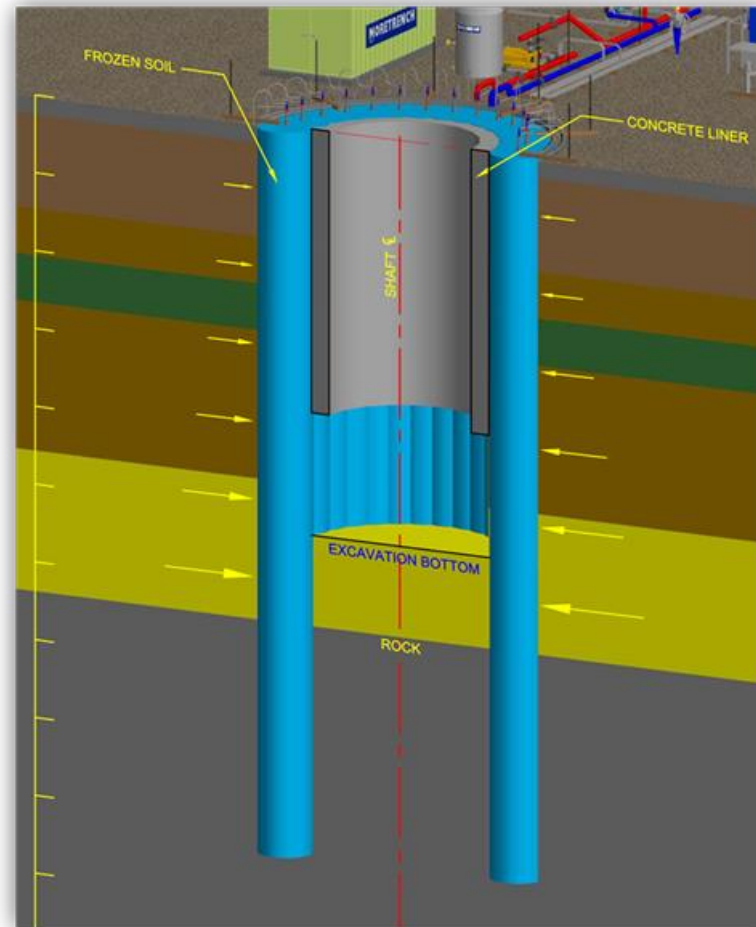


# REFRIGERATION PIPE DETAIL



# TYPICAL FROZEN SHAFT

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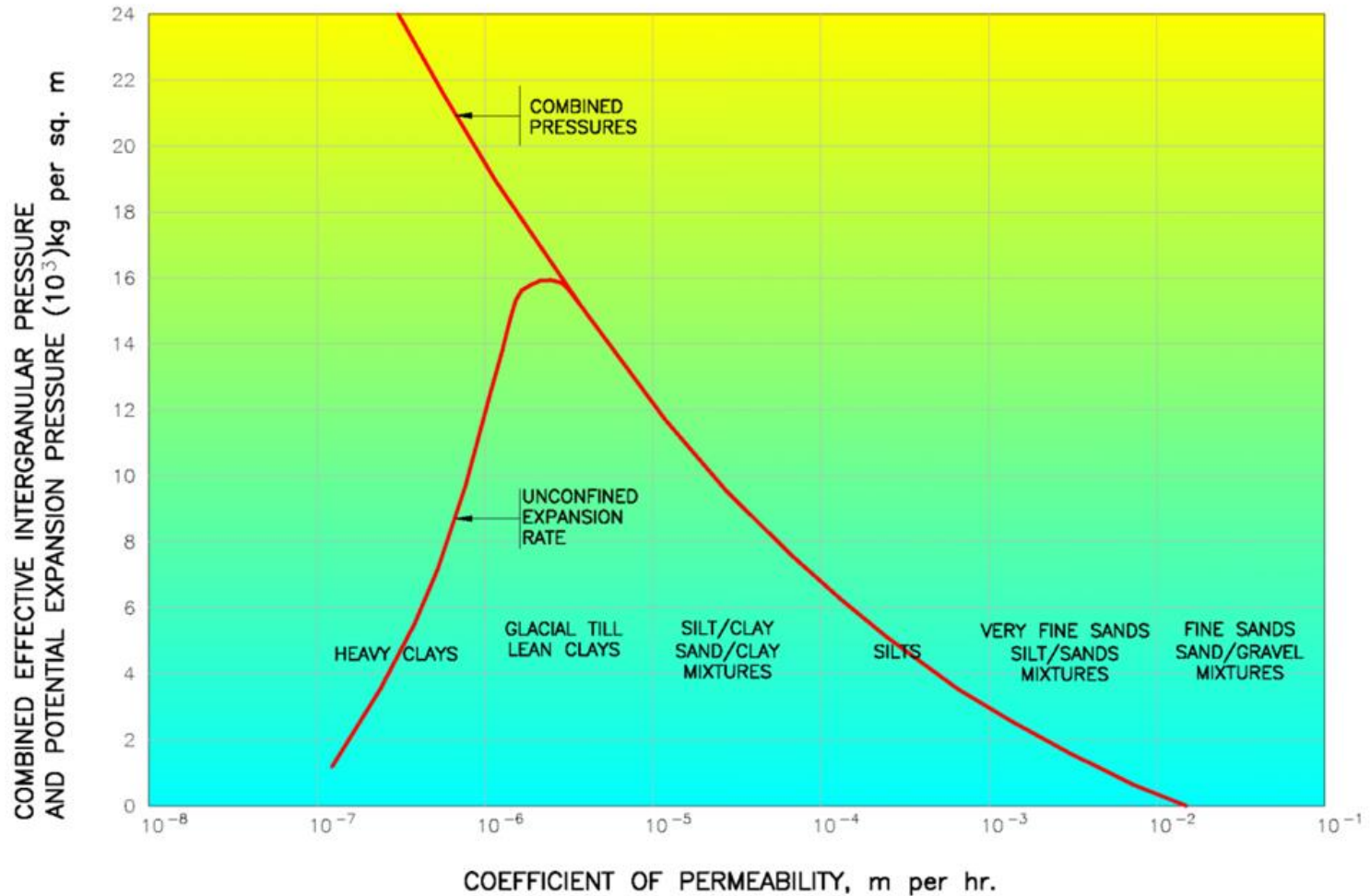


# FROST ACTION

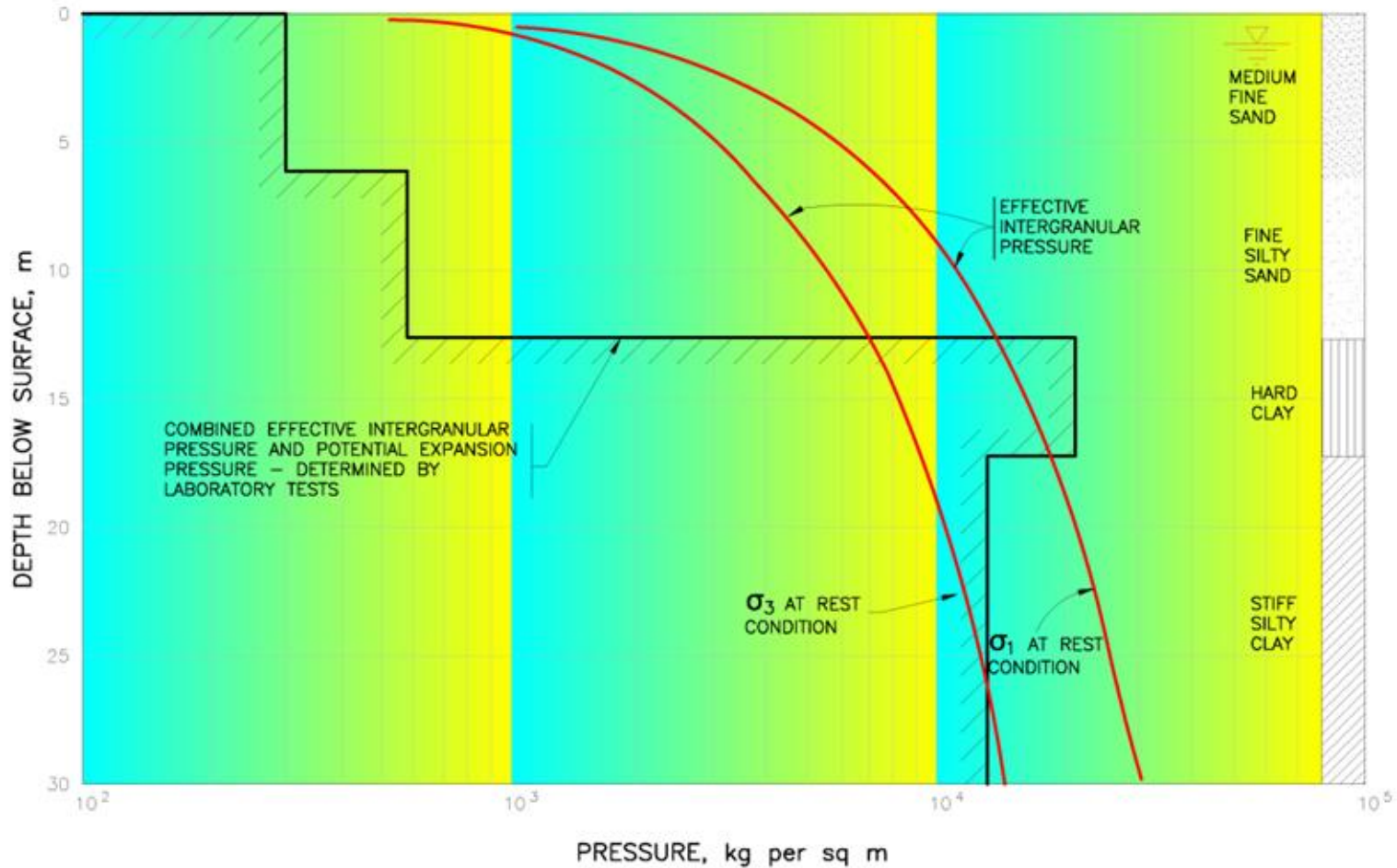
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- Combination of frost heave during and advance of the freezing front followed by a loss of strength during thaw
- Heaving is primarily:
  - a. Expansion of pore water
  - b. Ice segregation and forming of bands

