CEUs for this workshop

Be sure to scan the QR for Tuesday, Wednesday, and Thursday workshops to get points towards your IGSHPA certification CEUs.
Is Thermally Enhanced Grout the most Cost Effective way to Reduce Design Lengths

Geothermal: The Genius Renewable

Live at Groundwater Week in partnership with NGWA

Las Vegas, NV
December 5-7, 2023
OVERVIEW

• What is Grout
• Why are we Grouting
• What types of geothermal grouting products are available
• What is a Thermal Grout
• Technical Grouting Considerations
• Grout density and the impact on system design
• Thermal Conductivity directly impacts borehole resistance, system design, and system performance
• Misconceptions regarding borehole resistance
WHAT IS GROUT?

GROUT:
Sealing material placed in the annular space between the u-bend assembly and the bore hole wall.
WHAT IS GROUT?

GROUT:
Placed the entire bore length
GROUTING VS. BACKFILLING

• **Grouting** - Placement of low permeability material into annular space between the borehole wall and the pipes suspended in the borehole
  – Conscious effort made to form a hydraulic seal
    • Controlled process with goal to form hydraulic seal through all critical sections of the borehole

• **Backfilling** - The practice of placing drill cuttings or other material into borehole
  – Primary focus is filling the borehole volume
    • No specific effort directed toward creating a hydraulic barrier
REASONS FOR GROUTING

REGULATORY:

• To prevent surface water contamination.
• To prevent inter-aquifer communication.
• To comply with local regulation and/or industry standards.
REASONS FOR GROUTING

THERMODYNAMIC:

- To promote heat transfer between the fluid in the pipe and the geological formation.

Aquifer

Aquifer

Aquifer
CRITERIA FOR OBTAINING A PROPER SEAL

• Low Permeability ($< 1 \times 10^{-7} \text{ cm/s}$)
• Reasonably High Thermal Conductivity
• No Contaminants
• Chemically and Physically Inert
  • Native host soil/rock and piping material
• Short Hydration Time, Permanence, and Flexibility
  • Settling in Borehole
  • Changes with expansion/contraction of pipe
• Long-Lasting
  • Hydraulic barrier over the intended life of the GHEX
5.8.3 Grouting

5.8.3.1 General

5.8.3.1.1 Unless otherwise approved by an engineer or a geologist, boreholes shall be grouted to
(a) ensure continuous contact between the ground heat exchanger and the borehole annulus for
efficient heat transfer;
(b) prevent potential migration of surface water into confined aquifers pierced by the borehole;
(c) prevent potential cross-contamination path between one confined aquifer to another confined
aquifer; and
(d) surround the outside of the pipe, thereby balancing the hydrostatic pressure of the fluid inside the
pipe.

5.8.3.1.2 Unless otherwise approved by an engineer or geologist, grouting procedures shall be carried out as
follows:
(a) grout shall be placed in the borehole by pressure pumping through a tremie pipe after enough water
or other drilling fluid has been circulated in the annular space to clear obstructions;
(b) tremie grouting of the entire vertical borehole using the grout material specified in Clause 5.8.3.1.3
shall be done immediately following drilling and heat exchanger installation;
(c) once started, the grouting procedure of a borehole shall not be interrupted until completed;
(d) the borehole shall be grouted from the end to the starting point;
(e) the tremie pipe shall be lowered to the bottom of the borehole and raised slowly as the grout is
introduced;
(f) due consideration shall be taken against pipe buoyancy, until the grout has completely settled;
(g) closed-loop heat exchanger pipe shall remain hydrostatically pressurized during the entire grouting
process to protect it against shear forces caused by the grout;
(h) the hydrostatic pressure level shall be adapted with grout density and borehole depth;
(i) once the grout has settled for a minimum of 48 h, the driller shall ensure that the boreholes are filled
with grout to the start point of the borehole; and
(j) regular verification of the grout mixture shall be carried out as following:
(i) verification of grout mix ratio, mixing procedures, grouting, and topping off of boreholes with
grout shall be undertaken on an ongoing basis during heat exchanger installation; and
(ii) density and water content, or alternatively, grout thermal conductivity of the samples shall be
measured to ensure the grout mixture is in accordance with the specified grout recipe.
5.8.3.1.3

5.8.3.1.3.1
Once settled, all grouting mixtures being used shall
(a) have a minimum grout thermal conductivity of 0.71 W/(m*K) (0.41/btu/hr-ft°F);
(b) have a hydraulic conductivity not greater than 1 x 10^{-7} cm/sec (3.94*10^{-8} in/sec);
(c) remain “malleable” or flexible through the life span of the project;
(d) be inert and non toxic; and
(e) not be biodegradable.

