# ATLANTIC COAST PIPELINE, LLC
# ATLANTIC COAST PIPELINE

**and**

# DOMINION TRANSMISSION, INC.
# SUPPLY HEADER PROJECT

**Supplemental Filing**
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## APPENDIX B

## HDD Design Report

# HDD Design Report, Revision 2
# Atlantic Coast Pipeline Project

## December 14, 2016

***Prepared for***

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# 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.

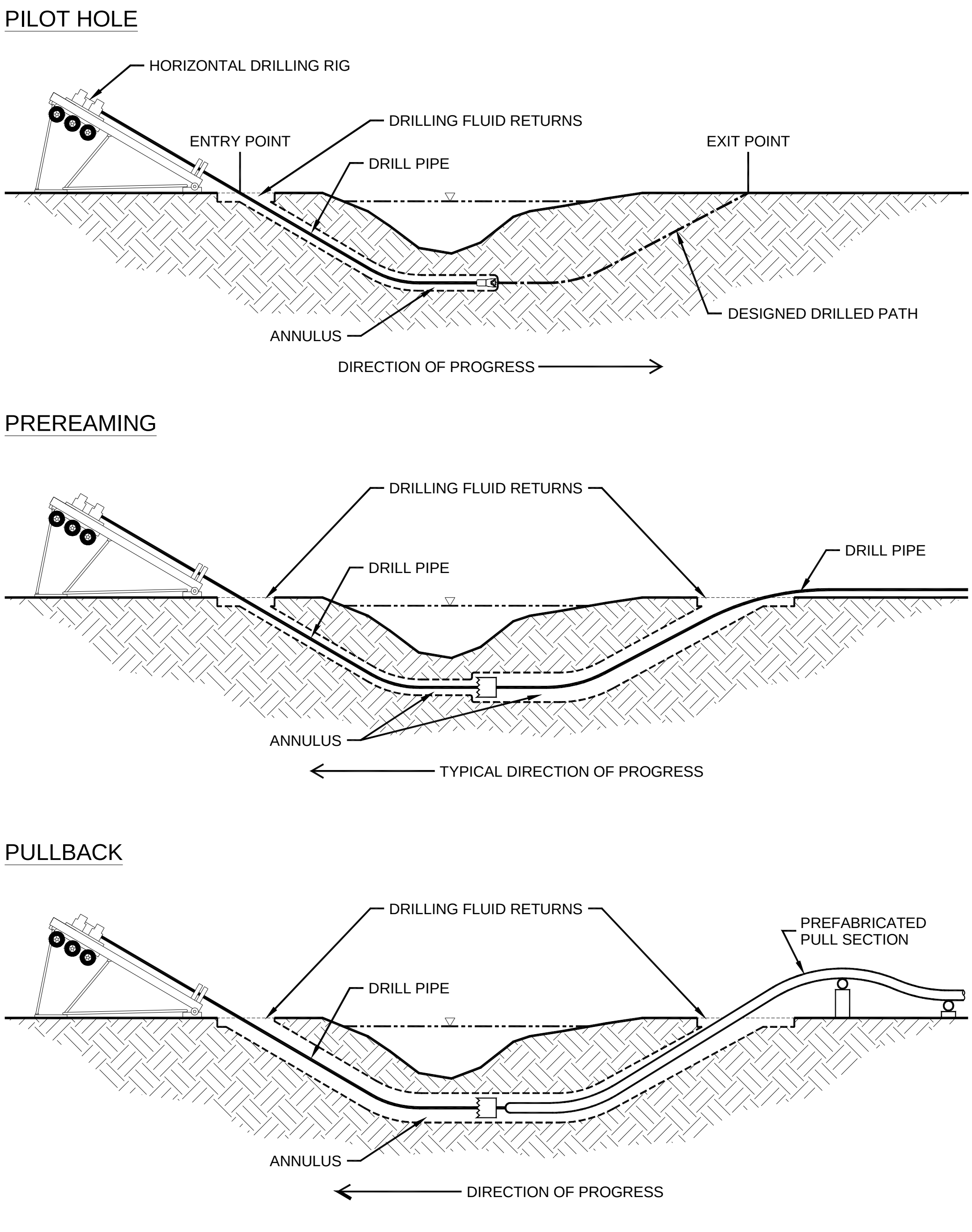


**Figure 1.** The HDD Process

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.

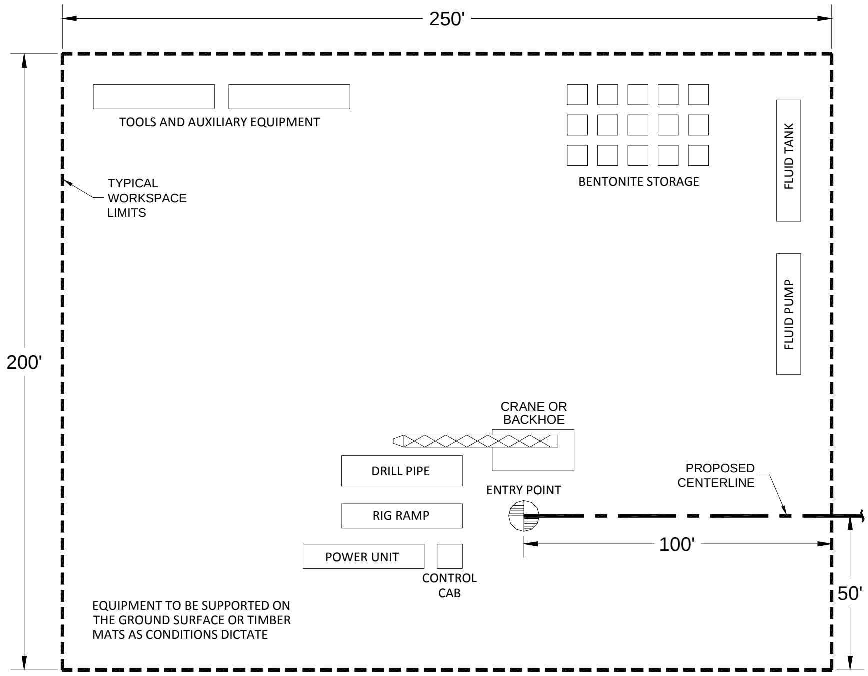


**Figure 2.** Typical Horizontal Drilling Rig Site Plan

### 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.

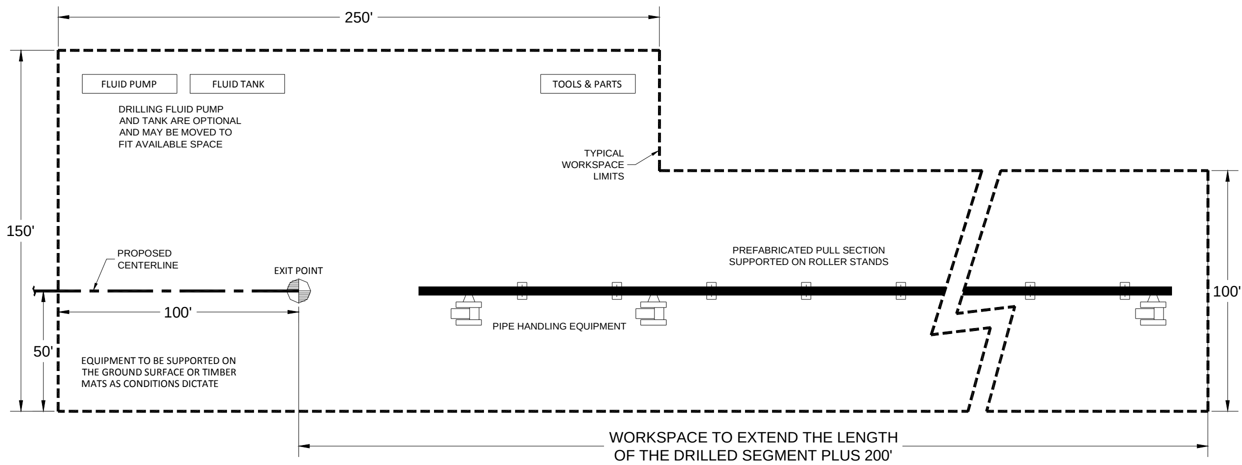


**Figure 3.** Typical Pull Section Fabrication Site Plan

## 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.

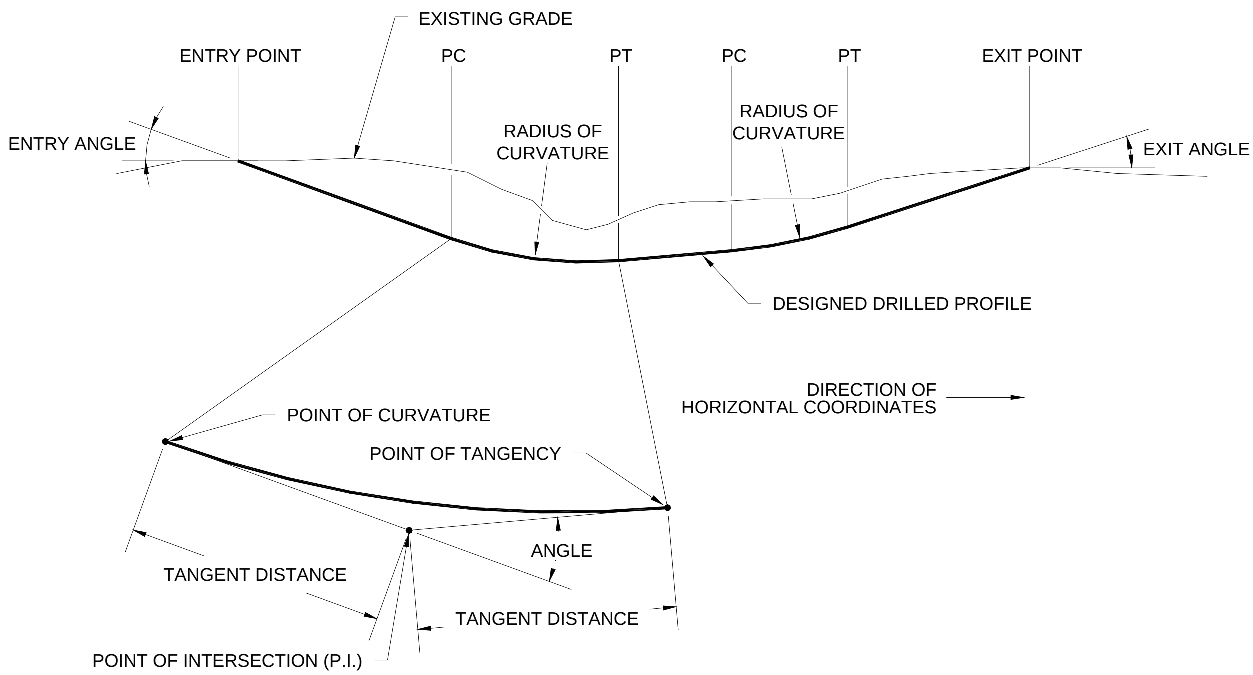


**Figure 5.** HDD Design Terminology

### 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.

[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.

