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

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

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Albany, NY
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Terry Proffer, CGD

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Perspective

- This presentation was originally composed in 2014
- Since 2014, the Plastic Pipe Institute and others have developed tools to predict safe pipe installations depth
- Others have taken this further to provide technical due diligence for thermally enhanced grout compositions, including graphite blends in addition to silica, for determination of safe installation depths. In particular, hats off to Ryan Carda with Geo-Connections & GeoPro for his 2022 (?) presentation and GeoOutlook article (v. 13, No. 1)
- The updated ASHRAE manual 'Geothermal Heating & Cooling, Design of Ground Source Heat Pump Systems' by Dr. Steve Kavanaugh & Kevin Rafferty, PE, references Pressure Ratings and Collapse Depths for Thermoplastic Pipe in Appendix C

Borehole Depth – Why Deeper?

- Deeper borehole designs for closed loop ground heat exchangers (GHX) can resolve loop installation conflicts for sites with limited access or restricted areas
- Fewer rig setups may result in slightly lower installation costs
- Potentially less excavation for headering
- Density of geology typically increases with depth, due to greater overburden pressure, which may enhance thermal conductance
- Deeper boreholes may reflect a higher average undisturbed temperature (higher thermal gradient with depth) – a potential advantage for heating dominant projects

Common Misconceptions – HDPE Integrity vs. Depth

Typical concerns for deeper vertical loops:

- *HDPE pipe will burst if the hole is too deep*
- *HDPE pipe will collapse (buckle) if the hole is too deep – ie, External Pressure Rating (EPR) exceeded*
- *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 lower number DR (greater wall thickness) HDPE pipe since higher DR (thinner wall) pipe will fail past (fill in the blank) depth*
  - *Have reviewed one project where the designer called for DR7 on 300' depth holes!*

Common Misconceptions – HDPE Integrity vs. Depth

If the preceding were true industry would be plagued with HDPE pipe failures…..

but anecdotal evidence alone counters these assumptions.

Examples of "Deep" Borehole Installations, HDPE Survival

Example of 500' to 650' depth GHX installations – 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*)

Examples of "Deep" Borehole Installations, HDPE Survival

Example 600' depth GHX installations – 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*)

Examples of "Deep" Borehole Installations, HDPE Survival

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.

Examples of "Deep" Borehole Installations, HDPE Survival

More recent "deeper" loop installations:

- 700' depth installation, Romney Hall, Montana State University, MT; 1.25" DR11, PE 4710
- 600' depth installation, Palmer Ridge High School, CO; 1.50" DR11, PE 4710
- 800' depth installation, King's College Circle, Toronto, Ontario, CA; 1.50" DR11, PE 4710 *(courtesy Geosource Energy Inc.)*
- 850' depth installation, Nordic Condos, Toronto, Ontario, CA; 1.50" DR11, PE4710 *(courtesy Geosource Energy Inc.)*
- 600' depth installation, Corner Brook Acute Care Hospital, Corner Brook, Newfoundland, CA; 1.50" DR11 PE4710 *(courtesy Geosource Energy Inc.)*
- 550' depth installation, Moby Arena, Colorado State University, Ft. Collins, CO; 1.25" DR11, PE 4710 *(courtesy Geo-Energy Services)*

Deeper Drilling – Ground Loop Installation

600’ depth loop installation in progress

Pressure Rating Exceeded – Yet the HDPE pipe survives

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?

Examples of “Deep” Borehole Installations, HDPE Survival

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

Deeper Drilling – High Rise Facility

81 boreholes x 450’ depth x 1.25” DR11
Nine story facility (Hirschfeld Towers, Denver, CO)

Pressure Rating Exceeded – Yet the HDPE pipe survives

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?

Pressure Rating – Accounting for the Environment of a Vertical GHX

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

	PSI at Depth					HDPE 3608 ASTM D 2837 RATING, PSI	
Depth, Feet	Water 0.4335 psi	0.90 Grout 0.71164 psi	0.90 Grout - Water Δ	1.00 Grout 0.73242 psi	1.00 Grout - Water Δ	**DR9**	**DR11**
50	21.7	35.6	13.9	36.6	14.9	200	160
100	43.4	71.2	27.8	73.2	29.9	200	160
200	86.7	142.3	55.6	146.5	59.8	200	160
250	108.4	177.9	69.5	183.1	74.7	200	160
300	130.1	213.5	83.4	219.7	89.7	200	160
350	151.7	249.1	97.3	256.3	104.6	200	160
400	173.4	284.7	111.3	293.0	119.6	200	160
450	195.1	320.2	125.2	329.6	134.5	200	160
500	216.8	355.8	139.1	366.2	149.5	200	160
550	238.4	391.4	153.0	402.8	164.4	200	160
600	260.1	427.0	166.9	439.5	179.4	200	160

