MORETRENCH

Lateral and Vertical Pressures on Structures During Artificial Ground Freezing

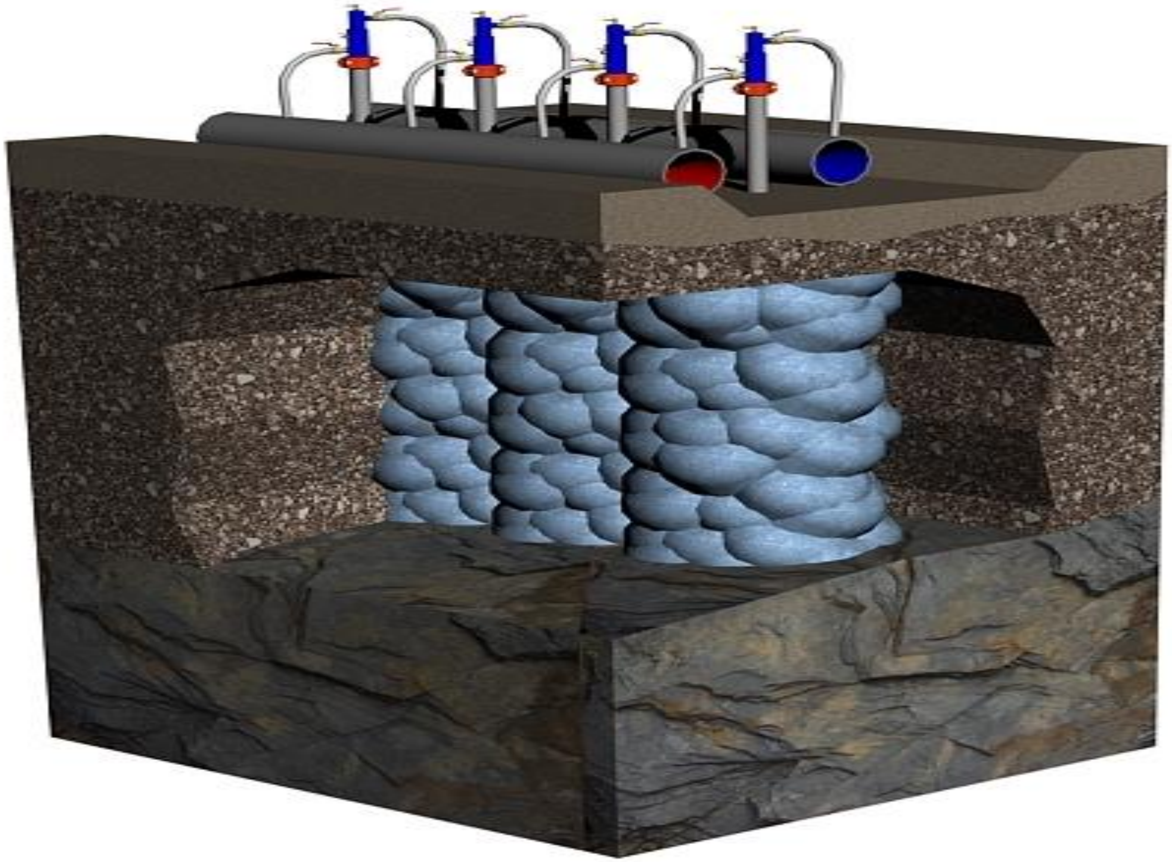
Lessons Learned from

First Street Tunnel, Washington, D.C.

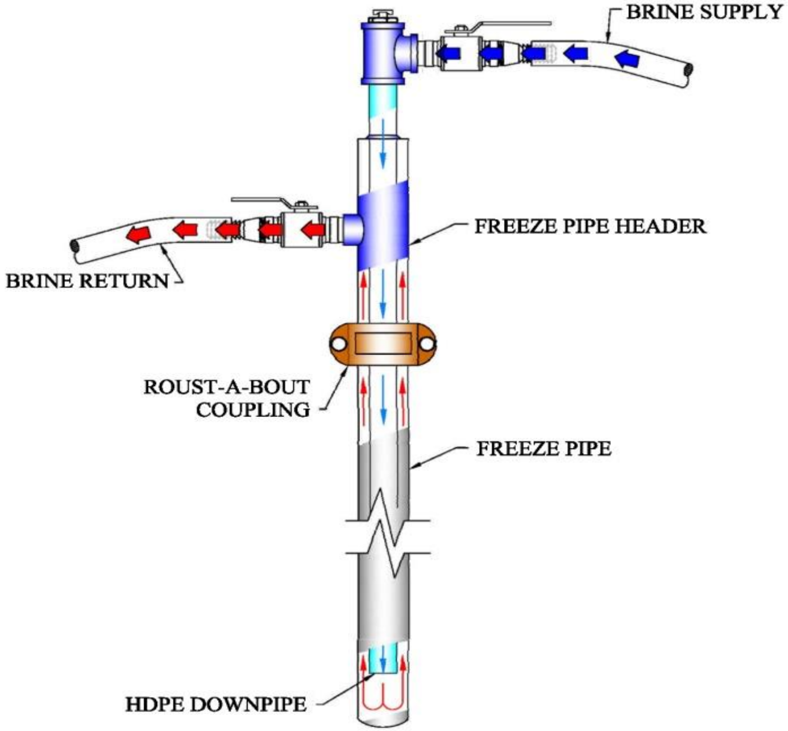
And

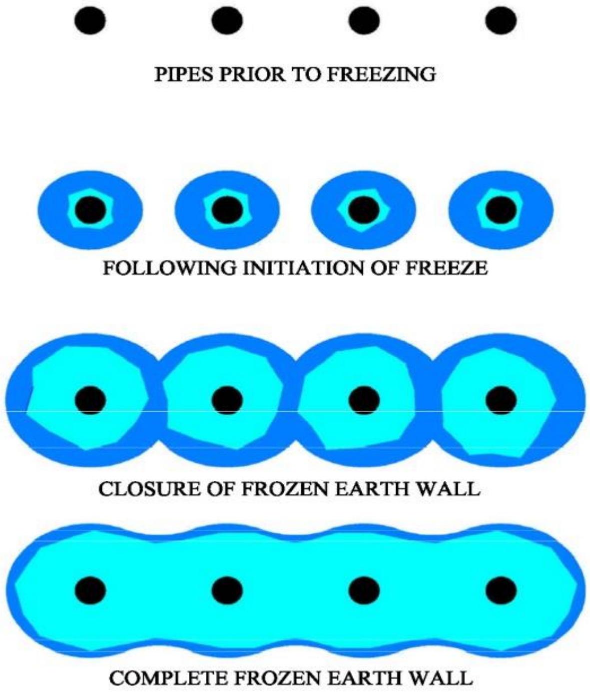
Access Shaft No. 3, Buenos Aires, Argentina