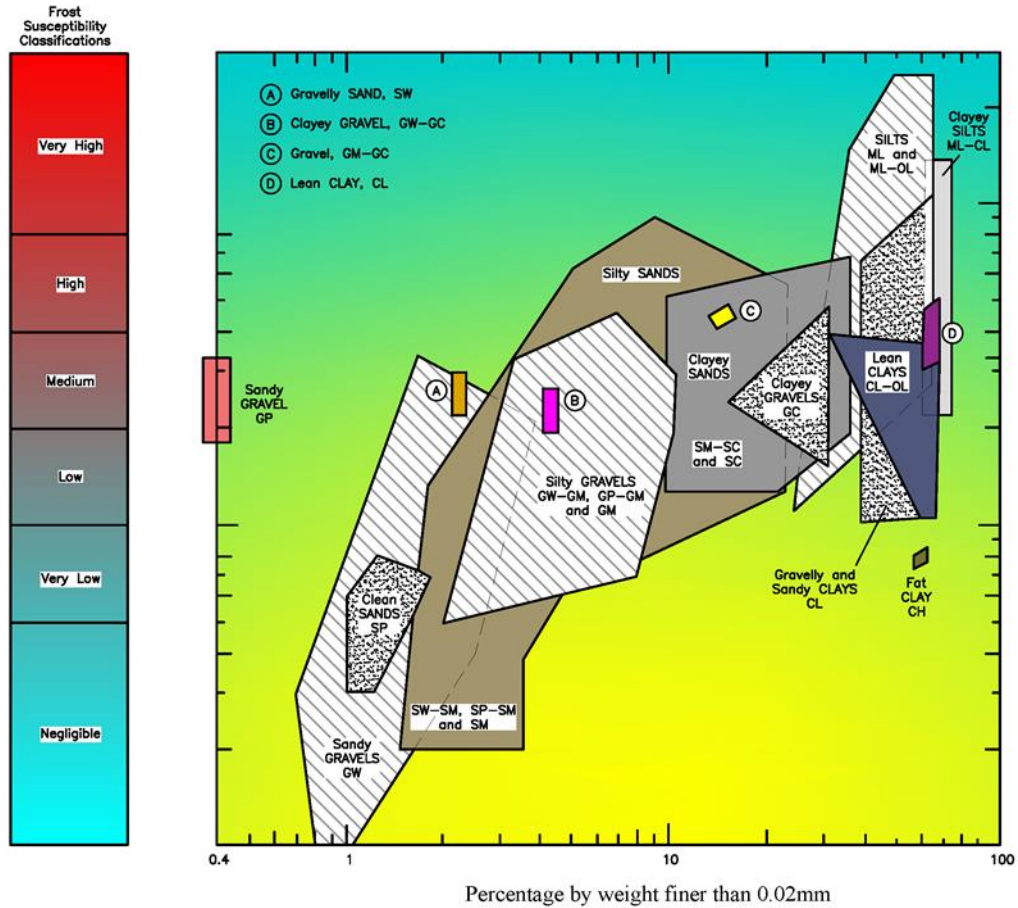
# FROST PRESSURE - PERMEABILITY



# EFFECTS OF OVERBURDEN



# FROST SUSCEPTIBLE SOILS





# ADDRESSING PRIMARY HEAVE

## VOLUMETRIC EXPANSION TEST

DATE	PROJECT					
	NAME: Moretrench - Boeing Project					
PROJECT NO.:	04.11160017					
Boring No.	S-1	S-1	S-1	S-1	S-1	S-1
Sample No.	8	8	7	7	6	6
Depth (ft)	3.5 - 15.0	13.50 - 15.0	12.0 - 13.50	12.0 - 13.50	7.5 - 9.0	7.5 - 9.0
Material	Silty Sand	Silty Sand	Silty Sand	Silty Sand	Silty Sand	Silty Sand
Visual Identification:	Dark Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray	Dark Gray
Sample Temperature (°C)	Room Temp	Frozen	Room Temp	Frozen	Room Temp	Frozen
Length (cm)	11.173	11.295	11.467	11.703	12.679	12.907
	11.172	11.31	11.466	11.70	12.677	13.045
	11.175	11.332	11.468	11.798	12.68	12.998
	11.174	11.34	11.466	11.788	12.678	12.996
	11.175	11.338	11.468	11.795	12.677	13.008
Average Length (cm)	11.1738	11.323	11.467	11.7568	12.6786	12.9908
Diameter (cm)	6.3	6.43	6.295	6.532	6.198	6.57
	6.31	6.428	6.345	6.542	6.186	6.7
	6.325	6.431	6.35	6.538	6.29	6.98
	6.351	6.433	6.375	6.533	6.345	7.03
	6.366	6.435	6.398	6.534	6.45	7.12
Average Diameter (cm)	6.3304	6.4314	6.3526	6.5358	6.2938	6.88
Volume (cm <sup>3</sup> )	351.69	367.84	363.45	394.44	394.4464697	482.95
Wet Mass of Specimen (g)	699.58	711.69	702.1	713.74	722.3	746.77
Water Content (%)	22.97%		21.60%		17.67%	
Wet Unit Wt. (g/cm <sup>3</sup> )	1.99	1.93	1.93	1.81	1.85	1.57
Dry Unit Wt. (g/cm <sup>3</sup> )	1.62		1.59		1.58	
REMARKS						

DATE: 8/9/16  
REVIEWED BY: JBA  
DATE: 8/9/16  
COMPUTED BY: JBA  
TESTED BY: JBA/AA

# PLAXIS INPUT PARAMETERS

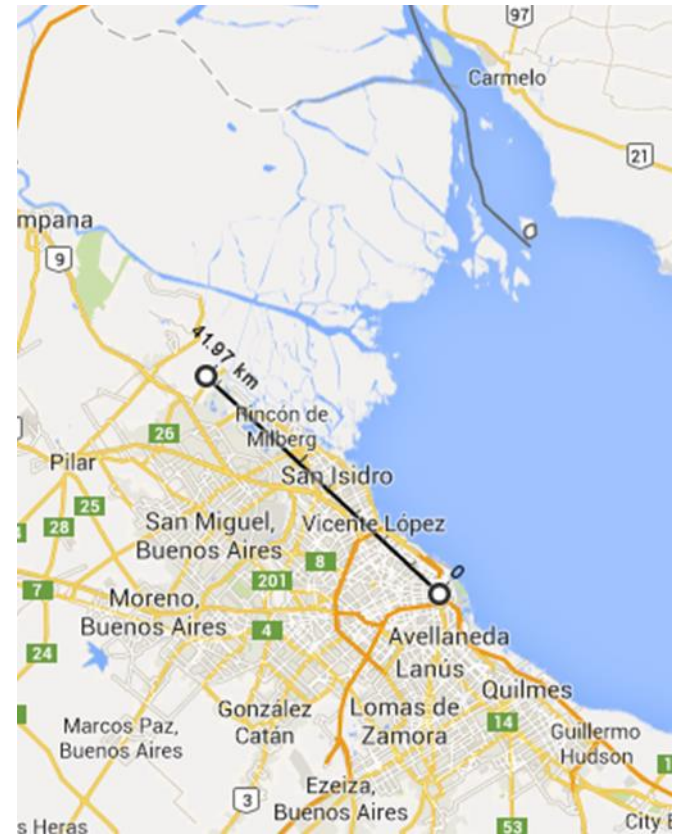
The screenshot displays the PLAXIS 3D AE software interface for a project named 'Ref\_project.p3d'. The main window shows a 3D model of an excavation with a circular structure and a rectangular excavation with bracing. The interface includes several panels:

- Phases explorer:** Lists various phases such as 'Frozen soil [Phase\_4]', 'Excavation level 1 [Phase\_3]', 'Bracing level 1 [Phase\_5]', etc. 'Excavation level 3 [Phase\_8]' is highlighted.
- Selection explorer (Phase\_8):** Shows the selected object 'CS\_GeneratedSoilVolume\_1\_Soilayer\_1' with its properties, including 'Material: FrozenSoil', 'VolumeStrain\_1\_21', and 'WaterConditions\_1\_21'. This panel is highlighted with a red box.
- Model explorer (Phase\_8):** Lists model components like 'Attributes library', 'Geometry', 'Groups', 'Beams', 'Node-to-node anchors', 'Plates', 'Interfaces', 'Soils', and 'Model conditions'.
- Command line:** Shows the following commands:

```
Session | Model history
point 1 2 3
info point_1
Use the "info" command to access information about an object
Use the "commands" command to view the command parameters expected by the commands of the target object
1224> _setcurrentphase Phase_8
Phase_8 set as current phase
1225> _set (VolumeStrain_1_21.Apply VolumeStrain_1_141.Apply VolumeStrain_1_23.Apply VolumeStrain_1_22.Apply) Phase_8 True
OK
1226> _set (VolumeStrain_1_21.epsvol VolumeStrain_1_141.epsvol VolumeStrain_1_23.epsvol VolumeStrain_1_22.epsvol) Phase_8 6
OK
```