Water vs. Grout Hydrostatic Pressure

Differential of water vs. grout hydrostatic pressure is what must be considered

Note: Grout densities for bentonite with silica thermal enhancement

Pressure Rating – Accounting for the Environment of a Vertical GHX, PE 3608

	PSI at Depth					HDPE 3608 ASTM D 2837 RATING, PSI	
Depth, Feet	Water 0.4335 psi	0.90 Grout 0.71164 psi	0.90 Grout - Water Δ	1.00 Grout 0.73242 psi	1.00 Grout - Water Δ	DR9	DR11
90	39.0	Above grade					
50	60.7	35.6	-25.1	36.6	-24.1	200	160
100	82.4	71.2	-11.2	73.2	-9.1	200	160
200	125.7	142.3	16.6	146.5	20.8	200	160
250	147.4	177.9	30.5	183.1	35.7	200	160
300	169.1	213.5	44.4	219.7	50.7	200	160
350	190.7	249.1	58.3	256.3	65.6	200	160
400	212.4	284.7	72.2	293.0	80.6	200	160
450	234.1	320.2	86.1	329.6	95.5	200	160
500	255.8	355.8	100.1	366.2	110.4	200	160
550	277.4	391.4	114.0	402.8	125.4	200	160
600	299.1	427.0	127.9	439.5	140.3	200	160

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

Differential of water vs. grout hydrostatic pressure is what must be considered

Note: Grout densities for bentonite with silica thermal enhancement

HDPE Pressure Ratings

- 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?

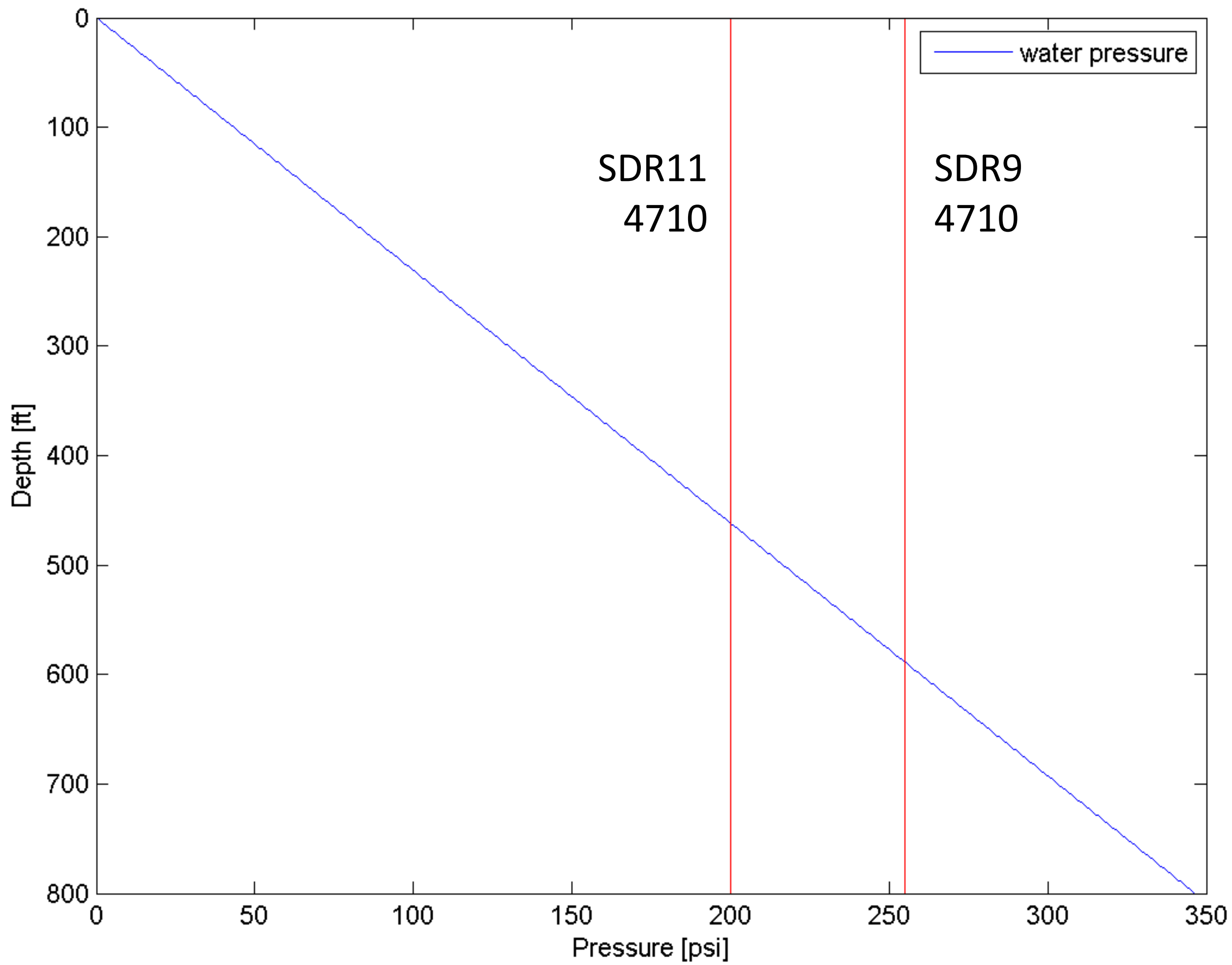
Pressure Rating – Accounting for the Environment of a Vertical GHX, PE 4710

