ATLANTIC COAST PIPELINE, LLC
ATLANTIC COAST PIPELINE

and

DOMINION TRANSMISSION, INC.
SUPPLY HEADER PROJECT

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HDD Design Report

HDD Design Report, Revision 2
Atlantic Coast Pipeline Project

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Prepared for

Dominion

DOMINION TRANSMISSION, INC.
707 East Main Street
Richmond, VA 23219

JEFFREY S PUCKETT
REGISTERED
22136
STATE OF
WEST VIRGINIA
PROFESSIONAL ENGINEER

NORTH CAROLINA
PROFESSIONAL
SEAL
PE 042468
ENGINEER
JEFFREY S. PUCKETT

COMMONWEALTH OF VIRGINIA
JEFFREY SCOTT
PUCKETT
Lic. No. 0402055955
PROFESSIONAL ENGINEER

12/14/2016

Prepared by

J.D.Hair&Associates,Inc.
2424 E 21st St, Suite 510
Tulsa, Oklahoma 74114-1723

Table of Contents

Atlantic Coast Pipeline Project
HDD Design Report, Revision 2

1. Introduction

1.1 Scope of Report

This report provides background information associated with design drawings produced by J. D. Hair & Associates, Inc. (JDH&A) for nineteen obstacle crossings on Dominion's Atlantic Coast Pipeline (ACP) Project that are proposed for installation by horizontal directional drilling (HDD). The table below provides a list of the crossings that are addressed in this report along with their diameters and horizontal lengths.

Crossing	Pipe Diameter	Horizontal Length
Interstate 79	42 inches	2,869 feet
Blue Ridge Parkway	42 inches	4,639 feet
James River	42 inches	2,965 feet
Roanoke River	36 inches	1,559 feet
Fishing Creek	36 inches	1,822 feet
Swift Creek	36 inches	1,629 feet
Tar River	36 inches	1,516 feet
Contentnea Creek	36 inches	1,327 feet
Little River	36 inches	1,446 feet
Cape Fear River	36 inches	1,654 feet
Nottaway River	20 inches	1,678 feet
Blackwater River	20 inches	2,234 feet
Lake Prince	20 inches	1,952 feet
Western Branch Reservoir	20 inches	1,464 feet
Nansemond River Tributary	20 inches	3,435 feet
Nansemond River	20 inches	4,127 feet
Interstate 64	20 inches	2,039 feet
Route 17	20 inches	2,951 feet
Elizabeth River	20 inches	1,730 feet

Table 1. Proposed HDD Crossings on the ACP Project

While the primary function of this report is to present design drawings, calculations, and opinions of feasibility for each of the proposed HDD crossings on the ACP Project, general information about the HDD construction method has also been included to provide a more thorough understanding of both project-specific considerations and standard industry practices.

1.2 Information Provided by Others

In producing the design drawings described in the previous section, JDH&A has relied upon the following information provided by others.

1.2.1 Base Survey Data

AutoCAD base files for each of the proposed crossing locations were provided by GAI Consultants, Canonsburg, Pennsylvania. These files present the results of the topographic and bathymetric surveys completed at the sites, providing grade elevations along the proposed HDD alignments and information about existing features in the vicinity of the proposed crossings.

1.2.2 Subsurface Information

Subsurface information at each of the crossing locations was provided by Geosyntec Consultants, Richmond, Virginia in crossing-specific Geotechnical Site Investigation Reports. In addition to the report text, boring logs, and laboratory testing data that were provided, Geosyntec's reports included geotechnical parameters for the soils encountered in each boring. This information was used by JDH&A to analyze the potential for drilling fluid circulation loss due to hydrofracture at each HDD crossing location.

1.2.3 Pipe Specifications and Operating Information

Line pipe specifications and maximum operating pressures applicable to the proposed crossings were provided by Ron Baker of Dominion in an email dated December 10, 2015. Installation and operating temperatures were assumed by JDH&A for the sake of analysis.

2. Horizontal Directional Drilling

2.1 Process Description

Installation of a pipeline by HDD is generally accomplished in three phases as indicated in Figure 1. First, a small diameter pilot hole is drilled along a designed directional path. Next, the pilot hole is enlarged to a diameter that will accommodate the pipeline to be installed. Finally, the pipeline is pulled into the enlarged hole.

2.1.1 Pilot Hole

Pilot hole directional control is achieved by using a non-rotating drill string with an asymmetrical leading edge. The asymmetry of the leading edge creates a steering bias while the non-rotating aspect of the drill string allows the steering bias to be held in a specific position while drilling. If a change in direction is required, the drill string is rolled so that the direction of bias is the same as the desired change in direction. Leading edge asymmetry is typically accomplished with either a bent sub or a bent motor housing located behind the bit.

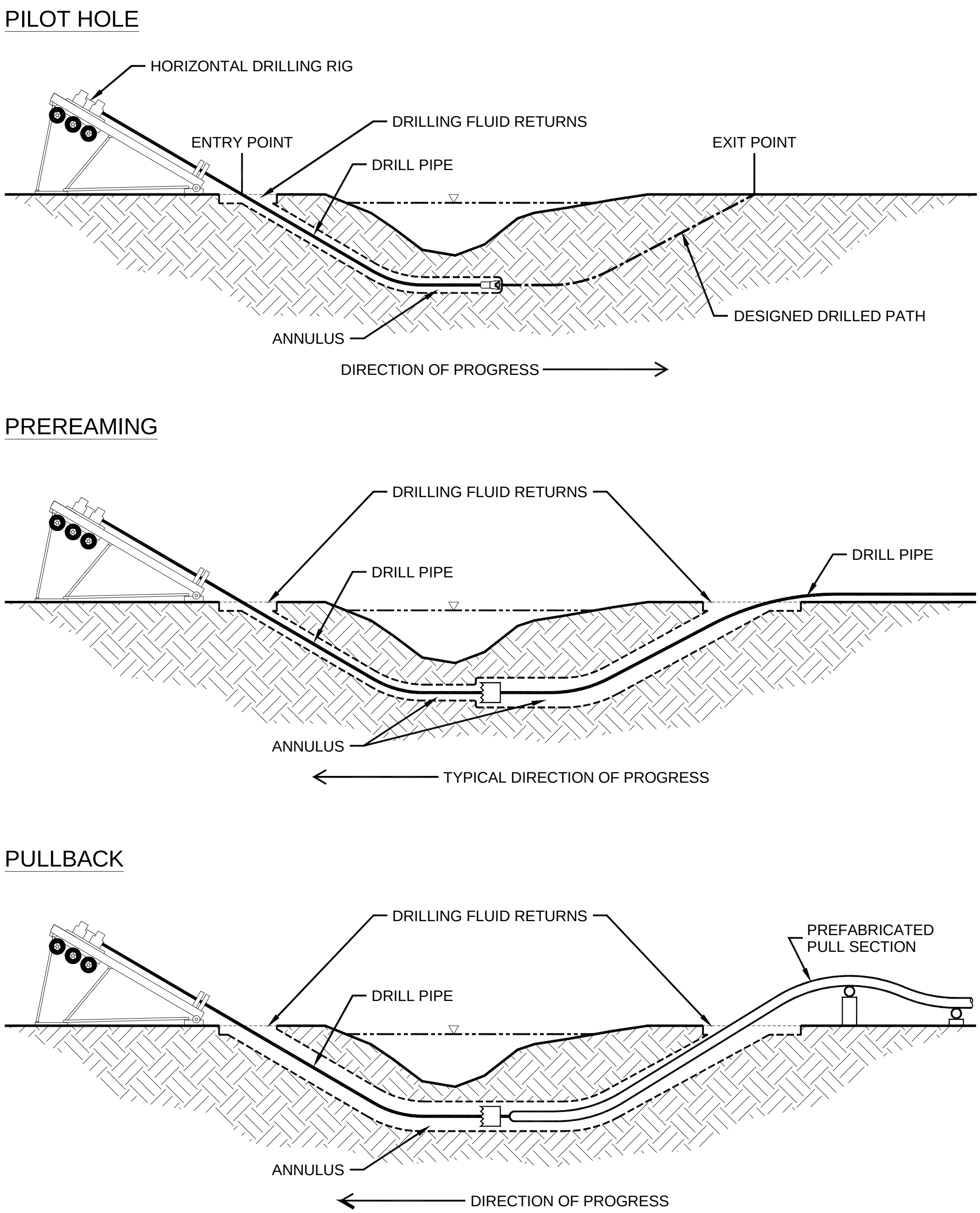

Figure 1. The HDD Process

In soft soils, drilling progress is achieved by hydraulic cutting with a jet nozzle. If hard zones are encountered, the drill string may be rotated to drill without directional control until the hard zone has been penetrated. Mechanical cutting action required for harder soils and rock is provided by a mud motor which converts hydraulic energy from drilling fluid to mechanical energy at the drill bit. This allows for bit rotation without drill string rotation.

The path of the pilot hole is monitored during drilling using a steering tool positioned near the bit. The steering tool provides continuous readings of the inclination and azimuth at the leading edge of the drill string. These readings, in conjunction with measurements of the distance drilled, are used to calculate the horizontal and vertical coordinates of the steering tool relative to the initial entry point on the surface. The path of the pilot hole can also be determined with a surface monitoring system that induces an artificial magnetic field using a wire placed on the surface. Measurements of this magnetic field's properties by instruments in the steering tool allow the position of the steering tool to be determined using triangulation. This provides data that can be used to correct downhole survey inaccuracy that results from inconsistencies in the earth's magnetic field.

2.1.2 Prereaming

Enlarging the pilot hole is accomplished using prereaming passes prior to pipe installation. Reaming tools generally consist of a circular array of cutters and drilling fluid jets and are often custom made by contractors for a particular hole size or type of soil. These tools are attached to the drill string and rotated and drawn along the pilot hole. Drill pipe is added behind the tools as they progress along the drilled path to ensure that a string of pipe is always maintained in the drilled hole.

2.1.3 Pullback

Pipe installation is accomplished by attaching a pipeline pull section behind a reaming assembly at the exit point, then pulling the reaming assembly and pull section back to the drilling rig. This is undertaken after completion of prereaming or, for smaller diameter lines in soft soils, directly after completion of the pilot hole. A swivel is utilized to connect the pull section to the reaming assembly to minimize torsion transmitted to the pipe. The pull section is supported using some combination of roller stands and pipe handling equipment to minimize tension and prevent damage to the pipe.

2.2 HDD Feasibility Considerations

The technical feasibility of an HDD installation can be determined by comparing it to past installations in three basic parameters: drilled length, pipe diameter, and subsurface conditions. These three parameters work in combination to limit what can be achieved at a given location. With pipe diameters ranging from 20 to 42 inches and horizontal drilled lengths ranging from 1,327 to 4,639 feet, all of the potential HDD installations on the ACP Project are within current HDD industry capabilities in terms of both length and diameter. However, while length and diameter are key components in an HDD installation's feasibility, technical feasibility is primarily limited by subsurface conditions. The material characteristic that most frequently prevents successful HDD installations is large grain content in the form of cobbles and boulders. Other conditions that can negatively impact HDD feasibility include poor rock quality, excessive rock strength and hardness, solution cavities in bedrock, and artesian groundwater pressure.

Soils consisting principally of coarse-grained material present a serious restriction on the feasibility of HDD. Coarse material cannot be readily fluidized by the drilling fluid and is too unstable to be cut and removed in a drilling fluid stream as is the case with a crossing in competent rock. A boulder or cluster of cobbles will remain in the drilled path and present an obstruction to a bit, reamer, or pipeline. Such obstructions must be mechanically displaced during hole enlargement. Displacement may be radially outward into voids formed by the entrainment of finer grained material. However, naturally dense, high gravel percentage soils contain little entrainable material, therefore voids sufficient to permit passage by larger diameter reamers or pipe may not develop. Coarse material may also migrate to low spots along the drilled path forming impenetrable blocks. An HDD installation through poor quality (extensively fractured or jointed) rock can present the same problems as coarse granular deposits. Cutting a hole through such materials may cause the overlying rock to fall in creating obstructions during subsequent passes.

Exceptionally strong and hard rock will hamper all phases of an HDD project. Experience has shown that competent rock with unconfined compressive strengths as high as 50,000 psi can be negotiated with today's technology. However, entry of such materials at depth can be problematic as the drill string may tend to deflect rather than penetrate. Extremely slow penetration rates in hard rock and frequent stoppages to replace worn bits and reamers can result in extended construction durations and corresponding increases in construction cost. Excessive rock hardness can also lead to tool failures downhole resulting from premature wear and drill pipe failures due to excessive torque.

Penetration of solution cavities found in karstic limestone formations can allow the drill string to deflect substantially, especially during pilot hole drilling when the drill string is in compression. Continued rotation of a drill string subjected to excessive deflection can result in failure of the drill pipe due to low-cycle fatigue. Penetration of an artesian aquifer on an HDD installation can result in a sustained inflow of groundwater and fine soils into the drilled hole. This can cause several serious problems including drilling fluid storage and disposal issues, degradation of the drilling fluid, deterioration of the hole, and stuck pipe or downhole tools.

2.3 Workspace Requirements

2.3.1 Rig Side

A typical large horizontal drilling spread can be moved onto a site in seven to ten tractor-trailer loads. A workspace of 250 feet by 200 feet is adequate for most operations. The locations of the principal components of the spread (rig ramp, drill pipe, and control trailer) are fixed by the entry point. The rig ramp must be positioned in line with the drilled segment and typically less than 25 feet back from the entry point. The control cab and drill pipe must be positioned adjacent to the rig.

The horizontal drilling rig workspace must be cleared and graded level. Equipment is typically supported on the ground surface, although timber mats may be used where soft ground is encountered. A typical horizontal drilling rig site plan is shown in Figure 2. Where possible, we recommend obtaining workspaces of similar dimensions to accommodate HDD rig side operations on the ACP Project.

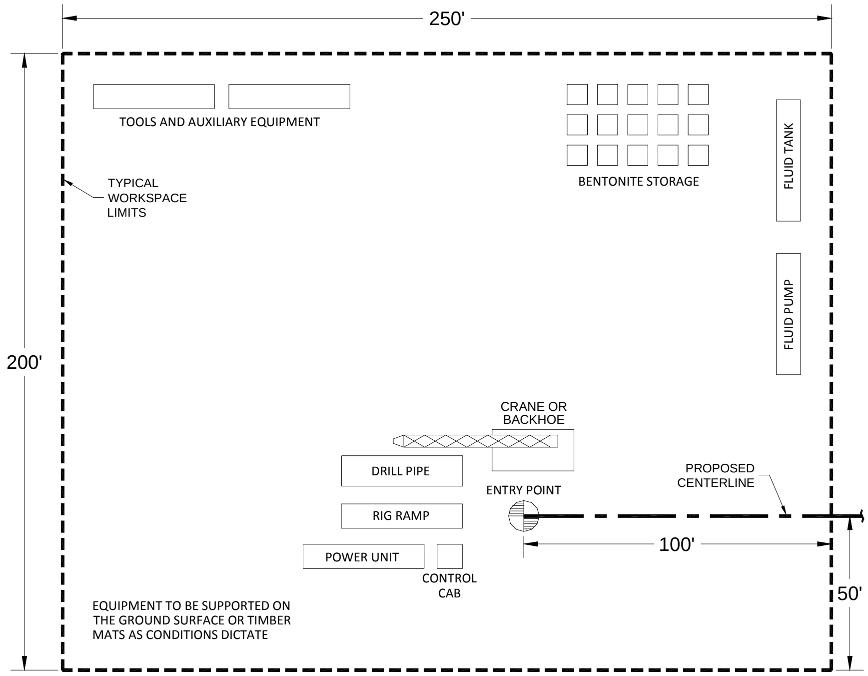

Figure 2. Typical Horizontal Drilling Rig Site Plan

2.3.2 Pipe Side

Pull section fabrication is accomplished using the same construction methods used to lay a pipeline; therefore, similar workspace is required. The drilled segment exit point controls the location of pull section fabrication workspace. Space must be available to allow the pipe to be fed into the drilled hole. It is preferable to have workspace aligned with the drilled segment extending back from the exit point the length of the pull section plus approximately 200 feet. This will allow the pull section to be prefabricated in one continuous length prior to installation. If space is not available, the pull section may be fabricated in two or more sections which are welded together during installation. It should be noted that delays associated with joining multiple pipe strings during pullback can increase the risk of the pipe becoming stuck in the hole.

Workspace for pull section fabrication should generally be around 100 feet wide; similar to what is required for conventional pipeline construction. Additional temporary workspace should be provided in the immediate vicinity of the exit point to facilitate personnel and equipment supporting drilling operations. Pull section workspace must be cleared but need not be graded level. Equipment is typically supported on the ground surface. Timber mats may be used where soft ground is encountered. A typical pull section fabrication site plan is shown in Figure 3. Where possible, we recommend obtaining workspaces of similar dimensions to accommodate HDD pipe side operations on the ACP Project.

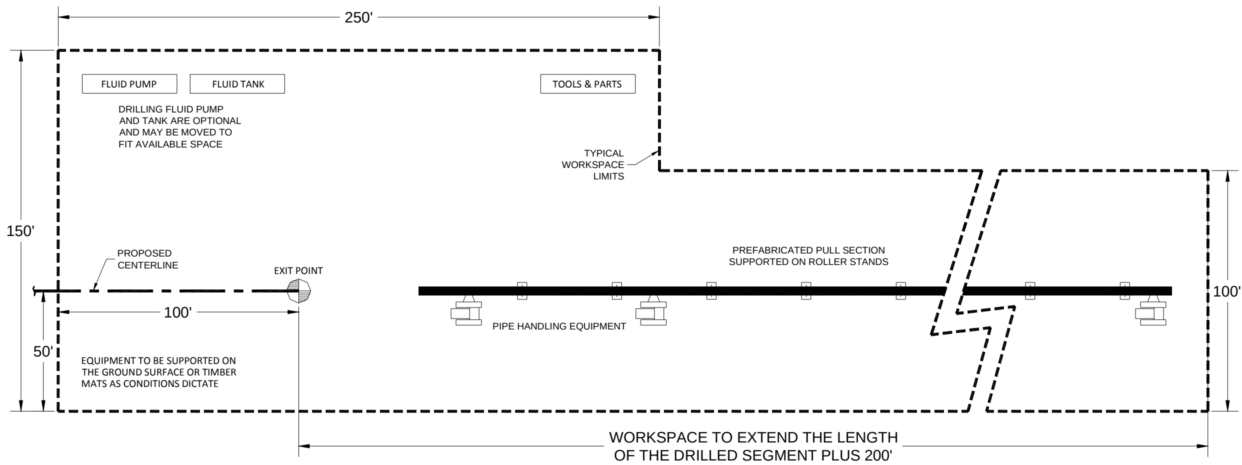

Figure 3. Typical Pull Section Fabrication Site Plan

2.4 Drilling Fluid

2.4.1 Introduction

Drilling fluid is used in all phases of the HDD process and typically consists of fresh water obtained at the crossing location, high-yield bentonite, and excavated soil or rock cuttings that accumulate as HDD operations progress. Typical HDD drilling fluids are composed of less than 2% high yield bentonite by volume. Drilling fluid serves several critical functions in HDD pipeline installation including hydraulic excavation of the soil along the drilled path, transmission of hydraulic power to a downhole motor that turns the bit, removal of soil or rock cuttings from the hole, stabilization of the hole, and reduction of friction between the pipe and the wall of the hole.

2.4.2 Inadvertent Returns

HDD involves the subsurface discharge of drilling fluid. Once discharged downhole, drilling fluid is uncontrolled and will flow in the path of least resistance. This can result in dispersal into the surrounding soils or discharge to the surface at some random location, which may not be a critical problem in an undeveloped location. However, in an urban environment or a high profile recreational area, inadvertent returns can be a major problem. In addition to the obvious public nuisance, drilling fluid flow can buckle streets or wash out embankments.

Drilling parameters may be adjusted to maximize drilling fluid circulation and minimize the risk of inadvertent returns. However, the possibility of lost circulation and inadvertent returns cannot be eliminated. Contingency plans addressing possible remedial action should be made in advance of construction and regulatory bodies should be informed.

Inadvertent returns are more likely to occur in less permeable soils with existing flow paths. Examples are slickensided clay or fractured rock structures. Coarse grained, permeable soils exhibit a tendency to absorb circulation losses. Manmade features, such as exploratory boreholes or piles, may also serve as conduits to the surface for drilling fluid. An example of an inadvertent drilling fluid return is shown in Figure 4.

Figure 4. Inadvertent Drilling Fluid Return

Research projects have been conducted in an attempt to identify the mechanisms that cause inadvertent returns and develop analytical methods for use in predicting their occurrence. Efforts have centered on predicting the point at which hydraulic fracture of the native soils will occur. These programs have met with limited success in providing a reliable prediction method. Engineering judgment and experience must be applied in utilizing the hydrofracture model to predict the occurrence, or nonoccurrence, of inadvertent returns.

2.4.3 Assessment of the Potential for Hydraulic Fracture

Hydraulic fracture, also known as hydrofracture, is a phenomenon that occurs when drilling fluid pressure in the annular space of the drilled hole exceeds the strength of the surrounding soil mass, resulting in deformation, cracking, and fracturing. The fractures may then serve as flow conduits for drilling fluid allowing the fluid to escape into the formation and possibly up to the ground surface. Drilling fluid that makes its way to the ground surface is known as an inadvertent drilling fluid return or, more commonly, a “frac-out.”

Although hydrofracture may be one mechanism by which inadvertent drilling fluid returns occur, it is not the only one. In fact, it is thought that inadvertent returns due to true hydrofracture occur in only a small percentage of cases.[1] Drilling fluid flows in the path of least resistance. Ideally, the path of least resistance is through the annulus of the drilled hole and back to the fluid containment pits at the HDD endpoints. However, the path of least resistance may also be through naturally occurring subsurface features such as fissures in the soil, shrinkage cracks, or porous deposits of gravel. Drilling fluid may also flow to the surface along existing piers, piles, utility poles, or other structures.

The risk of hydrofracture can be determined by comparing the confining capacity of the subsurface (formation limit pressure) to the annular pressure necessary to conduct HDD operations. If the anticipated drilling fluid pressure in the annulus exceeds the estimated formation limit pressure, there is a potential that inadvertent drilling fluid returns will occur as a result of hydrofracture.

The formation limit pressures for the proposed HDD crossings on the ACP Project were calculated using the “Delft Method” as described in an Army Corps of Engineers publication titled *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling*.[2] The Delft Method assumes uniform soil conditions in the soil column above the point on the drilled path that is being analyzed and requires engineering judgement with respect to the selection of the geotechnical parameters that are used in the associated equations. As noted previously, the geotechnical parameters used in our analysis were provided by Geosyntec Consultants. The estimated minimum annular pressure necessary for HDD pilot hole operations was calculated using the Bingham Plastic Model, which is described in Chapter 4 of the Society of Petroleum Engineers’ *Applied Drilling Engineering*.[3]

The formation limit pressures were calculated over the length of each proposed HDD crossing on the ACP Project and compared to the estimated annular pressures necessary for HDD operations. A graphical summary of the results for each crossing is provided in the Appendix. In reviewing this information, it should be noted that a factor of safety has not been applied to the formation limit pressure. As a result, the point at which the estimated annular pressure exceeds the formation limit pressure is the theoretical point at which plastic yielding and cracking reaches the ground surface resulting in an inadvertent drilling fluid return.

Table 2 presents a summary of the hydrofracture risk at each crossing location based on the calculation method described above.

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[1] Bennett, R.D. and K. Wallin. “Step by Step Evaluation of Hydrofracture Risks for HDD Projects.” Presentation, North American Society for Trenchless Technology, NoDig Conference, Grapevine, TX, 2008.

[2] Kimberlie Staheli et al, *Recommended Guidelines for Installation of Pipelines beneath Levees using Horizontal Directional Drilling* (prepared for U.S. Army Corps of Engineers, April 1998).

[3] *Applied Drilling Engineering*, Society of Petroleum Engineers, Richardson, Texas, A. T. Bourgoyne, Jr. [et al], 1991

Crossing	Risk of Hydrofracture	Notes
Interstate 79	Unknown	No geotechnical information available
Blue Ridge Parkway	Low	
James River	Low	
Roanoke River	Low	
Fishing Creek	Low	
Swift Creek	Low	
Tar River	Low	
Contentnea Creek	Unknown	No geotechnical information available
Little River	Low	
Cape Fear River	Low	
Nottaway River	Low	
Blackwater River	Moderate	Predicted annular pressure approaches formation limit pressure beneath river
Lake Prince	Low	
Western Branch Reservoir	Low-Moderate	Safety factor less than 2 below lake
Nansemond River Tributary	High	Predicted annular pressure exceeds formation limit pressure beneath river
Nansemond River	Moderate-High	Predicted annular pressure exceeds formation limit pressure at eastern water's edge
Interstate 64	Low	
Route 17	Moderate-High	Predicted annular pressure exceeds formation limit pressure beneath pond
Elizabeth River	Low	

Table 2. Summary of Hydrofracture Risk by Crossing

2.5 Design Criteria

2.5.1 Drilled Path Centerline

Drilled path designs for segments to be installed by HDD are defined by the following six parameters: 1) entry point, 2) exit point, 3) entry angle, 4) exit angle, 5) P.I. elevation, and 6) radius of curvature. The relationship of these parameters to each other is illustrated in Figure 5.

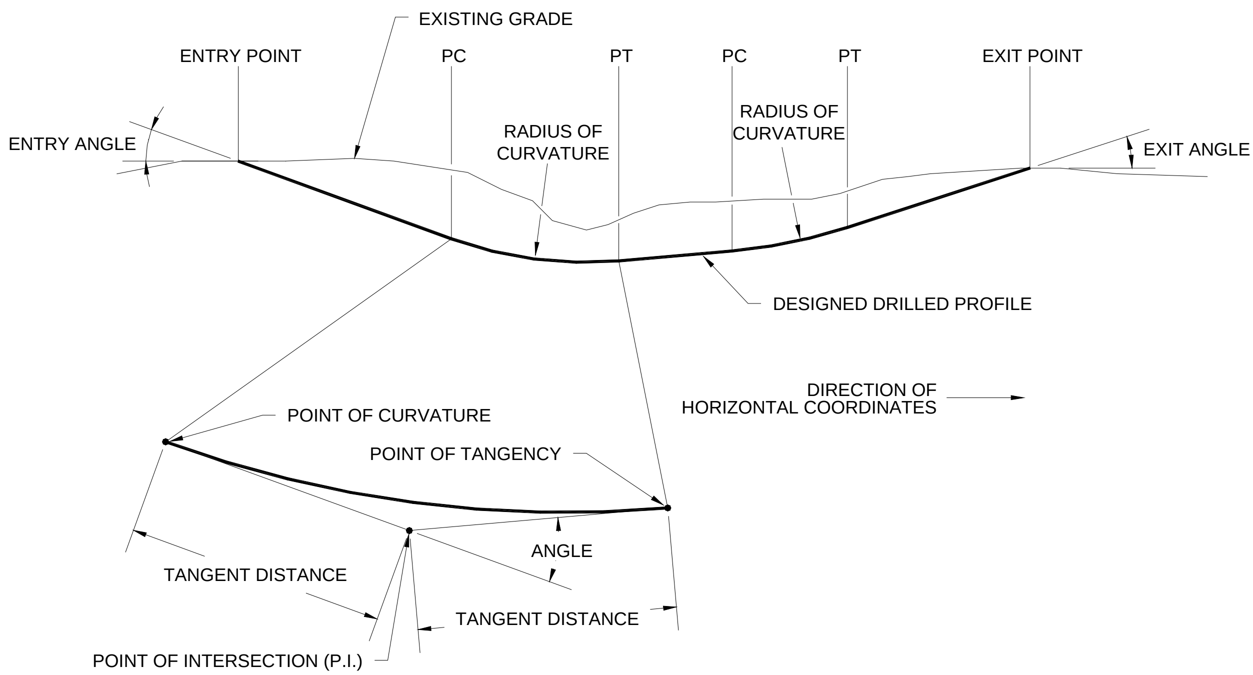

Figure 5. HDD Design Terminology

2.5.2 Entry and Exit Points

The entry and exit points are the endpoints of the designed drilled segment on the ground surface. The drilling rig is positioned at the entry point and the pipeline is pulled into the drilled hole from the exit point. The relative locations of the entry and exit points, and consequently the direction of pilot hole drilling and pullback, should be established by the site's geotechnical and topographical conditions. The following criteria were considered when selecting entry and exit point locations on the ACP Project: 1) steering precision and drilling effectiveness are greater near the drilling rig; 2) drilling fluid returns to the rig are enhanced if the entry point is lower than the exit point; 3) pullback operations are enhanced if there is sufficient workspace in line with the drilled path to allow the pull section to be fabricated in one continuous string. It is also important to recognize that the position of the drilling rig may be changed during construction to facilitate HDD operations and that a dual rig scenario may be employed during both the pilot hole and prereaming if deemed beneficial. In a dual rig scenario, drilling rigs are positioned at both ends of the drilled segment and work in tandem.

2.5.3 Entry and Exit Angles

Entry angles for drilled segments on the ACP Project were set at 10 degrees with the horizontal while exit angles were held between 8 and 10 degrees to facilitate breakover support during pullback. These angles are consistent with HDD industry standards.[4]

[4] *Manual of Practice No. 108, Pipeline Design for Installation by Horizontal Directional Drilling, Second Edition* (Reston, VA: American Society of Civil Engineers, 2014), 14.

2.5.4 P.I. Elevation

The P.I. elevation defines the depth of cover that the HDD installation will provide. Typically, HDD crossings are designed to provide no less than 25 feet of cover beneath critical obstacles.[5] This aids in reducing inadvertent drilling fluid returns and provides a margin for error with regard to downhole survey calculations. Due to the sensitive nature of the HDD segments on the ACP Project, the drilled profiles were designed to provide a minimum vertical clearance of 40 feet where possible in order to further reduce the risk of inadvertent drilling fluid returns. At some of the crossing locations, this clearance was either reduced or increased slightly due to site-specific concerns.

2.5.5 Radius of Curvature

The design radius of curvature for the HDD segments on the ACP Project was set at 2,000 feet for the 20-inch crossings, 3,600 feet for the 36-inch crossings, and 4,200 feet for the 42-inch crossings. These values are consistent with the HDD industry standard design radius of 1,200 times the nominal outside diameter of the pipe to be installed.[6] This relationship has been developed over a period of years in the HDD industry and is based on experience with constructability as opposed to any theoretical analysis.

3 Analysis of Installation and Operating Loads and Stresses

3.1 Installation Loads and Stresses

During HDD installation, a pipeline segment is subjected to tension, bending, and external pressure as it is pulled through a prereamed hole. The stresses in the pipe and its potential for failure are a result of the interaction of these loads.[7,8] In order to determine if a given pipe specification is adequate, HDD installation loads must first be estimated so that the stresses resulting from these loads can be calculated. A thorough design process requires examination of the stresses that result from each individual installation loading condition as well as an examination of the combined stresses that result from the interaction of these loads.

3.2 HDD Pulling Load Estimates

Calculation of the approximate tensile load required to install a pipeline by HDD is relatively complicated due to the fact that the geometry of the drilled path must be considered along with the properties of the pipe being installed and the subsurface conditions. Assumptions and simplifications are required. A method to accomplish this is presented in *Installation of Pipelines*

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[5] *Manual of Practice No. 108,* 16.

[6] *Manual of Practice No. 108,* 16.

[7] Fowler, J.R. and C.G. Langner. "Performance Limits for Deepwater Pipelines." Presentation, OTC 6757, 23rd Annual Offshore Technology Conference, Houston, TX, May 6-9, 1991.

[8] Loh, J.T. "A Unified Design Procedure for Tubular Members." Presentation, OTC 6310, 22nd Annual Offshore Technology Conference, Houston, TX, May 7-10, 1990.

by Horizontal Directional Drilling, An Engineering Design Guide, published by the Pipeline Research Council International (PRCI).[9]

The PRCI Method involves modeling the drilled path as a series of segments to define its shape and properties during installation. The individual loads acting on each segment are then resolved to determine a resultant tensile load for each segment. The estimated force required to install the entire pull section in the reamed hole is equal to the sum of the tensile loads acting on all of the defined segments. When utilizing the PRCI Method, pulling loads are affected by numerous variables, many of which are dependent upon site-specific conditions and individual contractor practices. These include prereaming diameter, hole stability, removal of cuttings, soil and rock properties, drilling fluid properties, and the effectiveness of buoyancy control measures.[10] It is also important to keep in mind that the PRCI Method considers pulling tension, pipe bending, and external pressure. It does not consider point loads that may result from subsurface conditions such as a rock ledge or boulder. Indeed, we know of no way to analyze potential point loads that may develop due to subsurface conditions. Although this type of damage is relatively rare, several cases have been observed in the last few years where pipelines suffered damage in the form of dents or pipe deformation due to point loads encountered during HDD installation.

Pulling load calculations for each of the proposed HDD crossings on the ACP Project were based on an assumed worst-case installation model in which the pilot hole is drilled up to 40 feet longer and 30 feet deeper than the designed path with a radius of curvature equal to two-thirds of the design radius. A conservative drilling fluid density of 12 pounds per gallon was assumed for the sake of analysis. For the 36 inch and 42-inch crossings, pulling load calculations were performed based on two scenarios: 1.) the pull sections being full of water for buoyancy control purposes, which is typical on large diameter crossings to reduce pulling loads, and 2.) the pull sections being installed empty to provide conservative results with regard to installation stresses. For the 20-inch crossings, only an empty pipe scenario was considered since buoyancy control measures are not typically employed for steel pipe less than 30 inches in diameter.

Our installation stress calculations indicated no violations of applicable stress criteria. As a result, it is our opinion that the proposed line pipe specifications are suitable for installation by HDD. This conclusion is based on three assumptions: 1) that the actual drilled paths will not exceed the lengths or depths of the worst-case models analyzed; 2) that the HDD contractor will not employ any improper construction procedures; and 3) that problematic subsurface conditions will not be encountered.

Table 3 provides a summary of the estimated pulling loads for each crossing based on the scenarios described above. Copies of our complete installation stress calculation spreadsheets are provided in the Appendix.

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[9] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide* (Arlington, VA: Pipeline Research Council International, Inc., 2008), 26-36.
[10] *Manual of Practice No. 108*, 22.

Crossing	Estimated Pulling Load with Buoyancy Control	Estimated Pulling Load without Buoyancy Control
Interstate 79	199,089 lbs.	430,756 lbs.
Blue Ridge Parkway	286,742 lbs.	979,838 lbs.
James River	187,844 lbs.	459,458 lbs.
Roanoke River	78,434 lbs.	287,363 lbs.
Fishing Creek	92,546 lbs.	323,050 lbs.
Swift Creek	82,857 lbs.	289,047 lbs.
Tar River	76,371 lbs.	277,573 lbs.
Contentnea Creek	66,579 lbs.	249,090 lbs.
Little River	67,335 lbs.	265,977 lbs.
Cape Fear River	83,086 lbs.	305,472 lbs.
Nottaway River	N/A	107,890 lbs.
Blackwater River	N/A	138,721 lbs.
Lake Prince	N/A	122,924 lbs.
Western Branch Reservoir	N/A	93,043 lbs.
Nansemond River Tributary	N/A	207,053 lbs.
Nansemond River	N/A	240,879 lbs.
Interstate 64	N/A	126,012 lbs.
Route 17	N/A	175,267 lbs.
Elizabeth River	N/A	109,466 lbs.

Table 3. Estimated HDD Pulling Loads

3.3 Operating Loads and Stresses

As with a pipeline installed by conventional methods, a pipeline installed by HDD will be subjected to internal pressure, thermal expansion, and external pressure during normal operation. A welded pipeline installed by HDD will also be subjected to elastic bending. The operating loads imposed on a pipeline installed by either of these methods are addressed in Chapter 5 of *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*.[11]

With one exception, the operating stresses in a pipeline installed by HDD are not materially different from those experienced by pipelines installed by cut and cover techniques. As a result, past procedures for calculating and limiting stresses can be applied. However, unlike a cut and cover installation in which the pipe is bent to conform to the ditch, a pipeline installed by HDD

[11] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, 24-26.

will contain elastic bends. Bending stresses imposed by the HDD installation process should be checked in combination with other operating stresses to evaluate if acceptable limits are exceeded. Other longitudinal and hoop stresses that should be considered will result from internal pressure and thermal expansion or contraction.

3.4 Project-Specific Operating Stress Calculations

The results of the operating stress calculations for each proposed pipe diameter are provided in the Appendix. Calculations were performed based on both the design radius and the specified minimum radius and, like the installation stress calculations, did not indicate any violations of applicable stress criteria. Specific information used in the calculations is provided below.

20-inch Crossings

Outside Diameter	20.00 inches
Wall Thickness	0.411 inches
Grade	API 5L X-70
Maximum Operating Pressure	1,440 psig
Minimum Installation Temperature	55 °F
Maximum Operating Temperature	125 °F

36-inch Crossings

Outside Diameter	36.00 inches
Wall Thickness	0.741 inches
Grade	API 5L X-70
Maximum Operating Pressure	1,440 psig
Minimum Installation Temperature	55 °F
Maximum Operating Temperature	125 °F

42-inch Crossings

Outside Diameter	42.00 inches
Wall Thickness	0.864 inches
Grade	API 5L X-70
Maximum Operating Pressure	1,440 psig
Minimum Installation Temperature	55 °F
Maximum Operating Temperature	125 °F

4 Crossing-Specific Summaries

4.1 42-inch Interstate 79 Crossing

The proposed HDD crossing of Interstate 79 has a horizontal drilled length of 2,869 feet and an outside diameter of 42 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

To date, we have not been provided with a geotechnical report for this crossing. However, based on subsurface information obtained on a previous project located roughly 3 miles to the northwest, we anticipate that the Interstate 79 crossing will be placed in bedrock consisting primarily of shale and/or limestone. At this point, we have no reason to believe that the rock at the Interstate 79 crossing would be adverse. Therefore, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of Interstate 79 and that the crossing can be completed successfully.

4.2 42-inch Blue Ridge Parkway Crossing

The proposed HDD crossing of the Blue Ridge Parkway has a horizontal drilled length of 4,639 feet and an outside diameter of 42 inches. This combination of length and diameter falls within the limits of current HDD industry capabilities. Pipe diameters up to 42 inches have been installed over lengths exceeding 7,000 feet and HDD crossings involving 42-inch diameter pipe over lengths on the order of 5,000 feet are fairly common.

The geotechnical site investigation report produced by Geosyntec presents the results of a geologic desktop study, two exploratory borings, and a geophysical survey conducted at the Blue Ridge Parkway crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter surficial alluvium containing gravel, cobbles and boulders in a sandy silt to clay matrix underlain by granodiorite bedrock of the Pedlar Formation and metamorphosed Basalt of the Catoctin Formation. Upon completion of the boring on the southeast end of the crossing in which bedrock was not encountered, there was a concern that the adverse alluvium may be so extensive that the feasibility of the proposed HDD installation would be questionable. However, the results of the boring on the northwest end of the crossing and the subsequent geophysical survey indicate that the adverse alluvial soils are not as extensive as initially feared. Based on that information, it is believed that bedrock can be reached within 90 to 130 feet of both HDD endpoints which will allow for large diameter surface casings to be set from the endpoints to competent rock. The ability to set surface casings through the adverse soils significantly reduces the risk of the proposed HDD installation.

The proposed HDD crossing will be complicated by the challenging topography at the site, which is likely to require some amount of excavation at both ends of the crossing to create level work areas for the HDD equipment. Also, since the product pipe will be laid downhill from the proposed exit point, it is anticipated that several cranes will be needed to handle the pipe and support it as it is lifted during pullback to be aligned with the reamed hole. However, the need for excavations and cranes does not cause any concern with regard to technical feasibility. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of the Blue Ridge Parkway and that the crossing can be completed successfully.

4.3 42-inch James River Crossing

The proposed HDD crossing of the James River has a horizontal drilled length of 2,965 feet and an outside diameter of 42 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of one exploratory boring conducted at the James River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter less than 20 feet of overburden soils (lean clay overlying silty gravel), underlain by weak shale and moderate to strong, excellent quality sandstone . Aside from the relatively thin layer of gravel overlying bedrock, these conditions are generally favorable for HDD installation. However, it should be noted that it would be advisable to obtain at least one additional boring on either end of the crossing to allow for a more comprehensive assessment of the subsurface conditions.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the James River and that the crossing can be completed successfully.

4.4 36-inch Roanoke River Crossing

The proposed HDD crossing of the Roanoke River has a horizontal drilled length of 1,559 feet and an outside diameter of 36 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Roanoke River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter primarily clay, sand, and silt, with a slight potential for partially weathered rock or competent bedrock at the low point of the crossing. Aside from possibly encountering bedrock at depth, which could be problematic, these are favorable conditions for HDD installation. If rock is encountered during the pilot hole, Dominion may wish to consider increasing the “up” tolerance (which currently allows being up to 5 feet above the designed profile) so that bedrock can be avoided.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Roanoke River and that the crossing can be completed successfully.

4.5 36-inch Fishing Creek Crossing

The proposed HDD crossing of Fishing Creek has a horizontal drilled length of 1,822 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Fishing Creek crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter alluvial overburden consisting of silty/clayey sand and fat clay with gravel, underlain by 20 to 35 feet of decomposed bedrock generally described as very dense silty and clayey sand, underlain by granite bedrock. On the south end of the crossing, the granite is generally competent and strong, with unconfined compressive strengths ranging from around 15,000 to 30,000 psi. On the north end of the crossing, the granite is described as completely to moderately weathered, with low recovery, low RQDs, and compressive strengths ranging from around 4,000 to 10,000 psi.

The HDD crossing of Fishing Creek has been designed with entry and exit tangents extending to bedrock, and we do not expect the alluvium or the decomposed bedrock (very dense sand) to be problematic. The fact that the granite on the south end of the crossing is competent and strong while the granite on the north end is highly weathered could present challenges during HDD operations, but we believe those challenges will not present insurmountable problems for skilled contractors. It should be noted that the relatively high strength of the competent bedrock will result in low production rates for pilot hole drilling and prereaming, which will increase both the duration and cost of HDD operations in comparison to crossings placed through alluvial soils or soft rock. Nonetheless, HDD installations of similar diameters have been completed through comparable subsurface conditions. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of Fishing Creek and that the crossing can be completed successfully.

4.6 36-inch Swift Creek Crossing

The proposed HDD crossing of Swift Creek has a horizontal drilled length of 1,629 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Swift Creek crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter around 50 feet of overburden on the west end of the crossing and 15 feet of overburden on the east end consisting primarily of silty/clayey sand with some gravel. The overburden soils on the west end of the crossing are underlain by amphibolite and granite bedrock while the overburden on the east end is underlain almost exclusively by granite. In general, the granite is competent, strong, and hard with compressive strengths approaching 40,000 psi and Mohs hardness values ranging from 4.5 to 9 while the amphibolite is of lower strength and quality.

As currently designed, the entry tangent on the west end of the crossing does not extend to bedrock, which is generally preferable for entry of the bit into rock and also in the event that installation of surface casing is necessary. As result, the HDD contractor may choose to drill the pilot hole from east to west, eventually moving the rig to the west end of the crossing for pullback. It may also be worth considering extending the entry tangent to bedrock, but we haven't done that as it would require increasing the length of the crossing. The high strength and hardness of the granite at this location will result in low production rates and relatively high construction cost in comparison to crossings placed through alluvial soils or soft rock. However, HDD installations of similar diameters have been completed through comparable subsurface conditions. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of Swift Creek and that the crossing can be completed successfully.

4.7 36-inch Tar River Crossing

The proposed HDD crossing of the Tar River has a horizontal drilled length of 1,516 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Tar River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter 25 to 35 feet of overburden consisting primarily of clayey and silty sand with gravel underlain by phyllite bedrock on the south end of the crossing and rhyolite, breccia, and phyllite bedrock on the north end. On the south end of the crossing, the upper 60 feet or so of the phyllite bedrock is moderately to completely weathered and soft with extremely low compressive strengths, while at greater depths (corresponding roughly to the lowest point of the designed crossing) the hardness and compressive strength of the bedrock increases significantly. On the north end of the crossing, the bedrock properties are more uniform, having mostly fair to excellent RQD’s and compressive strengths generally ranging from 3,000 to 7,000 psi.

Like the Swift Creek crossing, the entry tangent on the north end of the Tar River crossing does not extend to bedrock. Considering that the rhyolite bedrock at the rock/soil interface beneath the north bank is substantially softer and weaker than the granite encountered at Swift Creek, we anticipate that skilled contractors will not have much difficulty entering bedrock. However, if problems are encountered either in the overburden soils or at the rock/soil interface, the entry angle could be reduced to 8 degrees so that a surface casing could be set to bedrock. While placement through bedrock at this location will certainly result in slower production rates and higher costs than crossings placed through alluvial soils, production rates on the Tar River crossing should be significantly higher than in the granite expected at the Fishing Creek and Swift Creek crossings. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Tar River and that the crossing can be completed successfully.

4.8 36-inch Contentnea Creek Crossing

The proposed HDD crossing of Contentnea Creek has a horizontal drilled length of 1,327 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

To date, we have not been provided with a geotechnical report for this crossing. Based on the subsurface conditions at the Tar River crossing to the north and the Little River crossing to the south, we anticipate that the Contentnea Creek crossing will be placed in bedrock. However, since the bedrock at those crossing locations differs substantially, we’re not sure what to expect. Nonetheless, we have no reason to believe that the rock at the Contentnea Creek location would be any more adverse than any of the other proposed HDD crossing locations. Therefore, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of Contentnea Creek and that the crossing can be completed successfully.

4.9 36-inch Little River Crossing

The proposed HDD crossing of the Little River has a horizontal drilled length of 1,446 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Little River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter 15 to 25 feet of silty sand and sandy clay with gravel overlying siltstone bedrock. The quality of the siltstone varies significantly and the unconfined compressive strengths generally range from 3,000 to 15,000 psi with an 18,672 psi value at the bottom of boring LR B-2. In general, the rock is soft with typical Mohs hardness values of 2.5 to 3.5.

Despite the fact that some of the compressive strengths obtained in Boring LR B-2 are relatively high, sedimentary rock such as siltstone is generally a favorable medium for installation of an HDD crossing. Placement through siltstone will result in slower production rates and higher costs than crossings placed through alluvial soils, but production rates on the Little River crossing should be significantly higher than in the granite expected at Fishing Creek and Swift Creek. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Little River and that the crossing can be completed successfully.

4.10 36-inch Cape Fear River Crossing

The proposed HDD crossing of the Cape Fear River has a horizontal drilled length of 1,654 feet and an outside diameter of 36-inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Cape Fear River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter primarily lean clay and clayey sand, which are favorable conditions for HDD installation.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Cape Fear River and that the crossing can be completed successfully.

4.11 20-inch Nottaway River Crossing

The proposed HDD crossing of the Nottaway River has a horizontal drilled length of 1,678 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Nottaway River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter mostly sand and clayey sand over its entire length, which are favorable conditions for HDD installation. The only notable coarse material in the borings was a possible boulder at a depth of 48 feet on the west side of the crossing and a sample containing 15.3 percent gravel at a depth of 23 to 25 feet on the east side of the crossing. Otherwise only trace amounts of gravel were encountered.

While subsurface conditions that include boulders can be problematic for an HDD installation, it is reassuring that there was only one possible boulder encountered by the borings and that the geotechnical report provided no other indication that boulders are expected. As a result, we do not believe that boulders are a significant concern at this location. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of the Nottaway River and that the crossing can be completed successfully.

4.12 20-inch Blackwater River Crossing

The proposed HDD crossing of the Blackwater River has a horizontal drilled length of 2,234 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Blackwater River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter surficial sand and silt underlain by fat clay, which are favorable conditions for HDD installation. While it should be noted that the calculations we have completed for this crossing indicate a moderate risk of inadvertent drilling fluid returns as a result of hydrofracture, that risk does not necessarily impact the technical feasibility of the proposed crossing.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of the Blackwater River and that the crossing can be completed successfully.

4.13 20-inch Lake Prince Crossing

The proposed HDD crossing of Lake Prince has a horizontal drilled length of 1,952 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Lake Prince crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter sand and clayey sand, which are favorable conditions for HDD installation.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of Lake Prince and that the crossing can be completed successfully.

4.14 20-inch Western Branch Reservoir Crossing

The proposed HDD crossing of the Western Branch Reservoir has a horizontal drilled length of 1,464 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Western Branch Reservoir crossing site. In general, the boring logs indicate that the proposed HDD crossing is anticipated to encounter mainly sand and silt with some clay beneath both banks, underlain by clay directly beneath the river. These conditions are favorable for HDD installation.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of Western Branch Reservoir and that the crossing can be completed successfully.

4.15 20-inch Nansemond River Tributary Crossing

The proposed HDD crossing of the Nansemond River Tributary has a horizontal drilled length of 3,435 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Nansemond River Tributary crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter loose/soft sand, silt, and clay, which are favorable conditions for HDD installation. While it should be noted that the calculations we have completed for this crossing indicate a high risk of inadvertent drilling fluids in the mud flats and waterway as a result of hydrofracture, that risk does not necessarily impact the technical feasibility of the proposed crossing. In an attempt to reduce the potential for inadvertent returns at this location, we lowered the design elevation as much as possible without placing it below the termination depths of the borings. However, there is a still a significant risk of inadvertent returns at this location. It may be possible to mitigate the risk of inadvertent returns at this location by drilling a portion of the pilot hole from the western end of the crossing.

The proposed HDD crossing will be complicated by the fact that there is not sufficient space available for the pipeline pull section to be fabricated and staged in one complete length. As a result, it is envisioned that two tie-in welds will be required during pullback. Stoppages to make tie-in welds will increase the risk of getting stuck during pullback, especially considering the loose/soft nature of the anticipated soils. However, we don't believe this will ultimately prevent a competent HDD contractor from installing the crossing. Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion's proposed HDD crossing of the Nansemond River Tributary and that the crossing can be completed successfully.

4.16 20-inch Nansemond River Crossing

The proposed HDD crossing of the Nansemond River has a horizontal drilled length of 4,127 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Nansemond River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter loose/soft sand, silt, and clay, which are favorable conditions for HDD installation. While it should be noted that the calculations we have completed for this crossing indicate a moderate to high risk of inadvertent drilling fluids on the eastern edge of the mud flats as a result of hydrofracture, that risk does not necessarily impact the technical feasibility of the proposed crossing. We investigated lowering the design elevation by 26 feet in order to reduce the potential for inadvertent returns, but based on our calculations that change didn’t help. It may be possible to mitigate the risk of inadvertent returns at this location by drilling a portion of the pilot hole from the eastern end of the crossing.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Nansemond River and that the crossing can be completed successfully.

4.17 20-inch Interstate 64 Crossing

The proposed HDD crossing of Interstate 64 has a horizontal drilled length of 2,039 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of two exploratory borings conducted at the Interstate 64 crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter surficial clay overlying sand with silt and silty sand, which are favorable conditions for HDD installation.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of Interstate 64 and that the crossing can be completed successfully.

4.18 20-inch Route 17 Crossing

The proposed HDD crossing of Route 17 has a horizontal drilled length of 2,951 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of three exploratory borings conducted at the Route 17 crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter alternating layers of clay and sand overlying a layer of medium dense sand though which the majority of the crossing will be placed. These conditions are favorable for HDD installation. While it should be noted that the calculations we have completed for this crossing indicate a moderate to high risk of inadvertent drilling fluid returns as a result of hydrofracture in the pond to the west of the exit point, that risk does not necessarily impact the technical feasibility of the proposed crossing. It may be possible to mitigate the risk of inadvertent returns in the pond by drilling a portion of the pilot hole from the eastern end of the crossing.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of Route 17 and that the crossing can be completed successfully.

4.19 20-inch Elizabeth River Crossing

The proposed HDD crossing of the Elizabeth River has a horizontal drilled length of 1,730 feet and an outside diameter of 20 inches. This combination of length and diameter falls well within the limits of current HDD industry capabilities.

The geotechnical site investigation report produced by Geosyntec presents the results of three exploratory borings conducted at the Elizabeth River crossing site. In general, the geotechnical investigation found that the proposed HDD crossing is anticipated to encounter primarily silty sand and clayey sand, which are favorable conditions for HDD installation. The borings also encountered occasional wood fragments, gravel, and weathered rock fragments.

It should be noted that the depths of the sheet piling along the eastern water’s edge and the wood pilings in the river are not known. While the crossing has been designed at a depth that we anticipate will clear the existing pilings, there is a risk that the pilings could be encountered by the contractor’s downhole tools during HDD operations. If so, the crossing may need to be redesigned and installed at a greater depth.

Based on these considerations, it is our opinion that knowledgeable HDD contractors will submit fixed price, lump sum bids to install Dominion’s proposed HDD crossing of the Elizabeth River and that the crossing can be completed successfully.

