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PPI- BOREAID: A NEW POLYETHYLENE PIPELINE HORIZONTAL DIRECTIONAL DRILLING (HDD) DESIGN TOOL

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ABSTRACT: Over the past decade the use of horizontal directional drilling (HDD) has increased for the installation of municipal water, waste water, storm water, and gas pipelines. For most HDD pipeline installations medium and high density polyethylene (PE) is the product of choice. While consulting engineers and municipalities have vastly improved their HDD knowledge, the consulting and municipal personnel still lack detailed knowledge of the HDD technology. This lack of knowledge has limited and slowed HDD growth. To educate consultants and municipal personnel and to improve HDD polyethylene pipe designs the Plastics Pipe Institute (PPI) in conjunction with eTrenchless Group Inc. have developed Plastics Pipe Institute (PPI) Boreaid - a free web based and desktop PE plastic pipe design tool. This new pipe design tool allows user to complete preliminary HDD pipe designs in accordance with the PPI Handbook of Polyethylene Pipe Second Edition and ASTM F1962 design methods. PPI Boreaid is discussed in detail along with program limitations and assumptions. Using the design tool, a preliminary pipe design is completed for a 36in HDPE pipe installed 47 feet below the ground surface in a 4000 foot long bore. The design analysis shows that HDPE 4710 DR 9 pipe is required to resist operational loads and the pipe must be installed using rollers and ballast to meet installation load requirements.

1. INTRODUCTION

The 2010 Underground Construction Magazine Annual Municipal Survey (Carpenter 2010a) reports that trenchless construction accounts for 14.8 and 16.1 percent of new pipeline construction for sewer/storm water and potable water, respectively. In the survey, it is also reported that Horizontal Directional Drilling (HDD) is considered by municipal personnel to be the most beneficial of all trenchless construction methods. Since 1992 approximately 25,600 HDD drill rigs have been manufactured and sold. The maturity of the HDD construction marketplace can be traced to the diversity of materials that can be installed (such as High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), ductile iron and steel). In 2009, HDPE was used on approximately 41.3 percent of projects while PVC and ductile iron/steel pipe were used on 24.1 and 28.7 percent of projects (Carpenter 2010b). The HDD industry also continues to grow due to continued innovation in the areas of drill rig design and construction, drill tracking systems, electronics, mud and drill fluid systems, along with the development of good practice guidelines, contract specifications and experienced contractors.

In the 12th Annual HDD Survey Good Vibrations: HDD Industry Riding Out Recession Better Than Other Market Niches. Carpenter 2010b reports that:

"Consulting engineers and municipalities, while vastly improving their HDD knowledge the past two years, are still woefully lacking in detailed knowledge of the technology. Their inability to effectively inspect HDD leads to a lack of confidence in the technology and, in turn, often unnecessarily inhibits contractor management of projects by making invalid and extraneous demands. "Our jobs are hard enough without engineers expecting us to give them on-the-job training about what they should look for on a drill," complained a Southeast respondent. "Educating public officials is a major challenge for the HDD industry," emphasized a Northeastern contractor."

Carpenter 2010b concludes that these factors have been linked to the slow adoption of the HDD method for municipal new pipeline construction.

In August 1998, the Plastic Pipe Institute issued the technical Report "Polyethylene Pipe for Horizontal Directional Drilling". This report was prepared to be one of the chapters being prepared for inclusion in the Plastics Pipe Institute's PPI Handbook of Polyethylene Piping. This document details the design of polyethylene pipe for installation with a horizontal direction drill. In 1999, the American Society of Testing Materials (ASTM) released ASTM F1962 Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings. This standard follows the PE pipe design method noted in the PPI August 1998 technical report. In 2006, the Plastic Pipe Institute Released the Handbook of Polyethylene (PE) Pipe that contains Chapter 12 Horizontal Directional Drilling which details PE pipe design. In 2009, the second addition of the Plastic Pipe Institute Handbook of Polyethylene (PE) Pipe was released.

To date, several commercial HDD software programs have been developed by design consultants, plastic pipe manufacturers, and directional drill rig manufacturers to aid industry professionals (contractors and consulting engineers) with the design and construction of HDD projects. The following section provides a brief overview of HDD software tools.

(a) Petris Technology Inc. markets and sells a suite of independent PC-based software programs developed by Maurer - DrillPath, DrillMud and DrillEst. Drillpath consists of two modules: 1) surface/drill-path and 2) pipeline load/stress. The surface/drill-path module allows user to automate the drill path design and the pipeline load/stress module calculates plastic and steel pipe construction induced loads and stresses. DrillMud is designed to address a wide variety of hydraulics problems that can arise during HDD pilot-bore drilling and back-reaming operations. This program examines drill fluid volume requirements, borehole pressures versus fracture gradients, cuttings transport, and expected horsepower requirements. Input screens are designed to logically follow operations in typical field installations. DrillEst estimates costs for installing underground pipes and cables using mini-, midi- or maxi-HDD directional drilling systems. DrillEst is divided into the categories of labor, equipment and materials. Further information on Drillpath can be found in DrillPath (1996) and Kirby et al. (1997).