	PSI at Depth					HDPE 4710 ASTM D 2837 RATING, PSI	
Depth, Feet	Water 0.4335 psi	0.90 Grout 0.71164 psi	0.90 Grout - Water Δ	1.00 Grout 0.73242 psi	1.00 Grout - Water Δ	**DR9**	**DR11**
50	21.7	35.6	13.9	36.6	14.9	250	200
100	43.4	71.2	27.8	73.2	29.9	250	200
200	86.7	142.3	55.6	146.5	59.8	250	200
250	108.4	177.9	69.5	183.1	74.7	250	200
300	130.1	213.5	83.4	219.7	89.7	250	200
350	151.7	249.1	97.3	256.3	104.6	250	200
400	173.4	284.7	111.3	293.0	119.6	250	200
450	195.1	320.2	125.2	329.6	134.5	250	200
500	216.8	355.8	139.1	366.2	149.5	250	200
550	238.4	391.4	153.0	402.8	164.4	250	200
600	260.1	427.0	166.9	439.5	179.4	250	200

Water vs. Grout Hydrostatic Pressure – PE 4710

Note: Grout densities for bentonite with silica thermal enhancement

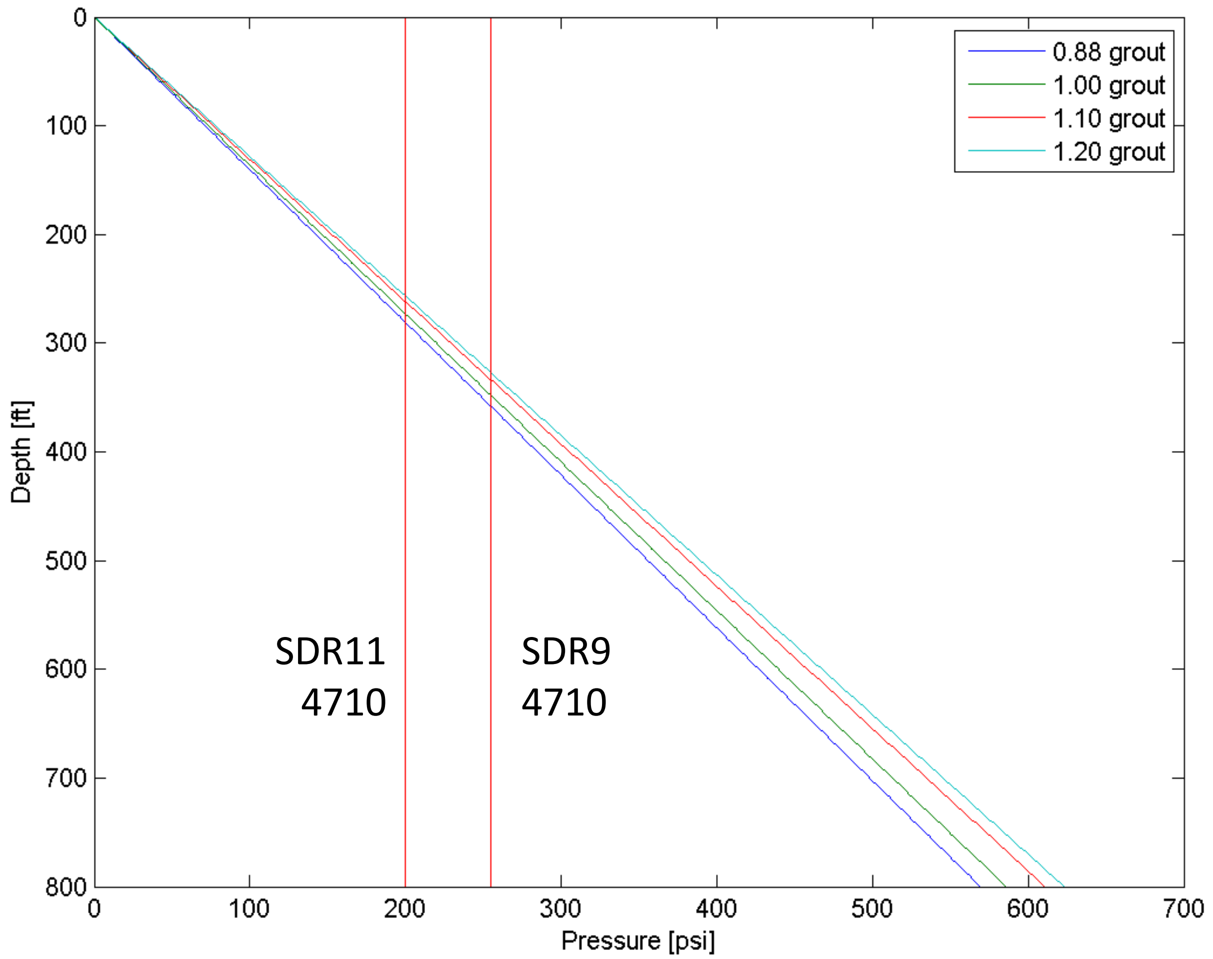
Internal water pressure against pipe vs. depth