APPENDIX

Operating Stress

Supporting Information

- Operating stress analysis, 20-inch crossings (1 page)
- Operating stress analysis, 36-inch crossings (1 page)
- Operating stress analysis, 42-inch crossings (1 page)

Operating Stress Analysis

PROJECT: Dominion Atlantic Coast Pipeline
20" Crossings
Installation and operating temperatures assumed

Pipe Properties				
	Design Radius (2,000')		Specified Min. Radius (1,350')	
Pipe Outside Diameter =	20.000	in	20.000	in
Wall Thickness =	0.411	in	0.411	in
Specified Minimum Yield Strength =	70,000	psi	70,000	psi
Young's Modulus =	2.9E+07	psi	2.9E+07	psi
Moment of Inertia =	1213.22	in^4	1213.22	in^4
Pipe Face Surface Area =	25.29	in^2	25.29	in^2
Diameter to Wall Thickness Ratio, D/t =	49		49	
Poisson's Ratio =	0.3		0.3	
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	6.5E-06	in/in/°F
Pipe Weight in Air =	85.99	lb/ft	85.99	lb/ft
Pipe Interior Volume =	2.01	ft^3/ft	2.01	ft^3/ft
Pipe Exterior Volume =	2.18	ft^3/ft	2.18	ft^3/ft
Operating Parameters				
Maximum Allowable Operating Pressure =	1,440	psig	1,440	psig
Radius of Curvature =	2,000	ft	1,350	ft
Installation Temperature =	55	°F	55	°F
Operating Temperature =	125	°F	125	°F
Groundwater Table Head =	0	ft	0	ft
Operating Stress Check	Scenario 1		Scenario 2	
Hoop Stress =	35,036	psi	35,036	psi
% SMYS =	50%		50%	
Longitudinal Stress from Internal Pressure =	10,511	psi	10,511	psi
% SMYS =	15%		15%	
Longitudinal Stress from Temperature Change =	-13,195	psi	-13,195	psi
% SMYS =	19%		19%	
Longitudinal Stress from Bending =	12,083	psi	17,901	psi
% SMYS =	17%		26%	
Net Longitudinal Stress (taking bending in tension) =	9,399	psi	15,217	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	13%	ok	22%	ok
Net Longitudinal Stress (taking bending in compression) =	-14,767	psi	-20,585	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	21%	ok	29%	ok
Combined Stress (NLS w/bending in tension) - Max. Shear Stress Theory =	25,637	psi	19,819	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	37%	ok	28%	ok
Combined Stress (NLS w/bending in compression) - Max. Shear Stress Theory =	49,804	psi	55,622	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	71%	ok	79%	ok
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	31,410	psi	30,430	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	45%	ok	43%	ok
Combined Stress (NLS w/bending in compression) - Max. Distortion Energy Theory =	44,306	psi	48,709	psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	63%	ok	70%	ok

Operating Stress Analysis

PROJECT: Dominion Atlantic Coast Pipeline
36" Crossings
Installation and operating temperatures assumed

Pipe Properties		
	Design Radius (3,600')	Specified Min. Radius (2,400')
Pipe Outside Diameter =	36.000 in	36.000 in
Wall Thickness =	0.741 in	0.741 in
Specified Minimum Yield Strength =	70,000 psi	70,000 psi
Young's Modulus =	2.9E+07 psi	2.9E+07 psi
Moment of Inertia =	12755.22 in^4	12755.22 in^4
Pipe Face Surface Area =	82.08 in^2	82.08 in^2
Diameter to Wall Thickness Ratio, D/t =	49	49
Poisson's Ratio =	0.3	0.3
Coefficient of Thermal Expansion =	6.5E-06 in/in/°F	6.5E-06 in/in/°F
Pipe Weight in Air =	279.04 lb/ft	279.04 lb/ft
Pipe Interior Volume =	6.50 ft^3/ft	6.50 ft^3/ft
Pipe Exterior Volume =	7.07 ft^3/ft	7.07 ft^3/ft
Operating Parameters		
Maximum Allowable Operating Pressure =	1,440 psig	1,440 psig
Radius of Curvature =	3,600 ft	2,400 ft
Installation Temperature =	55 °F	55 °F
Operating Temperature =	125 °F	125 °F
Groundwater Table Head =	0 ft	0 ft
Operating Stress Check	Scenario 1	Scenario 2
Hoop Stress =	34,980 psi	34,980 psi
% SMYS =	50%	50%
Longitudinal Stress from Internal Pressure =	10,494 psi	10,494 psi
% SMYS =	15%	15%
Longitudinal Stress from Temperature Change =	-13,195 psi	-13,195 psi
% SMYS =	19%	19%
Longitudinal Stress from Bending =	12,083 psi	18,125 psi
% SMYS =	17%	26%
Net Longitudinal Stress (taking bending in tension) =	9,382 psi	15,424 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	13% ok	22% ok
Net Longitudinal Stress (taking bending in compression) =	-14,784 psi	-20,826 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	21% ok	30% ok
Combined Stress (NLS w/bending in tension) - Max. Shear Stress Theory =	25,597 psi	19,556 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	37% ok	28% ok
Combined Stress (NLS w/bending in compression) - Max. Shear Stress Theory =	49,764 psi	55,806 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	71% ok	80% ok
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	31,360 psi	30,364 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	45% ok	43% ok
Combined Stress (NLS w/bending in compression) - Max. Distortion Energy Theory =	44,264 psi	48,845 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	63% ok	70% ok

Operating Stress Analysis

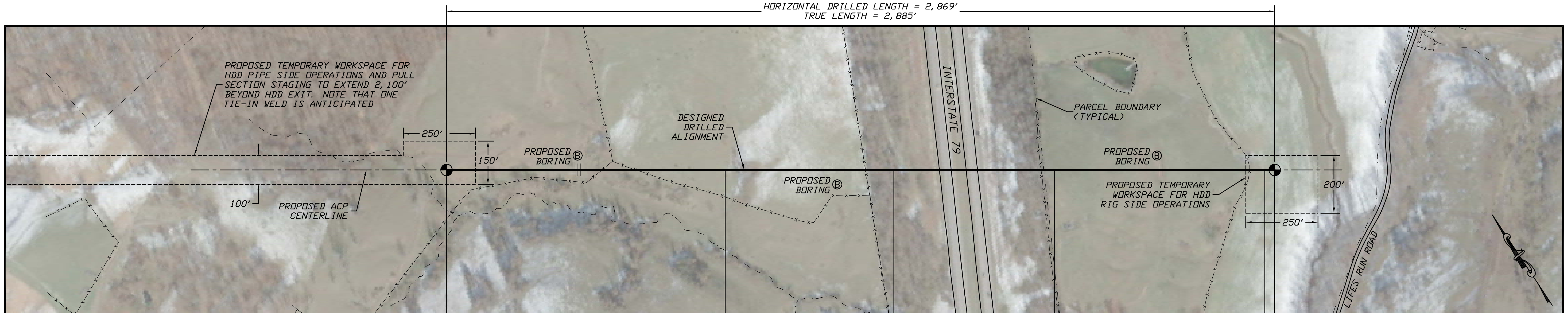
PROJECT: Dominion Atlantic Coast Pipeline
42" Crossings
Installation and operating temperatures assumed

Pipe Properties		
	Design Radius (4,200')	Specified Min. Radius (2,800')
Pipe Outside Diameter =	42.000 in	42.000 in
Wall Thickness =	0.864 in	0.864 in
Specified Minimum Yield Strength =	70,000 psi	70,000 psi
Young's Modulus =	2.9E+07 psi	2.9E+07 psi
Moment of Inertia =	23617.82 in^4	23617.82 in^4
Pipe Face Surface Area =	111.66 in^2	111.66 in^2
Diameter to Wall Thickness Ratio, D/t =	49	49
Poisson's Ratio =	0.3	0.3
Coefficient of Thermal Expansion =	6.5E-06 in/in/°F	6.5E-06 in/in/°F
Pipe Weight in Air =	379.58 lb/ft	379.58 lb/ft
Pipe Interior Volume =	8.85 ft^3/ft	8.85 ft^3/ft
Pipe Exterior Volume =	9.62 ft^3/ft	9.62 ft^3/ft
Operating Parameters		
Maximum Allowable Operating Pressure =	1,440 psig	1,440 psig
Radius of Curvature =	4,200 ft	2,800 ft
Installation Temperature =	55 °F	55 °F
Operating Temperature =	125 °F	125 °F
Groundwater Table Head =	0 ft	0 ft
Operating Stress Check	Scenario 1	Scenario 2
Hoop Stress =	35,000 psi	35,000 psi
% SMYS =	50%	50%
Longitudinal Stress from Internal Pressure =	10,500 psi	10,500 psi
% SMYS =	15%	15%
Longitudinal Stress from Temperature Change =	-13,195 psi	-13,195 psi
% SMYS =	19%	19%
Longitudinal Stress from Bending =	12,083 psi	18,125 psi
% SMYS =	17%	26%
Net Longitudinal Stress (taking bending in tension) =	9,388 psi	15,430 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	13% ok	22% ok
Net Longitudinal Stress (taking bending in compression) =	-14,778 psi	-20,820 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	21% ok	30% ok
Combined Stress (NLS w/bending in tension) - Max. Shear Stress Theory =	25,612 psi	19,570 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	37% ok	28% ok
Combined Stress (NLS w/bending in compression) - Max. Shear Stress Theory =	49,778 psi	55,820 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	71% ok	80% ok
Combined Stress (NLS w/bending in tension) - Max. Distortion Energy Theory =	31,378 psi	30,381 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	45% ok	43% ok
Combined Stress (NLS w/bending in compression) - Max. Distortion Energy Theory =	44,279 psi	48,859 psi
Limited to 90% of SMYS by ASME B31.8 (2010) B31.4 (2012) =	63% ok	70% ok

Interstate 79

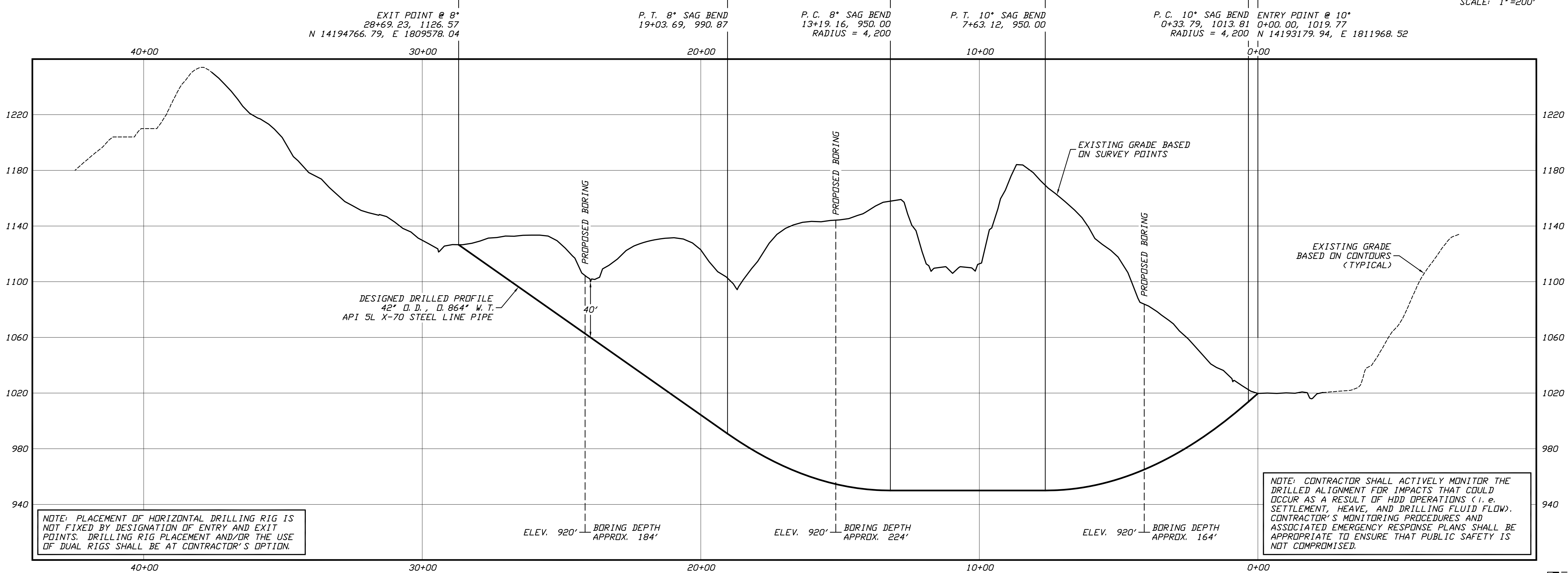
Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)



PLAN

SCALE: 1"=200'



PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 40' VERTICAL

400 200 100 0
40 20 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,800 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

PRELIMINARY

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
42-INCH PIPELINE CROSSING OF INTERSTATE 79
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: LEWIS COUNTY, WEST VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM/LKB	11/29/16	JSP	JSP	SHOWN FOR D-SIZED PLOT	INTERSTATE 79	P0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP1-14

Interstate 79 P0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	LKB
Crossing :	42" Interstate 79 Crossing		Date :	11/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,400' radius) with 12 ppg mud and BC			

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	

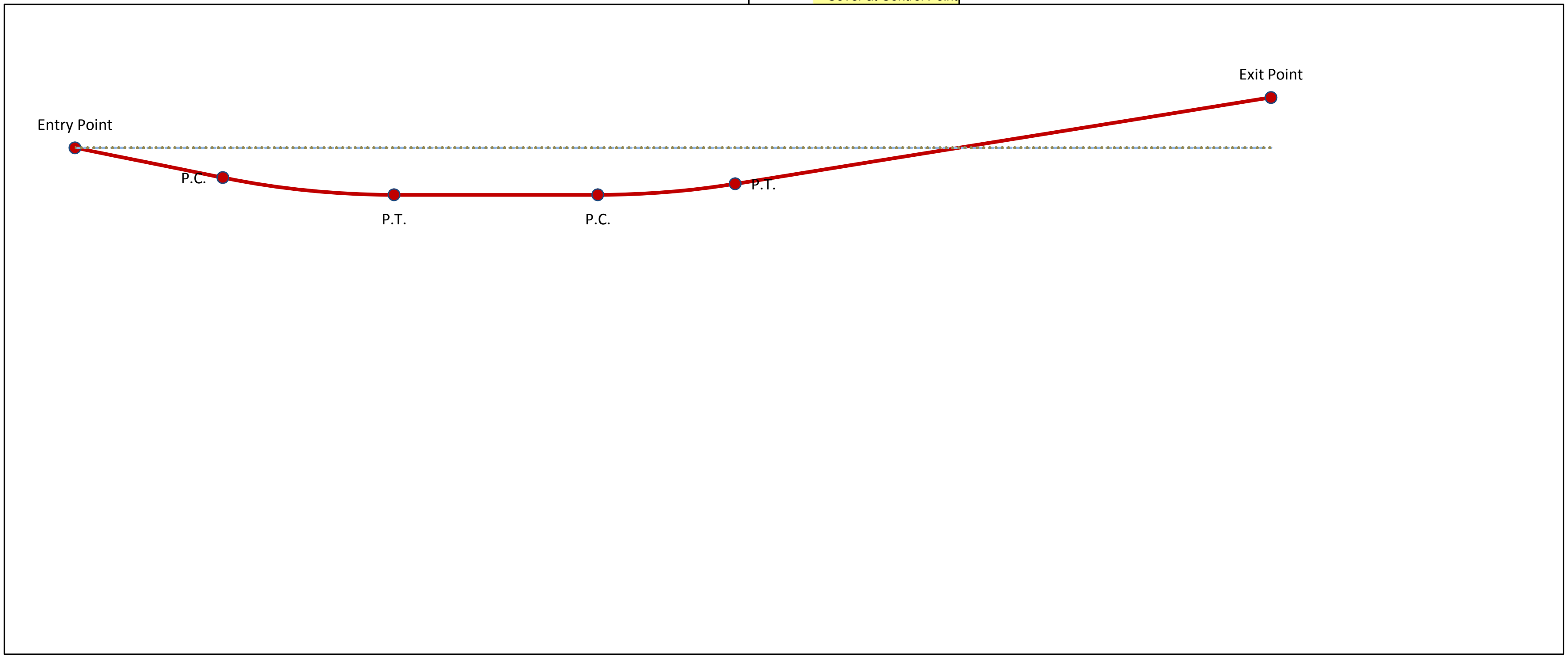
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,200	psi	

Interstate 79 P0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	1019.77	10.00				199,089
Entry Tangent						364.58		
Entry Sag Bend	PC	349.04	956.46					173,034
	PI	555.82	920.00	10.00	2400	418.88	155,414	
	PT	765.80	920.00				0	137,794
Bottom Tangent				0.00		495.79		
Exit Sag Bend	PC	1261.58	920.00					108,060
	PI	1429.41	920.00	8.00	2400	335.10	93,483	
	PT	1595.60	943.36				0	78,906
Exit Tangent						1316.44		
Exit Point		2899.23	1126.57	8.00	Above Ground Load			0
Drilling Mud			1019.77	(Graph =)				
Ballast			1019.77	(Graph =)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1316.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	379.6	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	148,451	lb	
Fluidic Drag = 12 π D L C_d =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input
Axial Segment Weight = W_e L sinθ =	-69,545	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**78,906**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	93,483	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	2,707	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	3.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	151.54	
U = (12 L) / j =	1.49		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	29,129	lb
Bending Frictional Drag = 2 μ N =	17,478	lb			
Fluidic Drag = 12 π D L C_d =	13,265	lb			
Axial Segment Weight = W_e L sinθ =	-1,589	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**29,154**	**lb**			
Total Pulling Load =	**108,060**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	495.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

Frictional Drag = W_e L μ =	10,109	lb
Fluidic Drag = 12 π D L C_d =	19,625	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**29,734**	**lb**
Total Pulling Load =	**137,794**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 155,414 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = 68.0 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 2,099

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 1.2E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 382.49

$U = (12 L) / j$ = 2.39

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 26,963 lb

Bending Frictional Drag = $2 \mu N$ = 16,178 lb

Fluidic Drag = $12 \pi D L C_d$ = 16,581 lb

Axial Segment Weight = $W_e L \sin\theta$ = 2,481 lb

Pulling Load on Entry Sag Bend = 35,240 lb
Total Pulling Load = 173,034 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 364.6 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 68.0 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 7,321 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,432 lb

Axial Segment Weight = $W_e L \sin\theta$ = 4,303 lb

Pulling Load on Entry Tangent = 26,055 lb
Total Pulling Load = 199,089 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	1,783	ok	0	ok	0	ok	0.03	ok	0.00	ok
	1,550	ok	0	ok	292	ok	0.02	ok	0.00	ok
PC										
	1,550	ok	21,146	ok	292	ok	0.49	ok	0.17	ok
	1,234	ok	21,146	ok	461	ok	0.48	ok	0.18	ok
PT										
	1,234	ok	0	ok	461	ok	0.02	ok	0.01	ok
	968	ok	0	ok	461	ok	0.02	ok	0.00	ok
PC										
	968	ok	21,146	ok	461	ok	0.48	ok	0.17	ok
	707	ok	21,146	ok	353	ok	0.47	ok	0.16	ok
PT										
	707	ok	0	ok	353	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Interstate 79 P0 Installation Stress Analysis (worst-case).xlsm

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Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	LKB
Crossing :	42" Interstate 79 Crossing		Date :	11/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,400' radius) with 12 ppg mud and no BC			

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	

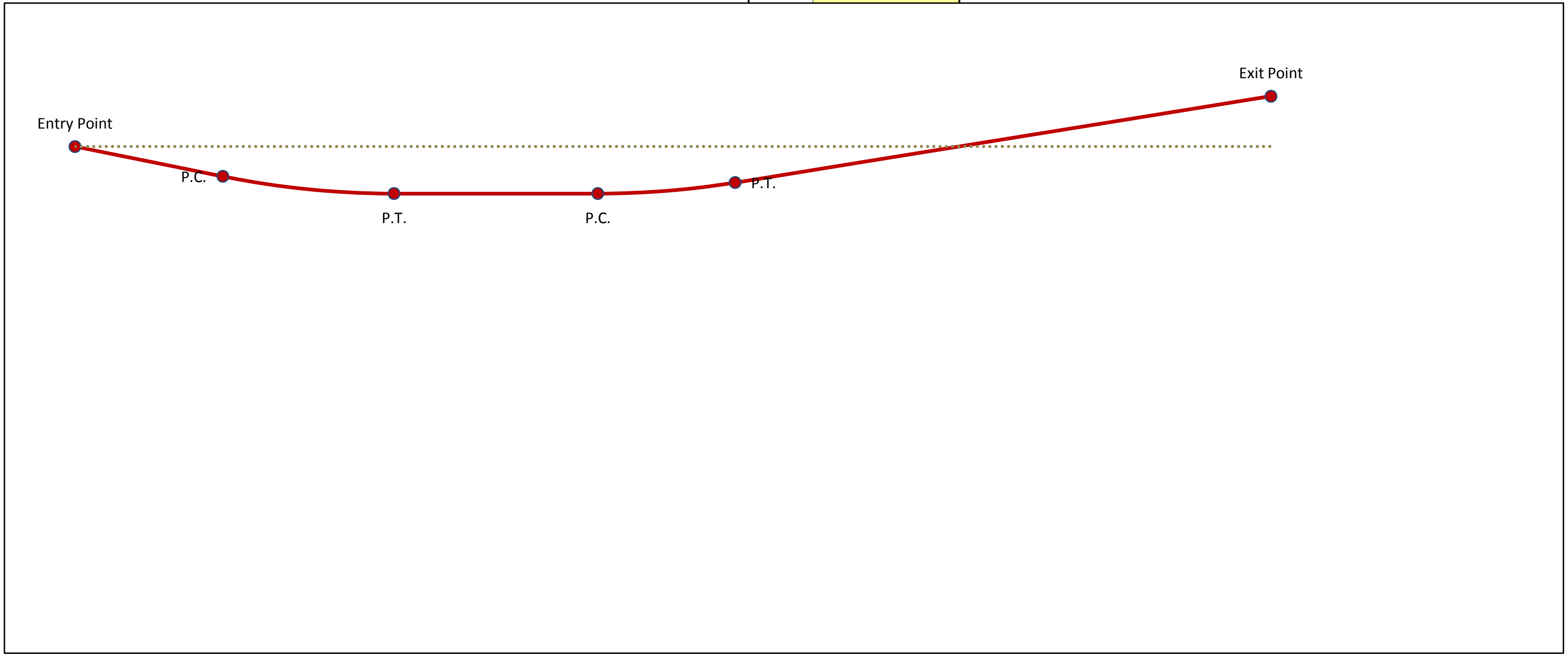
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,200	psi	

Interstate 79 P0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	1019.77	10.00				430,756
Entry Tangent						364.58		
Entry Sag Bend	PC	349.04	956.46					394,833
	PI	555.82	920.00	10.00	2400	418.88	339,178	
	PT	765.80	920.00				0	283,523
Bottom Tangent				0.00		495.79		
Exit Sag Bend	PC	1261.58	920.00					191,908
	PI	1429.41	920.00	8.00	2400	335.10	135,407	
	PT	1595.60	943.36				0	78,906
Exit Tangent						1316.44		
Exit Point		2899.23	1126.57	8.00			Above Ground Load	0
Drilling Mud			1019.77	(Graph = · · · · · · · ·)				
Ballast				(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1316.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	379.6	lb/ft
Exit Angle, θ =	8.0	º			

Frictional Drag = $W_e\, L\, \mu \cos\theta$ =	148,451	lb	
Fluidic Drag = $12\,\pi\, D\, L\, C_d$ =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input
Axial Segment Weight = $W_e\, L \sin\theta$ =	-69,545	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**78,906**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	135,407	lb
Segment Angle with Horizontal, θ =	-8.0	º	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	º	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

$h = R\,[1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E\, I) / T]^{1/2}$ =	2,249	
$Y = [18\,(L)^2] - [(j)^2\,(1 - \cosh(U/2)^{-1}]$ =	5.1E+05		$X = (3\,L) - [\,(j/2) \tanh(U/2)\,]$ =	203.12	
$U = (12\,L) / j$ =	1.79		$N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X/12)$ =	147,372	lb
Bending Frictional Drag = $2\,\mu\,N$ =	88,423	lb			
Fluidic Drag = $12\,\pi\, D\, L\, C_d$ =	13,265	lb			
Axial Segment Weight = $W_e\, L \sin\theta$ =	11,314	lb			
Pulling Load on Exit Sag Bend =	**113,002**	**lb**			
Total Pulling Load =	**191,908**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	495.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

Frictional Drag = $W_e\, L\, \mu$ =	71,990	lb
Fluidic Drag = $12\,\pi\, D\, L\, C_d$ =	19,625	lb
Axial Segment Weight = $W_e\, L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**91,615**	**lb**
Total Pulling Load =	**283,523**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 339,178 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = -484.0 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 1,421

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 1.8E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 586.29

$U = (12 L) / j$ = 3.54

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 187,331 lb

Bending Frictional Drag = $2 \mu N$ = 112,399 lb

Fluidic Drag = $12 \pi D L C_d$ = 16,581 lb

Axial Segment Weight = $W_e L \sin\theta$ = -17,670 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 111,310 lb
Total Pulling Load = 394,833 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 364.6 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -484.0 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 52,134 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,432 lb

Axial Segment Weight = $W_e L \sin\theta$ = -30,642 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 35,923 lb
Total Pulling Load = 430,756 lb

Summary of Calculated Stress vs. Allowable Stress

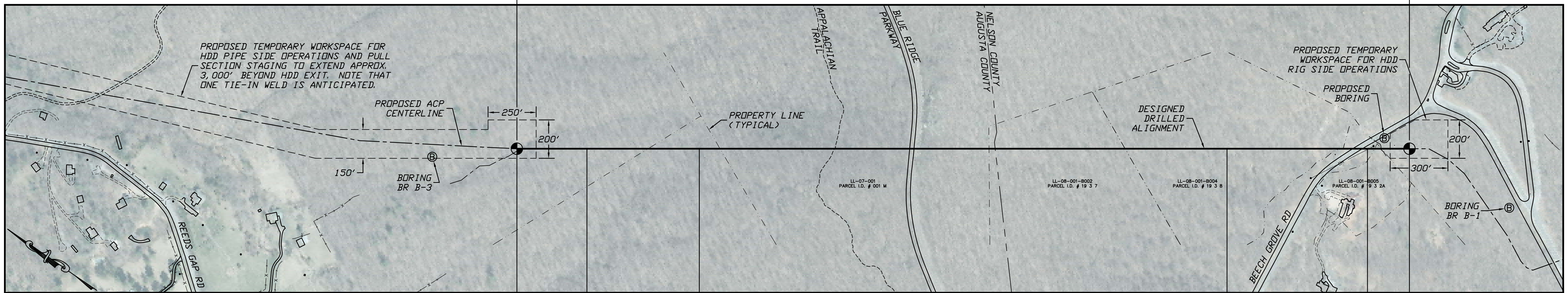
	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,858	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,536	ok	0	ok	959	ok	0.06	ok	0.03	ok
PC										
	3,536	ok	21,146	ok	959	ok	0.52	ok	0.24	ok
	2,539	ok	21,146	ok	1512	ok	0.50	ok	0.26	ok
PT										
	2,539	ok	0	ok	1512	ok	0.04	ok	0.05	ok
	1,719	ok	0	ok	1512	ok	0.03	ok	0.05	ok
PC										
	1,719	ok	21,146	ok	1512	ok	0.49	ok	0.25	ok
	707	ok	21,146	ok	1158	ok	0.47	ok	0.21	ok
PT										
	707	ok	0	ok	1158	ok	0.01	ok	0.03	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Blue Ridge Parkway

Supporting Information

- Plan & profile drawing presenting HDD crossing design (2 pages, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 4,639'
TRUE LENGTH = 4,652'



PLAN

SCALE: 1"=300'

EXIT POINT @ 8°
46+39.05, 2012.00
N 13773798.63, E 2223025.61

P.T. 8° SAG BEND
42+75.27, 1960.87

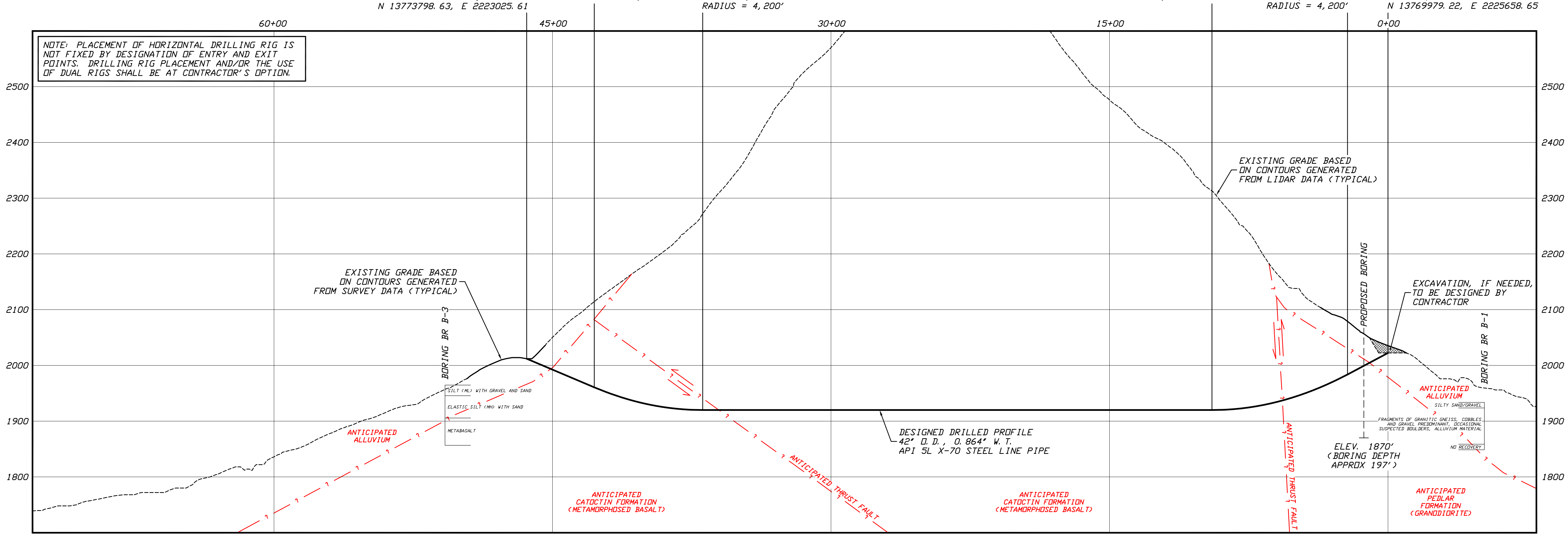
P.C. 8° SAG BEND
36+90.74, 1920.00
RADIUS = 4,200'

P.T. 10° SAG BEND
9+47.61, 1920.00

P.C. 10° SAG BEND
2+18.28, 1983.81
RADIUS = 4,200'

ENTRY POINT @ 10°
0+00.00, 2022.30
N 13769979.22, E 2225658.65

NOTE: PLACEMENT OF HORIZONTAL DRILLING RIG IS NOT FIXED BY DESIGNATION OF ENTRY AND EXIT POINTS. DRILLING RIG PLACEMENT AND/OR THE USE OF DUAL RIGS SHALL BE AT CONTRACTOR'S OPTION.



PROFILE

SCALE: 1"=300' HORIZONTAL
1"=100' VERTICAL

600 300 150 0
100 50 0

GENERAL LEGEND

- DRILLED PATH ENTRY/EXIT POINT
- BORING LOCATION

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.
2. STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES.
3. THE ANTICIPATED SUBSURFACE CONDITIONS SHOWN IN RED ARE BASED ON A GENERAL GEOLOGIC PROFILE INCLUDED IN THE GEOTECHNICAL SITE INVESTIGATION REPORT AS FIGURE 4.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 15 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,800 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
42-INCH PIPELINE CROSSING OF THE BLUE RIDGE PARKWAY BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: AUGUSTA COUNTY & NELSON COUNTY, VIRGINIA

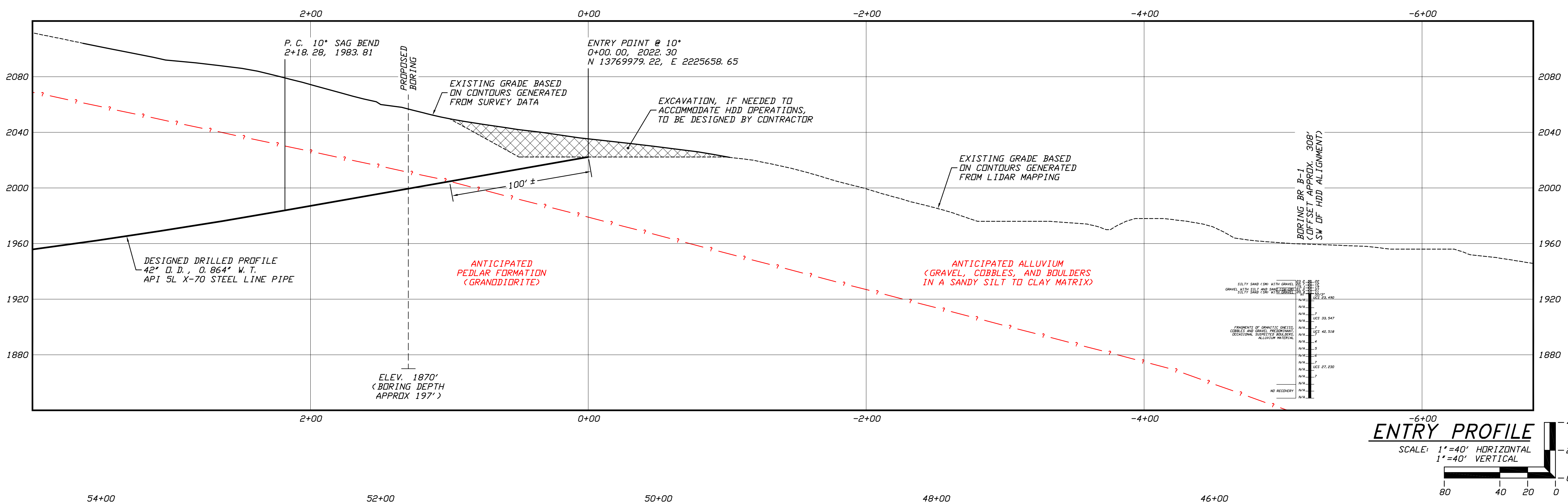
DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	05/19/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	BR PARKWAY 1	0

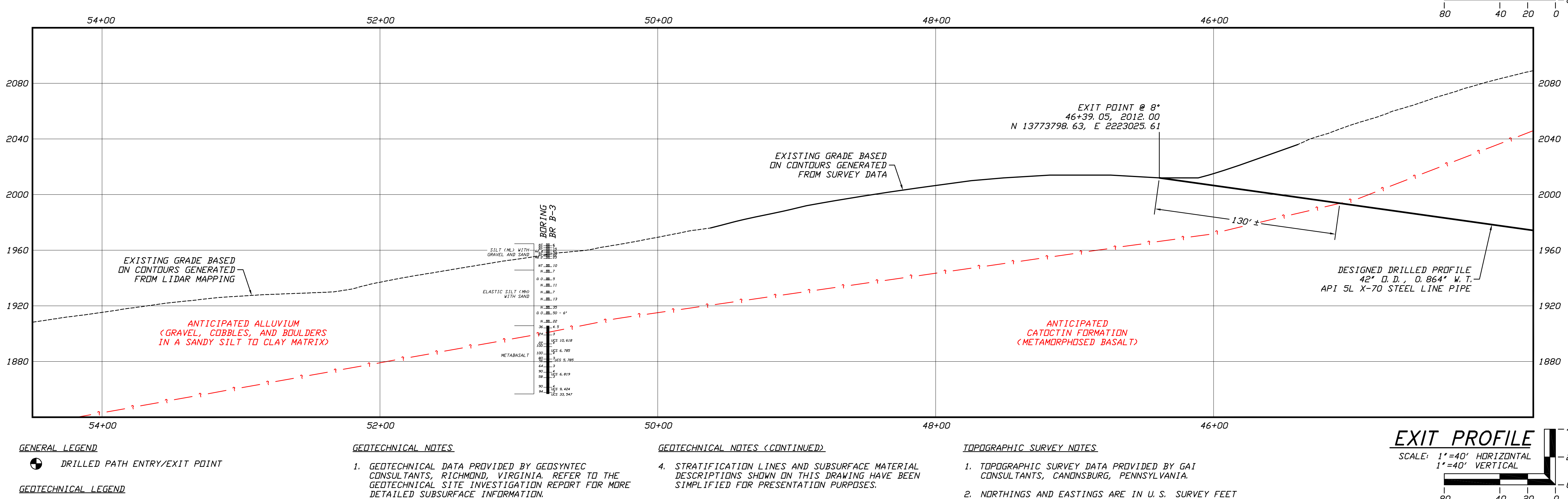
NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP1-158





GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

SPLIT SPOON SAMPLE

53 / 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES; PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 ← UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 / 6 ← MOHS HARDNESS
ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

GEOTECHNICAL NOTES (CONTINUED)

4. STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES.
5. THE ANTICIPATED SUBSURFACE CONDITIONS SHOWN IN RED ARE BASED ON A GENERAL GEOLOGIC PROFILE INCLUDED IN THE GEOTECHNICAL SITE INVESTIGATION REPORT AS FIGURE 4.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

ENTRY/EXIT PROFILES - NATURAL SCALE
42-INCH PIPELINE CROSSING OF THE BLUE RIDGE PARKWAY BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: AUGUSTA COUNTY & NELSON COUNTY, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	05/19/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	BR PARKWAY 2	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO. Dominion\1508

MILE POST AP1-158

Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	KMN
Crossing :	42" Blue Ridge Parkway Crossing		Date :	2/9/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,800' radius) with 12 ppg mud with BC			

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	

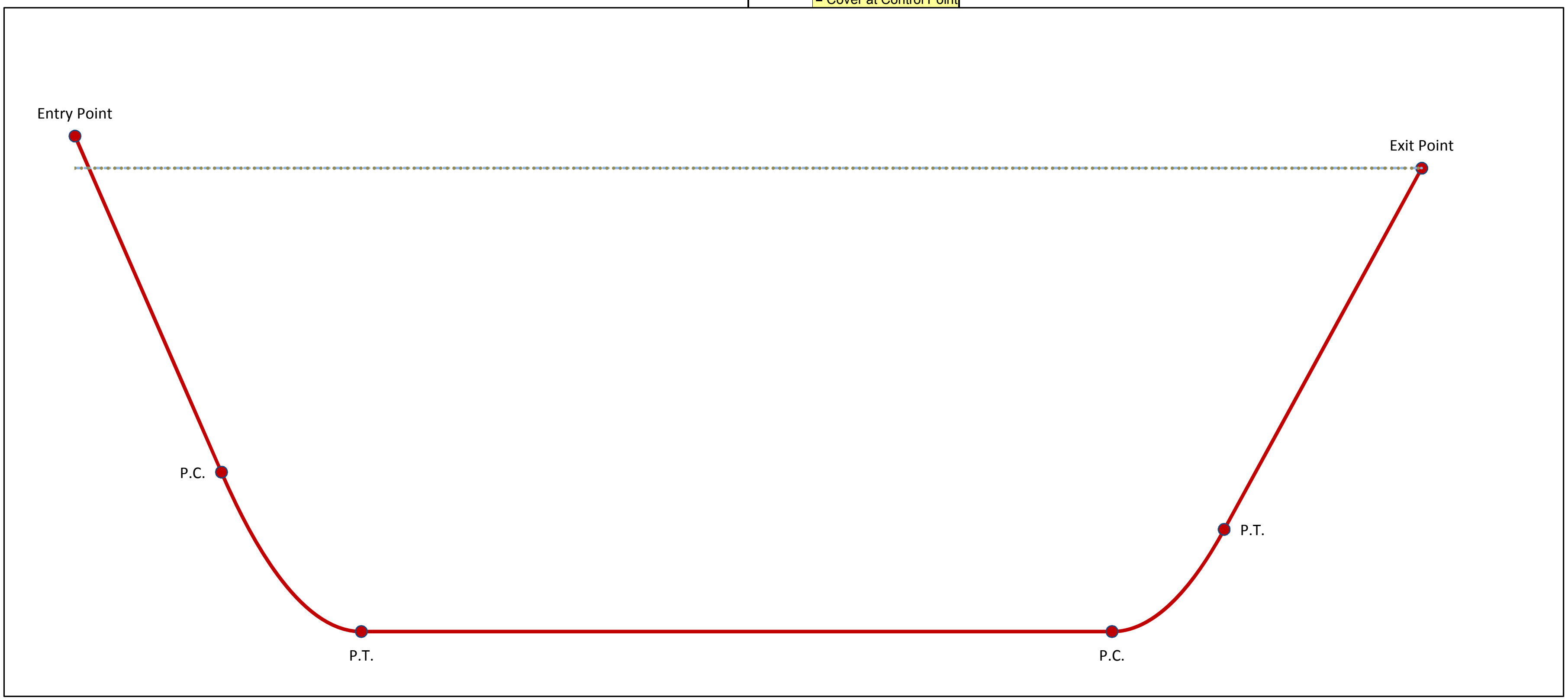
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,200	psi	

Blue Ridge Parkway R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	2022.30	10.00				286,742
Entry Tangent						516.92		
Entry Sag Bend	PC	499.06	1932.54					249,800
	PI	740.31	1890.00	10.00	2800	488.69	231,351	
	PT	985.28	1890.00				0	212,902
Bottom Tangent				0.00		2607.73		
Exit Sag Bend	PC	3593.01	1890.00					56,508
	PI	3788.81	1890.00	8.00	2800	390.95	45,691	
	PT	3982.70	1917.25				0	34,874
Exit Tangent						693.10		
Exit Point		4669.05	2013.71	8.00	Above Ground Load			0
Drilling Mud			2013.71	(Graph = ········)				
Ballast			2013.71	(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	693.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft
Exit Angle, θ =	8.0	º			

Frictional Drag = W_e L μ cosθ =	13,994	lb	
Fluidic Drag = 12 π D L C_d =	27,436	lb	
Axial Segment Weight = W_e L sinθ =	-6,556	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**34,874**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	391.0	ft	Average Tension, T =	45,691	lb
Segment Angle with Horizontal, θ =	-8.0	º	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	-4.0	º	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

h = R [1 - cos(α/2)] =	6.82	ft	$j = [(E\ I) / T]^{1/2}$ =	3,872	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.7E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	125.16	
U = (12 L) / j =	1.21		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	13,353	lb
Bending Frictional Drag = 2 μ N =	8,012	lb			
Fluidic Drag = 12 π D L C_d =	15,476	lb			
Axial Segment Weight = W_e L sinθ =	-1,853	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**21,634**	**lb**			
Total Pulling Load =	**56,508**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	2607.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

Frictional Drag = W_e L μ =	53,170	lb
Fluidic Drag = 12 π D L C_d =	103,225	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**156,395**	**lb**
Total Pulling Load =	**212,902**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 488.7 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 231,351 lb
Radius of Curvature, R = 2,800 ft
Effective Weight, $W_e = W + W_b - W_m$ = 68.0 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 10.65 ft

$j = [(E I) / T]^{1/2}$ = 1,721

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 2.4E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 660.90

$U = (12 L) / j$ = 3.41

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 24,431 lb

Bending Frictional Drag = $2 \mu N$ = 14,659 lb

Fluidic Drag = $12 \pi D L C_d$ = 19,344 lb

Axial Segment Weight = $W_e L \sin\theta$ = 2,895 lb

Pulling Load on Entry Sag Bend = 36,898 lb
Total Pulling Load = 249,800 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 516.9 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 68.0 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 10,379 lb

Fluidic Drag = $12 \pi D L C_d$ = 20,462 lb

Axial Segment Weight = $W_e L \sin\theta$ = 6,101 lb

Pulling Load on Entry Tangent = 36,942 lb
Total Pulling Load = 286,742 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	2,568	ok	0	ok	0	ok	0.04	ok	0.00	ok
	2,237	ok	0	ok	375	ok	0.04	ok	0.01	ok
PC										
	2,237	ok	18,125	ok	375	ok	0.43	ok	0.14	ok
	1,907	ok	18,125	ok	571	ok	0.43	ok	0.15	ok
PT										
	1,907	ok	0	ok	571	ok	0.03	ok	0.01	ok
	506	ok	0	ok	571	ok	0.01	ok	0.01	ok
PC										
	506	ok	18,125	ok	571	ok	0.41	ok	0.13	ok
	312	ok	18,125	ok	445	ok	0.40	ok	0.12	ok
PT										
	312	ok	0	ok	445	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Blue Ridge Parkway R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	42" Blue Ridge Parkway Crossing	Date :	2/9/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,800' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,200	psi	

Blue Ridge Parkway R0 Installation Stress Analysis (worst-case).xlsm

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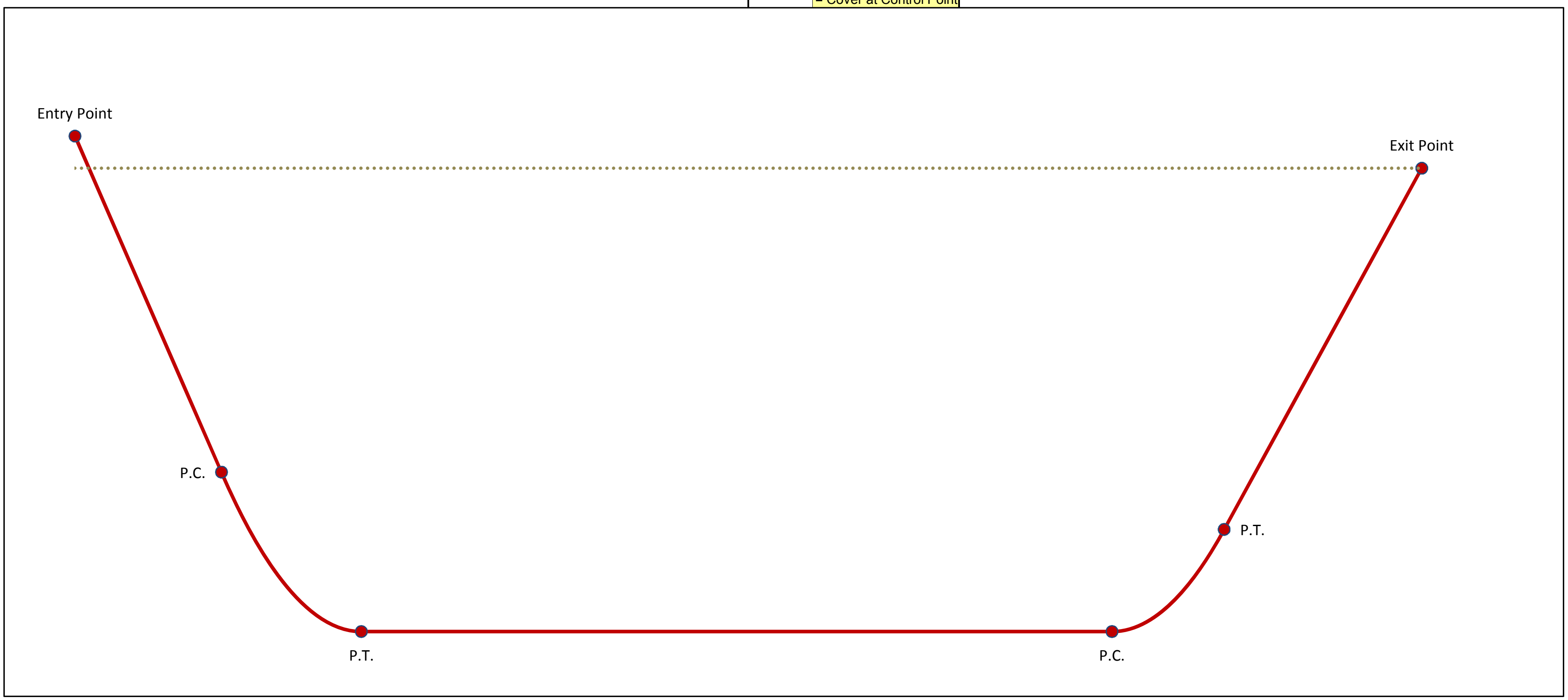
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	2022.30	10.00				979,838
Entry Tangent						516.92		
Entry Sag Bend	PC	499.06	1932.54					928,905
	PI	740.31	1890.00	10.00	2800	488.69	855,318	
	PT	985.28	1890.00				0	781,730
Bottom Tangent				0.00		2607.73		
Exit Sag Bend	PC	3593.01	1890.00					299,856
	PI	3788.81	1890.00	8.00	2800	390.95	236,820	
	PT	3982.70	1917.25				0	173,784
Exit Tangent						693.10		
Exit Point		4669.05	2013.71	8.00	Above Ground Load			0
Drilling Mud			2013.71	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Blue Ridge Parkway R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	693.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	99,660	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	27,436	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	46,688	lb
Pulling Load on Exit Tangent =	**173,784**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	391.0	ft	Average Tension, T =	236,820	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	6.82	ft	$j = [(E\ I) / T]^{1/2}$ =	1,701	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	1.2E+06		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	423.90	
$U = (12\ L) / j$ =	2.76		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$	162,328	lb
Bending Frictional Drag = $2\ \mu\ N$ =	97,397	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	15,476	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	13,200	lb			
Pulling Load on Exit Sag Bend =	**126,072**	**lb**			
Total Pulling Load =	**299,856**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	2607.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	378,650	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	103,225	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**481,875**	**lb**
Total Pulling Load =	**781,730**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	488.7	ft	Average Tension, T =	855,318	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

$h = R\,[1 - \cos(\alpha/2)]$ =	10.65	ft	$j = [(E\,I) / T]^{1/2}$ =	895	
$Y = [18\,(L)^2] - [(j)^2\,(1 - \cosh(U/2)^{-1}]$ =	3.6E+06		$X = (3\,L) - [\,(j/2)\tanh(U/2)\,]$ =	1019.92	
$U = (12\,L) / j$ =	6.55		$N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X/12)$ =	247,408	lb
Bending Frictional Drag = $2\,\mu\,N$ =	148,445	lb			
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ =	19,344	lb			
Axial Segment Weight = $W_e\,L\sin\theta$ =	-20,615	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**147,174**	**lb**			
Total Pulling Load =	**928,905**	**lb**			

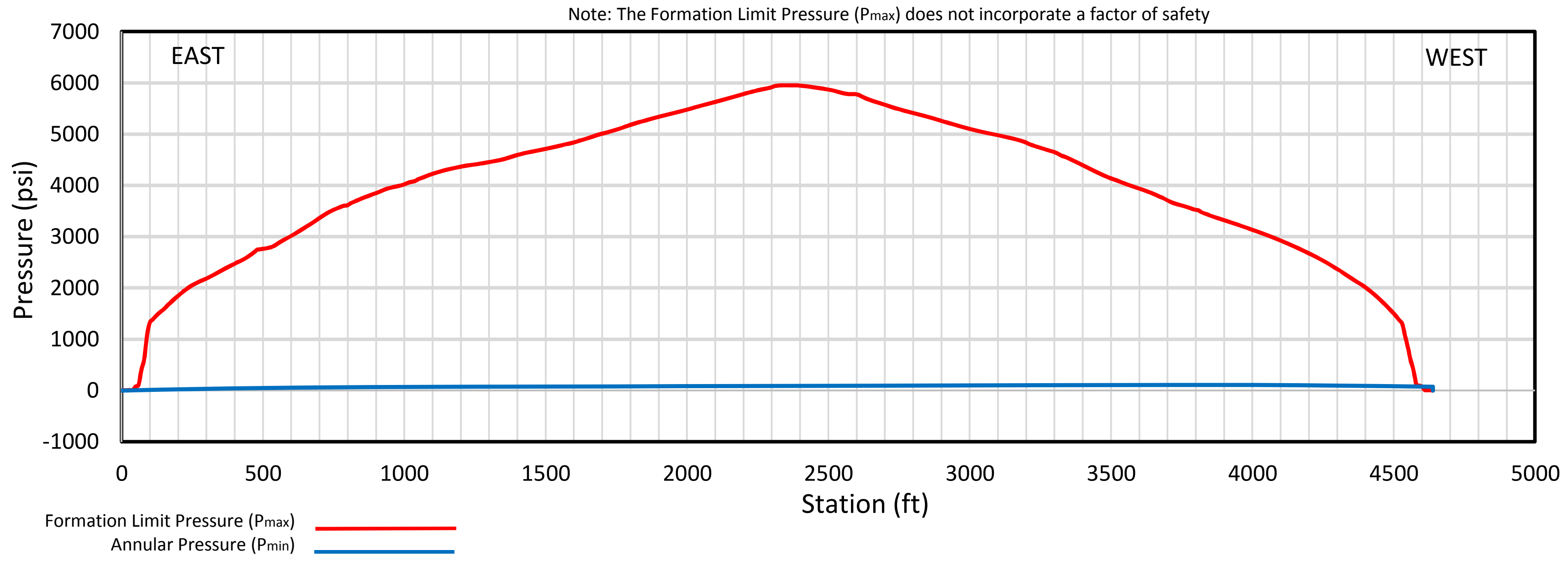
Entry Tangent - Summary of Pulling Load Calculations

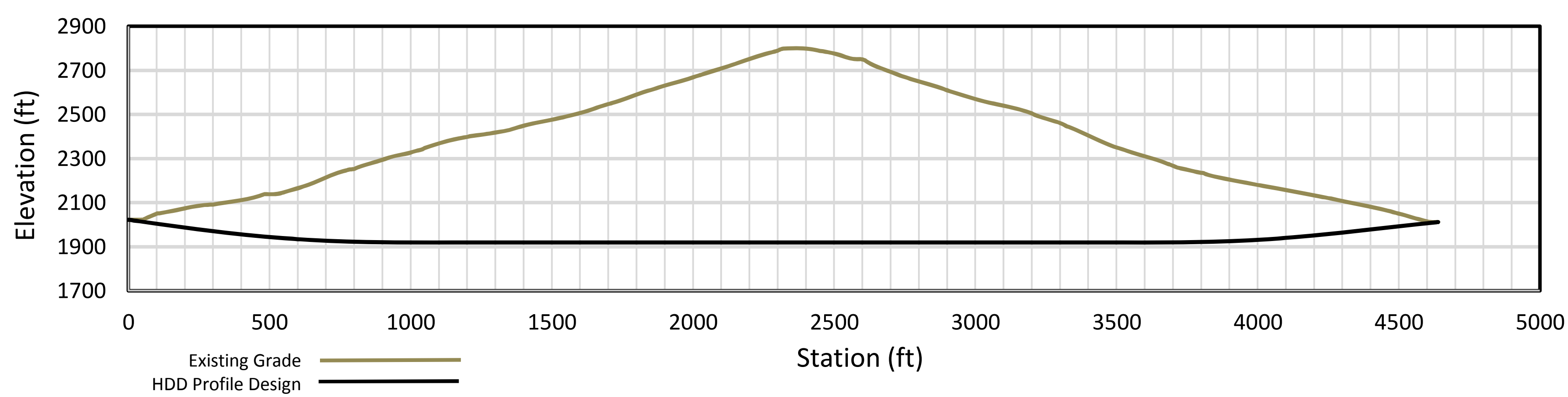
Segment Length, L =	516.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e\,L\,\mu\cos\theta$ =	73,917	lb	
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ =	20,462	lb	
Axial Segment Weight = $W_e\,L\sin\theta$ =	-43,445	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**50,934**	**lb**	
Total Pulling Load =	**979,838**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	8,775	ok	0	ok	0	ok	0.14	ok	0.02	ok
	8,319	ok	0	ok	1230	ok	0.13	ok	0.06	ok
PC										
	8,319	ok	18,125	ok	1230	ok	0.53	ok	0.29	ok
	7,001	ok	18,125	ok	1874	ok	0.51	ok	0.32	ok
PT										
	7,001	ok	0	ok	1874	ok	0.11	ok	0.10	ok
	2,686	ok	0	ok	1874	ok	0.04	ok	0.07	ok
PC										
	2,686	ok	18,125	ok	1874	ok	0.44	ok	0.25	ok
	1,556	ok	18,125	ok	1461	ok	0.42	ok	0.20	ok
PT										
	1,556	ok	0	ok	1461	ok	0.02	ok	0.04	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
42-INCH BLUE RIDGE PARKWAY CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