5.8.3.1.3.2
Grout mixture should keep its thermal, hydrological and mechanical properties over time with less than
10% degradation over a 100 year time frame.
## INDEPENDENT VERIFICATION

### 1.294 (2.239)

per D-5334

### 3.69 x 10^-8

per D-5084

### Target = 1.20 Btu/hr ft°F

### Target = <6.9x10^-8 cm/sec
NSF PRODUCT & SERVICE LISTING

Typical NSF Listing as printed from the Internet
GROUT TYPES

- Material types:
  - Bentonite-based (sodium bentonite)
    - Conventional Bentonite Grout (20% - 30% Solids)
    - Thermally-Enhanced Bentonite Grout (30% to 80% Solids)
  - Cement-based (Standard Portland being replaced by Type IL)
    - Neat Cement: Portland Cement & 6 gal (22.7 L) of Water
    - Sand / Cement: >2:1 ratio by weight & 6 gal (22.7 L) of Water
    - Grout 111: Thermally-Enhanced Cement Grout
  - Hybrid Products
    - Cement/Bentonite: Combination that provides benefits of both (25% to 33% Solids)
THE ANATOMY OF THERMAL GROUT

• Thermal grout is made up of 3 primary components:
  - Bentonite / Cement
    - Provides the sealing characteristics of the mixture
    - Suspends the thermal additive in the bore column to provide uniform heat transfer from top to bottom.
  - Thermal additive - either silica sand or graphite-based
    - Improves overall thermal grout conductivity (TC) and subsequent heat transfer capabilities.
  - Mix water
    - The amount to use in a given recipe is specified by the manufacturer to ensure that the thermal grout will perform as advertised.
# 1.20 Recipe Comparison

## Silica Sand “Mix Batch”

<table>
<thead>
<tr>
<th>TG Select (lbs)</th>
<th>PowerTEC (lbs)</th>
<th>Silica Sand (lbs)</th>
<th>Water (gal)</th>
<th>Yield (gal)</th>
<th>Density (lbs/gal)</th>
<th>TS/AS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (1)</td>
<td>0</td>
<td>400 (8)</td>
<td>21.6</td>
<td>42.2</td>
<td>14.93</td>
<td>71.4/21.7</td>
</tr>
</tbody>
</table>

## PowerTEC “Mix Batch” (no sand)

<table>
<thead>
<tr>
<th>TG Lite (lbs)</th>
<th>PowerTEC (lbs)</th>
<th>Silica Sand (lbs)</th>
<th>Water (gal)</th>
<th>Yield (gal)</th>
<th>Density (lbs/gal)</th>
<th>TS/AS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 (2)</td>
<td>32 (1)</td>
<td>0</td>
<td>30.0</td>
<td>36.4</td>
<td>10.5</td>
<td>34.5/28.6</td>
</tr>
</tbody>
</table>

## PowerTEC “Mix Batch” (CG PLUS)

<table>
<thead>
<tr>
<th>TG Lite (lbs)</th>
<th>PowerTEC (lbs)</th>
<th>TYPE II (lbs)</th>
<th>Water (gal)</th>
<th>Yield (gal)</th>
<th>Density (lbs/gal)</th>
<th>TS/AS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 (2)</td>
<td>64 (2)</td>
<td>47 (2)</td>
<td>52.0</td>
<td>65.8</td>
<td>10.6</td>
<td>32.7/25.2</td>
</tr>
</tbody>
</table>
GENERAL MIXING GUIDELINES

• Follow our instructions
  – Sounds trivial but very important
    • Mix with reasonable accuracy to exceed spec. every time

• Don’t overwater
  – Natural tendency of new contractors
  – Diluting the mixture:
    • Lowers solids content
    • Reduces ability to provide adequate seal
    • Reduces grout TC value
    • Causes sand settling in mixing tank
      – Plugging issues
WATER MEASUREMENTS