Graph from 'Vertical drill hole pressure' narrative, Dr. Matt Anderson, PhD, 2/18/2014

- Internal water pressure against pipe, excludes surrounding grout pressure
- Red lines indicate nom. HDPE pressure ratings of SDR9 and SDR11, HDPE 4710

External grout downhole pressure vs. depth

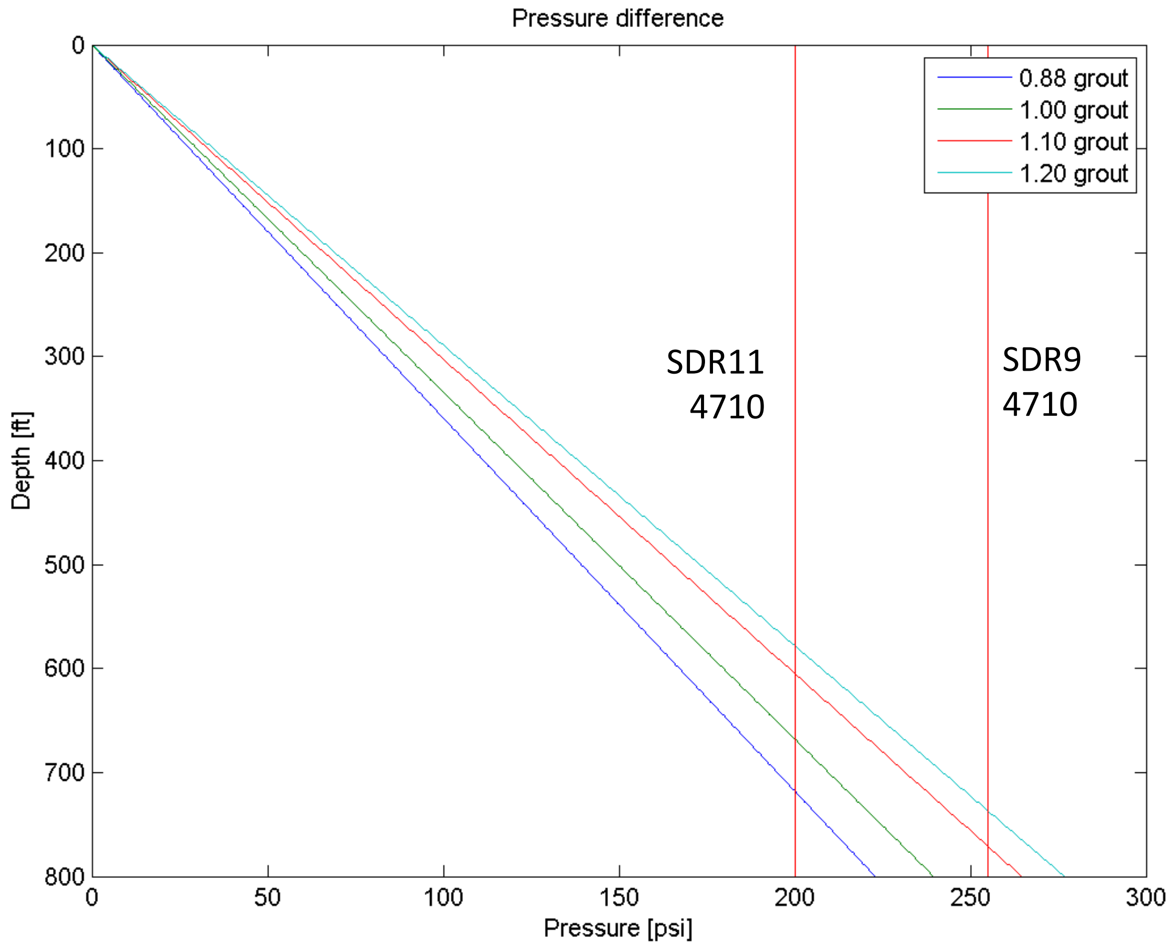


Graph from 'Vertical drill hole pressure' narrative, Dr. Matt Anderson, PhD, 2/18/2014

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

Note: Grout densities for bentonite with silica thermal enhancement

Grout vs. water differential pressure across pipe vs. depth



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!