(b) Performance Pipe produces and distributes PLEXCALC II. This program is developed as a supplementary calculator for Performance Pipe Engineering Manual Books 2 and 3 so that HDD installed polyethylene pipelines safe pull load and allowable bending radius can be determined.

(c) Atlas Bore Planner, developed by Vermeer Manufacturing Ltd., is a bore planning and bore mapping tool that allows drill rig operators to plan the bore path prior to construction and to produce "as constructed" drawings once the pilot bore is completed. The tool provides a graphic visualization of the job, during both the planning phase and with an "as constructed" profile. The tool is designed to work with a variety of locating systems.

(d) The FieldCalc system, developed by Vermeer Manufacturing Ltd., is a software tool with features that include setback distance calculation, point-to-point bore path calculation, pullback time estimation, outside diameter and orientation configuration of multiple, same-sized ducts, and a pre-drill checklist reminder.

(e) MDrill, developed by Delft Geosystems, enables the design of a pipeline configuration by considering three construction stages: 1) pilot drilling, 2) reaming the initial pilot borehole, and 3) pulling back the pipeline. The graphical user interface allows input of the soil layers. The upper soil layers can be designated as load for settlement calculation purposes. Drilling fluid pressures are calculated for all installation stages (pilot,

reaming and pull back). MDrill is capable of dealing with pipelines made of steel and polyethylene. MDrill calculates the pulling force on the pipeline that is required to pull the pipeline into a pre-reamed bore and determines pipeline installation stresses. MDrill can be linked to advance pipeline structural analysis and settlement analysis programs.

(f) Technical ToolBox offers HDD Toolbox, a suite of integrated software applications specifically developed for design, engineering, and installation of pipelines and utilities by horizontal directional drilling. The software contains more than 20 program modules grouped by drilling fluids management and hydraulics, installation of steel pipe by HDD, installation of plastic pipe by HDD, installation of cable in conduit (CIC) by HDD, and integrated pipe and soil databases.

(g) Boreaid™, developed by Terein Inc., consists of a family of interlinked modules, developed to assist industry professionals with the planning, design and construction of horizontal directional drilling pipeline installations. The program's advanced graphical tools also allow the user to check all input and design values and to generate project design and construction documents. Boreaid consists of six interconnect sequential modules that pass on previously entered data and calculated values: 1) Bore Planner, 2) Loads/Deflections Calculator, 3) Drill Planner, 4) Bore Pressure Estimator, 5) Equipment/Tooling Selection and 6) Cost Estimator. Boreaid™, was developed to be user-friendly by providing the user with input fields, automated warnings/comments/recommendations, and advanced graphical interfaces. The program was also designed to permit the user to easily navigate through virtual site conditions and to view and check all input and calculated values in summary tables and/or graphically. Input along with calculate variables can be exported for upload into other programs, such as MS Excel, MS WORD and/or AutoCAD. Details on Boreaid are presented in Bayat et al. (2009).

In July 2010 the PPI and eTrenchless Group Inc. (owned and operated by the developers of Boreaid) entered into an agreement to develop PPI-Boreaid, a free web based and desktop software tool that:

- provides a user-friendly interface that completes preliminary HDD PE pipe calculations in accordance with Chapter 12 of 2nd edition PPI PE Handbook and ASTM F1962;
- promotes the use of PPI PE Handbook and ASTMF1962 design methodologies and;
- provide hyperlinks to PPI PE Handbook so that users can learn about HDD PE plastic pipe design.

2. PPI-Boreaid

PPI- Boreaid was developed to:

- be easy and quick to use by novice and experienced HDD users;
- guide users through HDD PE plastic pipe design;
- improve polyethylene pipe HDD designs so that successful HDD projects are completed;
- be transparent by providing all detailed calculations and assumed input values;
- provide users with typical input values and ranges; and
- be an HDD industry education tool

PPI-Boreaid consists of a limited version of two of the six Boreaid™ modules shown in Figure 1 - Bore Planner and HDPE pipe design.