**<u>20-inch Crossings</u>**

| | |
|---|---|
| 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 |

**<u>36-inch Crossings</u>**

| | |
|---|---|
| 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 |

**<u>42-inch Crossings</u>**

| | |
|---|---|
| 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

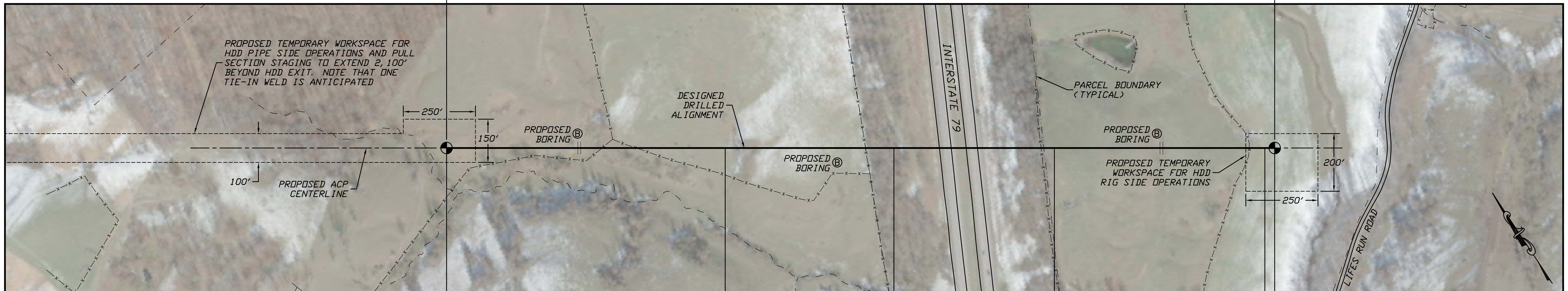
| Pipe Properties | | |
|---|---|---|
| | Design Radius (4,200') | Specified Min. Radius (2,800') |
| Pipe Outside Diameter = | 42.000 in | 42.000 in |
| Wall Thickness = | 0.864 in | 0.864 in |
| Specified Minimum Yield Strength = | 70,000 psi | 70,000 psi |
| Young's Modulus = | 2.9E+07 psi | 2.9E+07 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**

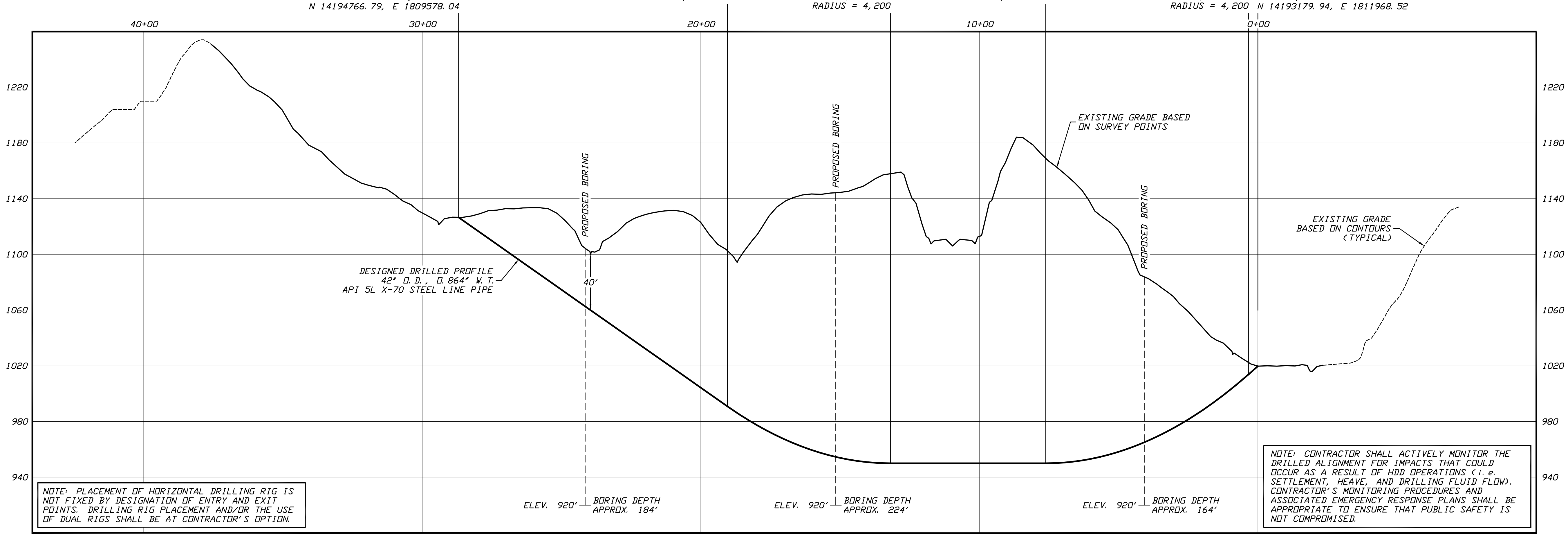
- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, with buoyancy control (4 pages)
- Installation stress analysis, without buoyancy control (4 pages)

HORIZONTAL DRILLED LENGTH = 2,869'
TRUE LENGTH = 2,885'




## PLAN

SCALE: 1"=200'




## PROFILE

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

400 200 100 0 / 0 20 40

**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 | $ft^3/ft$ | |

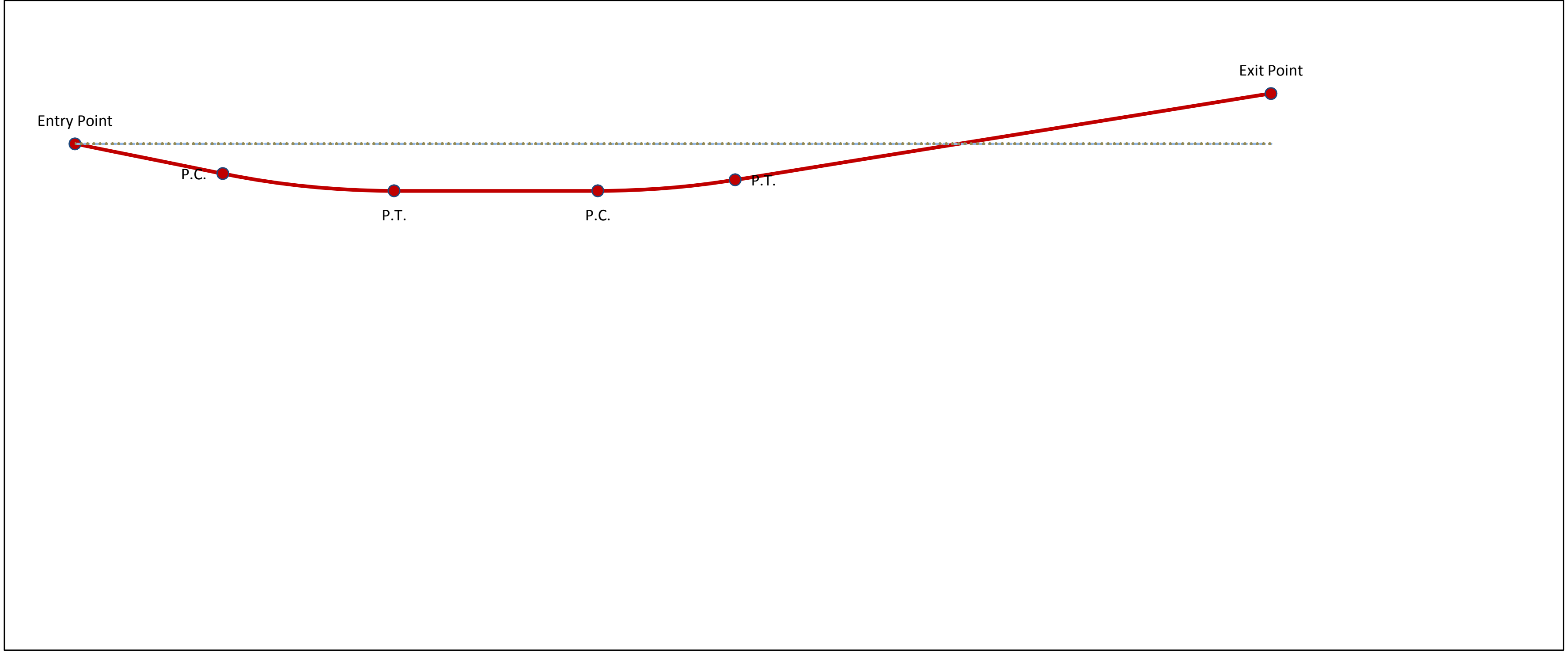
| HDD Installation Properties | | | |
|---|---|---|---|
| Drilling Mud Density = | 12.0 | ppg | |
| = | 89.8 | $lb/ft^3$ | |
| Ballast Density = | 62.4 | $lb/ft^3$ | |
| Coefficient of Soil Friction = | 0.30 | | |
| Fluid Drag Coefficient = | 0.025 | psi | |
| Ballast Weight = | 551.97 | lb/ft | |
|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




**Step 2, Drilled Path Input**

# Interstate 79 P0 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, $\mu$ = | 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, $\theta$ = | 8.0 | ° | | | |

| | | | |
|---|---|---|---|
| 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 = | 93,483 | lb |
| Segment Angle with Horizontal, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | 68.0 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R [1 - \cos(\alpha/2)]$ = | 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 | | $N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ = | 29,129 | lb |
| Bending Frictional Drag = $2 \mu N$ = | 17,478 | lb | | | |
| Fluidic Drag = $12 \pi D L C_d$ = | 13,265 | lb | | | |
| Axial Segment Weight = $W_e L \sin\theta$ = | -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 = $W_e L \mu$ = | 10,109 | 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 =** | **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(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) = 26,963 lb

Bending Frictional Drag = 2 μ N = 16,178 lb

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

Axial Segment Weight = $W_e$ L sinθ = 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 μ cosθ = 7,321 lb

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

Axial Segment Weight = $W_e$ L sinθ = 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

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 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 | |

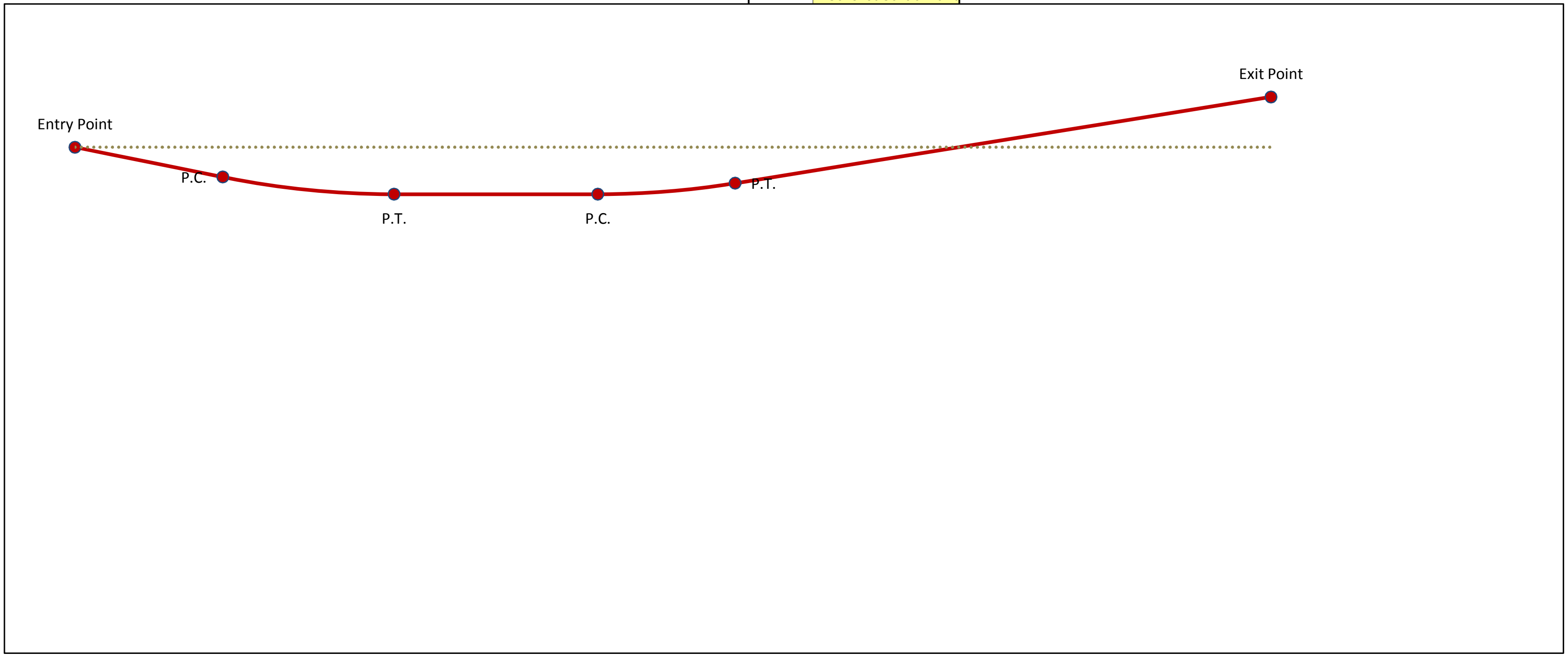
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,508 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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