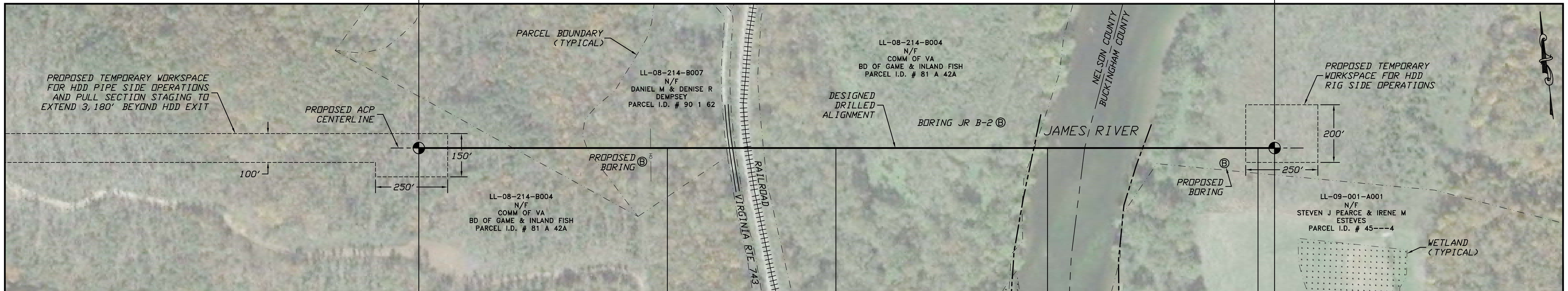
Date: 7/26/2016 Revision: 0

James River

Supporting Information

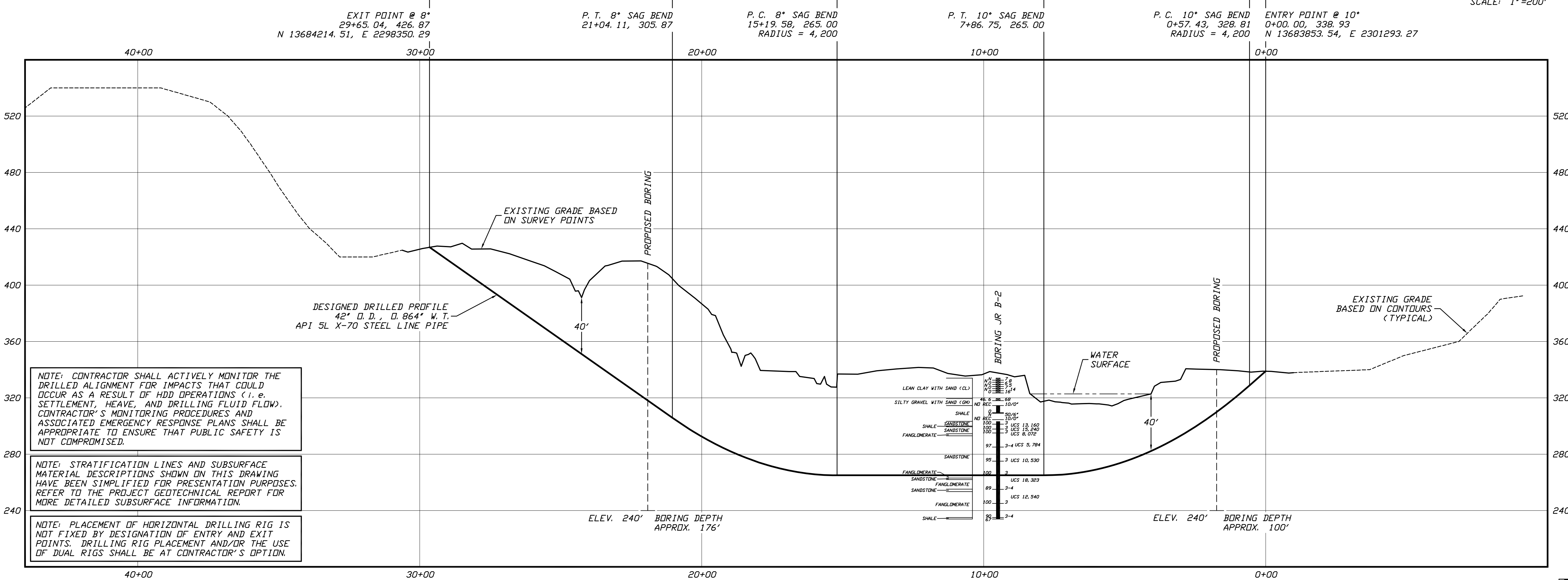
- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 2,965'
TRUE LENGTH = 2,980'



PLAN

SCALE: 1"=200'



PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 40' VERTICAL

400 200 100 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT DATED JUNE 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,800 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
42-INCH PIPELINE CROSSING OF THE JAMES RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: BUCKINGHAM & NELSON COUNTIES, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM	07/27/16	DLB	JSP	SHOWN FOR D-SIZED PLOT	JAMES RIVER	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP1-184

James River P5 Installation Stress Analysis (worst-case) - with buoyancy.xlsm
J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	42" James River Crossing	Date :	2/9/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,800' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	

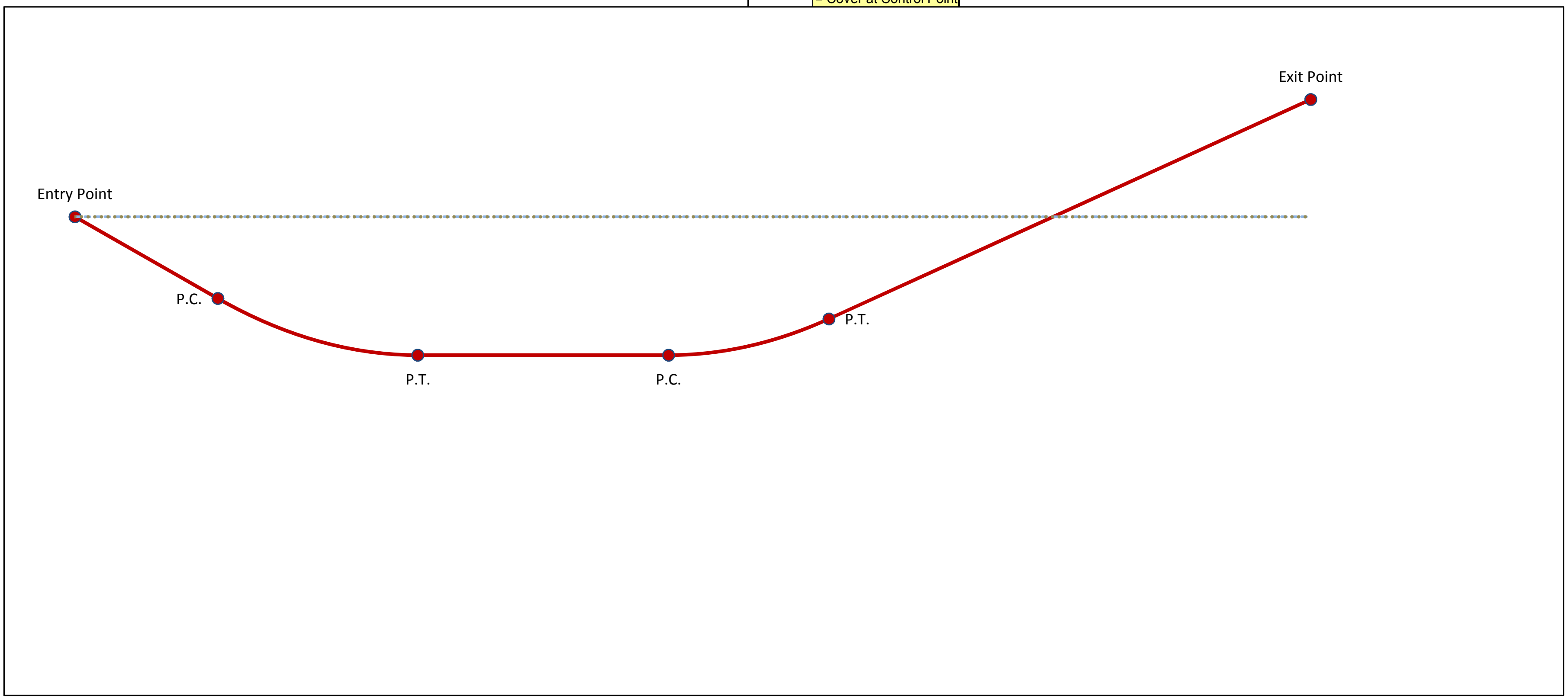
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,200	psi	

James River P5 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	338.89	10.00				187,844
Entry Tangent						353.31		
Entry Sag Bend	PC	337.94	277.54					162,594
	PI	579.19	235.00	10.00	2800	488.69	146,785	
	PT	824.16	235.00				0	130,975
Bottom Tangent				0.00		609.86		
Exit Sag Bend	PC	1434.02	235.00					94,399
	PI	1629.81	235.00	8.00	2800	390.95	82,649	
	PT	1823.70	262.25				0	70,899
Exit Tangent						1182.85		
Exit Point		2995.04	426.87	8.00	Above Ground Load			0
Drilling Mud			338.89	(Graph = ········)				
Ballast			338.89	(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

James River P5 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1182.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	379.6	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	133,386	lb	
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input
Axial Segment Weight = $W_e\ L \sin\theta$ =	-62,487	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**70,899**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	391.0	ft	Average Tension, T =	82,649	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	6.82	ft	$j = [(E\ I) / T]^{1/2}$ =	2,879	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	6.0E+05		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	205.24	
$U = (12\ L) / j$ =	1.63		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	16,464	lb
Bending Frictional Drag = $2\ \mu\ N$ =	9,879	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	15,476	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-1,853	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**23,501**	**lb**			
Total Pulling Load =	**94,399**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	609.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	12,435	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	24,141	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**36,575**	**lb**
Total Pulling Load =	**130,975**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	488.7	ft	Average Tension, T =	146,785	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	10.65	ft	$j = [(E\ I) / T]^{1/2}$ =	2,160	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.9E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	520.17	
$U = (12 L) / j$ =	2.71		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	15,634	lb
Bending Frictional Drag = $2 \mu N$ =	9,381	lb			
Fluidic Drag = $12 \pi D L C_d$ =	19,344	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	2,895	lb			
Pulling Load on Entry Sag Bend =	**31,620**	**lb**			
Total Pulling Load =	**162,594**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	353.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	7,094	lb
Fluidic Drag = $12 \pi D L C_d$ =	13,985	lb
Axial Segment Weight = $W_e L \sin\theta$ =	4,170	lb
Pulling Load on Entry Tangent =	**25,250**	**lb**
Total Pulling Load =	**187,844**	**lb**

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	1,682	ok	0	ok	0	ok	0.03	ok	0.00	ok
	1,456	ok	0	ok	283	ok	0.02	ok	0.00	ok
PC										
	1,456	ok	18,125	ok	283	ok	0.42	ok	0.13	ok
	1,173	ok	18,125	ok	480	ok	0.42	ok	0.13	ok
PT										
	1,173	ok	0	ok	480	ok	0.02	ok	0.01	ok
	845	ok	0	ok	480	ok	0.01	ok	0.00	ok
PC										
	845	ok	18,125	ok	480	ok	0.41	ok	0.13	ok
	635	ok	18,125	ok	354	ok	0.41	ok	0.12	ok
PT										
	635	ok	0	ok	354	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

James River P5 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	42" James River Crossing	Date :	2/9/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 2,800' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	42.000	in	
Wall Thickness =	0.864	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	23617.82	in^4	
Pipe Face Surface Area =	111.66	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	379.58	lb/ft	
Pipe Interior Volume =	8.85	ft^3/ft	
Pipe Exterior Volume =	9.62	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	551.97	lb/ft	
Displaced Mud Weight =	863.59	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,508	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,636	psi	Yes
Allowable Bending Stress, F_b =	45,636	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,800	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,444	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,016	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,800	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,200	psi	

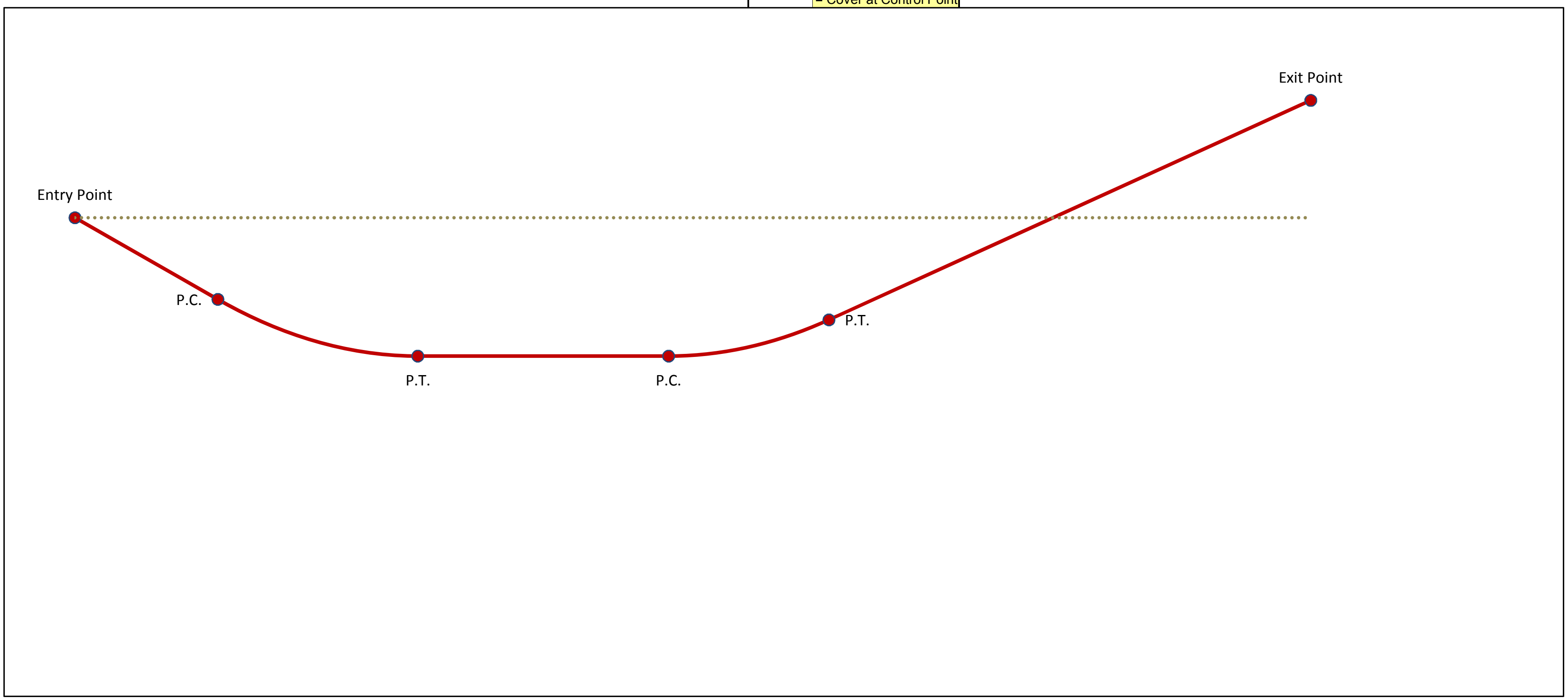
James River P5 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	338.89	10.00				459,458
Entry Tangent						353.31		
Entry Sag Bend	PC	337.94	277.54					424,645
	PI	579.19	235.00	10.00	2800	488.69	364,718	
	PT	824.16	235.00				0	304,791
Bottom Tangent				0.00		609.86		
Exit Sag Bend	PC	1434.02	235.00					192,096
	PI	1629.81	235.00	8.00	2800	390.95	131,497	
	PT	1823.70	262.25				0	70,899
Exit Tangent						1182.85		
Exit Point		2995.04	426.87	8.00	Above Ground Load			0
Drilling Mud			338.89	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	42.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	379.6	lb/ft	Ballast Weight / ft Pipe, W_b =	552.0	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	863.6	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1182.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	379.6	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	133,386	lb	
Fluidic Drag = 12 π D L C_d =	0	lb	Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid. Please reference Step 2, Drilled Path Input
Axial Segment Weight = W_e L sinθ =	-62,487	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**70,899**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	391.0	ft	Average Tension, T =	131,497	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

h = R [1 - cos(α/2)] =	6.82	ft	$j = [(E\ I) / T]^{1/2}$ =	2,282	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.5E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	290.74	
U = (12 L) / j =	2.06		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	154,204	lb
Bending Frictional Drag = 2 μ N =	92,522	lb			
Fluidic Drag = 12 π D L C_d =	15,476	lb			
Axial Segment Weight = W_e L sinθ =	13,200	lb			
Pulling Load on Exit Sag Bend =	**121,198**	**lb**			
Total Pulling Load =	**192,096**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	609.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

Frictional Drag = W_e L μ =	88,554	lb
Fluidic Drag = 12 π D L C_d =	24,141	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**112,694**	**lb**
Total Pulling Load =	**304,791**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	488.7	ft	Average Tension, T =	364,718	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,800	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	10.65	ft	$j = [(E\ I) / T]^{1/2}$ =	1,370	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.9E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	799.61	
$U = (12 L) / j$ =	4.28		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	201,875	lb
Bending Frictional Drag = $2 \mu N$ =	121,125	lb			
Fluidic Drag = $12 \pi D L C_d$ =	19,344	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-20,615	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**119,854**	**lb**			
Total Pulling Load =	**424,645**	**lb**			

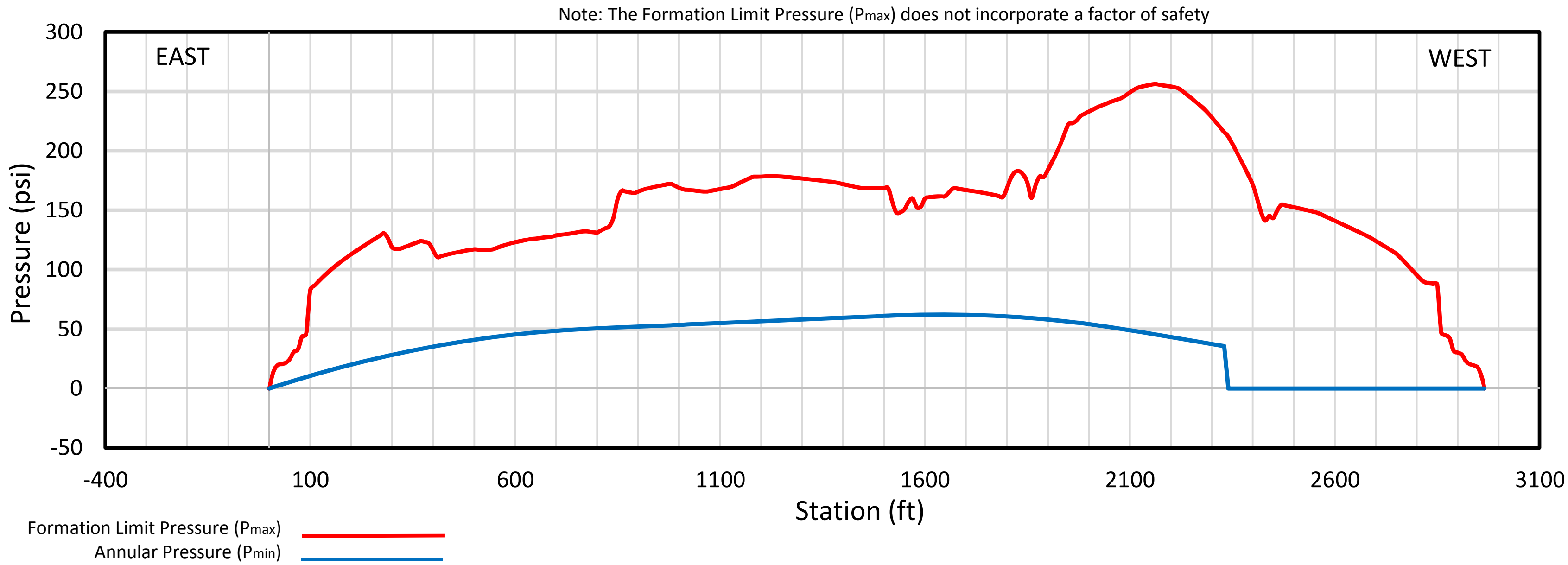
Entry Tangent - Summary of Pulling Load Calculations

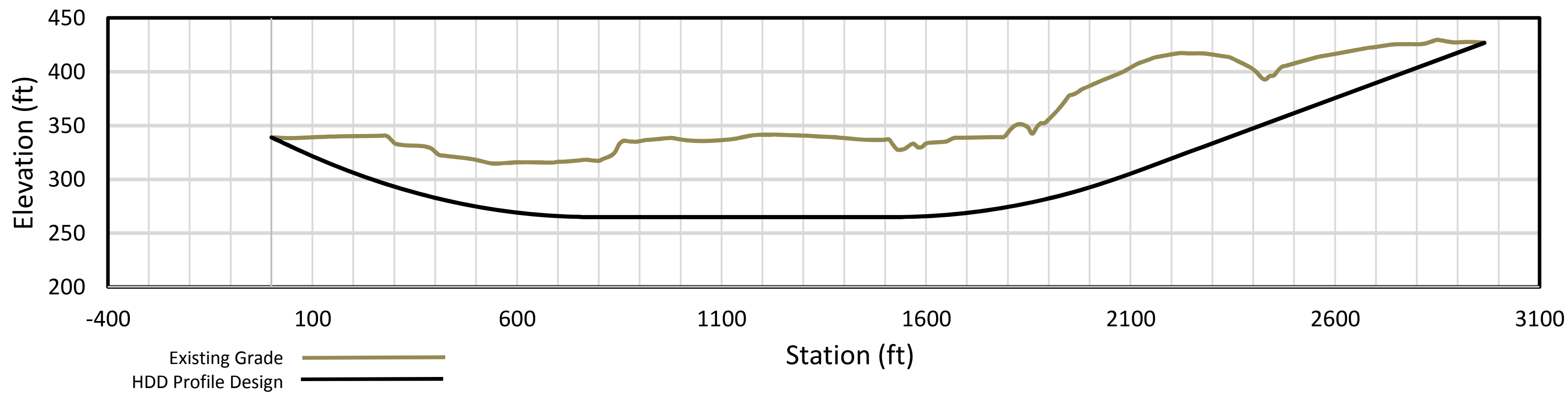
Segment Length, L =	353.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	50,522	lb	
Fluidic Drag = $12 \pi D L C_d$ =	13,985	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-29,695	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**34,813**	**lb**	
Total Pulling Load =	**459,458**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,115	ok	0	ok	0	ok	0.07	ok	0.01	ok
	3,803	ok	0	ok	930	ok	0.06	ok	0.02	ok
PC										
	3,803	ok	18,125	ok	930	ok	0.46	ok	0.19	ok
	2,730	ok	18,125	ok	1574	ok	0.44	ok	0.22	ok
PT										
	2,730	ok	0	ok	1574	ok	0.04	ok	0.05	ok
	1,720	ok	0	ok	1574	ok	0.03	ok	0.05	ok
PC										
	1,720	ok	18,125	ok	1574	ok	0.42	ok	0.21	ok
	635	ok	18,125	ok	1161	ok	0.41	ok	0.16	ok
PT										
	635	ok	0	ok	1161	ok	0.01	ok	0.03	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

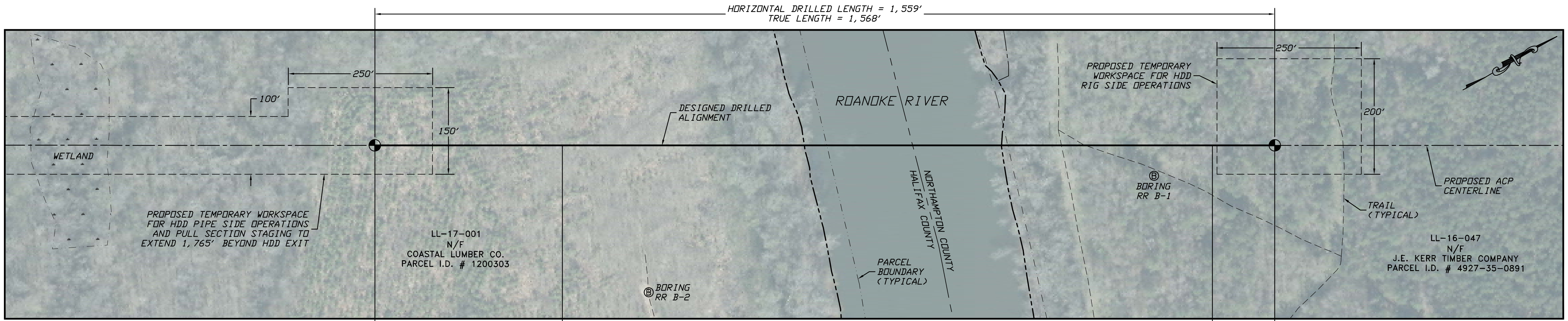
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
42-INCH JAMES RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 7/26/2016 Revision: 0

Roanoke River

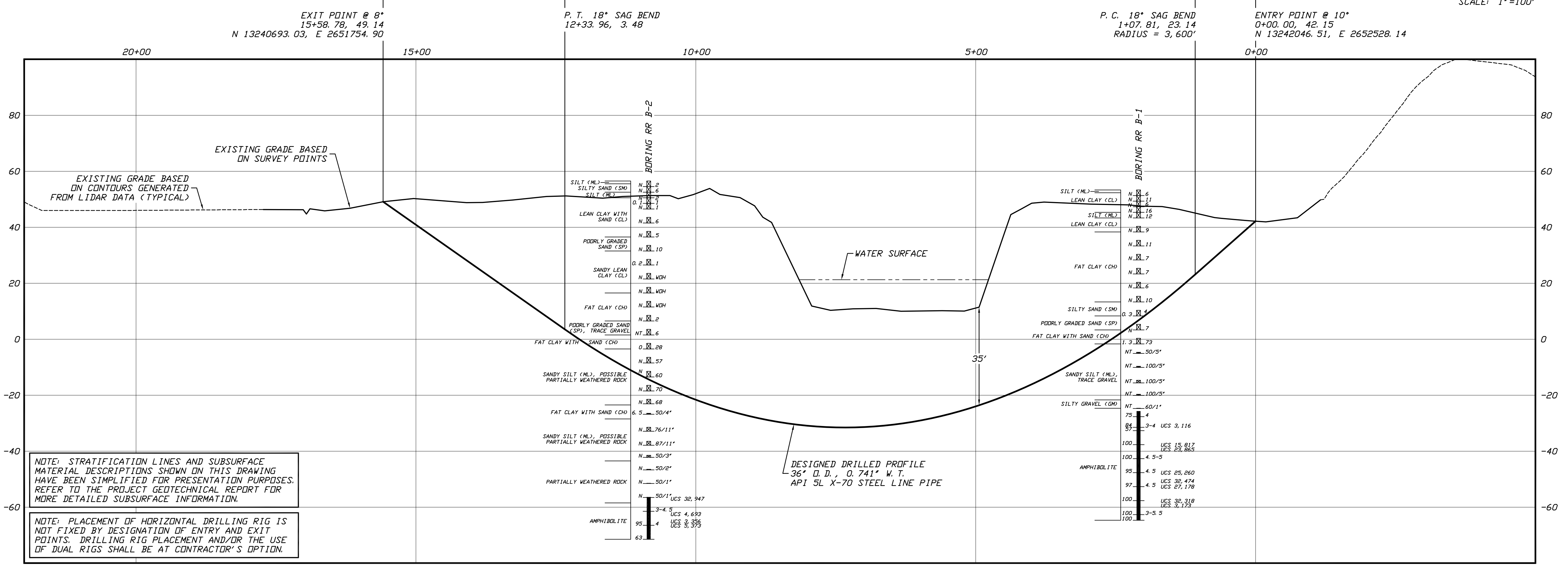
Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 20 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE 36-INCH PIPELINE CROSSING OF THE ROANOKE RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: HALIFAX & NORTHAMPTON COUNTIES, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	06/17/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	ROANOKE	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

SHEET NO.
AP2-10

Roanoke River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	36" Roanoke River Crossing	Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

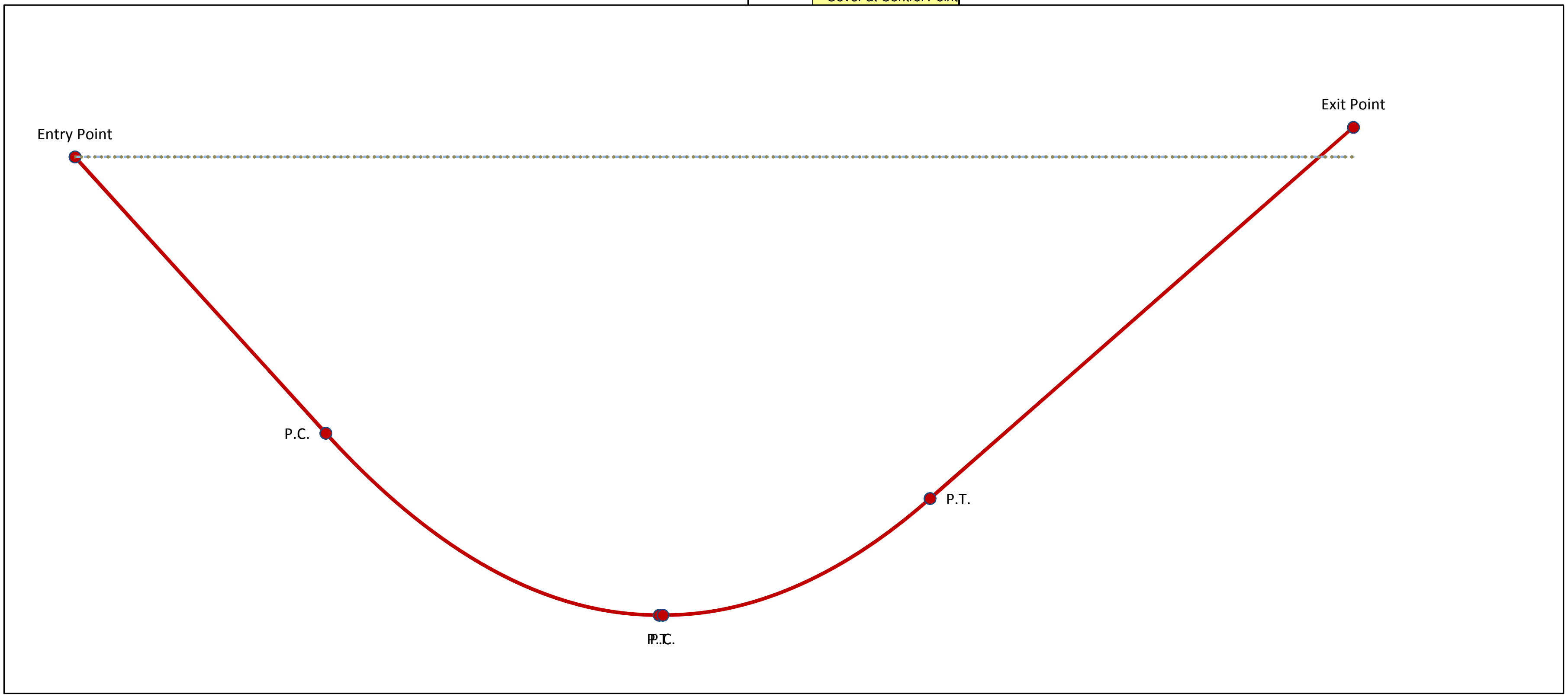
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Roanoke River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	42.00	10.00				78,434
Entry Tangent						318.74		
Entry Sag Bend	PC	303.90	-13.35					60,133
	PI	510.68	-49.81	10.00	2400	418.88	49,854	
	PT	720.65	-49.81				0	39,574
Bottom Tangent				0.00		4.70		
Exit Sag Bend	PC	725.36	-49.81					39,344
	PI	893.18	-49.81	8.00	2400	335.10	30,855	
	PT	1059.37	-26.45				0	22,366
Exit Tangent						534.61		
Exit Point		1588.78	47.95	8.00	Above Ground Load			0
Drilling Mud			42.00	(Graph = ...)				
Ballast			42.00	(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	534.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	7,952	lb	
Fluidic Drag = 12 π D L C_d =	18,139	lb	
Axial Segment Weight = W_e L sinθ =	-3,725	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**22,366**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	30,855	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E I) / T]^{1/2}$ =	3,462	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.5E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	99.59	
U = (12 L) / j =	1.16		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	11,298	lb
Bending Frictional Drag = 2 μ N =	6,779	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**16,978**	**lb**			
Total Pulling Load =	**39,344**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	4.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = W_e L μ =	71	lb
Fluidic Drag = 12 π D L C_d =	160	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**230**	**lb**
Total Pulling Load =	**39,574**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 49,854 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 2,724

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 8.3E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 266.28

$U = (12 L) / j$ = 1.85

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 7,531 lb

Bending Frictional Drag = $2 \mu N$ = 4,519 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = 1,828 lb

Pulling Load on Entry Sag Bend = 20,559 lb
Total Pulling Load = 60,133 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 318.7 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 4,715 lb

Fluidic Drag = $12 \pi D L C_d$ = 10,815 lb

Axial Segment Weight = $W_e L \sin\theta$ = 2,771 lb

Pulling Load on Entry Tangent = 18,301 lb
Total Pulling Load = 78,434 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	956	ok	0	ok	0	ok	0.02	ok	0.00	ok
	733	ok	0	ok	255	ok	0.01	ok	0.00	ok
PC										
	733	ok	18,125	ok	255	ok	0.41	ok	0.12	ok
	482	ok	18,125	ok	424	ok	0.40	ok	0.12	ok
PT										
	482	ok	0	ok	424	ok	0.01	ok	0.00	ok
	479	ok	0	ok	424	ok	0.01	ok	0.00	ok
PC										
	479	ok	18,125	ok	424	ok	0.40	ok	0.12	ok
	272	ok	18,125	ok	316	ok	0.40	ok	0.12	ok
PT										
	272	ok	0	ok	316	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	-27	ok	0.00	ok	0.00	ok

Roanoke River R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	36" Roanoke River Crossing	Date :	2/12/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (58' longer and 20' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Roanoke River R0 Installation Stress Analysis (worst-case).xlsm
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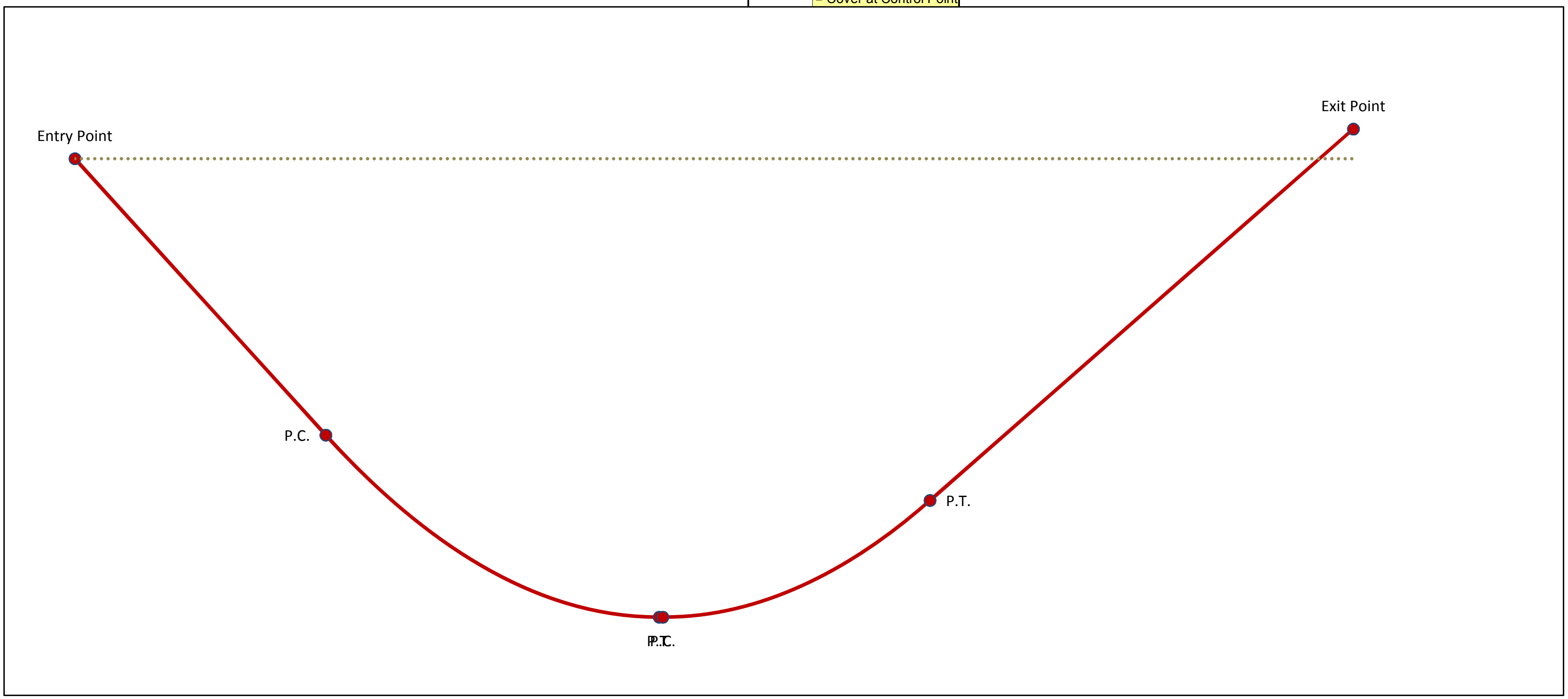
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	42.00	10.00				287,363
Entry Tangent						318.74		
Entry Sag Bend	PC	303.90	-13.35					262,750
	PI	510.68	-49.81	10.00	2400	418.88	223,422	
	PT	720.65	-49.81				0	184,094
Bottom Tangent				0.00		4.70		
Exit Sag Bend	PC	725.36	-49.81					183,432
	PI	893.18	-49.81	8.00	2400	335.10	142,235	
	PT	1059.37	-26.45				0	101,037
Exit Tangent						534.61		
Exit Point		1588.78	47.95	8.00	Above Ground Load			0
Drilling Mud			42.00	(Graph = ········)				
Ballast				(Graph = – – – – –)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Step 2, Drilled Path Input

Roanoke River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	534.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	56,452	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	18,139	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	26,446	lb
Pulling Load on Exit Tangent =	**101,037**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	142,235	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	1,613	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	8.0E+05		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	322.05	
$U = (12\ L) / j$ =	2.49		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$	104,529	lb
Bending Frictional Drag = $2\ \mu\ N$ =	62,717	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	11,370	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**82,396**	**lb**			
Total Pulling Load =	**183,432**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	4.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	502	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	160	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**661**	**lb**
Total Pulling Load =	**184,094**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	223,422	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E\ I) / T]^{1/2}$ =	1,287	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.0E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	638.65	
$U = (12 L) / j$ =	3.91		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	129,034	lb
Bending Frictional Drag = $2 \mu N$ =	77,420	lb			
Fluidic Drag = $12 \pi D L C_d$ =	14,212	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-12,976	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**78,656**	**lb**			
Total Pulling Load =	**262,750**	**lb**			

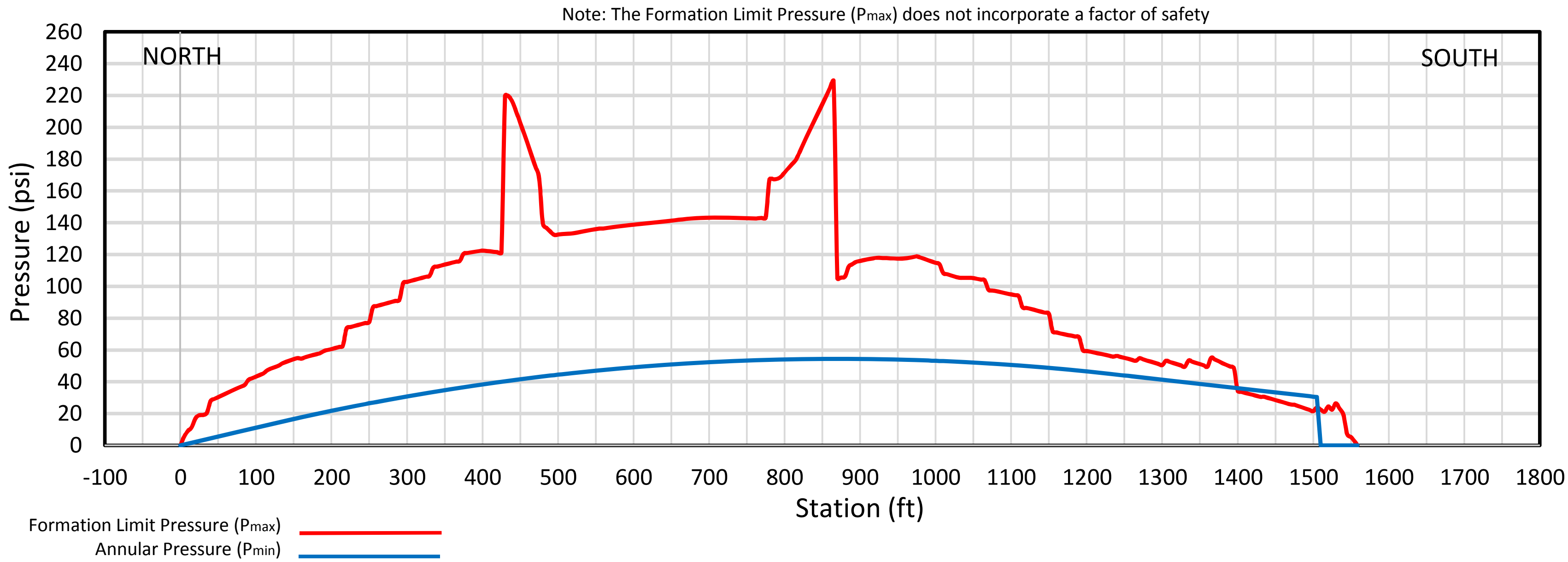
Entry Tangent - Summary of Pulling Load Calculations

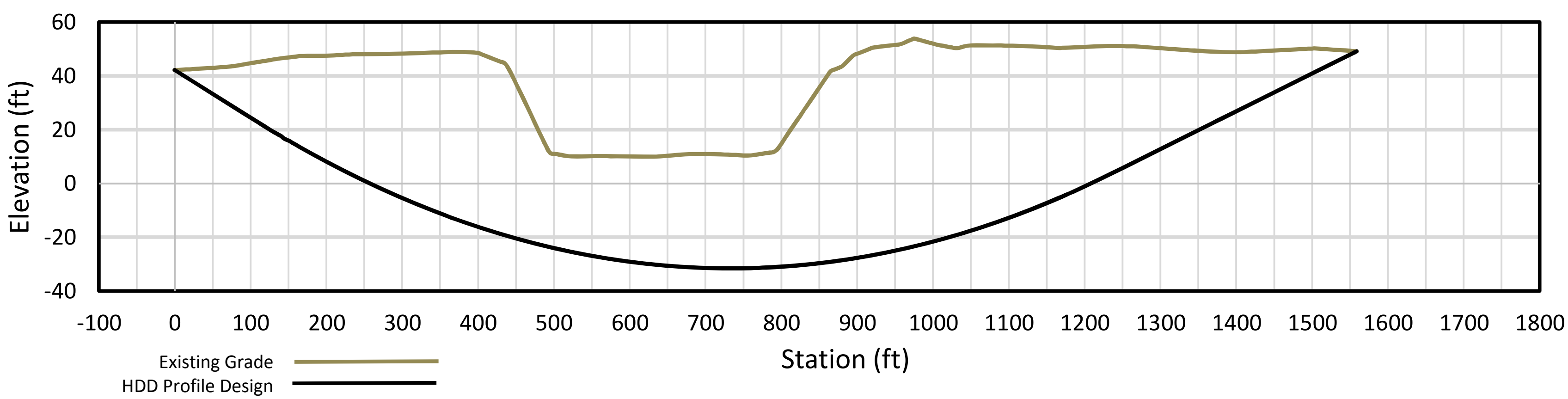
Segment Length, L =	318.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	33,472	lb	
Fluidic Drag = $12 \pi D L C_d$ =	10,815	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-19,673	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**24,613**	**lb**	
Total Pulling Load =	**287,363**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,501	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,201	ok	0	ok	838	ok	0.05	ok	0.02	ok
PC										
	3,201	ok	18,125	ok	838	ok	0.45	ok	0.18	ok
	2,243	ok	18,125	ok	1390	ok	0.43	ok	0.20	ok
PT										
	2,243	ok	0	ok	1390	ok	0.04	ok	0.04	ok
	2,235	ok	0	ok	1390	ok	0.04	ok	0.04	ok
PC										
	2,235	ok	18,125	ok	1390	ok	0.43	ok	0.20	ok
	1,231	ok	18,125	ok	1037	ok	0.42	ok	0.16	ok
PT										
	1,231	ok	0	ok	1037	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-90	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
36-INCH ROANOKE RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

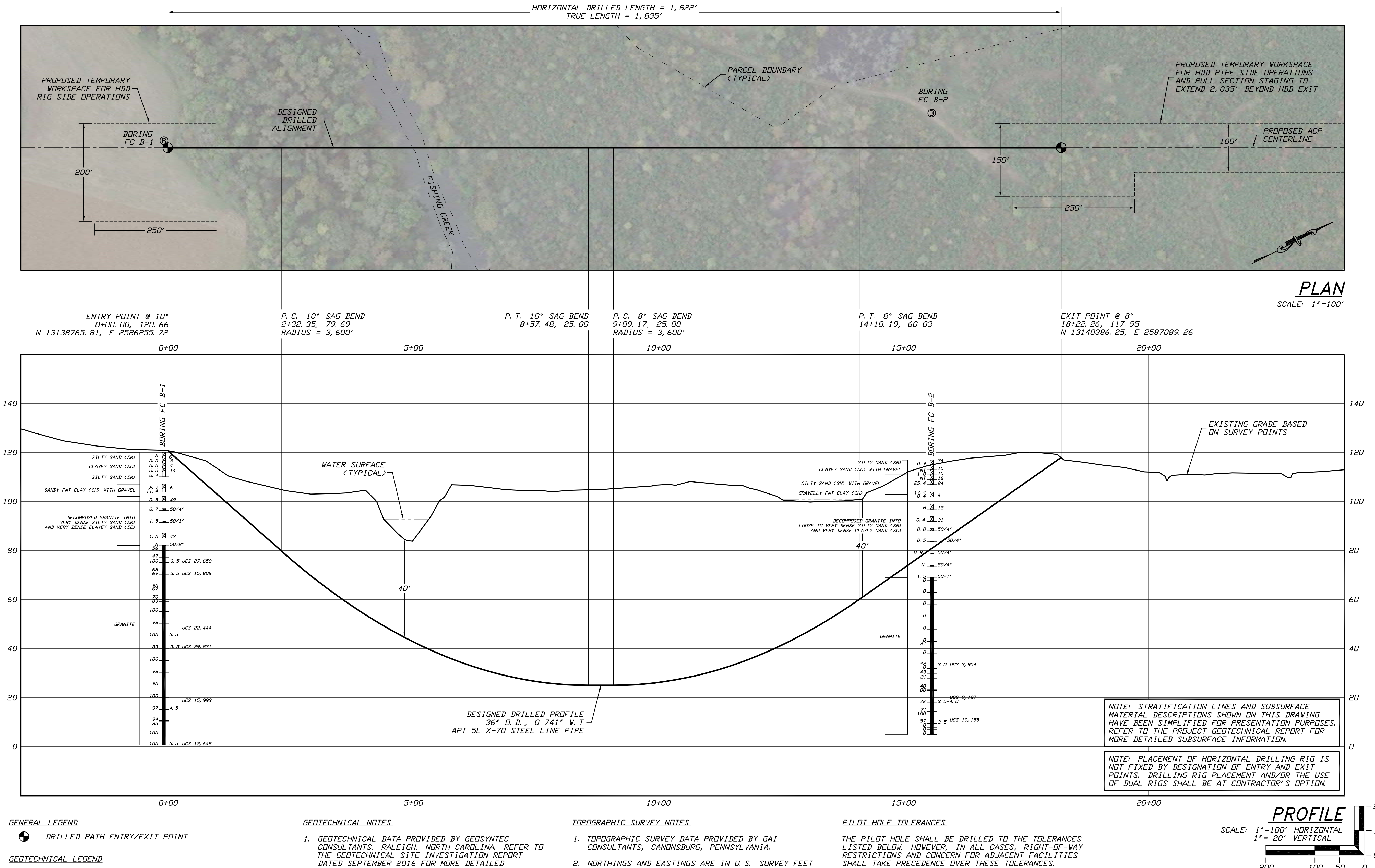
Date: 5/31/2016

Revision: 0

Fishing Creek

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RALEIGH, NORTH CAROLINA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT DATED SEPTEMBER 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 20 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE 36-INCH PIPELINE CROSSING OF FISHING CREEK BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: HALIFAX & NASH COUNTIES, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN/LKB	10/07/16	DMP/ACM	JSP	SHOWN FOR D-SIZED PLOT	FISHING CREEK	0

NO.	DATE	REVISION DESCRIPTION	BY	CHKD	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

AP2-034

Fishing Creek P1 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Fishing Creek Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 20' deeper than design with a 2,400' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Fishing Creek P1 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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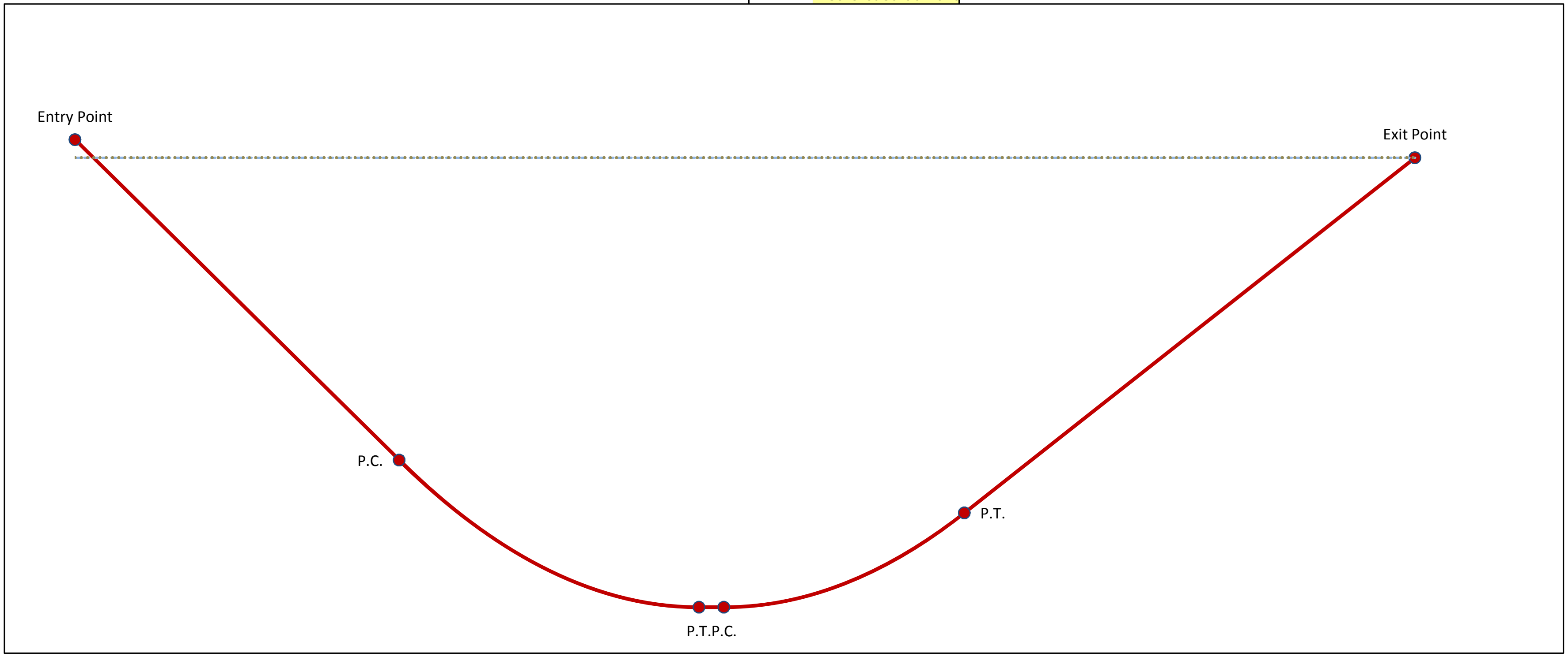
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	120.87	10.00				92,546
Entry Tangent						457.30		
Entry Sag Bend	PC	440.35	41.46					66,290
	PI	647.13	5.00	10.00	2400	418.88	55,822	
	PT	857.10	5.00				0	45,354
Bottom Tangent				0.00		34.75		
Exit Sag Bend	PC	891.85	5.00					43,653
	PI	1059.68	5.00	8.00	2400	335.10	35,058	
	PT	1225.87	28.36				0	26,463
Exit Tangent						632.55		
Exit Point		1852.26	116.39	8.00			Above Ground Load	0
Drilling Mud			116.39	(Graph = ·········)				
Ballast			116.39	(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	632.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	9,409	lb	
Fluidic Drag = $12 \pi D L C_d$ =	21,462	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-4,408	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**26,463**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	35,058	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E I) / T]^{1/2}$ =	3,248	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.8E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	111.36	
$U = (12 L) / j$ =	1.24		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	11,652	lb

Bending Frictional Drag = $2 \mu N$ =	6,991	lb	
Fluidic Drag = $12 \pi D L C_d$ =	11,370	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Sag Bend =	**17,190**	**lb**	
Total Pulling Load =	**43,653**	**lb**	

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	34.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = $W_e L \mu$ =	522	lb
Fluidic Drag = $12 \pi D L C_d$ =	1,179	lb
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**1,701**	**lb**
Total Pulling Load =	**45,354**	**lb**

Fishing Creek P1 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	55,822	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E\ I) / T]^{1/2}$ =	2,574	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	9.0E+05		$X = (3\ L) - [(j / 2) \tanh(U/2)]$ =	289.42	
$U = (12\ L) / j$ =	1.95		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	8,159	lb
Bending Frictional Drag = $2\ \mu\ N$ =	4,895	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	14,212	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	1,828	lb			
Pulling Load on Entry Sag Bend =	**20,935**	**lb**			
Total Pulling Load =	**66,290**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	457.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	6,765	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	15,516	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	3,976	lb
Pulling Load on Entry Tangent =	**26,257**	**lb**
Total Pulling Load =	**92,546**	**lb**

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	1,128	ok	0	ok	0	ok	0.02	ok	0.00	ok
	808	ok	0	ok	346	ok	0.01	ok	0.00	ok
PC										
	808	ok	18,125	ok	346	ok	0.41	ok	0.12	ok
	553	ok	18,125	ok	514	ok	0.41	ok	0.13	ok
PT										
	553	ok	0	ok	514	ok	0.01	ok	0.01	ok
	532	ok	0	ok	514	ok	0.01	ok	0.01	ok
PC										
	532	ok	18,125	ok	514	ok	0.41	ok	0.13	ok
	322	ok	18,125	ok	406	ok	0.40	ok	0.12	ok
PT										
	322	ok	0	ok	406	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Fishing Creek P1 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Fishing Creek Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 20' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Fishing Creek P1 Installation Stress Analysis (worst-case).xlsm