BASIC GROUND FREEZING

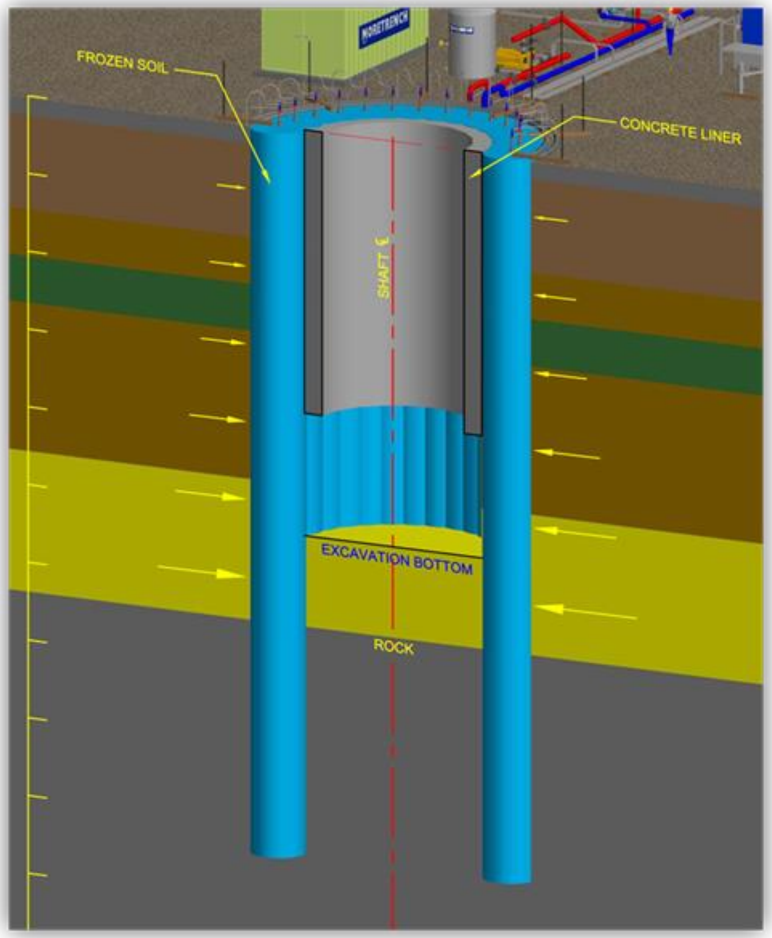


REFRIGERATION PIPE DETAIL





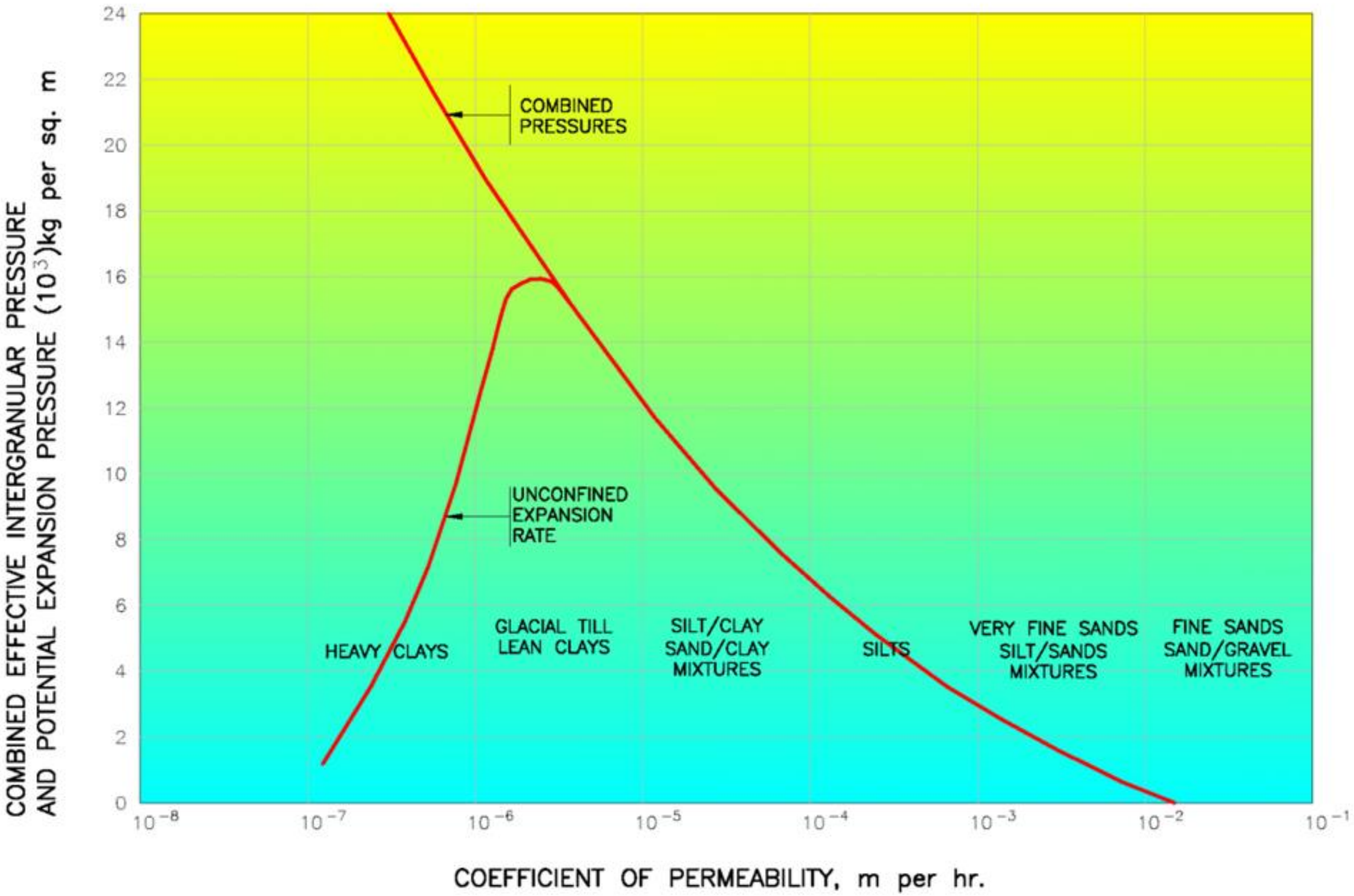
TYPICAL FROZEN SHAFT



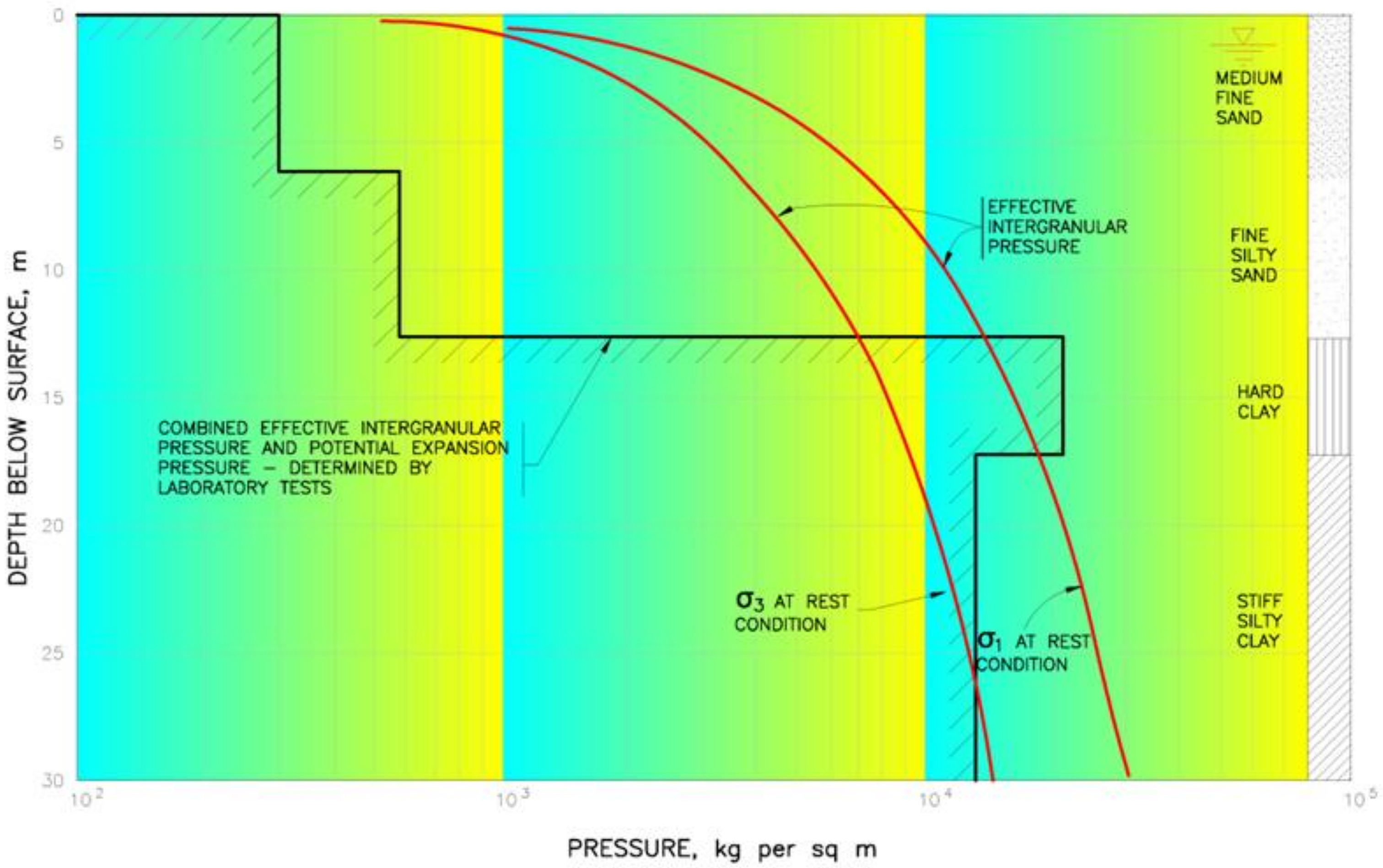
FROST ACTION

- 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

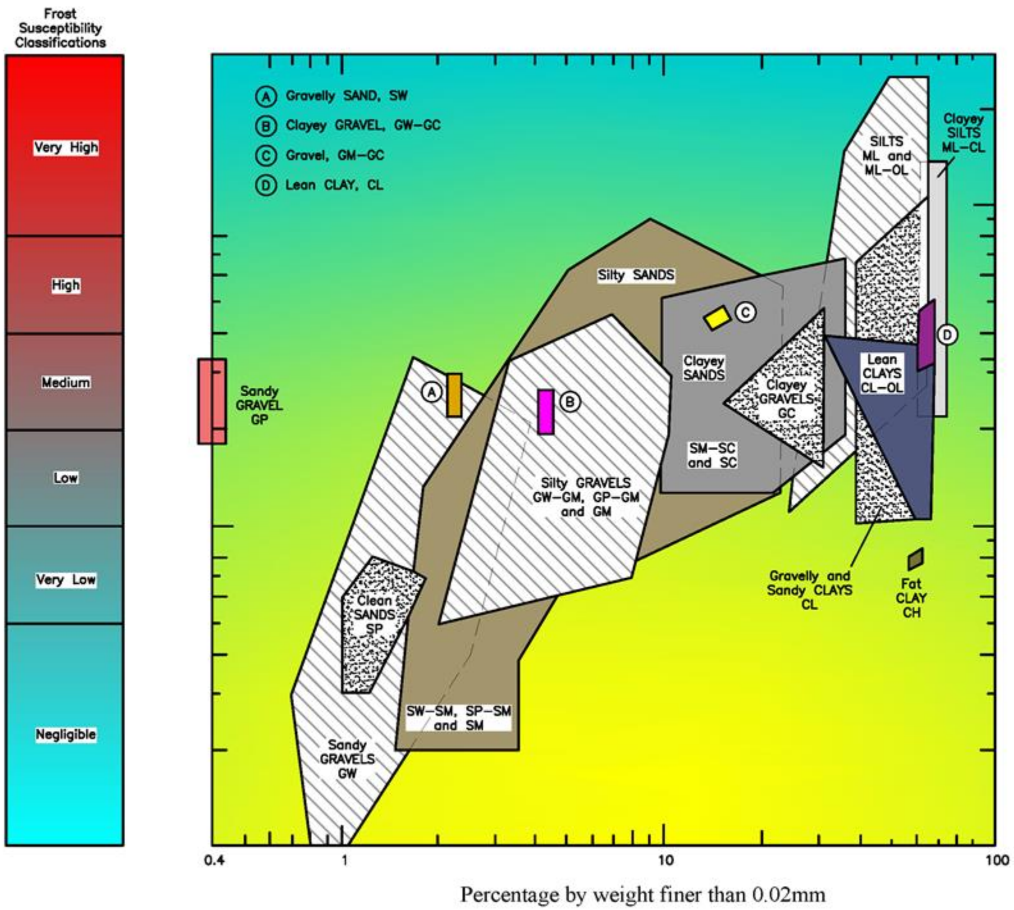
FROST PRESSURE - PERMEABILITY



EFFECTS OF OVERBURDEN



FROST SUSCEPTIBLE SOILS



ADDRESSING PRIMARY HEAVE

VOLUMETRIC EXPANSION TEST

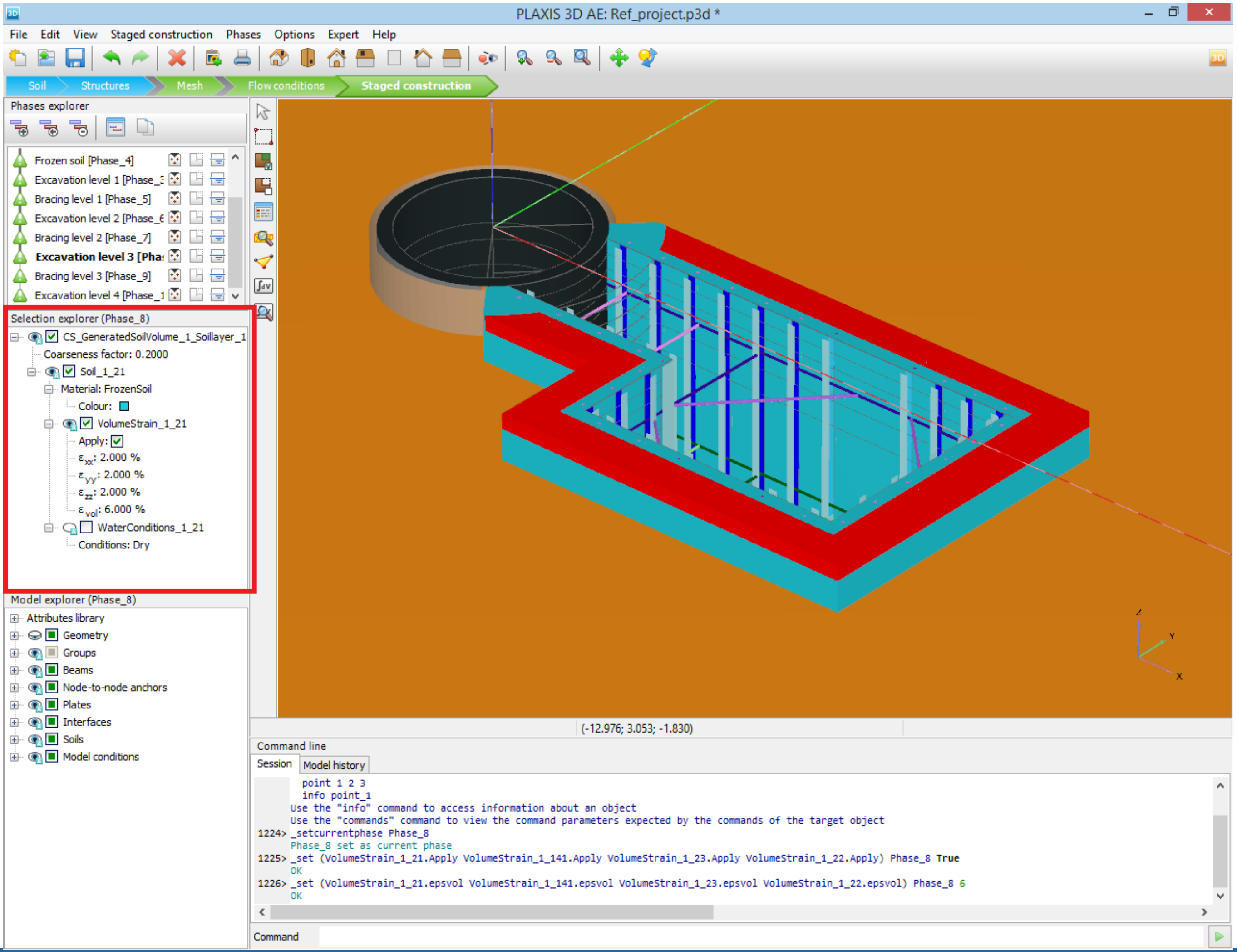
DATE: 8/9/16
REVIEWED BY:JBA
DATE:8/9/16
COMPUTED BY: JBA
TESTED BY: JBA/AA

