HDPE Pipe Integrity at Depth: Vertical Closed Loop Ground Heat Exchangers

IGSHPA Conference – Baltimore, MD
October 15-16, 2014

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Major Geothermal
www.majorgeothermal.com
Deeper borehole designs for closed loop ground heat exchangers (GHX) can resolve loop installation conflicts for sites with limited access or restricted areas.

Denser rock, due to greater overburden pressure, may enhance thermal conductance.

Avoidance of more complex hybrid systems – if cooling is the concern this means additional 1\textsuperscript{st} cost for hardware, controls, other infrastructure, and greater operating cost, maintenance.
Typical concerns for deeper vertical loops:

- **HDPE pipe will burst if the hole is too deep**
- **HDPE pipe will collapse if the hole is too deep**
- **Need to install an intermediate HX on high rise buildings between the mechanical system and GHX (excessive hydrostatic pressure on the HDPE ground loop)**
- **If we go deeper we need to go to DR9 HDPE pipe since DR11 will fail past (fill in the blank) depth**
  
  – Have reviewed one project where the designer called for DR7 on 300’ depth holes!
If all the preceding were true we would have deep hole HDPE pipe failures throughout the industry..... but anecdotal evidence alone counters these assumptions.
Example of 500’ to 650’ depth GHX installations in Canada – 1.25” DR11 HDPE, PE 3408 & 3608:

- University of Ontario Institute of Technology, Oshawa, ON (2003), 375 boreholes x 650’, PE 3408
- The Edge Condominium, Toronto, ON (2011), 146 boreholes x 650’, PE 3608
- Pan Am Aquatic Center, Toronto, ON (2013), 100 boreholes x 600’, PE 3608
- Fuzion Condominium, Toronto, ON (2011), 98 boreholes x 550’, PE 3608
- University of Toronto Mississauga, Mississauga, ON (2009), 117 boreholes x 550’, PE 3608
- Toronto Community Housing Corporation (2011), Toronto, ON, 240 boreholes x 500’, PE 3608

(courtesy Beatty Geothermal Inc., www.beattygeo.ca)
Example 600’ depth GHX installations in Canada – 1.25” DR11 HDPE, PE 3608 or 4710:

- City Square Condos Phase II, Hamilton, ON (2013), 44 boreholes x 600’
- Alliance Phase I office facility, Toronto, ON (2013), 23 boreholes x 625'
- Greenlife Westside Condos, Milton, ON (2013), 55 boreholes x 605’
- Delridge Greenlife Business Centre, Milton, ON (2012), 12 boreholes x 620’
- Canterbury Place (senior care facility), Toronto, ON (2010), 70 boreholes x 600’
- City Square Condos Phase I, Hamilton, ON (2011), 30 boreholes x 620'

(courtesy Geosource Energy Inc., www.geosourceenergy.com)
Other known “deep” loop installations:

• 600’ depth installations in US – Chicago, Kansas City, other – DR9, DR11

• Swedish installations to 200 meters (656 feet)... with DR17!

• Commonly install 500’ vertical closed loop systems in Colorado (DR11) – Mitchell Hall, USAFA, Co. Sprgs.; IKEA, Centennial; Denver School of Science & Technology, DPS, Denver; Mirasol Ph. 2, Loveland Housing Authority, Loveland; other.
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Deeper Drilling – Ground Loop Installation

600’ depth loop installation in progress
If we have a 600’ borehole using a 1.25” DR11 HDPE u-bend assembly with a nominal 160 psi pressure rating for PE 3608 plastic, we should have the following:

- 260 psi hydrostatic pressure on the inside of the pipe (0.4335 psi/ft x 600)

So why does the HDPE pipe survive?
Hirschfeld Towers, Denver Housing Authority, GSHP retrofit using a vertical GHX:

• 81 boreholes x 450’ depth x 1.25” DR11 HDPE (PE 3608)
• Nine story retrofit, ~90+ feet vertical additional head pressure on GHX
• No intermediate heat exchanger
• System up and running since 2008
81 boreholes x 450’ depth x 1.25” DR11
Nine story facility (Hirschfeld Towers, Denver, CO)
If we have 450’ boreholes using 1.25” DR11 HDPE u-bend assemblies with a nominal 160 psi pressure rating for PE 3608 plastic, with over 90 feet of additional building head pressure due to building elevation piping, we should have the following:

- 234 psi hydrostatic pressure on the inside of the pipe (0.4335 psi/ft x [450’ + 90’])

So why does the HDPE pipe survive?
The reason that the DR11 PE 3608 works on both examples without failing is due to the following:

• Concentric grout or water pressure around the pipe is insufficient to collapse the pipe without other mechanical force.

• With water in the pipe, the surrounding force is countered – water does not like to compress!