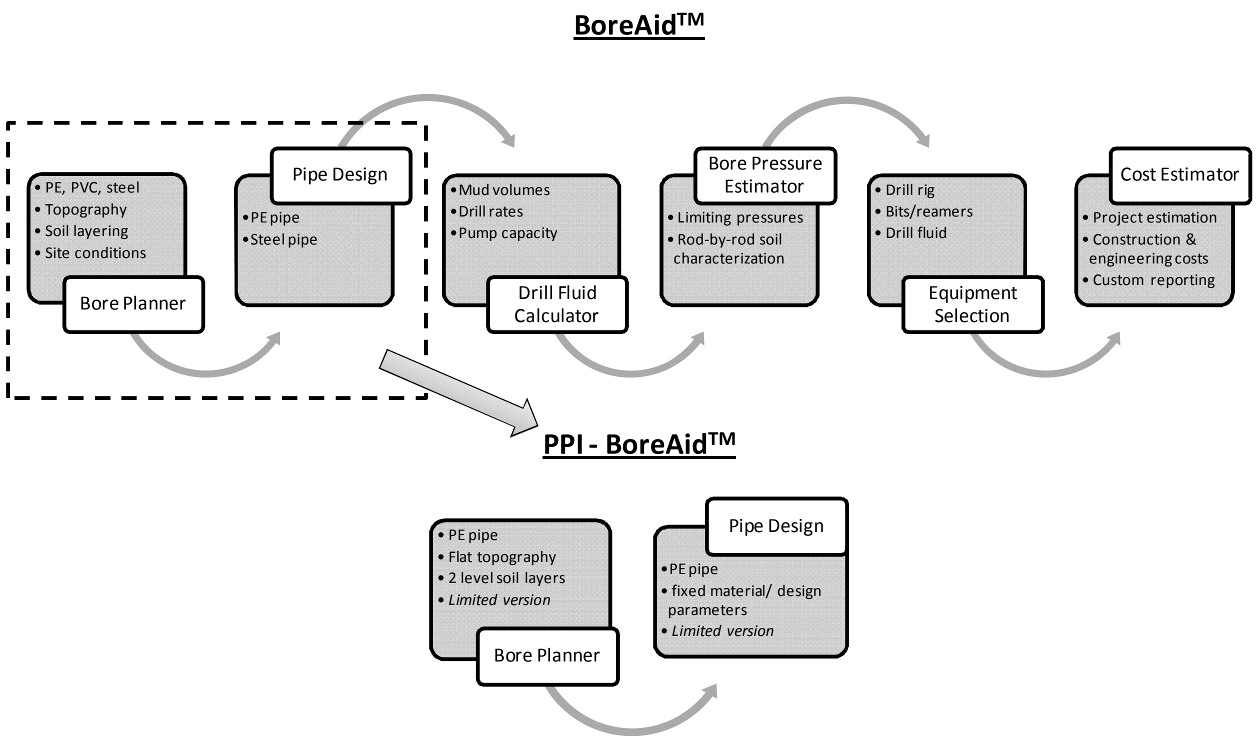


Figure 1. PPI-Boreaid modules developed from Boreaid™.

In the Fall of 2010, Version 1 of PPI-Boreaid was tested by PPI personnel and attendees at the Plastics Pipes XV Conference, held in Vancouver, BC during September 20-22, 2010. Based on user feedback, a number of software design modifications were implemented. In November 2010, the revised PPI-BoreAid tool was presented to PPI members so it could be balloted for public release in early 2011. PPI membership suggested additional modifications which were implemented. In December 2010, PPI membership approved the release of PPI-BoreAid to the public. On February 4, 2011, eTrenchless Group Inc. posted PPI-Boreaid on **http://ppi.Boreaid.com/**, a public access website, hosted and managed by eTrenchless Group Inc.

When entering the website the first page to load is the Terms of Use as shown in Figure 2.

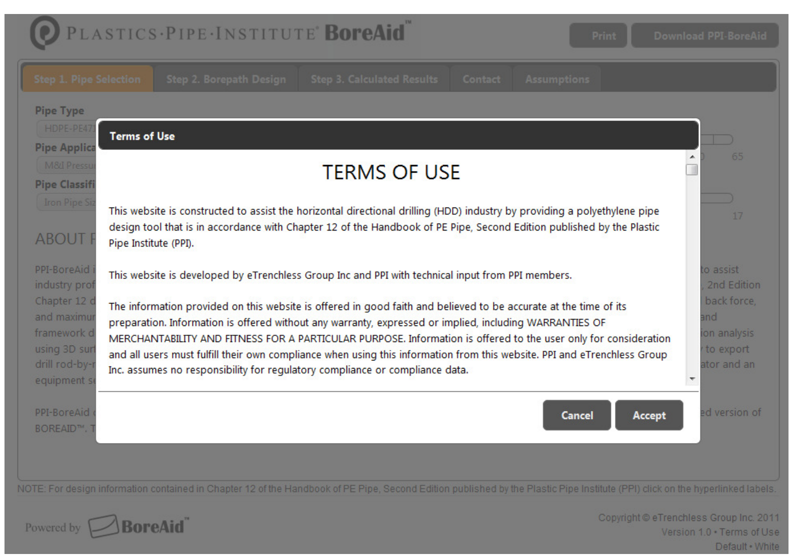


Figure 2. PPI-Boreaid Terms of Use page.

The web based tool consists of five web tabs across the top of the webpage as shown in Figure 3:

1. Step 1. Pipe Selection;
2. Step 2. Borepath Design;
3. Step 3. Calculated Results;
4. Contact; and
5. Assumptions.

Each tab is discussed in the following sections. A link to the Terms of Use is provided on the bottom right of all pages.