DATE: August 8, 2016 | PROJECT NAME: Moretrench - Boeing Project | PROJECT NO.: 04.11160017

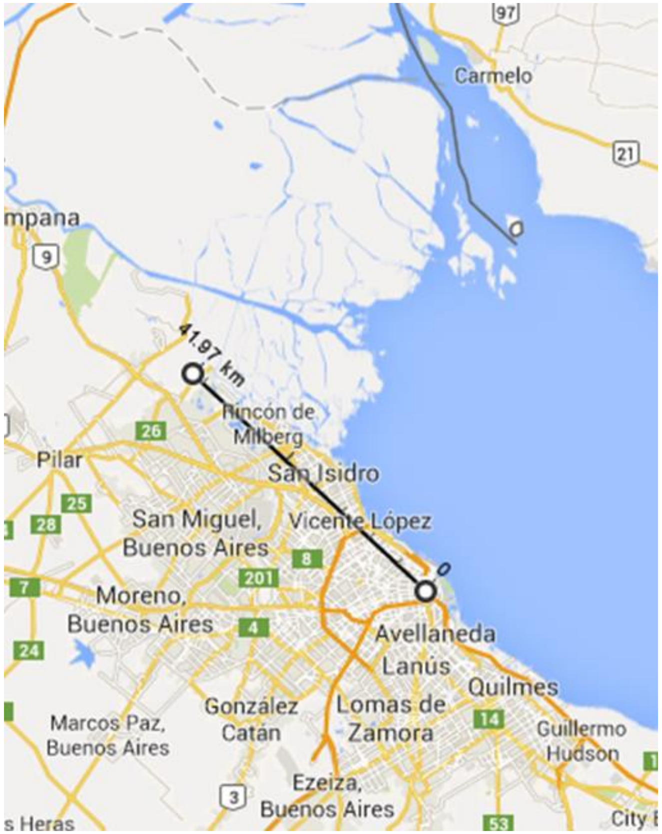
Boring No.	S-1	S-1	S-1	S-1	S-1	S-1
Sample No.	8	8	7	7	6	6
Depth (ft)	13.5 - 15.0	13.50 - 15.0	12.0 - 13.50	12.0 - 13.50	7.5 - 9.0	7.5 - 9.0
Material Visual Identification:	Silty Sand Dark Gray	Silty Sand Dark Gray	Silty Sand Dark Gray	Silty Sand Dark Gray	Silty Sand Dark Gray	Silty Sand Dark Gray
Sample Temperature (ºC)	Room Temp	Frozen	Room Temp	Frozen	Room Temp	Frozen
Length (cm) 1	11.173	11.295	11.467	11.703	12.679	12.907
2	11.172	11.31	11.466	11.70	12.677	13.045
3	11.175	11.332	11.468	11.798	12.68	12.998
4	11.174	11.34	11.466	11.788	12.678	12.996
5	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) 1	6.3	6.43	6.295	6.532	6.198	6.57
2	6.31	6.428	6.345	6.542	6.186	6.7
3	6.325	6.431	6.35	6.538	6.29	6.98
4	6.351	6.433	6.375	6.533	6.345	7.03
5	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^3)	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^3)	1.99	1.93	1.93	1.81	1.85	1.57
Dry Unit Wt. (g/cm^3)	1.62		1.59		1.58	

REMARKS

PLAXIS INPUT PARAMETERS



FROST PRESSURES AGAINST TUNNEL LINER



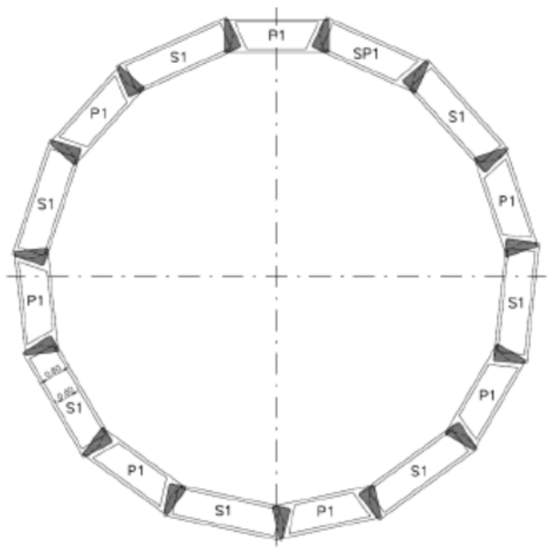
TUNNEL – PARANA RIVER TO WATER TREATMENT PLANT

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

ACCESS SHAFT #3 (CA3)

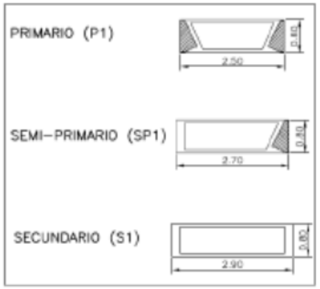
- 10.8m diameter
- Diaphragm wall panels and jet grouted bottom seal

MODULACIÓN PANELES – CÁMARA DE ACCESO

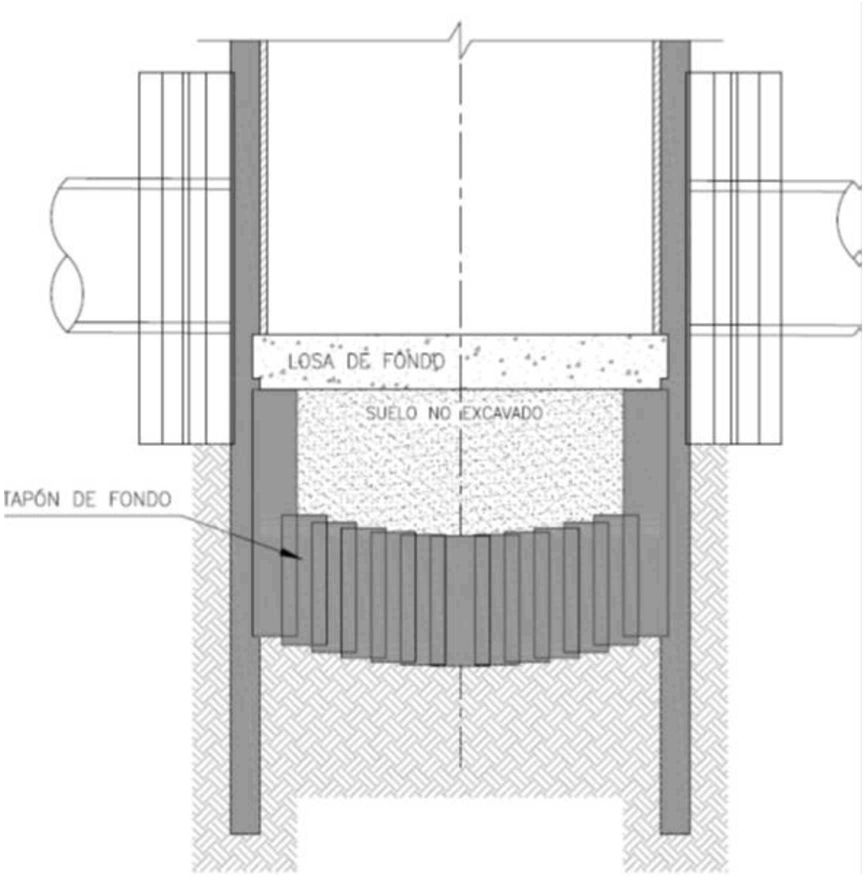


CANTIDAD DE PANELES POR TIPOS

TIPO DE PANEL		CANTIDAD
1	P1	7
2	S1	7
3	SP1	1



ACCESS SHAFT #3 (CA3)



EXCAVATION

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

LEAKS - OCTOBER 10

REPAIR – TREMIE GROUTING

- October 12, 2012 Injected 4m3 of grout

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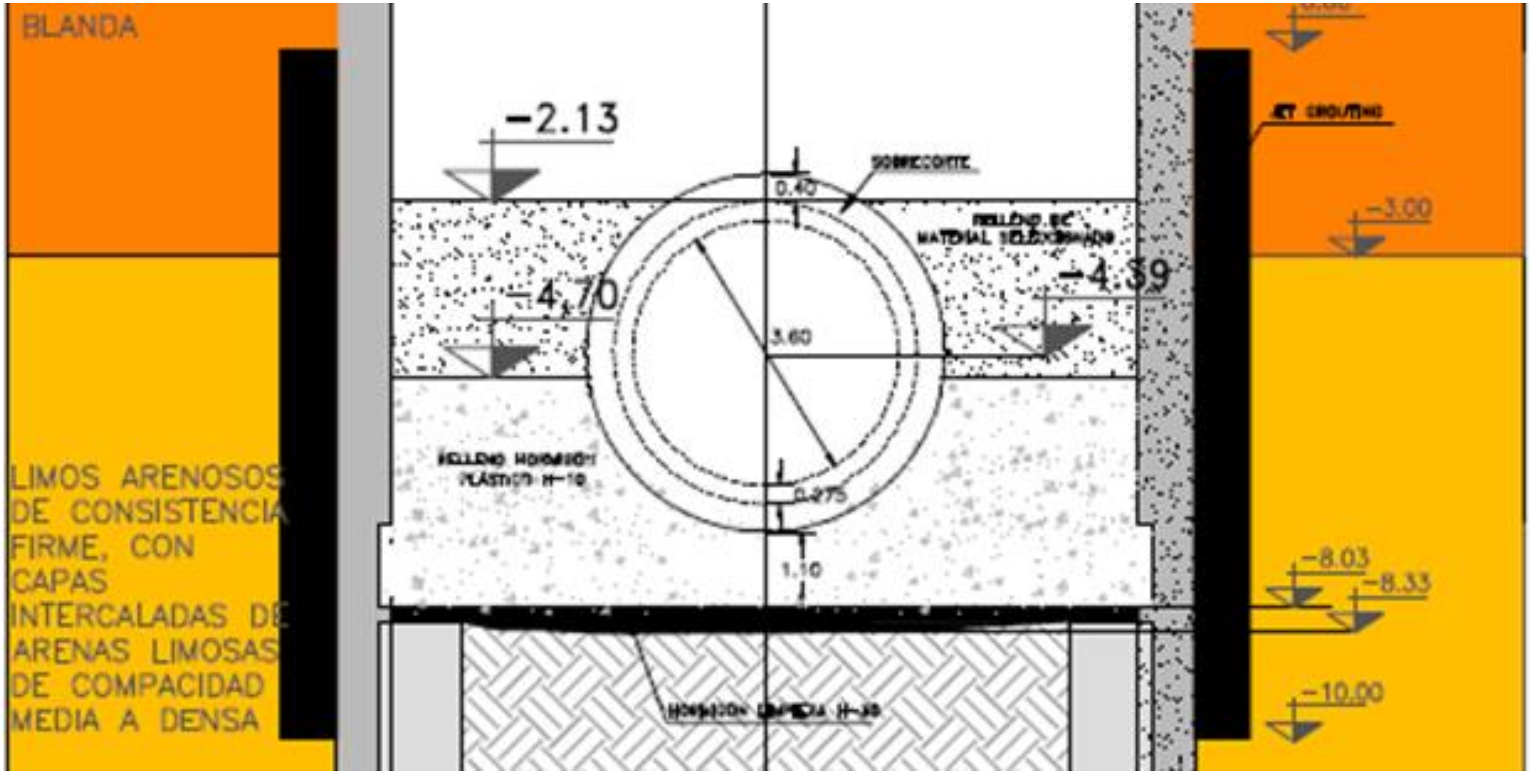
MORE LEAKS – OCTOBER 15, 2012