**Step 2, Drilled Path Input**

2:23 PM12/13/2016

## Interstate 79 P0 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 = | 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 = | 135,407 | lb |
| Segment Angle with Horizontal, θ = | -8.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, α = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -484.0 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| h = R [1 - cos(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) = | 147,372 | lb |
| Bending Frictional Drag = 2 μ N = | 88,423 | lb | | | |
| Fluidic Drag = 12 π D L $C_d$ = | 13,265 | lb | | | |
| Axial Segment Weight = $W_e$ L sinθ = | 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 μ = | 71,990 | 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 =** | **91,615** | **lb** |
| **Total Pulling Load =** | **283,523** | **lb** |

## Entry Sag Bend - Summary of Pulling Load Calculations

| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 418.9 | ft | Average Tension, T = | 339,178 | lb |
| Segment Angle with Horizontal, θ = | 10.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, α = | 5.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -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 | Effective Weight, $W_e = W + W_b - W_m$ = | -484.0 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| Frictional Drag = $W_e\,L\,\mu\cos\theta$ = | 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** | |

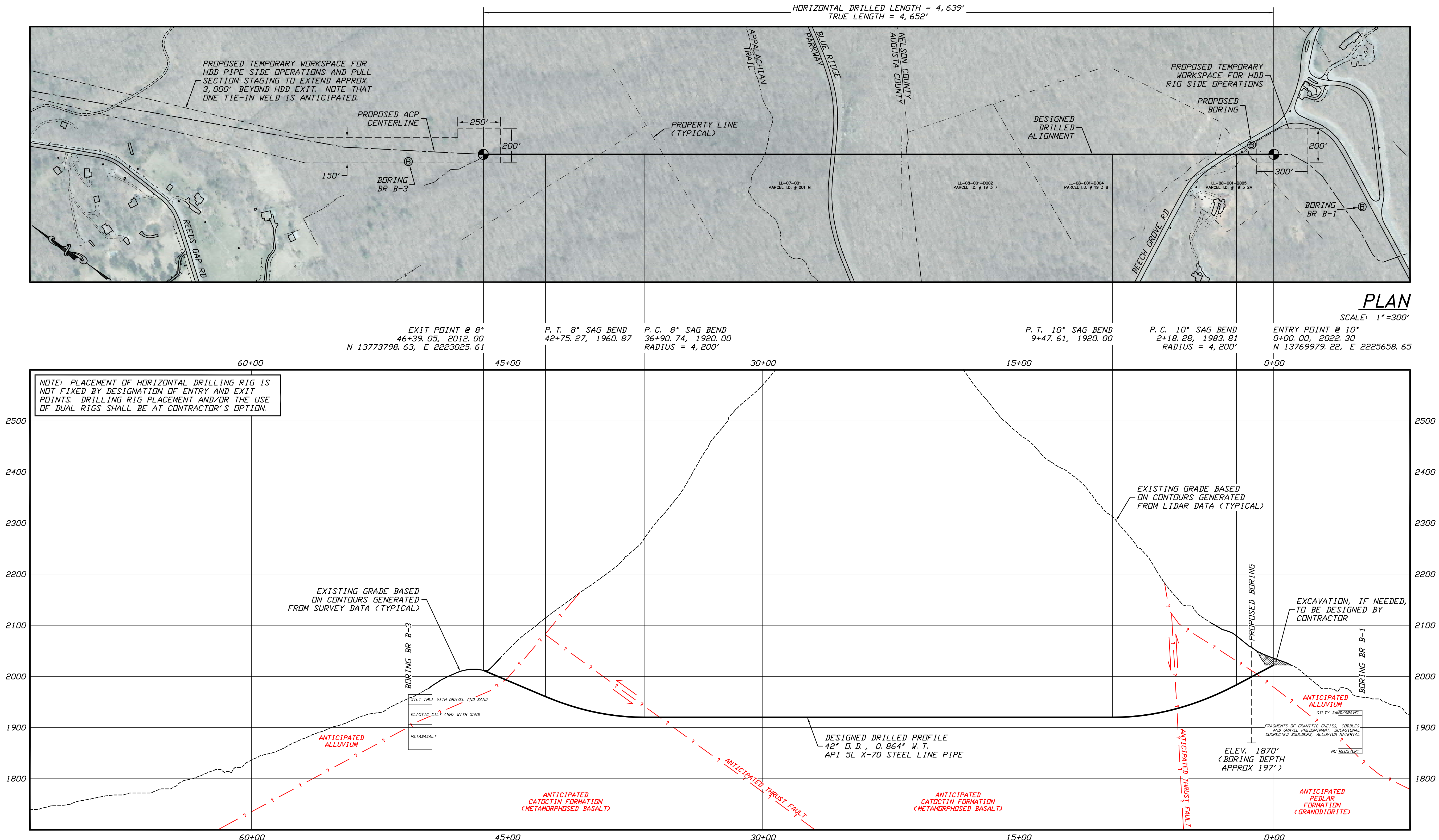
## Summary of Calculated Stress vs. Allowable Stress

| | 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

**<u>Supporting Information</u>**

- 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)




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. |
|---|---|---|---|---|---|

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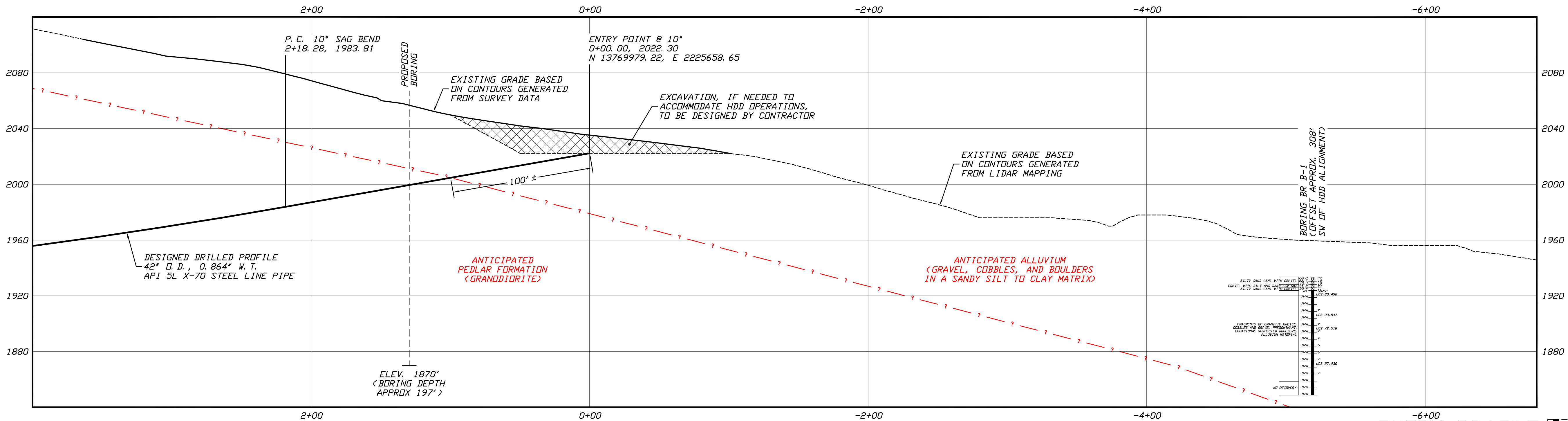
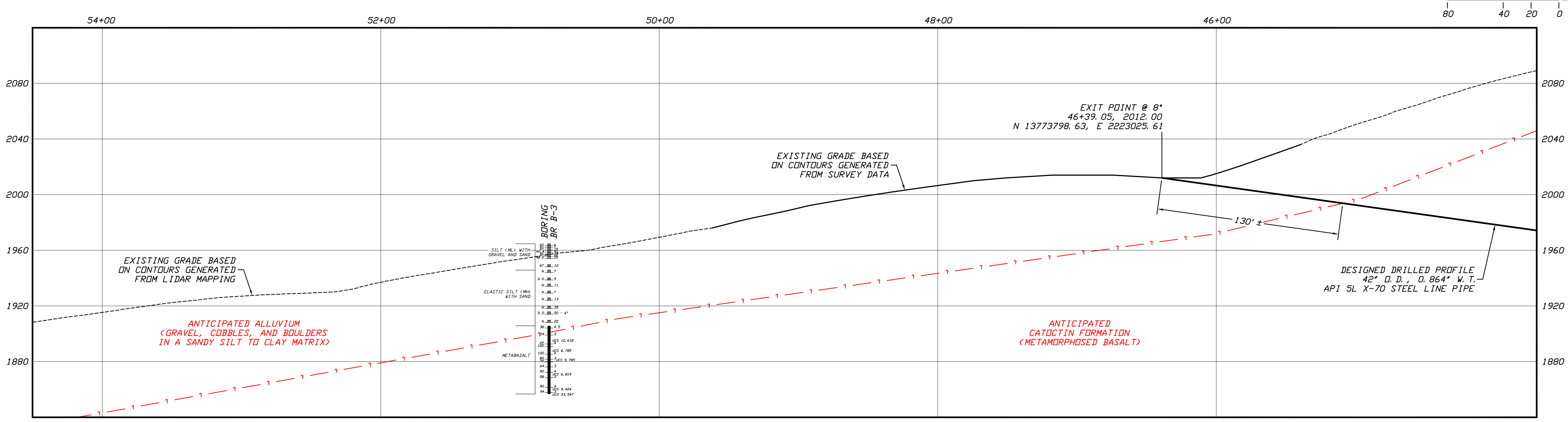
PROJECT NO.
Dominion\1508

MILE POST
AP1-158




## ENTRY PROFILE

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




## EXIT PROFILE

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

### 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. |
|---|---|---|---|---|---|
| | | | | | |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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 | |