• With additional head pressure from the building piping, further counteractive hydrostatic pressure is achieved, adding additional safety to assure the HDPE will not fail.
### Pressure Rating – Accounting for the Environment of a Vertical GHX, PE 3608

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**Water vs. Grout Hydrostatic Pressure**

Differential of water vs. grout hydrostatic pressure is what must be considered
### HDPE Pipe Integrity at Depth: Vertical Closed Loop Ground Heat Exchangers

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**Water vs. Grout Hydrostatic Pressure, with building elevation factored in**

Differential of water vs. grout hydrostatic pressure is what must be considered.
• PE 4710 has a higher pressure rating for both DR9 and DR11 pipe
• If relying strictly on the hydrostatic pressure differentials between grout density and water, what depths might be considered safe?
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**Pressure Rating – Accounting for the Environment of a Vertical GHX, PE 4710**

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**Water vs. Grout Hydrostatic Pressure – PE 4710**
Internal water pressure against pipe, excludes surrounding grout pressure

Red lines indicate nom. HDPE pressure ratings of SDR9 and SDR11, HDPE 4710

Graph from ‘Vertical drill hole pressure’ narrative, Dr. Matt Anderson, PhD, 2/18/2014
HDPE Pipe Integrity at Depth: Vertical Closed Loop Ground Heat Exchangers

External grout downhole pressure vs. depth

- Different grout densities for different TE compositions, excludes internal water pressure

*Graph from ‘Vertical drill hole pressure’ narrative, Dr. Matt Anderson, PhD, 2/18/2014*
Grout density vs. water pressure differential well within conservative pipe pressure ratings for depth approaching or exceeding 800’

Substantial safety margin for deeper boreholes!

*Graph from ‘Vertical drill hole pressure’ narrative, Dr. Matt Anderson, PhD, 2/18/2014*
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Water vs. Grout Hydrostatic Pressure, with building elevation factored in – PE 4710
What might the aforementioned tables suggest?

- Grout density hydrostatic vs water hydrostatic pressures tend to counter one another
- The water vs grout hydrostatic differentials suggest just on the pressure rating of the pipe alone that PE 4710 is the safer option for deeper boreholes

It is the opinion of the presenter that there is no advantage to PE 4710 over PE 3608 for boreholes in the 600’ depth range considering the surrounding pressure of the grouted borehole environment, that the pipe is filled with incompressible water, and considering the conservative aspect of HDPE pressure ratings:

- Even with surrounding grout pressure and the pipe not completely filled with water (or even dry), we suspect the pipe will maintain integrity to 600’ and greater (note following slides, including running a plumb bob inside of pipe to total depth)
- The ASTM pressure ratings are empirical and extremely conservative, and do not reflect what the pipe will actually tolerate for vertical closed loop installs
Conceptual cross section of borehole, assuming both legs of u-bend assembly are surrounded by grout – water and grout counteracting pressure against pipe.
Rotary drilling does not result in perfectly straight boreholes, pipe placement in cross section will vary, but hydrostatic pressure both internal and external to pipe is assumed to be consistent.
600’ depth u-bend loop, precharged with water and fusion sealed prior to plumb bob test. Had surrounding hydrostatic pressure collapsed the loop, water would have shot out of the freshly cut ends similar to a geyser.
Drilling contractor was convinced HDPE 4710 pipe was deforming at depth (500’ to 600’). DR11 pipe actual ID is 1.358”; plumb bob OD is 1.25”, or a net 0.054” clearance between the bob and pipe ID if perfectly centered. On all loops tested the bob dropped to full depth (600’) without issues, and was just as easily recovered.
One reason for the concern over “deeper” boreholes vs. HDPE pipe integrity are published pressure ratings

- Misinterpretation of the ASTM (D 2837) pressure rating determination adhered to by most PPI-associated manufacturers and what it means
- ASTM directly refers to PPI Handbook (November 2007) for testing and rating determinations, yet the PPI Handbook focuses on horizontal pipelining concerns and does not fully account for a closed loop vertical borehole environment typical for a ground loop
• The ASTM D 2837 values are derived from an *empirical* calculation:
  
  Pressure rating in PSI = 2 x HDS / DR – 1
  
  HDS – Hydrostatic Design Stress rating in psi
  DR – Dimension ratio of pipe (OD of pipe/wall thickness)

• HDS is a hydrostatic (water) *burst* rating, without confinement

• The “8” in PE 3608 refers to an HDS rating of 800 psi, the “10” in PE 4710 refers to an HDS rating of 1000 psi, etc.

• Due to the overwhelmingly robust nature of PE pipe the HDS stress ratings are extremely conservative to begin with!!!!!
• For PE 3608, DR11, the ASTM D 2837 value is determined as follows:
  \[2 \times \frac{800 \text{ psi}}{11 - 1} = 160 \text{ psi}\]
  \[(2 \times \text{HDS} / \text{DR} - 1)\]
• For PE 4710, DR11, the ASTM D 2837 value is determined as follows:
  \[2 \times \frac{1000 \text{ psi}}{11 - 1} = 200 \text{ psi}\]
  \[(2 \times \text{HDS} / \text{DR} - 1)\]
What exists in the downhole environment of a vertical borehole is a concentric pipe with a 800 or 1000 psi *burst* pressure rating for the HDS (Hydrostatic Design Stress rating in psi), enclosed in a *confining environment with external concentric pressure*. HDS is defined as a *burst pressure with no surrounding concentric pressure*. This is from the manual TN-41/2007, High Performance PE Materials for Water Piping Applications (November 2007), from the Plastic Pipe Institute, pages 3-4. ASTM directly refers to the PPI Handbook for testing and rating determinations, yet the PPI Handbook focuses on horizontal pipelining concerns and does not fully account for HDPE pipe in a confined vertical borehole environment.
Example from the PPI handbook inconsistent with considerations for vertical closed loop applications, often ref’d why HDPE cannot tolerate deeper loops:

Unconstrained Pipe Wall Buckling, Hydrostatic Buckling, ch. 6, p. 238

The equation for buckling given in this section is here to provide assistance when designing shallow cover applications. However, it may be used to calculate the buckling resistance of above grade pipes subject to external air pressure due to an internal vacuum, for submerged pipes in lakes or ponds, and for pipes placed in casings without grout encasement. (presenter emphasis)
The PPI handbook does not expressly consider the environment of a vertical ground loop for HDPE:

- Most stress and test considerations in the handbook are concerned with unequal or point loading external to the pipe; pressure surging; incomplete fluid filling of the pipe resulting in less structural integrity; other as related to civil and process use applications.
- Main concern of the handbook tends to be towards process and horizontal pipelining (oil, gas, water, septic) applications of HDPE pipe
- Ch. 13, HVAC Applications for PE Pipe, discusses the use of HDPE for use as a ground heat exchanger but provides no additional technical data relevant to pipe tolerance for deeper borehole applications
As the need for deeper GHX installations increase we as designers and the industry in general could use some help:

- Determination of how deep we can go with what type of HDPE pipe – this is where we need research, testing and validation from ASTM, PPI, IGSHPA and ?

- As deeper loops are considered, we may need to consider 1.50” and larger pipe to relieve pressure drop
  - This will entail the necessity for powered pipe handling equipment
  - Development of u-bend assemblies that are not excessively wide
  - Paradigm shift of how we do things, from designer to contractor
Assuming you are now convinced that deeper ground loops are both feasible and viable, there are some design and quality control issues to be concerned with........
While not excessively common, drilling into a previously completed borehole does occasionally occur (rotary drill rigs rarely drill straight holes). Deeper boreholes tend to ‘walk’ more so than shallower vertical ground loops, although we have observed this situation on 200’ bores with 20’ and 25’ spacing. For this reason consider greater borehole spacing when appropriate, particularly where drilling will be done in disturbed geology (faulting, steeply dipping formations, etc.).
• Ratings and standards (ASTM, PPI, IGSHPA) need to be upgraded to recognize, reflect and be commensurate with the confined (grouted) environment of deeper boreholes where the HDPE pipe is completely filled with fluid

• There is a need for definitive research for determination of what depths are actually safe for various types of HDPE pipe in vertical borehole depths, and what industry can rely on for design limitations

• Suggest IGSHPA be the lead on this effort, maybe working with an appropriate 3rd party independent entity with the physical research resources required to achieve these goals
• Dr. Matt Anderson, PhD, Milwaukee School of Engineering – Personal communications, for validating my calculations and additional insight regarding component integrity and pressure considerations
• Mr. Joel Poppert, MSc. Global Energy Management/BSc. Geology & Geophysics, Major Geothermal – Colleague, referencing Dr. Anderson for validation assistance and pressure calculations
• Mr. Michael Golightly, ISCO Industries – Personal communications, explanation of HDPE ratings, testing and industry history
• Mr. Ed Lohrenz, GeoOptimize – Personal communications, experience with deep loop installations
• Mr. Stan Reitsma, Geosource Energy, Inc. – Personal communications, example deep loop installations and installation techniques
• Mr. Brian Beatty, Beatty Geothermal, Inc. - Personal communications, example deep loop installations and installation techniques
• Mr. Allan Skouby, GRTI, GeoConnections– Personal communications, ‘reality checks’
• Mr. Chuck Remund, GRTI, GeoConnections – Personal communications, ‘reality checks’
• Mr. Erik Larson, Building Energy – Personal communications, via Joel Poppert, experience with deep loop installations
• And many others I am likely missing!

HDPE Pipe Integrity at Depth: Vertical Closed Loop Ground Heat Exchangers

Special thanks – one can never have enough friends......
• Narrative response (Feb. 2014), 600’ depth holes vs. DR9/DR11 integrity, Dr. Matt Anderson, PhD, Milwaukee School of Engineering
• 2nd Edition Handbook of PE Piping, Plastic Pipe Institute: Ch. 3, Material Properties; Ch. 5, Standard Specifications, Standard Test Methods and Codes for PE (Polyethylene) Piping Systems; Ch. 6, Design of PE Piping Systems; Ch. 13, HVAC Applications for PE Pipe (November 2007)
• ASTM D 2837-13 standard; Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products (December 2013)
• Thermia, www.thermia.com; 200 meter borehole installations
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