CASE HISTORY: CONDUCTIVITY & COST COMPARISON FOR VERTICAL AND HORIZONTAL CLOSED LOOP GROUND HEAT EXCHANGERS

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IGSHPA – Baltimore MD
Vertical Loops are common design practice for buildings >50,000 Sq. Ft.

Vertical bores may be incompatible with artesian flow conditions or groundwater protection closures.
Similar 350-ton horizontal systems at two sites, 12 miles apart and in the same year

October, 2014

John Geyer & Associates, Inc.
Community College Campus
(new 140,00 SF Main Building)
Proposed 440 Borehole Vertical Field hit Artesian Flow with Upward Leakage past Grout
Vertical field construction was partially done when multiple artesian leaks jeopardized drilling permits.
ARTESIAN LEAKAGE required Plug & Abandon cementing of vertical loops and design change to horizontal bores
Project Re-design

• Due to concerns of leakage and pressure from permitting authorities, vertical installation was halted
• Horizontal options were considered – excavated pit loop and horizontal borehole installation
• No area available for excavated GHX, leaving only a horizontal borehole option
• Loads and heat pump schedule were integrated into horizontal borehole simulations
• Preliminary field scope defined by simulations considering available area, site restrictions and asset capabilities
• TC test parameters defined by simulations
Heat with >15 Watts/ Foot for 48 Hours
(Soil Temperature, Thermal Capacity and Dissipation Rate)
1.25” HDPE Loops 650 to 1,000 feet long; no grout. U-Bend Assembly length is twice loop length.

Bores start and end at -3 feet. U-Bends are -10 Feet. Header at drilling end.
Vertical Loop Field changed to horizontal across four Baseball Fields (800 Ft)

Horizontal re-design required Thermal Conductivity Testing at two loop levels. In-situ Testing at two levels was done with and without bentonite grout.
Medium-sized horizontal directional drills drilled 800 foot bores in 5 hours

1,600’ 1.25” HDPE u-bend loop assembly pulled from opposite end of field
Three drills and a crew of 8 drilled 110 bores in 5 weeks
For testing purposes, two horizontal loops (-15’, -30’) were grouted and two were not.

20% solids bentonite grout used: k = 0.45
48 hour In-situ Thermal Conductivity test

Testing provided design input for: undisturbed temperature, thermal conductivity, diffusivity, formation lithology and preferred drilling procedures.
Summary of 6 tests: 2 vertical and 4 horizontal
Grout or Not to Grout?

• Four horizontal test bores were installed
  • Two 800’ x 15’ (nominal depth), one grouted and one not grouted
  • Two 800’ x 30’ (nominal depth), one grouted and one not grouted
• Concern was that without grouting voids could be created harming thermal performance
• We expected this would be a non-issue as the geology is unconsolidated and wet to saturated
• Testing proved that, at least for these conditions, there was no benefit to grouting
• Other soil conditions may require grouting – project specific
Table 1
Test Data, School

<table>
<thead>
<tr>
<th>Test Loop</th>
<th>Grout TE - btuh/ft/°F</th>
<th>Measured TC - btuh/ft/°F</th>
<th>Est'd Diffusivity - ft²/day</th>
<th>Undisturbed Temp. - °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>180’ vertical</td>
<td>1.00</td>
<td>0.97</td>
<td>0.63</td>
<td>~67</td>
</tr>
<tr>
<td>400’ vertical*</td>
<td>0.88</td>
<td>1.09</td>
<td>0.89</td>
<td>~68</td>
</tr>
<tr>
<td>15’ horizontal</td>
<td>no grout</td>
<td>0.92</td>
<td>0.60</td>
<td>~64</td>
</tr>
<tr>
<td>30’ horizontal</td>
<td>no grout</td>
<td>0.97</td>
<td>0.63</td>
<td>N/A</td>
</tr>
<tr>
<td>15’ horizontal</td>
<td>0.45</td>
<td>1.00</td>
<td>0.65</td>
<td>N/A</td>
</tr>
<tr>
<td>30’ horizontal</td>
<td>0.45</td>
<td>0.87</td>
<td>0.57</td>
<td>~64</td>
</tr>
</tbody>
</table>