# FROST PRESSURES AGAINST TUNNEL LINER

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# TUNNEL – PARANA RIVER TO WATER TREATMENT PLANT

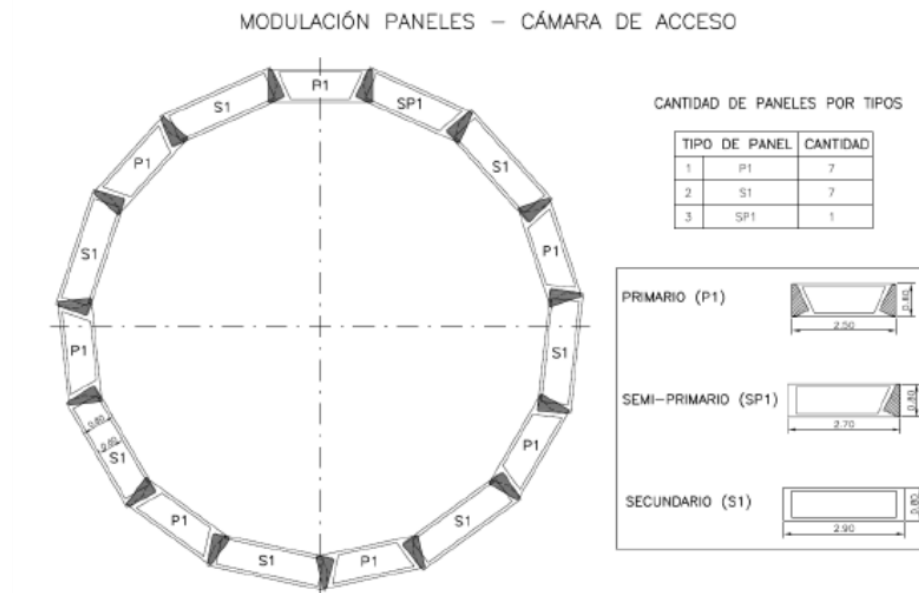
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- 3.6m diameter
- 15km long
- 18-22m deep
- Bored with 2 TBMs
- 5 Access shafts



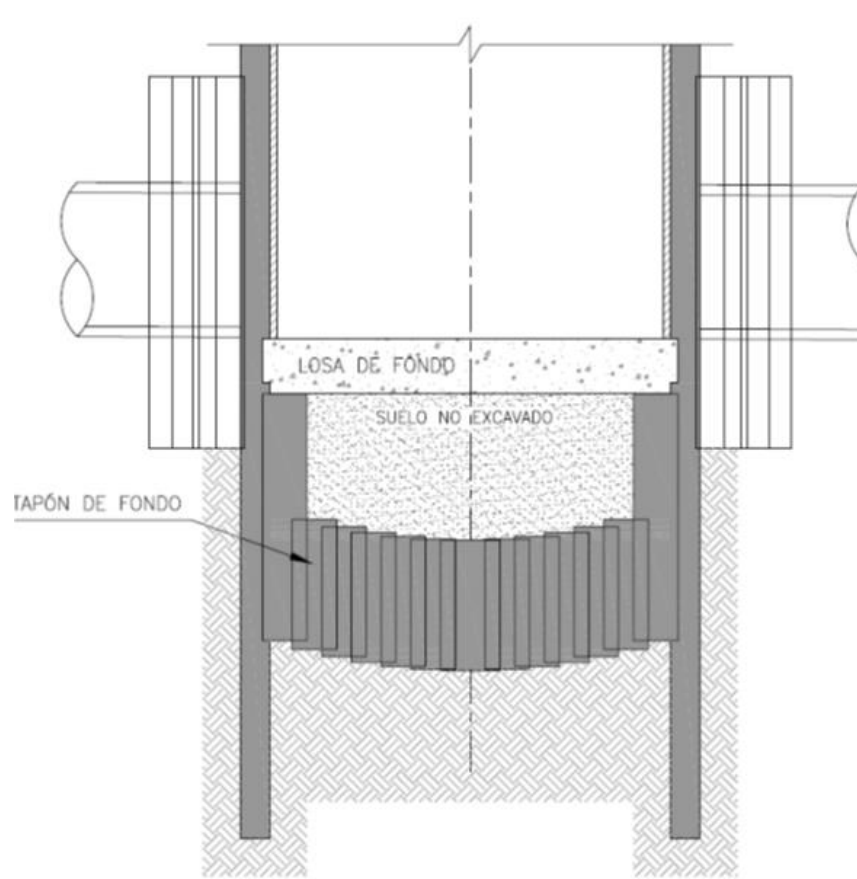
# ACCESS SHAFT #3 (CA3)

- 10.8m diameter
- Diaphragm wall panels and jet grouted bottom seal



# ACCESS SHAFT #3 (CA3)

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# EXCAVATION

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- Started October 2, 2012
- 12m deep by October 10



# LEAKS - OCTOBER 10

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# REPAIR – TREMIE GROUTING

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- October 12, 2012 Injected 4m<sup>3</sup> of grout



# MORE LEAKS – OCTOBER 15, 2012

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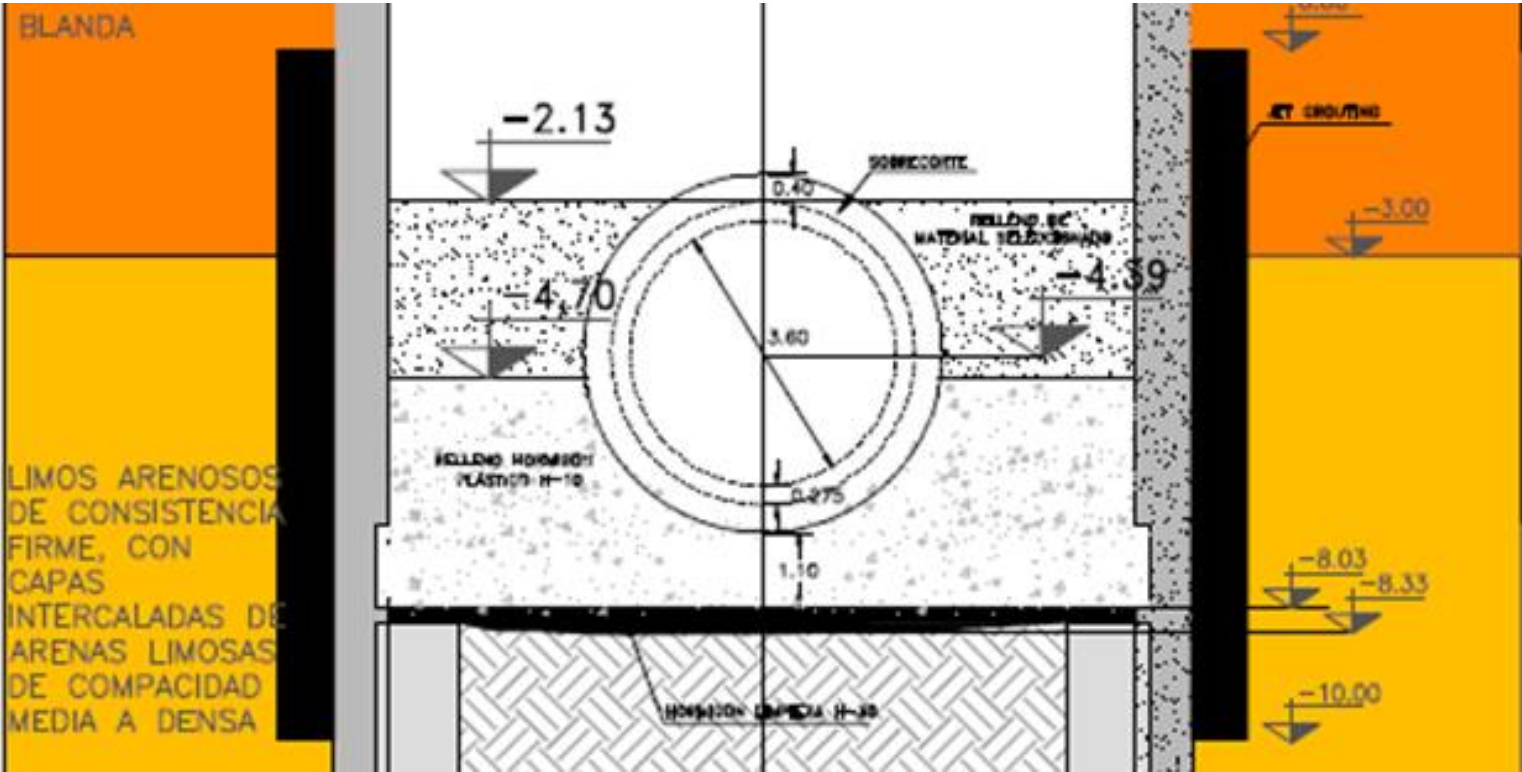


# REPAIRS

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- Permeation grouting near joints
- Jet grouting
- Dewatering
- December 5, flooded again