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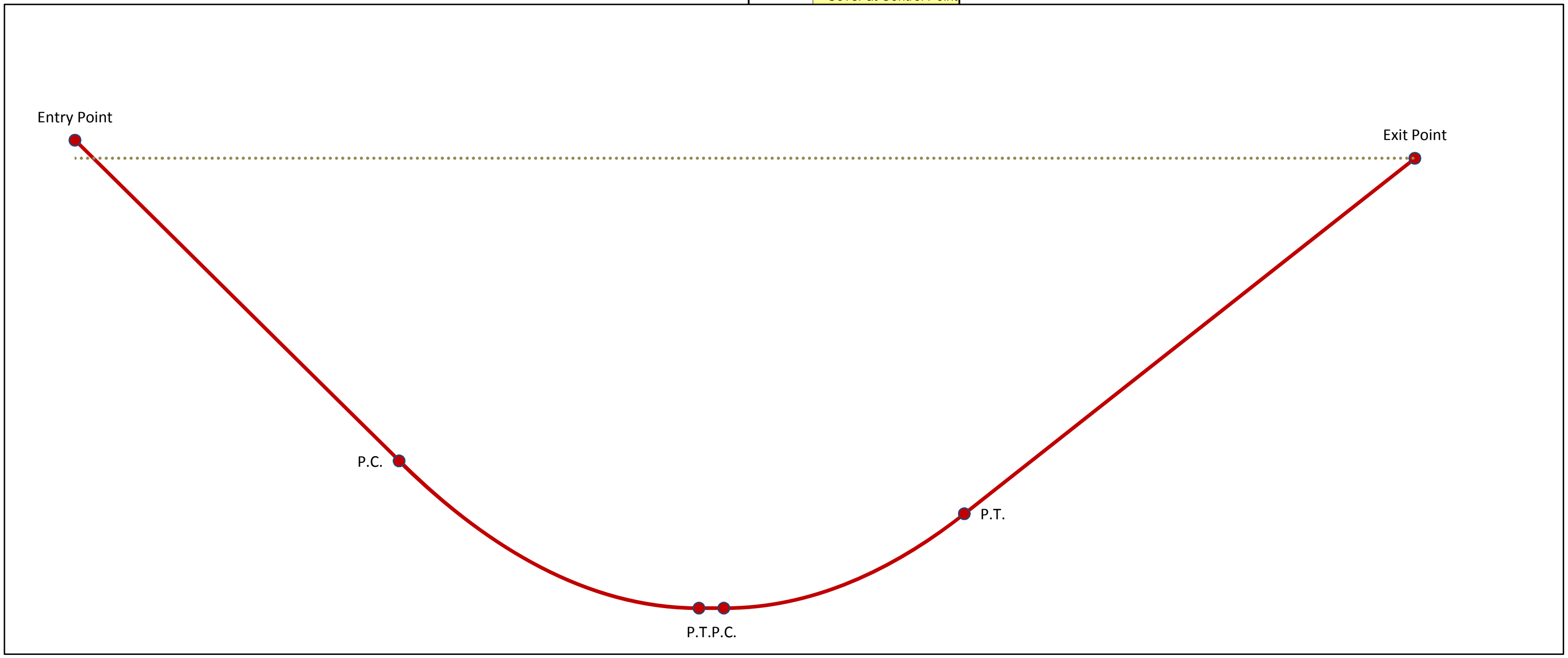
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	120.87	10.00				323,050
Entry Tangent						457.30		
Entry Sag Bend	PC	440.35	41.46					287,738
	PI	647.13	5.00	10.00	2400	418.88	247,725	
	PT	857.10	5.00				0	207,712
Bottom Tangent				0.00		34.75		
Exit Sag Bend	PC	891.85	5.00					202,827
	PI	1059.68	5.00	8.00	2400	335.10	161,186	
	PT	1225.87	28.36				0	119,546
Exit Tangent						632.55		
Exit Point		1852.26	116.39	8.00	Above Ground Load			0
Drilling Mud			116.39	(Graph = ·········)				
Ballast				(Graph = - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Fishing Creek P1 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	632.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	66,793	lb
Fluidic Drag = 12 π D L C_d =	21,462	lb
Axial Segment Weight = W_e L sinθ =	31,291	lb
Pulling Load on Exit Tangent =	**119,546**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	161,186	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	1,515	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.6E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	347.42	
U = (12 L) / j =	2.65		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	106,005	lb
Bending Frictional Drag = 2 μ N =	63,603	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**83,281**	**lb**			
Total Pulling Load =	**202,827**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	34.8	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = W_e L μ =	3,706	lb
Fluidic Drag = 12 π D L C_d =	1,179	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**4,885**	**lb**
Total Pulling Load =	**207,712**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 247,725 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

h = R [1 - cos(α/2)] = 9.13 ft

j = [(E I) / T]$^{1/2}$ = 1,222

Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] = 2.0E+06

X = (3 L) - [(j / 2) tanh(U/2)] = 665.31

U = (12 L) / j = 4.11

N = [(T h) - W_e cosθ (Y/144)] / (X / 12) = 131,318 lb

Bending Frictional Drag = 2 μ N = 78,791 lb

Fluidic Drag = 12 π D L C_d = 14,212 lb

Axial Segment Weight = W_e L sinθ = -12,976 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 80,027 lb
Total Pulling Load = 287,738 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 457.3 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = W_e L μ cosθ = 48,022 lb

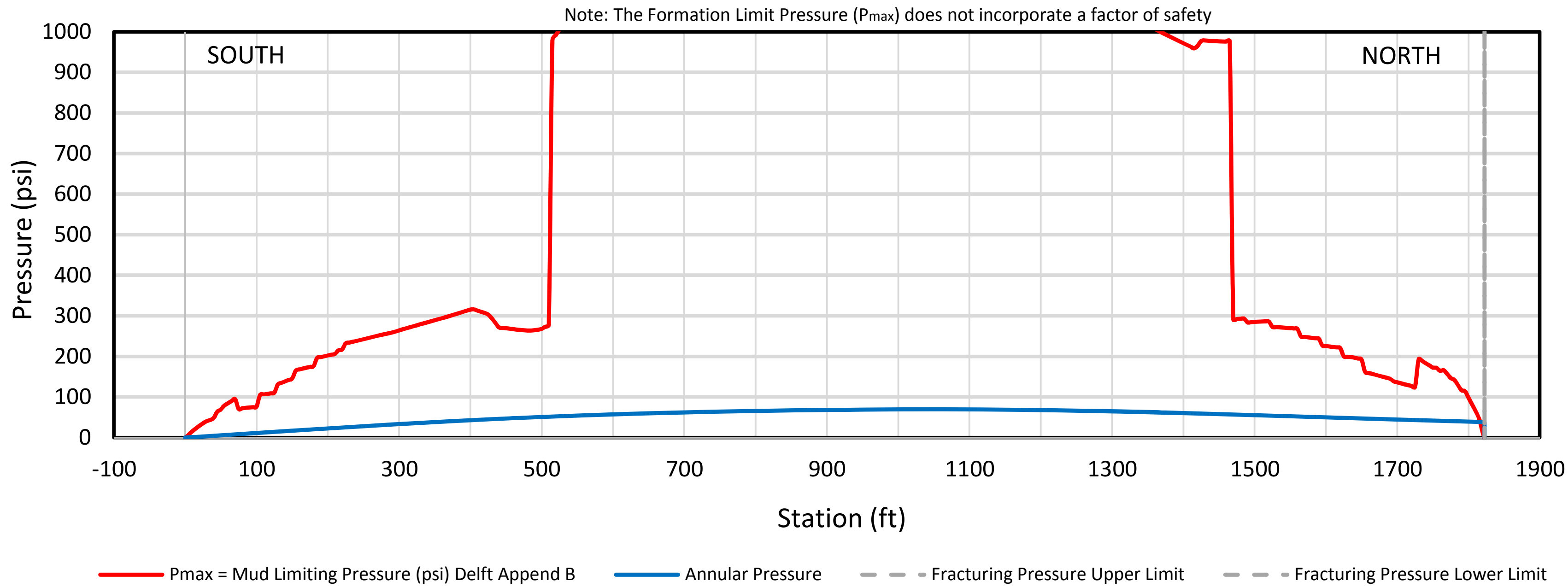
Fluidic Drag = 12 π D L C_d = 15,516 lb

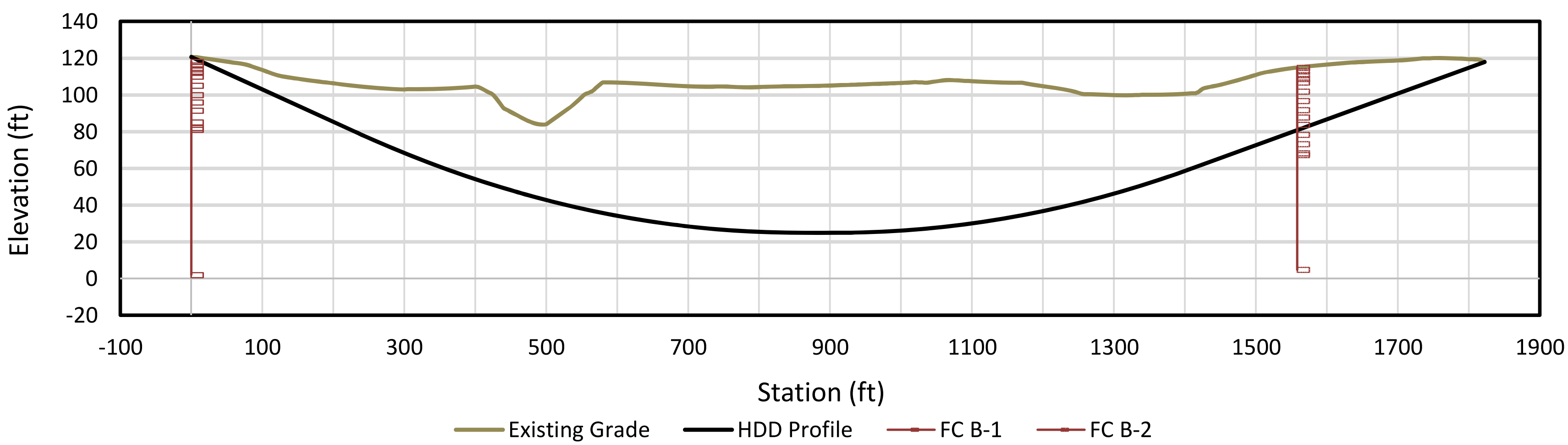
Axial Segment Weight = W_e L sinθ = -28,225 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 35,312 lb
Total Pulling Load = 323,050 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,936	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,506	ok	0	ok	1135	ok	0.06	ok	0.03	ok
PC										
	3,506	ok	18,125	ok	1135	ok	0.45	ok	0.20	ok
	2,531	ok	18,125	ok	1687	ok	0.44	ok	0.23	ok
PT										
	2,531	ok	0	ok	1687	ok	0.04	ok	0.06	ok
	2,471	ok	0	ok	1687	ok	0.04	ok	0.06	ok
PC										
	2,471	ok	18,125	ok	1687	ok	0.44	ok	0.23	ok
	1,456	ok	18,125	ok	1333	ok	0.42	ok	0.19	ok
PT										
	1,456	ok	0	ok	1333	ok	0.02	ok	0.04	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

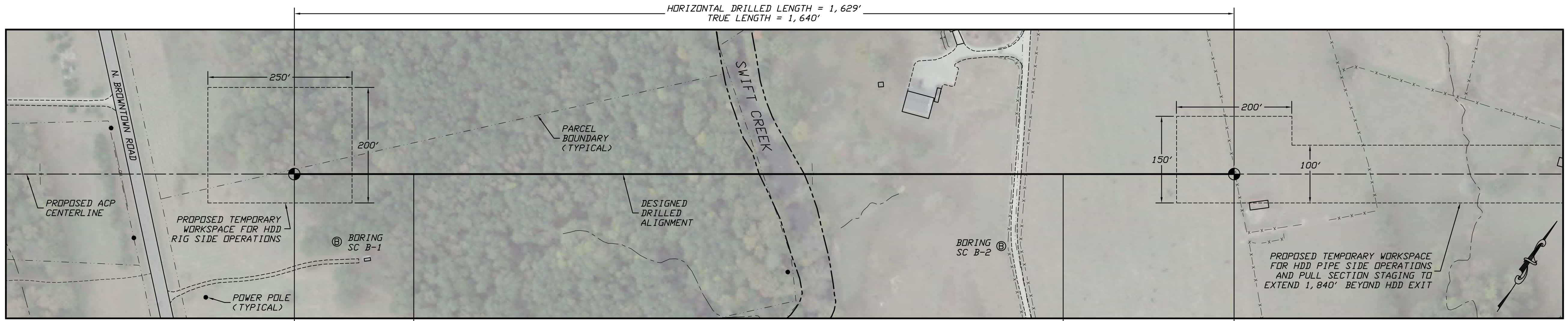
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
FISHING CREEK CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

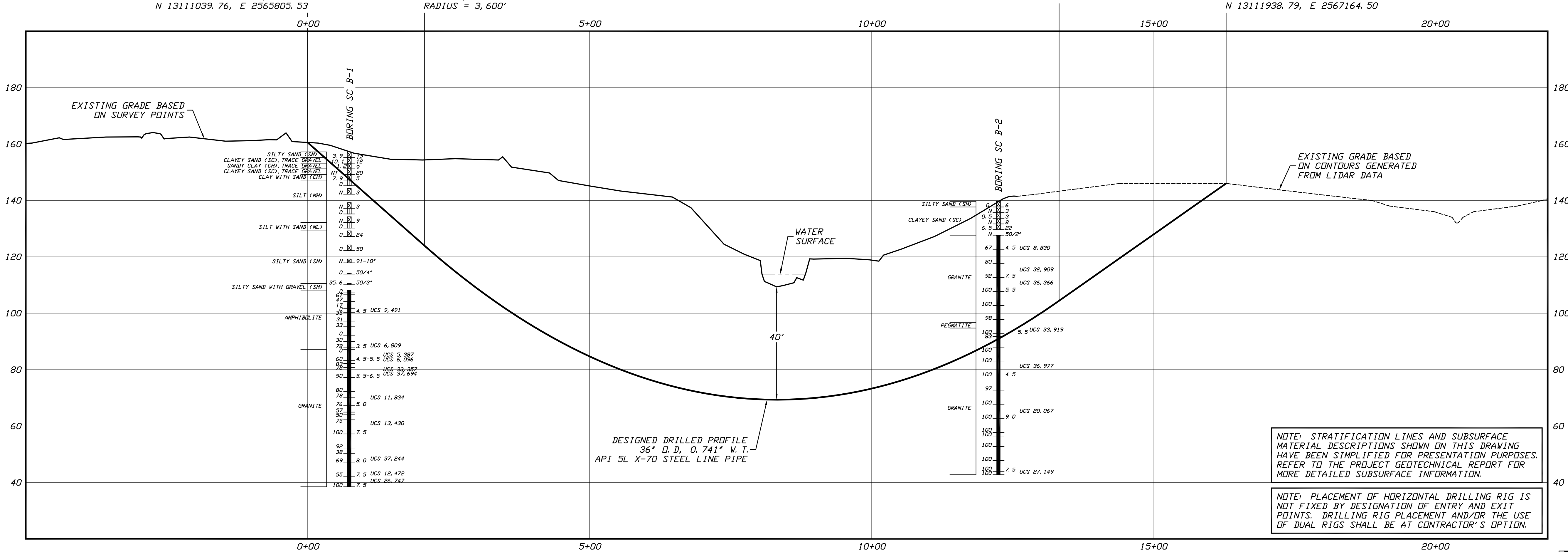
Date: 9/26/2016 Revision: 0

Swift Creek

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)





GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)

53 6 — MOHS HARDNESS — ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RALEIGH, NORTH CAROLINA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED SEPTEMBER 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
36-INCH PIPELINE CROSSING OF SWIFT CREEK BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: NASH COUNTY, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM/KMN	10/07/16	KMN/LKB	JSP	SHOWN FOR D-SIZED PLOT	SWIFT CREEK	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP2-041

Swift Creek R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	JSP
Crossing :	36" Swift Creek Crossing		Date :	10/10/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 15' deeper than design with a 2,400' radius) with 12 ppg mud with BC			

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

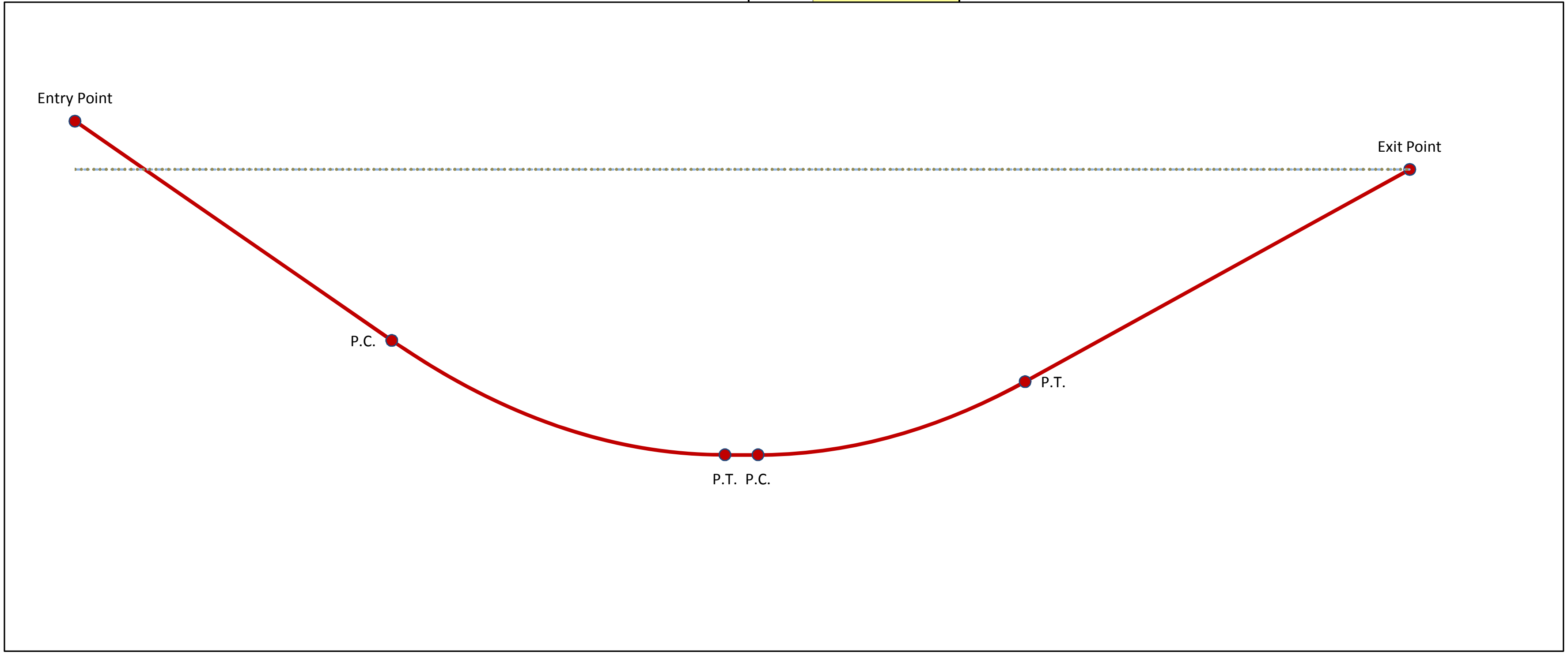
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Swift Creek R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	160.66	10.00				82,857
Entry Tangent						402.36		
Entry Sag Bend	PC	386.24	90.79					59,755
	PI	593.03	54.33	10.00	2400	418.88	49,487	
	PT	803.00	54.33				0	39,219
Bottom Tangent				0.00		41.25		
Exit Sag Bend	PC	844.25	54.33					37,200
	PI	1012.07	54.33	8.00	2400	335.10	28,764	
	PT	1178.26	77.69				0	20,328
Exit Tangent						485.89		
Exit Point		1659.43	145.31	8.00	Above Ground Load			0
Drilling Mud			145.31	(Graph = ·········)				
Ballast			145.31	(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Swift Creek R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	485.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	7,228	lb	
Fluidic Drag = 12 π D L C_d =	16,486	lb	
Axial Segment Weight = W_e L sinθ =	-3,386	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**20,328**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	28,764	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	3,586	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.3E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	93.59	
U = (12 L) / j =	1.12		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	11,122	lb
Bending Frictional Drag = 2 μ N =	6,673	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**16,872**	**lb**			
Total Pulling Load =	**37,200**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	41.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = W_e L μ =	620	lb
Fluidic Drag = 12 π D L C_d =	1,400	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**2,019**	**lb**
Total Pulling Load =	**39,219**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	49,487	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E I) / T]^{1/2}$ =	2,734	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.3E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	264.81	
$U = (12 L) / j$ =	1.84		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	7,492	lb
Bending Frictional Drag = $2 \mu N$ =	4,495	lb			
Fluidic Drag = $12 \pi D L C_d$ =	14,212	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	1,828	lb			
Pulling Load on Entry Sag Bend =	**20,536**	**lb**			
Total Pulling Load =	**59,755**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	402.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	5,952	lb
Fluidic Drag = $12 \pi D L C_d$ =	13,652	lb
Axial Segment Weight = $W_e L \sin\theta$ =	3,498	lb
Pulling Load on Entry Tangent =	**23,102**	**lb**
Total Pulling Load =	**82,857**	**lb**

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	1,009	ok	0	ok	0	ok	0.02	ok	0.00	ok
	728	ok	0	ok	252	ok	0.01	ok	0.00	ok
PC										
	728	ok	18,125	ok	252	ok	0.41	ok	0.12	ok
	478	ok	18,125	ok	420	ok	0.40	ok	0.12	ok
PT										
	478	ok	0	ok	420	ok	0.01	ok	0.00	ok
	453	ok	0	ok	420	ok	0.01	ok	0.00	ok
PC										
	453	ok	18,125	ok	420	ok	0.40	ok	0.12	ok
	248	ok	18,125	ok	312	ok	0.40	ok	0.12	ok
PT										
	248	ok	0	ok	312	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	JSP
Crossing :	36" Swift Creek Crossing		Date :	10/10/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 15' deeper than design with a 2,400' radius) with 12 ppg mud and no BC			

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Swift Creek R0 Installation Stress Analysis (worst-case).xlsm

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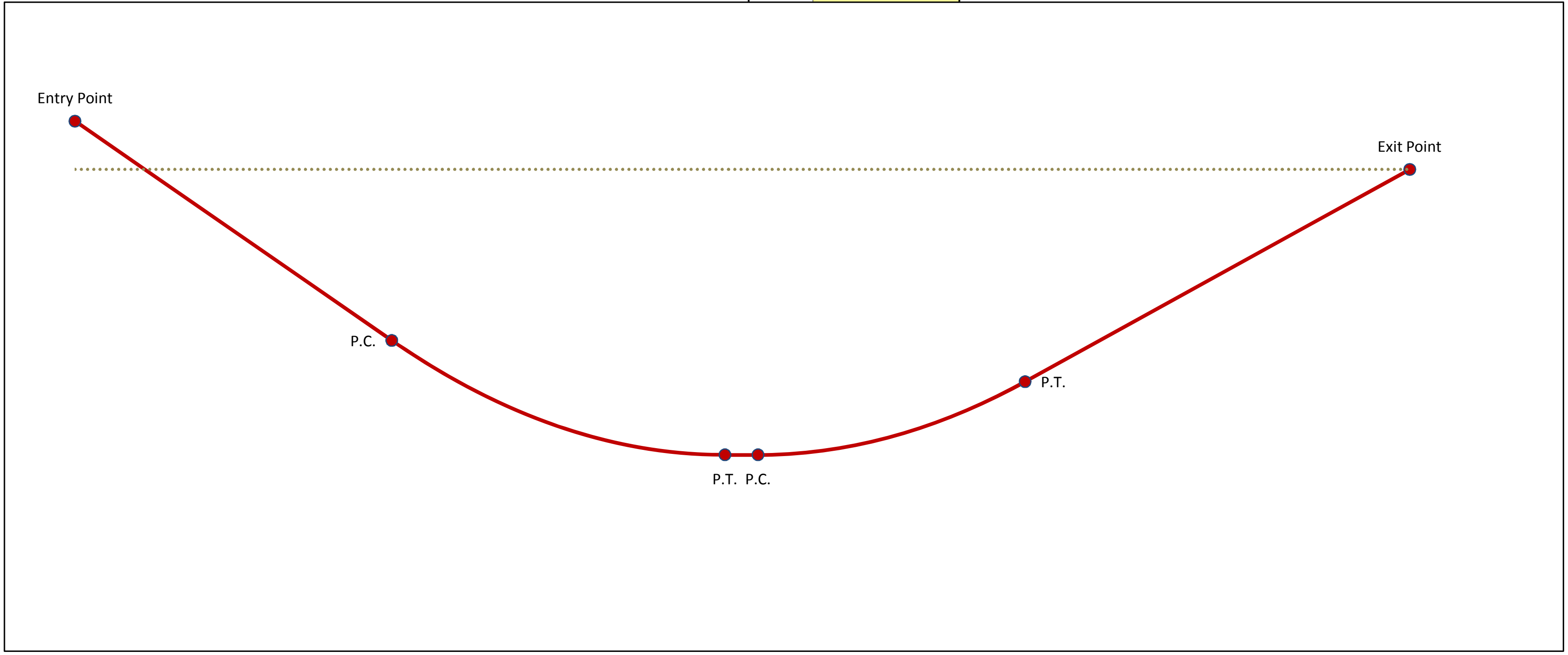
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	160.66	10.00				289,047
Entry Tangent						402.36		
Entry Sag Bend	PC	386.24	90.79					257,977
	PI	593.03	54.33	10.00	2400	418.88	218,780	
	PT	803.00	54.33				0	179,583
Bottom Tangent				0.00		41.25		
Exit Sag Bend	PC	844.25	54.33					173,785
	PI	1012.07	54.33	8.00	2400	335.10	132,807	
	PT	1178.26	77.69				0	91,830
Exit Tangent						485.89		
Exit Point		1659.43	145.31	8.00	Above Ground Load			0
Drilling Mud			145.31	(Graph =)				
Ballast				(Graph =)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	485.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	51,308	lb
Fluidic Drag = 12 π D L C_d =	16,486	lb
Axial Segment Weight = W_e L sinθ =	24,036	lb
Pulling Load on Exit Tangent =	**91,830**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	132,807	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	1,669	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	7.7E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	308.46	
U = (12 L) / j =	2.41		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	103,794	lb
Bending Frictional Drag = 2 μ N =	62,276	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**81,955**	**lb**			
Total Pulling Load =	**173,785**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	41.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = W_e L μ =	4,398	lb
Fluidic Drag = 12 π D L C_d =	1,400	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**5,798**	**lb**
Total Pulling Load =	**179,583**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 218,780 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 1,300

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 1.9E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 633.17

$U = (12 L) / j$ = 3.87

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 128,598 lb

Bending Frictional Drag = $2 \mu N$ = 77,159 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = -12,976 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 78,394 lb
Total Pulling Load = 257,977 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 402.4 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 42,252 lb

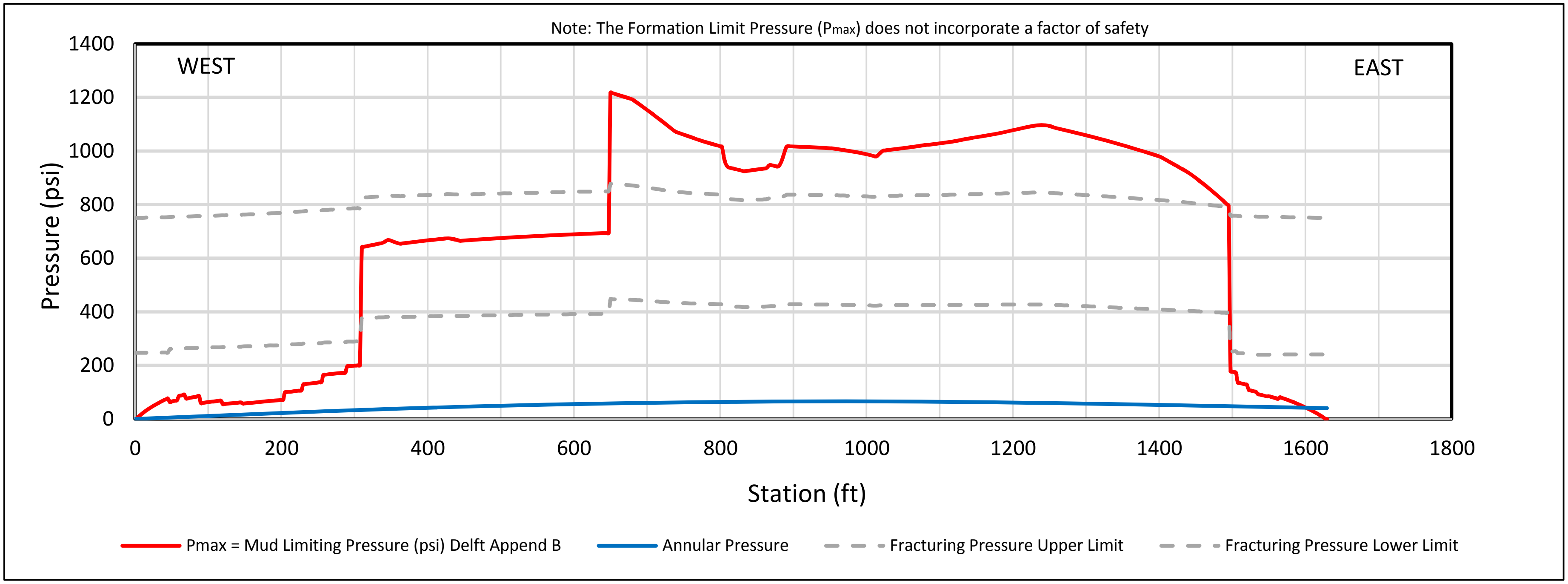
Fluidic Drag = $12 \pi D L C_d$ = 13,652 lb

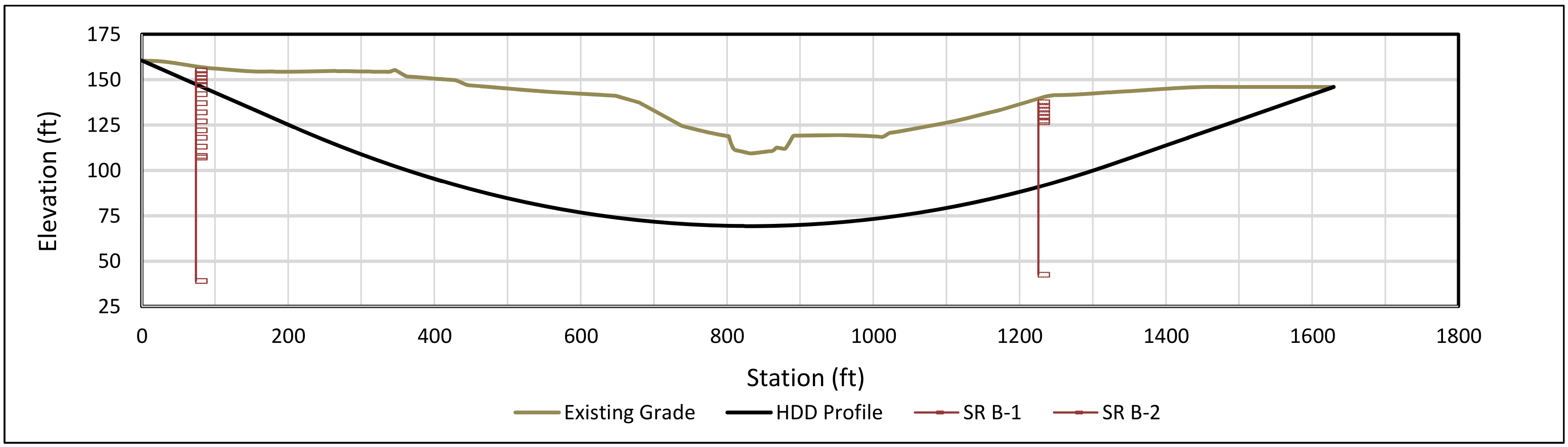
Axial Segment Weight = $W_e L \sin\theta$ = -24,834 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 31,070 lb
Total Pulling Load = 289,047 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,522	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,143	ok	0	ok	826	ok	0.05	ok	0.02	ok
PC										
	3,143	ok	18,125	ok	826	ok	0.45	ok	0.18	ok
	2,188	ok	18,125	ok	1378	ok	0.43	ok	0.20	ok
PT										
	2,188	ok	0	ok	1378	ok	0.03	ok	0.04	ok
	2,117	ok	0	ok	1378	ok	0.03	ok	0.04	ok
PC										
	2,117	ok	18,125	ok	1378	ok	0.43	ok	0.20	ok
	1,119	ok	18,125	ok	1024	ok	0.41	ok	0.16	ok
PT										
	1,119	ok	0	ok	1024	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION

FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE

SWIFT CREEK CROSSING

BY HORIZONTAL DIRECTIONAL DRILLING

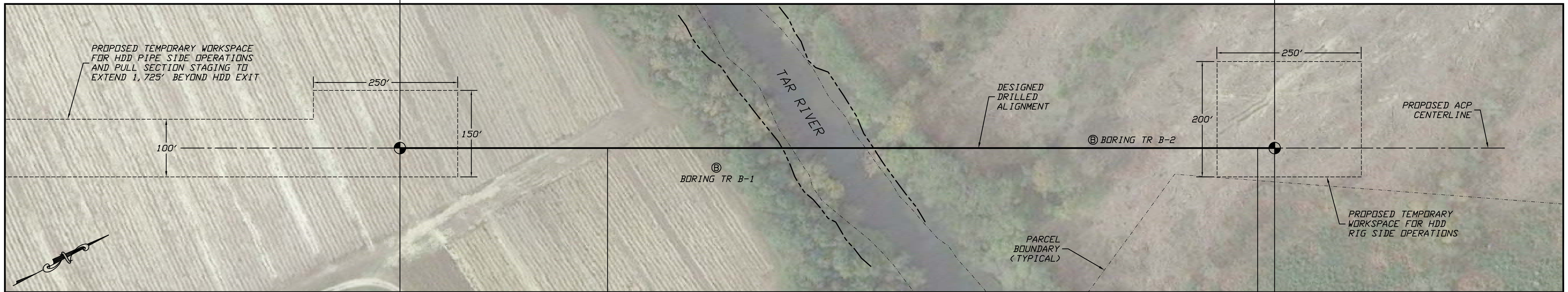
Date: 9/23/2016 Revision: 0

Tar River

Supporting Information

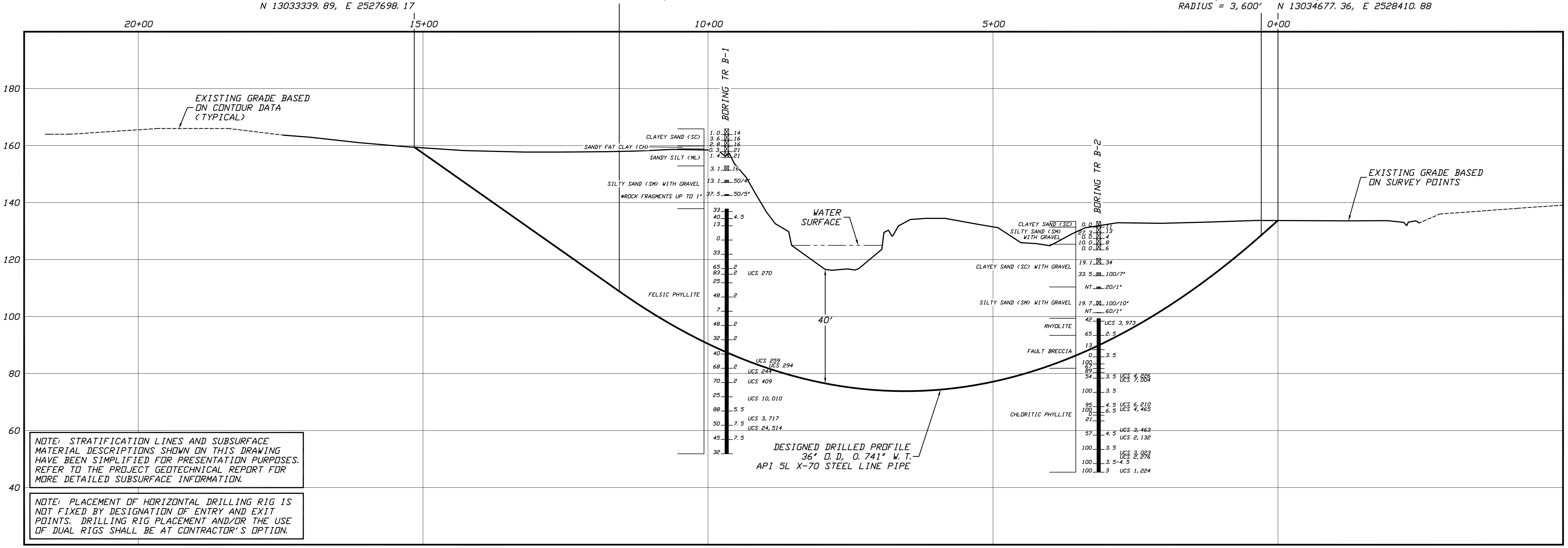
- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 1,516'
TRUE LENGTH = 1,524'



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RALEIGH, NORTH CAROLINA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT DATED SEPTEMBER 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 20 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
36-INCH PIPELINE CROSSING OF THE TAR RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: NASH COUNTY, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM/LKB	10/06/16	KMN	JSP	SHOWN FOR D-SIZED PLOT	TAR RIVER	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508
MILE POST
AP2-060

Tar River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Tar River Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 17' deeper than design with a 2,400' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

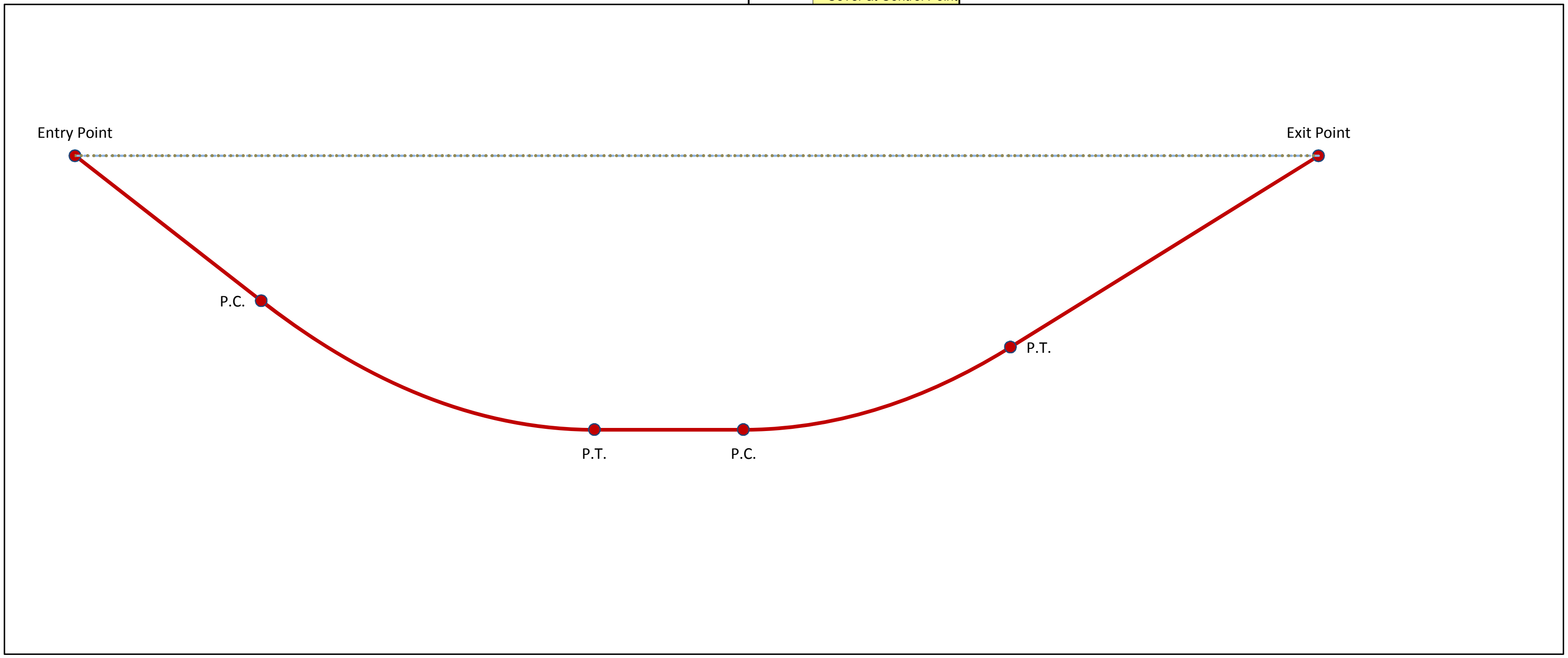
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Tar River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm
J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	133.72	10.00				76,371
Entry Tangent						236.50		
Entry Sag Bend	PC	222.91	92.65					62,792
	PI	429.69	56.19	10.00	2400	418.88	52,431	
	PT	639.67	56.19				0	42,070
Bottom Tangent				0.00		186.37		
Exit Sag Bend	PC	826.04	56.19					32,947
	PI	993.87	56.19	8.00	2400	335.10	24,616	
	PT	1160.06	79.55				0	16,285
Exit Tangent						389.25		
Exit Point		1545.52	133.72	8.00	Above Ground Load			0
Drilling Mud			133.72	(Graph =)				
Ballast			133.72	(Graph =)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	389.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	5,790	lb	
Fluidic Drag = 12 π D L C_d =	13,207	lb	
Axial Segment Weight = W_e L sinθ =	-2,713	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**16,285**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	24,616	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	3,876	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.0E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	81.40	
U = (12 L) / j =	1.04		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	10,772	lb
Bending Frictional Drag = 2 μ N =	6,463	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**16,663**	**lb**			
Total Pulling Load =	**32,947**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	186.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = W_e L μ =	2,800	lb
Fluidic Drag = 12 π D L C_d =	6,324	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**9,123**	**lb**
Total Pulling Load =	**42,070**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	52,431	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E I) / T]^{1/2}$ =	2,656	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.6E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	276.44	
$U = (12 L) / j$ =	1.89		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	7,802	lb
Bending Frictional Drag = $2 \mu N$ =	4,681	lb			
Fluidic Drag = $12 \pi D L C_d$ =	14,212	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	1,828	lb			
Pulling Load on Entry Sag Bend =	**20,722**	**lb**			
Total Pulling Load =	**62,792**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	236.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	3,499	lb
Fluidic Drag = $12 \pi D L C_d$ =	8,024	lb
Axial Segment Weight = $W_e L \sin\theta$ =	2,056	lb
Pulling Load on Entry Tangent =	**13,579**	**lb**
Total Pulling Load =	**76,371**	**lb**

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	930	ok	0	ok	0	ok	0.01	ok	0.00	ok
	765	ok	0	ok	190	ok	0.01	ok	0.00	ok
PC										
	765	ok	18,125	ok	190	ok	0.41	ok	0.12	ok
	513	ok	18,125	ok	358	ok	0.41	ok	0.12	ok
PT										
	513	ok	0	ok	358	ok	0.01	ok	0.00	ok
	401	ok	0	ok	358	ok	0.01	ok	0.00	ok
PC										
	401	ok	18,125	ok	358	ok	0.40	ok	0.12	ok
	198	ok	18,125	ok	250	ok	0.40	ok	0.11	ok
PT										
	198	ok	0	ok	250	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Tar River R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Tar River Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Tar River R0 Installation Stress Analysis (worst-case).xlsm

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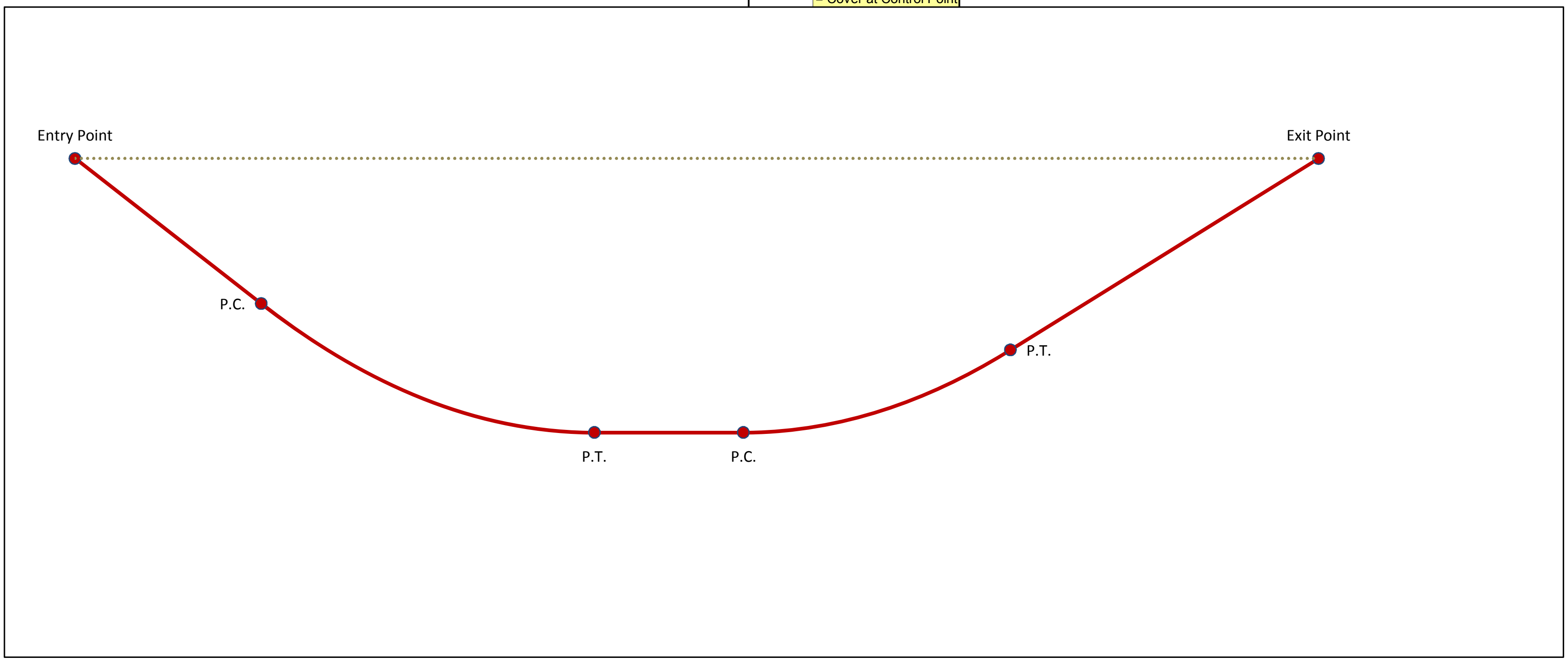
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	133.72	10.00				277,573
Entry Tangent						236.50		
Entry Sag Bend	PC	222.91	92.65					259,310
	PI	429.69	56.19	10.00	2400	418.88	220,076	
	PT	639.67	56.19				0	180,842
Bottom Tangent			.	0.00		186.37		
Exit Sag Bend	PC	826.04	56.19					154,645
	PI	993.87	56.19	8.00	2400	335.10	114,105	
	PT	1160.06	79.55				0	73,565
Exit Tangent						389.25		
Exit Point		1545.52	133.72	8.00	Above Ground Load			0
Drilling Mud			133.72	(Graph = ········)				
Ballast				(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Tar River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	389.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\, L\, \mu \cos\theta$ =	41,103	lb
Fluidic Drag = $12\, \pi\, D\, L\, C_d$ =	13,207	lb
Axial Segment Weight = $W_e\, L \sin\theta$ =	19,255	lb
Pulling Load on Exit Tangent =	**73,565**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	114,105	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R\,[1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E\, I) / T]^{1/2}$ =	1,800	
$Y = [18\,(L)^2] - [(j)^2\,(1 - \cosh(U/2)^{-1}]$ =	7.0E+05		$X = (3\,L) - [\,(j / 2)\tanh(U/2)\,]$ =	279.33	
$U = (12\,L) / j$ =	2.23		$N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X / 12)$ =	102,336	lb
Bending Frictional Drag = $2\,\mu\,N$ =	61,402	lb			
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ =	11,370	lb			
Axial Segment Weight = $W_e\,L\sin\theta$ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**81,080**	**lb**			
Total Pulling Load =	**154,645**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	186.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = $W_e\,L\,\mu$ =	19,873	lb
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ =	6,324	lb
Axial Segment Weight = $W_e\,L\sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**26,197**	**lb**
Total Pulling Load =	**180,842**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 220,076 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 1,296

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 2.0E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 634.72

$U = (12 L) / j$ = 3.88

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 128,719 lb

Bending Frictional Drag = $2 \mu N$ = 77,232 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = -12,976 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 78,468 lb
Total Pulling Load = 259,310 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 236.5 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 24,836 lb

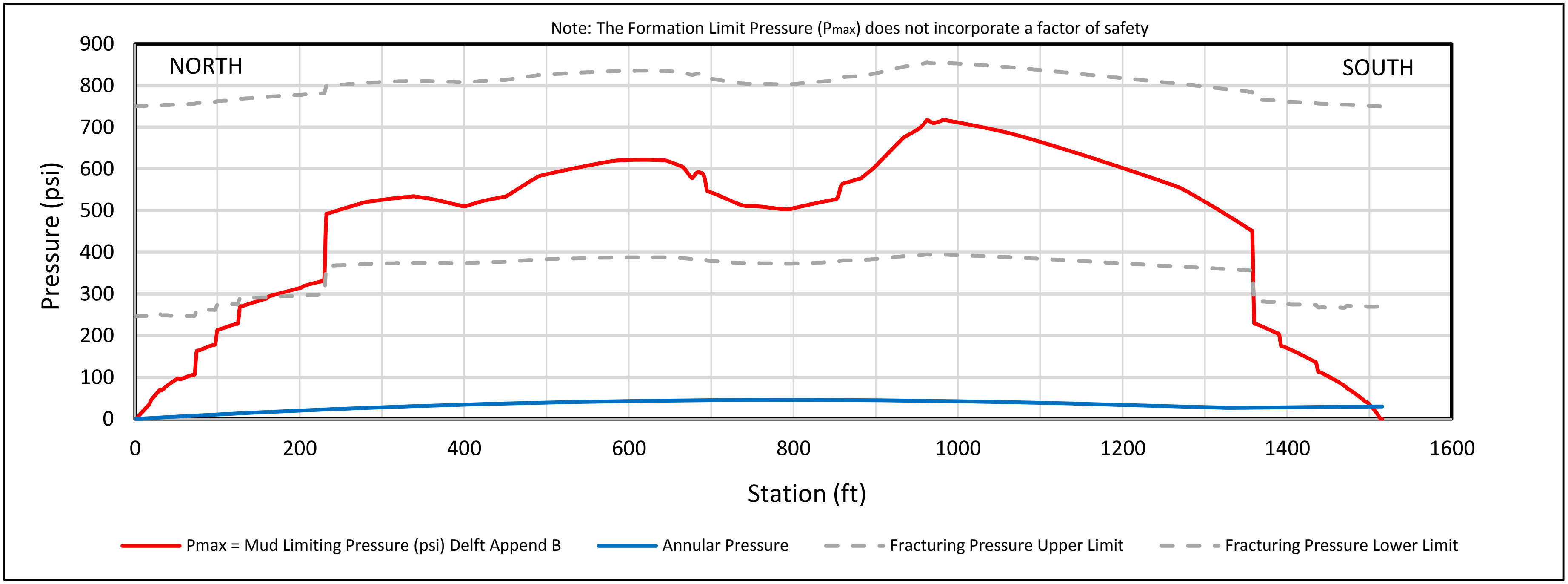
Fluidic Drag = $12 \pi D L C_d$ = 8,024 lb

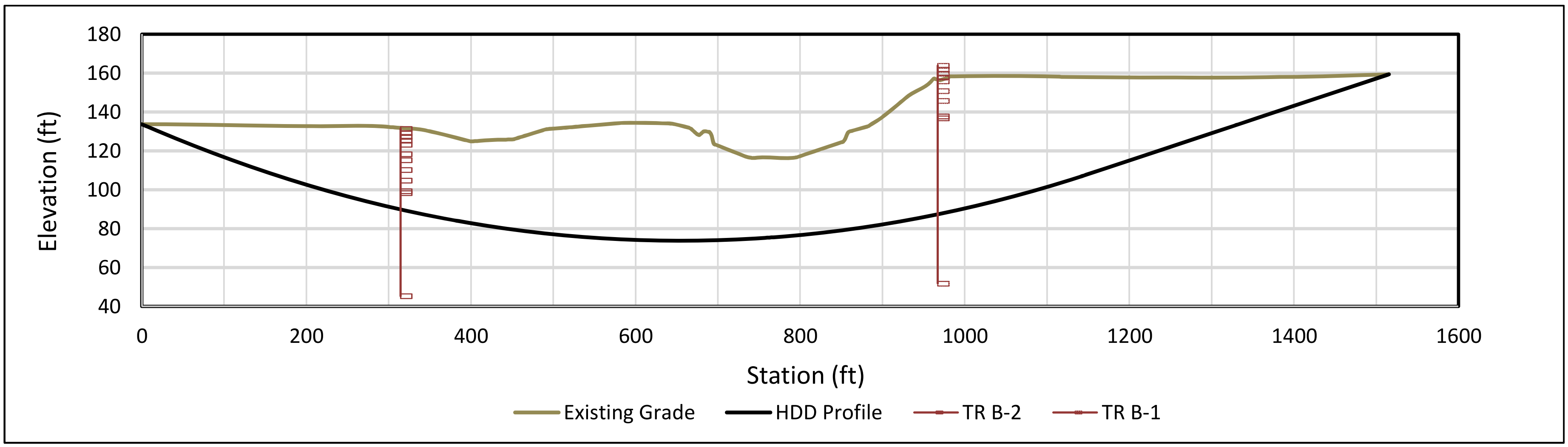
Axial Segment Weight = $W_e L \sin\theta$ = -14,597 lb   Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 18,263 lb
Total Pulling Load = 277,573 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,382	ok	0	ok	0	ok	0.05	ok	0.00	ok
	3,159	ok	0	ok	622	ok	0.05	ok	0.01	ok
PC										
	3,159	ok	18,125	ok	622	ok	0.45	ok	0.17	ok
	2,203	ok	18,125	ok	1174	ok	0.43	ok	0.19	ok
PT										
	2,203	ok	0	ok	1174	ok	0.03	ok	0.03	ok
	1,884	ok	0	ok	1174	ok	0.03	ok	0.03	ok
PC										
	1,884	ok	18,125	ok	1174	ok	0.43	ok	0.18	ok
	896	ok	18,125	ok	820	ok	0.41	ok	0.15	ok
PT										
	896	ok	0	ok	820	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
TAR RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