* by others, from preliminary design effort

- Horizontal tests confirmed no substantial difference in performance between grouted and ungrouted bores
- TC values for 180’ test similar to 15’ and 30’ horizontal bores
- 400’ test for perspective only, TC value not substantially greater for this location
Figure 2

Site 1: School

1st Order Data from IGSHPA / ASHRAE test procedures

42- 48 Hours, > 15w/ft

Conductivity “k”

Diffusivity Ratio

Label Key: “180 V 1 1.00
180 = Loop length
15 = loop depth
V, H = Vertical / Horizontal
1 = Site #1, School
1.00 = grout conductivity, “k”
None = No Grout
Final GHX Installation

• 110 bores installed
  • 55 x 800’ x 1.25” DR11 HDPE at 15’ nominal
  • 55 x 800’ x 1.25” DR11 HDPE at 30’ nominal
• Field simulations based upon hourly load profile – horizontal GHX designed to handle 100% of facility cooling and heating
• A portion of the vertical GHX was retained and is also integrated into the operating system
• Field and headering infrastructure managed using two HDPE vaults – one for the horizontal field and the other for the vertical field
125,000 SF
Corporate Building
(Green field site, 12 miles away)
Project Perspective

- Client determined to have energy efficient mechanical system, needed more energy points (LEED “Gold” target)
- Permitting authority would not consider a vertical GHX:
  - Seawater encroachment into bay area aquifers serious concern, fear of aquifer comingling via vertical loops
- Excavated pit GHX eliminated
  - High water table (very brackish) would make an excavated GHX impractical, also invite more permitting scrutiny
- Horizontal borehole GHX determined to be feasible through mechanical evaluation – only option available
- Client, Design Team (architect, mechanical engineer) and Contractor assets pro-active – key to project’s success
Building Load → Total Loop Length → Fit to Site

15 Acre site; 8 Acre Loop Field
Building and Loop field Co-located at Different Depths

18 foot Loop Depth under
12 foot foundation, footings and utilities
Table 2
Test Data, Corporate
(same formation as school, 12 miles to south)

<table>
<thead>
<tr>
<th>Test Loop</th>
<th>Grout TE - btuh/ft/°F</th>
<th>Measured TC - btuh/ft/°F</th>
<th>Est'd Diffusivity - ft²/day</th>
<th>Undisturbed Temp. - °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>15' horizontal</td>
<td>no grout</td>
<td>0.95</td>
<td>0.60</td>
<td>~71</td>
</tr>
<tr>
<td>30' horizontal</td>
<td>no grout</td>
<td>0.93</td>
<td>0.59</td>
<td>~67</td>
</tr>
</tbody>
</table>

- Higher ambient temperature at 15 Ft may be due to climate influence
- Soil conditions wet at test depths
Site 2: Corporate

1st Order Data from IGSHPA/ASHRAE test procedures

42-48 Hours, > 15w/ft
Final GHX Installation

- 100 bores installed
  - 50 x 650’ x 1.25” DR11 HDPE at 15’ nominal
  - 50 x 650’ x 1.25” DR11 HDPE at 30’ nominal
- Field simulations based upon hourly load profile – horizontal GHX designed to handle ~70% to 100% of facility cooling and heating:
  - Intended central chiller plant vendor could not provide sufficient performance tables for data integration into simulation software – comparison simulations projected GHX could handle part to all peak loads depending on ‘moving target’ variables (controls SOO, actual EER of chiller, etc.)
  - No more available area for additional ground loops
  - System is configured to add hybrid cooling device if necessary
Figure 4
Conductivity “k”
7 tests at 2 sites