• Two ways to measure water volume
  – Accurate measurements are critical

![Diagram of water level measurement](image)
WATER MEASUREMENTS
MIX WATER

- Use potable water only
- No polymers or additives required in field
- TG & BH20 not sensitive to water chemistry
  - pH value
    - Typical range 5-6
    - Suitable range 5-9
  - Dissolved sodium
    - < 0.5 G/L for use with TG & BH20
    - 35 G/L for salt water
  - Chlorine content
    - < 20 ppm for use with TG & BH20
    - Human health hazard > 5 ppm
GROUT MIXING & PUMPING

• Equipment should be suited for the job
  • May require one-time investment by the contractor

• Low shear paddle mixing & pumping
  – No recirculation or jet mixing
  – Positive displacement
    • Piston & progressive cavity (moyno)

• Tremie line
  – HDPE most common
  – 1.25” recommended (1” min)

• Tremie reel
  – Hydraulically-controlled & swivel mount
MIXING & PUMPING GRAPHITE BASE THERMAL GROUT

- Start paddle mixer.
- Add required water
- Add PowerTEC
- Add thermal grout
- Pump into bore
- Follow Manufacturer Recommendations
MIXING / PUMPING EQUIPMENT

- Repeatable results
  - Ensure each batch meets specification

- For the driller - all about productivity
  - Maximize efficiency for maximum output
  - Equipment capability very important
COMPLETE “BULK SAND” GROUTING SYSTEM

- Bulk Sand Handler
- Power Tremie Real
- Material Platform / Water Tank
- Grout Mixing Plant

Photo courtesy of Geo-Loop, Inc.
NOT RECOMMENDED
SAMPLE TC TESTING

• Performed according to industry standards
  – ASTM D-5334 “Line Source Method”
• Free service (Typically)
  – Blind testing to guarantee accuracy
  – Recommend corrective action when necessary
  – Turnaround 3-5 days after receiving samples
• Contact us to request forms & containers

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www.geoproinc.com
• What to know about TC testing
  o Sampling is crucial
  o Only direct TC measurement
  o There is a lead time
  o Sample collection timing is critical

• If values are lower than target
  o Sand source is not approved
  o Wrong mix ratio
  o Grout is being overwatered
  o Poor sampling
FREQUENCY FOR GROUT TC TESTING

• How frequent should grout sampling be done? (Depends)
  o Sand : Minimum of 3 samples for average commercial project (~50 bores)
  o Sand : Larger projects 3 samples taken per 50 bores
  o Graphite : 2-3 samples per 10 bores
    o Reduce frequency as confidence and repeated results are achieved.
  o Once at the beginning of the project
  o Once at 1/3 of completion
  o Once at 2/3 of completion
  o Not intended to police every batch
SAMPLING ISSUES

• Sampling error
  – Most common reason for missing TC target

• Proper sampling is critical
  – Mixing tank: take from center
    • Don’t skim off top
  – Tremie line: take at middle-end of pumping a batch
    • Usually have leftover material in tank when a bore is full
ADDITIONAL CONSIDERATIONS

• Grout within 24 hours of drilling
  – Grout immediately in unstable formations
  – Grout within a timeframe to ensure total loop well grouting (CSA 6.3.2.1.2)

• Stake or weigh down u-bend
  – Prevent pipe from floating out prior to full hydration

• Contain displaced drill cuttings/fluid
FORMATION LOSSES

• Some grout will be lost to surrounding soil
  – Fractured rock / cavernous formations
• Bentonite chip & pea rock to bridge fractured zone
• May wash away with water movement
  – Grout above and below
  – Moving water promotes heat transfer
  – Unconsolidated formation – gravel/cobbles
• Thicker grout will not flow
  – Reduce mix water
  – Increase mix time
• “Top-off” required when grout settling >10-20 ft.