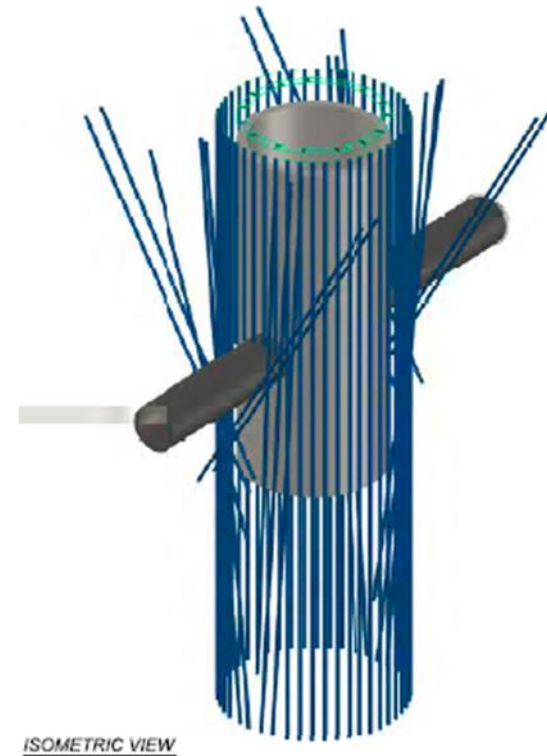
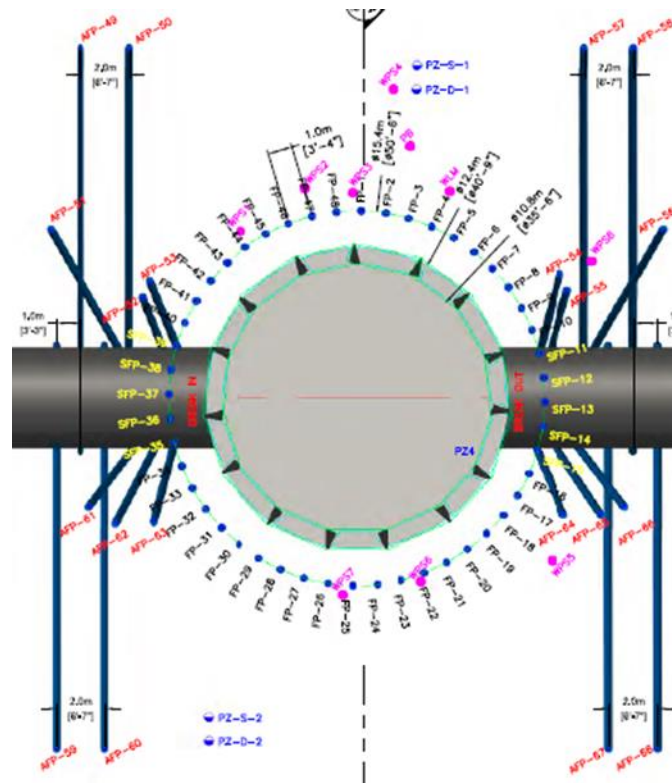
# TEMPORARY FIX



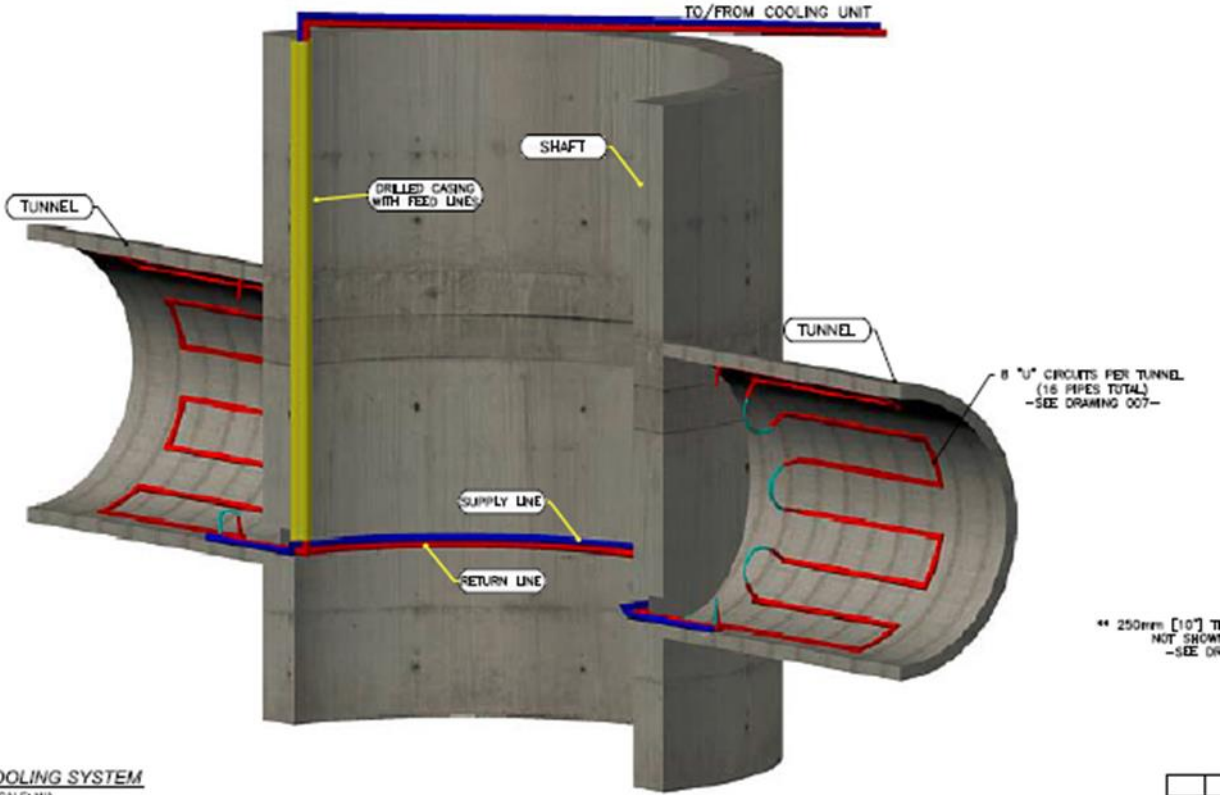
LIMOS ARENOSOS DE CONSISTENCIA FIRME, CON CAPAS INTERCALADAS DE ARENAS LIMOSAS DE COMPACIDAD MEDIA A DENSA

# GROUND FREEZING OPTION

- 48 Vertical refrigeration pipes around the perimeter of the shaft
- 20 Angled refrigeration pipes to form a cradle under the tunnel



# TUNNEL COOLING SYSTEM



TUNNEL COOLING SYSTEM  
SCALE: N/A



# THERMAL DESIGN

- Design based on lowest strength sandy silt
- Not a structural wall, limited to groundwater cutoff
- Compute freezing time and required refrigeration capacity

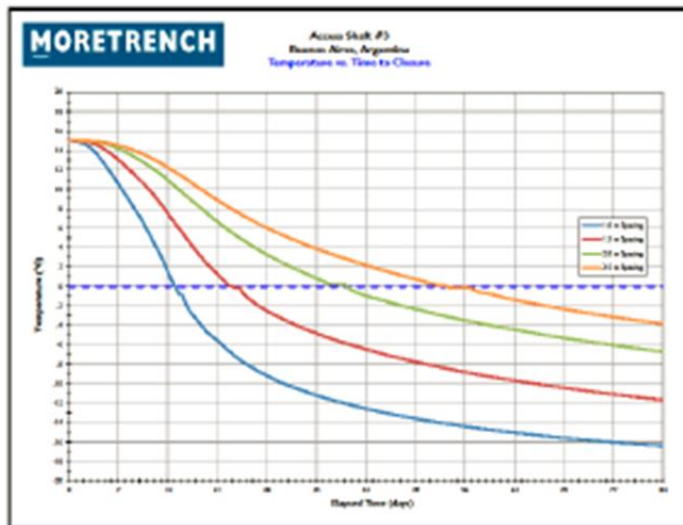


Figure 1A – Computed Freezing Times to Wall Closure

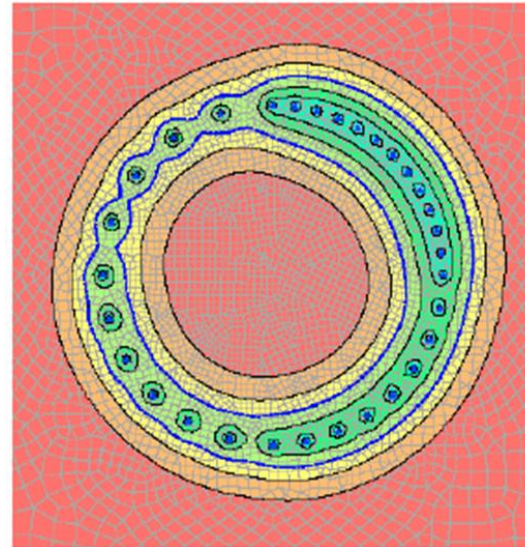


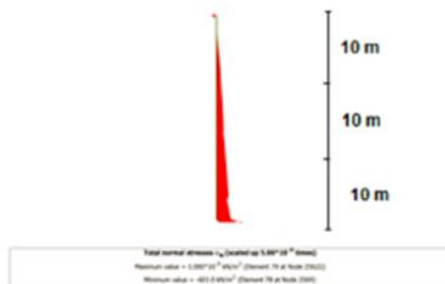
Figure 2 – Thermal Model after 8 Weeks

# STRUCTURAL DESIGN – 2D

- Computed soil pressures on slurry wall before and after freezing
- Used hoop stresses to calculate load on tunnel lining