- School
  - Vertical
  - Horizontal 800 Ft
- Corporate
  - Horizontal 650 Ft

- 1.00 Grout
- No Grout
- 0.45 Grout
- No Grout

<table>
<thead>
<tr>
<th>Test</th>
<th>Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 V1</td>
<td>1.00</td>
</tr>
<tr>
<td>15 H1 None</td>
<td></td>
</tr>
<tr>
<td>30 H1 None</td>
<td></td>
</tr>
<tr>
<td>15 H1 0.45</td>
<td></td>
</tr>
<tr>
<td>30 H1 0.45</td>
<td></td>
</tr>
<tr>
<td>15 H2 None</td>
<td></td>
</tr>
<tr>
<td>30 H2 None</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5
Diffusivity Ratios
7 Tests, 2 Sites

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>1.00</td>
<td>Corporate</td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td></td>
<td>Horizontal 800 Ft</td>
<td></td>
</tr>
<tr>
<td>Horizontal 650 Ft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00 Grout</td>
<td></td>
<td>0.45 Grout</td>
<td></td>
</tr>
<tr>
<td>No Grout</td>
<td></td>
<td>No Grout</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- V1: 180 V
- H1: 15 H
- H2: 15 H
- None: No Grout

Data Points:
- 180 V1 1.00
- 15 H1 None
- 30 H1 None
- 15 H1 0.45
- 30 H1 0.45
- 15 H2 None
- 30 H2 None
<table>
<thead>
<tr>
<th></th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bores</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Length</td>
<td>350</td>
<td>700</td>
</tr>
<tr>
<td>Total Drilling</td>
<td>70,000 feet</td>
<td>70,000 feet</td>
</tr>
<tr>
<td>Loop field Area</td>
<td>~ 2 acres</td>
<td>~9 acres</td>
</tr>
<tr>
<td>Headering Area Disturbed</td>
<td>~ 2 acres</td>
<td>~0.8 acres</td>
</tr>
<tr>
<td>Headering as % of Drilling Cost</td>
<td>~ 25%</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>Headering Time</td>
<td>~ 5 weeks</td>
<td>&lt; 3 weeks</td>
</tr>
</tbody>
</table>
### Table 4

**Budget**
*(Approximate)*

<table>
<thead>
<tr>
<th></th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost per foot</strong></td>
<td>$14 - $18</td>
<td>$8 - $13</td>
</tr>
<tr>
<td><strong>70,000 ft drilling cost</strong></td>
<td>$980k - $1.25M</td>
<td>$560k - $910k</td>
</tr>
<tr>
<td><strong>Headering cost</strong></td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Total headering</strong></td>
<td>$245k - $315k</td>
<td>$85k - $135k</td>
</tr>
<tr>
<td><strong>Dirt Management (15%)</strong></td>
<td>$150k - $190k</td>
<td>$85k - $135k</td>
</tr>
<tr>
<td><strong>Ancillary Costs (20%, est)</strong></td>
<td>$200k - $250k</td>
<td>$110k - $180k</td>
</tr>
<tr>
<td><strong>Site Restoration (10%)</strong></td>
<td>$100k - $125k</td>
<td>$55k - $90k</td>
</tr>
<tr>
<td><strong>All-in Job Cost</strong></td>
<td><strong>$1.6 - $2.1M</strong></td>
<td><strong>$900 - $1,450k</strong></td>
</tr>
</tbody>
</table>
Conclusions

• In non-rocky soils to 40 feet deep, **horizontal boring may offer a viable design alternative with multiple advantages** over vertical drilling and headering.

• **Observed Conductivity and Diffusivity were similar on all tests** regardless of loop orientation or length for these project locations. All tests were performed in dry summer season.

• Conductivity was **essentially the same with and without grout**. No voids or subsurface gaps were created.

• Horizontal construction involved about **half the cost, half the time and one-third the surface disturbance** as vertical drilling and headering.

• **Co-location of loop field under buildings** was accomplished without physical interference or degraded thermal performance.

• Horizontal construction allows **ongoing surface activities and use** during 12-month construction season.

• Cost and operational events have been **repeated three times** without variance.

• Horizontal areas for horizontal borefields may be up to 4x larger than for a vertical loop field. **Schools with parking and athletic fields are superior sites** for horizontal construction.
Thank you for your time and attention!

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