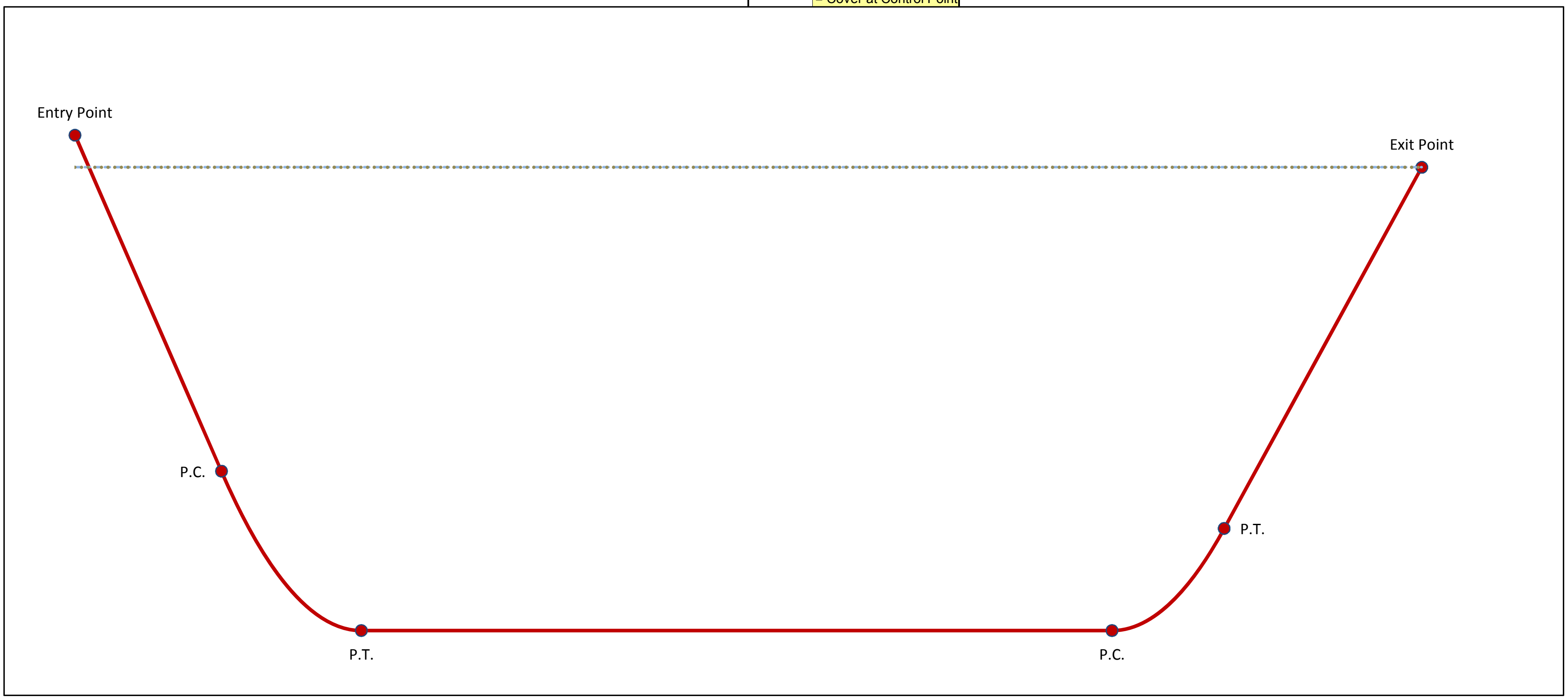
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,508 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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 | |




**Step 2, Drilled Path Input**

# Blue Ridge Parkway R0 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, $\mu$ = | 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, $\theta$ = | 8.0 | ° | | | |

| | | | |
|---|---|---|---|
| Frictional Drag = $W_e \, L \, \mu \cos\theta$ = | 13,994 | lb | |
| Fluidic Drag = $12 \, \pi \, D \, L \, C_d$ = | 27,436 | lb | |
| Axial Segment Weight = $W_e \, L \sin\theta$ = | -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, $\theta$ = | -8.0 | ° | Radius of Curvature, $R$ = | 2,800 | ft |
| Deflection Angle, $\alpha$ = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | 68.0 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R\,[1 - \cos(\alpha/2)]$ = | 6.82 | ft | $j = [(E\,I) / T]^{1/2}$ = | 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 | | $N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X / 12)$ = | 13,353 | lb |
| Bending Frictional Drag = $2\,\mu\,N$ = | 8,012 | 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 =** | **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 = $W_e \, L \, \mu$ = | 53,170 | 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 =** | **156,395** | **lb** |
| **Total Pulling Load =** | **212,902** | **lb** |

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

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

## Entry Sag Bend - Summary of Pulling Load Calculations

| | | | | | |
|---|---|---|---|---|---|
| Segment Length, $L$ = | 488.7 | ft | Average Tension, $T$ = | 231,351 | lb |
| Segment Angle with Horizontal, $\theta$ = | 10.0 | ° | Radius of Curvature, $R$ = | 2,800 | ft |
| Deflection Angle, $\alpha$ = | 5.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | 68.0 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R\,[1 - \cos(\alpha/2)]$ = | 10.65 | ft | $j = [(E\,I) / T]^{1/2}$ = | 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 | Effective Weight, $W_e = W + W_b - W_m$ = | 68.0 | lb/ft |
| Entry Angle, $\theta$ = | 10.0 | ° | | | |

| | | |
|---|---|---|
| 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 |

| 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 | |

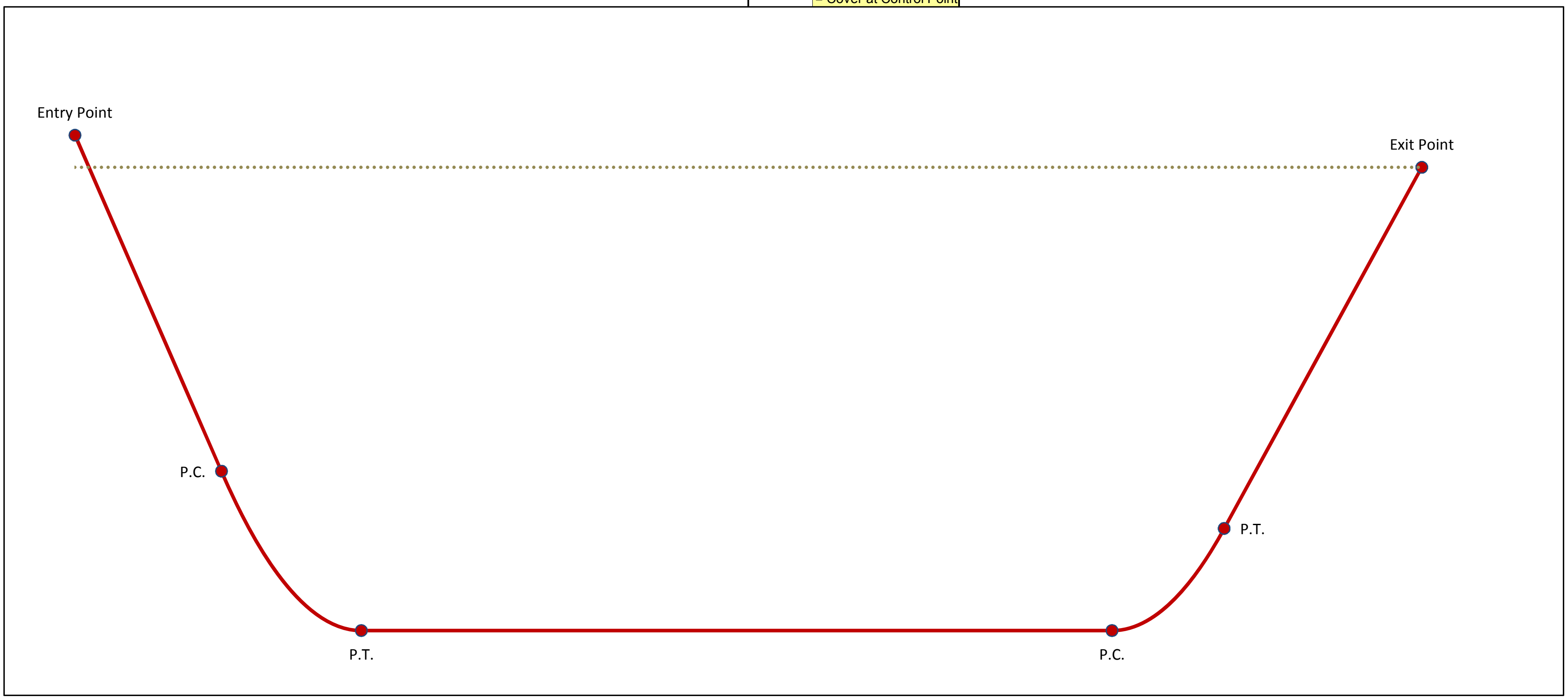
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,508 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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

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 | | | | 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 | |



## 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 μ cosθ = | 99,660 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 27,436 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) | 162,328 | lb |
| Bending Frictional Drag = 2 μ N = | 97,397 | 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 =** | **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 μ = | 378,650 | 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 =** | **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** | | | |

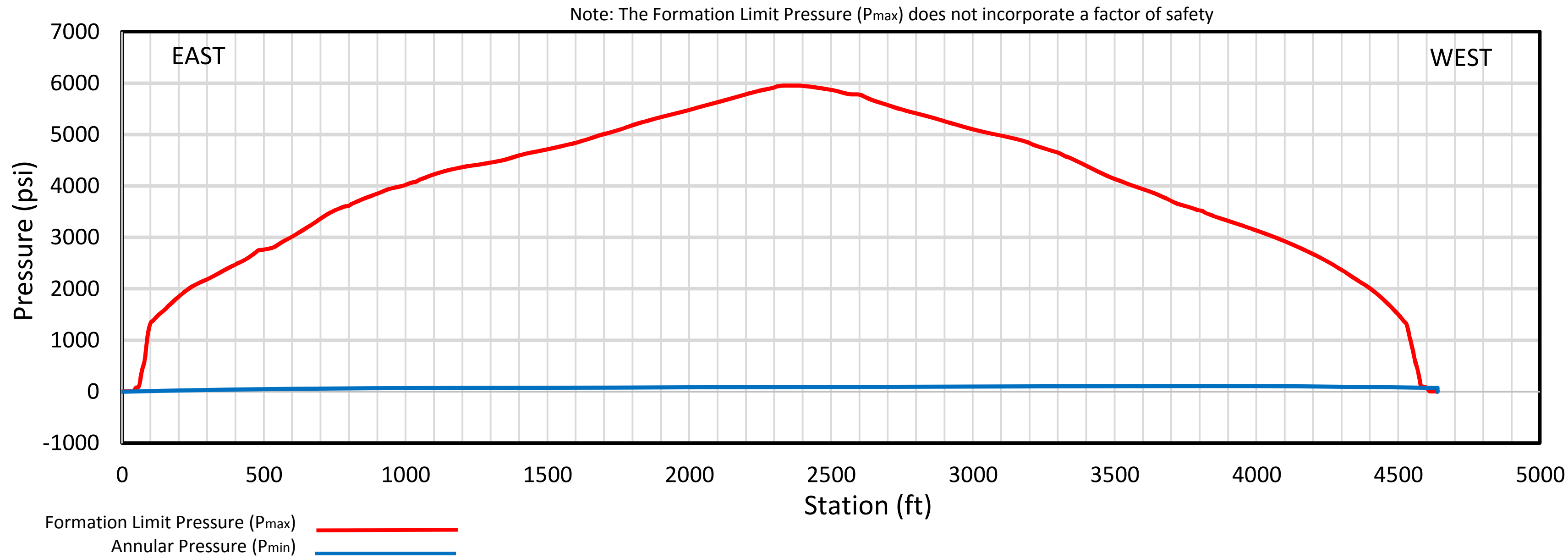
## Entry Tangent - Summary of Pulling Load Calculations