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FORMATION LOSSES

• Some grout will be lost to surrounding soil
  o Thicker grout will not flow
    ▪ Reduce mix water
    ▪ Increase mix time
    ▪ PowerTEC as possible solution

• Extreme cases
  o Fractured rock
  o Cavernous formations
  o Water movement
    ▪ Bridge fracture zone (bent. chip & pea gravel)

• “Top-off” required when grout settling >10-20 ft.
From construction project tracking databases:

- Since 2013, over 28% of bores have been deeper than 400 ft. (120 m) deep

GHEX Bore Depths

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DEEP BORE CONCERNS/CONSIDERATIONS

• Cross-drilling due to drill bit veer
• Grouting pressures due to pumping through long tremie lines
• Buoyancy of plastic u-bend
• Internal working pressure due to water-filled loop during placement
  • Concern in deep bores that are completely dry
• Hydrostatic pressure of liquid grout slurry on outer wall of loop
  • Concern prior to grout hydration (i.e. set)
DEEP BORE CONCERNS/CONSIDERATIONS

<table>
<thead>
<tr>
<th>Angle (degrees)</th>
<th>Depth</th>
<th>Deviation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1.75</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>3.49</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>5.23</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>6.98</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>8.72</td>
</tr>
</tbody>
</table>

Horizontal Deviation / 100 ft

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### PIPE PRESSURE BUCKLING RATINGS

**EPR** for HDPE vs. Temperature and Ovality

<table>
<thead>
<tr>
<th>Temp (°F)</th>
<th>3408/3608</th>
<th>4710</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DR-9</td>
<td>DR-11</td>
</tr>
<tr>
<td>0%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>30</td>
<td>630.7</td>
<td>382.9</td>
</tr>
<tr>
<td>50</td>
<td>504.5</td>
<td>306.3</td>
</tr>
<tr>
<td>73.4</td>
<td>382.2</td>
<td>232.0</td>
</tr>
<tr>
<td>90</td>
<td>313.4</td>
<td>190.3</td>
</tr>
<tr>
<td>110</td>
<td>244.6</td>
<td>148.5</td>
</tr>
</tbody>
</table>

- **Ovality** is calculated as the percentage reduction in pipe diameter compared to its nominal diameter.
- Based on the 0.5-hour apparent modulus rating for HDPE. No safety factor was used in the calculations. PPI recommends using a safety factor, N=2.0.
# TYPICAL MIX TABLES

## Thermal Grout - Silica Sand Mix Table:

<table>
<thead>
<tr>
<th>Target TC (Btu/hr-ft. F)</th>
<th>Thermal Grout (lb)</th>
<th>Silica Sand (lb)</th>
<th>Fresh Water (gal)</th>
<th>Yield (gal/bag)</th>
<th>Density (lb/gal)</th>
<th>% Solids (by weight)</th>
<th>Grout Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>50</td>
<td>0</td>
<td>24</td>
<td>26.7</td>
<td>9.37</td>
<td>20</td>
<td>5.4</td>
</tr>
<tr>
<td>0.57</td>
<td>50</td>
<td>50</td>
<td>14.5</td>
<td>19.6</td>
<td>11.27</td>
<td>45.26</td>
<td>15.2</td>
</tr>
<tr>
<td>0.69</td>
<td>50</td>
<td>100</td>
<td>15.5</td>
<td>23</td>
<td>12.14</td>
<td>53.71</td>
<td>19.7</td>
</tr>
<tr>
<td>0.79</td>
<td>50</td>
<td>150</td>
<td>16.5</td>
<td>26.2</td>
<td>12.89</td>
<td>59.24</td>
<td>23.6</td>
</tr>
<tr>
<td>0.88</td>
<td>50</td>
<td>200</td>
<td>17.5</td>
<td>29.3</td>
<td>13.51</td>
<td>63.14</td>
<td>26.9</td>
</tr>
<tr>
<td>1.00</td>
<td>50</td>
<td>250</td>
<td>18.5</td>
<td>32.6</td>
<td>13.94</td>
<td>66.04</td>
<td>29.1</td>
</tr>
<tr>
<td>1.07</td>
<td>50</td>
<td>300</td>
<td>19.2</td>
<td>35.7</td>
<td>14.29</td>
<td>68.6</td>
<td>30.9</td>
</tr>
<tr>
<td>1.14</td>
<td>50</td>
<td>350</td>
<td>20.4</td>
<td>39.1</td>
<td>14.58</td>
<td>70.2</td>
<td>32.4</td>
</tr>
<tr>
<td>1.20</td>
<td>50</td>
<td>400</td>
<td>21.6</td>
<td>42.2</td>
<td>14.93</td>
<td>71.4</td>
<td>34.2</td>
</tr>
</tbody>
</table>