REPAIRS

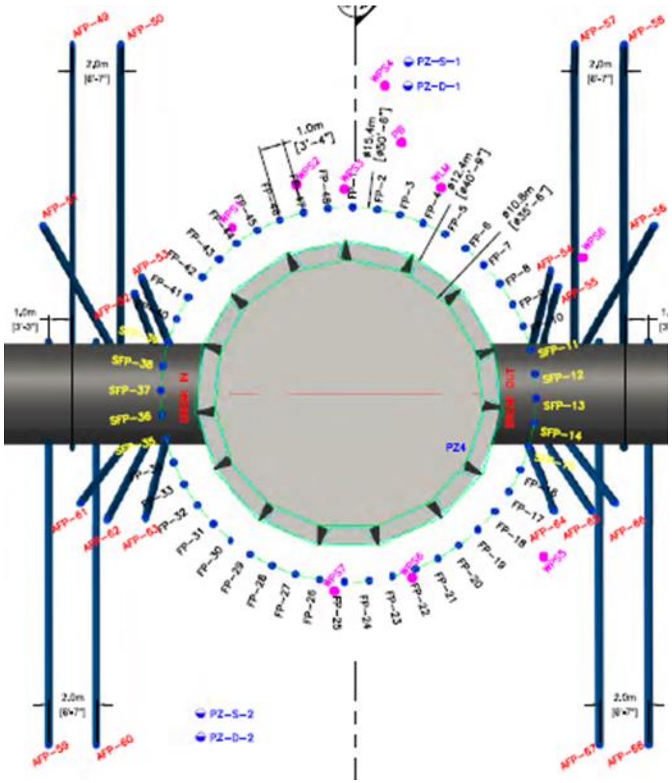
- Permeation grouting near joints
- Jet grouting
- Dewatering
- December 5, flooded again

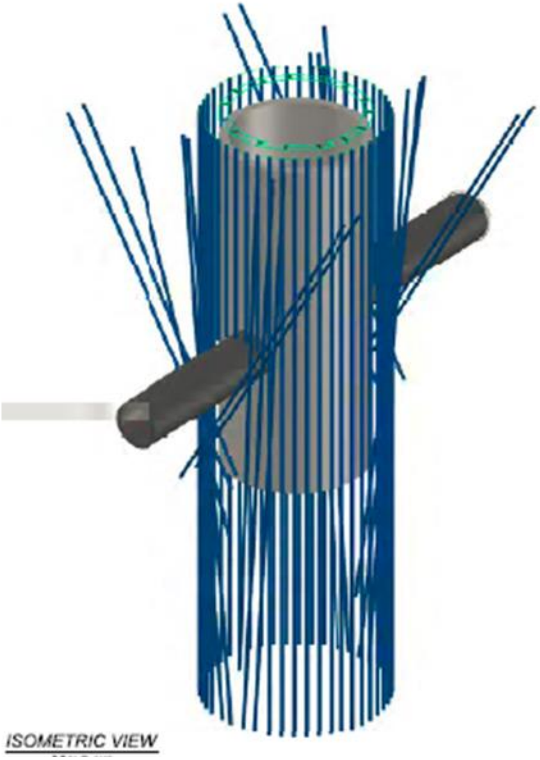
TEMPORARY FIX



GROUND FREEZING OPTION

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





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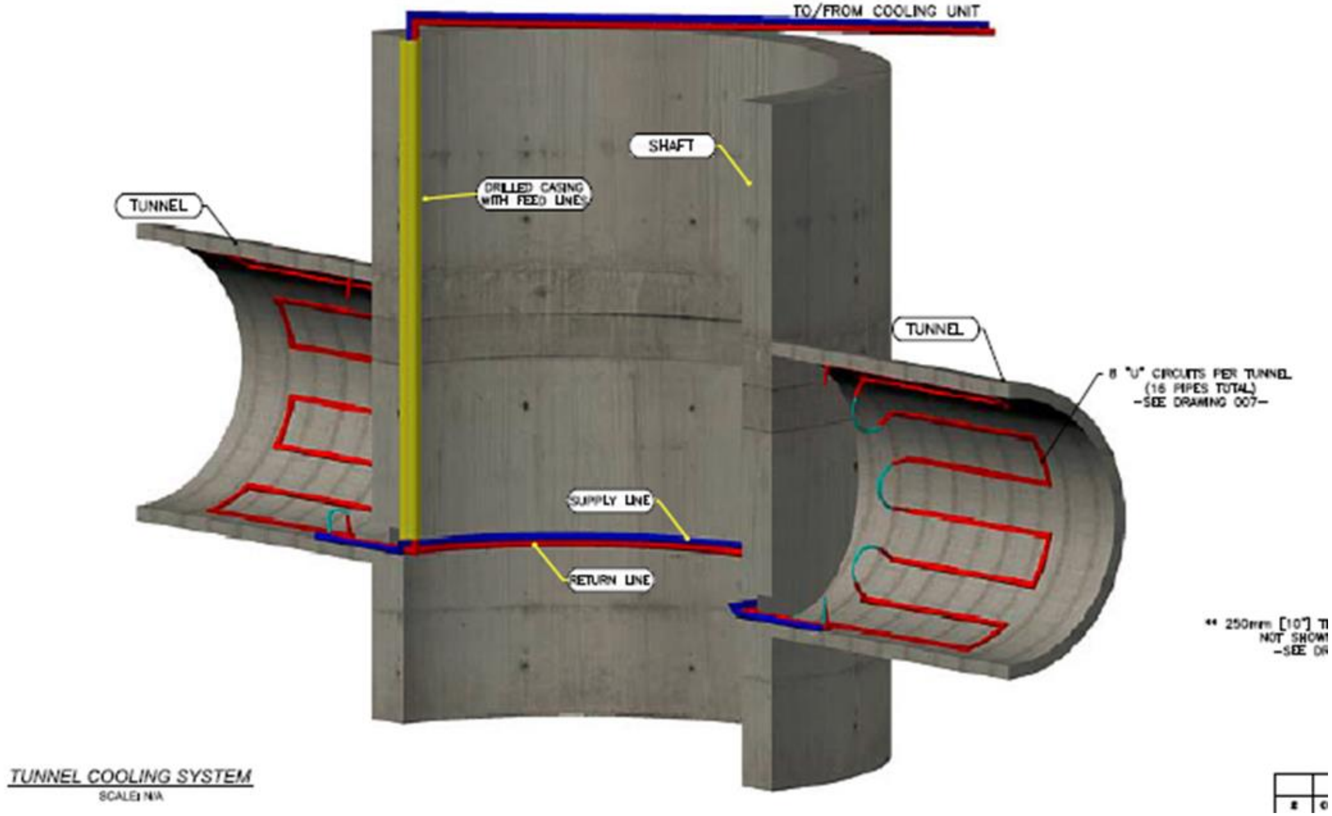
TUNNEL COOLING SYSTEM



THERMAL DESIGN

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

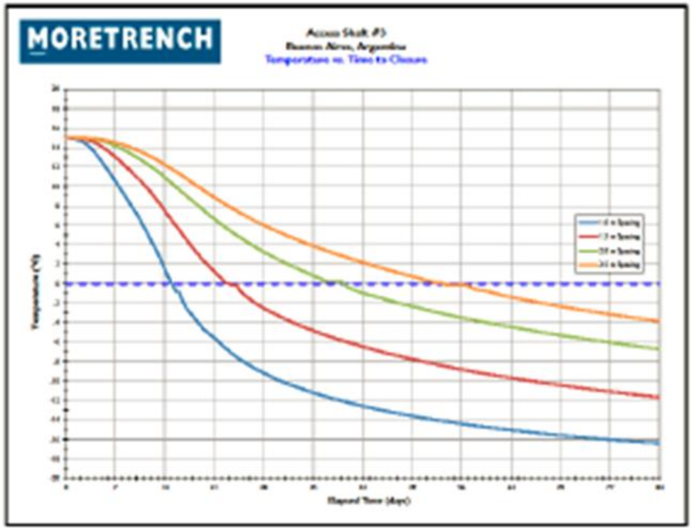


Figure 1A – Computed Freezing Times to Wall Closure

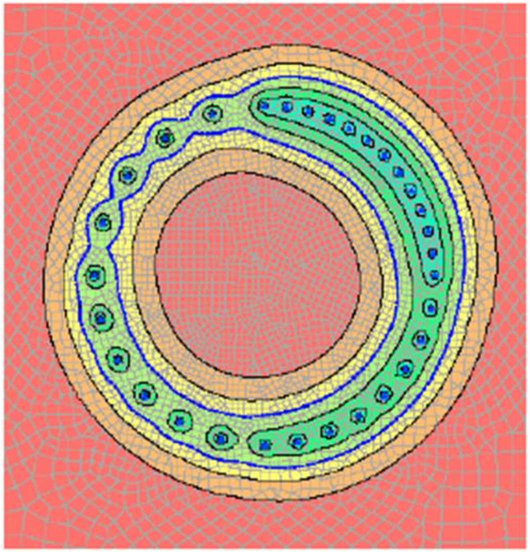
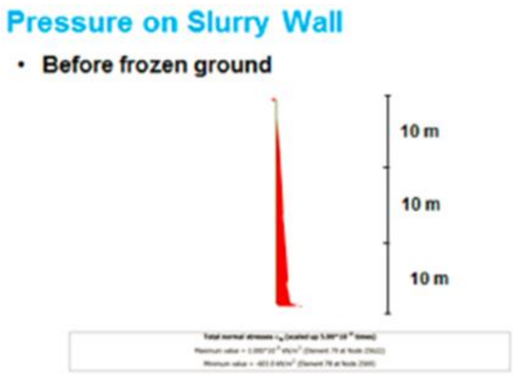
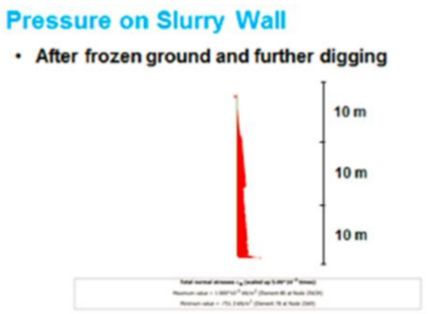