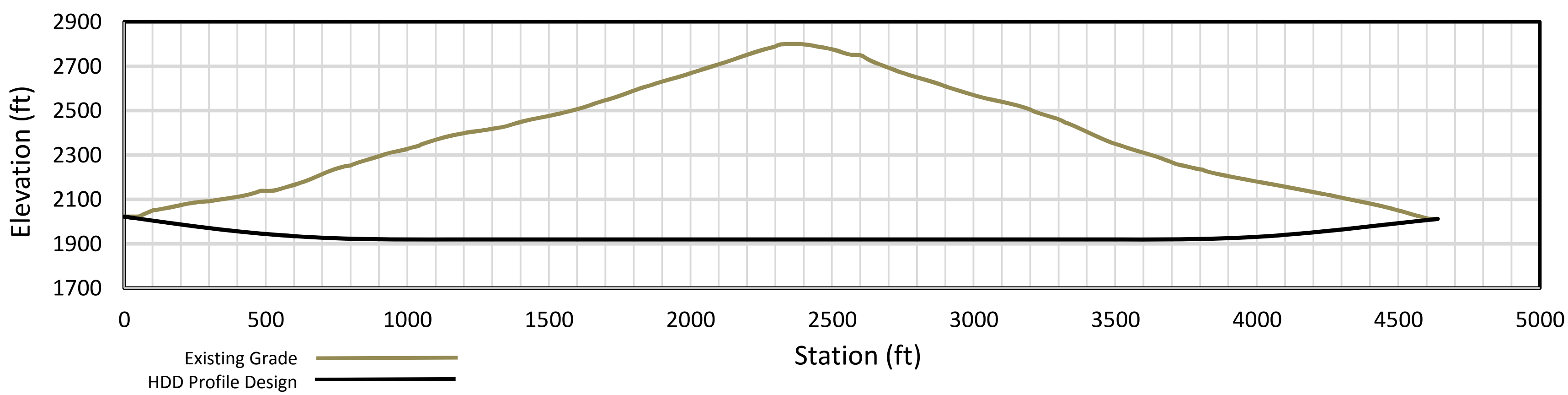
| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 516.9 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -484.0 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| 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 |




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

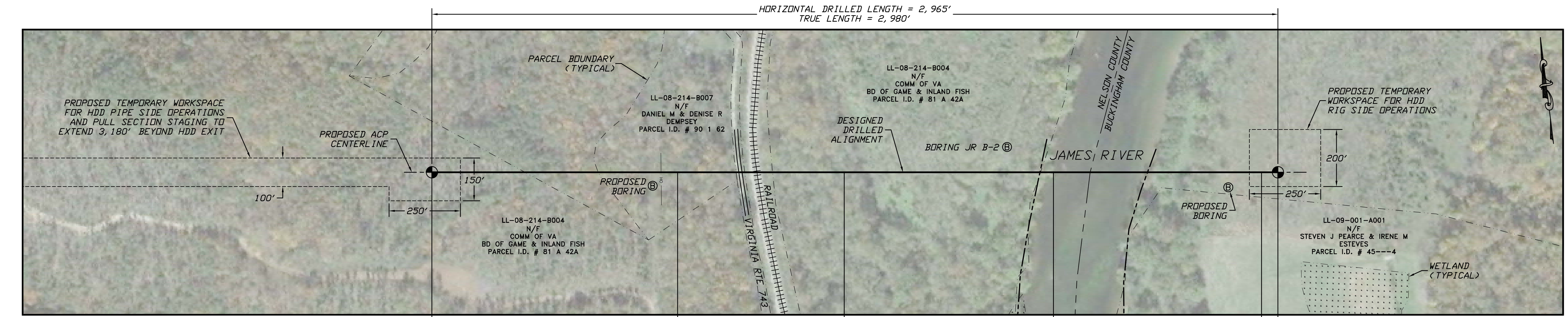
Date: 7/26/2016 Revision: 0

J.D.Hair&Associates, Inc.

# James River

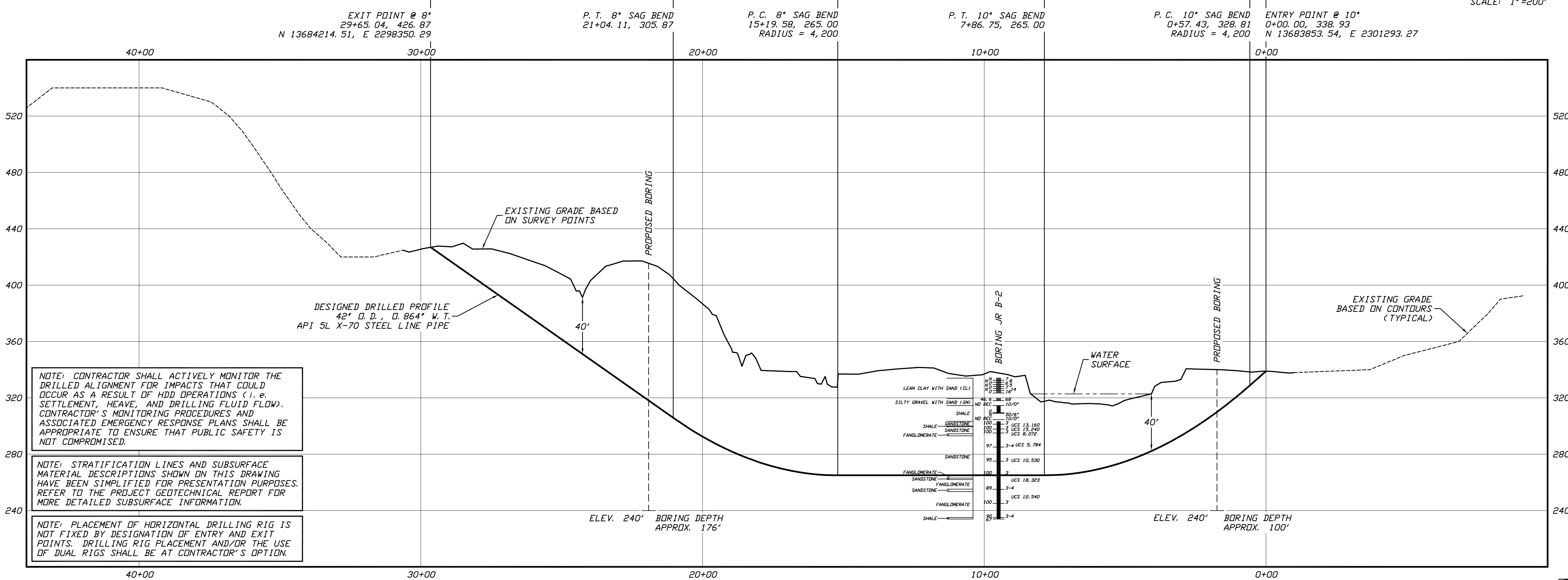
**Supporting Information**

- 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)




## PLAN

SCALE: 1"=200'




## PROFILE

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

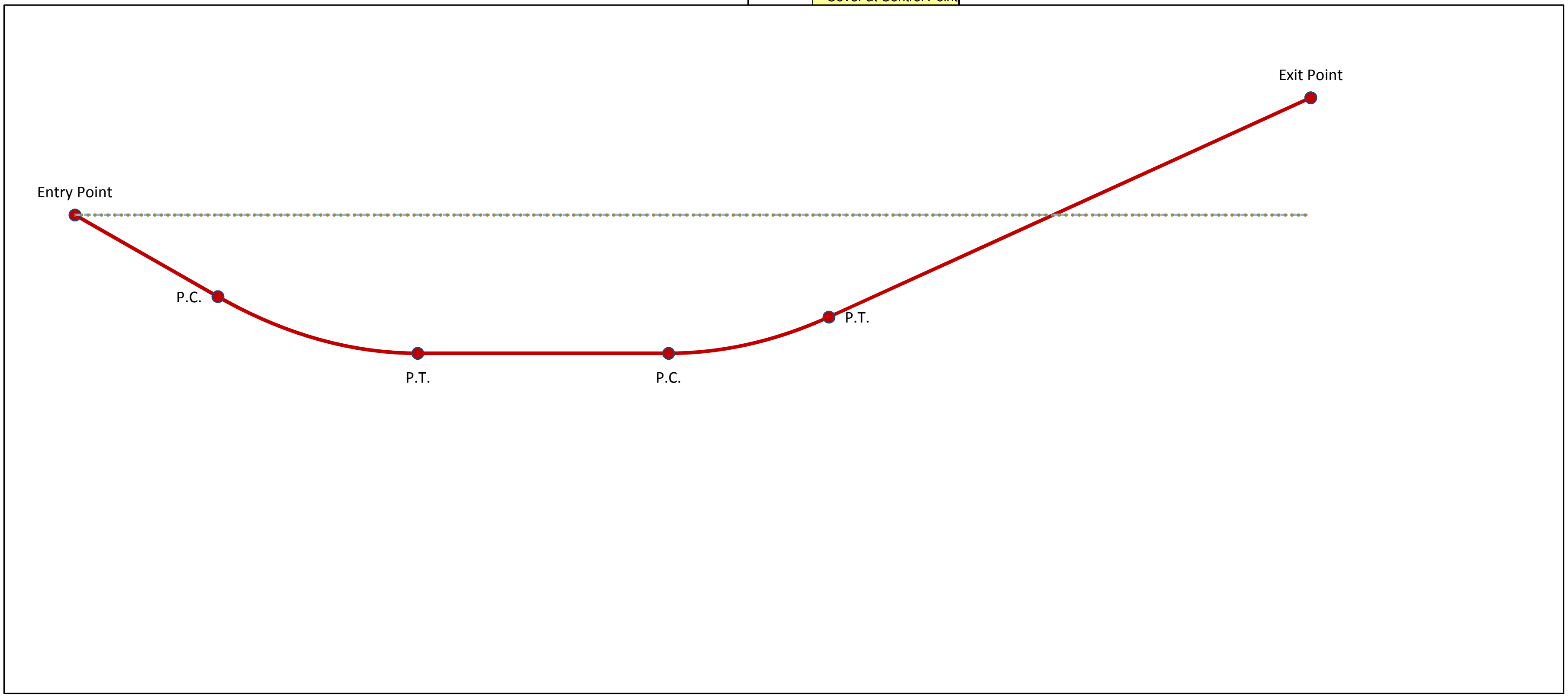
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,508 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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**

## 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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,800 | ft |
| Deflection Angle, $\alpha$ = | -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

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 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 | $ft^3/ft$ | |