## Pressure on Slurry Wall

- Before frozen ground



## Pressure on Slurry Wall

- After frozen ground and further digging

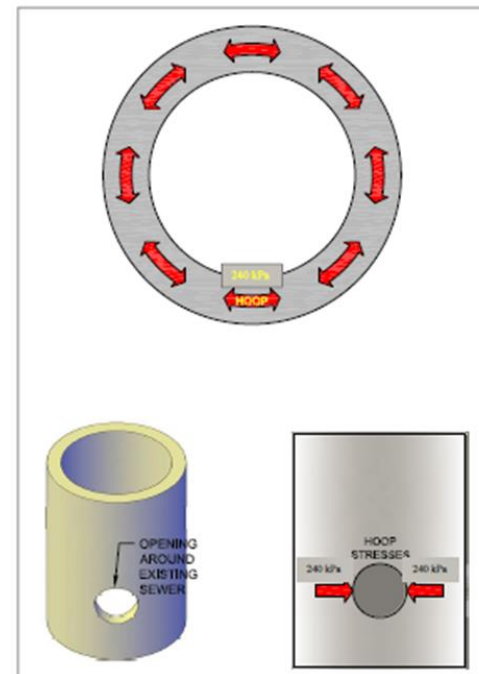
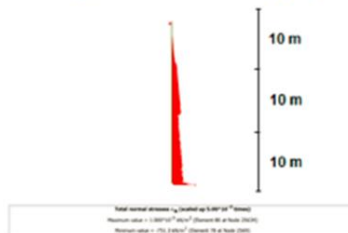


Figure 7 – Hoop stresses acting on tunnel in two-dimensional analysis



# STRUCTURAL DESIGN – 3D

- Computed maximum pressures using PLAXIS 3D

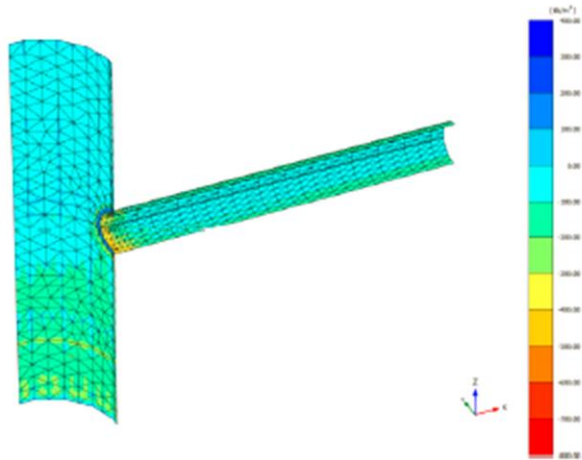


Figure 8 – Computed stresses on the existing shaft and tunnel in three-dimensional analysis

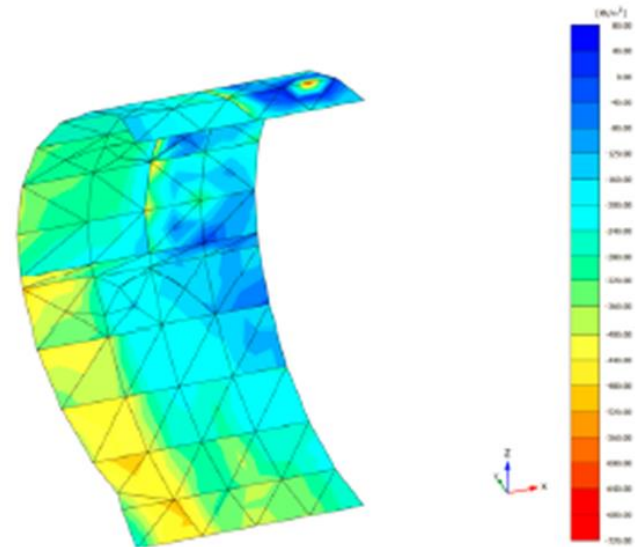
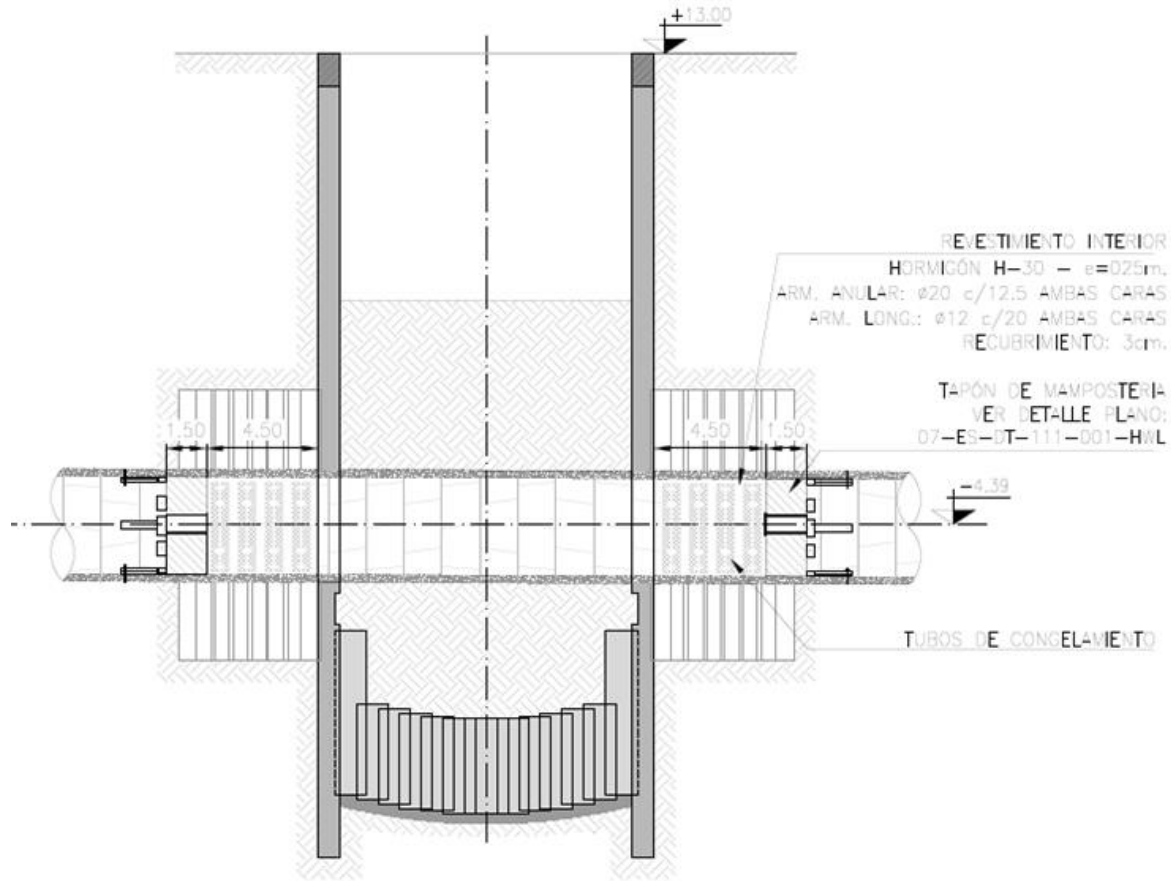


Figure 9 – Computed stresses on the existing tunnel in three-dimensional analysis

# STRUCTURAL REINFORCEMENT



# COOLING LOOP INSTALLATION

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# BULKHEADS

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# STRUCTURAL REINFORCEMENT

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# 2 YEARS AND SIX WEEKS LATER

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# COMPLETION

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# LESSONS LEARNED

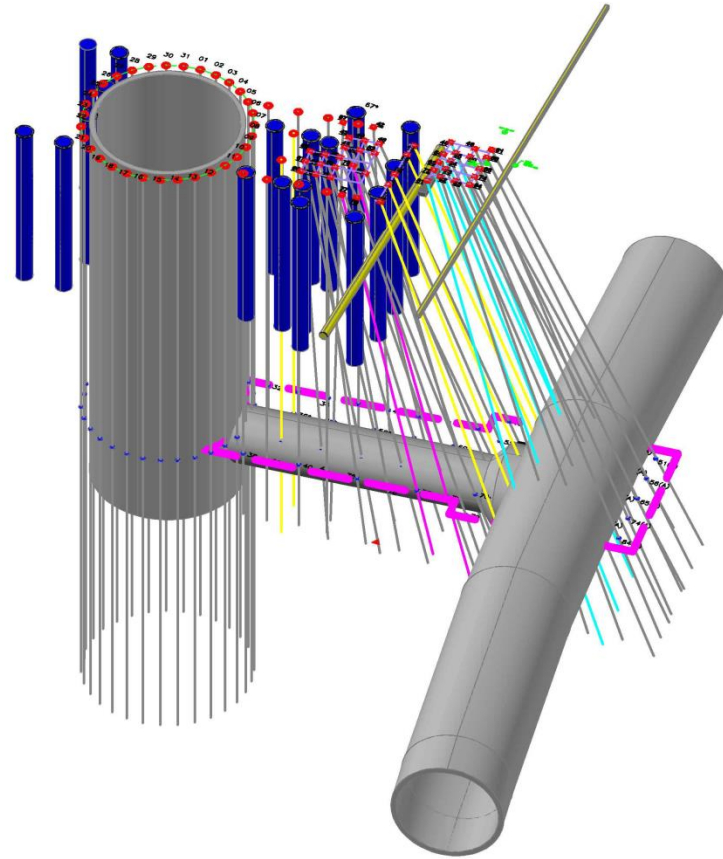
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- Approach of using volumetric expansion as a PLAXIS input was successful
- Need more data on future projects
- We are getting better after a recent project in Cleveland