1 PSI per 100 ft. of column height, assuming the u-bend is completely full of water during grout placement

## Thermal Grout – Graphite Mix Table:

<table>
<thead>
<tr>
<th>Target TC (Btu/hr-ft. F)</th>
<th>Thermal Grout (lb)</th>
<th>PowerTEC (lb)</th>
<th>Fresh Water (gal)</th>
<th>Yield (gal/bag)</th>
<th>Density (lb/gal)</th>
<th>% Solids (by weight)</th>
<th>Grout Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.79</td>
<td>50</td>
<td>8</td>
<td>15</td>
<td>17.5</td>
<td>10.46</td>
<td>31.68</td>
<td>11</td>
</tr>
<tr>
<td>0.88</td>
<td>50</td>
<td>10.7</td>
<td>15</td>
<td>17.6</td>
<td>10.56</td>
<td>32.66</td>
<td>11.5</td>
</tr>
<tr>
<td>1.00</td>
<td>50</td>
<td>16</td>
<td>16.5</td>
<td>19.3</td>
<td>10.55</td>
<td>32.41</td>
<td>11.5</td>
</tr>
<tr>
<td>1.07</td>
<td>50</td>
<td>16</td>
<td>16</td>
<td>18.8</td>
<td>10.61</td>
<td>33.09</td>
<td>11.8</td>
</tr>
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<td>1.14</td>
<td>50</td>
<td>16</td>
<td>15.5</td>
<td>18.3</td>
<td>10.67</td>
<td>33.8</td>
<td>12.1</td>
</tr>
<tr>
<td>1.20</td>
<td>50</td>
<td>16</td>
<td>15</td>
<td>17.8</td>
<td>10.74</td>
<td>34.54</td>
<td>12.5</td>
</tr>
<tr>
<td>1.40</td>
<td>50</td>
<td>21.33</td>
<td>16</td>
<td>19.1</td>
<td>10.72</td>
<td>34.8</td>
<td>12.4</td>
</tr>
<tr>
<td>1.50</td>
<td>50</td>
<td>21.33</td>
<td>15.5</td>
<td>18.6</td>
<td>10.78</td>
<td>35.5</td>
<td>12.7</td>
</tr>
<tr>
<td>1.60</td>
<td>50</td>
<td>25.6</td>
<td>16</td>
<td>19.3</td>
<td>10.83</td>
<td>36.2</td>
<td>12.9</td>
</tr>
</tbody>
</table>

1 PSI per 100 ft. of column height, assuming the u-bend is completely full of water during grout placement
DEEP BORE CONCERNS/CONSIDERATIONS

Buckle Depth vs. TC for sand mixes:

Based on 0.5-hour apparent modulus for 3108/3608 at 73.4°F and no safety factor (N=1.0)
DEEP BORE CONCERNS/CONSIDERATIONS
QUESTIONS?
IMPORTANCE OF GROUT TC

• Radial Heat Transfer Equation:

\[
\frac{q}{L} = \frac{(T_{\text{loop}} - T_{\text{soil}})}{R_{\text{total}}}
\]
FINITE ELEMENT ANALYSIS ($R_g$)

- 1 Pipe, 2 Pipe, and 4 Pipe HEXs will be compared for B and C configurations
FINITE ELEMENT ANALYSIS ($R_g$)

- Formation (TC Varies)
- Geothermal Grout (TC Varies)
- Constant Temperature

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FINITE ELEMENT ANALYSIS ($R_g$)
FINITE ELEMENT ANALYSIS ($R_g$)
DESIGNING FOR PERFORMANCE

- Ultimate Goal: Deliver specific level of performance for the least cost
- Grout TC impacts design length & first cost
  - Calculate cost difference between non-thermal & thermal grout
  - Determine design length for non-thermal grout
  - Recalculate design length for thermal grout
    - Determine drilling & pipe costs
    - Estimate savings from bore length reduction
- Double U-Bend GHEX
  - Twice the amount of U-bends (3/4”)
  - Flow considerations
  - Higher Install Costs
    - Estimate Savings from bore length reduction
- Quad U-bend GHEX
  - 1.6x the amount of U-bends (3/4”)
  - Flow considerations x2
  - Higher Install Costs
    - Estimate Savings from bore length reduction
DESIGN EXAMPLE