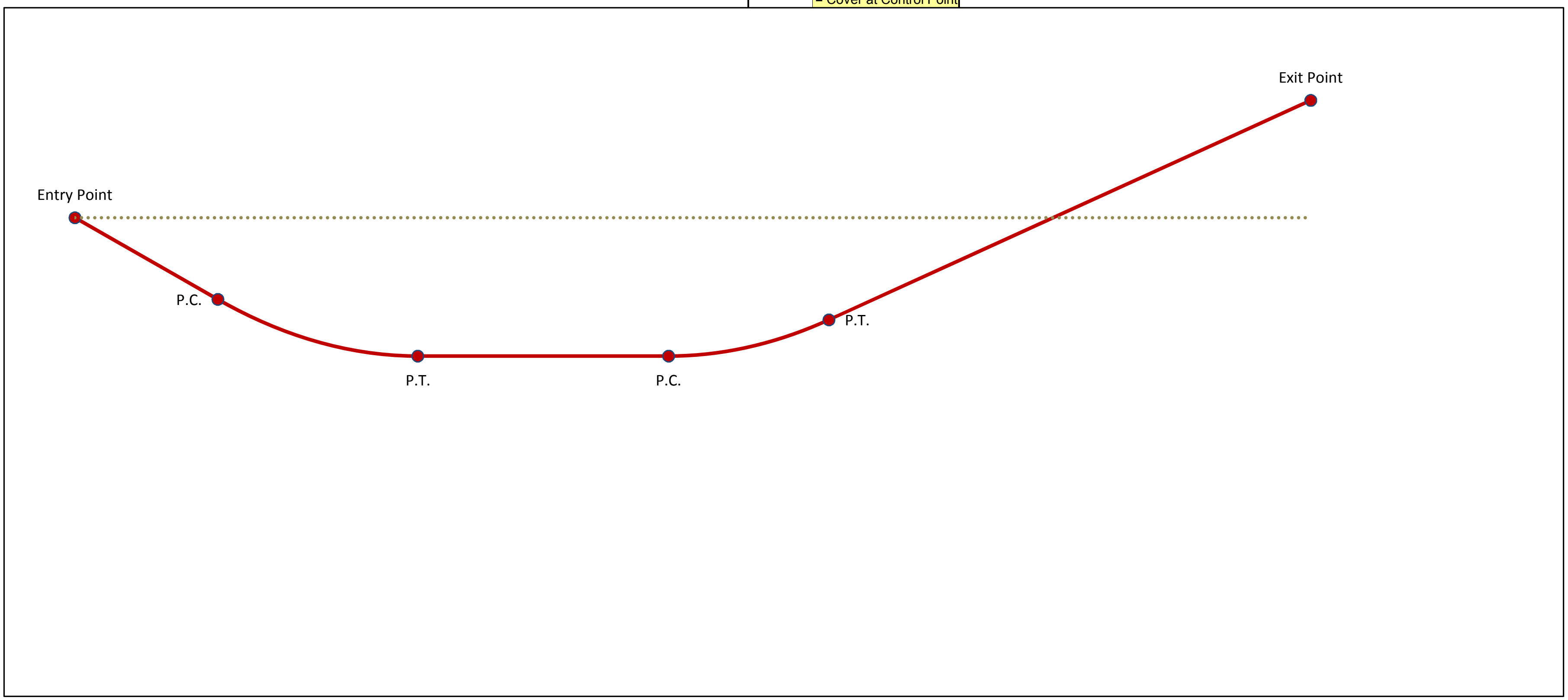
| HDD Installation Properties | | | |
|---|---|---|---|
| Drilling Mud Density = | 12.0 | ppg | |
| = | 89.8 | $lb/ft^3$ | |
| Ballast Density = | 62.4 | $lb/ft^3$ | |
| Coefficient of Soil Friction = | 0.30 | | |
| Fluid Drag Coefficient = | 0.025 | psi | |
| Ballast Weight = | 551.97 | lb/ft | |
|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

| | | 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 |
|---|---|



# James River P5 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 = | 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, $\mu$ = | 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, $\theta$ = | 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 = | 131,497 | lb |
| Segment Angle with Horizontal, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,800 | ft |
| Deflection Angle, $\alpha$ = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -484.0 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R [1 - \cos(\alpha/2)]$ = | 6.82 | ft | $j = [(E\ I) / T]^{1/2}$ = | 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 | | $N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ | 154,204 | lb |
| Bending Frictional Drag = $2 \mu N$ = | 92,522 | 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 =** | **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 = $W_e L \mu$ = | 88,554 | 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 =** | **112,694** | **lb** |
| **Total Pulling Load =** | **304,791** | **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 = 364,718 lb
Radius of Curvature, R = 2,800 ft
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
Entry Angle, θ = 10.0 °

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

Frictional Drag = $W_e\ L\ \mu \cos\theta$ = 50,522 lb

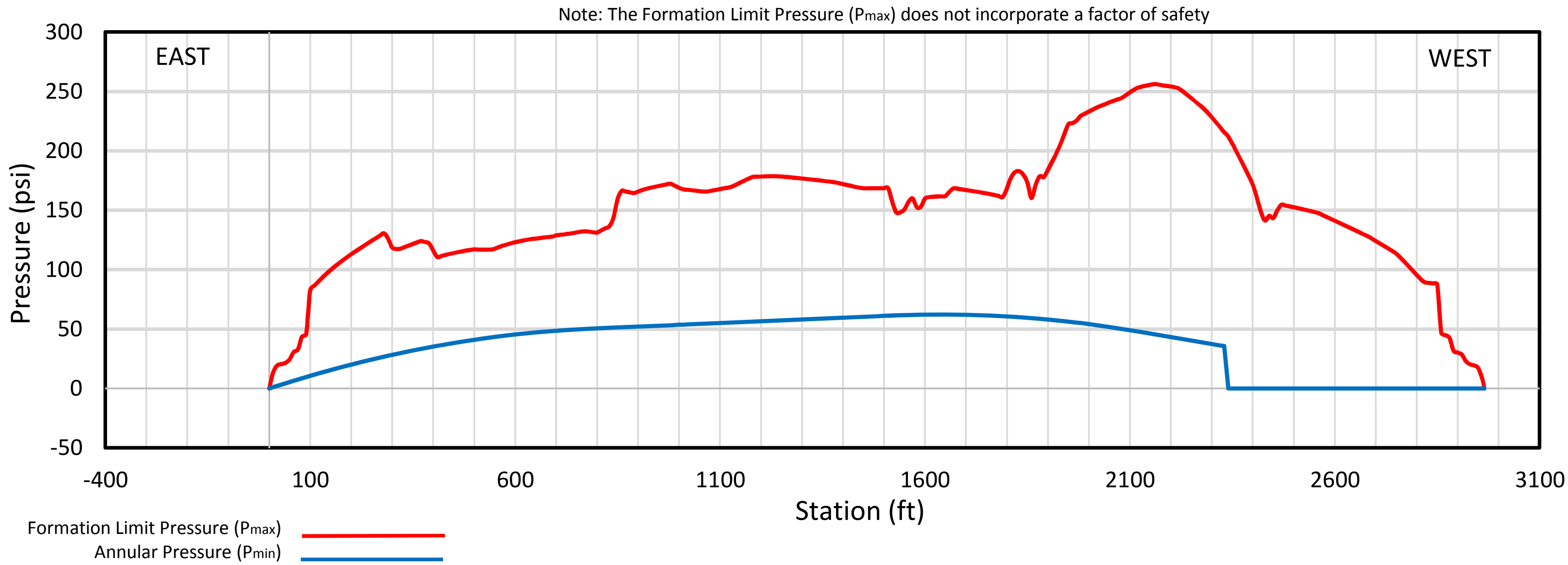
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 13,985 lb

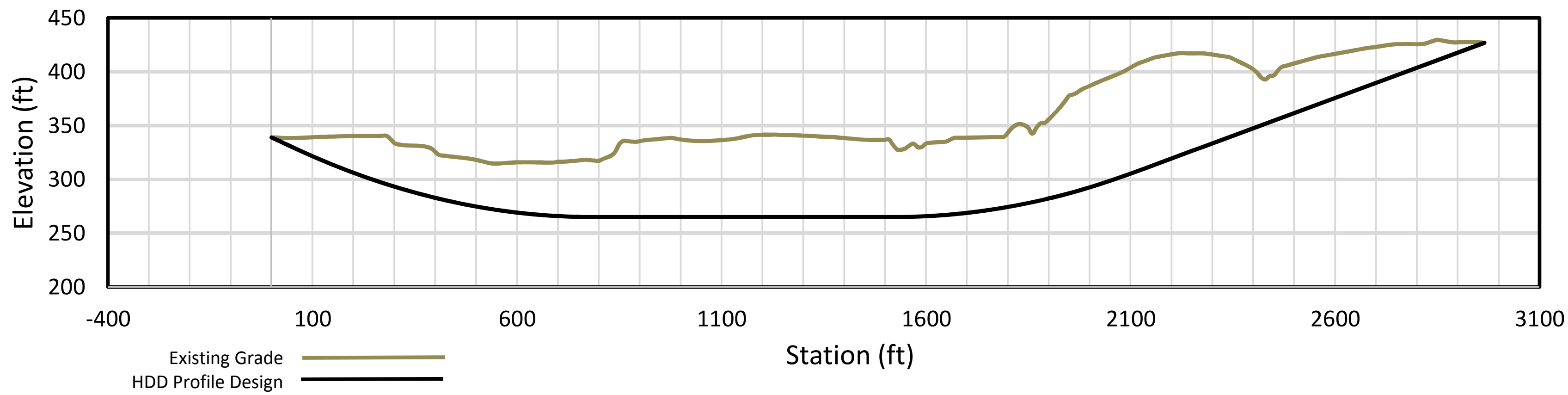
Axial Segment Weight = $W_e\ L \sin\theta$ = -29,695 lb — Negative value indicates axial weight applied in direction of installation

**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.

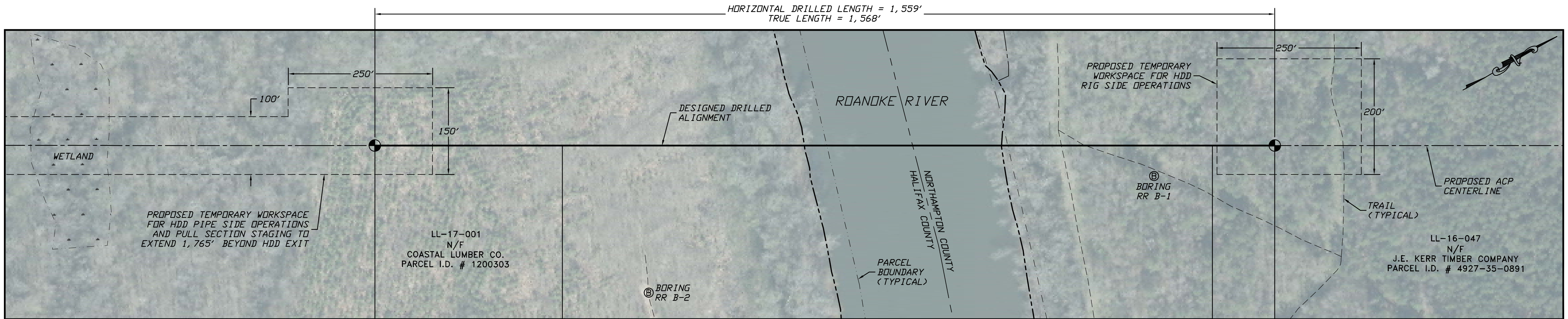
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
42-INCH JAMES RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 7/26/2016 Revision: 0