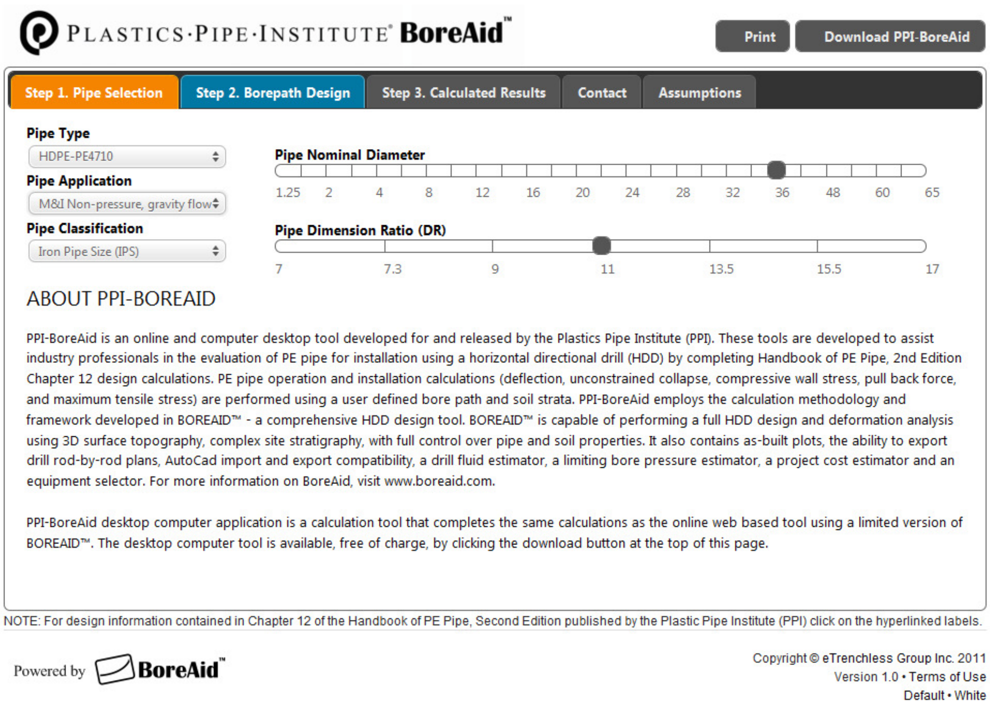


Figure 3. Screen shot of first page of PPI-Boreaid.

3. STEP 1 PIPE SELECTION

On the first tab, users are required to select the pipe type from the down drop menu – HDPE PE 4710 or 3608 or MDPE PE 2708. The selection is based on the PE resin used for the pipe design. If the user is unclear of the pipe type they can click on the hyperlinked label “Pipe Type” and the appropriate section of Chapter 3 of the PPI PE Handbook will open as a portable document format (PDF) file as shown in Figure 4. In Figure 3, the Pipe type is set to HDPE PE 4710.

The next step is the selection of Pipe Application: Gas, M & I Pressure Pipe and M &I Non-pressure, gravity flow where M&I is the short form for Municipal and Industrial applications. Once again the text Pipe Application is hyperlinked to the appropriate section of the PPI PE Handbook. In Figure 3, the pipe application is M&I Non-pressure, gravity flow.

The next step consists of selection of the Pipe Classification – Iron Pipe size (IPS) or ductile Iron Pipe Size (DIPS). In Figure 3, the pipe classification is set to Iron Pipe Size (IPS). Changing the pipe classification will automatically load various selections for the Pipe Dimension Ratio (DR) and Pipe Nominal Diameter (OD) applicable to the selected application. The user may change the scroll position of the DR and OD bars to select the appropriate product pipe (a 36’’ DR11 pipe as shown in Figure 3).

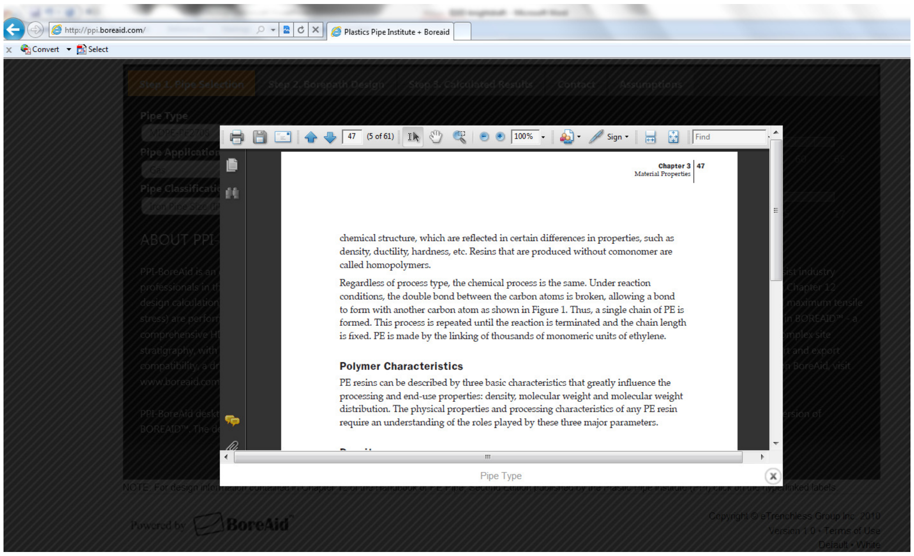


Figure 4. PPI PE Handbook Chapter 3 opened by clicking on the hyperlinked text labels.