- 100-ton, (1200 MBH) balanced loads
- Equivalent FLRHs (Cooling-500, Heating 500)
- Flow rate of 3 gpm/ton
- Heating COP = 3.50 at 30°F EWT
- Cooling EER = 15.0 at 90°F EWT
- 62°F (16.7°C) deep earth temp
- Grout TC 0.40 - 1.60 Btu/hr-ft-°F
- Soil, FTC = 0.80, 1.20, 1.60 Btu/hr-ft-°F (2.08 W/m-K)
- Turbulent flow through 1.25” (25 mm) u-bends in 5” (127 mm) bore
- Propylene Glycol @ 23 %
- 15’ c-c spacing
- 5 x 10 grid, single u-bend (B/C config)
- 2 x 10 grid Quad Loop (3/4” Loop)
- Double U-Bend connected in series (3/4” Loop)
# GROUTS IMPACT ON DESIGN

## Bore Length Reductions vs Grout TC for Various Soil Properties

<table>
<thead>
<tr>
<th>Grout TC (Btu/hr-ft-F)</th>
<th>Soil TC = 0.80 Btu/hr-ft-F</th>
<th>Soil TC = 1.20 Btu/hr-ft-F</th>
<th>Soil TC = 1.60 Btu/hr-ft-F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bore Length (Total ft)</td>
<td>Bore Length (Total ft)</td>
<td>Bore Length (Total ft)</td>
</tr>
<tr>
<td></td>
<td>ft/Ton Reduction</td>
<td>% Reduction</td>
<td>ft/Ton Reduction</td>
</tr>
<tr>
<td>0.4</td>
<td>32,852</td>
<td>--</td>
<td>25,914</td>
</tr>
<tr>
<td>0.57</td>
<td>31,183</td>
<td>16.69%</td>
<td>24,439</td>
</tr>
<tr>
<td>0.69</td>
<td>30,459</td>
<td>23.93%</td>
<td>23,794</td>
</tr>
<tr>
<td>0.79</td>
<td>30,008</td>
<td>28.44%</td>
<td>23,391</td>
</tr>
<tr>
<td>0.88</td>
<td>29,681</td>
<td>31.71%</td>
<td>23,097</td>
</tr>
<tr>
<td>1</td>
<td>29,328</td>
<td>35.24%</td>
<td>22,779</td>
</tr>
<tr>
<td>1.07</td>
<td>29,155</td>
<td>36.97%</td>
<td>22,622</td>
</tr>
<tr>
<td>1.14</td>
<td>29,001</td>
<td>38.51%</td>
<td>22,483</td>
</tr>
<tr>
<td>1.2</td>
<td>28,882</td>
<td>39.7%</td>
<td>22,374</td>
</tr>
<tr>
<td>1.4</td>
<td>28,552</td>
<td>43%</td>
<td>22,073</td>
</tr>
<tr>
<td>1.6</td>
<td>28,297</td>
<td>45.55%</td>
<td>21,838</td>
</tr>
</tbody>
</table>

Annual Conference, December 6 - 8, 2022 – Las Vegas, NV
BORE LENGTH VS GROUT TC

Bore Length vs Grout TC

- Soil TC = 0.80 Btu/hr-ft-F
- Soil TC = 1.20 Btu/hr-ft-F
- Soil TC = 1.60 Btu/hr-ft-F

Annual Conference, December 6 - 8, 2022 – Las Vegas, NV
### DOUBLE U-BEND IMPACT ON DESIGN