Note: Grout densities for bentonite with silica thermal enhancement

Pressure Rating – Accounting for the Environment of a Vertical GHX, PE 4710

Depth, Feet	PSI at Depth					HDPE 4710 ASTM D 2837 RATING, PSI	
	Water 0.4335 psi	0.90 Grout 0.71164 psi	0.90 Grout - Water Δ	1.00 Grout 0.73242 psi	1.00 Grout - Water Δ	**DR9**	**DR11**
90	39.0	Above grade					
50	60.7	35.6	-25.1	36.6	-24.1	250	200
100	82.4	71.2	-11.2	73.2	-9.1	250	200
200	125.7	142.3	16.6	146.5	20.8	250	200
250	147.4	177.9	30.5	183.1	35.7	250	200
300	169.1	213.5	44.4	219.7	50.7	250	200
350	190.7	249.1	58.3	256.3	65.6	250	200
400	212.4	284.7	72.2	293.0	80.6	250	200
450	234.1	320.2	86.1	329.6	95.5	250	200
500	255.8	355.8	100.1	366.2	110.4	250	200
550	277.4	391.4	114.0	402.8	125.4	250	200
600	299.1	427.0	127.9	439.5	140.3	250	200

Water vs. Grout Hydrostatic Pressure,
with building elevation factored in – PE 4710

Note: Grout densities for bentonite with silica thermal enhancement

Water vs Grout Density vs HDPE Pipe

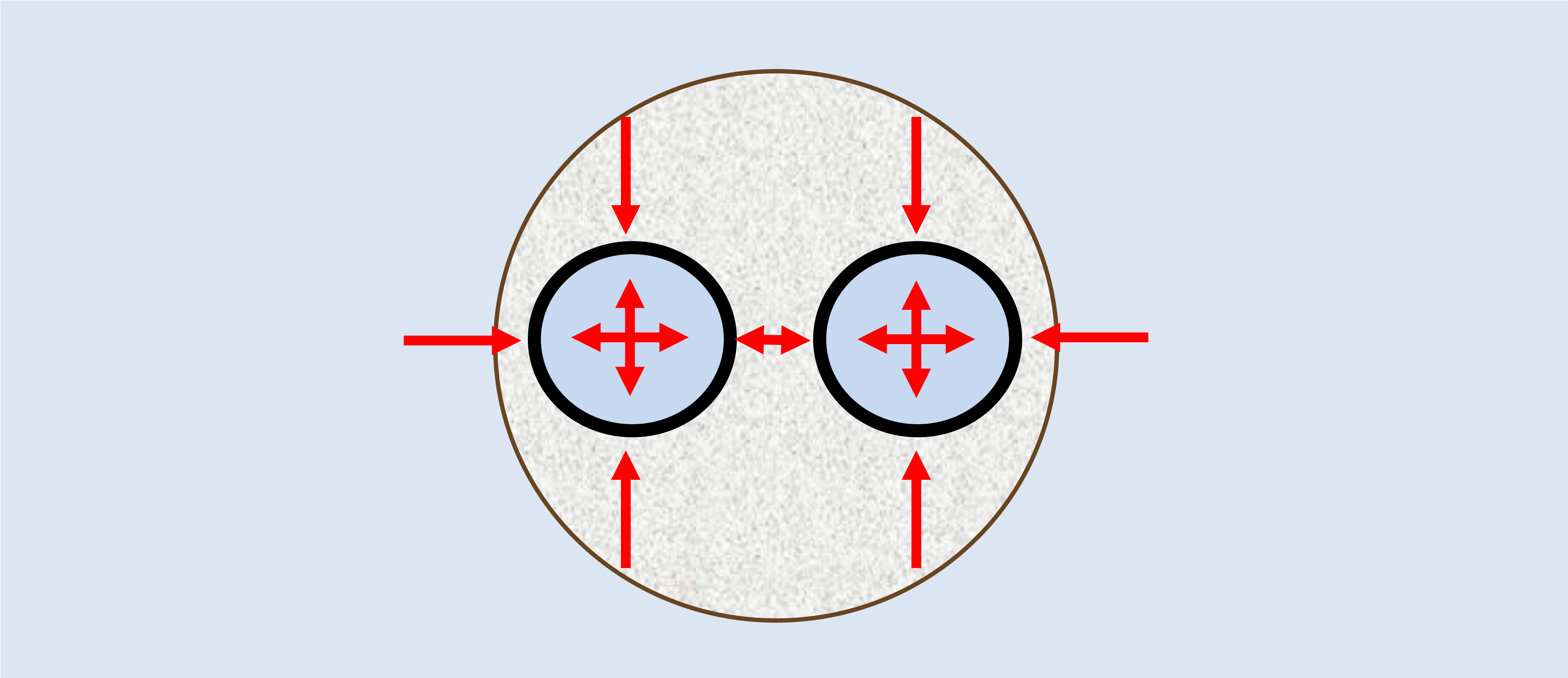
What might the aforementioned tables suggest?