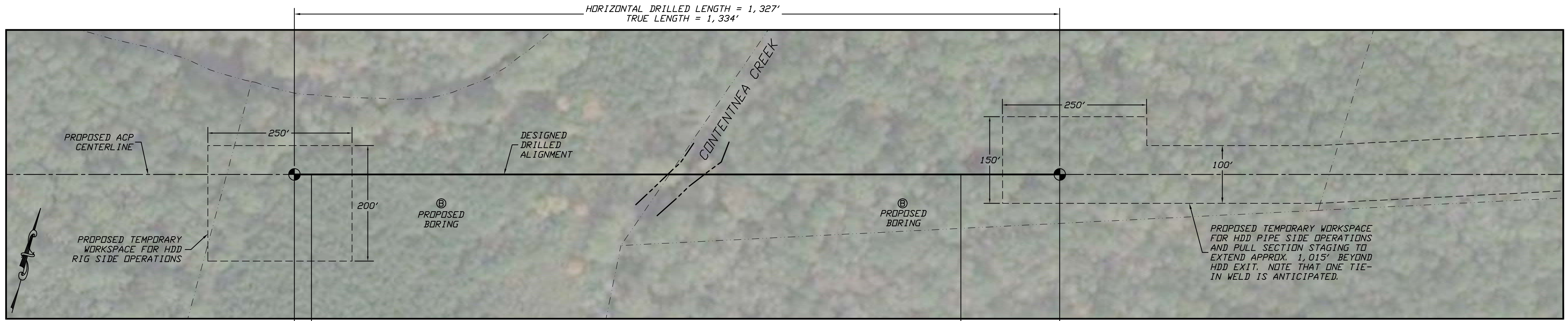
Date: 9/23/2016

Revision: 0

Contentnea Creek

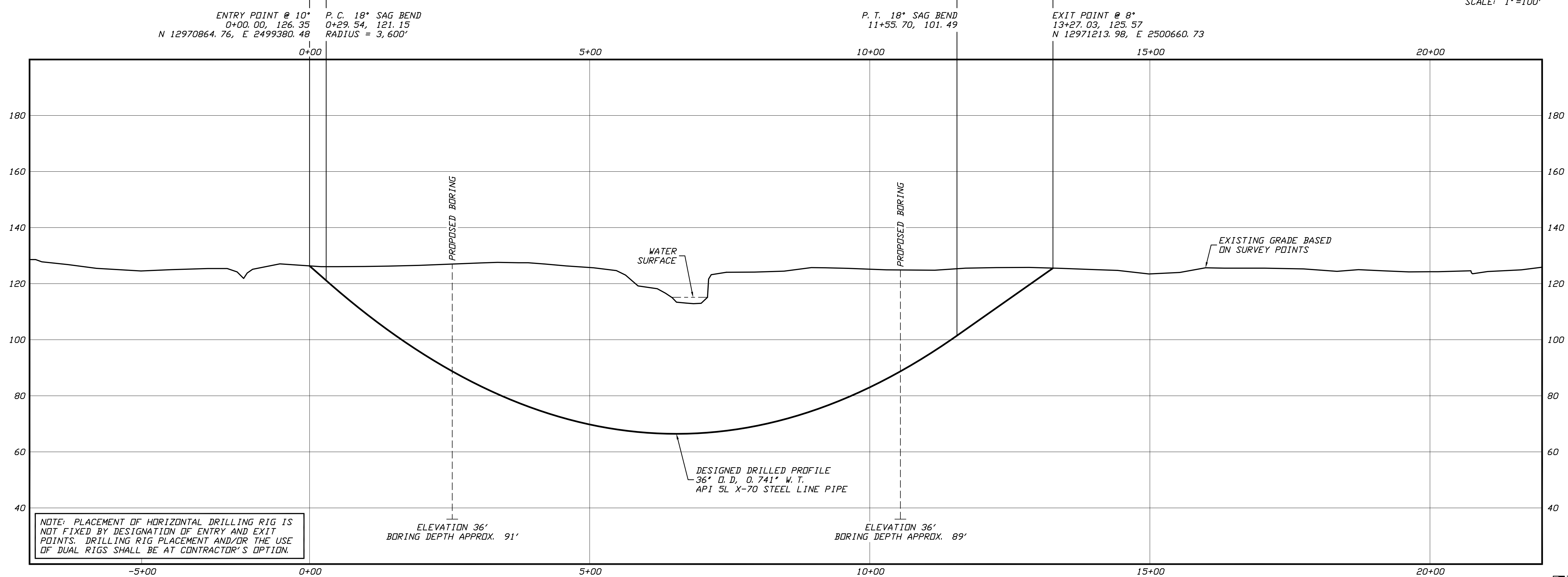
Supporting Information

- Preliminary plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

200 100 50 0
20 10 0

GENERAL LEGEND

● DRILLED PATH ENTRY/EXIT POINT

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

PRELIMINARY

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE 36-INCH PIPELINE CROSSING OF CONTENTNEA CREEK BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: WILSON COUNTY, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM	07/25/16	KMN	JSP	SHOWN FOR D-SIZED PLOT	CONTENTNEA CREEK	P2

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
P2	09/20/16	MODIFY TEMP. WORKSPACE AS DIRECTED BY DOMINION	JSP	KMN	JSP
P1	08/10/16	UPDATE DESIGN BASED ON SURVEY DATA FROM GAI	KMN	ACM	JSP

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO. Dominion\1508

MILE POST AP2-074

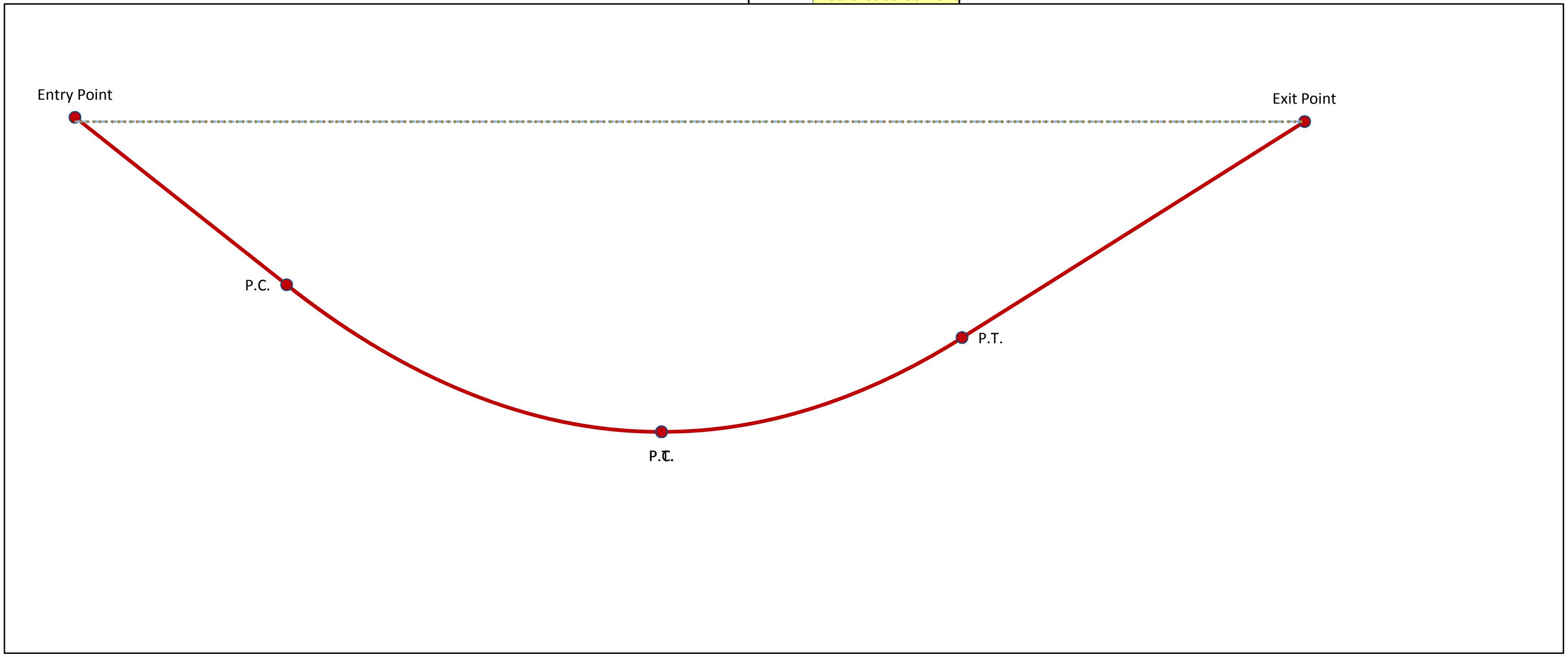
Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	ACM
Crossing :	36" Contentnea Creek Crossing		Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud with BC			
Line Pipe Properties				
Pipe Outside Diameter =		36.000	in	
Wall Thickness =		0.741	in	
Specified Minimum Yield Strength =		70,000	psi	
Young's Modulus =		2.9E+07	psi	
Moment of Inertia =		12755.22	in^4	
Pipe Face Surface Area =		82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =		49		
Poisson's Ratio =		0.3		
Coefficient of Thermal Expansion =		6.5E-06	in/in/°F	
Pipe Weight in Air =		279.04	lb/ft	
Pipe Interior Volume =		6.50	ft^3/ft	
Pipe Exterior Volume =		7.07	ft^3/ft	
HDD Installation Properties				
Drilling Mud Density =		12.0	ppg	
=		89.8	lb/ft^3	
Ballast Density =		62.4	lb/ft^3	
Coefficient of Soil Friction =		0.30		
Fluid Drag Coefficient =		0.025	psi	
Ballast Weight =		405.51	lb/ft	
Displaced Mud Weight =		634.48	lb/ft	
Installation Stress Limits				
Tensile Stress Limit, 90% of SMYS, F_t =		63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =		52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =		44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =		45,639	psi	Yes
Allowable Bending Stress, F_b =		45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =		10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =		10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =		33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =		12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =		70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =		10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =		7,208	psi	

Contentnea Creek P2 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		0.00	126.35	10.00				66,579
Entry Tangent						238.75		
Entry Sag Bend	PC	235.12	84.89					52,871
	PI	441.91	48.43	10.00	2400	418.88	42,814	
	PT	651.88	48.43				0	32,757
Bottom Tangent				0.00		0.37		
Exit Sag Bend	PC	652.25	48.43					32,739
	PI	820.07	48.43	8.00	2400	335.10	24,412	
	PT	986.26	71.79				0	16,086
Exit Tangent						384.51		
Exit Point		1367.03	125.30	8.00	Above Ground Load			0
Drilling Mud			125.30	(Graph =)				
Ballast			125.30	(Graph =)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	384.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	5,720	lb	
Fluidic Drag = 12 π D L C_d =	13,046	lb	
Axial Segment Weight = W_e L sinθ =	-2,679	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**16,086**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	24,412	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	3,893	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.0E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	80.79	
U = (12 L) / j =	1.03		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	10,755	lb
Bending Frictional Drag = 2 μ N =	6,453	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**16,652**	**lb**			
Total Pulling Load =	**32,739**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = W_e L μ =	6	lb
Fluidic Drag = 12 π D L C_d =	12	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**18**	**lb**
Total Pulling Load =	**32,757**	**lb**

Contentnea Creek P2 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 42,814 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 2,939

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 7.4E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 237.13

$U = (12 L) / j$ = 1.71

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 6,790 lb

Bending Frictional Drag = $2 \mu N$ = 4,074 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = 1,828 lb

Pulling Load on Entry Sag Bend = 20,114 lb
Total Pulling Load = 52,871 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 238.8 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 3,532 lb

Fluidic Drag = $12 \pi D L C_d$ = 8,101 lb

Axial Segment Weight = $W_e L \sin\theta$ = 2,076 lb

Pulling Load on Entry Tangent = 13,708 lb
Total Pulling Load = 66,579 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	811	ok	0	ok	0	ok	0.01	ok	0.00	ok
	644	ok	0	ok	187	ok	0.01	ok	0.00	ok
PC										
	644	ok	18,125	ok	187	ok	0.41	ok	0.12	ok
	399	ok	18,125	ok	355	ok	0.40	ok	0.12	ok
PT										
	399	ok	0	ok	355	ok	0.01	ok	0.00	ok
	399	ok	0	ok	355	ok	0.01	ok	0.00	ok
PC										
	399	ok	18,125	ok	355	ok	0.40	ok	0.12	ok
	196	ok	18,125	ok	247	ok	0.40	ok	0.11	ok
PT										
	196	ok	0	ok	247	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Contentnea Creek P2 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Contentnea Creek Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Contentnea Creek P2 Installation Stress Analysis (worst-case).xlsm

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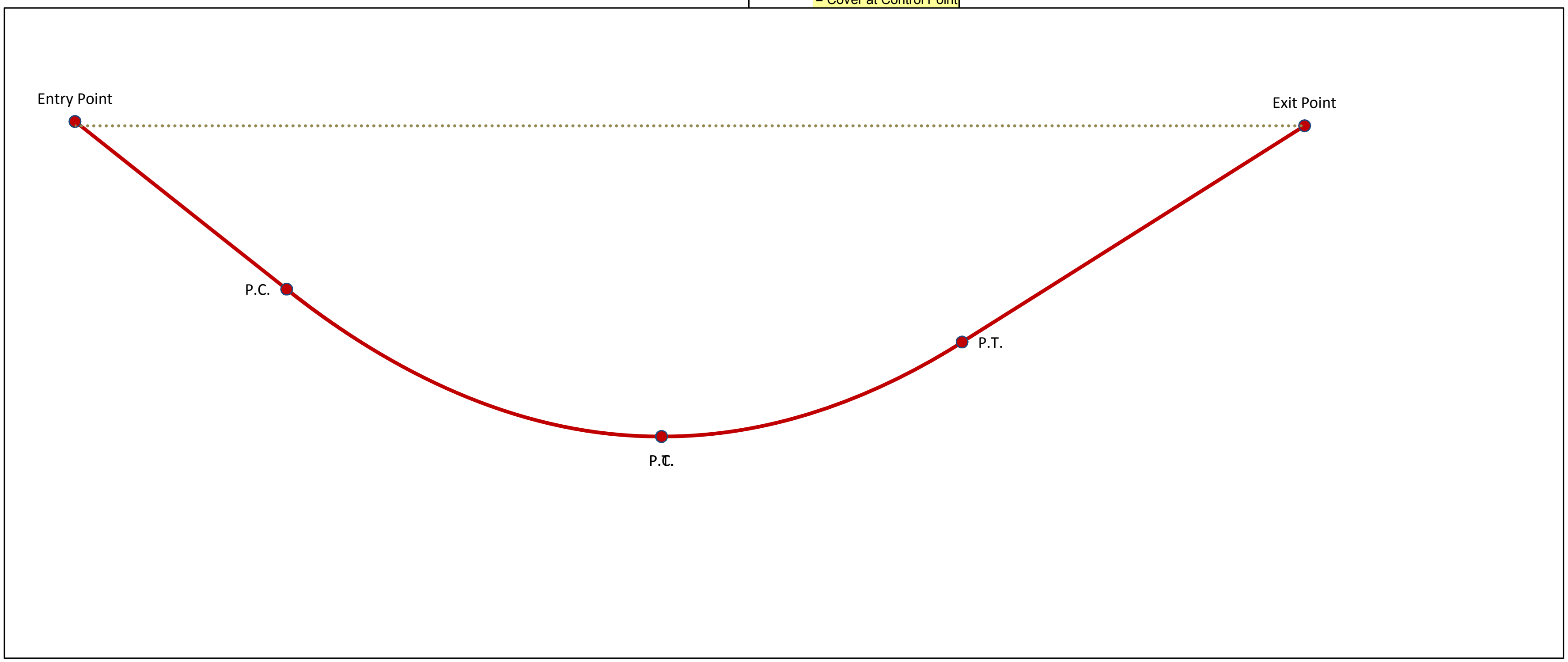
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		0.00	126.35	10.00				249,090
Entry Tangent						238.75		
Entry Sag Bend	PC	235.12	84.89					230,654
	PI	441.91	48.43	10.00	2400	418.88	192,206	
	PT	651.88	48.43				0	153,758
Bottom Tangent				0.00		0.37		
Exit Sag Bend	PC	652.25	48.43					153,706
	PI	820.07	48.43	8.00	2400	335.10	113,188	
	PT	986.26	71.79				0	72,669
Exit Tangent						384.51		
Exit Point		1367.03	125.30	8.00	Above Ground Load			0
Drilling Mud			125.30	(Graph = ········)				
Ballast				(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	384.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu\ \cos\theta$ =	40,602	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	13,046	lb
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	19,021	lb
Pulling Load on Exit Tangent =	**72,669**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	113,188	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	1,808	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	6.9E+05		$X = (3\ L) - [\ (j / 2)\ \tanh(U/2)\ ]$ =	277.82	
$U = (12\ L) / j$ =	2.22		$N = [(T\ h) - W_e\ \cos\theta\ (Y/144)] / (X / 12)$ =	102,264	lb
Bending Frictional Drag = $2\ \mu\ N$ =	61,359	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	11,370	lb			
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**81,037**	**lb**			
Total Pulling Load =	**153,706**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	39	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	12	lb
Axial Segment Weight = $W_e\ L\ \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**52**	**lb**
Total Pulling Load =	**153,758**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 192,206 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 1,387

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 1.8E+06

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 599.07

$U = (12 L) / j$ = 3.62

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 126,100 lb

Bending Frictional Drag = $2 \mu N$ = 75,660 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = -12,976 lb

Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 76,896 lb
Total Pulling Load = 230,654 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 238.8 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -355.4 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 25,072 lb

Fluidic Drag = $12 \pi D L C_d$ = 8,101 lb

Axial Segment Weight = $W_e L \sin\theta$ = -14,736 lb

Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 18,436 lb
Total Pulling Load = 249,090 lb

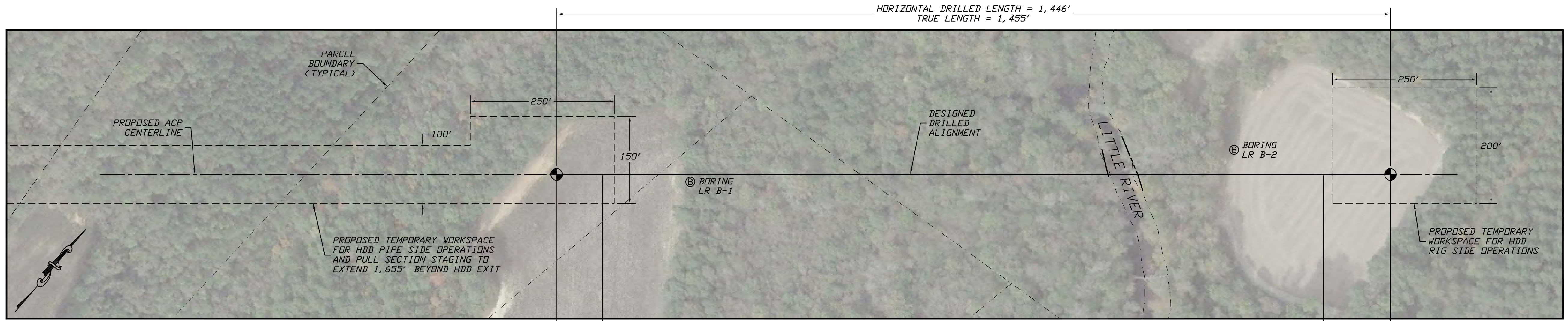
Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,035	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,810	ok	0	ok	612	ok	0.04	ok	0.01	ok
PC										
	2,810	ok	18,125	ok	612	ok	0.44	ok	0.16	ok
	1,873	ok	18,125	ok	1164	ok	0.43	ok	0.18	ok
PT										
	1,873	ok	0	ok	1164	ok	0.03	ok	0.03	ok
	1,873	ok	0	ok	1164	ok	0.03	ok	0.03	ok
PC										
	1,873	ok	18,125	ok	1164	ok	0.43	ok	0.18	ok
	885	ok	18,125	ok	810	ok	0.41	ok	0.15	ok
PT										
	885	ok	0	ok	810	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Little River

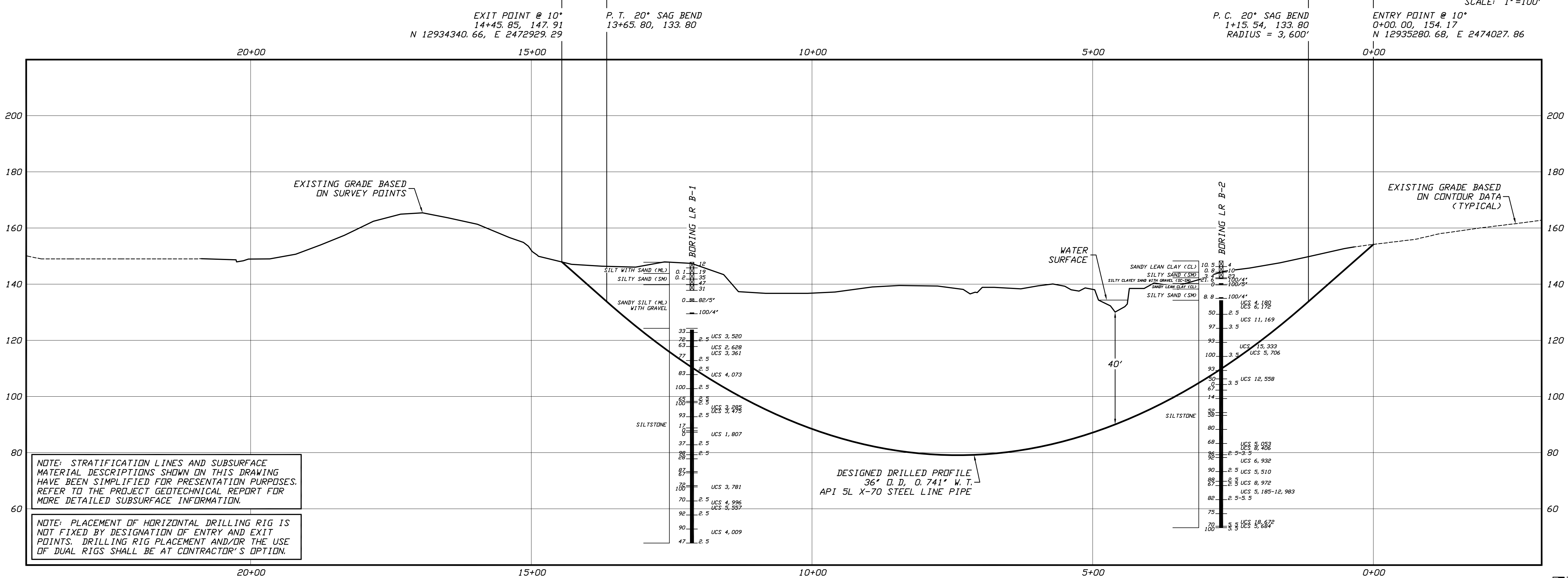
Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

200 100 50 0 — 20 — 10 — 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 N 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

CORE BARREL SAMPLE

UCS 6,250 — UNCONFINED COMPRESSIVE STRENGTH (PSI)
53 6 — MOHS HARDNESS
— ROCK QUALITY DESIGNATION (PERCENT)

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE DRAFT GEOTECHNICAL SITE INVESTIGATION REPORT DATED SEPTEMBER 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 20 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
36-INCH PIPELINE CROSSING OF THE LITTLE RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: JOHNSTON COUNTY, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
ACM/LKB	09/29/16	JSP	JSP	SHOWN FOR D-SIZED PLOT	LITTLE RIVER	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP2-083

Little River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Little River Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 22' deeper than design with a 2,400' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Little River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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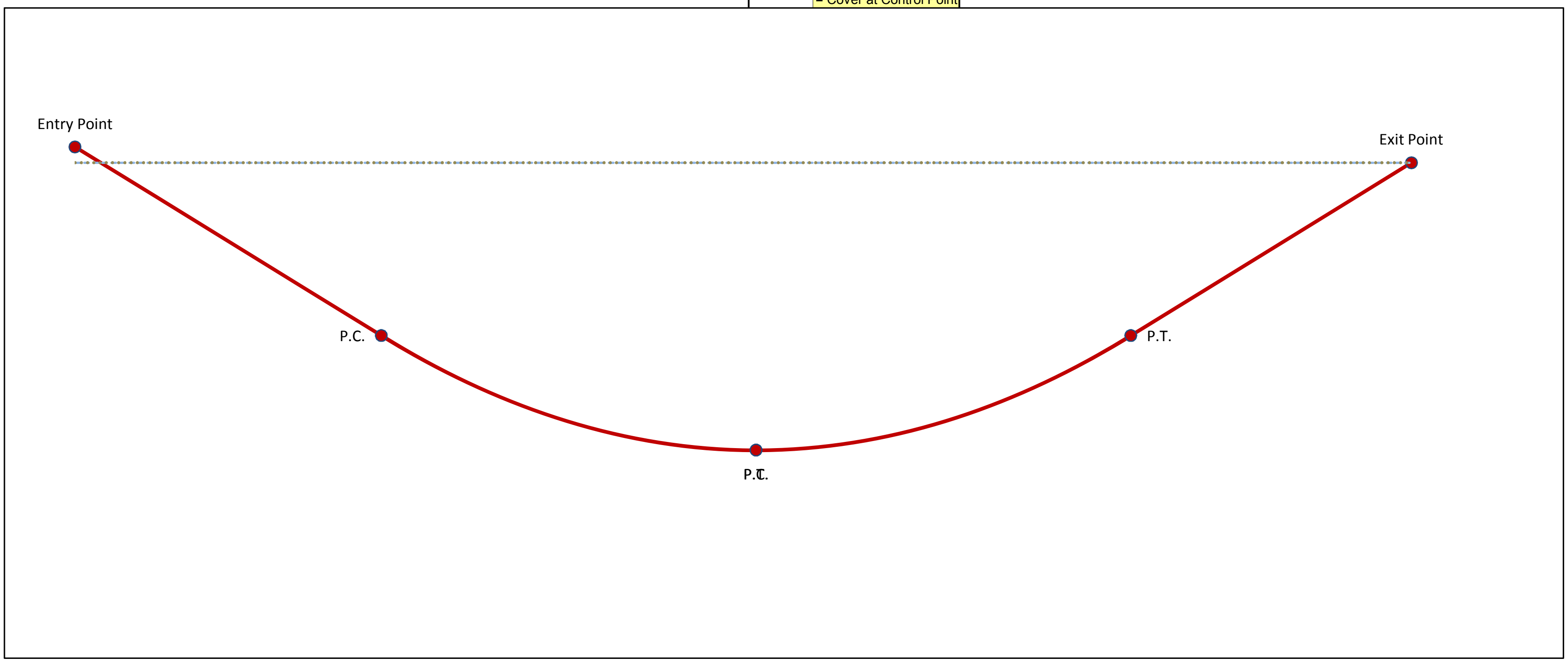
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	154.41	10.00				67,335
Entry Tangent						345.69		
Entry Sag Bend	PC	330.44	94.38					47,487
	PI	537.22	57.92	10.00	2400	418.88	37,595	
	PT	747.19	57.92				0	27,703
Bottom Tangent				0.00		0.04		
Exit Sag Bend	PC	747.24	57.92					27,701
	PI	957.21	57.92	10.00	2400	418.88	20,188	
	PT	1163.99	94.38				0	12,675
Exit Tangent						316.67		
Exit Point		1475.85	149.37	10.00	Above Ground Load			0
Drilling Mud			149.37	(Graph = ········)				
Ballast			149.37	(Graph = – – – –)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Step 2, Drilled Path Input

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Little River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	316.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	10.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	4,684	lb	
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	10,744	lb	
Axial Segment Weight = $W_e\ L \sin\theta$ =	-2,753	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**12,675**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	20,188	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E\ I) / T]^{1/2}$ =	4,281	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	4.0E+05		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	126.93	
$U = (12\ L) / j$ =	1.17		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	4,402	lb
Bending Frictional Drag = $2\ \mu\ N$ =	2,641	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	14,212	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-1,828	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**15,025**	**lb**			
Total Pulling Load =	**27,701**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	1	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	1	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**2**	**lb**
Total Pulling Load =	**27,703**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 37,595 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 3,137

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 6.7E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 214.10

$U = (12 L) / j$ = 1.60

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 6,240 lb

Bending Frictional Drag = $2 \mu N$ = 3,744 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = 1,828 lb

Pulling Load on Entry Sag Bend = 19,784 lb
Total Pulling Load = 47,487 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 345.7 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 5,114 lb

Fluidic Drag = $12 \pi D L C_d$ = 11,729 lb

Axial Segment Weight = $W_e L \sin\theta$ = 3,006 lb

Pulling Load on Entry Tangent = 19,849 lb
Total Pulling Load = 67,335 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	820	ok	0	ok	0	ok	0.01	ok	0.00	ok
	579	ok	0	ok	254	ok	0.01	ok	0.00	ok
PC										
	579	ok	18,125	ok	254	ok	0.41	ok	0.12	ok
	338	ok	18,125	ok	422	ok	0.40	ok	0.12	ok
PT										
	338	ok	0	ok	422	ok	0.01	ok	0.00	ok
	337	ok	0	ok	422	ok	0.01	ok	0.00	ok
PC										
	337	ok	18,125	ok	422	ok	0.40	ok	0.12	ok
	154	ok	18,125	ok	254	ok	0.40	ok	0.11	ok
PT										
	154	ok	0	ok	254	ok	0.00	ok	0.00	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok

Little River R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Little River Crossing	Date :	9/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 22' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,208	psi	

Little River R0 Installation Stress Analysis (worst-case).xlsm

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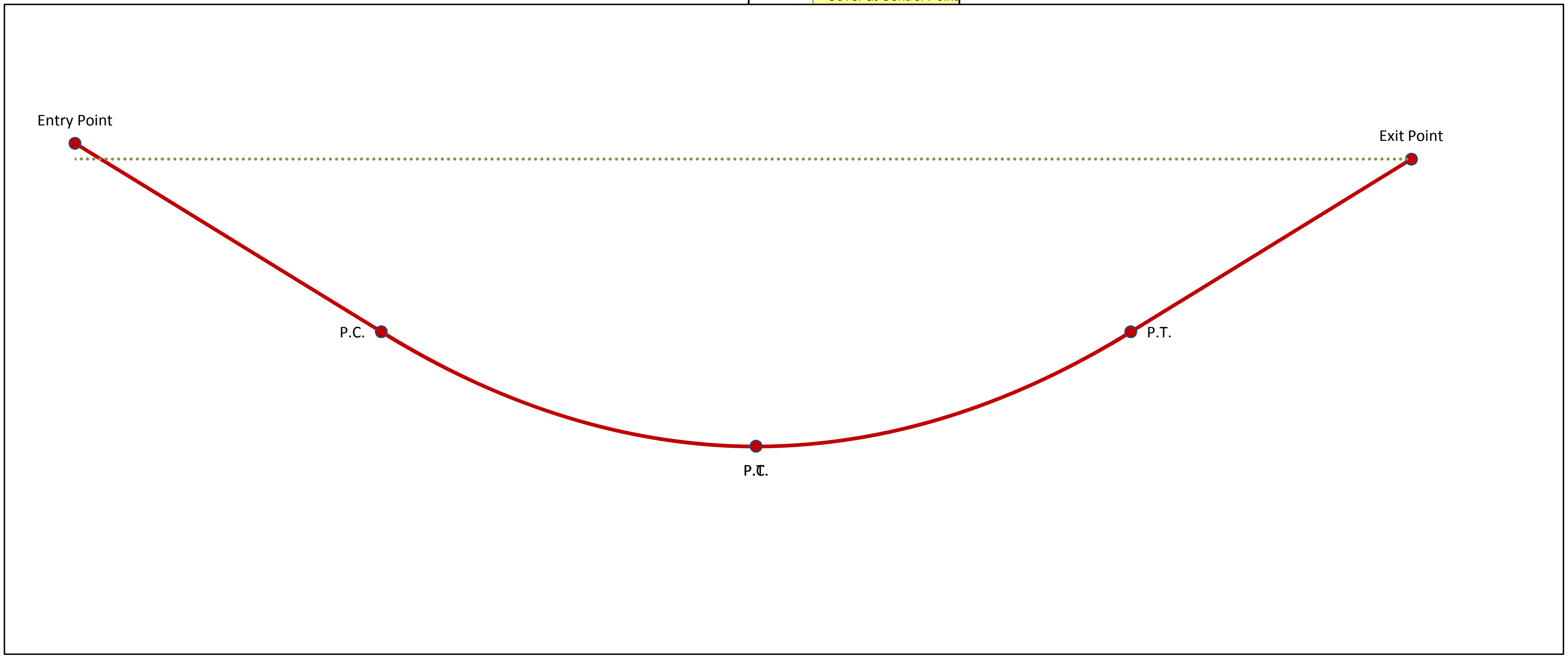
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	154.41	10.00				265,977
Entry Tangent						345.69		
Entry Sag Bend	PC	330.44	94.38					239,283
	PI	537.22	57.92	10.00	2400	418.88	200,598	
	PT	747.19	57.92				0	161,914
Bottom Tangent				0.00		0.04		
Exit Sag Bend	PC	747.24	57.92					161,908
	PI	957.21	57.92	10.00	2400	418.88	112,726	
	PT	1163.99	94.38				0	63,543
Exit Tangent						316.67		
Exit Point		1475.85	149.37	10.00			Above Ground Load	0
Drilling Mud			149.37	(Graph = ·········)				
Ballast				(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Little River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	316.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	10.0	°			

Frictional Drag = W_e L μ cosθ =	33,254	lb
Fluidic Drag = 12 π D L C_d =	10,744	lb
Axial Segment Weight = W_e L sinθ =	19,545	lb
Pulling Load on Exit Tangent =	**63,543**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	112,726	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

h = R [1 - cos(α/2)] =	9.13	ft	$j = [(E\ I) / T]^{1/2}$ =	1,811	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.4E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	457.23	
U = (12 L) / j =	2.77		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	118,626	lb
Bending Frictional Drag = 2 μ N =	71,176	lb			
Fluidic Drag = 12 π D L C_d =	14,212	lb			
Axial Segment Weight = W_e L sinθ =	12,976	lb			
Pulling Load on Exit Sag Bend =	**98,364**	**lb**			
Total Pulling Load =	**161,908**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = W_e L μ =	5	lb
Fluidic Drag = 12 π D L C_d =	1	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**6**	**lb**
Total Pulling Load =	**161,914**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	200,598	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

h = R [1 - cos(α/2)] =	9.13	ft	j = [(E I) / T]$^{1/2}$ =	1,358	
Y = [18 (L)^2] - [(j)^2 (1 - cosh(U/2)$^{-1}$] =	1.9E+06		X = (3 L) - [(j / 2) tanh(U/2)] =	610.38	
U = (12 L) / j =	3.70		N = [(T h) - W_e cosθ (Y/144)] / (X / 12) =	126,889	lb
Bending Frictional Drag = 2 μ N =	76,133	lb			
Fluidic Drag = 12 π D L C_d =	14,212	lb			
Axial Segment Weight = W_e L sinθ =	-12,976	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**77,369**	**lb**			
Total Pulling Load =	**239,283**	**lb**			

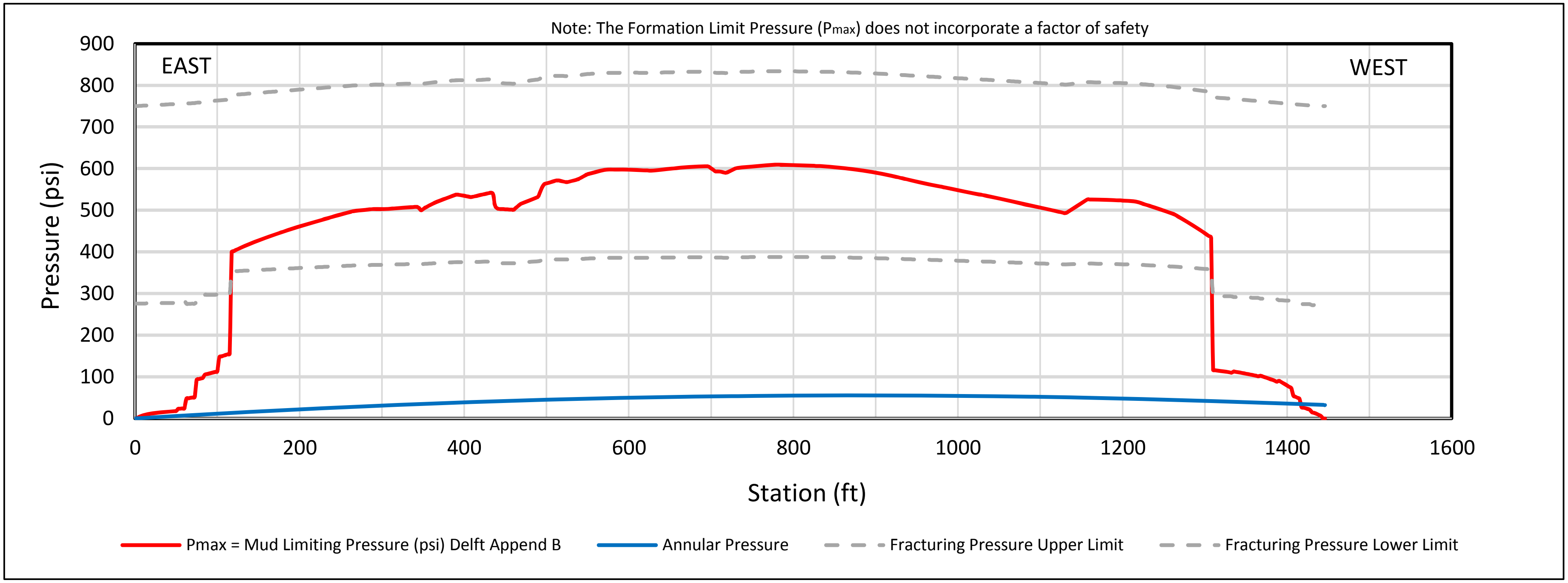
Entry Tangent - Summary of Pulling Load Calculations

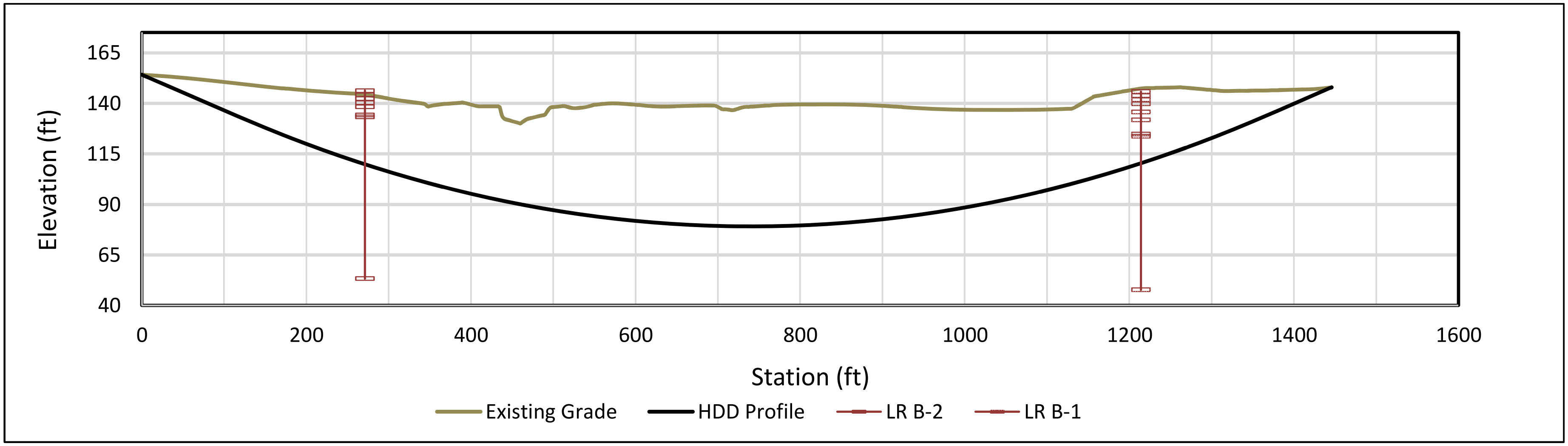
Segment Length, L =	345.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = W_e L μ cosθ =	36,302	lb	
Fluidic Drag = 12 π D L C_d =	11,729	lb	
Axial Segment Weight = W_e L sinθ =	-21,337	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**26,694**	**lb**	
Total Pulling Load =	**265,977**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,240	ok	0	ok	0	ok	0.05	ok	0.00	ok
	2,915	ok	0	ok	833	ok	0.05	ok	0.02	ok
PC										
	2,915	ok	18,125	ok	833	ok	0.44	ok	0.17	ok
	1,973	ok	18,125	ok	1385	ok	0.43	ok	0.20	ok
PT										
	1,973	ok	0	ok	1385	ok	0.03	ok	0.04	ok
	1,973	ok	0	ok	1385	ok	0.03	ok	0.04	ok
PC										
	1,973	ok	18,125	ok	1385	ok	0.43	ok	0.20	ok
	774	ok	18,125	ok	833	ok	0.41	ok	0.15	ok
PT										
	774	ok	0	ok	833	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

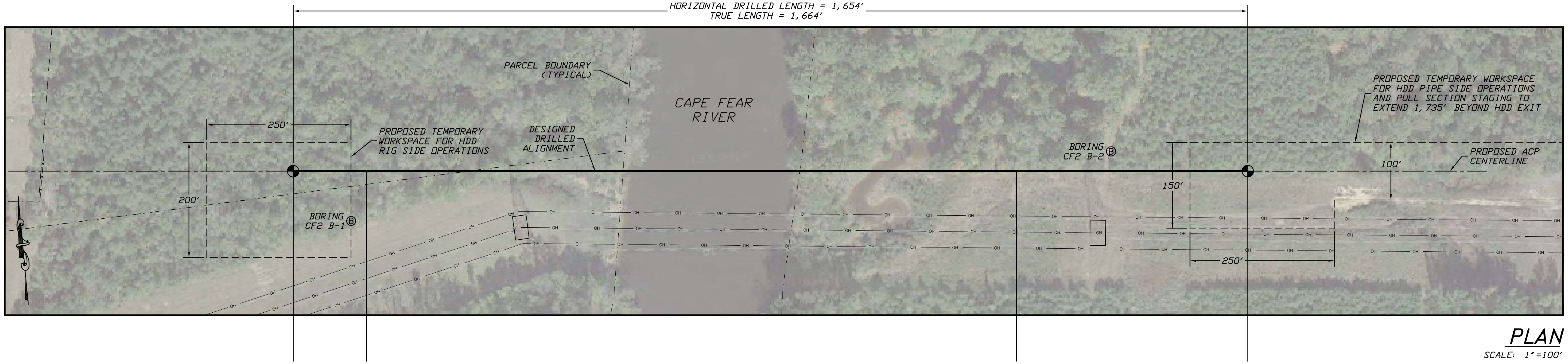
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
LITTLE RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

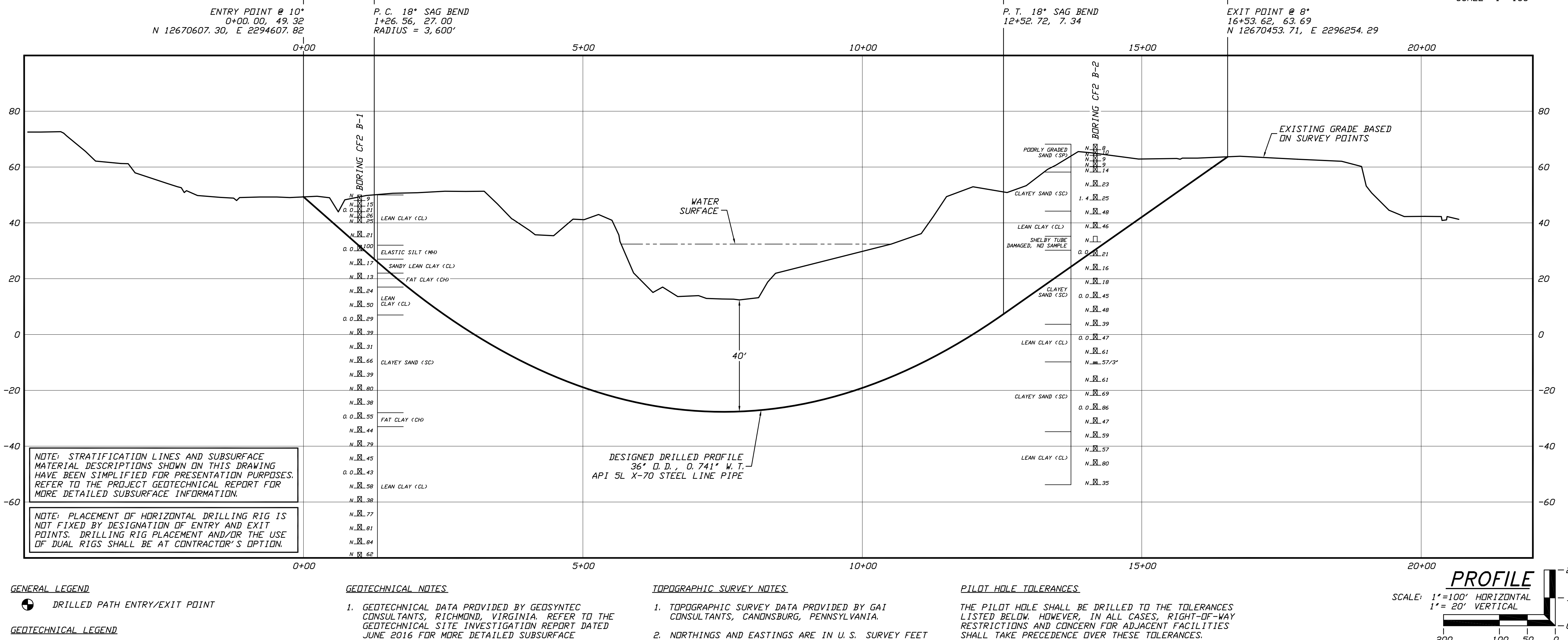
Date: 9/26/2016 Revision: 0

Cape Fear River

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)





GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 ⊠ 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

53 — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT DATED JUNE 2016 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 20 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 2,400 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
36-INCH PIPELINE CROSSING OF THE CAPE FEAR RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: CUMBERLAND COUNTY, NORTH CAROLINA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN/ACM	08/18/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	CAPE FEAR	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP2-006A

Cape Fear River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	36" Cape Fear River Crossing	Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud with BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

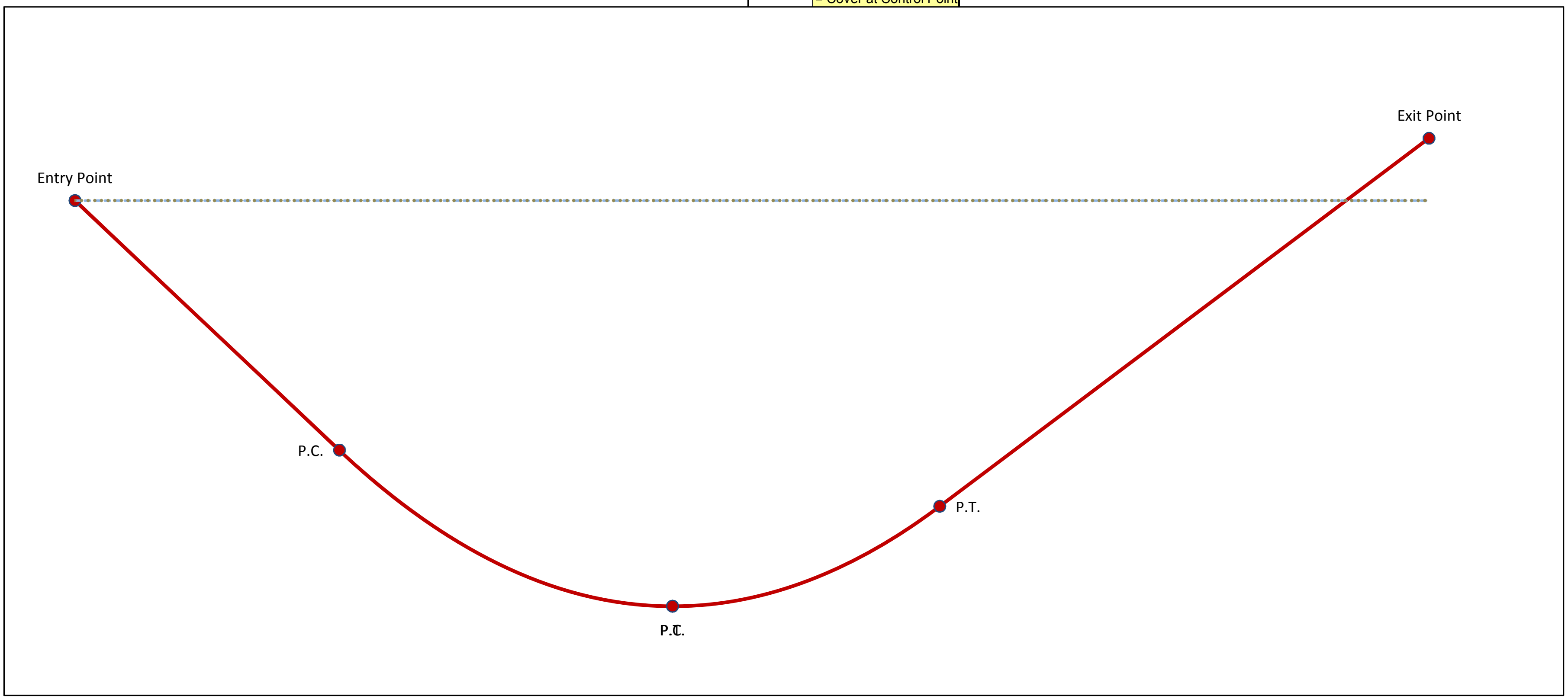
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,208	psi	

Cape Fear River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	49.22	10.00				83,086
Entry Tangent						335.90		
Entry Sag Bend	PC	320.80	-9.11					63,800
	PI	527.58	-45.57	10.00	2400	418.88	53,408	
	PT	737.55	-45.57				0	43,016
Bottom Tangent				0.00		0.03		
Exit Sag Bend	PC	737.59	-45.57					43,015
	PI	905.41	-45.57	8.00	2400	335.10	34,435	
	PT	1071.60	-22.21				0	25,856
Exit Tangent						618.03		
Exit Point		1683.62	63.80	8.00	Above Ground Load			0
Drilling Mud			49.22	(Graph = ········)				
Ballast			49.22	(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Cape Fear River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	618.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	9,193	lb	
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	20,969	lb	
Axial Segment Weight = $W_e\ L \sin\theta$ =	-4,307	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Exit Tangent =	**25,856**	**lb**	

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	34,435	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

$h = R\,[1 - \cos(\alpha/2)]$ =	5.85	ft	$j = [(E\ I) / T]^{1/2}$ =	3,277	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	2.7E+05		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	109.64	
$U = (12\ L) / j$ =	1.23		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ =	11,599	lb
Bending Frictional Drag = $2\ \mu\ N$ =	6,960	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	11,370	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	-1,170	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Exit Sag Bend =	**17,159**	**lb**			
Total Pulling Load =	**43,015**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	50.1	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	1	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	1	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**2**	**lb**
Total Pulling Load =	**43,016**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 418.9 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 53,408 lb
Radius of Curvature, R = 2,400 ft
Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 9.13 ft

$j = [(E I) / T]^{1/2}$ = 2,632

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 8.8E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 280.22

$U = (12 L) / j$ = 1.91

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 7,905 lb

Bending Frictional Drag = $2 \mu N$ = 4,743 lb

Fluidic Drag = $12 \pi D L C_d$ = 14,212 lb

Axial Segment Weight = $W_e L \sin\theta$ = 1,828 lb

Pulling Load on Entry Sag Bend = 20,783 lb
Total Pulling Load = 63,800 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 335.9 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = 50.1 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 4,969 lb

Fluidic Drag = $12 \pi D L C_d$ = 11,397 lb

Axial Segment Weight = $W_e L \sin\theta$ = 2,921 lb

Pulling Load on Entry Tangent = 19,286 lb
Total Pulling Load = 83,086 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	1,012	ok	0	ok	0	ok	0.02	ok	0.00	ok
	777	ok	0	ok	269	ok	0.01	ok	0.00	ok
PC										
	777	ok	18,125	ok	269	ok	0.41	ok	0.12	ok
	524	ok	18,125	ok	437	ok	0.41	ok	0.12	ok
PT										
	524	ok	0	ok	437	ok	0.01	ok	0.00	ok
	524	ok	0	ok	437	ok	0.01	ok	0.00	ok
PC										
	524	ok	18,125	ok	437	ok	0.41	ok	0.12	ok
	315	ok	18,125	ok	330	ok	0.40	ok	0.12	ok
PT										
	315	ok	0	ok	330	ok	0.01	ok	0.00	ok
Exit Point	0	ok	0	ok	-67	ok	0.00	ok	0.00	ok

Cape Fear River R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	36" Cape Fear River Crossing	Date :	6/15/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 18' deeper than design with a 2,400' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	36.000	in	
Wall Thickness =	0.741	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	12755.22	in^4	
Pipe Face Surface Area =	82.08	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	279.04	lb/ft	
Pipe Interior Volume =	6.50	ft^3/ft	
Pipe Exterior Volume =	7.07	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	405.51	lb/ft	
Displaced Mud Weight =	634.48	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,517	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,639	psi	Yes
Allowable Bending Stress, F_b =	45,639	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,812	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,446	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	12,027	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,812	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,208	psi	

Cape Fear River R0 Installation Stress Analysis (worst-case).xlsm
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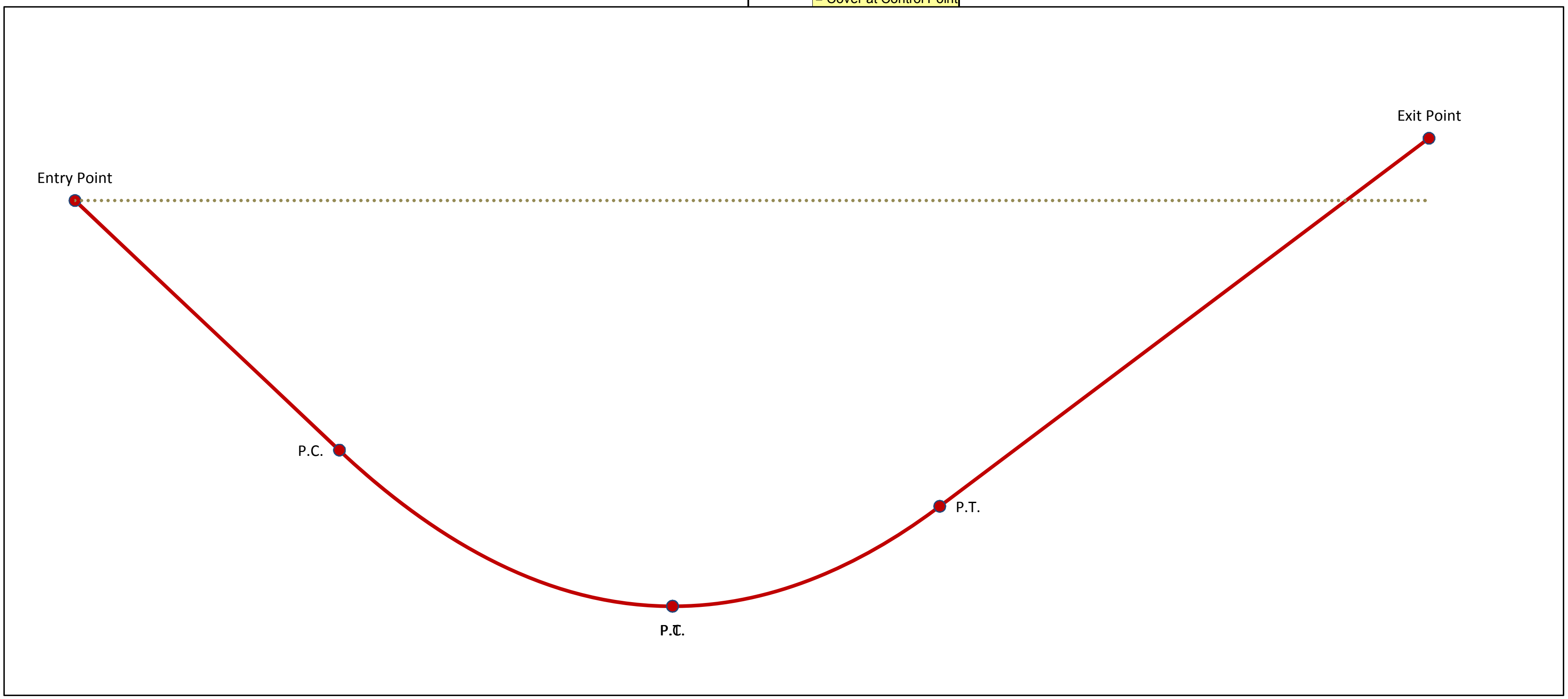
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	49.22	10.00				305,472
Entry Tangent						335.90		
Entry Sag Bend	PC	320.80	-9.11					279,534
	PI	527.58	-45.57	10.00	2400	418.88	239,746	
	PT	737.55	-45.57				0	199,957
Bottom Tangent				0.00		0.03		
Exit Sag Bend	PC	737.59	-45.57					199,953
	PI	905.41	-45.57	8.00	2400	335.10	158,378	
	PT	1071.60	-22.21				0	116,803
Exit Tangent						618.03		
Exit Point		1683.62	63.80	8.00	Above Ground Load			0
Drilling Mud			49.22	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