Figure 2 – Thermal Model after 8 Weeks

STRUCTURAL DESIGN – 2D

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





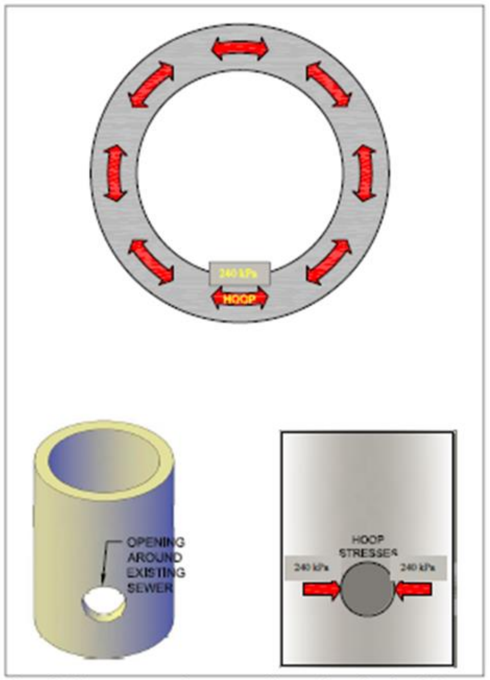


Figure 7 – Hoop stresses acting on tunnel in two-dimensional analysis

STRUCTURAL DESIGN – 3D

- Computed maximum pressures using PLAXIS 3D

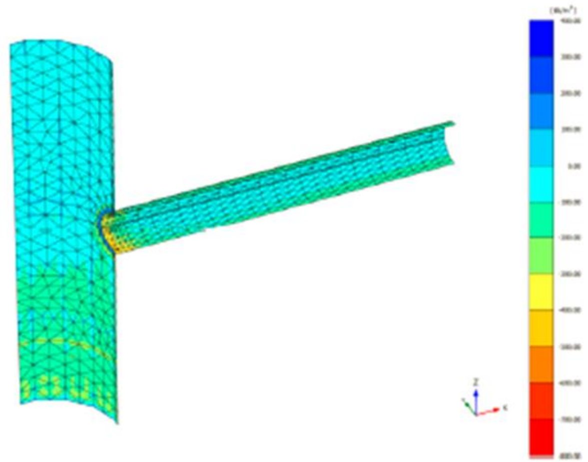


Figure 8 – Computed stresses on the existing shaft and tunnel in three-dimensional analysis

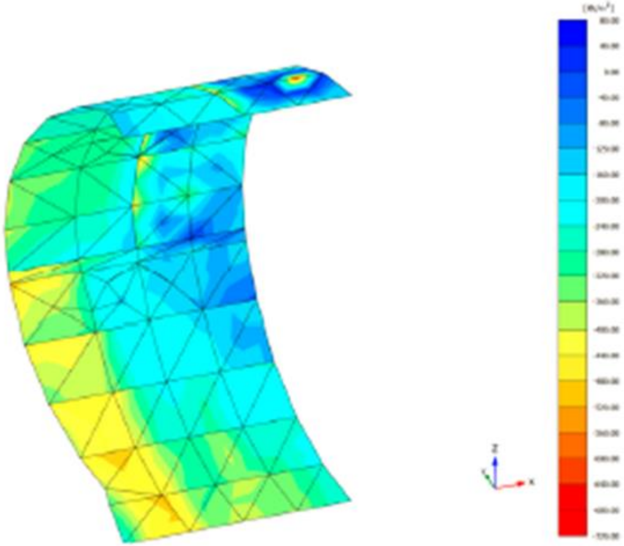


Figure 9 – Computed stresses on the existing tunnel in three-dimensional analysis

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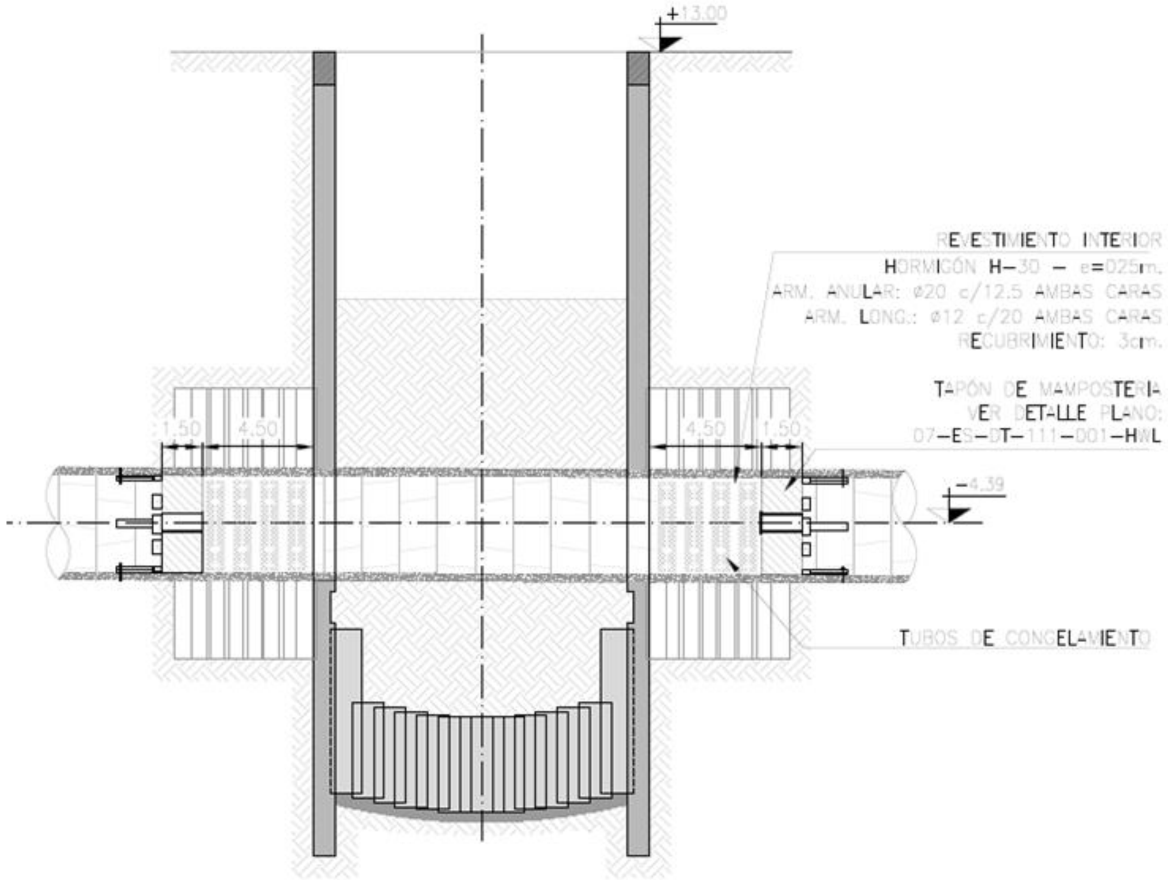
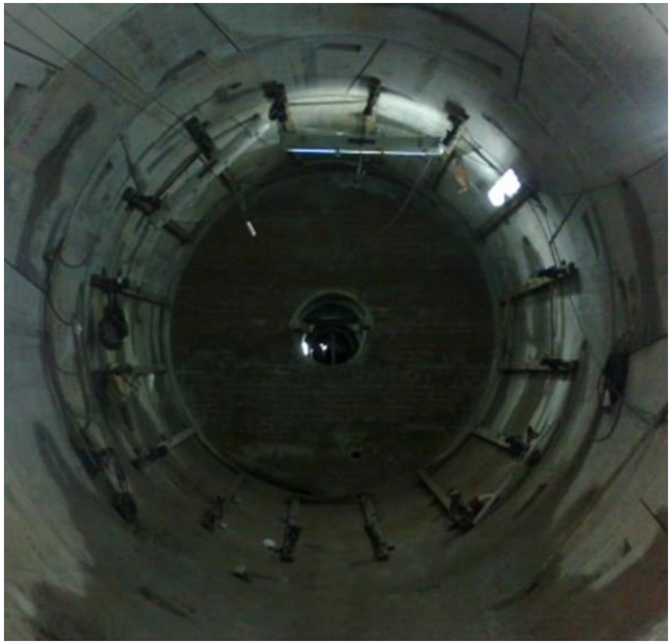
STRUCTURAL REINFORCEMENT