**Single 1 ¼” U-Bend (0.40 Grout) vs Double ¾” U-Bend Connected in Series**

<table>
<thead>
<tr>
<th>Grout TC (Btu/hr·ft·F)</th>
<th>Soil TC = 0.80 Btu/hr·ft·F</th>
<th>Soil TC = 1.20 Btu/hr·ft·F</th>
<th>Soil TC = 1.60 Btu/hr·ft·F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bore Length (ft)</td>
<td>ft/Ton Reduction</td>
<td>% Reduction</td>
</tr>
<tr>
<td>0.4</td>
<td>29,759</td>
<td>30.93</td>
<td>9.41%</td>
</tr>
<tr>
<td>0.57</td>
<td>28,313</td>
<td>45.39</td>
<td>13.82%</td>
</tr>
<tr>
<td>0.69</td>
<td>27,700</td>
<td>51.52</td>
<td>15.68%</td>
</tr>
<tr>
<td>0.79</td>
<td>27,324</td>
<td>55.28</td>
<td>16.83%</td>
</tr>
<tr>
<td>0.88</td>
<td>27,054</td>
<td>57.98</td>
<td>17.65%</td>
</tr>
<tr>
<td>1</td>
<td>26,765</td>
<td>60.87</td>
<td>18.53%</td>
</tr>
<tr>
<td>1.07</td>
<td>26,624</td>
<td>62.28</td>
<td>18.96%</td>
</tr>
<tr>
<td>1.14</td>
<td>26,499</td>
<td>63.53</td>
<td>19.34%</td>
</tr>
<tr>
<td>1.2</td>
<td>26,403</td>
<td>64.49</td>
<td>19.63%</td>
</tr>
<tr>
<td>1.4</td>
<td>26,138</td>
<td>67.14</td>
<td>20.44%</td>
</tr>
<tr>
<td>1.6</td>
<td>25,934</td>
<td>69.18</td>
<td>21.06%</td>
</tr>
</tbody>
</table>
BORE LENGTH VS GROUT TC

Bore Length vs Grout TC

Soil TC = 0.80 Btu/hr-ft-F
Soil TC = 1.20 Btu/hr-ft-F
Soil TC = 1.60 Btu/hr-ft-F

Annual Conference, December 6 - 8, 2022 – Las Vegas, NV
## QUAD LOOP IMPACT ON DESIGN

**Single 1 ¼” U-Bend (0.40 Grout) vs Quad ¾” U-Bend Connected in II @ 2 x 10 Grid**

<table>
<thead>
<tr>
<th>Grout TC (Btu/hr-ft-F)</th>
<th>Soil TC = 0.80 Btu/hr-ft-F</th>
<th>Soil TC = 1.20 Btu/hr-ft-F</th>
<th>Soil TC = 1.60 Btu/hr-ft-F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bore Length (Total ft)</td>
<td>Bore Length (Total ft)</td>
<td>Bore Length (Total ft)</td>
</tr>
<tr>
<td></td>
<td>ft/Ton Reduction</td>
<td>% Reduction</td>
<td>ft/Ton Reduction</td>
</tr>
<tr>
<td>0.4</td>
<td>26,041</td>
<td>68.11</td>
<td>20.73%</td>
</tr>
<tr>
<td>0.57</td>
<td>25,129</td>
<td>77.23</td>
<td>23.51%</td>
</tr>
<tr>
<td>0.69</td>
<td>24,755</td>
<td>80.97</td>
<td>24.65%</td>
</tr>
<tr>
<td>0.79</td>
<td>24,530</td>
<td>83.22</td>
<td>25.33%</td>
</tr>
<tr>
<td>0.88</td>
<td>24,371</td>
<td>84.81</td>
<td>25.82%</td>
</tr>
<tr>
<td>1</td>
<td>24,204</td>
<td>86.48</td>
<td>26.32%</td>
</tr>
<tr>
<td>1.07</td>
<td>24,123</td>
<td>87.29</td>
<td>26.57%</td>
</tr>
<tr>
<td>1.14</td>
<td>24,053</td>
<td>87.99</td>
<td>26.78%</td>
</tr>
<tr>
<td>1.2</td>
<td>23,999</td>
<td>88.53</td>
<td>26.95%</td>
</tr>
<tr>
<td>1.4</td>
<td>23,852</td>
<td>90.00</td>
<td>27.40%</td>
</tr>
<tr>
<td>1.6</td>
<td>23,742</td>
<td>91.11</td>
<td>27.73%</td>
</tr>
</tbody>
</table>
BORE LENGTH VS GROUT TC

Soil TC = 0.80 Btu/hr-ft-F
Soil TC = 1.20 Btu/hr-ft-F
Soil TC = 1.60 Btu/hr-ft-F
SUMMARIZED COMPARISON

<table>
<thead>
<tr>
<th>Grout TC</th>
<th>Soil TC = 0.80 Btu/hr-ft-F</th>
<th>Soil TC = 1.20 Btu/hr-ft-F</th>
<th>Soil TC = 1.60 Btu/hr-ft-F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bore Length (ft)</td>
<td>ft/Ton Reduction</td>
<td>% Reduction</td>
</tr>
<tr>
<td>0.4</td>
<td>32,852</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>0.88</td>
<td>29,681</td>
<td>31.71</td>
<td>9.65%</td>
</tr>
<tr>
<td>1.2</td>
<td>28,882</td>
<td>39.70</td>
<td>12.08%</td>
</tr>
<tr>
<td>1.6</td>
<td>28,297</td>
<td>45.55</td>
<td>13.87%</td>
</tr>
</tbody>
</table>