4. STEP 2 BOREPATH DESIGN

Figure 5 shows the Step 2. Borepath Design tab which mimics the methodology discussed in Chapter 12 of the PPI PE Handbook.

PPI-Boreaid pipe design is limited to a bore in two horizontal soil layers and a flat surface topography. Clicking on the Soil 1 or 2 tabs allows the following choice of soil types: Sand, Silty-Sand, Clayey-Sand, and Lithified Rock. Soil properties are provided in Table 1.

Table 1. Soil material properties.

Soil Type	Unit Weight (lbs/ft^3) Dry	Unit Weight (lbs/ft^3) Saturated	Internal Angle of Friction (degrees)
Sandy-Clay	107	126	20
Silty-Sand	113	130	27
Sand	119	134	36

The web page is set up with required input parameters on the left side of the page and calculated values on the right side of the page, as shown in Figure 5. To assist users who are unfamiliar with the design method all input and calculated text labels are hyperlinked to the appropriate sections of PPI PE Handbook.

User bore path input parameters include: Project Length (ft), Pipe Entry Angle (degrees), Pipe Exit Angle (degrees), Depth of Cover (ft), Depth to Water Table (ft), Soil Thickness (ft), and Extra Length of Pipe (ft).

The thickness of the top layer of soil (Soil 1), is set by inputting a value into the Soil Thickness (T1, ft) input box. The depth of cover is the maximum depth of the pipe from the ground surface. If a user enters a pipe entry angle or pipe exit angle that is outside 5 to 10 degrees or 8 to 20 degrees, respectively, a warning is automatically returned stating that input values are outside industry recommended values. It should be noted that the pipe exit angle is the drill rig entrance and the pipe entrance is the drill rig exit angle.

In the full version of Boreaid, the user has the ability to set site material properties to user-defined values, as well as develop complex subsurface geology and surface topography profiles.

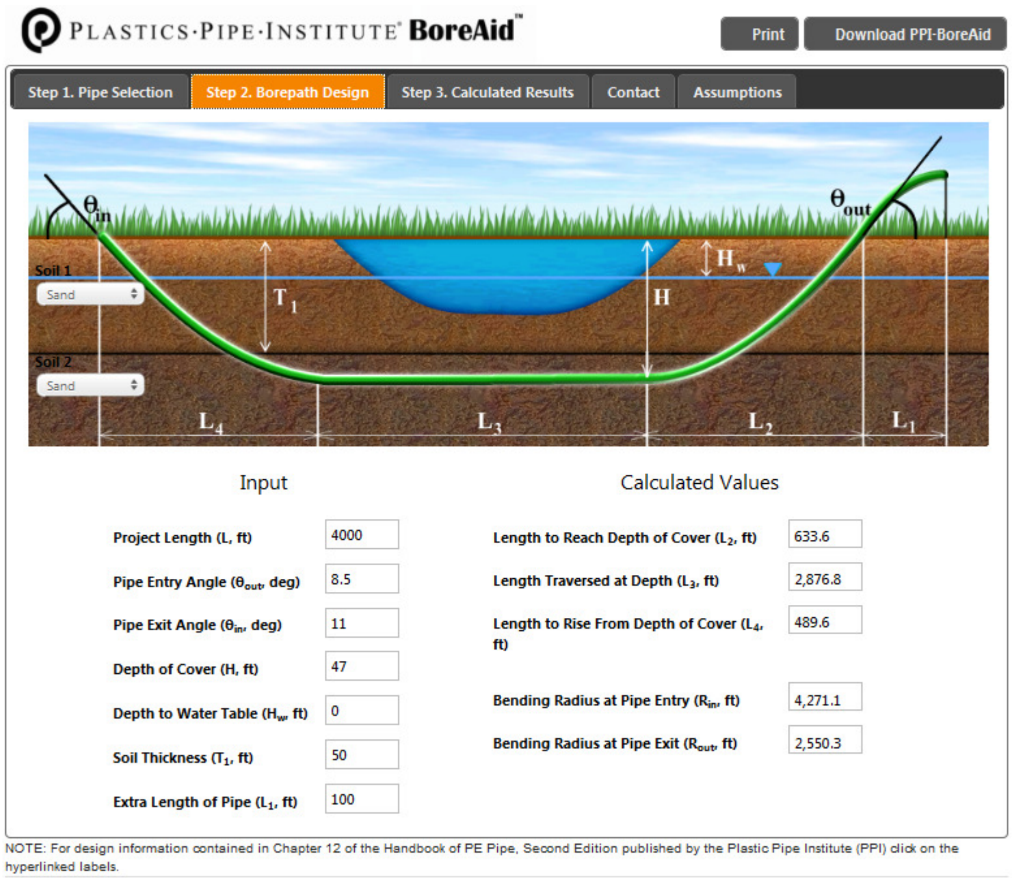


Figure 5. Step 2 Borepath design page.

5. STEP 3 CALCULATED RESULTS

Figure 6 shows the *Step 3. Calculated Results* tab. This tab provides calculated values and factors of safety values for pipe operation and installation conditions. Figure 7 shows calculated values.