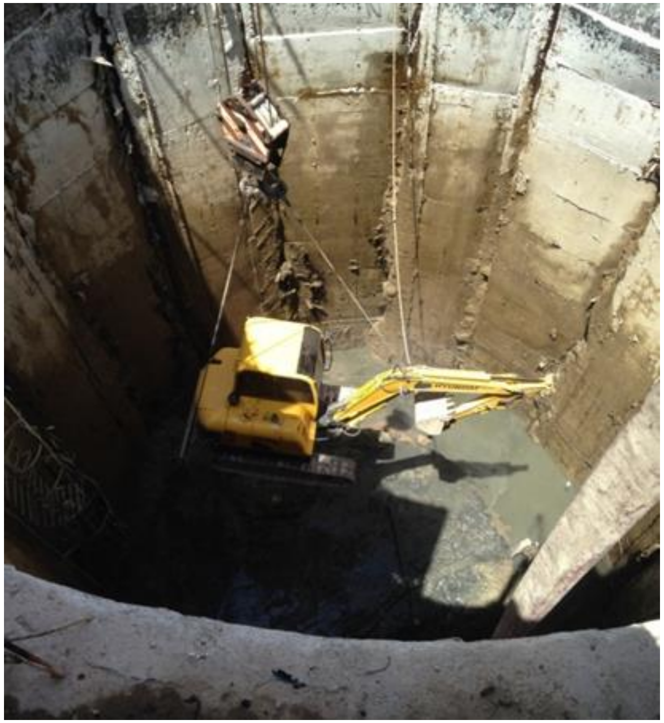
COOLING LOOP INSTALLATION



BULKHEADS

STRUCTURAL REINFORCEMENT

2 YEARS AND SIX WEEKS LATER

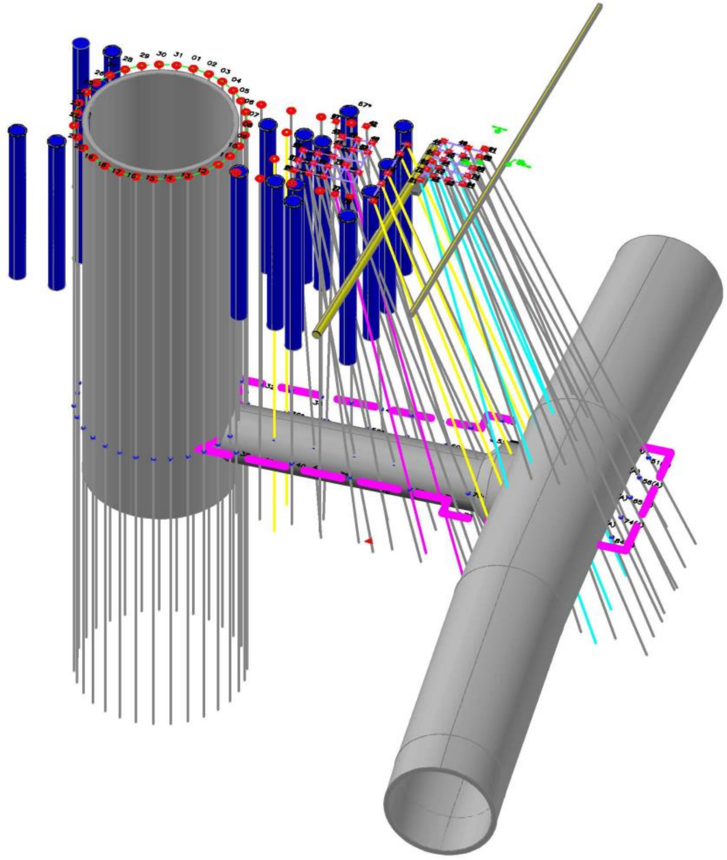


COMPLETION

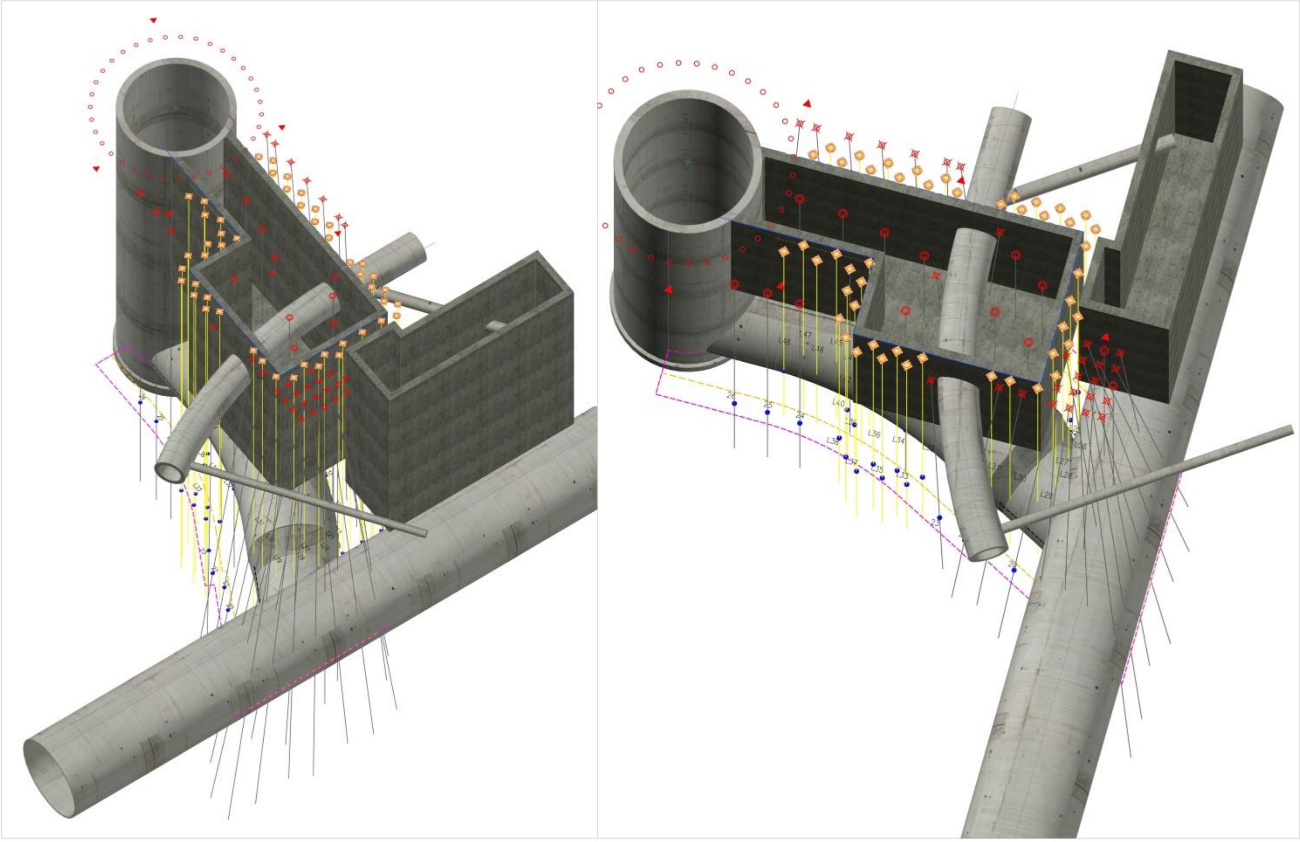
LESSONS LEARNED

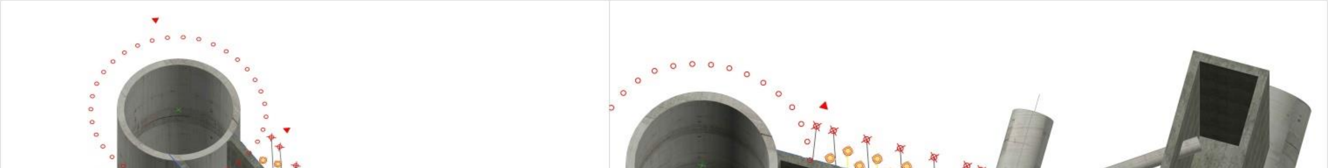
- Approach of using volumetric expansion as a PLAXIS input was successful
- Need more data on future projects
- We are getting better after a recent project in Cleveland

FIRST STREET TUNNEL – D.C.



FIRST STREET TUNNEL – D.C.

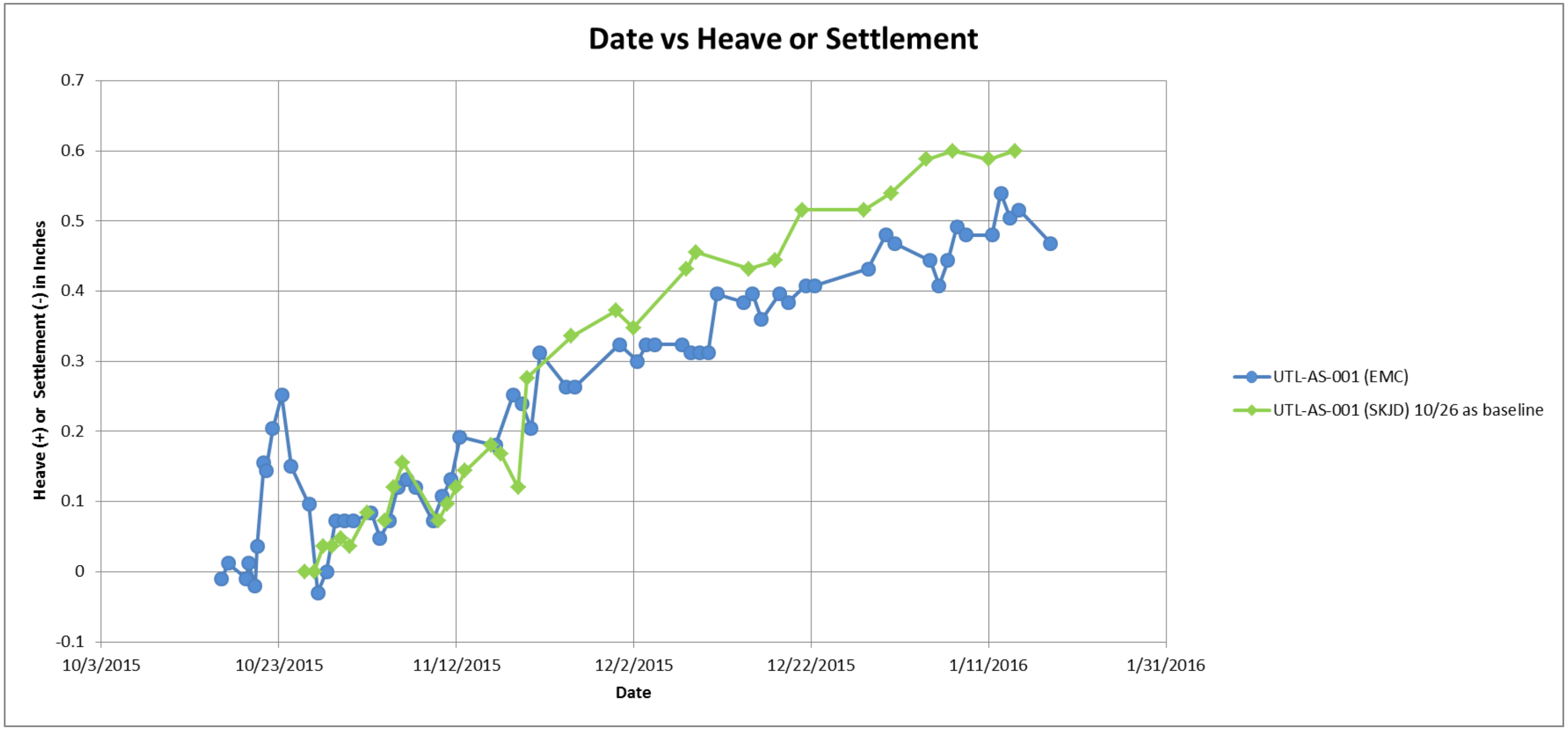




REVIEWED FROST SUSCEPTIBILITY

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

UTILITY HEAVE



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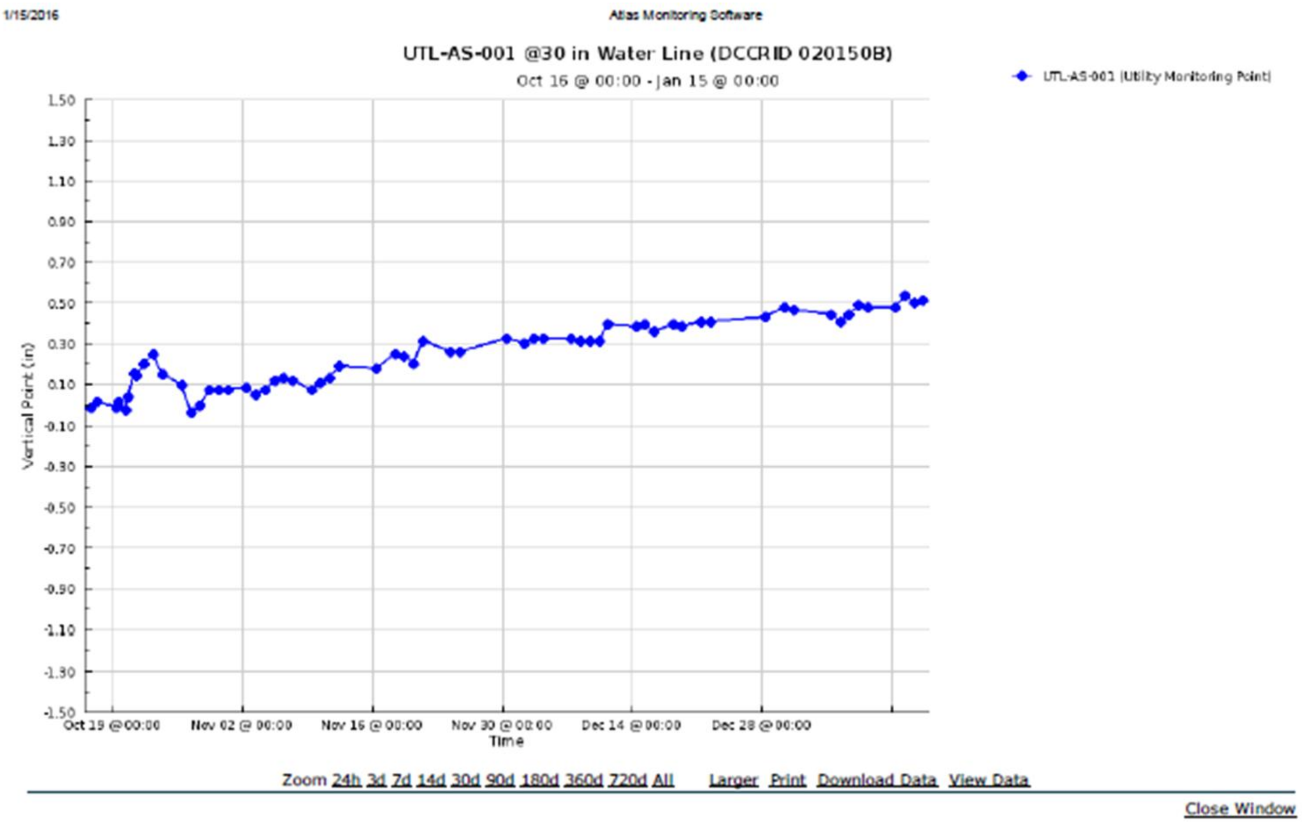
UTILITY HEAVE