# Roanoke River

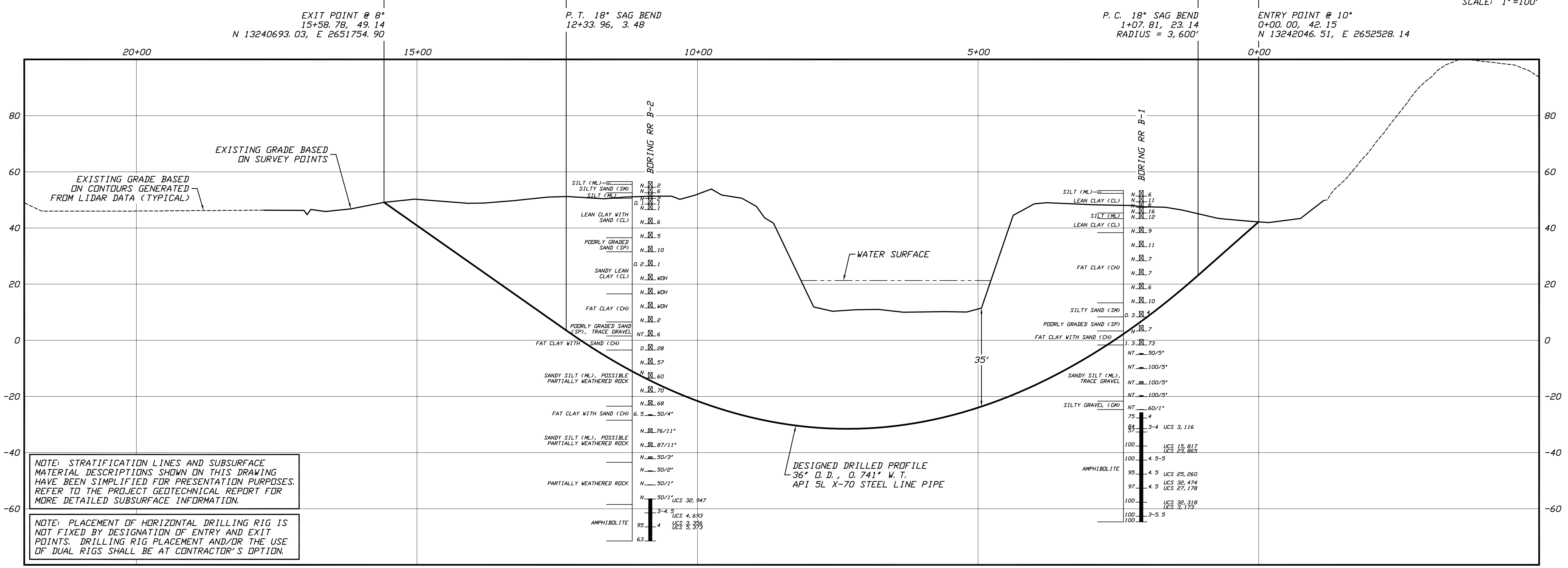
**Supporting Information**

- 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 | |

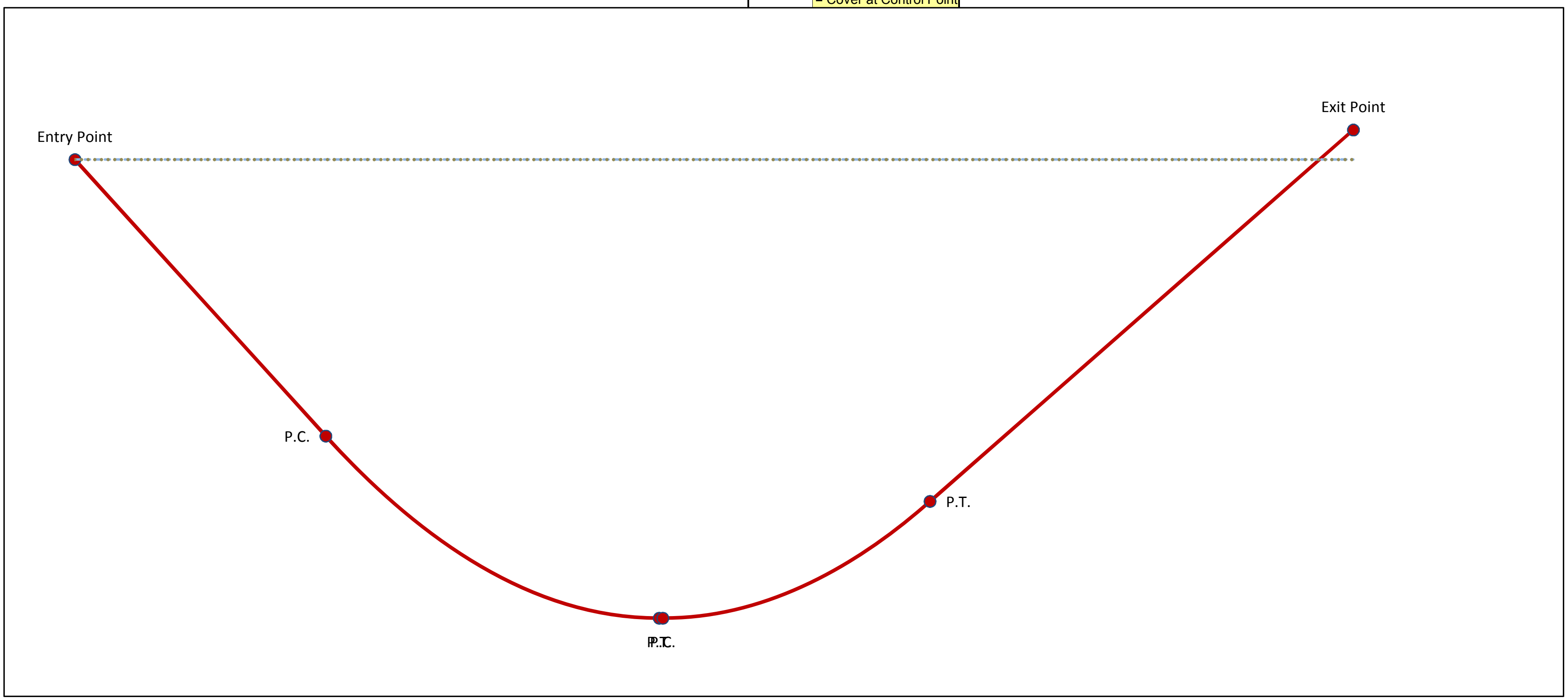
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,517 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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 | |



# Roanoke River R0 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 = | 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 | º | | | |

| | | | |
|---|---|---|---|
| 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 | º | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, α = | -4.0 | º | 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** |

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

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

## 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

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

| 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 | |

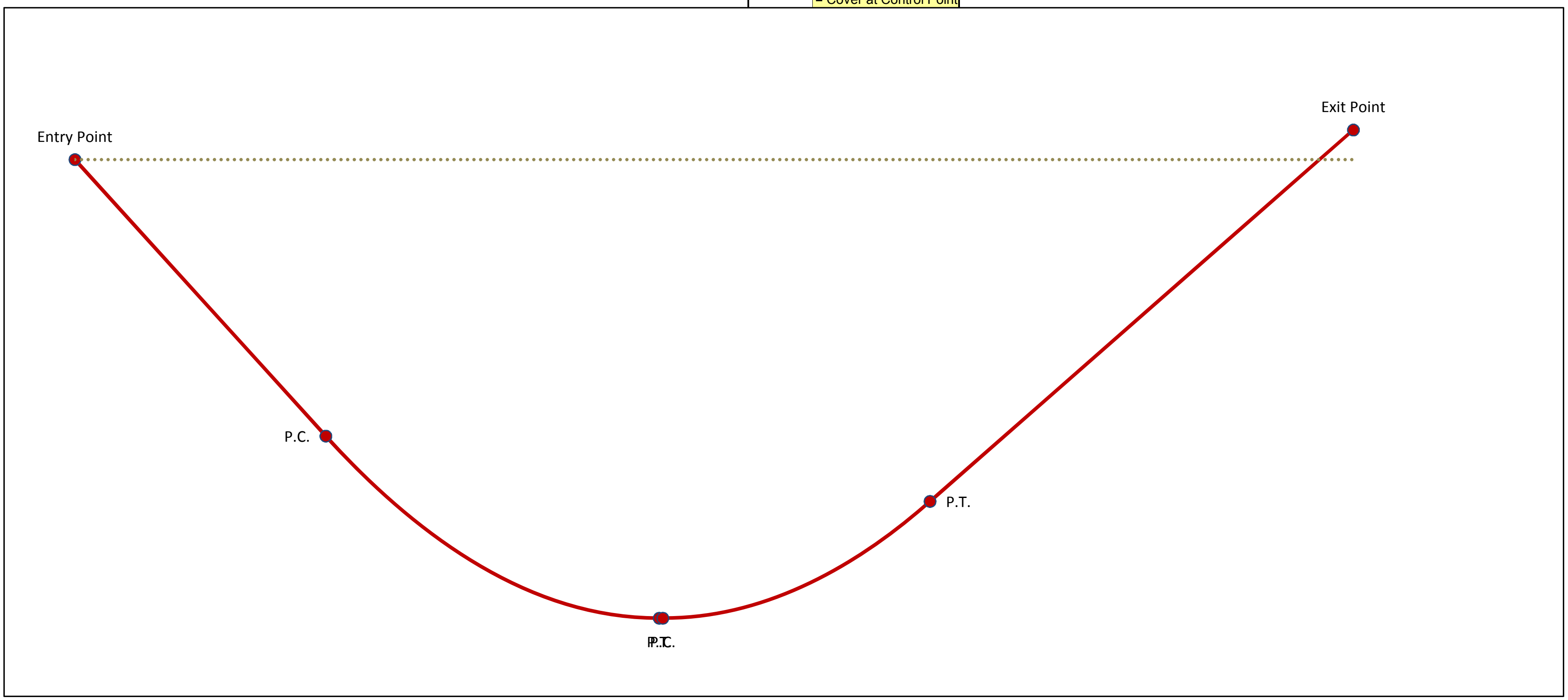
## Roanoke River R0 Installation Stress Analysis (worst-case).xlsm

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 | | | | 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**

## 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** |

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

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

## 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 = 223,422 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

$j = [(E I) / T]^{1/2}$ = 1,287

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 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
Entry Angle, θ = 10.0 °

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

Frictional Drag = $W_e L \mu \cos\theta$ = 33,472 lb

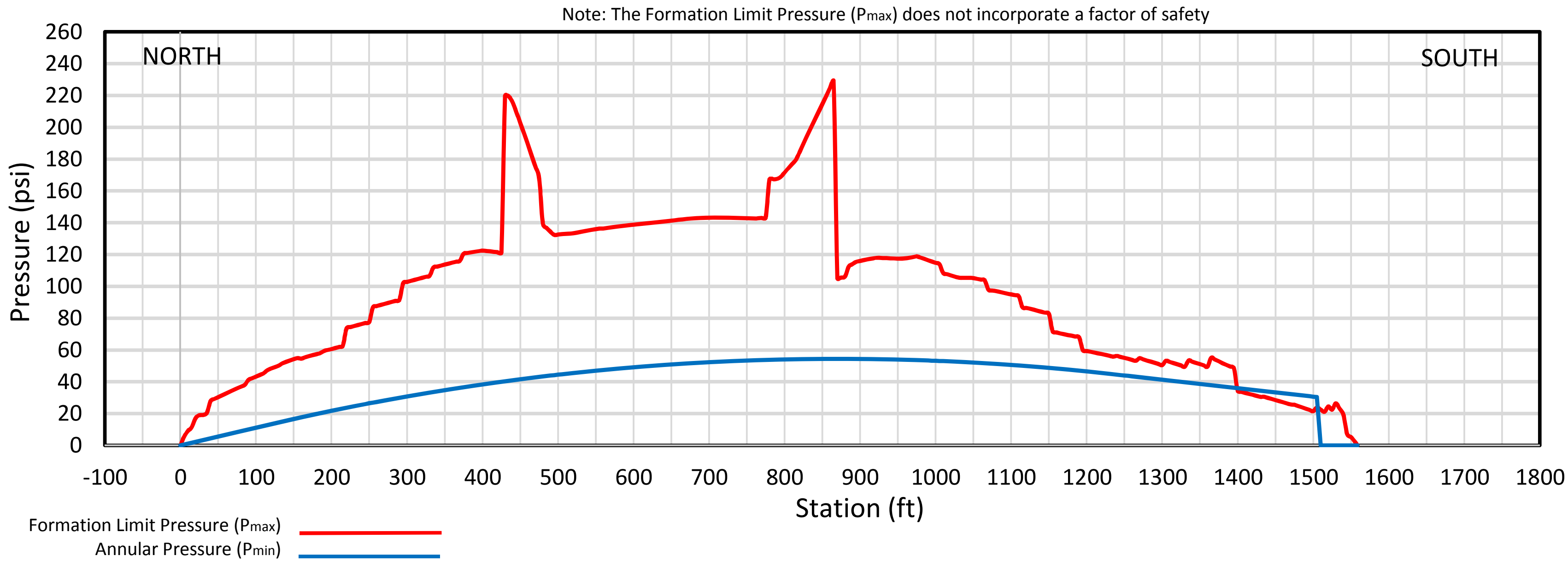
Fluidic Drag = $12 \pi D L C_d$ = 10,815 lb

