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

BRINE RETURN

FREEZE PIPE HEADER

ROUST-A-BOUT COUPLING

FREEZE PIPE

HDPE DOWNPIPE

BRINE SUPPLY

PIPS PRIOR TO FREEZING

FOLLOWING INITIATION OF FREEZE

CLOSURE OF FROZEN EARTH WALL

COMPLETE FROZEN EARTH WALL
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

The diagram illustrates the relationship between frost pressure and permeability. The y-axis represents combined effective intergranular pressure and potential expansion pressure (10^x) kg per sq. m, while the x-axis represents the coefficient of permeability (m per hr.). The graph shows different materials such as heavy clays, glacial till, lean clays, silt/clay mixtures, silts, very fine sands, silt/sands mixtures, and fine sands/sand/gravel mixtures, each with distinct permeability characteristics.

Key points:
- Combined pressures:
- Unconfined expansion rate:
- Heavy clays
- Glacial till
- Lean clays
- Silt/clay mixtures
- Silts
- Very fine sands
- Silt/sands mixtures
- Fine sands/sand/gravel mixtures
EFFECTS OF OVERBURDEN
FROST SUSCEPTIBLE SOILS

Percentage by weight finer than 0.02mm
# ADDRESSING PRIMARY HEAVE

## VOLUMETRIC EXPANSION TEST

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<th>DATE</th>
<th>PROJECT NAME</th>
<th>PROJECT NO.</th>
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<td>August 8, 2016</td>
<td>Moretrench - Boeing Project</td>
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<th>Boring No.</th>
<th>Sample No.</th>
<th>Depth (ft)</th>
<th>Material Visual Identification</th>
<th>Sample Temperature (°C)</th>
<th>Length (cm)</th>
<th>Average Length (cm)</th>
<th>Diameter (cm)</th>
<th>Volume (cm³)</th>
<th>Wet Mass of Specimen (g)</th>
<th>Water Content (%)</th>
<th>Wet Unit Wt. (g/cm³)</th>
<th>Dry Unit Wt. (g/cm³)</th>
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Moretrench
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
ACCESS SHAFT #3 (CA3)
EXCAVATION

• Started October 2, 2012
• 12m deep by October 10
REPAIR – TREMIE GROUTING

- October 12, 2012  Injected 4m3 of grout
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
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
STRUCTURAL DESIGN – 2D

- Computed soil pressures on slurry wall before and after freezing
- Used hoop stresses to calculate load on tunnel lining
STRUCTURAL DESIGN – 3D

- Computed maximum pressures using PLAXIS 3D
STRUCTURAL REINFORCEMENT
COOLING LOOP INSTALLATION
BULKHEADS
STRUCTURAL REINFORCEMENT
2 YEARS AND SIX WEEKS LATER
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

Date vs Heave or Settlement

- UTL-AS-001 (EMC)
- UTL-AS-001 (SKID) 10/26 as baseline

Date

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Heave (H) or Settlement (S) in Inches

10/3/2015
10/23/2015
11/12/2015
12/2/2015
12/22/2015
1/11/2016
1/31/2016
UTILITY HEAVE
WHY?
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