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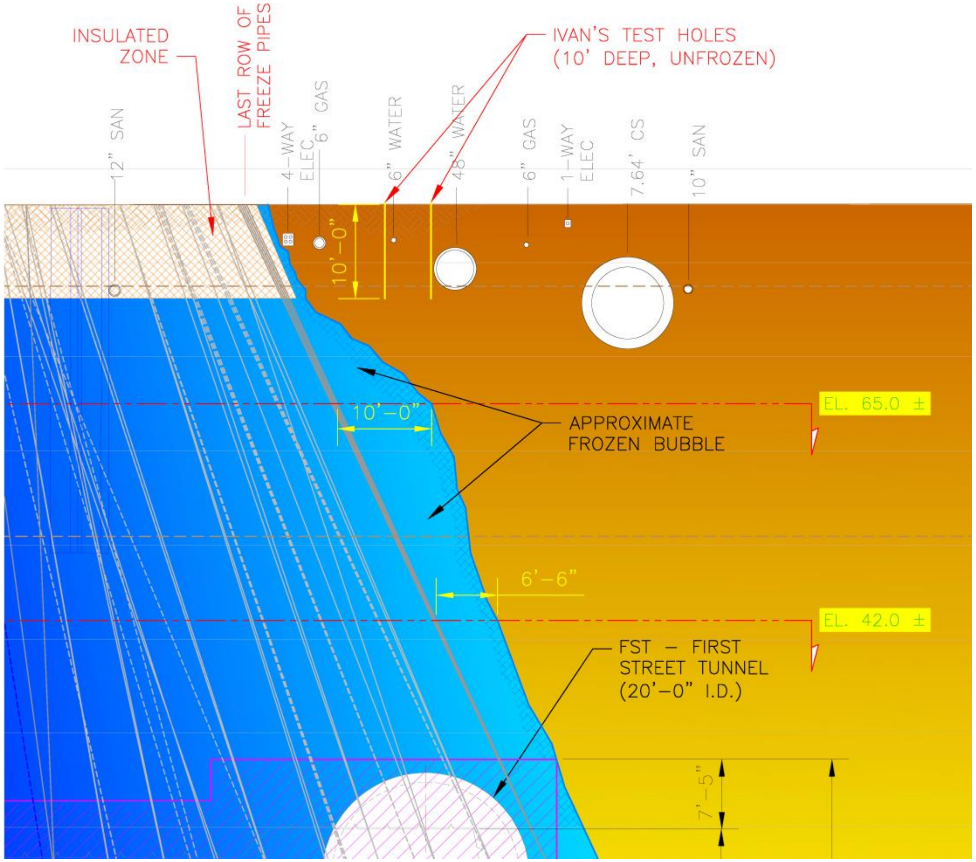
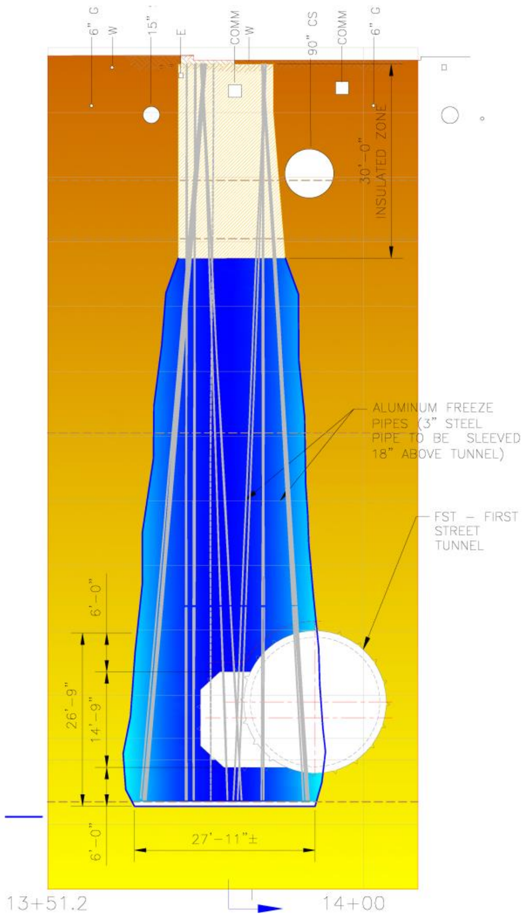
WHY?



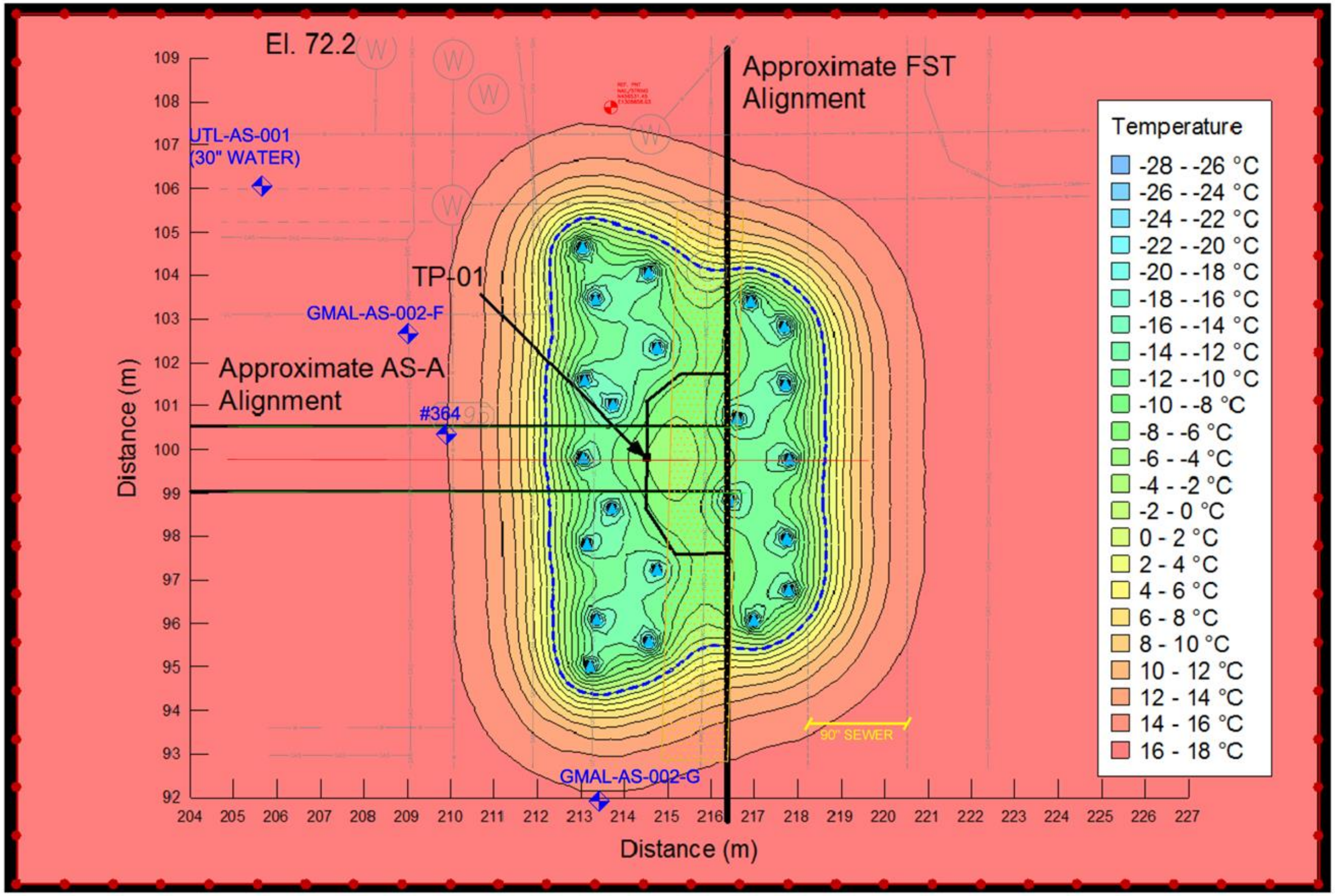
INSULATED ZONE
LAST ROW OF FREEZE PIPES
IVAN'S TEST HOLES (10' DEEP, UNFROZEN)
12" SAN
4-WAY ELEC
6" GAS
6" WATER
48" WATER
6" GAS
1-WAY ELEC
7.64' CS
10" SAN
10'-0"
10'-0"
APPROXIMATE FROZEN BUBBLE
EL. 65.0 ±
6'-6"
EL. 42.0 ±
FST - FIRST STREET TUNNEL (20'-0" I.D.)
7'-5"