Cape Fear River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	36.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	279.0	lb/ft	Ballast Weight / ft Pipe, W_b =	405.5	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	634.5	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	618.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	65,261	lb
Fluidic Drag = 12 π D L C_d =	20,969	lb
Axial Segment Weight = W_e L sinθ =	30,573	lb
Pulling Load on Exit Tangent =	**116,803**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	335.1	ft	Average Tension, T =	158,378	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

h = R [1 - cos(α/2)] =	5.85	ft	$j = [(E I) / T]^{1/2}$ =	1,528	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.5E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	343.81	
U = (12 L) / j =	2.63		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	105,786	lb
Bending Frictional Drag = 2 μ N =	63,472	lb			
Fluidic Drag = 12 π D L C_d =	11,370	lb			
Axial Segment Weight = W_e L sinθ =	8,309	lb			
Pulling Load on Exit Sag Bend =	**83,150**	**lb**			
Total Pulling Load =	**199,953**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

Frictional Drag = W_e L μ =	4	lb
Fluidic Drag = 12 π D L C_d =	1	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**5**	**lb**
Total Pulling Load =	**199,957**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	418.9	ft	Average Tension, T =	239,746	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	2,400	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	9.13	ft	$j = [(E\ I) / T]^{1/2}$ =	1,242	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.0E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	656.91	
$U = (12 L) / j$ =	4.05		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	130,568	lb
Bending Frictional Drag = $2 \mu N$ =	78,341	lb			
Fluidic Drag = $12 \pi D L C_d$ =	14,212	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-12,976	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**79,577**	**lb**			
Total Pulling Load =	**279,534**	**lb**			

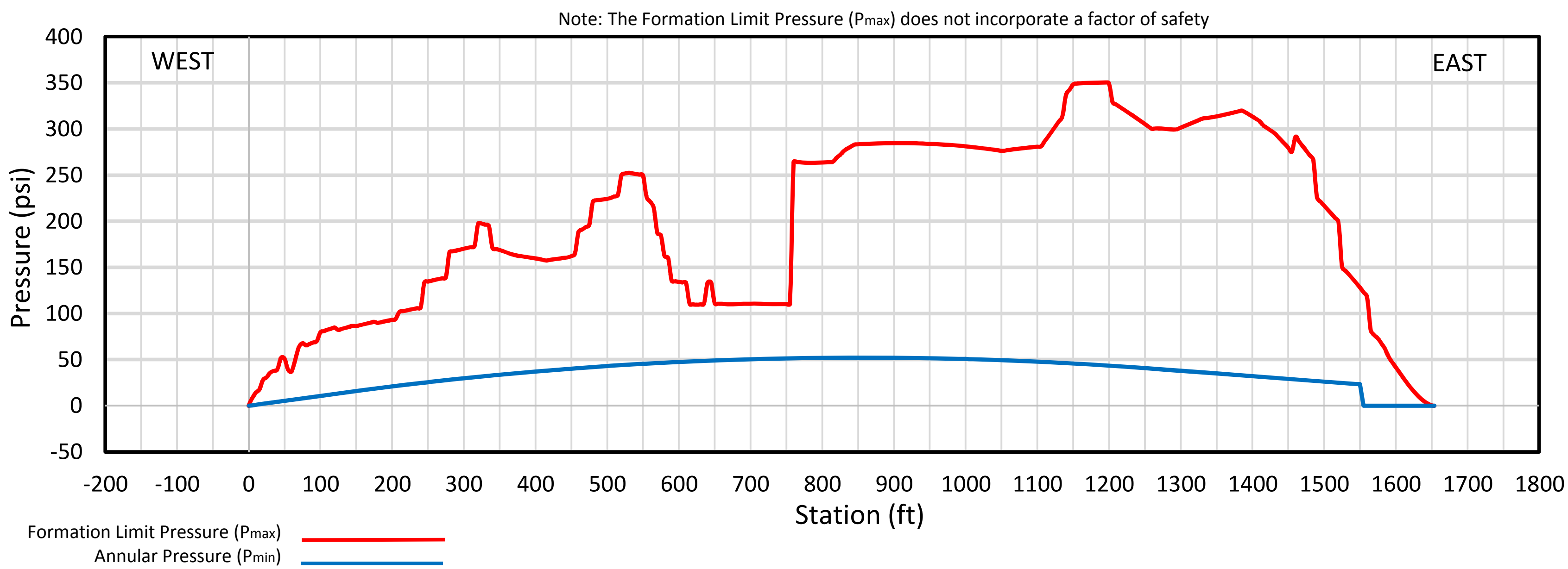
Entry Tangent - Summary of Pulling Load Calculations

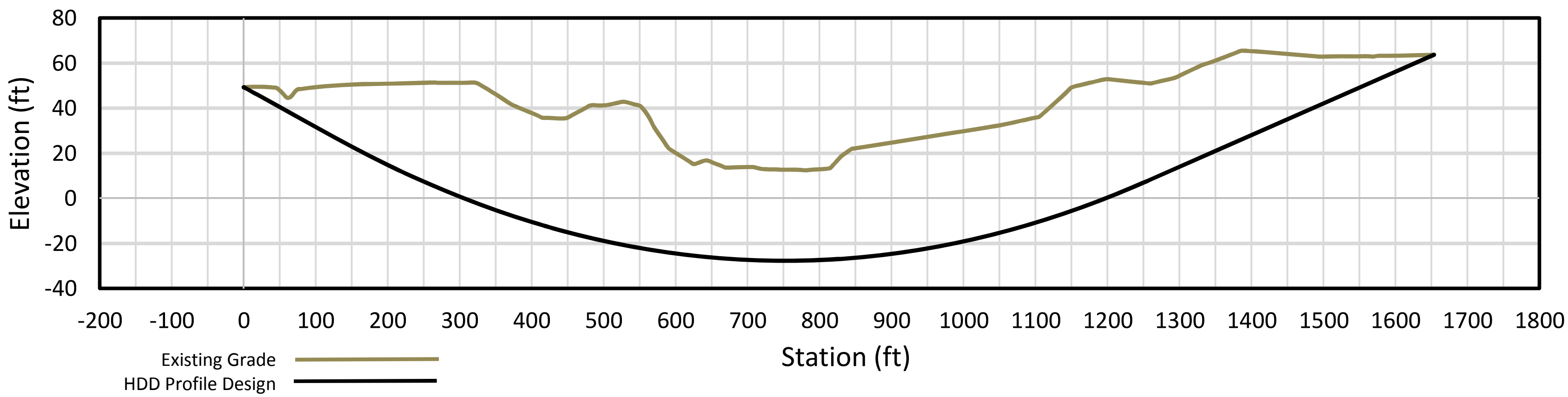
Segment Length, L =	335.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-355.4	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	35,274	lb	
Fluidic Drag = $12 \pi D L C_d$ =	11,397	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-20,732	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**25,938**	**lb**	
Total Pulling Load =	**305,472**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,722	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,406	ok	0	ok	883	ok	0.05	ok	0.02	ok
PC										
	3,406	ok	18,125	ok	883	ok	0.45	ok	0.18	ok
	2,436	ok	18,125	ok	1435	ok	0.44	ok	0.21	ok
PT										
	2,436	ok	0	ok	1435	ok	0.04	ok	0.04	ok
	2,436	ok	0	ok	1435	ok	0.04	ok	0.04	ok
PC										
	2,436	ok	18,125	ok	1435	ok	0.44	ok	0.21	ok
	1,423	ok	18,125	ok	1082	ok	0.42	ok	0.17	ok
PT										
	1,423	ok	0	ok	1082	ok	0.02	ok	0.02	ok
Exit Point	0	ok	0	ok	-221	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

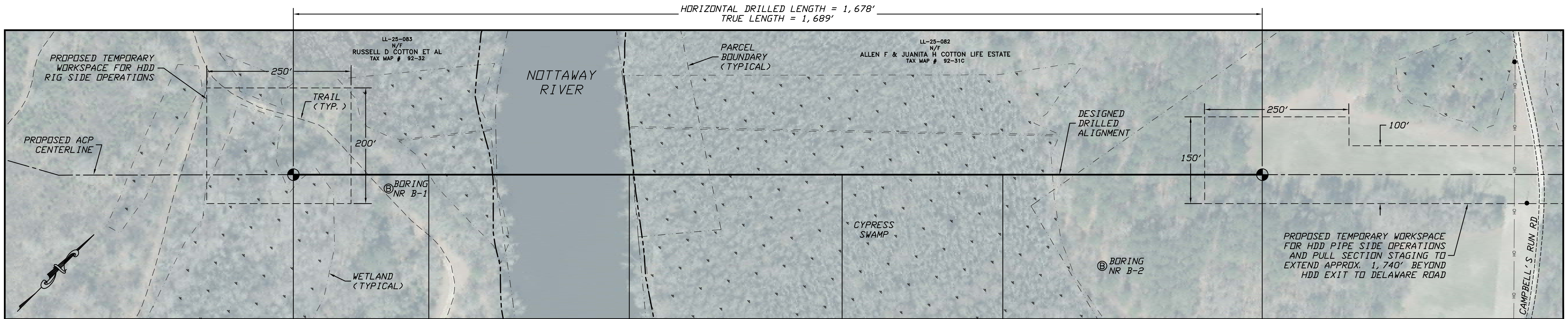
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
36-INCH CAPE FEAR REROUTE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 7/11/2016 Revision: 0

Nottaway River

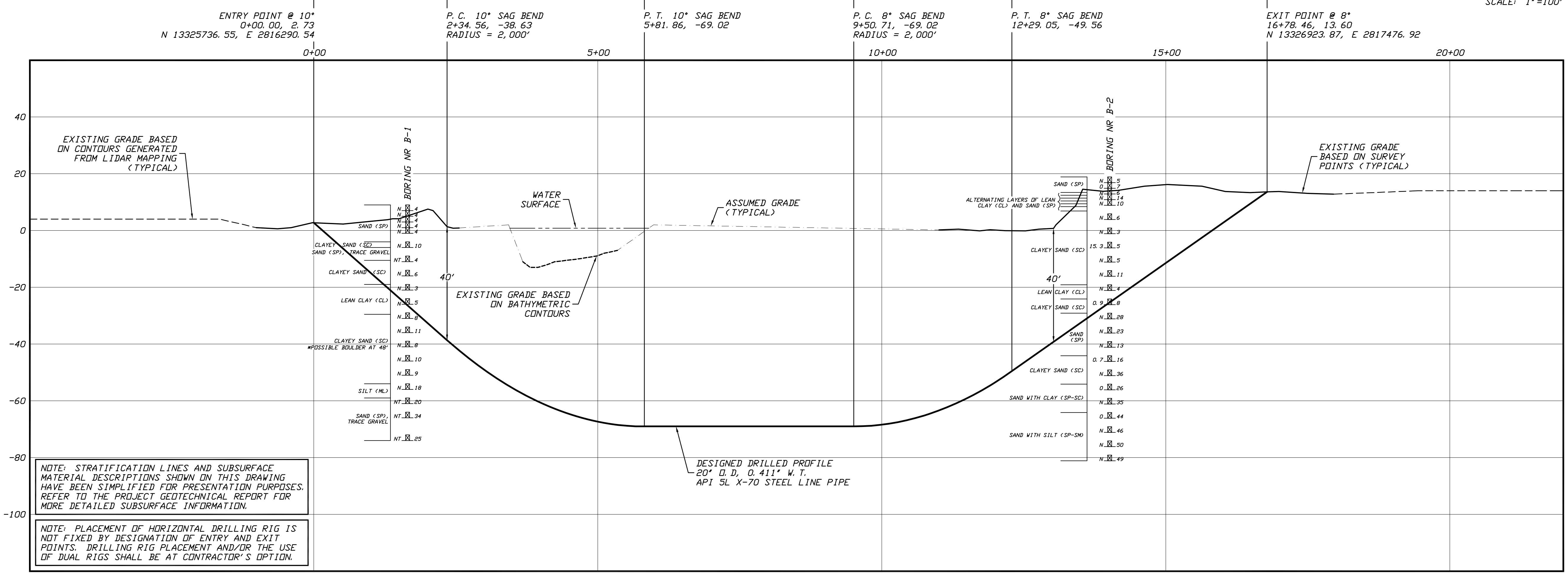
Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

200 100 50 0 — 20 10 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 ⊠ 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT DATED DECEMBER 2015 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF THE NOTTAWAY RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SOUTHAMPTON COUNTY, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	02/04/16	JSP	JSP	SHOWN FOR D-SIZED PLOT	NOTTAWAY	1

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
1	07/13/16	UPDATE HDD ALIGNMENT & BORING LOCATIONS	ACM	DMP	JSP

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-033

Nottaway River R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	JSP
Crossing :	20" Nottaway River Crossing	Date :	2/4/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

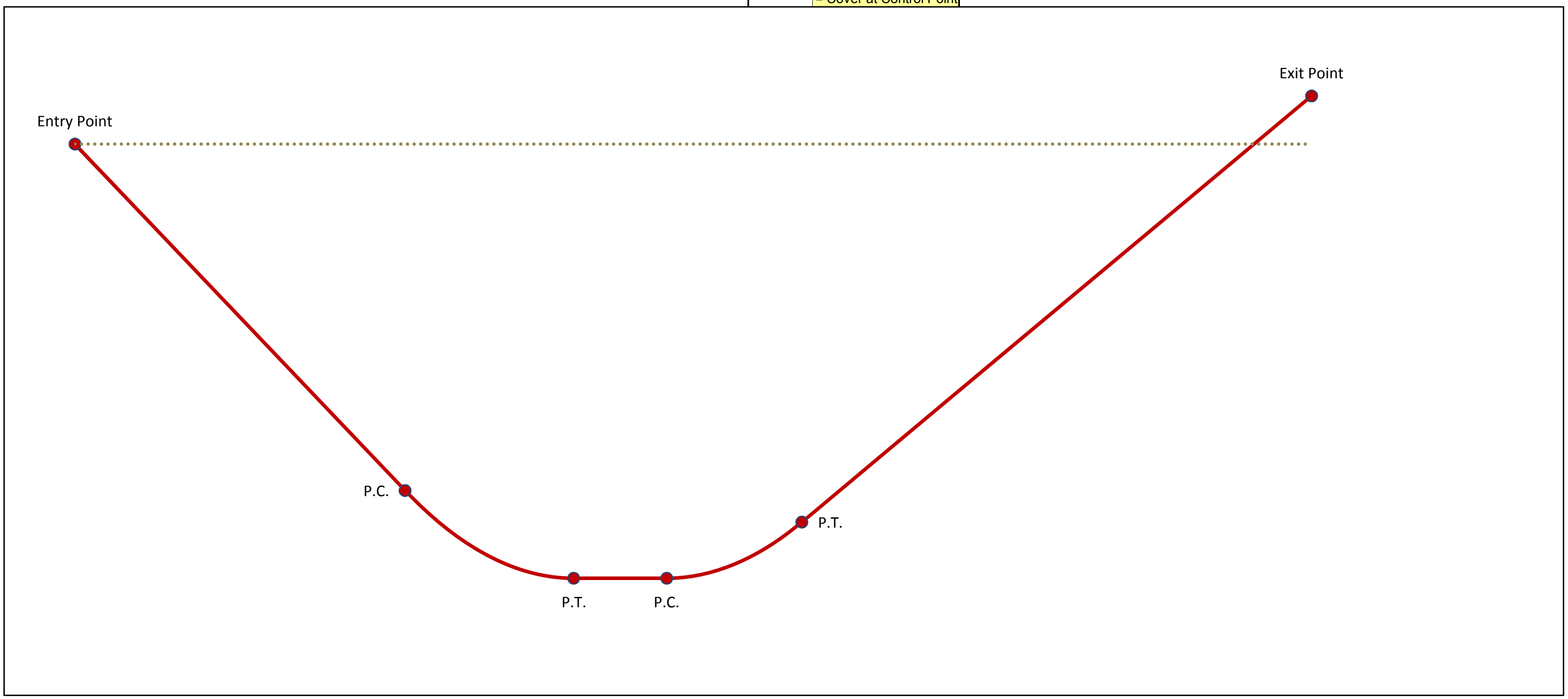
Nottaway River R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	2.40	10.00				107,890
Entry Tangent						465.94		
Entry Sag Bend	PC	448.86	-78.51					92,874
	PI	565.17	-99.01	10.00	1350	235.62	83,129	
	PT	683.28	-99.01				0	73,384
Bottom Tangent				0.00		129.18		
Exit Sag Bend	PC	812.46	-99.01					66,693
	PI	906.86	-99.01	8.00	1350	188.50	57,218	
	PT	1000.35	-85.88				0	47,744
Exit Tangent						715.08		
Exit Point		1708.46	13.64	8.00	Above Ground Load			0
Drilling Mud			2.40	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Nottaway River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	715.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	23,334	lb
Fluidic Drag = $12 \pi D L C_d$ =	13,479	lb
Axial Segment Weight = $W_e L \sin\theta$ =	10,931	lb
Pulling Load on Exit Tangent =	**47,744**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	57,218	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	3.29	ft	$j = [(E I) / T]^{1/2}$ =	784	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.0E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	214.91	
$U = (12 L) / j$ =	2.88		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	23,252	lb
Bending Frictional Drag = $2 \mu N$ =	13,951	lb			
Fluidic Drag = $12 \pi D L C_d$ =	3,553	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**18,949**	**lb**			
Total Pulling Load =	**66,693**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	129.2	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = $W_e L \mu$ =	4,257	lb
Fluidic Drag = $12 \pi D L C_d$ =	2,435	lb
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**6,692**	**lb**
Total Pulling Load =	**73,384**	**lb**

Nottaway River R0 Installation Stress Analysis (worst-case).xlsm

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Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6 ft	Average Tension, T =	83,129 lb
Segment Angle with Horizontal, θ =	10.0 °	Radius of Curvature, R =	1,350 ft
Deflection Angle, α =	5.0 °	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8 lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	5.14 ft	$j = [(E I) / T]^{1/2}$ =	651
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.7E+05	$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	389.90
$U = (12 L) / j$ =	4.35	$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	28,840 lb
Bending Frictional Drag = $2 \mu N$ =	17,304 lb		
Fluidic Drag = $12 \pi D L C_d$ =	4,441 lb		
Axial Segment Weight = $W_e L \sin\theta$ =	-2,256 lb	Negative value indicates axial weight applied in direction of installation	
Pulling Load on Entry Sag Bend =	**19,490 lb**		
Total Pulling Load =	**92,874 lb**		

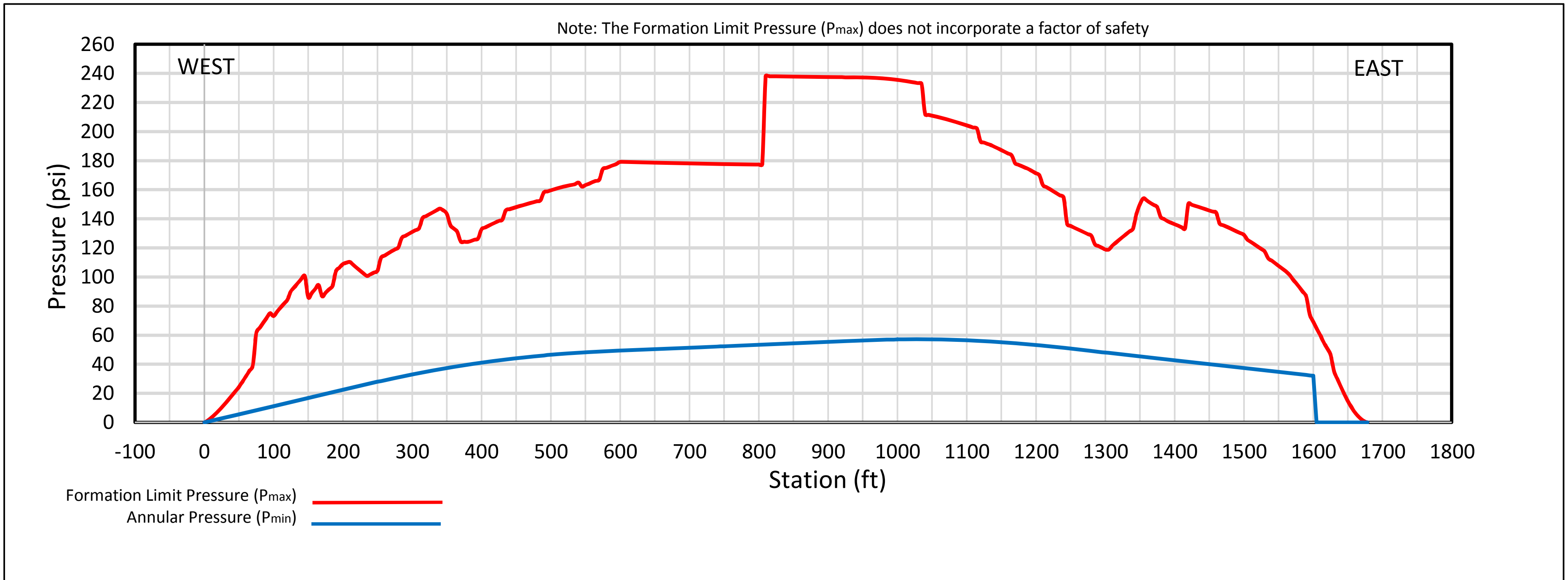
Entry Tangent - Summary of Pulling Load Calculations

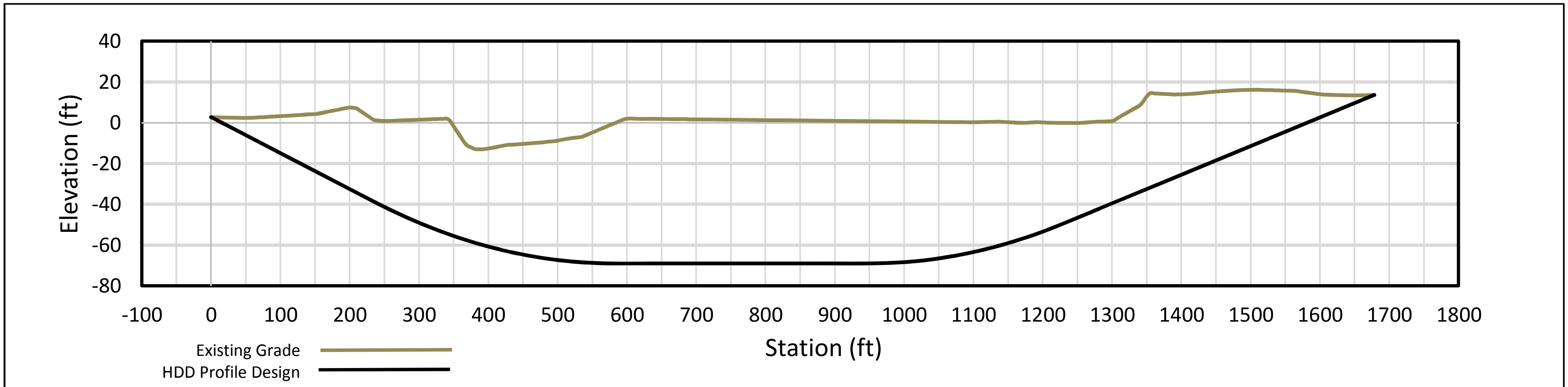
Segment Length, L =	465.9 ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8 lb/ft
Entry Angle, θ =	10.0 °		

Frictional Drag = $W_e L \mu \cos\theta$ =	15,120 lb	
Fluidic Drag = $12 \pi D L C_d$ =	8,783 lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-8,887 lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**15,016 lb**	
Total Pulling Load =	**107,890 lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,266	ok	0	ok	0	ok	0.07	ok	0.01	ok
	3,672	ok	0	ok	1227	ok	0.06	ok	0.04	ok
PC										
	3,672	ok	17,901	ok	1227	ok	0.45	ok	0.21	ok
	2,901	ok	17,901	ok	1538	ok	0.44	ok	0.22	ok
PT										
	2,901	ok	0	ok	1538	ok	0.05	ok	0.05	ok
	2,637	ok	0	ok	1538	ok	0.04	ok	0.05	ok
PC										
	2,637	ok	17,901	ok	1538	ok	0.43	ok	0.22	ok
	1,888	ok	17,901	ok	1339	ok	0.42	ok	0.19	ok
PT										
	1,888	ok	0	ok	1339	ok	0.03	ok	0.04	ok
Exit Point	0	ok	0	ok	-170	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH NOTTAWAY RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 7/12/2016

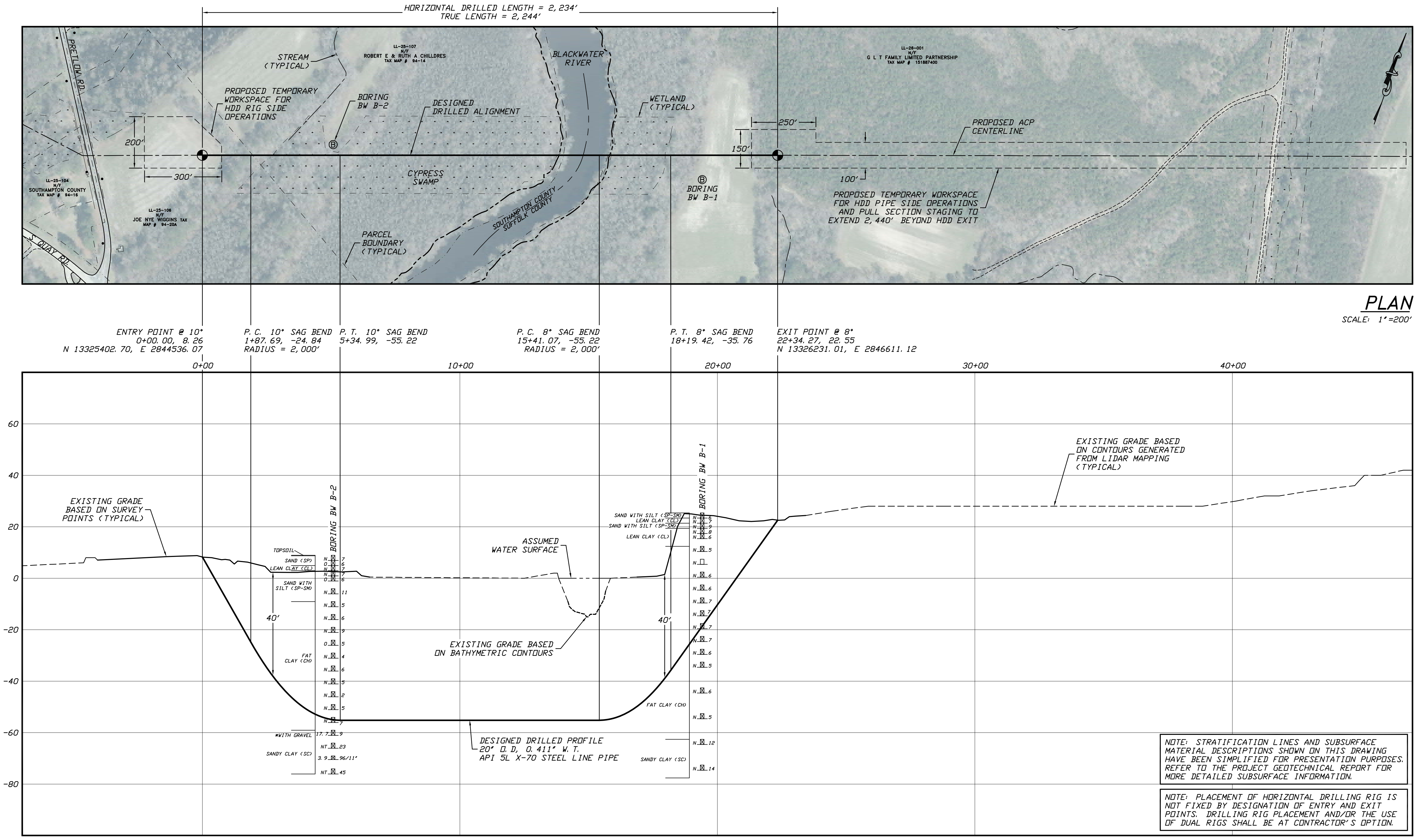
Revision: 1

J.D.Hair&Associates, Inc.

Blackwater River

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

53 — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE DRAFT PROJECT GEOTECHNICAL REPORT DATED DECEMBER 2015 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
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TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF THE BLACKWATER RIVER
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SOUTHAMPTON & SUFFOLK COUNTIES, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	02/09/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	BLACKWATER	1

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
1	04/28/16	UPDATE HDD ALIGNMENT BASED ON SURVEYED CL	ACM	DMP	JSP

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-039

Blackwater River R1 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	ACM
Crossing :	20" Blackwater River Crossing		Date :	6/15/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC			

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Blackwater River R1 Installation Stress Analysis (worst-case).xlsm

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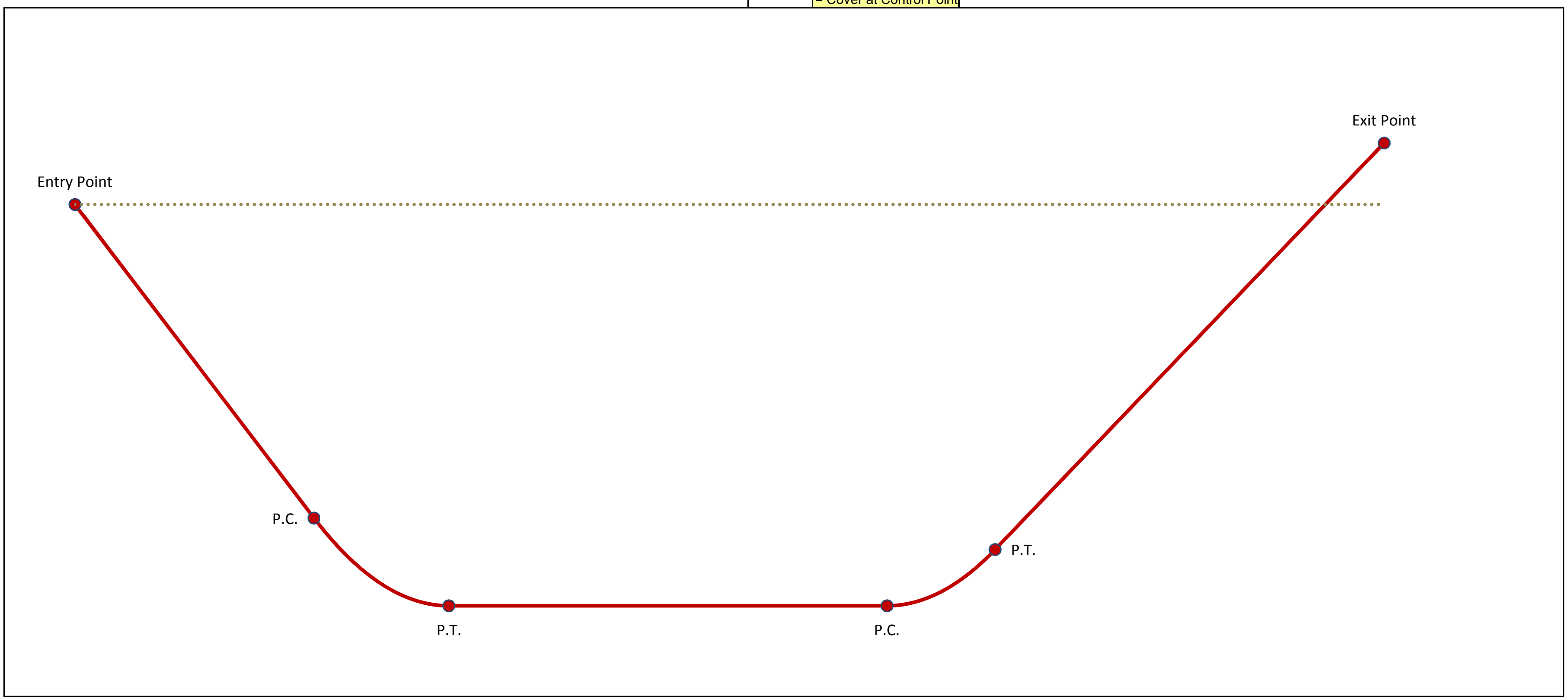
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	8.51	10.00				138,721
Entry Tangent						421.66		
Entry Sag Bend	PC	405.25	-64.71					125,132
	PI	521.57	-85.22	10.00	1350	235.62	114,477	
	PT	639.68	-85.22				0	103,822
Bottom Tangent				0.00		760.95		
Exit Sag Bend	PC	1400.63	-85.22					64,404
	PI	1495.03	-85.22	8.00	1350	188.50	54,983	
	PT	1588.51	-72.08				0	45,562
Exit Tangent						682.40		
Exit Point		2264.27	22.89	8.00	Above Ground Load			0
Drilling Mud			8.51	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Step 2, Drilled Path Input

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Blackwater River R1 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	682.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e\ L\ \mu \cos\theta$ =	22,268	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	12,863	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	10,432	lb
Pulling Load on Exit Tangent =	**45,562**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	54,983	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R\ [1 - \cos(\alpha/2)]$ =	3.29	ft	$j = [(E\ I) / T]^{1/2}$ =	800	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	2.9E+05		$X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ =	210.19	
$U = (12\ L) / j$ =	2.83		$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$	23,074	lb
Bending Frictional Drag = $2\ \mu\ N$ =	13,844	lb			
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	3,553	lb			
Axial Segment Weight = $W_e\ L \sin\theta$ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**18,842**	**lb**			
Total Pulling Load =	**64,404**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	760.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = $W_e\ L\ \mu$ =	25,075	lb
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ =	14,344	lb
Axial Segment Weight = $W_e\ L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**39,418**	**lb**
Total Pulling Load =	**103,822**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 114,477 lb
Radius of Curvature, R = 1,350 ft
Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

$h = R\,[1 - \cos(\alpha/2)]$ = 5.14 ft

$j = [(E\,I) / T]^{1/2}$ = 554

$Y = [18\,(L)^2] - [(j)^2\,(1 - \cosh(U/2)^{-1}]$ = 7.4E+05

$X = (3\,L) - [\,(j / 2)\tanh(U/2)\,]$ = 433.03

$U = (12\,L) / j$ = 5.10

$N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X / 12)$ = 31,873 lb

Bending Frictional Drag = $2\,\mu\,N$ = 19,124 lb

Fluidic Drag = $12\,\pi\,D\,L\,C_d$ = 4,441 lb

Axial Segment Weight = $W_e\,L\sin\theta$ = -2,256 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 21,309 lb
Total Pulling Load = 125,132 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 421.7 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e\,L\,\mu\cos\theta$ = 13,683 lb

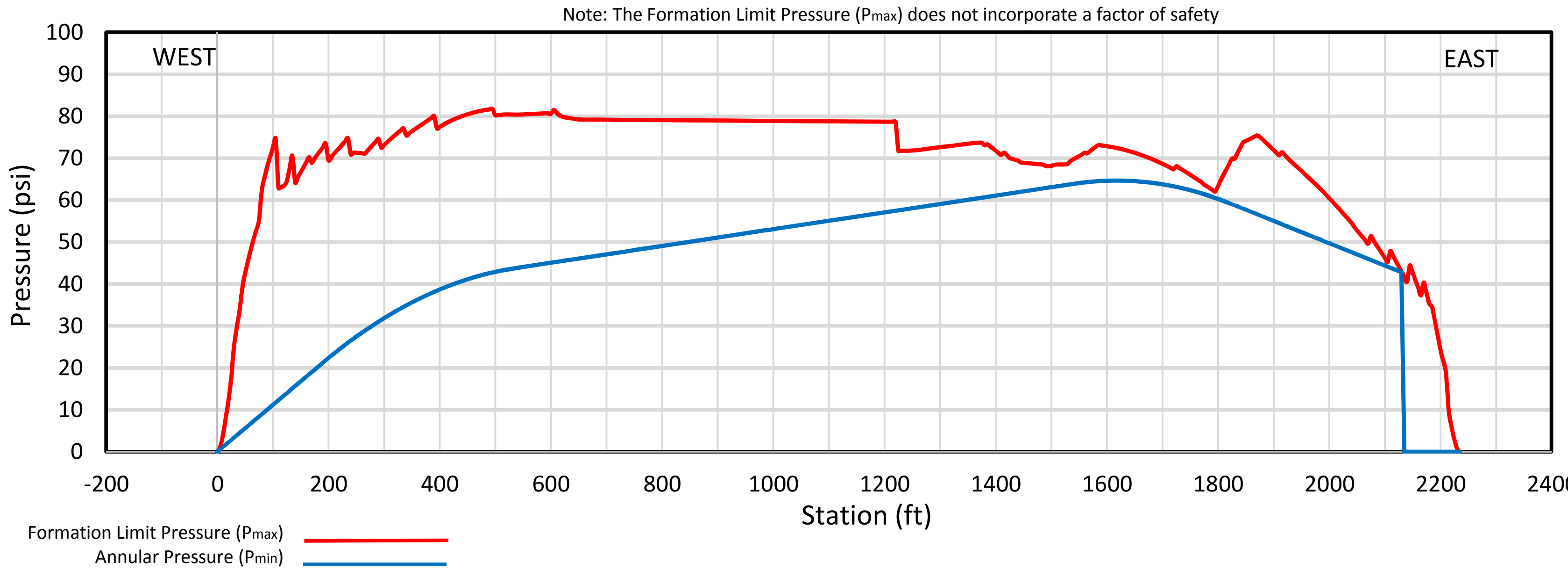
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ = 7,948 lb

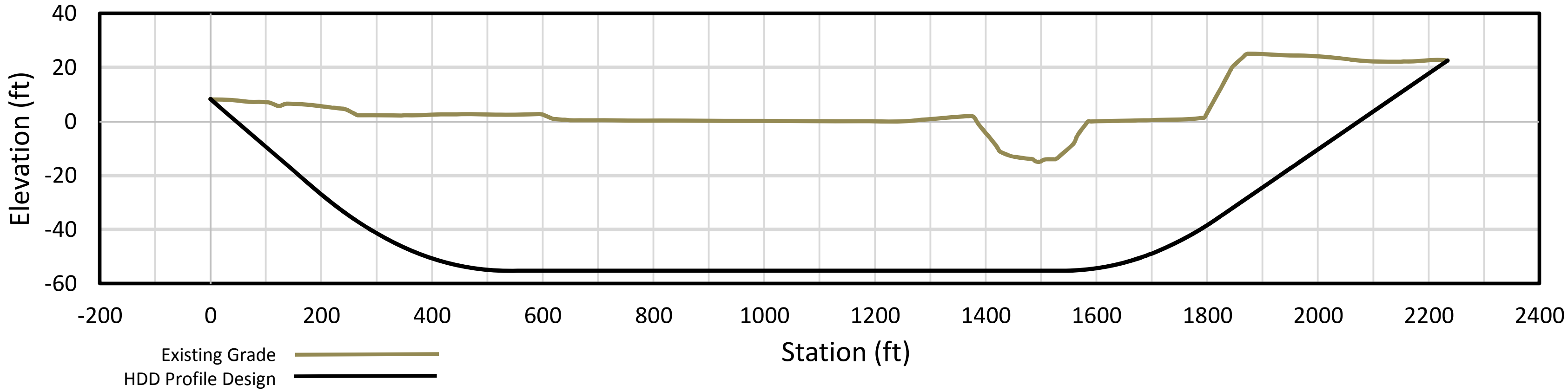
Axial Segment Weight = $W_e\,L\sin\theta$ = -8,043 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 13,589 lb
Total Pulling Load = 138,721 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	5,485	ok	0	ok	0	ok	0.09	ok	0.01	ok
	4,947	ok	0	ok	1110	ok	0.08	ok	0.04	ok
PC										
	4,947	ok	17,901	ok	1110	ok	0.47	ok	0.22	ok
	4,105	ok	17,901	ok	1422	ok	0.46	ok	0.23	ok
PT										
	4,105	ok	0	ok	1422	ok	0.07	ok	0.05	ok
	2,546	ok	0	ok	1422	ok	0.04	ok	0.04	ok
PC										
	2,546	ok	17,901	ok	1422	ok	0.43	ok	0.21	ok
	1,801	ok	17,901	ok	1222	ok	0.42	ok	0.18	ok
PT										
	1,801	ok	0	ok	1222	ok	0.03	ok	0.03	ok
Exit Point	0	ok	0	ok	-218	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH BLACKWATER RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 1/12/2016

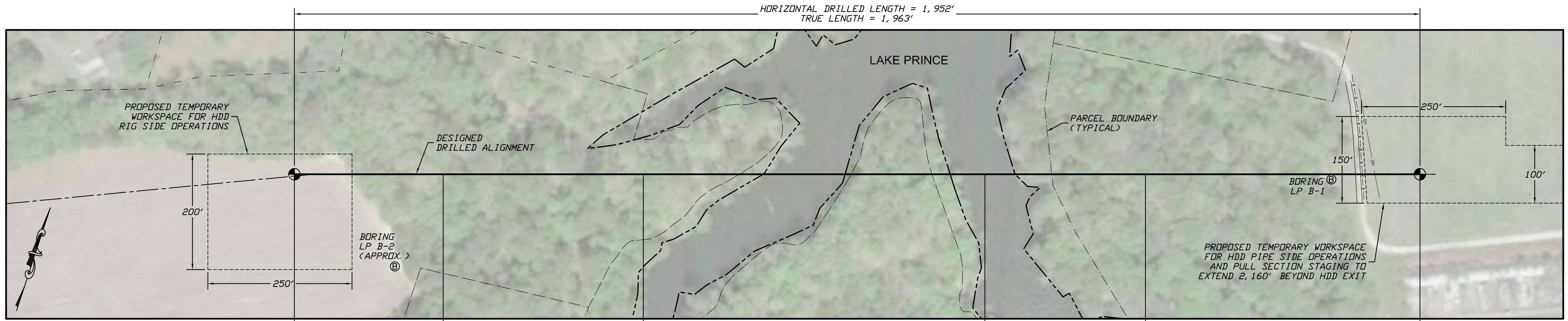
Revision: 1

J.D.Hair&Associates, Inc.

Lake Prince

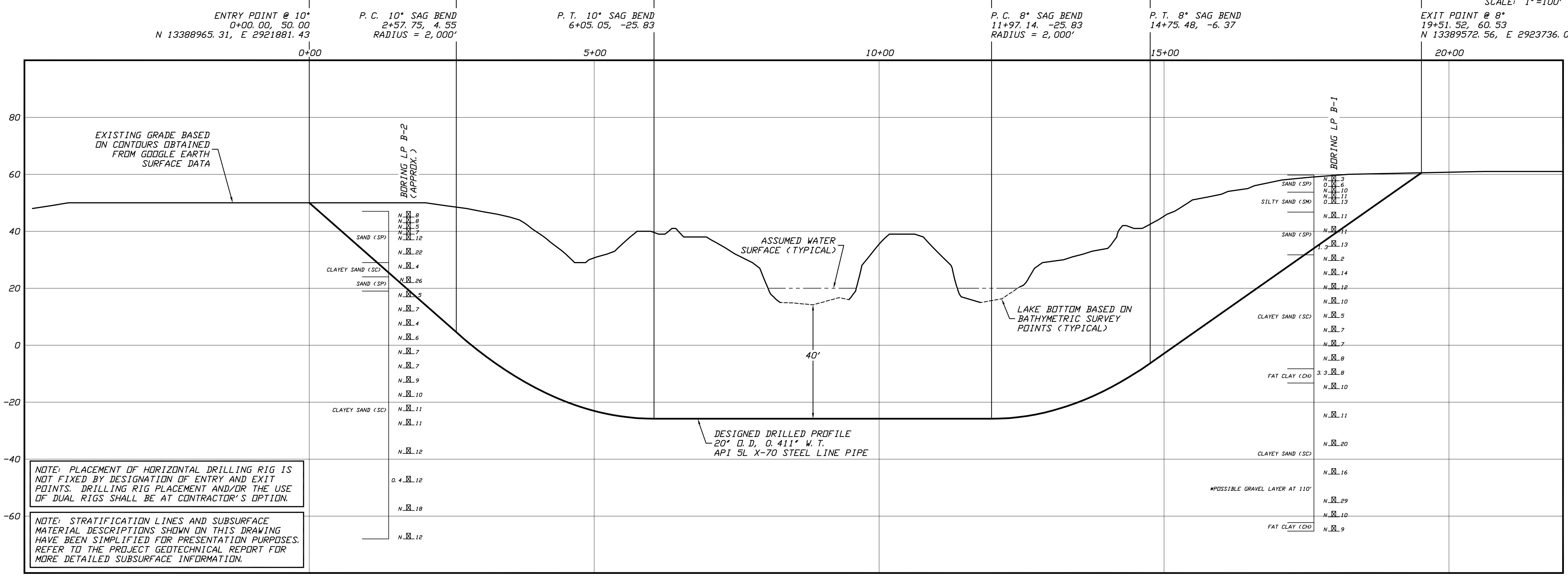
<u>Supporting Information</u>

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

SCALE: 1"=100'



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE DRAFT PROJECT GEOTECHNICAL REPORT DATED DECEMBER 2015 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF LAKE PRINCE
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SUFFOLK, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	02/12/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	LAKE PRINCE	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-061

Lake Prince R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	20" Lake Prince Crossing	Date :	2/9/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	
HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Lake Prince R0 Installation Stress Analysis (worst-case).xlsm

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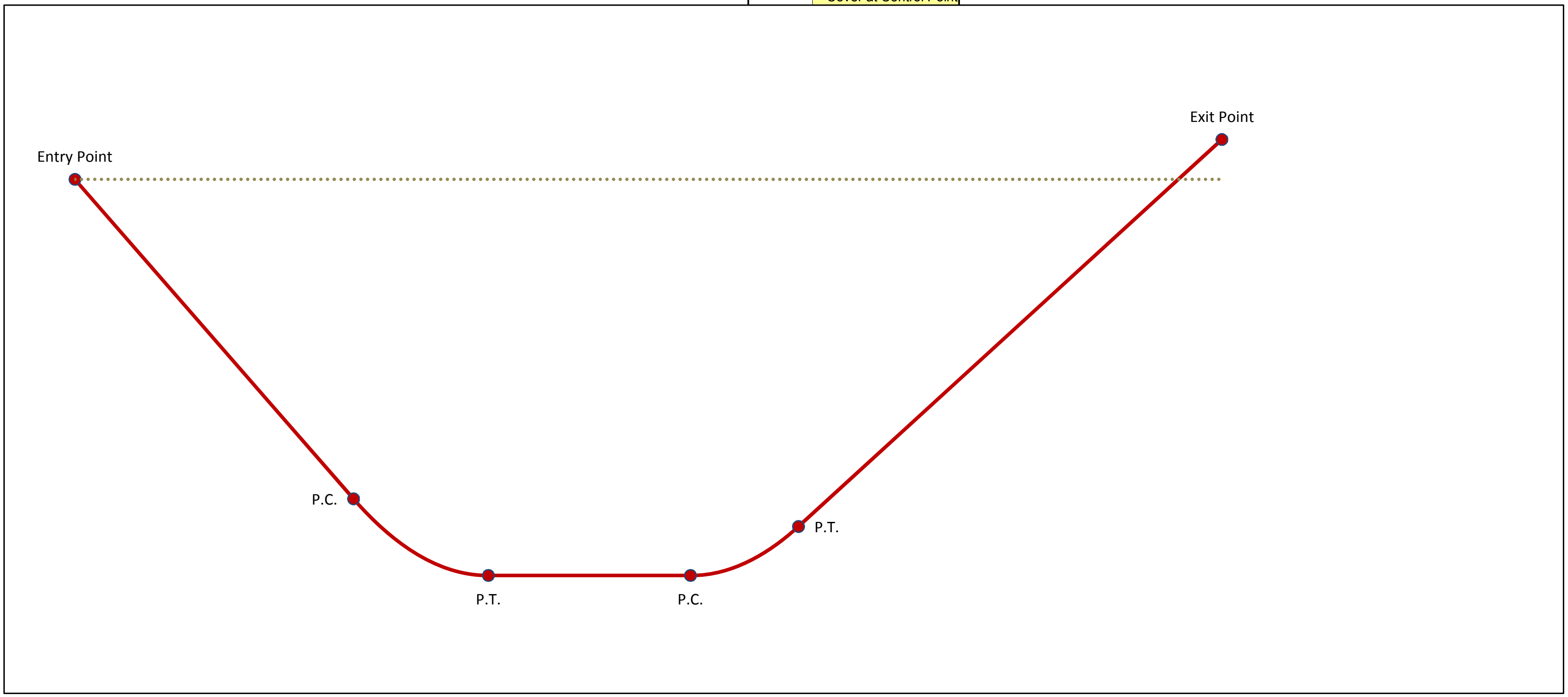
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	50.00	10.00				122,924
Entry Tangent						491.34		
Entry Sag Bend	PC	473.88	-35.32					107,090
	PI	590.19	-55.83	10.00	1350	235.62	96,943	
	PT	708.30	-55.83				0	86,797
Bottom Tangent				0.00		350.87		
Exit Sag Bend	PC	1059.17	-55.83					68,621
	PI	1153.57	-55.83	8.00	1350	188.50	59,102	
	PT	1247.05	-42.69				0	49,583
Exit Tangent						742.61		
Exit Point		1982.44	60.66	8.00	Above Ground Load			0
Drilling Mud			50.00	(Graph = ·········)				
Ballast				(Graph = - - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Step 2, Drilled Path Input

Lake Prince R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	742.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	º			

Frictional Drag = W_e L μ cosθ =	24,233	lb
Fluidic Drag = 12 π D L C_d =	13,998	lb
Axial Segment Weight = W_e L sinθ =	11,352	lb
Pulling Load on Exit Tangent =	**49,583**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	59,102	lb
Segment Angle with Horizontal, θ =	-8.0	º	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	º	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

h = R [1 - cos(α/2)] =	3.29	ft	$j = [(E\ I) / T]^{1/2}$ =	772	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.1E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	218.76	
U = (12 L) / j =	2.93		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	23,402	lb
Bending Frictional Drag = 2 μ N =	14,041	lb			
Fluidic Drag = 12 π D L C_d =	3,553	lb			
Axial Segment Weight = W_e L sinθ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**19,039**	**lb**			
Total Pulling Load =	**68,621**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	350.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	11,562	lb
Fluidic Drag = 12 π D L C_d =	6,614	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**18,176**	**lb**
Total Pulling Load =	**86,797**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6	ft	Average Tension, T =	96,943	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	5.14	ft	$j = [(E\ I) / T]^{1/2}$ =	602	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	7.1E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	411.11	
$U = (12 L) / j$ =	4.69		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	30,178	lb
Bending Frictional Drag = $2 \mu N$ =	18,107	lb			
Fluidic Drag = $12 \pi D L C_d$ =	4,441	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-2,256	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**20,293**	**lb**			
Total Pulling Load =	**107,090**	**lb**			

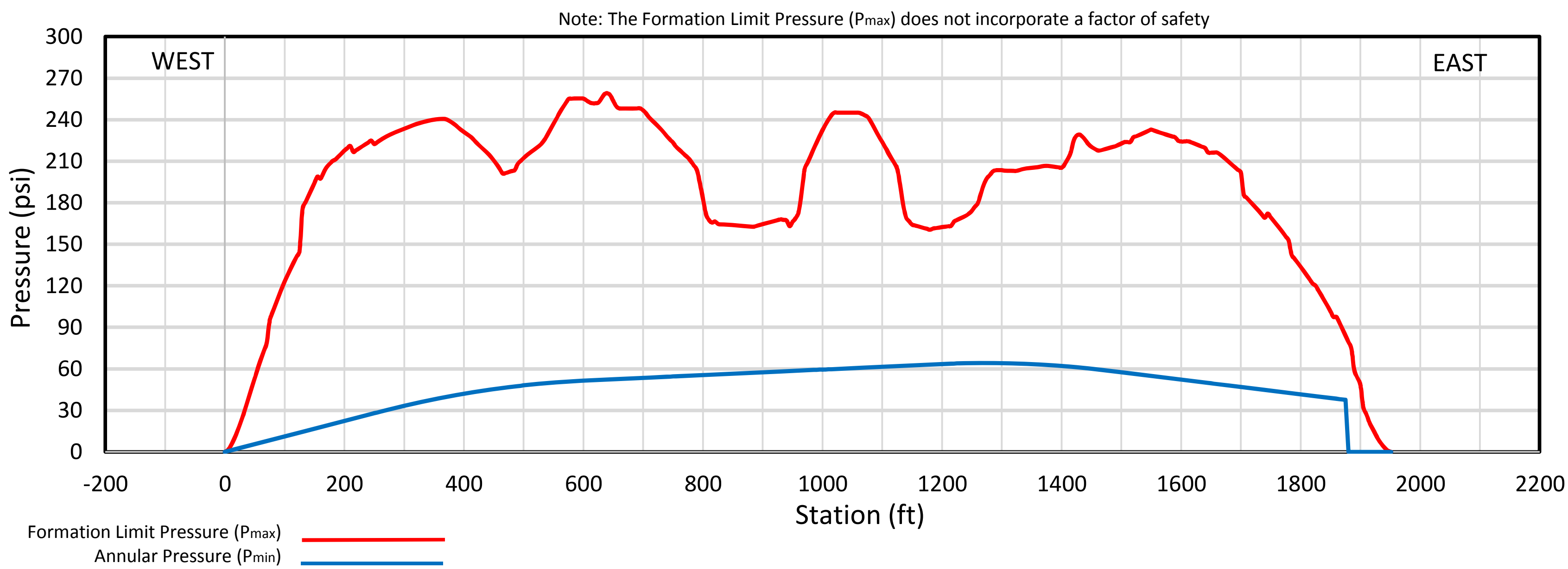
Entry Tangent - Summary of Pulling Load Calculations

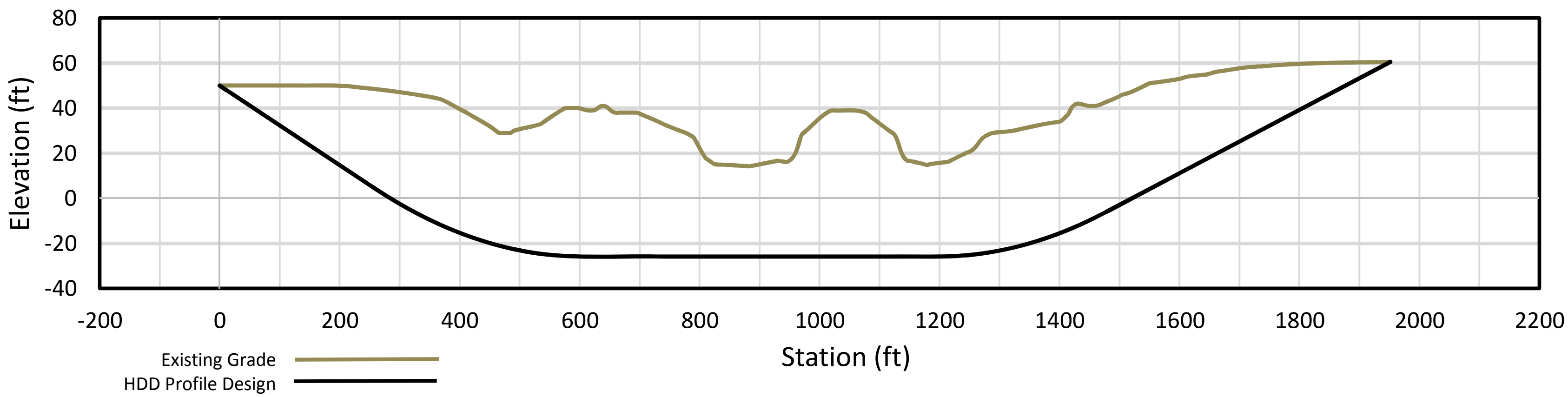
Segment Length, L =	491.3	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	15,945	lb	
Fluidic Drag = $12 \pi D L C_d$ =	9,262	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-9,372	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**15,835**	**lb**	
Total Pulling Load =	**122,924**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,860	ok	0	ok	0	ok	0.08	ok	0.01	ok
	4,234	ok	0	ok	1294	ok	0.07	ok	0.04	ok
PC										
	4,234	ok	17,901	ok	1294	ok	0.46	ok	0.22	ok
	3,432	ok	17,901	ok	1605	ok	0.45	ok	0.23	ok
PT										
	3,432	ok	0	ok	1605	ok	0.05	ok	0.06	ok
	2,713	ok	0	ok	1605	ok	0.04	ok	0.06	ok
PC										
	2,713	ok	17,901	ok	1605	ok	0.44	ok	0.22	ok
	1,960	ok	17,901	ok	1406	ok	0.42	ok	0.20	ok
PT										
	1,960	ok	0	ok	1406	ok	0.03	ok	0.04	ok
Exit Point	0	ok	0	ok	-162	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH LAKE PRINCE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