- 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:

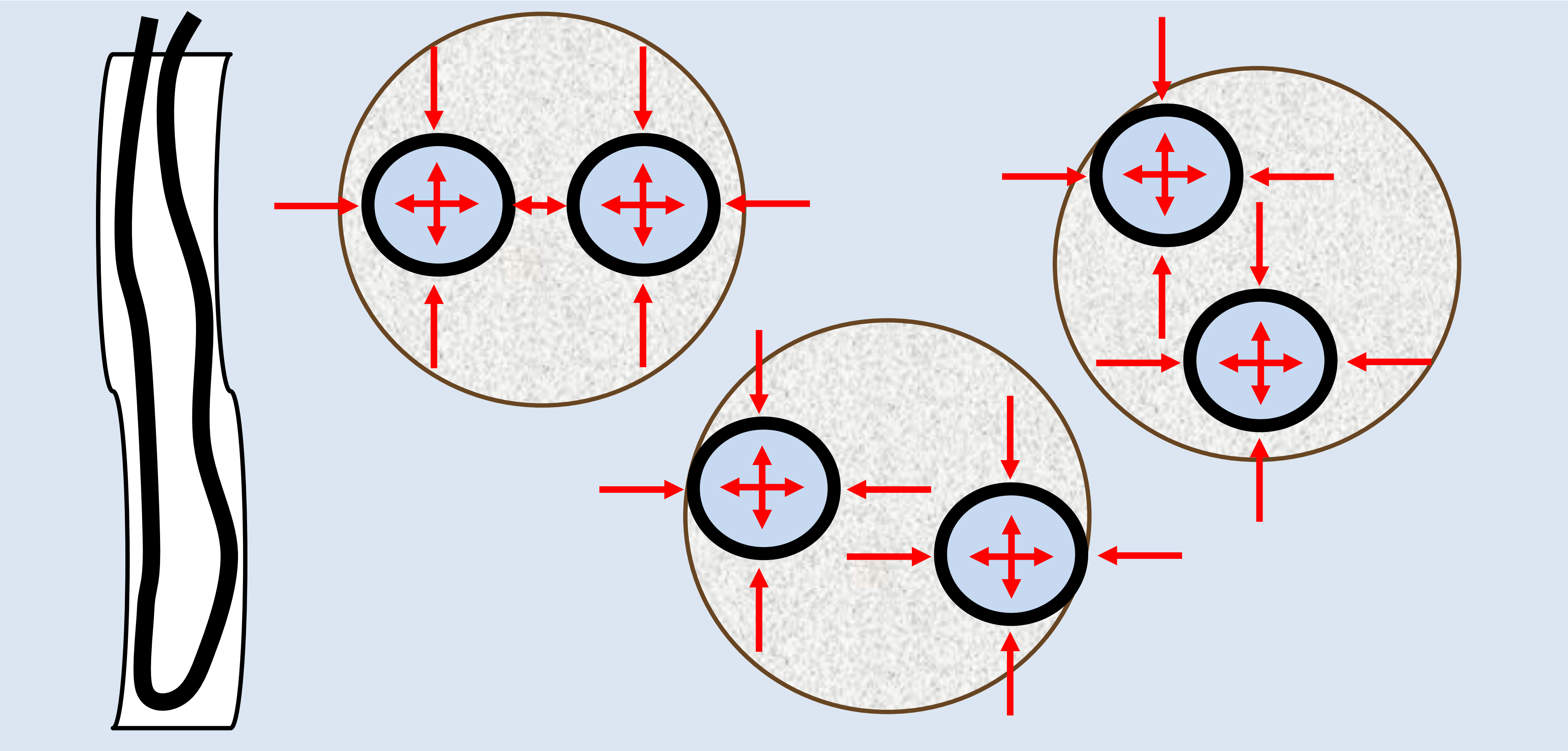
- Even with surrounding grout pressure and the pipe not completely filled with water (or even dry), we suspect the pipe will maintain integrity to 600' and greater (note following slides, including running a plumb bob inside of pipe to total depth)
- The ASTM pressure ratings are empirical and extremely conservative, and do not reflect what the pipe will actually tolerate for vertical loop installations
- **The question of PE 3608 vs 4710 is now mostly a moot point as industry standard now seems to be PE 4710**

Conceptual Cross Section



Conceptual cross section of borehole, assuming both legs of u-bend assembly are surrounded by grout – water and grout counteracting pressure against pipe