SECTION

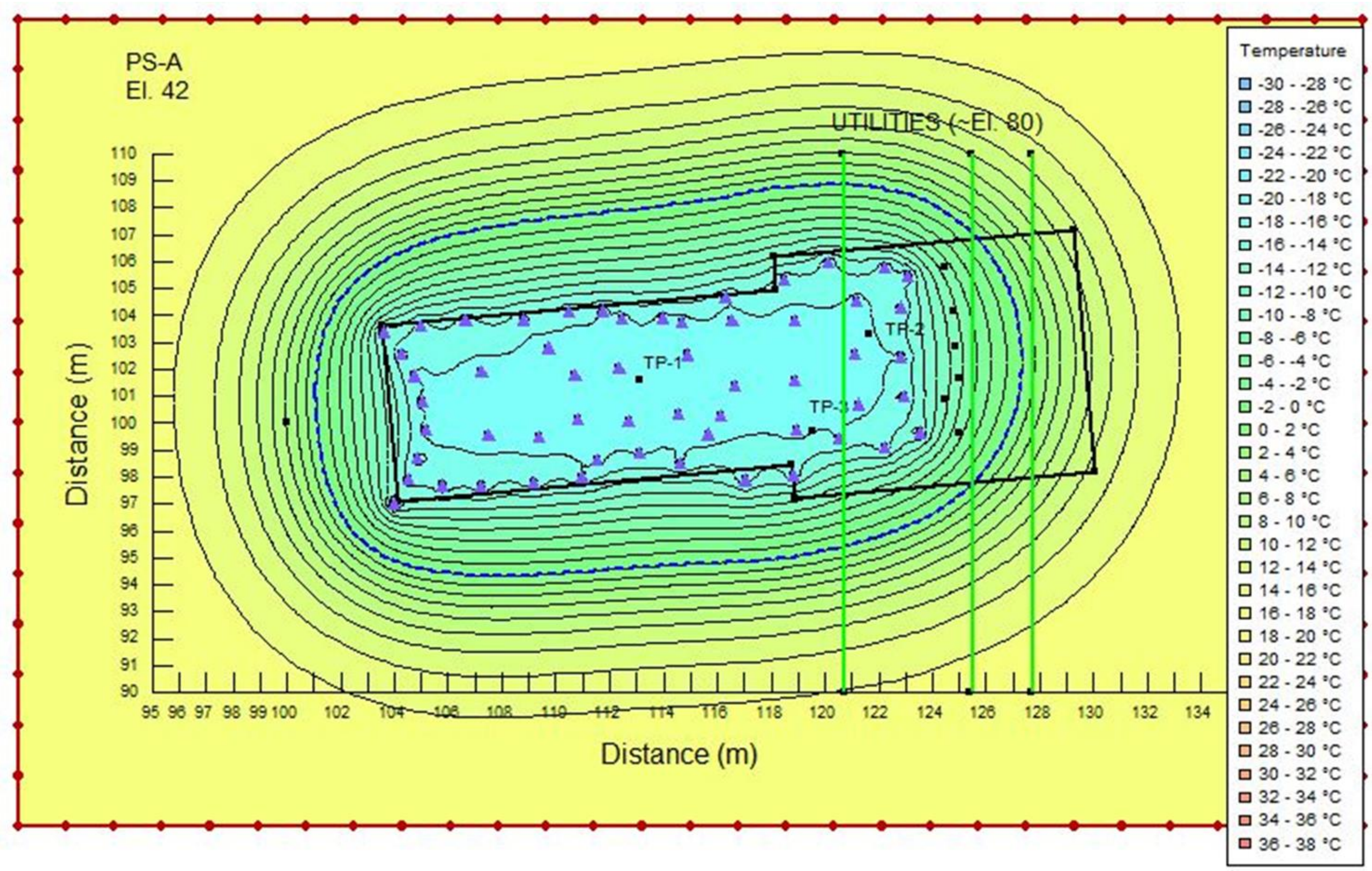


6" G
W
15"
E
COMM
W
90" CS
COMM
6" G
30'-0" INSULATED ZONE
ALUMINUM FREEZE PIPES (3" STEEL PIPE TO BE SLEEVED 18" ABOVE TUNNEL)
FST – FIRST STREET TUNNEL
6'-0"
26'-9"
14'-9"
6'-0"
27'-11"±
13+51.2
14+00

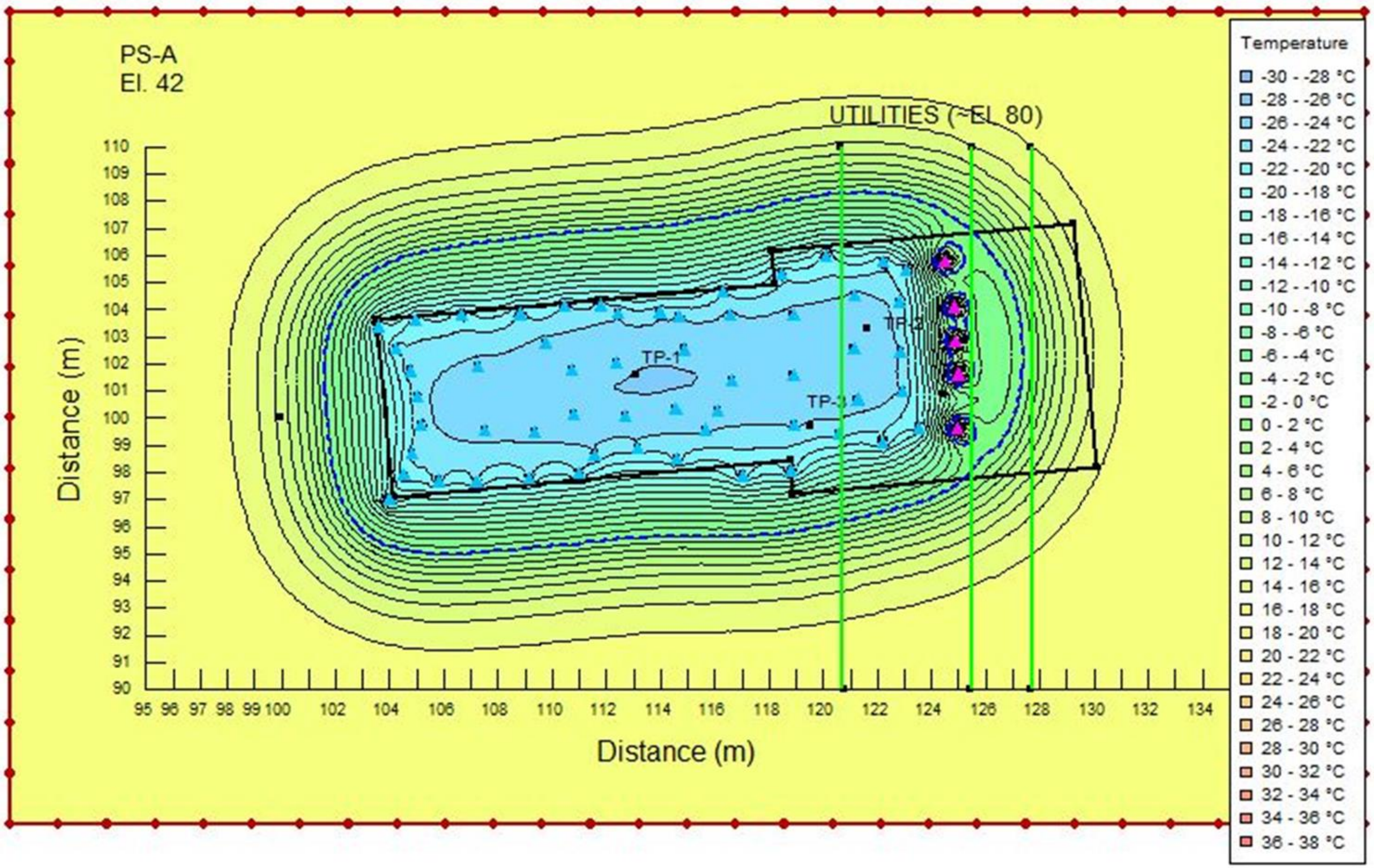
INSTALLATION OF HEATING PIPES



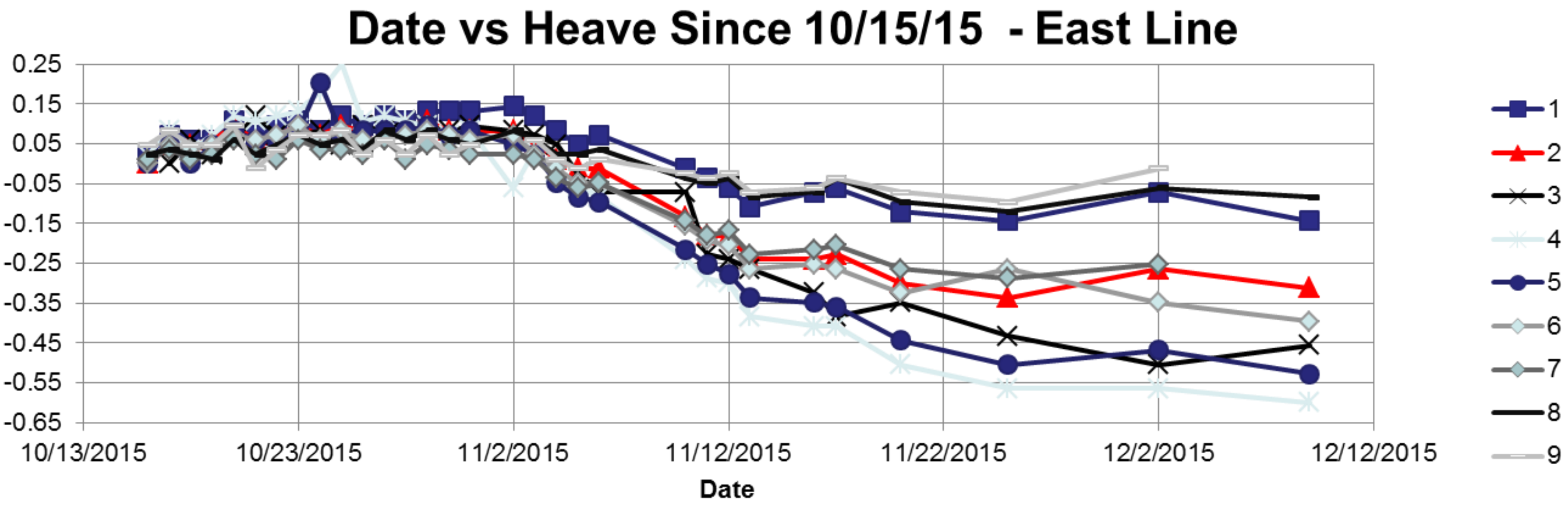
REDUCING REFRIGERATION



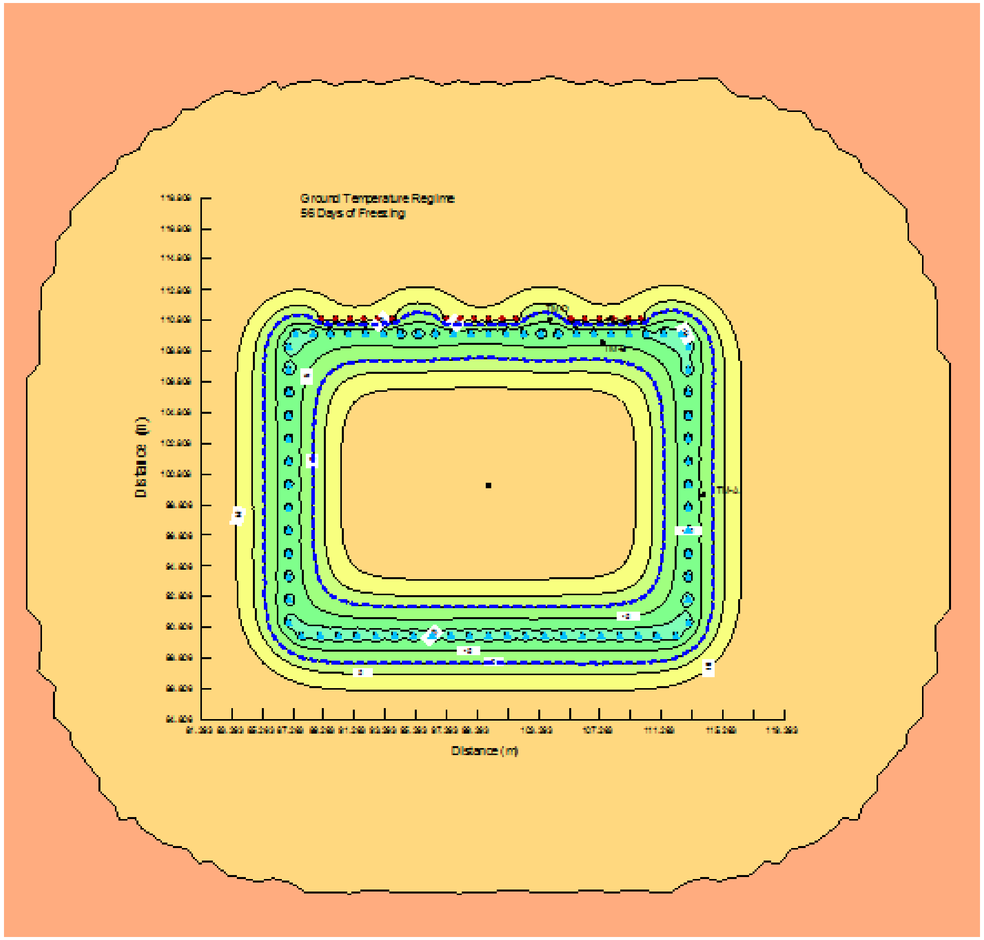
ACTIVATION OF HEAT PIPES



EFFECTS OF HEAT PIPES



PROACTIVE PROCEDURE



LESSONS LEARNED

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

SUMMARY

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