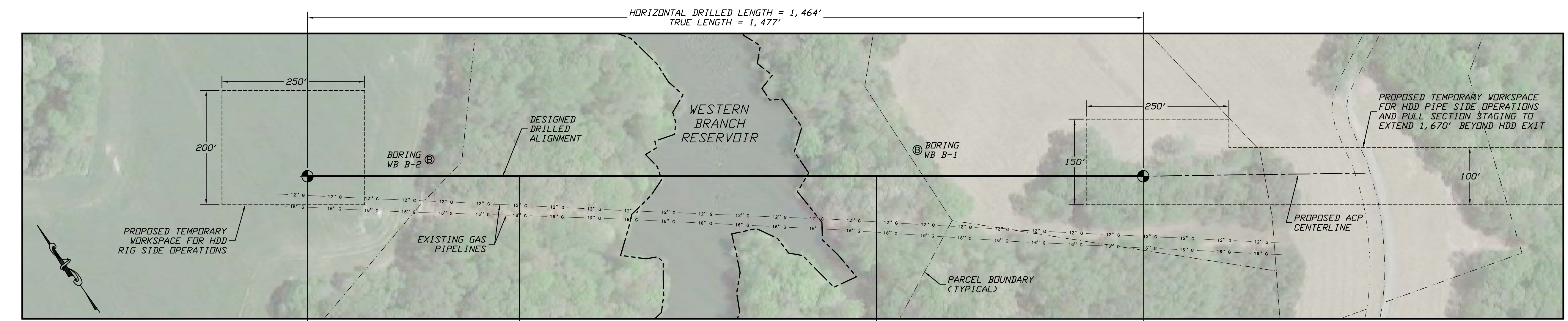
Date: 7/12/2016

Revision: 0

Western Branch Reservoir

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

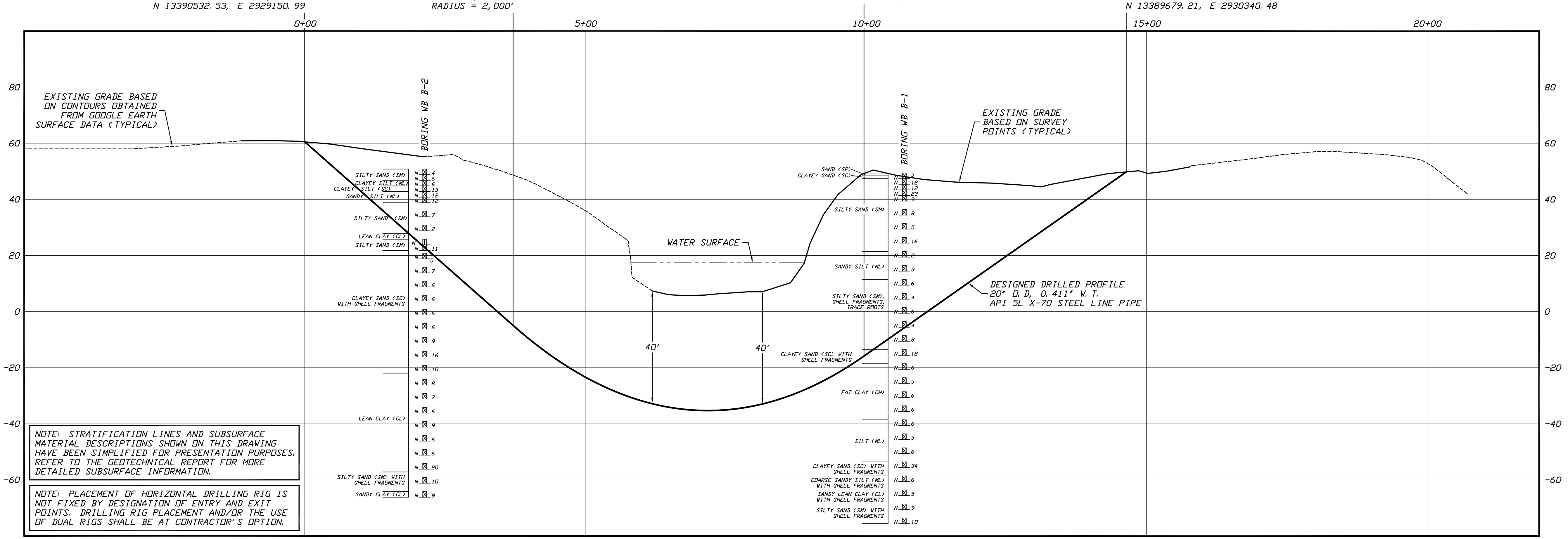
SCALE: 1"=100'

ENTRY POINT @ 10°
0+00.00, 60.51
N 13390532.53, E 2929150.99

P.C. 18° SAG BEND
3+71.17, -4.93
RADIUS = 2,000'

P.T. 18° SAG BEND
9+96.82, -15.85

EXIT POINT @ 8°
14+63.91, 49.79
N 13389679.21, E 2930340.48



PROFILE

SCALE: 1"=100' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 N 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
— PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

53 — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

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2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
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3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

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1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

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2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 15 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF WESTERN BRANCH RESERVOIR BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SUFFOLK, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	05/20/16	ACM	JSP	SHOWN FOR D-SIZED PLOT	WB RESERVOIR	1

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
1	06/10/16	REVISE GEOTECHNICAL LEGEND	JSP	JSP	JSP

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-063

Western Branch Reservoir R1 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	ACM
Crossing :	20" Western Branch Reservoir Crossing	Date :	6/15/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer, up to 11' deeper than design with 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Western Branch Reservoir R1 Installation Stress Analysis (worst-case).xlsm

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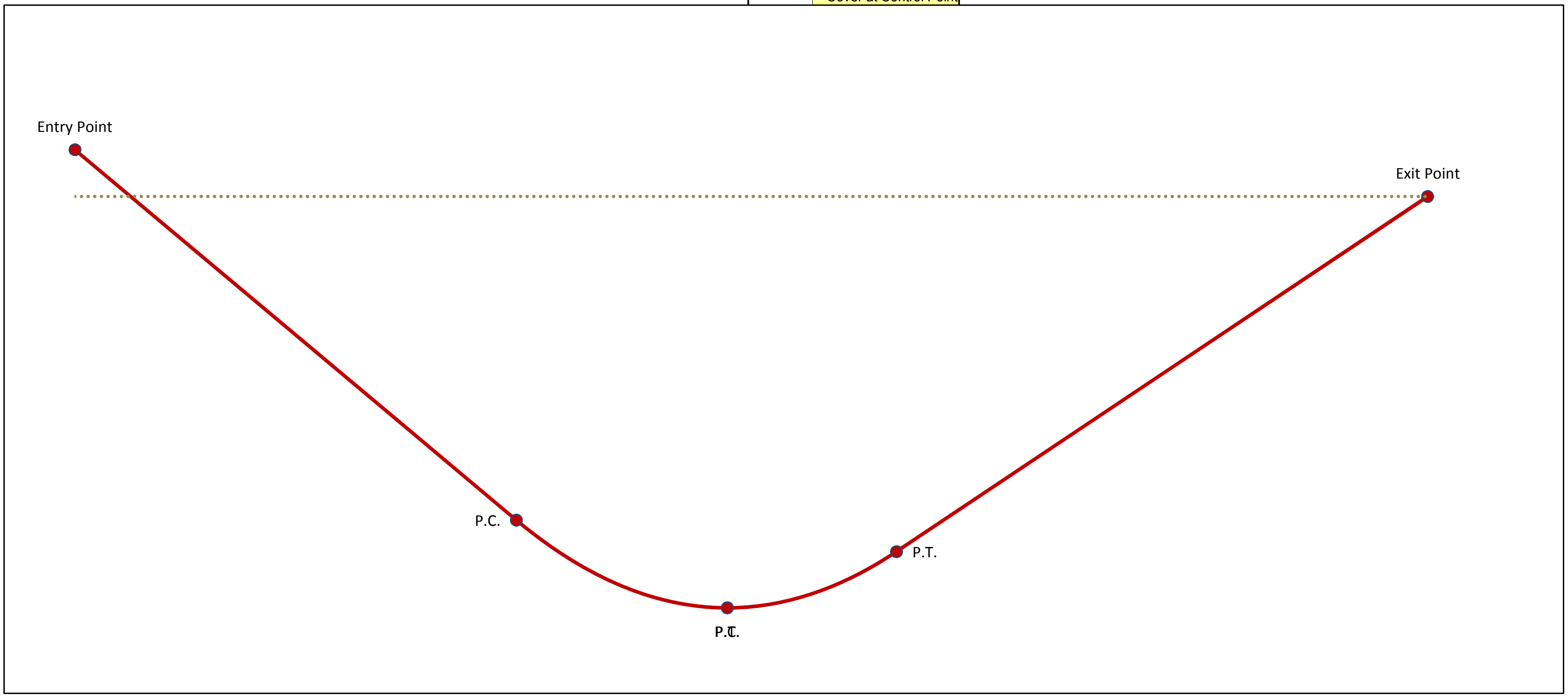
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	60.67	10.00				93,043
Entry Tangent						498.42		
Entry Sag Bend	PC	480.85	-25.88					76,980
	PI	597.17	-46.39	10.00	1350	235.62	67,685	
	PT	715.28	-46.39				0	58,390
Bottom Tangent				0.00		0.09		
Exit Sag Bend	PC	715.37	-46.39					58,385
	PI	809.77	-46.39	8.00	1350	188.50	49,105	
	PT	903.25	-33.25				0	39,825
Exit Tangent						596.47		
Exit Point		1493.91	49.76	8.00	Above Ground Load			0
Drilling Mud			49.76	(Graph = ········)				
Ballast				(Graph = – – – – –)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

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Western Branch Reservoir R1 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	596.5	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	19,464	lb
Fluidic Drag = 12 π D L C_d =	11,243	lb
Axial Segment Weight = W_e L sinθ =	9,118	lb
Pulling Load on Exit Tangent =	**39,825**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	49,105	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	3.29	ft	$j = [(E I) / T]^{1/2}$ =	846	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.8E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	196.96	
$U = (12 L) / j$ =	2.67		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$	22,605	lb
Bending Frictional Drag = 2 μ N =	13,563	lb			
Fluidic Drag = 12 π D L C_d =	3,553	lb			
Axial Segment Weight = W_e L sinθ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**18,560**	**lb**			
Total Pulling Load =	**58,385**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	3	lb
Fluidic Drag = 12 π D L C_d =	2	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**5**	**lb**
Total Pulling Load =	**58,390**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6	ft	Average Tension, T =	67,685	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	5.14	ft	$j = [(E\ I) / T]^{1/2}$ =	721	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.2E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	360.37	
$U = (12 L) / j$ =	3.92		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	27,341	lb
Bending Frictional Drag = $2 \mu N$ =	16,405	lb			
Fluidic Drag = $12 \pi D L C_d$ =	4,441	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-2,256	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**18,590**	**lb**			
Total Pulling Load =	**76,980**	**lb**			

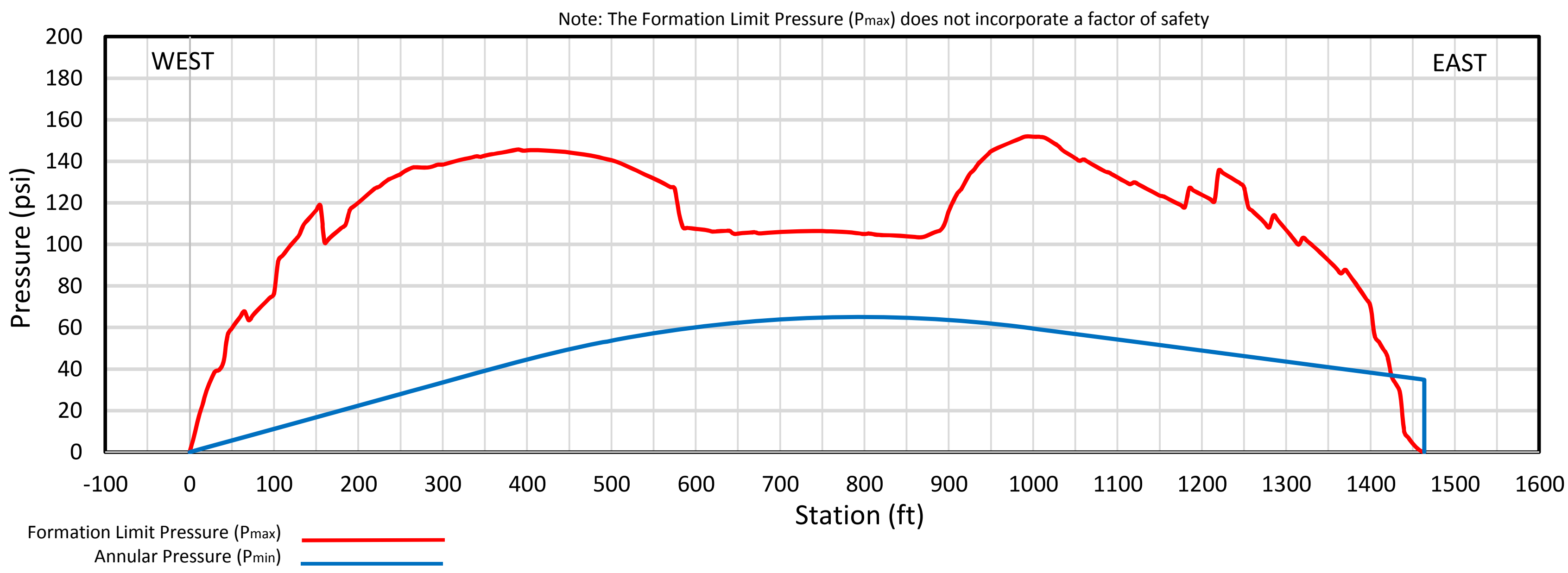
Entry Tangent - Summary of Pulling Load Calculations

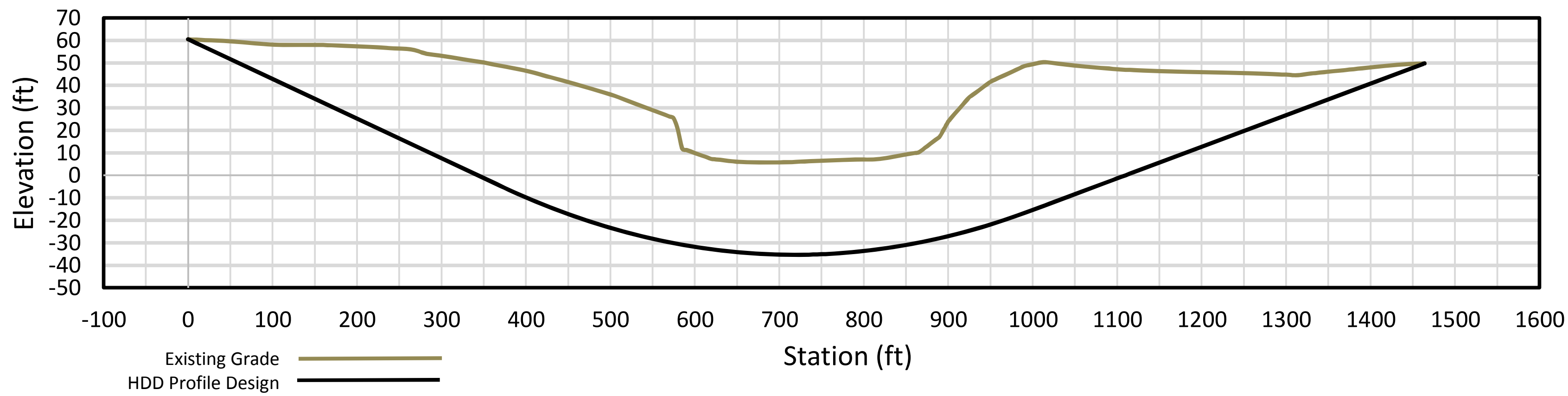
Segment Length, L =	498.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	16,175	lb	
Fluidic Drag = $12 \pi D L C_d$ =	9,395	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-9,507	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**16,063**	**lb**	
Total Pulling Load =	**93,043**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	3,679	ok	0	ok	0	ok	0.06	ok	0.00	ok
	3,044	ok	0	ok	1147	ok	0.05	ok	0.03	ok
PC										
	3,044	ok	17,901	ok	1147	ok	0.44	ok	0.19	ok
	2,309	ok	17,901	ok	1458	ok	0.43	ok	0.20	ok
PT										
	2,309	ok	0	ok	1458	ok	0.04	ok	0.05	ok
	2,308	ok	0	ok	1458	ok	0.04	ok	0.05	ok
PC										
	2,308	ok	17,901	ok	1458	ok	0.43	ok	0.20	ok
	1,575	ok	17,901	ok	1259	ok	0.42	ok	0.18	ok
PT										
	1,575	ok	0	ok	1259	ok	0.02	ok	0.03	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH WESTERN BRANCH RESERVOIR CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 6/16/2015 Revision: 1

J.D.Hair&Associates, Inc.

Nansemond River Tributary

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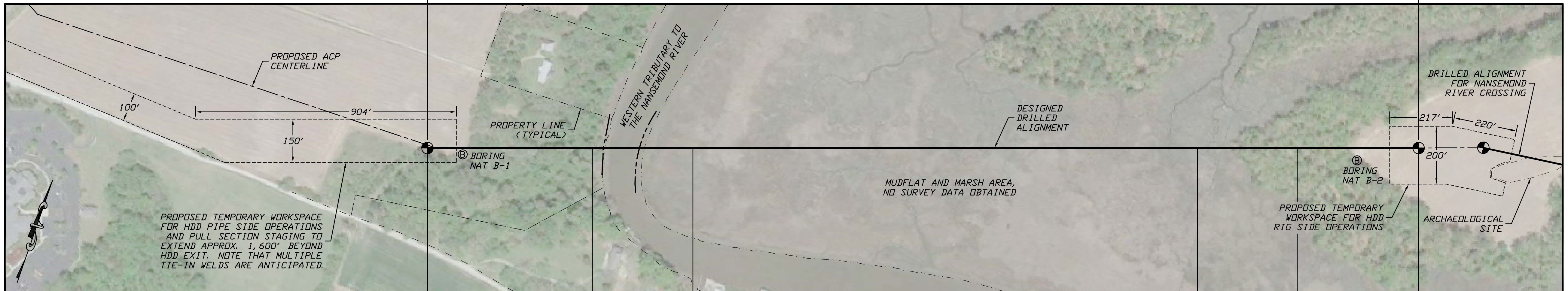
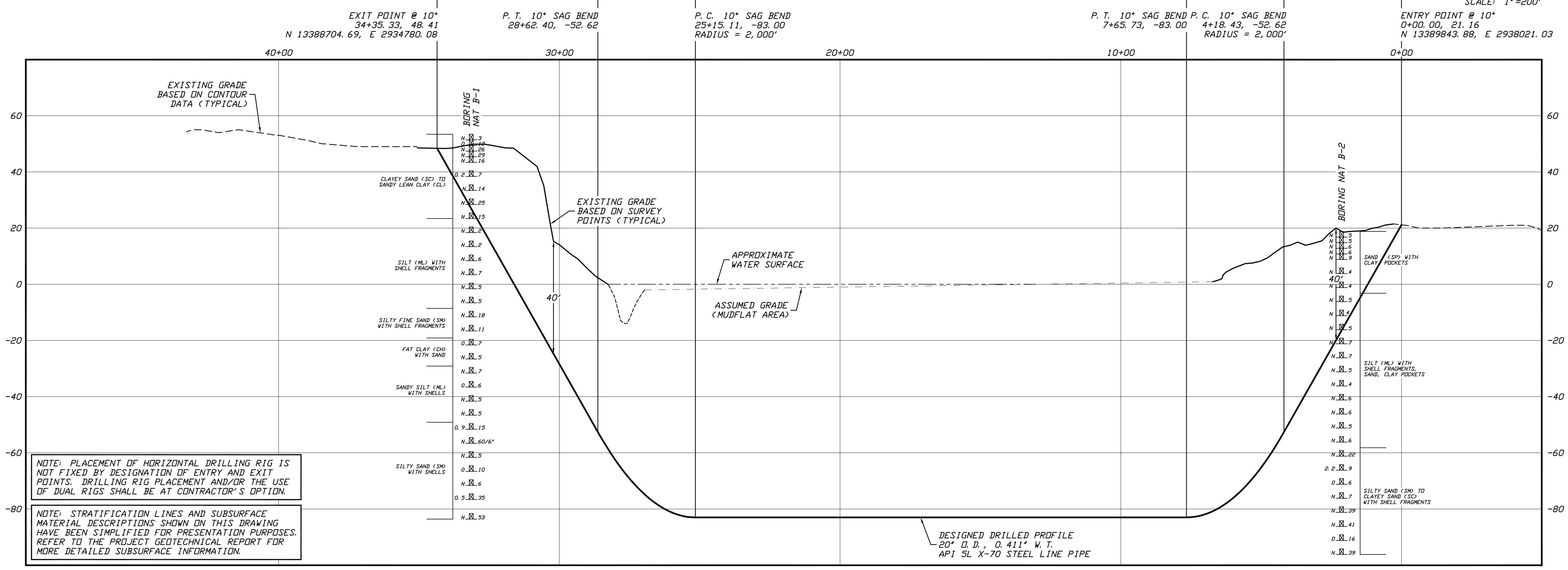


PLAN

SCALE: 1"=200'



PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

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BORING LOCATION

SPLIT SPOON SAMPLE

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ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF THE NANSEMOND RIVER TRIB. BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SUFFOLK, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	04/08/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	NANSEMOND TRIB	2

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.
2	06/10/16	UPDATED RIG SIDE WORKSPACE	ACM	JSP	JSP
1	04/29/16	LOWER DESIGN TO REDUCE RISK OF INAD. RETURNS	KMN	ACM	JSP

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-064

Nansemond Tributary R1 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	JSP
Crossing :	20" Nansemond Tributary Crossing	Date :	4/29/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,185	psi	

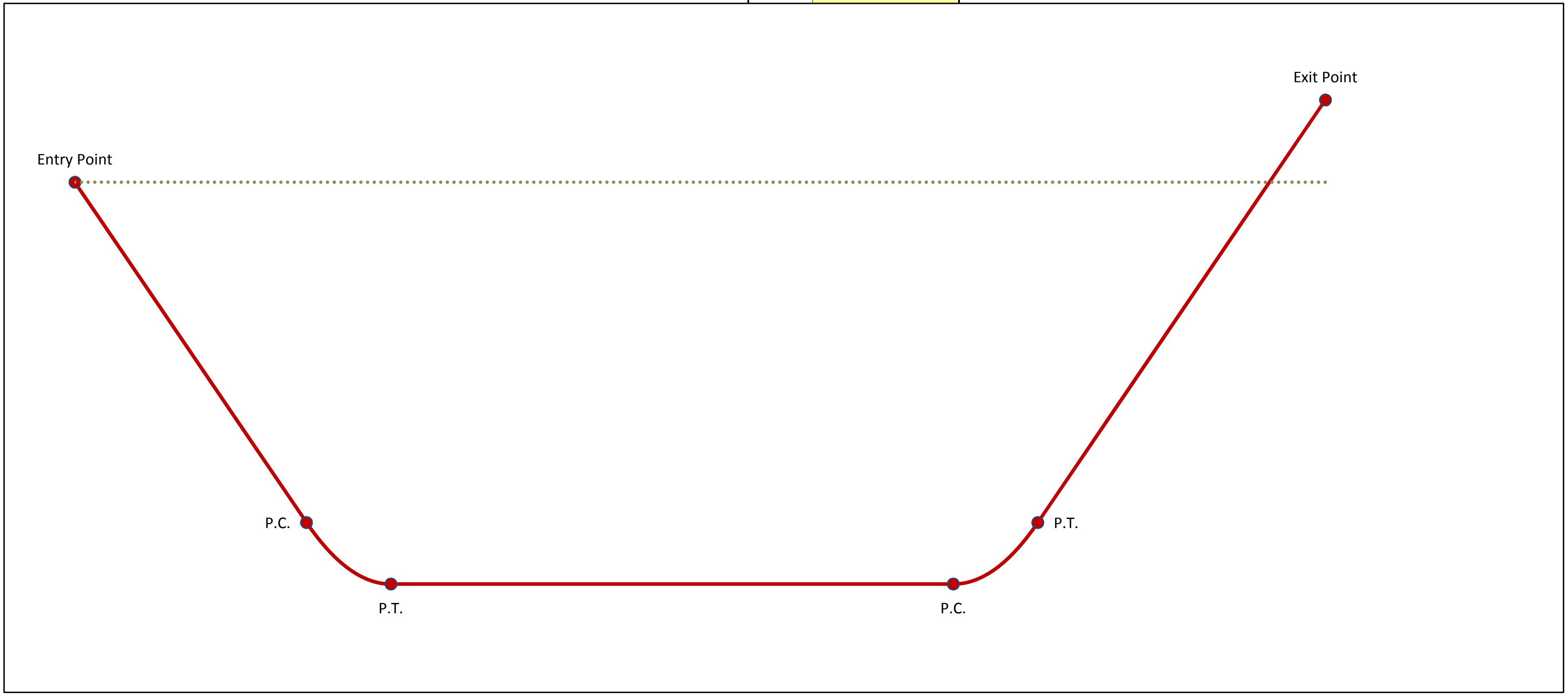
Nansemond Tributary R1 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	21.06	10.00				207,053
Entry Tangent						653.93		
Entry Sag Bend	PC	633.99	-92.49					185,978
	PI	750.31	-113.00	10.00	1350	235.62	173,618	
	PT	868.42	-113.00				0	161,257
Bottom Tangent				0.00		1563.09		
Exit Sag Bend	PC	2431.51	-113.00					80,286
	PI	2549.62	-113.00	10.00	1350	235.62	68,706	
	PT	2665.94	-92.49				0	57,125
Exit Tangent						811.73		
Exit Point		3465.33	48.47	10.00	Above Ground Load			0
Drilling Mud			21.06	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point

	= Cover at Control Point



Step 2, Drilled Path Input

Nansemond Tributary R1 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	811.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	10.0	°			

Frictional Drag = W_e L μ cosθ =	26,342	lb
Fluidic Drag = 12 π D L C_d =	15,301	lb
Axial Segment Weight = W_e L sinθ =	15,483	lb
Pulling Load on Exit Tangent =	**57,125**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6	ft	Average Tension, T =	68,706	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

h = R [1 - cos(α/2)] =	5.14	ft	$j = [(E\ I) / T]^{1/2}$ =	716	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	6.3E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	362.56	
U = (12 L) / j =	3.95		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	27,440	lb
Bending Frictional Drag = 2 μ N =	16,464	lb			
Fluidic Drag = 12 π D L C_d =	4,441	lb			
Axial Segment Weight = W_e L sinθ =	2,256	lb			
Pulling Load on Exit Sag Bend =	**23,161**	**lb**			
Total Pulling Load =	**80,286**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	1563.1	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	51,507	lb
Fluidic Drag = 12 π D L C_d =	29,464	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**80,971**	**lb**
Total Pulling Load =	**161,257**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6	ft	Average Tension, T =	173,618	lb
Segment Angle with Horizontal, θ =	10.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	5.14	ft	$j = [(E\ I) / T]^{1/2}$ =	450	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	8.1E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	482.62	
$U = (12 L) / j$ =	6.28		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	37,559	lb
Bending Frictional Drag = $2 \mu N$ =	22,535	lb			
Fluidic Drag = $12 \pi D L C_d$ =	4,441	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	-2,256	lb	Negative value indicates axial weight applied in direction of installation		
Pulling Load on Entry Sag Bend =	**24,721**	**lb**			
Total Pulling Load =	**185,978**	**lb**			

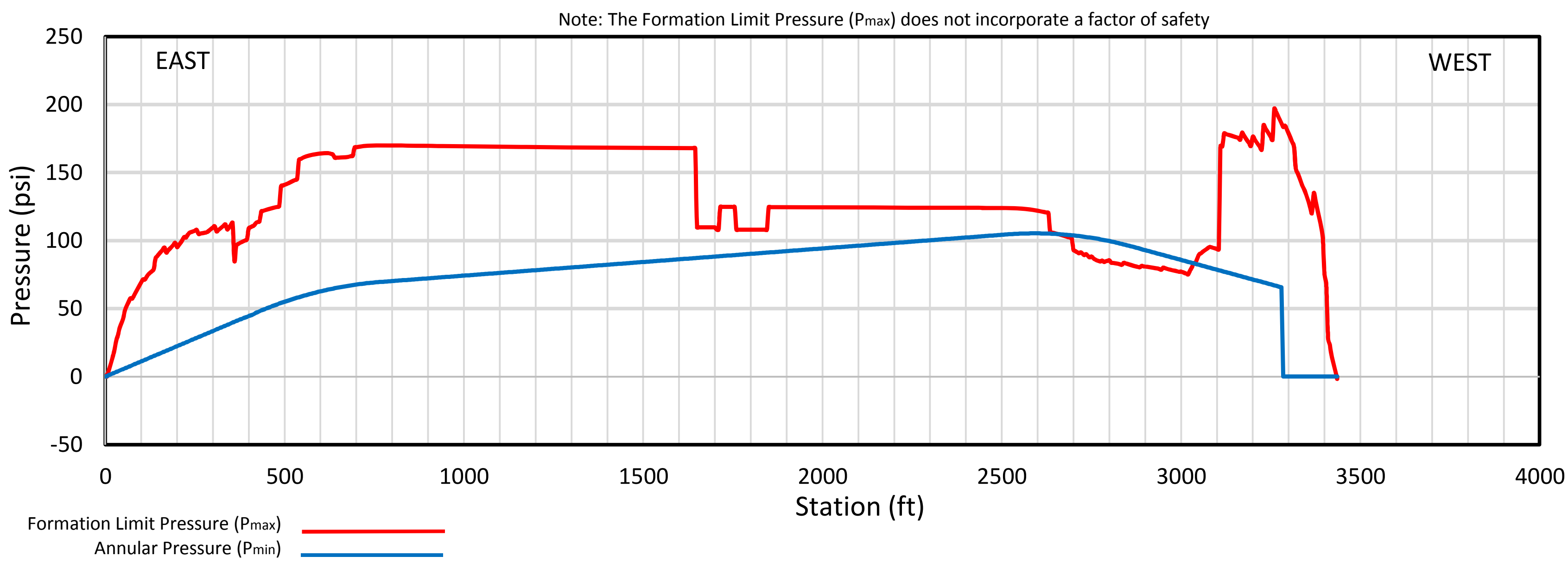
Entry Tangent - Summary of Pulling Load Calculations

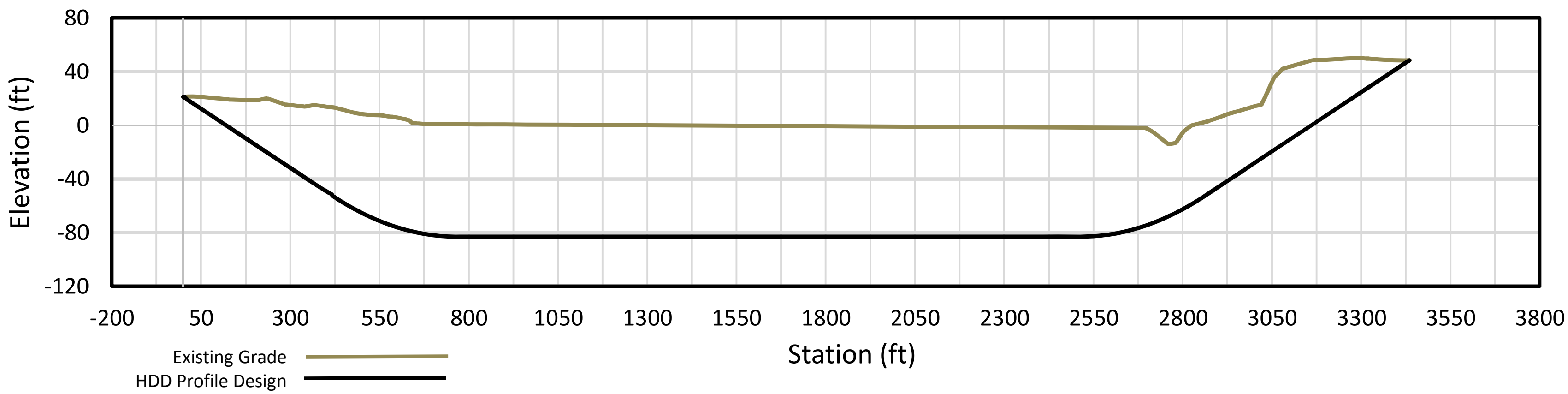
Segment Length, L =	653.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Entry Angle, θ =	10.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	21,221	lb	
Fluidic Drag = $12 \pi D L C_d$ =	12,326	lb	
Axial Segment Weight = $W_e L \sin\theta$ =	-12,473	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**21,074**	**lb**	
Total Pulling Load =	**207,053**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	8,186	ok	0	ok	0	ok	0.13	ok	0.02	ok
	7,353	ok	0	ok	1722	ok	0.12	ok	0.09	ok
PC										
	7,353	ok	17,901	ok	1722	ok	0.51	ok	0.31	ok
	6,376	ok	17,901	ok	2033	ok	0.49	ok	0.32	ok
PT										
	6,376	ok	0	ok	2033	ok	0.10	ok	0.11	ok
	3,174	ok	0	ok	2033	ok	0.05	ok	0.09	ok
PC										
	3,174	ok	17,901	ok	2033	ok	0.44	ok	0.27	ok
	2,259	ok	17,901	ok	1722	ok	0.43	ok	0.23	ok
PT										
	2,259	ok	0	ok	1722	ok	0.04	ok	0.06	ok
Exit Point	0	ok	0	ok	-416	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
NANSEMOND TRIB. CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 4/19/2016 Revision: 1

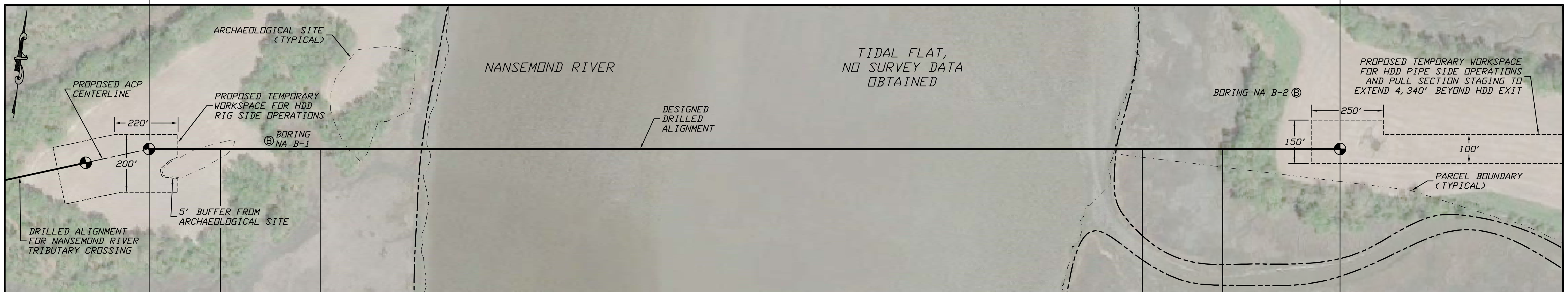
J.D.Hair&Associates, Inc.

Nansemond River

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 4,127'
TRUE LENGTH = 4,138'



PLAN
SCALE: 1"=200'

ENTRY POINT @ 10°
0+00.00, 20.00
N 13389919.29, E 2938232.57

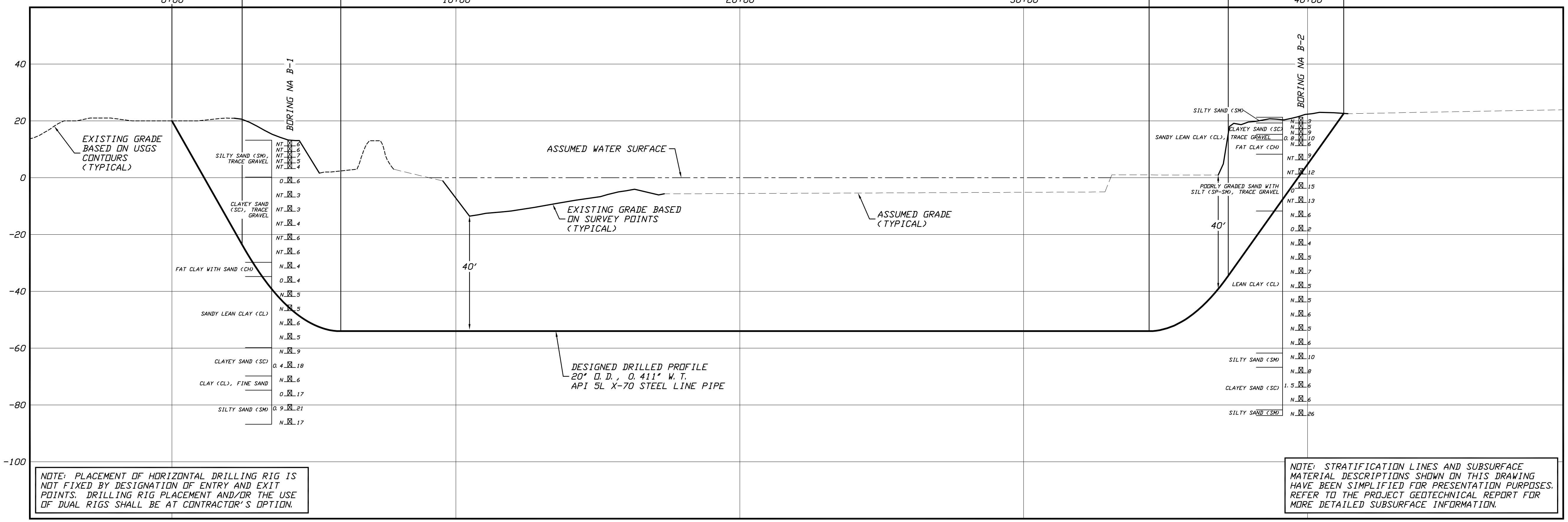
P.C. 10° SAG BEND
2+47.36, -23.62
RADIUS = 2,000'

P.T. 10° SAG BEND
5+94.65, -54.00

P.C. 8° SAG BEND
34+41.88, -54.00
RADIUS = 2,000'

P.T. 8° SAG BEND
37+20.23, -34.54

EXIT POINT @ 8°
41+27.10, 22.65
N 13390444.72, E 2942326.09



PROFILE
SCALE: 1"=200' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES; PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE GEOTECHNICAL SITE INVESTIGATION REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

400 200 100 0

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF THE NANSEMOND RIVER
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: SUFFOLK, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	06/03/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	NANSEMOND	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-065

Nansemond River R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	20" Nansemond River Crossing	Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

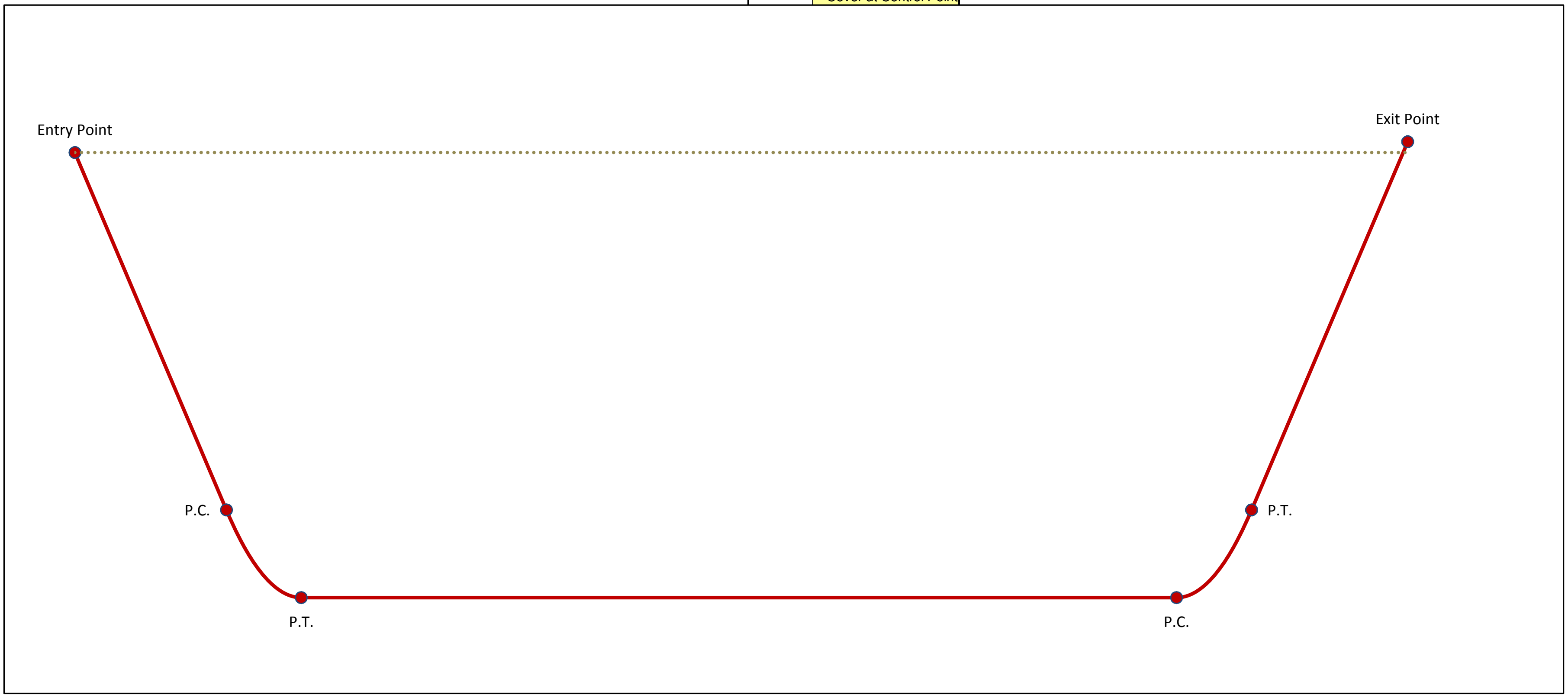
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, F_{hc}/1.5 =	7,185	psi	

Nansemond River R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	20.00	10.00				240,879
Entry Tangent						480.80		
Entry Sag Bend	PC	463.50	-63.49					225,384
	PI	579.81	-84.00	10.00	1350	235.62	211,924	
	PT	697.92	-84.00				0	198,465
Bottom Tangent				0.00		2736.68		
Exit Sag Bend	PC	3434.60	-84.00					56,700
	PI	3552.71	-84.00	10.00	1350	235.62	45,789	
	PT	3669.03	-63.49				0	34,878
Exit Tangent						495.60		
Exit Point		4157.10	22.57	10.00	Above Ground Load			0
Drilling Mud			20.00	(Graph = ·········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Nansemond River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	495.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	10.0	°			

Frictional Drag = W_e L μ cosθ =	16,083	lb
Fluidic Drag = 12 π D L C_d =	9,342	lb
Axial Segment Weight = W_e L sinθ =	9,453	lb
Pulling Load on Exit Tangent =	**34,878**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	235.6	ft	Average Tension, T =	45,789	lb
Segment Angle with Horizontal, θ =	-10.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-5.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

h = R [1 - cos(α/2)] =	5.14	ft	$j = [(E\ I) / T]^{1/2}$ =	877	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	5.3E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	302.07	
U = (12 L) / j =	3.23		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	25,209	lb
Bending Frictional Drag = 2 μ N =	15,125	lb			
Fluidic Drag = 12 π D L C_d =	4,441	lb			
Axial Segment Weight = W_e L sinθ =	2,256	lb			
Pulling Load on Exit Sag Bend =	**21,822**	**lb**			
Total Pulling Load =	**56,700**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	2736.7	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	90,179	lb
Fluidic Drag = 12 π D L C_d =	51,585	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**141,765**	**lb**
Total Pulling Load =	**198,465**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 211,924 lb
Radius of Curvature, R = 1,350 ft
Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 5.14 ft

$j = [(E\ I) / T]^{1/2}$ = 407

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 8.4E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 503.53

$U = (12 L) / j$ = 6.94

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 41,223 lb

Bending Frictional Drag = $2 \mu N$ = 24,734 lb

Fluidic Drag = $12 \pi D L C_d$ = 4,441 lb

Axial Segment Weight = $W_e L \sin\theta$ = -2,256 lb

Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 26,919 lb
Total Pulling Load = 225,384 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 480.8 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 15,603 lb

Fluidic Drag = $12 \pi D L C_d$ = 9,063 lb

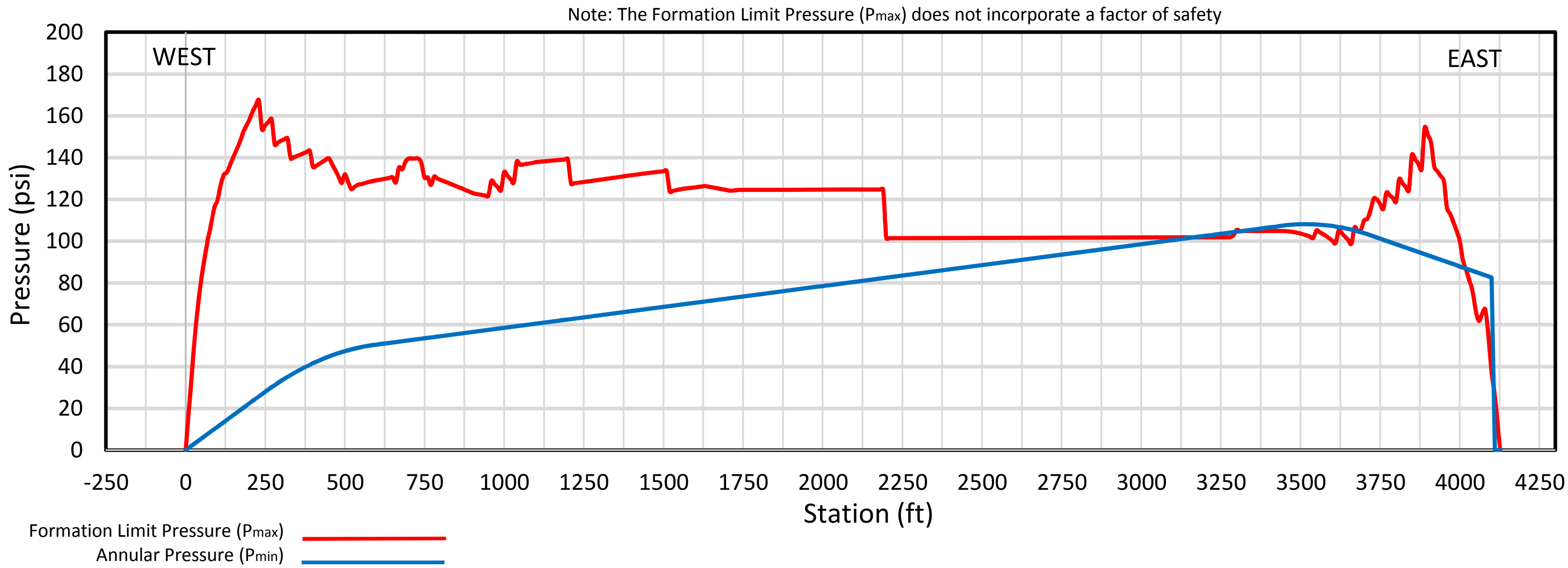
Axial Segment Weight = $W_e L \sin\theta$ = -9,171 lb

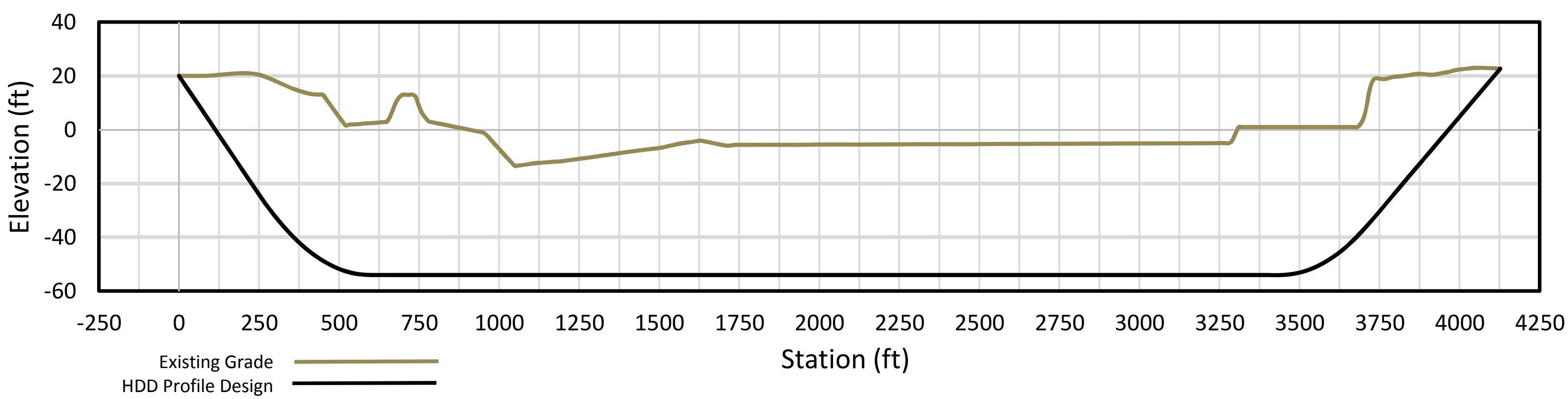
Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 15,495 lb
Total Pulling Load = 240,879 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	9,523	ok	0	ok	0	ok	0.15	ok	0.03	ok
	8,911	ok	0	ok	1266	ok	0.14	ok	0.07	ok
PC										
	8,911	ok	17,901	ok	1266	ok	0.53	ok	0.30	ok
	7,847	ok	17,901	ok	1577	ok	0.52	ok	0.31	ok
PT										
	7,847	ok	0	ok	1577	ok	0.12	ok	0.08	ok
	2,242	ok	0	ok	1577	ok	0.04	ok	0.05	ok
PC										
	2,242	ok	17,901	ok	1577	ok	0.43	ok	0.21	ok
	1,379	ok	17,901	ok	1266	ok	0.41	ok	0.18	ok
PT										
	1,379	ok	0	ok	1266	ok	0.02	ok	0.03	ok
Exit Point	0	ok	0	ok	-39	ok	0.00	ok	0.00	ok





J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH NANSEMOND RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 5/31/2016 Revision: 0

Interstate 64

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
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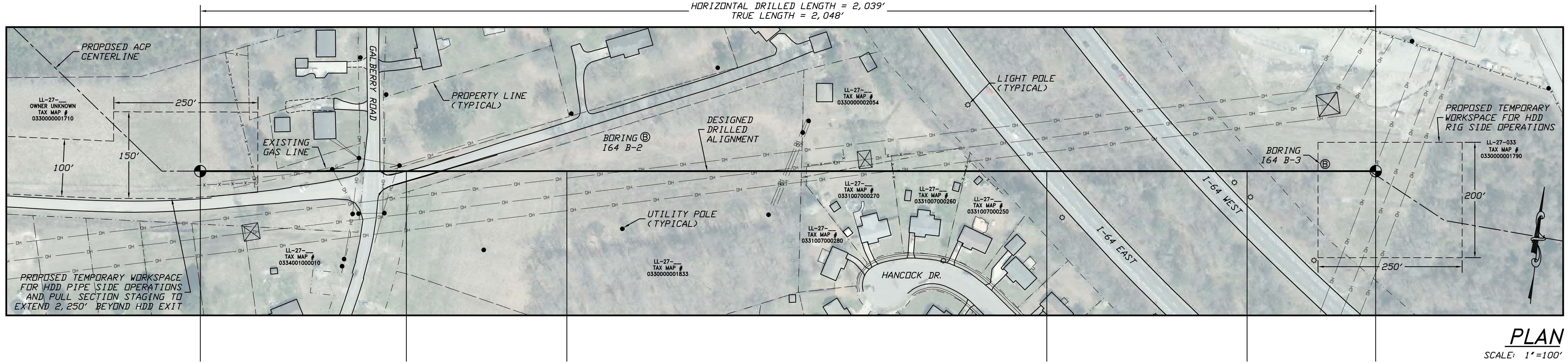

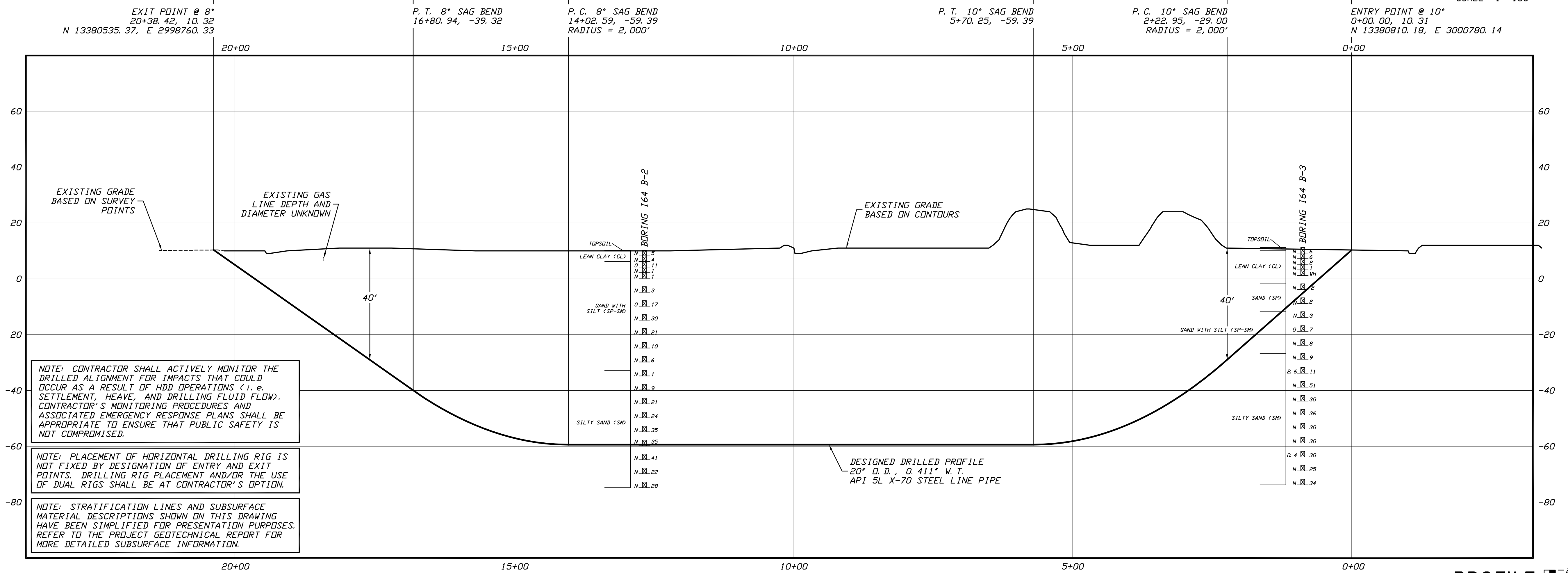

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 N 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES; PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