Double U-Bend In Series

|          | Bore Length (ft) | ft/Ton Reduction | % Reduction | Bore Length (ft) | ft/Ton Reduction | % Reduction |
| 0.4      | 29,759          | 30.93           | 9.41%        | 23,156          | 27.58           | 10.64%       | 19,561          | 25.48           | 11.52%       |
| 0.88     | 27,054          | 57.98           | 17.65%       | 20,609          | 53.05           | 20.47%       | 17,110          | 49.99           | 22.61%       |
| 1.2      | 26,403          | 64.49           | 19.63%       | 19,994          | 59.20           | 22.84%       | 16,517          | 55.92           | 25.29%       |
| 1.6      | 25,934          | 69.18           | 21.06%       | 19,547          | 63.67           | 24.57%       | 16,085          | 60.24           | 27.25%       |

Quad U-Bend 2 x 10

|          | Bore Length (ft) | ft/Ton Reduction | % Reduction | Bore Length (ft) | ft/Ton Reduction | % Reduction |
| 0.4      | 26,041          | 68.11           | 20.73%       | 19,851          | 60.63           | 23.40%       | 16,506          | 56.03           | 25.34%       |
| 0.88     | 24,371          | 84.81           | 25.82%       | 18,185          | 77.29           | 29.83%       | 14,842          | 72.67           | 32.87%       |
| 1.2      | 23,999          | 88.53           | 26.95%       | 17,813          | 81.01           | 31.26%       | 14,471          | 76.38           | 34.55%       |
| 1.6      | 23,742          | 91.10           | 27.73%       | 17,557          | 83.57           | 32.25%       | 14,216          | 78.93           | 35.70%       |
WHAT DID WE LEARN?

- Reducing bore resistance yields shorter design lengths
  - Via single u-bend and thermally enhanced grout
  - Via different heat exchanger (i.e. not a single u-bend)
  - At some point returns diminish
- Applies to all scenarios
- Standard u-bend with 1.20 btu/hr-ft-F grout reduces calculated design lengths by roughly 14%
- Double U-bend (2x the # of u-bends) with 0.40 btu/hr-ft-F roughly 11%
- Quad Loop (1.6x the # of u-bends) with 0.40 btu/hr-ft-F roughly 23%. 
Sensitivity Analysis
### DESIGN RESULTS

<table>
<thead>
<tr>
<th>Grout TC (Btu/hr-ft-F)</th>
<th>Soil TC = 1.20 Btu/hr-ft-F</th>
<th>Soil Diff = 0.80 ft²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Htg</td>
<td>Peak Clg</td>
</tr>
<tr>
<td>0.4</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.08</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.2</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.2</td>
<td>1320</td>
<td>1320</td>
</tr>
<tr>
<td>1.08</td>
<td>1320</td>
<td>1320</td>
</tr>
<tr>
<td>0.4</td>
<td>1320</td>
<td>1320</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grout TC (Btu/hr-ft-F)</th>
<th>Soil TC = 1.08 Btu/hr-ft-F</th>
<th>Soil Diff = 0.72 ft²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Htg</td>
<td>Peak Clg</td>
</tr>
<tr>
<td>0.4</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.08</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.2</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1.2</td>
<td>1320</td>
<td>1320</td>
</tr>
<tr>
<td>1.08</td>
<td>1320</td>
<td>1320</td>
</tr>
<tr>
<td>0.4</td>
<td>1320</td>
<td>1320</td>
</tr>
</tbody>
</table>
REFERENCES

- Thermal Grout and Pipe Buckling: Geo Outlook Volume 13, Number 1, (Ryan Carda PE)
- Grouting Standards : https://www.csagroup.org/
- LoopLink Pro Design Software (Open-Source)
- Importance of Grout Thermal Conductivity (GeoProinc.com)
- Product Handling Guide (GeoProinc.com)
- Thermal Grout Commissioning & Quality Assurance (GeoProinc.com)
Contact Info:

Tyler Harbeck
Lead Product Engineer
tharbeck@geoproinc.com