Conceptual Cross Section

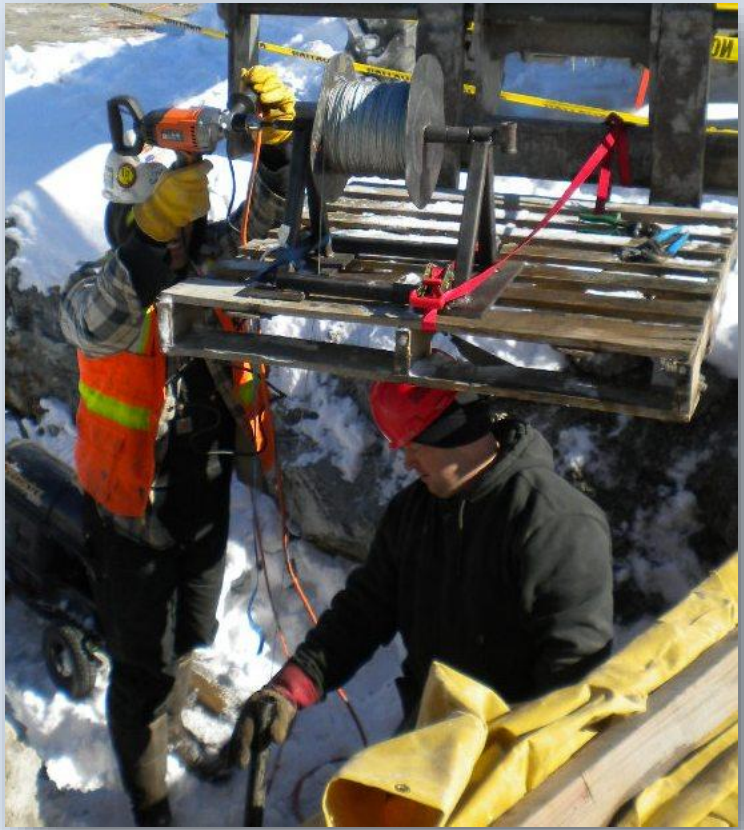


Rotary drilling does not result in perfectly straight boreholes, pipe placement in cross section will vary, but hydrostatic pressure both internal and external to pipe is assumed to be consistent

Deeper Drilling – Further Proof of HDPE Pipe Integrity at Depth

600’ depth 1.25” DR11 u-bend loop, precharged with water and fusion sealed prior to plumb bob test. Had surrounding hydrostatic pressure collapsed the loop, one would expect water in the loop to be ejected from the pipe when ends are cut off for testing.

Deeper Drilling – Further Proof of HDPE Pipe Integrity at Depth



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.

Assumptions

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

Background - ASTM D 2837

- 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!!!!!

Background - ASTM D 2837

- For PE 3608, DR11, the ASTM D 2837 value is determined as follows:

  2 x 800 psi / 11 – 1 = 160 psi

  (2 x HDS / DR – 1)

- For PE 4710, DR11, the ASTM D 2837 value is determined as follows:

  2 x 1000 psi / 11 – 1 = 200 psi

  (2 x HDS / DR – 1)

Background - ASTM D 2837

What exists in the downhole environment of a vertical borehole is a concentric pipe with a 800 or 1000 psi unconfined *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.

Background – PPI Handbook (note: from original due diligence, 2014)

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)

Background – PPI Handbook (note: from original due diligence, 2014)

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

ASTM, PPI, IGSHPA, HDPE Vendors

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, manufacturers and other stakeholders
- For deeper bores, consider 1.50" and larger pipe to relieve pressure drop
  - This may entail the necessity for powered pipe handling equipment
  - Development of u-bend assemblies that minimize u-bend width
  - Paradigm shift of how we do things, from designer to contractor

Hydrostatic Buckling / Pipe Collapse Calculator

Hydrostatic Buckling/Pipe Collapse Calculator is now available on the IGSHPA website to estimate max safe installation depths:

- Go to Members login *(you are an IGSHPA member, right?)*
- Go to Member Portal Resources
- Click on 'IGSHPA Calculators'
- Select 'Hydrostatic Buckling / Pipe Collapse Calculator'
- Calculator assumes HDPE pipe, PE 4710 grade

Hydrostatic Buckling / Pipe Collapse Calculator

From 'Thermal Grout & Pipe Buckling', Ryan Carda, GeoPro:

- *When pressure is applied to the outer wall of a pipe that exceeds its External Pressure Rating (EPR), it will (theoretically) collapse, which is referred to 'pipe buckling'. The EPR of a u-bend depends on its temperature, wall thickness, ovality (degree of roundness/deformation) and duration of exposure to external pressures. EPR for HDPE can be calculated using equation 3-39 from Ch. 6 of the PPI Handbook of Plastic Pipe:*

$$P_{wu} = \frac{f_o}{N_S} \frac{2E}{(1 - \mu^2)} \left(\frac{1}{DR - 1} \right)^3$$

WHERE:

P_{wu} = allowable unconstrained pipe wall buckling pressure, psi

DR = Dimmension Ratio

E = apparent modulus of elasticity of pipe material, psi

N_S = safety factor

f_o = Ovality Correction Factor

μ = Poisson's Ratio

Hydrostatic Buckling / Pipe Collapse Calculator

- As pointed out by Ryan Carda, "…The EPR of a u-bend depends on its temperature, wall thickness, ovality (degree of roundness/deformation) and ***duration of exposure to external pressures***." The emphasis added is taken to mean the time it takes to install a u-bend until it can be grouted can be critical to the survival of the HDPE pipe for deeper holes. This is an important consideration when using the calculator and may be relevant for commercial specifications for deeper loop installations.