It should be noted that values are provided for the DR selected on the first tab, as well as, for one dimension ratio higher and one dimension ratio lower than the selected value. For example, in Figure 6 calculations are performed for DR 11, DR 13.5 and DR 9, when DR11 is selected. As noted on the vertical tabs of the table, each analysis is completed for three design conditions: 1) no rollers and no ballast, 2) with rollers and no ballast and 3) with rollers and ballast.

The calculation procedure for installation critical collapse is outlined on page 450 of the PPI PE Handbook. In PPI-BoreAid, 75 percent of the maximum calculated tensile stress is used to determine the installation critical collapse pressure. The 1-hour collapse pressure includes the effect of fluid drag (hydrokinetic pressure) whereas the 10-hour does not.

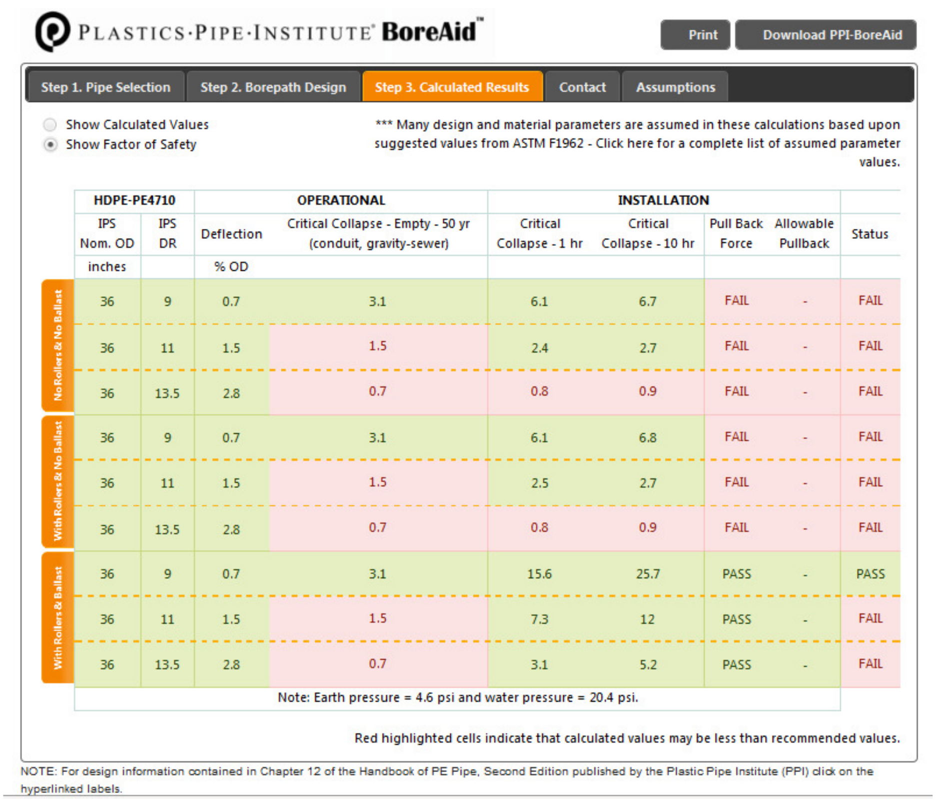
PPI-BoreAid calculates the maximum pipe pull back force required to overcome the combined frictional drag, capstan effect, and hydrokinetic drag. The calculation method implemented is the same provided in ASTM F1962 and the PPI PE Handbook. The pipe DR must be sufficient so that the tensile stress in the pipe wall, due to the pullback force, is equal to or lower than the pipe allowable safe tensile stress.

The last column in the Calculation Table is the installation pass or fail criterion. For the pipe to achieve a pass it must have a critical collapse factor of safety of 2.0 or greater and a pullback factor of safety of 1.0 or greater. Since the allowable pipe pullback stress includes a built in factor of safety, a pullback factor of safety factor of unity is deemed reasonable.

The pipe pass fail criterion does not consider operation deflection limit analysis, pipe wall stress, or the buoyant deflection during installation. Fields that do not meet required values are colored for easy identification.

A complete list of assumed design parameters are provided by clicking on hyperlinked text "*** *Many design and material parameters are assumed in these calculations based upon suggested values from ASTM F1962 - Click here for a complete list of assumed parameter values"* located above the table of values and on the Assumption Tab.

On the upper right corner of the page is a Print button. Clicking this tab produces an Adobe Acrobat PDF file for the analysis completed that users may download to their computer or print. Next to the Print Button is a Download PPI-Boreaid button. Clicking this button downloads a desktop version of PPI-Boreaid that can perform the same calculations as the web version without the need for internet access.