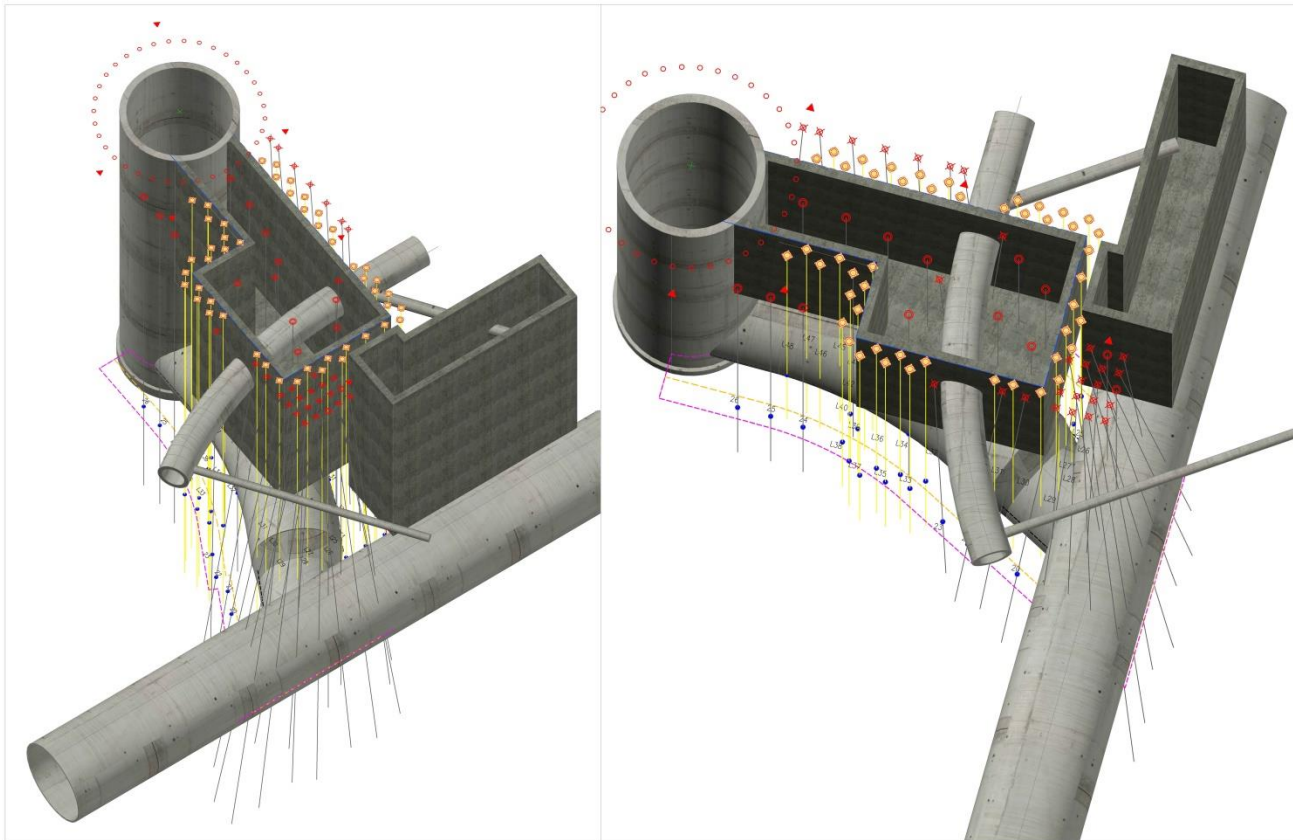
# FIRST STREET TUNNEL – D.C.

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# FIRST STREET TUNNEL – D.C.

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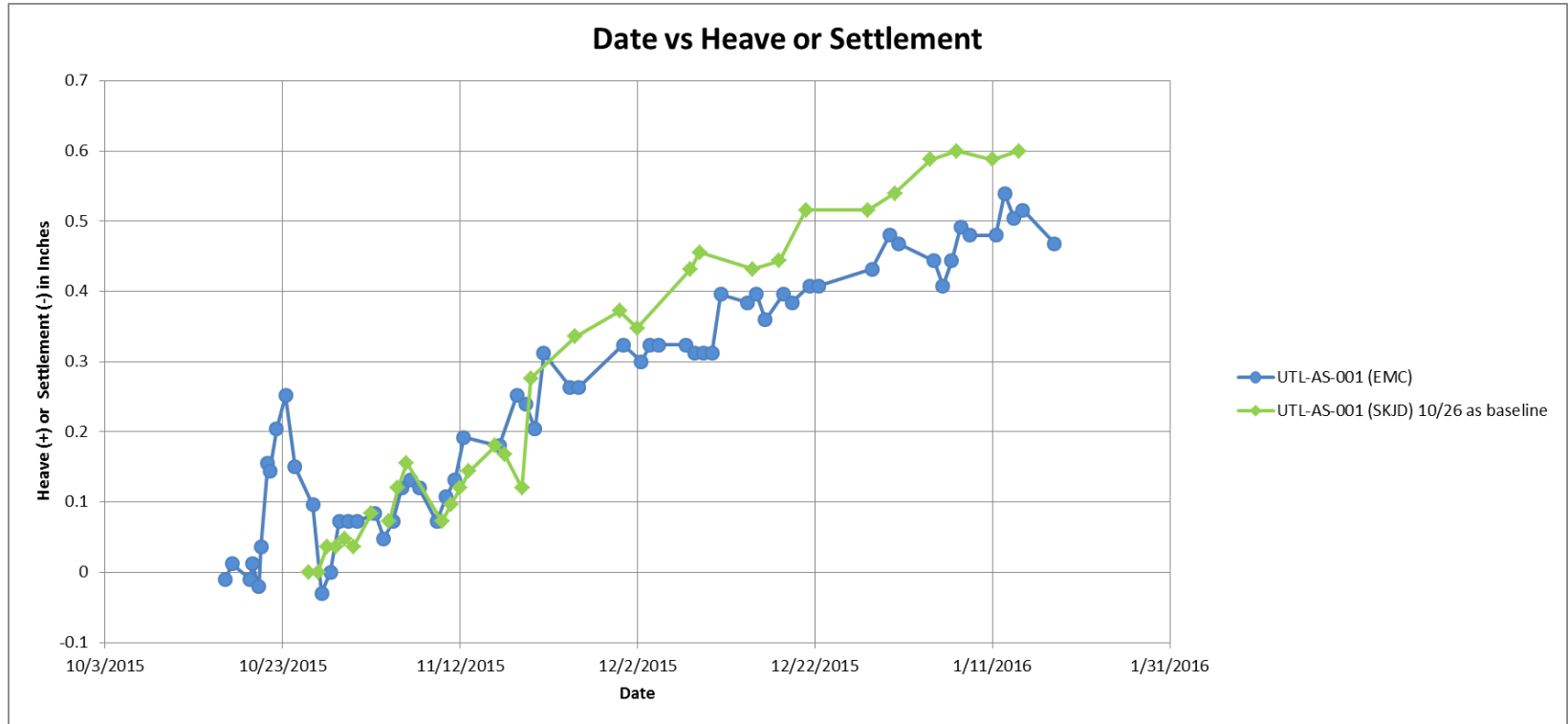


# REVIEWED FROST SUSCEPTIBILITY

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- Looked at each boring
- Soils were not frost susceptible
- Some heave was experienced

# UTILITY HEAVE



# UTILITY HEAVE

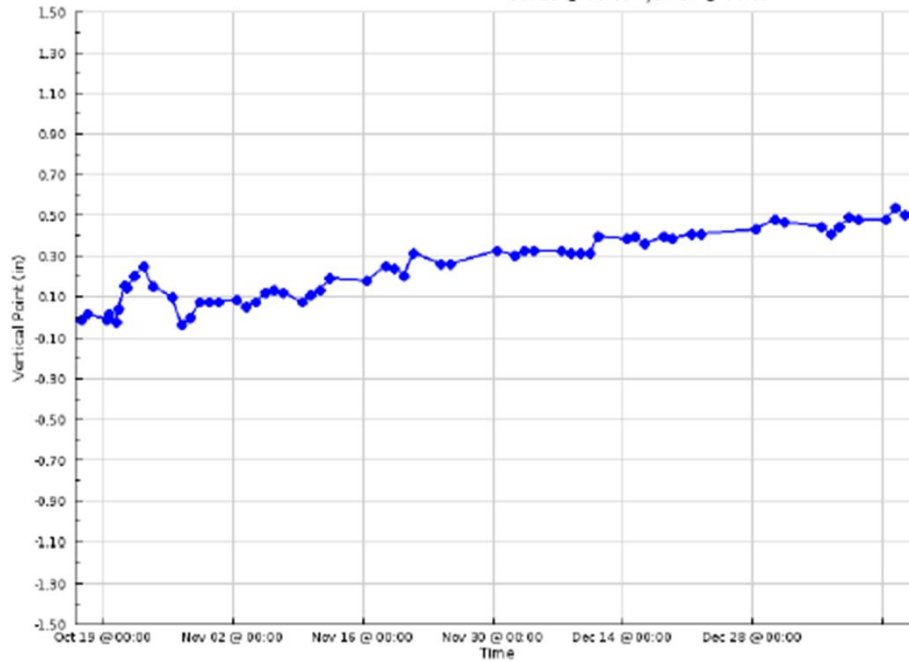
1/15/2016

Atlas Monitoring Software

UTL-AS-001 @30 in Water Line (DCCRID 020150B)