Hydrostatic Buckling / Pipe Collapse Calculator – Example 1

Hydrostatic Buckling/Pipe Collapse Calculator example calculation inputs and result:

- HDPE dimension ratio: DR11
- Pipe ovality: 3%
- Safety factor: 1.5
- Duration, sustained loading: 1.0 hour *(installation time until pipe is safely grouted)*
- Poisson's Ratio: 0.45 (typical)
- Pipe temperature, °F: 95.0 (EWT to heat pumps 85.0)
- Fluid density, lbs/ft^3: 62.4
- Grout density, lbs/gallon: 10.2 (1.00 btuh/ft/°F, graphite TE)
- **Allowable borehole depth with water-filled pipe: 821 feet**

Hydrostatic Buckling / Pipe Collapse Calculator – Example 2

Hydrostatic Buckling/Pipe Collapse Calculator example calculation inputs and result:

- HDPE dimension ratio: DR11
- **Pipe ovality: 1% (changed from 3%)**
- Safety factor: 1.5
- Duration, sustained loading: 1.0 hour *(installation time until pipe is safely grouted)*
- Poisson's Ratio: 0.45 (typical)
- **Pipe temperature, °F: 85.0 (changed from 95.0)**
- Fluid density, lbs/ft^3: 62.4
- Grout density, lbs/gallon: 10.2 (1.00 btuh/ft/°F, graphite TE)
- **Allowable borehole depth with water-filled pipe: 1,094 feet**

Hydrostatic Buckling / Pipe Collapse Calculator – Example 3

Hydrostatic Buckling/Pipe Collapse Calculator example calculation inputs and result:

- HDPE dimension ratio: DR11
- **Pipe ovality: 0% (changed from 1%, Example 2)**
- Safety factor: 1.5
- Duration, sustained loading: 1.0 hour *(installation time until pipe is safely grouted)*
- Poisson's Ratio: 0.45 (typical)
- **Pipe temperature, °F: 85.0 (changed from 95.0, Example 1)**
- Fluid density, lbs/ft^3: 62.4
- Grout density, lbs/gallon: 10.2 (1.00 btuh/ft/°F, graphite TE)
- **Allowable borehole depth with water-filled pipe: 1,215 feet**

HDPE Pipe Condition - Considerations

Another consideration recently brought to this presenter's attention by Mr. Stan Reitsma (PE, PhD, CEO, GeoSource Energy), an experienced industry veteran in our industry who routinely designs and installs deep GHX systems, is the condition of an HDPE u-bend pipe assembly and could installation and handling reduce pipe integrity? Example considerations:

- Could scratches and other exterior impacts (ie, abrasion, other) reduce pipe integrity? Such exterior impacts may be caused by handling issues, or through installation where the pipe scrapes against the borehole wall during placement.
- As suggested by the Hydrostatic Buckling/Pipe Collapse calculation, ovality of the HDPE pipe may compromise depth integrity. When loading a u-bend assembly on a reel, and other handling considerations, are there steps that can be taken to reduce ovality potential? In addition to more thorough inspections of u-bend assemblies and greater care during staging, maybe consider larger diameter loading reels, be cognizant of the temperature during installation, etc.

Conclusion and Opinions

- HDPE purpose milled u-bend ground loops tolerate much deeper borehole depths than assumed ASTM unconfined pressure ratings
- Reasonable pipe handling and installation practices are encouraged to guard against compromising HDPE pipe integrity – ovality, structural integrity, external abrasions/scratches
- For deeper loop installations, the loop should be filled with water upon installation and grouted from TD to surface in the shortest time possible to minimize stress on the u-bend assembly
- There may be a need for more definitive research, where u-bend pipes are installed in deeper bores for the express purpose of testing for failure against maximum depths as industry moves towards deeper design depths for projects with limited area for GHX installation

Special thanks – one can never have enough friends……

From original 2014 presentation…

- 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’
- Dr. Chuck Remund, Phd, 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!

Additional help/input since 2014….

- Mr. Jeff Hammond, Executive Director, IGSHPA
- Mr. Lance MacNevin, Director of Engineering, Plastic Pipe Institute

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DISCUSSION, QUESTIONS

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