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2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
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3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF INTERSTATE 64
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: CHESAPEAKE, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	03/31/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	INTERSTATE 64	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-078

Interstate 64 R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	20" Interstate 64 Crossing	Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Interstate 64 R0 Installation Stress Analysis (worst-case).xlsm
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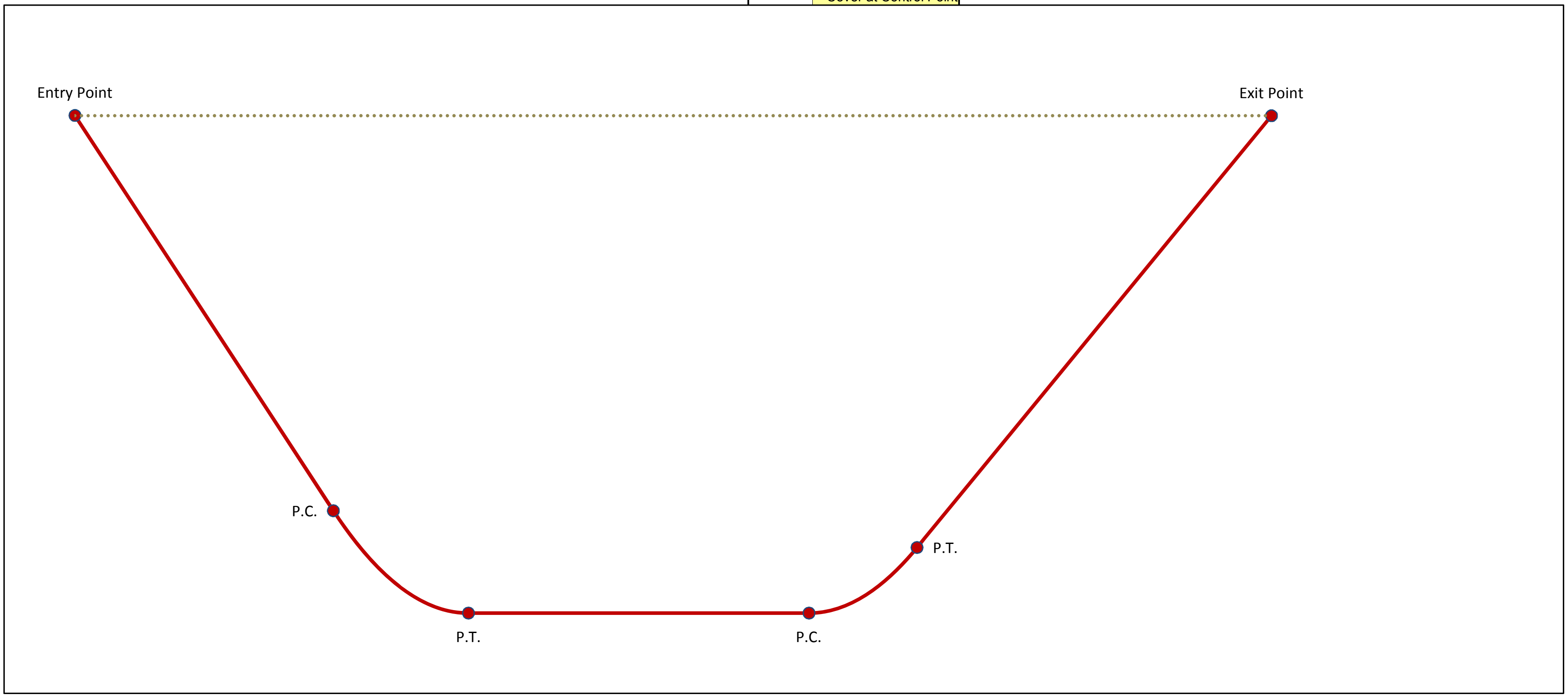
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	10.31	10.00				126,012
Entry Tangent						456.04		
Entry Sag Bend	PC	439.11	-68.88					111,315
	PI	555.43	-89.39	10.00	1350	235.62	101,049	
	PT	673.54	-89.39				0	90,784
Bottom Tangent				0.00		591.44		
Exit Sag Bend	PC	1264.97	-89.39					60,147
	PI	1359.37	-89.39	8.00	1350	188.50	50,825	
	PT	1452.86	-76.25				0	41,504
Exit Tangent						621.61		
Exit Point		2068.42	10.26	8.00	Above Ground Load			0
Drilling Mud			10.26	(Graph = ...)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	621.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	20,284	lb
Fluidic Drag = 12 π D L C_d =	11,717	lb
Axial Segment Weight = W_e L sinθ =	9,503	lb
Pulling Load on Exit Tangent =	**41,504**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	50,825	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

h = R [1 - cos(α/2)] =	3.29	ft	$j = [(E\ I) / T]^{1/2}$ =	832	
$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ =	2.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	200.97	
U = (12 L) / j =	2.72		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	22,742	lb
Bending Frictional Drag = 2 μ N =	13,645	lb			
Fluidic Drag = 12 π D L C_d =	3,553	lb			
Axial Segment Weight = W_e L sinθ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**18,643**	**lb**			
Total Pulling Load =	**60,147**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	591.4	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	19,489	lb
Fluidic Drag = 12 π D L C_d =	11,148	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**30,637**	**lb**
Total Pulling Load =	**90,784**	**lb**

Interstate 64 R0 Installation Stress Analysis (worst-case).xlsm

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Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft

Segment Angle with Horizontal, θ = 10.0 °

Deflection Angle, α = 5.0 °

Average Tension, T = 101,049 lb

Radius of Curvature, R = 1,350 ft

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 5.14 ft

$j = [(E\ I) / T]^{1/2}$ = 590

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 7.1E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 416.68

$U = (12 L) / j$ = 4.79

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 30,575 lb

Bending Frictional Drag = $2 \mu N$ = 18,345 lb

Fluidic Drag = $12 \pi D L C_d$ = 4,441 lb

Axial Segment Weight = $W_e L \sin\theta$ = -2,256 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 20,531 lb

Total Pulling Load = 111,315 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 456.0 ft

Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 14,799 lb

Fluidic Drag = $12 \pi D L C_d$ = 8,596 lb

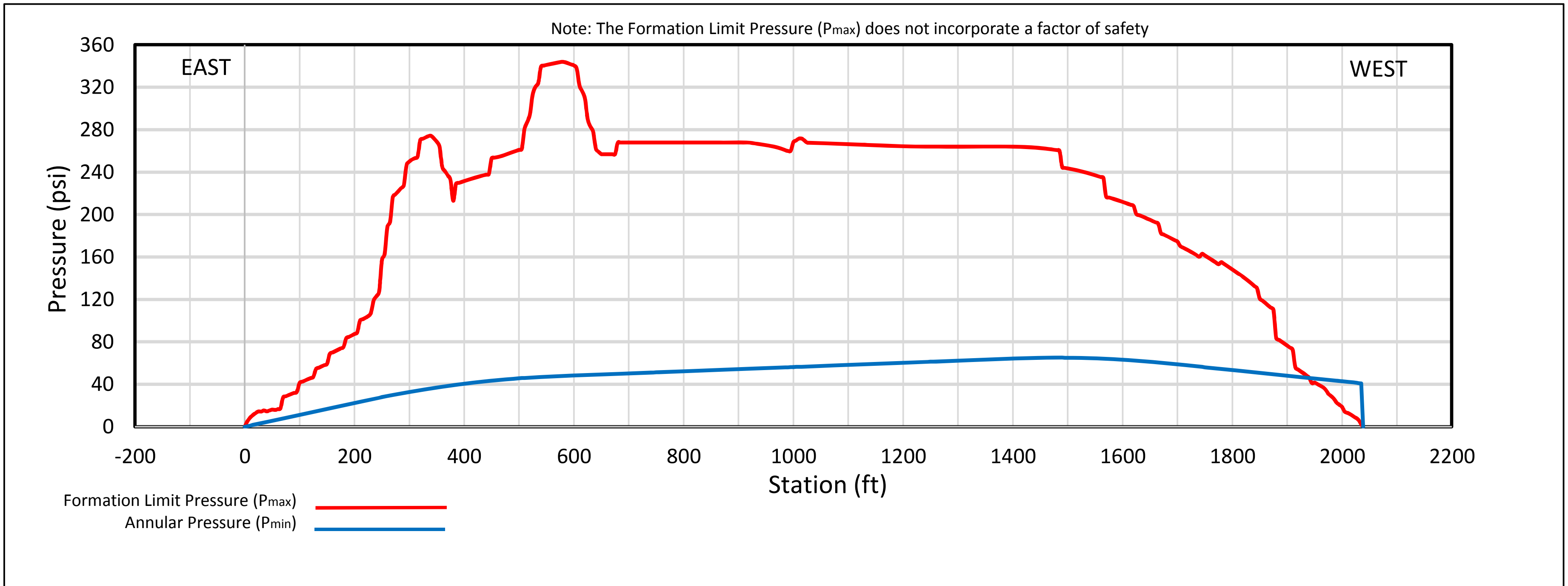
Axial Segment Weight = $W_e L \sin\theta$ = -8,698 lb — Negative value indicates axial weight applied in direction of installation

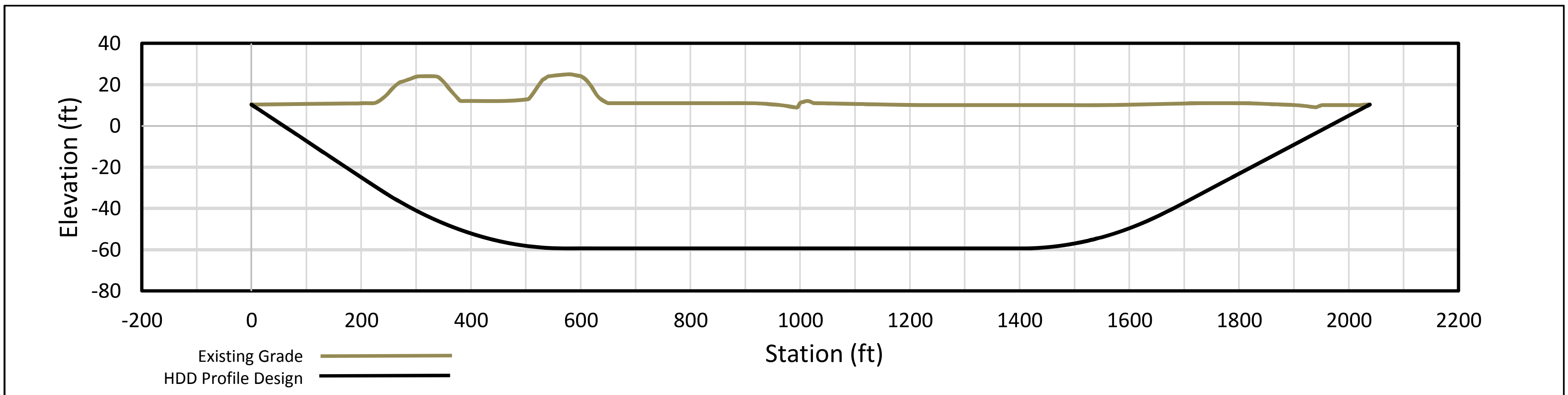
Pulling Load on Entry Tangent = 14,697 lb

Total Pulling Load = 126,012 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,982	ok	0	ok	0	ok	0.08	ok	0.01	ok
	4,401	ok	0	ok	1200	ok	0.07	ok	0.04	ok
PC										
	4,401	ok	17,901	ok	1200	ok	0.46	ok	0.22	ok
	3,589	ok	17,901	ok	1511	ok	0.45	ok	0.23	ok
PT										
	3,589	ok	0	ok	1511	ok	0.06	ok	0.05	ok
	2,378	ok	0	ok	1511	ok	0.04	ok	0.05	ok
PC										
	2,378	ok	17,901	ok	1511	ok	0.43	ok	0.21	ok
	1,641	ok	17,901	ok	1312	ok	0.42	ok	0.18	ok
PT										
	1,641	ok	0	ok	1312	ok	0.03	ok	0.04	ok
Exit Point	0	ok	0	ok	0	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH INTERSTATE 64 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 6/16/2015 Revision: 0

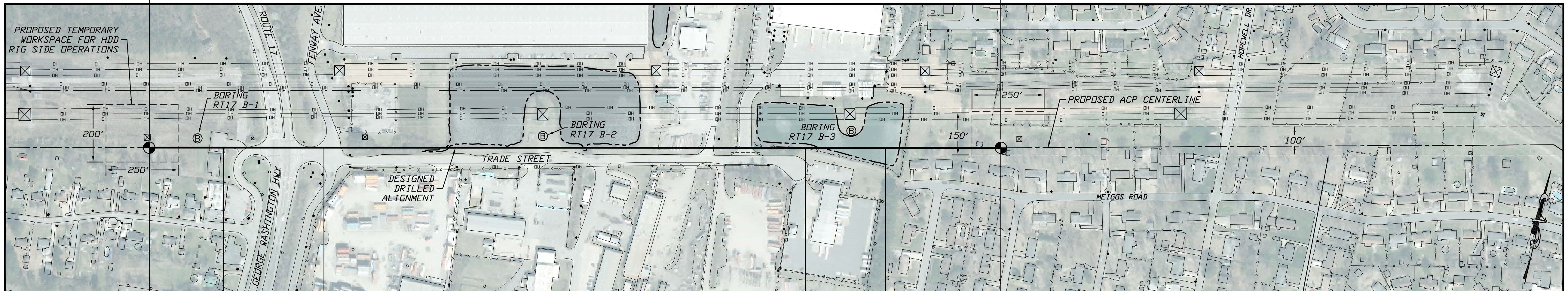
J.D.Hair&Associates, Inc.

Route 17

Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 2,951'
TRUE LENGTH = 2,961'



PROPOSED TEMPORARY WORKSPACE FOR HDD PIPE SIDE OPERATIONS AND PULL SECTION STAGING TO EXTEND 3,150' BEYOND HDD EXIT

PLAN

SCALE: 1"=200'

ENTRY POINT @ 10°
0+00.00, 10.37
N 13381684.57, E 3003630.63

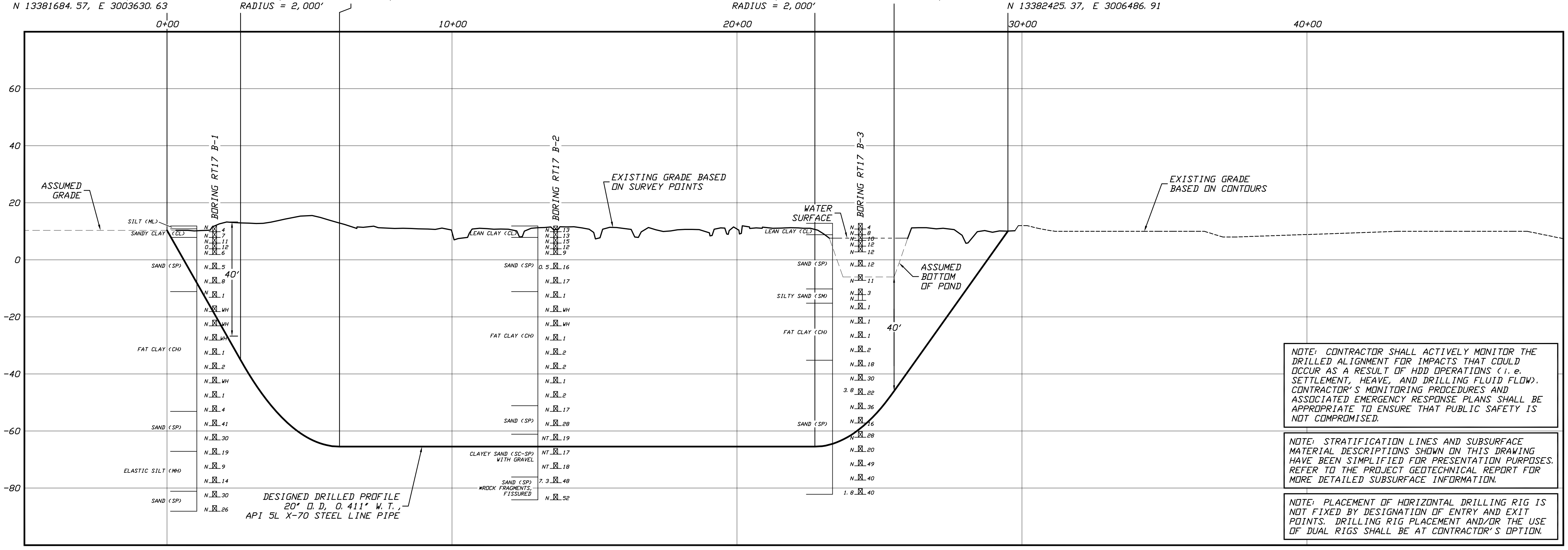
P.C. 10° SAG BEND
2+57.75, -35.08
RADIUS = 2,000'

P.T. 10° SAG BEND
6+05.05, -65.46

P.C. 8° SAG BEND
22+73.19, -65.46
RADIUS = 2,000'

P.T. 8° SAG BEND
25+51.54, -46.00

EXIT POINT @ 8°
29+50.78 10.11
N 13382425.37, E 3006486.91



NOTE: CONTRACTOR SHALL ACTIVELY MONITOR THE DRILLED ALIGNMENT FOR IMPACTS THAT COULD OCCUR AS A RESULT OF HDD OPERATIONS (i.e. SETTLEMENT, HEAVE, AND DRILLING FLUID FLOW). CONTRACTOR'S MONITORING PROCEDURES AND ASSOCIATED EMERGENCY RESPONSE PLANS SHALL BE APPROPRIATE TO ENSURE THAT PUBLIC SAFETY IS NOT COMPROMISED.

NOTE: STRATIFICATION LINES AND SUBSURFACE MATERIAL DESCRIPTIONS SHOWN ON THIS DRAWING HAVE BEEN SIMPLIFIED FOR PRESENTATION PURPOSES. REFER TO THE PROJECT GEOTECHNICAL REPORT FOR MORE DETAILED SUBSURFACE INFORMATION.

NOTE: PLACEMENT OF HORIZONTAL DRILLING RIG IS NOT FIXED BY DESIGNATION OF ENTRY AND EXIT POINTS. DRILLING RIG PLACEMENT AND/OR THE USE OF DUAL RIGS SHALL BE AT CONTRACTOR'S OPTION.

PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 20' VERTICAL

400 200 100 0
20 10 0

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 N 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

SHELBY TUBE SAMPLE

53 — PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED DECEMBER 2015 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS:

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE
20-INCH PIPELINE CROSSING OF ROUTE 17
BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: CHESAPEAKE, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	04/01/16	ACM	JSP	SHOWN FOR D-SIZED PLOT	ROUTE 17	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-079

Route 17 R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

Project Information				
Project :	Dominion Atlantic Coast Pipeline		User :	KMN
Crossing :	20" Route 17 Crossing		Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 30' deeper than design with a 1,350' radius) with 12 ppg mud and no BC			

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

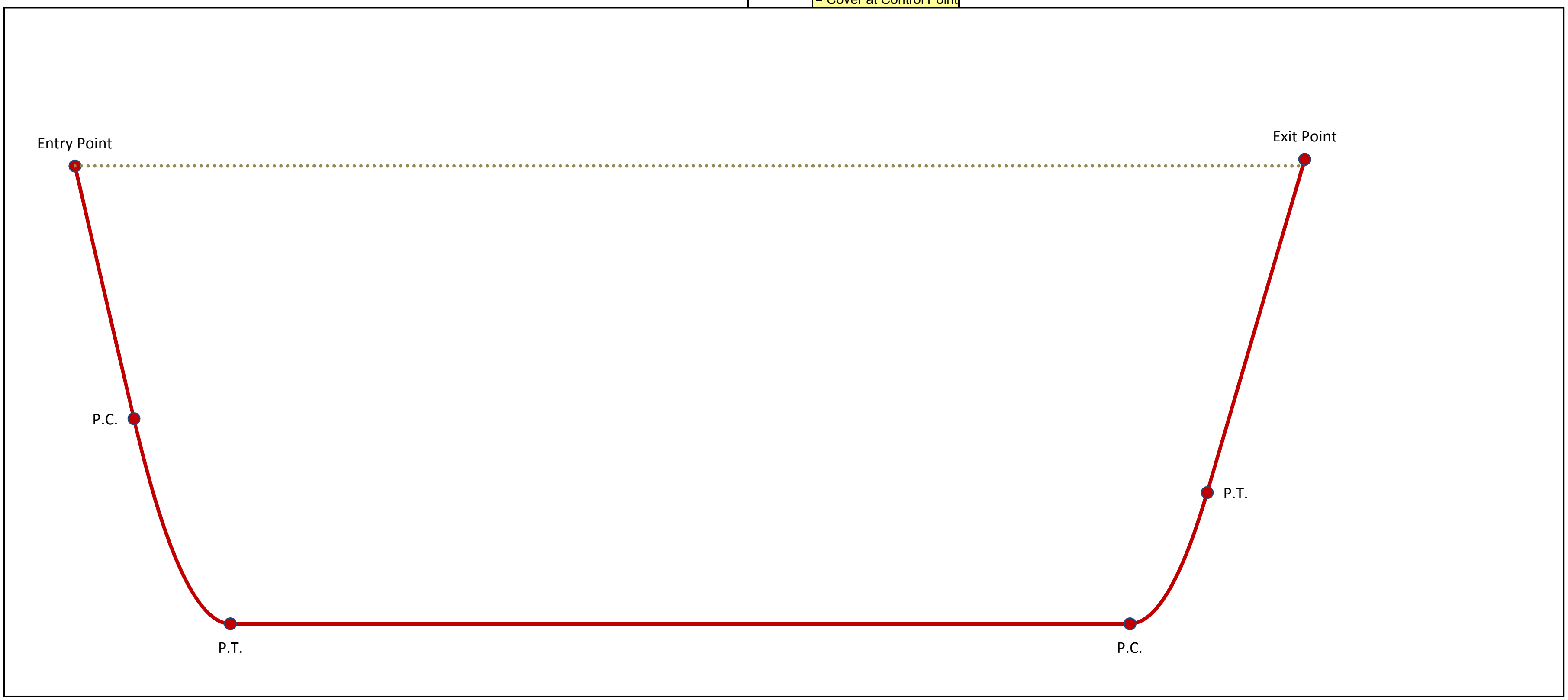
Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Route 17 R0 Installation Stress Analysis (worst-case).xlsm

J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	10.37	10.00				175,267
Entry Tangent						145.81		
Entry Sag Bend	PC	133.60	-14.95					170,568
	PI	249.91	-35.46	10.00	1350	235.62	158,638	
	PT	368.02	-35.46				0	146,709
Bottom Tangent				0.00		2187.56		
Exit Sag Bend	PC	2555.59	-35.46					33,389
	PI	2649.99	-35.46	8.00	1350	188.50	24,695	
	PT	2743.47	-22.32				0	16,000
Exit Tangent						239.64		
Exit Point		2980.78	11.03	8.00	Above Ground Load			0
Drilling Mud			10.37	(Graph = ••••••••)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	239.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = W_e L μ cosθ =	7,820	lb
Fluidic Drag = 12 π D L C_d =	4,517	lb
Axial Segment Weight = W_e L sinθ =	3,663	lb
Pulling Load on Exit Tangent =	**16,000**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	24,695	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

h = R [1 - cos(α/2)] =	3.29	ft	$j = [(E I) / T]^{1/2}$ =	1,194	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	1.8E+05		X = (3 L) - [(j / 2) tanh(U/2)] =	124.65	
U = (12 L) / j =	1.90		N = [(T h) - W_e cosθ (Y/144)] / (X / 12)	20,653	lb
Bending Frictional Drag = 2 μ N =	12,392	lb			
Fluidic Drag = 12 π D L C_d =	3,553	lb			
Axial Segment Weight = W_e L sinθ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**17,389**	**lb**			
Total Pulling Load =	**33,389**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	2187.6	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = W_e L μ =	72,085	lb
Fluidic Drag = 12 π D L C_d =	41,235	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**113,319**	**lb**
Total Pulling Load =	**146,709**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft
Segment Angle with Horizontal, θ = 10.0 º
Deflection Angle, α = 5.0 º

Average Tension, T = 158,638 lb
Radius of Curvature, R = 1,350 ft
Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

h = R [1 - cos(α/2)] = 5.14 ft

$j = [(E\ I) / T]^{1/2}$ = 471

$Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ = 8.0E+05

X = (3 L) - [(j / 2) tanh(U/2)] = 472.55

U = (12 L) / j = 6.00

$N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ = 36,123 lb

Bending Frictional Drag = 2 μ N = 21,674 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 4,441 lb

Axial Segment Weight = $W_e\ L \sin\theta$ = -2,256 lb

Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 23,859 lb
Total Pulling Load = 170,568 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 145.8 ft
Entry Angle, θ = 10.0 º

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e\ L\ \mu \cos\theta$ = 4,732 lb

Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 2,749 lb

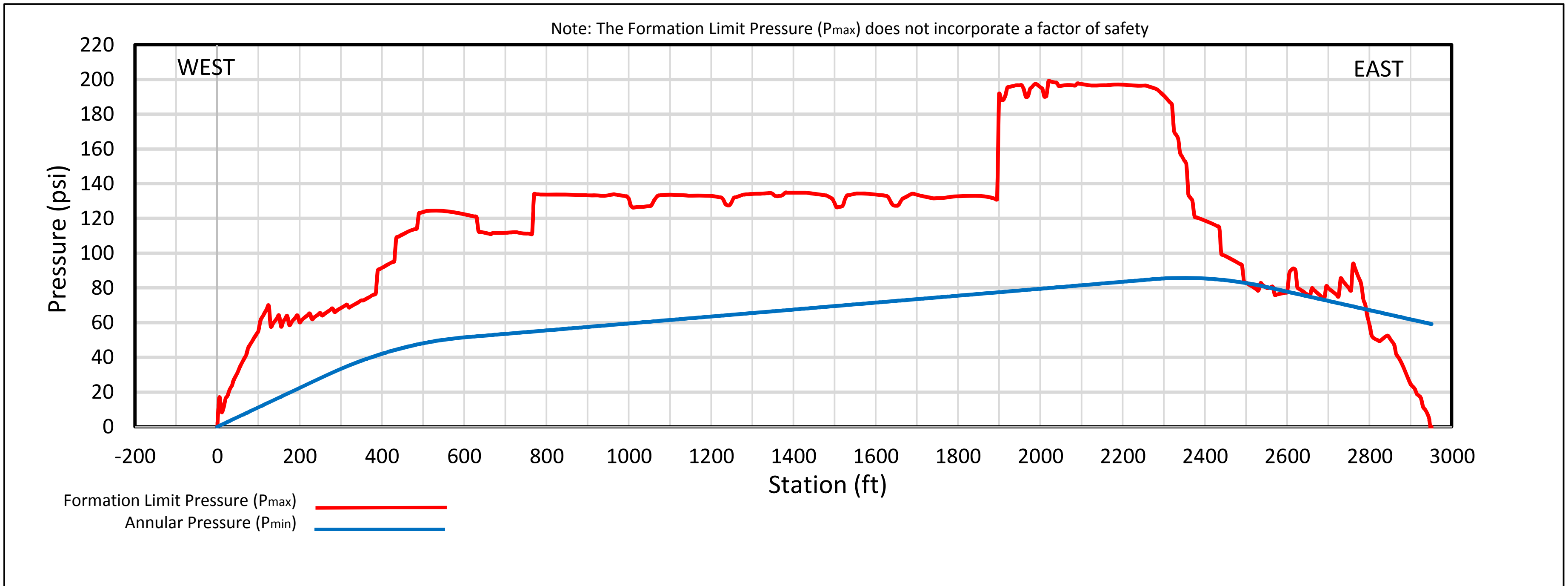
Axial Segment Weight = $W_e\ L \sin\theta$ = -2,781 lb

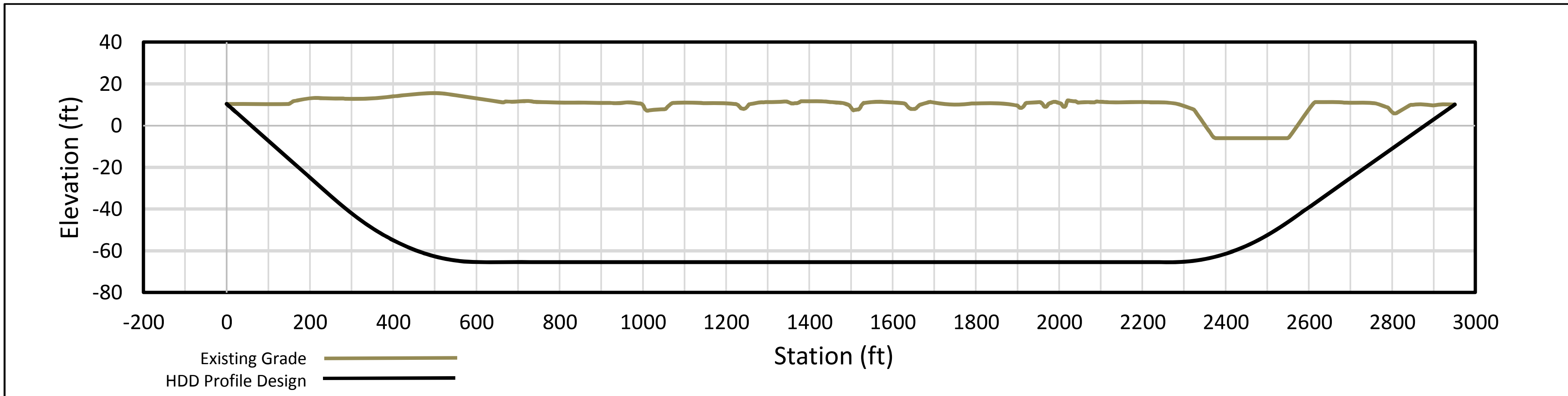
Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 4,699 lb
Total Pulling Load = 175,267 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	6,929	ok	0	ok	0	ok	0.11	ok	0.02	ok
	6,744	ok	0	ok	384	ok	0.11	ok	0.02	ok
PC										
	6,744	ok	17,901	ok	384	ok	0.50	ok	0.21	ok
	5,800	ok	17,901	ok	695	ok	0.48	ok	0.21	ok
PT										
	5,800	ok	0	ok	695	ok	0.09	ok	0.02	ok
	1,320	ok	0	ok	695	ok	0.02	ok	0.01	ok
PC										
	1,320	ok	17,901	ok	695	ok	0.41	ok	0.14	ok
	633	ok	17,901	ok	496	ok	0.40	ok	0.12	ok
PT										
	633	ok	0	ok	496	ok	0.01	ok	0.01	ok
Exit Point	0	ok	0	ok	-10	ok	0.00	ok	0.00	ok





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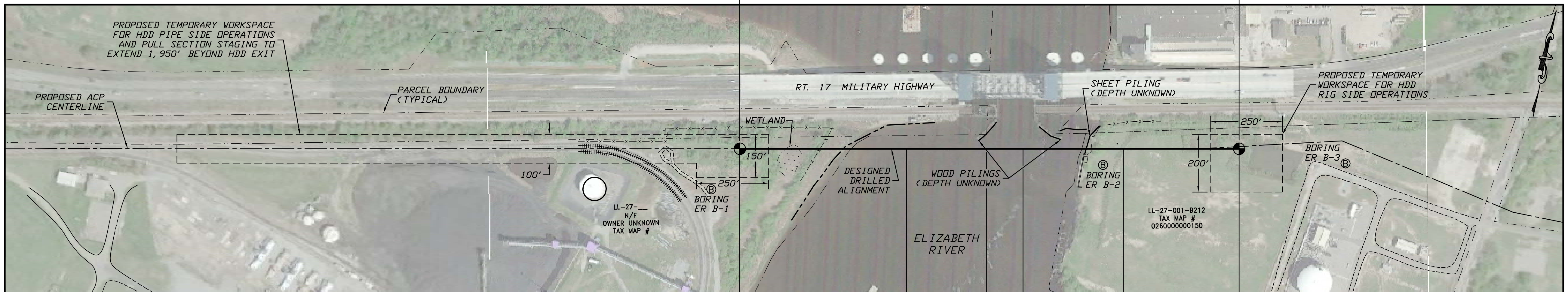
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH ROUTE 17 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 6/16/2015 Revision: 0

Elizabeth River

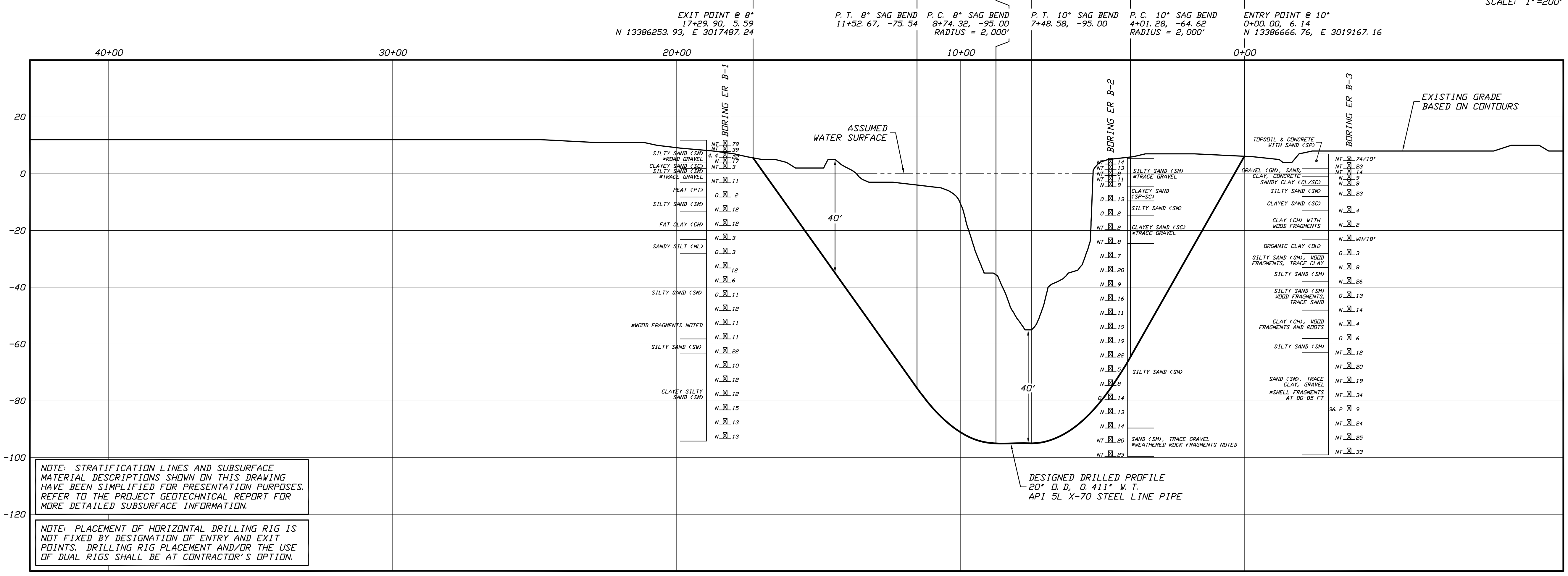
Supporting Information

- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)



PLAN

SCALE: 1"=200'



PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 20' VERTICAL

GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

BORING LOCATION

SPLIT SPOON SAMPLE

53 23 — PENETRATION RESISTANCE IN BLOWS PER FOOT FOR A 140 POUND HAMMER FALLING 30 INCHES
PERCENTAGE OF GRAVEL BY WEIGHT FOR SAMPLES CONTAINING GRAVEL

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE DRAFT PROJECT GEOTECHNICAL REPORT DATED DECEMBER 2015 FOR MORE DETAILED SUBSURFACE INFORMATION.
2. THE LETTER "N" TO THE LEFT OF A SPLIT SPOON SAMPLE INDICATES THAT NO GRAVEL WAS OBSERVED IN THE SAMPLE. THE LETTERS "NT" INDICATE THAT GRAVEL WAS OBSERVED BUT NO GRADATION TEST WAS PERFORMED.
3. THE GEOTECHNICAL DATA IS ONLY DESCRIPTIVE OF THE LOCATIONS ACTUALLY SAMPLED. EXTENSION OF THIS DATA OUTSIDE OF THE ORIGINAL BORINGS MAY BE DONE TO CHARACTERIZE THE SOIL CONDITIONS, HOWEVER, COMPANY DOES NOT GUARANTEE THESE CHARACTERIZATIONS TO BE ACCURATE. CONTRACTOR MUST USE HIS OWN EXPERIENCE AND JUDGMENT IN INTERPRETING THIS DATA.

TOPOGRAPHIC SURVEY NOTES

1. TOPOGRAPHIC SURVEY DATA PROVIDED BY GAI CONSULTANTS, CANONSBURG, PENNSYLVANIA.
2. NORTHINGS AND EASTINGS ARE IN U.S. SURVEY FEET REFERENCED TO UTM COORDINATES, ZONE 17, NAD 83.
3. ELEVATIONS ARE IN FEET REFERENCED TO NAVD 88.

DRILLED PATH NOTES

1. DRILLED PATH STATIONING IS IN FEET BY HORIZONTAL MEASUREMENT AND IS REFERENCED TO CONTROL ESTABLISHED FOR THE DRILLED SEGMENT.
2. DRILLED PATH COORDINATES REFER TO CENTERLINE OF PILOT HOLE AS OPPOSED TO TOP OF INSTALLED PIPE.

PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT FACILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ENTRY POINT: UP TO 10 FEET FORWARD OR BACK FROM THE DESIGNED ENTRY POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
2. EXIT POINT: UP TO 10 FEET SHORT OR 30 FEET LONG RELATIVE TO THE DESIGNED EXIT POINT; UP TO 5 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
3. ELEVATION: UP TO 5 FEET ABOVE AND 30 FEET BELOW THE DESIGNED PROFILE
4. ALIGNMENT: UP TO 10 FEET RIGHT OR LEFT OF THE DESIGNED ALIGNMENT
5. CURVE RADIUS: NO LESS THAN 1,350 FEET BASED ON A 3-JOINT AVERAGE (RANGE 2 DRILL PIPE)

PROTECTION OF EXISTING FACILITIES

CONTRACTOR SHALL UNDERTAKE THE FOLLOWING STEPS PRIOR TO COMMENCING DRILLING OPERATIONS.

1. CONTACT THE UTILITY LOCATION/NOTIFICATION SERVICE FOR THE CONSTRUCTION AREA.
2. POSITIVELY LOCATE AND STAKE ALL EXISTING UNDERGROUND FACILITIES. ANY FACILITIES LOCATED WITHIN 10 FEET OF THE DESIGNED DRILLED PATH SHALL BE EXPOSED.
3. MODIFY DRILLING PRACTICES AND DOWNHOLE ASSEMBLIES AS NECESSARY TO PREVENT DAMAGE TO EXISTING FACILITIES.

ATLANTIC COAST PIPELINE PROJECT

PLAN AND PROFILE 20-INCH PIPELINE CROSSING OF THE ELIZABETH RIVER BY HORIZONTAL DIRECTIONAL DRILLING

LOCATION: PORTSMOUTH COUNTY, VIRGINIA

DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL	REVISION
KMN	03/30/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	ELIZABETH RIVER	0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

Jeffrey S. Puckett, P.E.
Consulting Engineer
2424 East 21st Street
Suite 510
Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP3-082

Elizabeth River R0 Installation Stress Analysis (worst-case).xlsm

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Project Information			
Project :	Dominion Atlantic Coast Pipeline	User :	KMN
Crossing :	20" Elizabeth River Crossing	Date :	7/22/2016
Comments :	Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 20' deeper than design with a 1,350' radius) with 12 ppg mud and no BC		

Line Pipe Properties			
Pipe Outside Diameter =	20.000	in	
Wall Thickness =	0.411	in	
Specified Minimum Yield Strength =	70,000	psi	
Young's Modulus =	2.9E+07	psi	
Moment of Inertia =	1213.22	in^4	
Pipe Face Surface Area =	25.29	in^2	
Diameter to Wall Thickness Ratio, D/t =	49		
Poisson's Ratio =	0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F	
Pipe Weight in Air =	85.99	lb/ft	
Pipe Interior Volume =	2.01	ft^3/ft	
Pipe Exterior Volume =	2.18	ft^3/ft	

HDD Installation Properties			
Drilling Mud Density =	12.0	ppg	
=	89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30		
Fluid Drag Coefficient =	0.025	psi	
Ballast Weight =	125.18	lb/ft	
Displaced Mud Weight =	195.83	lb/ft	

Installation Stress Limits			
Tensile Stress Limit, 90% of SMYS, F_t =	63,000	psi	
For D/t <= 1,500,000/SMYS, F_b =	52,500	psi	No
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	44,493	psi	No
For D/t > 3,000,000/SMYS and <= 300, F_b =	45,631	psi	Yes
Allowable Bending Stress, F_b =	45,631	psi	
Elastic Hoop Buckling Stress, F_{he} =	10,777	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	33,440	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	11,994	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	70,000	psi	No
Critical Hoop Buckling Stress, F_{hc} =	10,777	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	7,185	psi	

Elizabeth River R0 Installation Stress Analysis (worst-case).xlsm

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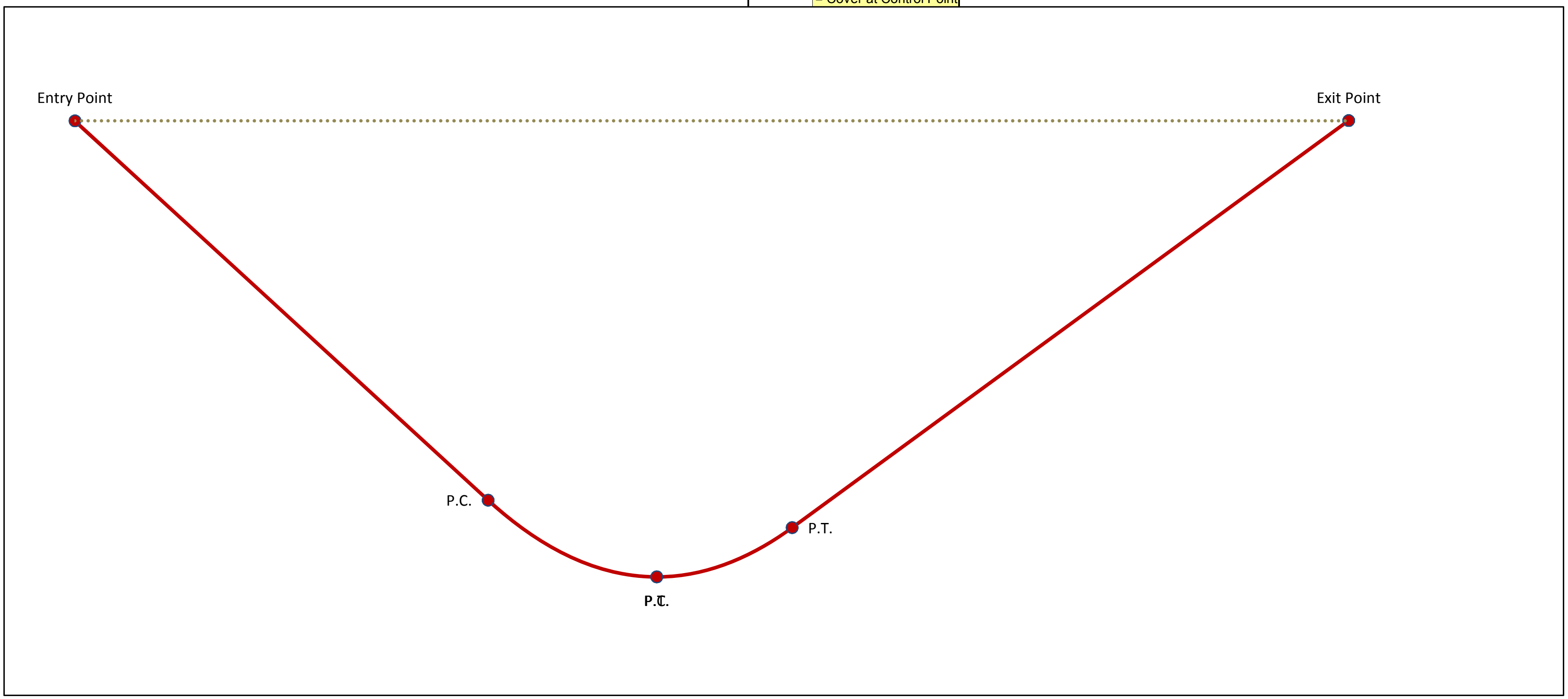
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	6.09	10.00				109,466
Entry Tangent						583.02		
Entry Sag Bend	PC	564.16	-95.15					90,677
	PI	680.48	-115.66	10.00	1350	235.62	80,994	
	PT	798.59	-115.66				0	71,311
Bottom Tangent				0.00		0.05		
Exit Sag Bend	PC	798.63	-115.66					71,309
	PI	893.03	-115.66	8.00	1350	188.50	61,727	
	PT	986.52	-102.52				0	52,145
Exit Tangent						780.98		
Exit Point		1759.90	6.17	8.00	Above Ground Load			0
Drilling Mud			6.09	(Graph = ········)				
Ballast				(Graph = - - - - -)				

No.	Station	Elevation	
1			Grade Elevation Points
2			
3			
4			
5			
6			
7			
8			
9			
10			
1			Control Point
		= Cover at Control Point	



Step 2, Drilled Path Input

Elizabeth River R0 Installation Stress Analysis (worst-case).xlsm

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Pipe and Installation Properties

Based on profile design entered in 'Step 2, Drilled Path Input'.

Pipe Diameter, D =	20.000	in	Fluid Drag Coefficient, C_d =	0.025	psi	
PIpe Weight, W =	86.0	lb/ft	Ballast Weight / ft Pipe, W_b =	125.2	lb	(If Ballasted)
Coefficient of Soil Friction, μ =	0.30		Drilling Mud Displaced / ft Pipe, W_m =	195.8	lb	(If Submerged)
			Above Ground Load =	0	lb	

Exit Tangent - Summary of Pulling Load Calculations

Segment Length, L =	781.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft
Exit Angle, θ =	8.0	°			

Frictional Drag = $W_e L \mu \cos\theta$ =	25,485	lb
Fluidic Drag = $12 \pi D L C_d$ =	14,721	lb
Axial Segment Weight = $W_e L \sin\theta$ =	11,939	lb
Pulling Load on Exit Tangent =	**52,145**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

Segment Length, L =	188.5	ft	Average Tension, T =	61,727	lb
Segment Angle with Horizontal, θ =	-8.0	°	Radius of Curvature, R =	1,350	ft
Deflection Angle, α =	-4.0	°	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

$h = R [1 - \cos(\alpha/2)]$ =	3.29	ft	$j = [(E I) / T]^{1/2}$ =	755	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	3.1E+05		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	223.94	
$U = (12 L) / j$ =	3.00		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	23,611	lb
Bending Frictional Drag = $2 \mu N$ =	14,167	lb			
Fluidic Drag = $12 \pi D L C_d$ =	3,553	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	1,444	lb			
Pulling Load on Exit Sag Bend =	**19,164**	**lb**			
Total Pulling Load =	**71,309**	**lb**			

Bottom Tangent - Summary of Pulling Load Calculations

Segment Length, L =	0.0	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-109.8	lb/ft

Frictional Drag = $W_e L \mu$ =	1	lb
Fluidic Drag = $12 \pi D L C_d$ =	1	lb
Axial Segment Weight = $W_e L \sin\theta$ =	0	lb
Pulling Load on Bottom Tangent =	**2**	**lb**
Total Pulling Load =	**71,311**	**lb**

Fluidic drag is calculated as zero unless entire segment is submerged in drilling fluid.
Please reference Step 2, Drilled Path Input

Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 80,994 lb
Radius of Curvature, R = 1,350 ft
Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 5.14 ft

$j = [(E\ I) / T]^{1/2}$ = 659

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 6.7E+05

$X = (3 L) - [(j / 2) \tanh(U/2)]$ = 386.23

$U = (12 L) / j$ = 4.29

$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = 28,633 lb

Bending Frictional Drag = $2 \mu N$ = 17,180 lb

Fluidic Drag = $12 \pi D L C_d$ = 4,441 lb

Axial Segment Weight = $W_e L \sin\theta$ = -2,256 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Sag Bend = 19,366 lb
Total Pulling Load = 90,677 lb

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L = 583.0 ft
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 18,920 lb

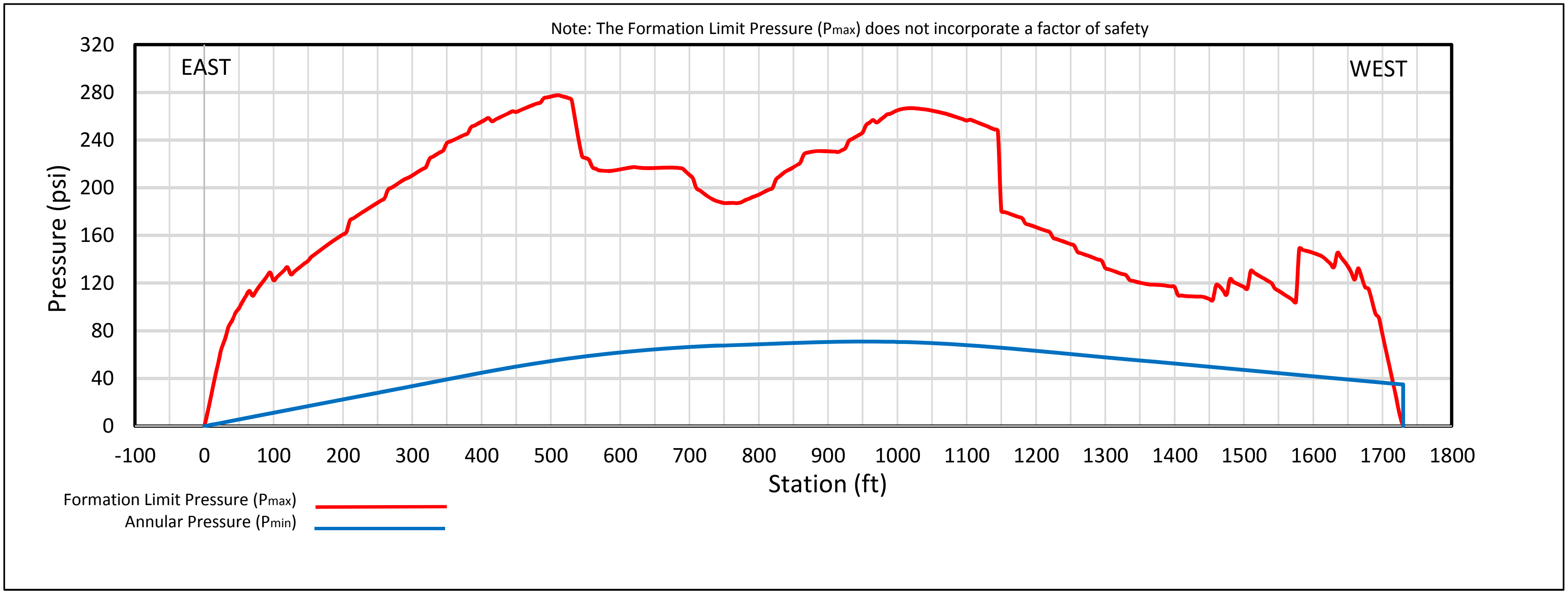
Fluidic Drag = $12 \pi D L C_d$ = 10,990 lb

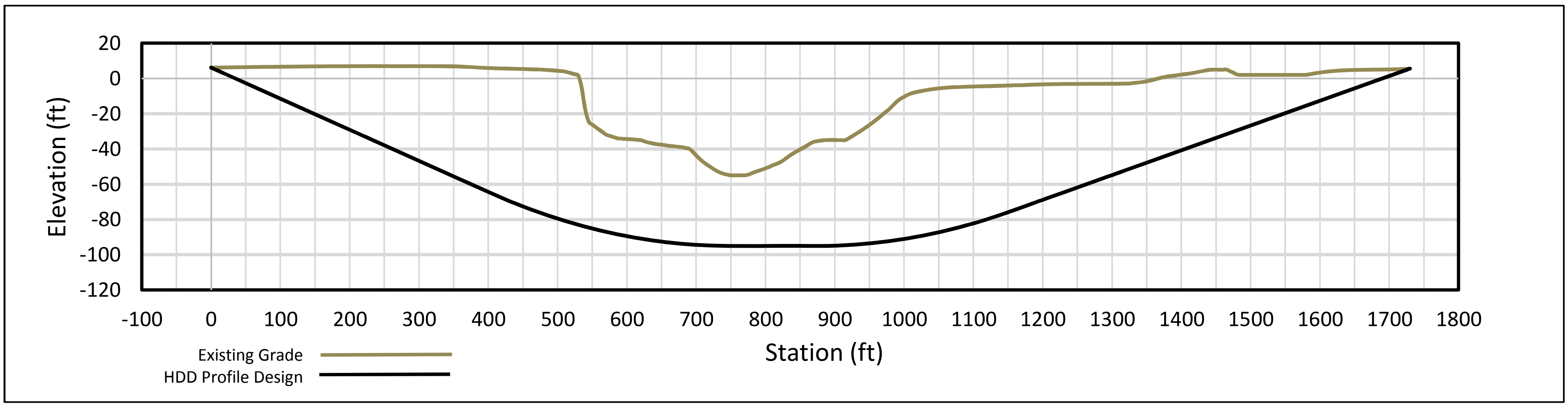
Axial Segment Weight = $W_e L \sin\theta$ = -11,120 lb — Negative value indicates axial weight applied in direction of installation

Pulling Load on Entry Tangent = 18,789 lb
Total Pulling Load = 109,466 lb

Summary of Calculated Stress vs. Allowable Stress

	Tensile Stress		Bending Stress		External Hoop Stress		Combined Tensile & Bending		Combined Tensile, Bending & Ext. Hoop	
Entry Point	4,328	ok	0	ok	0	ok	0.07	ok	0.01	ok
	3,585	ok	0	ok	1535	ok	0.06	ok	0.05	ok
PC										
	3,585	ok	17,901	ok	1535	ok	0.45	ok	0.23	ok
	2,819	ok	17,901	ok	1846	ok	0.44	ok	0.25	ok
PT										
	2,819	ok	0	ok	1846	ok	0.04	ok	0.07	ok
	2,819	ok	0	ok	1846	ok	0.04	ok	0.07	ok
PC										
	2,819	ok	17,901	ok	1846	ok	0.44	ok	0.25	ok
	2,062	ok	17,901	ok	1647	ok	0.43	ok	0.22	ok
PT										
	2,062	ok	0	ok	1647	ok	0.03	ok	0.06	ok
Exit Point	0	ok	0	ok	-1	ok	0.00	ok	0.00	ok





HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH ELIZABETH RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 6/16/2015 Revision: 0

J.D.Hair&Associates, Inc.