Oct 15 @ 00:00 - Jan 15 @ 00:00

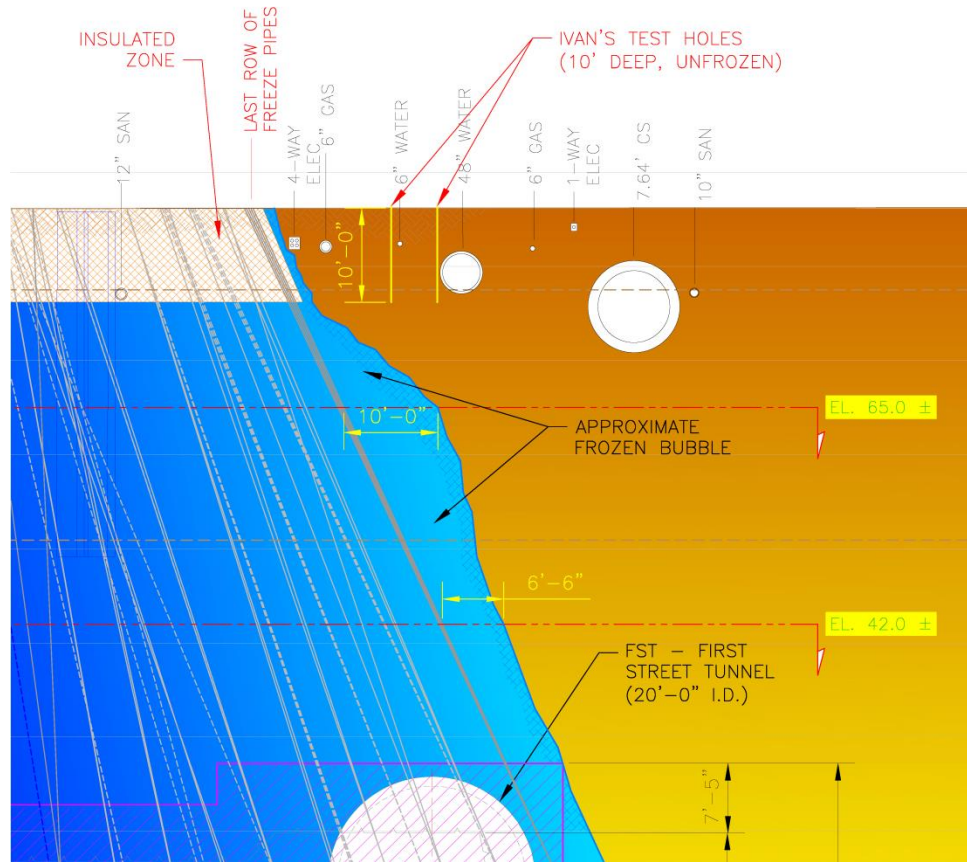
◆ UTL-AS-001 (Utility Monitoring Point)



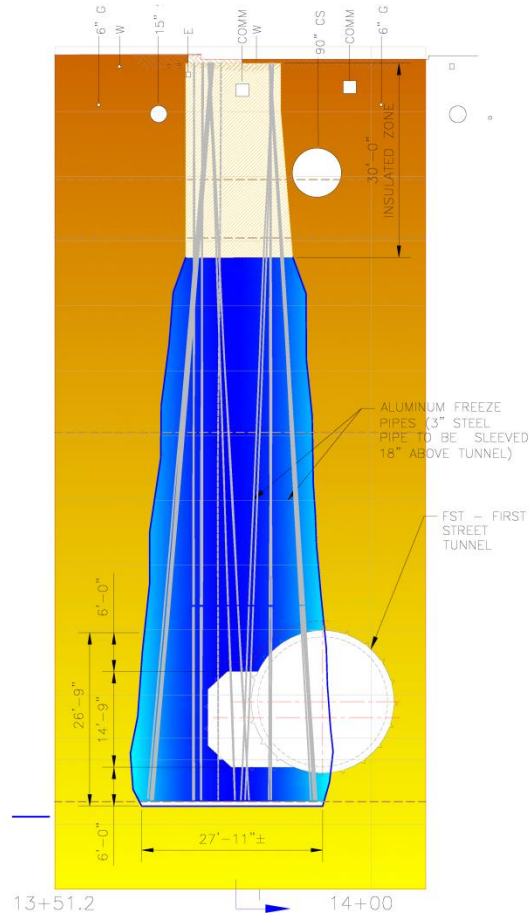
Zoom 24h 3d 7d 14d 30d 90d 180d 360d 720d All Larger Print Download Data View Data

[Close Window](#)

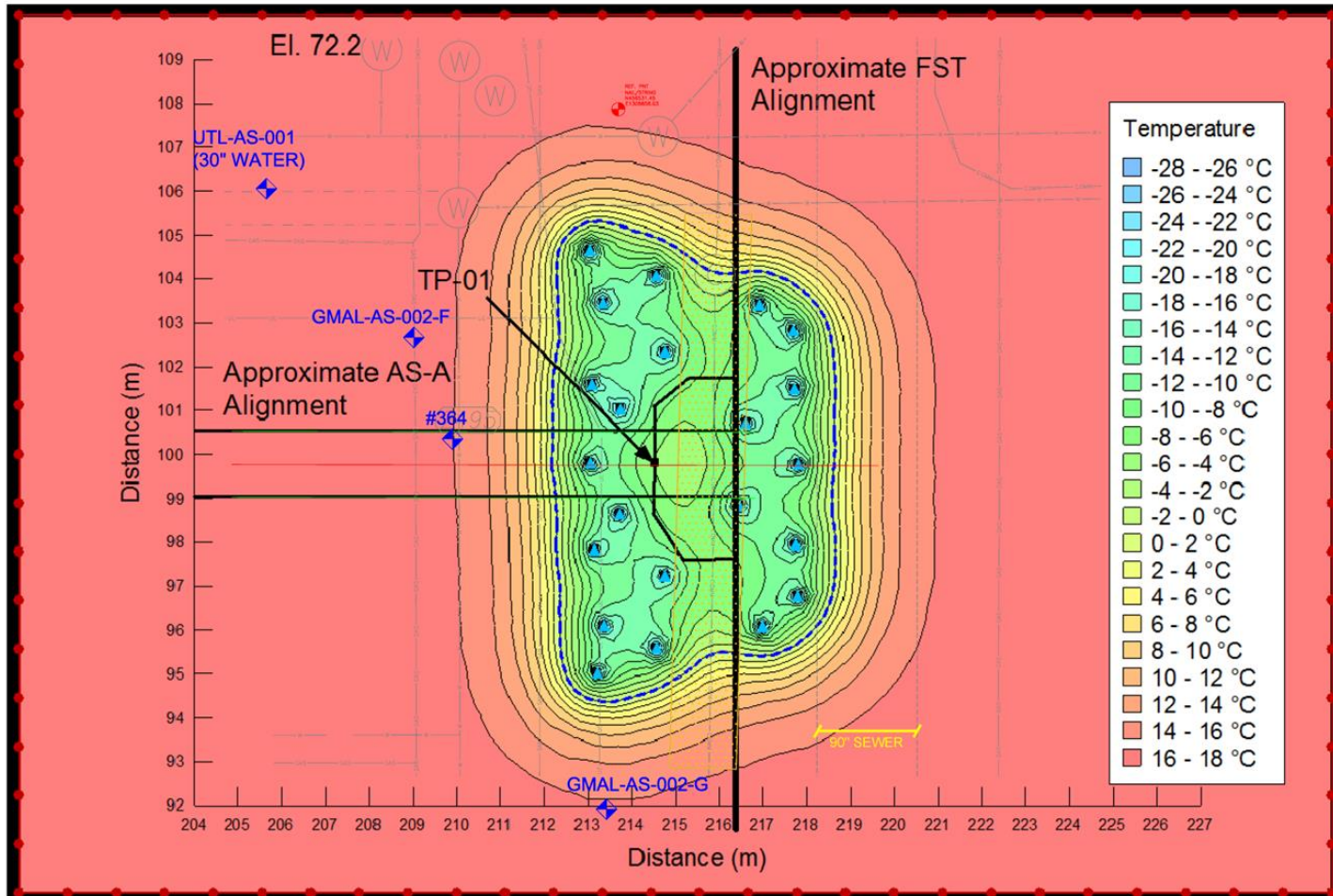
# WHY?