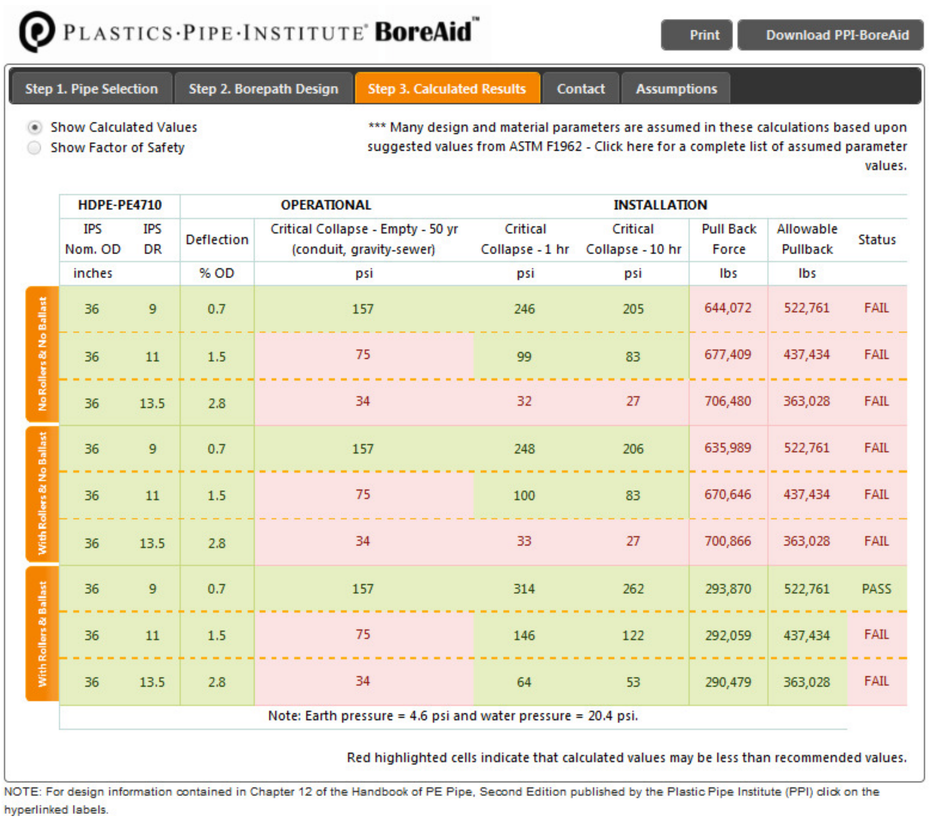
	HDPE-PE4710		OPERATIONAL		INSTALLATION				
	IPS Nom. OD	IPS DR	Deflection	Critical Collapse - Empty - 50 yr (conduit, gravity-sewer)	Critical Collapse - 1 hr	Critical Collapse - 10 hr	Pull Back Force	Allowable Pullback	Status
	inches		% OD						
No Rollers & No Ballast	36	9	0.7	3.1	6.1	6.7	FAIL	-	FAIL
	36	11	1.5	1.5	2.4	2.7	FAIL	-	FAIL
	36	13.5	2.8	0.7	0.8	0.9	FAIL	-	FAIL
With Rollers & No Ballast	36	9	0.7	3.1	6.1	6.8	FAIL	-	FAIL
	36	11	1.5	1.5	2.5	2.7	FAIL	-	FAIL
	36	13.5	2.8	0.7	0.8	0.9	FAIL	-	FAIL
With Rollers & Ballast	36	9	0.7	3.1	15.6	25.7	PASS	-	PASS
	36	11	1.5	1.5	7.3	12	PASS	-	FAIL
	36	13.5	2.8	0.7	3.1	5.2	PASS	-	FAIL

Note: Earth pressure = 4.6 psi and water pressure = 20.4 psi.

Red highlighted cells indicate that calculated values may be less than recommended values.

NOTE: For design information contained in Chapter 12 of the Handbook of PE Pipe, Second Edition published by the Plastic Pipe Institute (PPI) click on the hyperlinked labels.

Figure 6. Step 3 Calculated Factor of Safety Results.



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Step 1. Pipe Selection | Step 2. Borepath Design | Step 3. Calculated Results | Contact | Assumptions

Show Calculated Values
Show Factor of Safety

*** Many design and material parameters are assumed in these calculations based upon suggested values from ASTM F1962 - Click here for a complete list of assumed parameter values.

	HDPE-PE4710		OPERATIONAL		INSTALLATION				
	IPS Nom. OD	IPS DR	Deflection	Critical Collapse - Empty - 50 yr (conduit, gravity-sewer)	Critical Collapse - 1 hr	Critical Collapse - 10 hr	Pull Back Force	Allowable Pullback	Status
	inches		% OD	psi	psi	psi	lbs	lbs	
No Rollers & No Ballast	36	9	0.7	157	246	205	644,072	522,761	FAIL
	36	11	1.5	75	99	83	677,409	437,434	FAIL
	36	13.5	2.8	34	32	27	706,480	363,028	FAIL
With Rollers & No Ballast	36	9	0.7	157	248	206	635,989	522,761	FAIL
	36	11	1.5	75	100	83	670,646	437,434	FAIL
	36	13.5	2.8	34	33	27	700,866	363,028	FAIL
With Rollers & Ballast	36	9	0.7	157	314	262	293,870	522,761	PASS
	36	11	1.5	75	146	122	292,059	437,434	FAIL
	36	13.5	2.8	34	64	53	290,479	363,028	FAIL

Note: Earth pressure = 4.6 psi and water pressure = 20.4 psi.