# SECTION

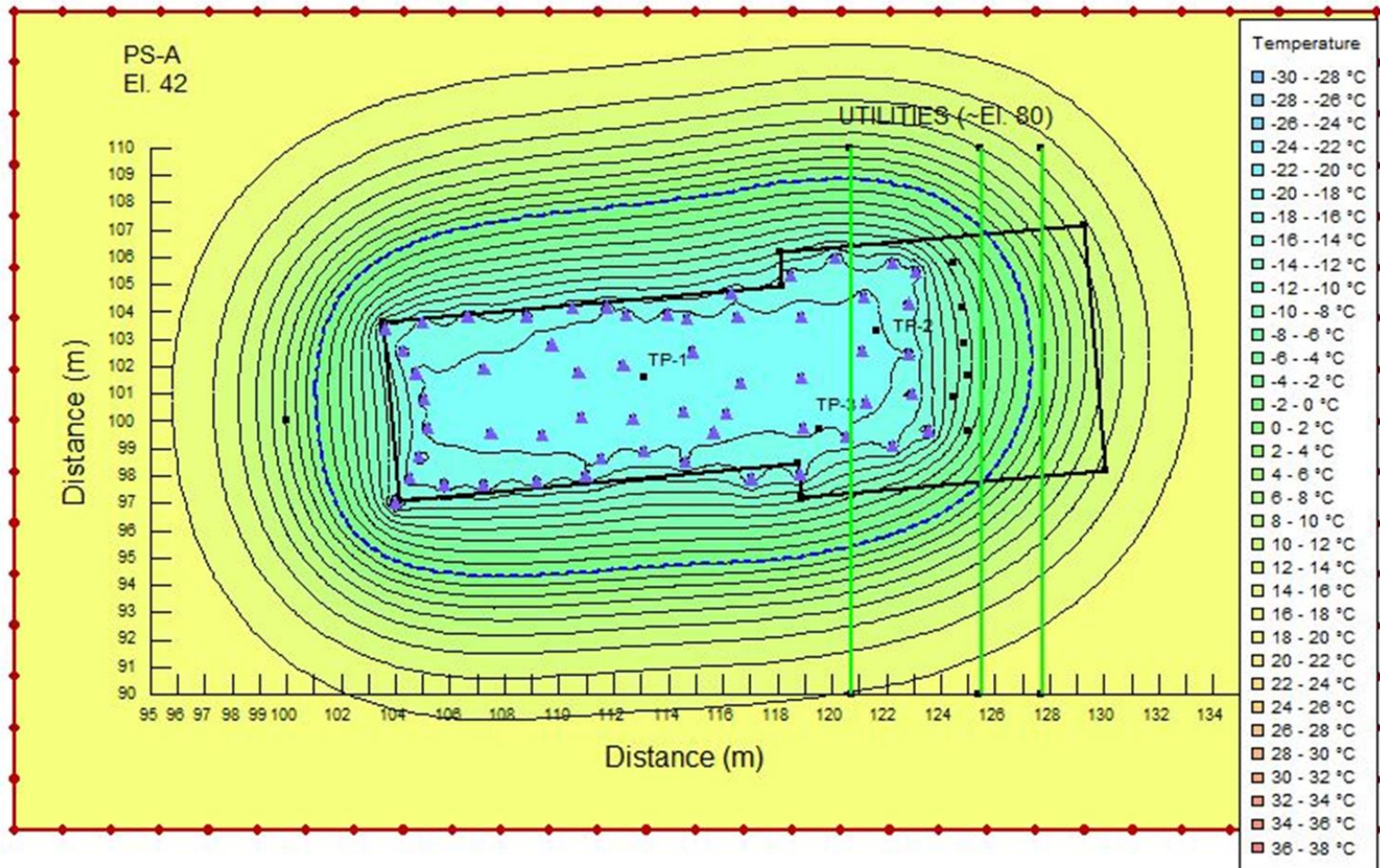


# INSTALLATION OF HEATING PIPES

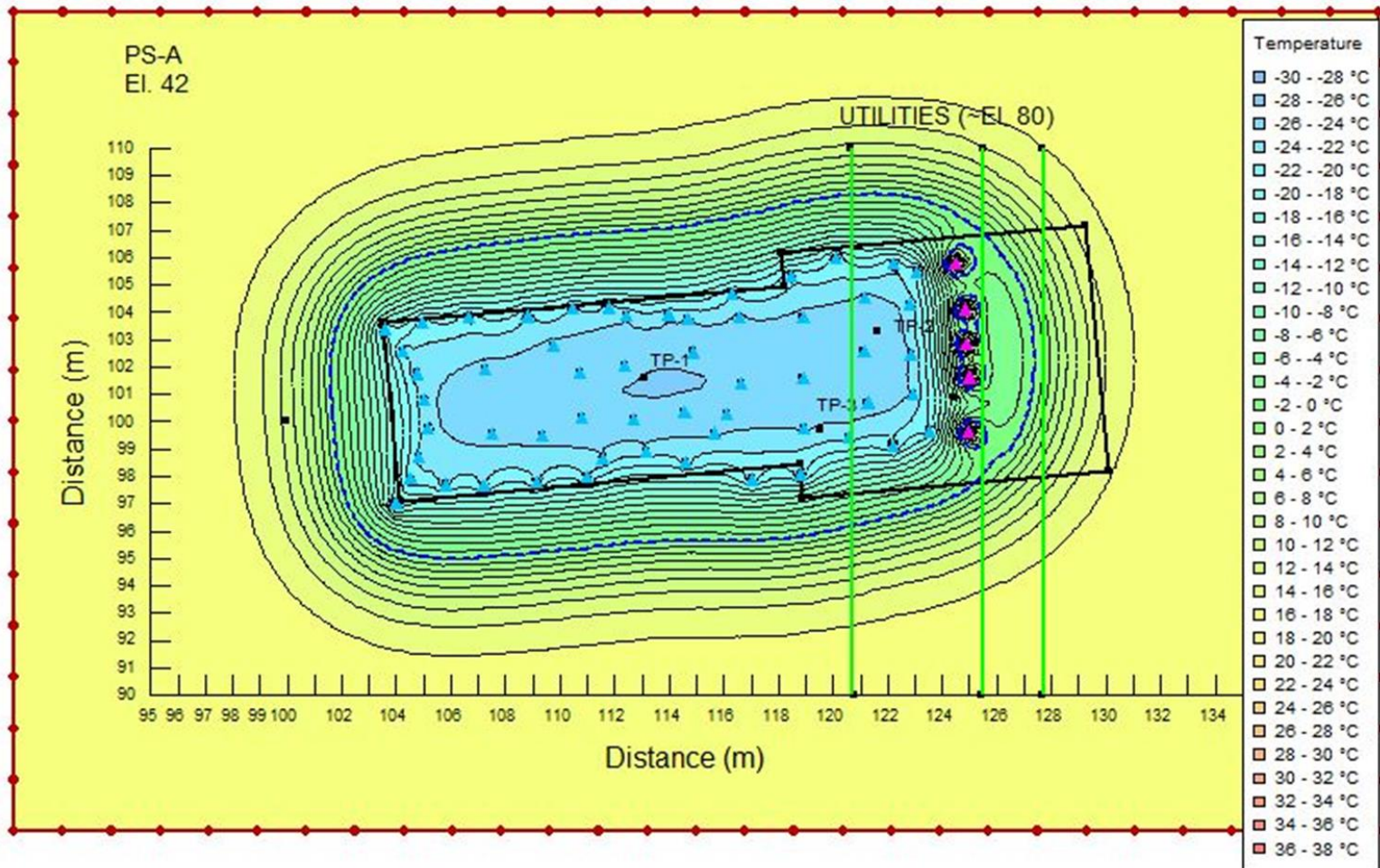




# REDUCING REFRIGERATION



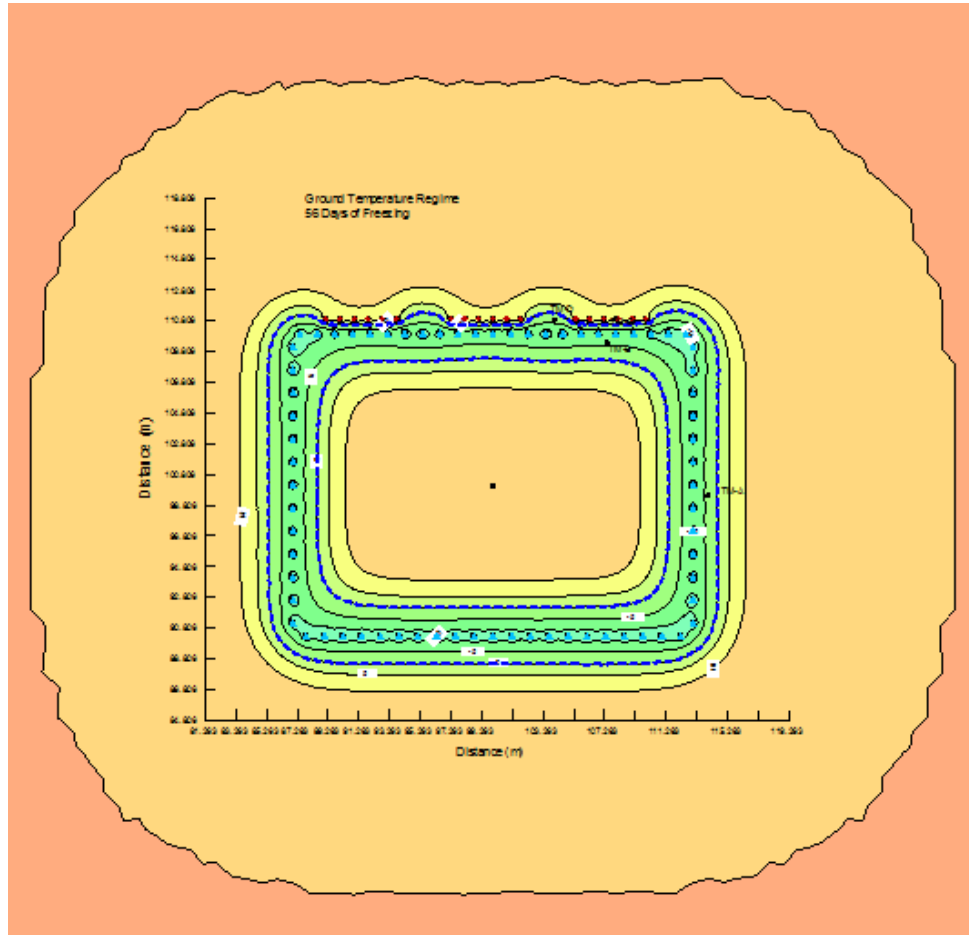
# ACTIVATION OF HEAT PIPES





# PROACTIVE PROCEDURE

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# LESSONS LEARNED

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- Soils don't always behave as expected
- When in doubt, heat

# SUMMARY

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- We are getting better at lateral pressures
- Vertical heave is hard to predict, but can be prevented with heating pipes