Red highlighted cells indicate that calculated values may be less than recommended values.

NOTE: For design information contained in Chapter 12 of the Handbook of PE Pipe, Second Edition published by the Plastic Pipe Institute (PPI) click on the hyperlinked labels.

Figure 7. Step 3 Calculated Values.

Figures 6 and 7 show the analysis for a 36in DR 11 4710 HDPE installed in a 4000 ft bore located 47 feet below a horizontal ground surface. Input and bore design parameters are provided in Figures 3 and 5. The design analysis provided in Figures 6 and 7 show that the initially selected DR 11 HDPE 4710 pipe will not meet recommended operational requirements and that the installation pull force will exceed the recommended allowable pipe pull force when rollers and ballast are not used. These tables also show that the HDPE pipe needs to be at least DR 9 to meet operational and installation design requirements and that pipe rollers and pipe ballast is required to ensure pipe pullback force is less than the pipe allowable pullback force.

6. CONTACT

The Contact tab contains information and links to the PPI and Boreaid. It also provides an email contact for website and/or technical support.

7. ASSUMPTIONS

The Assumptions tab provides a hyperlink for a complete list of assumed parameter values and highlights the following list of calculation procedure assumptions:

- The earth pressure coefficient used in the calculations is based upon Stein's theory.
- The safe pull stress is calculated based upon minimum tensile stress requirements for PE 2406 (PE234373), PE3608 (PE345464), and PE4710 (PE445574) as outlined in ASTM D3350 - 10a Standard Specification for Polyethylene Plastics Pipe and Fittings Materials.

- The operational critical collapse calculation displays the result for a water filled pipe (i.e., pressure pipe) and empty pipe (i.e., conduit, gravity-sewer).
- Operational compressive wall stress and buoyant deflection during installation are not shown.
- ¾ of the maximum calculated tensile stress is used in the installation critical collapse calculation since the maximum depth is typically not encountered past three-quarters of the bore distance.
- Entry and exit elevations are assumed equal and additional loads due to variation in topography are not considered (topography is flat).
- To calculate the soil arching factor acting on top of the pipe the silo width is assumed equal to the bore diameter.
- The 1-hr installation critical collapse pressure includes the drag pressure but the 10-hr calculation does not.
- For bores in lithified rock, the earth pressure and deflection are not calculated but an ovality deflection of 3% is assumed for collapse calculations. The long term safety factor against collapse is calculated using a slurry unit weight of 93.57 pcf.
- These are preliminary calculations only. Qualified professionals should be contracted to consider all aspects of the design for horizontal directional drilling.

8. CONCLUSIONS

PPI-Boreaid is a free online and desktop plastic pipe calculation tool that allows users to complete preliminary HDD pipe designs for the condition of a horizontal ground surface and two horizontal soil or rock layers. PPI PE Handbook Chapter 12 and ASTM F1962 design methodologies are implemented in three tabs. Calculated operation and installation pipe design values are output for the user selected product pipe as well as one DR above and below the selected value. Calculations are also performed when installation features such as rollers and/or ballast are used. All text labels are hyperlinked to the appropriate sections of the PPI PE Handbook to allow users to learn more about HDD PE plastic pipe design. The user friendly tool allows for quick assessment of HDPE and MDPE pipe for a HDD project. It also allows users, consulting engineers, and municipal personnel to learn about HDD pipe design.

For a detailed HDD pipe design, users are referred to BoreAid or other software programs and an experienced HDD professional capable of understanding site conditions, project specific material properties and construction issues.

9. REFERENCES

ASTM-F1962, 2007. Standard guide for use of maxi-horizontal directional drilling for placement of polyethylene pipe or conduit under obstacles, including river crossings. ASTM International.

Bayat A., Knight M., Lawrence K, (2009). Horizontal Directional Drilling Pipeline Design and QA/QC Using the Boreaid Software Program. ASCE Pipelines pp. 765-774, (doi 10.1061/41069(360)71).

Carpenter R. (2010a). Underground Construction's 13th Annual Municipal Infrastructure Survey: Signs of Life in Sewer/Water Economy Stimulus Offers Small Aid; Slow Turnaround as Year Progresses. Underground Construction, February 2010, Vol. 65 No. 2.

Carpenter R. (2010b). 12th Annual HDD Survey Good Vibrations: HDD Industry Riding Out Recession Better Than Other Market Niches. Underground Construction, June 2010, Vol. 65 No. 6.

DrillPath, 1996. DrillPath: theory and user manual. Infrasoft, Houston.

Kirby, M. J., Kramer, S. R., Pittard, G. T., Mamoun, M., 1997. Design guidelines and procedures for guided horizontal drilling. part ii. No-Dig Engineering 3:(4), 13–15.

Plastics Pipe Institute Handbook of Polyethylene Pipe, Second Edition (2008). Plastics Pipe Institute, Irving, Texas.