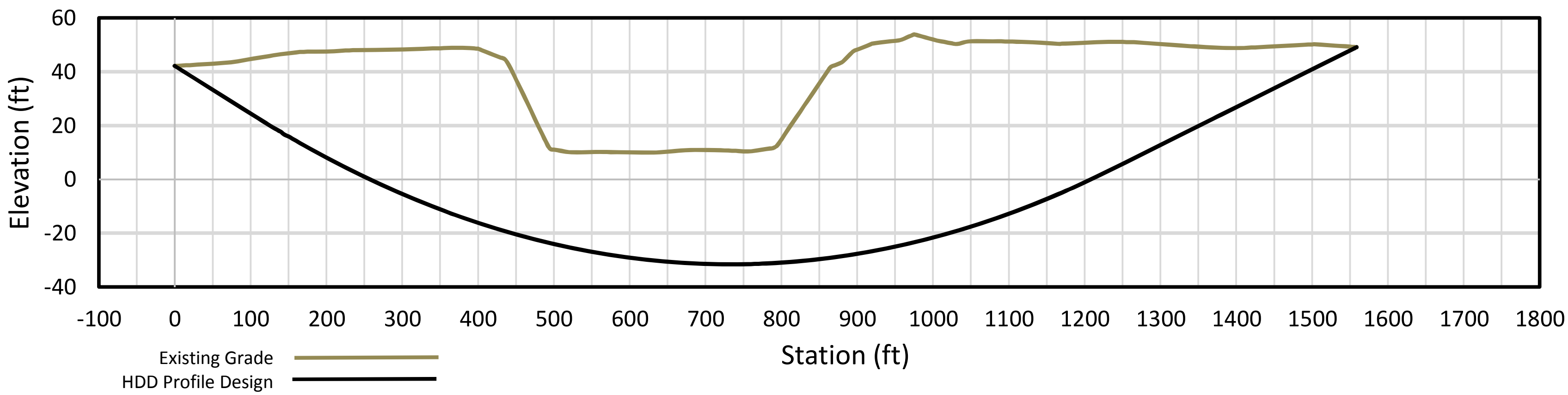
Axial Segment Weight = $W_e L \sin\theta$ = -19,673 lb — Negative value indicates axial weight applied in direction of installation

**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

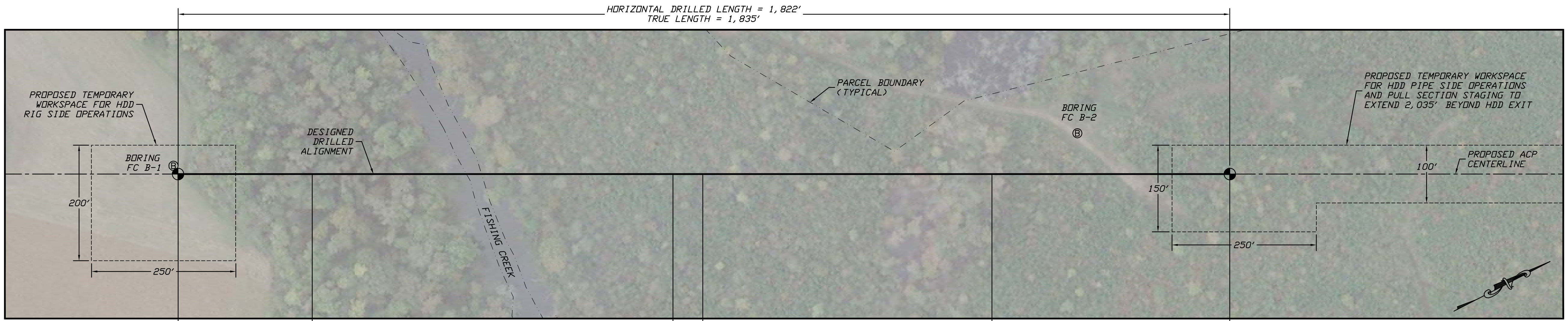
Date: 5/31/2016

Revision: 0

# Fishing Creek

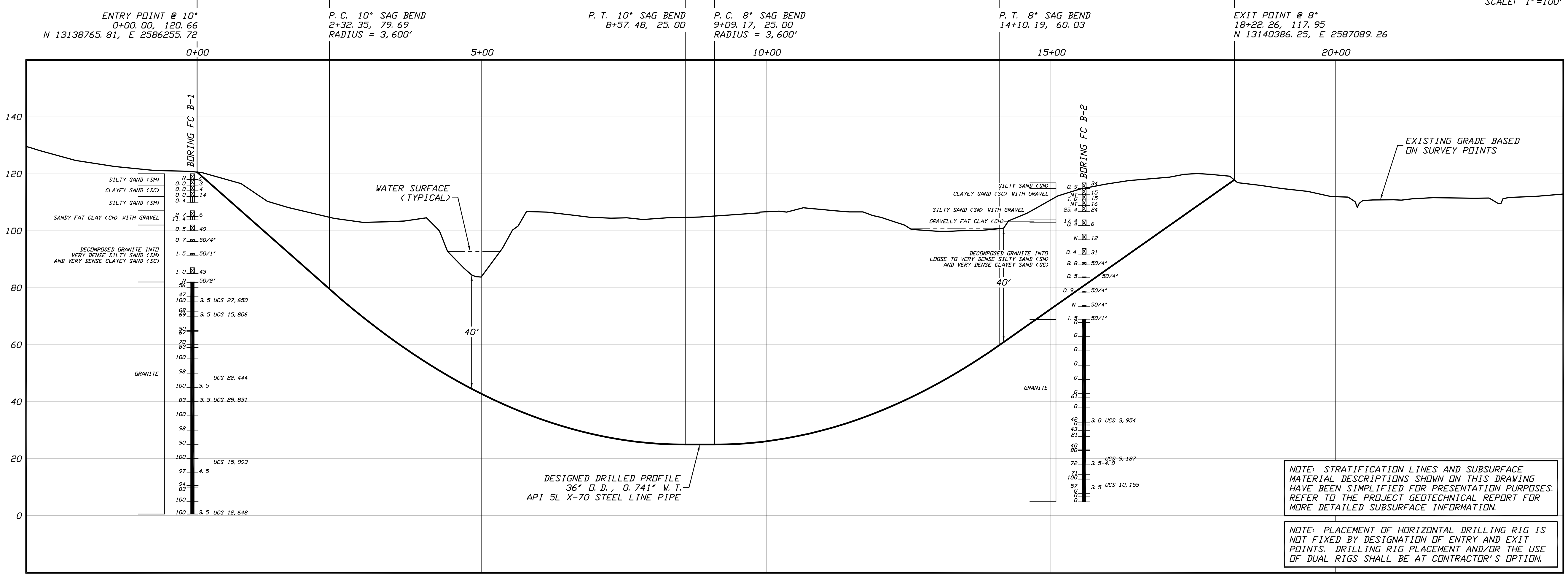
**Supporting Information**

- 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)




## 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

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 | CHK'D | 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

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

| 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 | |

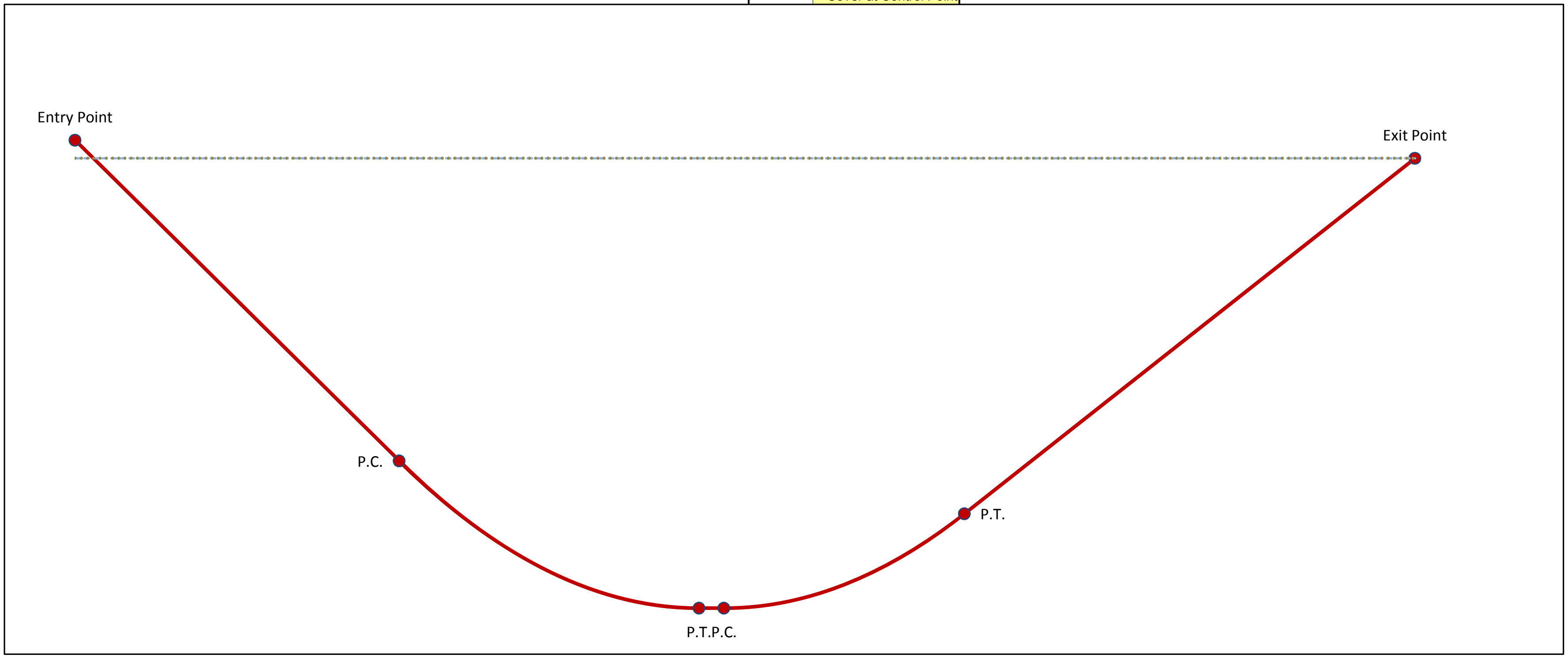
**Fishing Creek P1 Installation Stress Analysis (worst-case) - with buoyancy.xlsm**

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

| | | 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 |
|---|---|



# Fishing Creek P1 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 = | 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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -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** |

## 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 | º | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, α = | 5.0 | º | Effective Weight, $W_e = W + W_b - W_m$ = | 50.1 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| h = R [1 - cos(α/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 μ N = | 4,895 | lb | | | |
| Fluidic Drag = 12 π D L $C_d$ = | 14,212 | lb | | | |
| Axial Segment Weight = $W_e$ L sinθ = | 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 | º | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e$ L μ cosθ = | 6,765 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 15,516 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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

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

| 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 | |

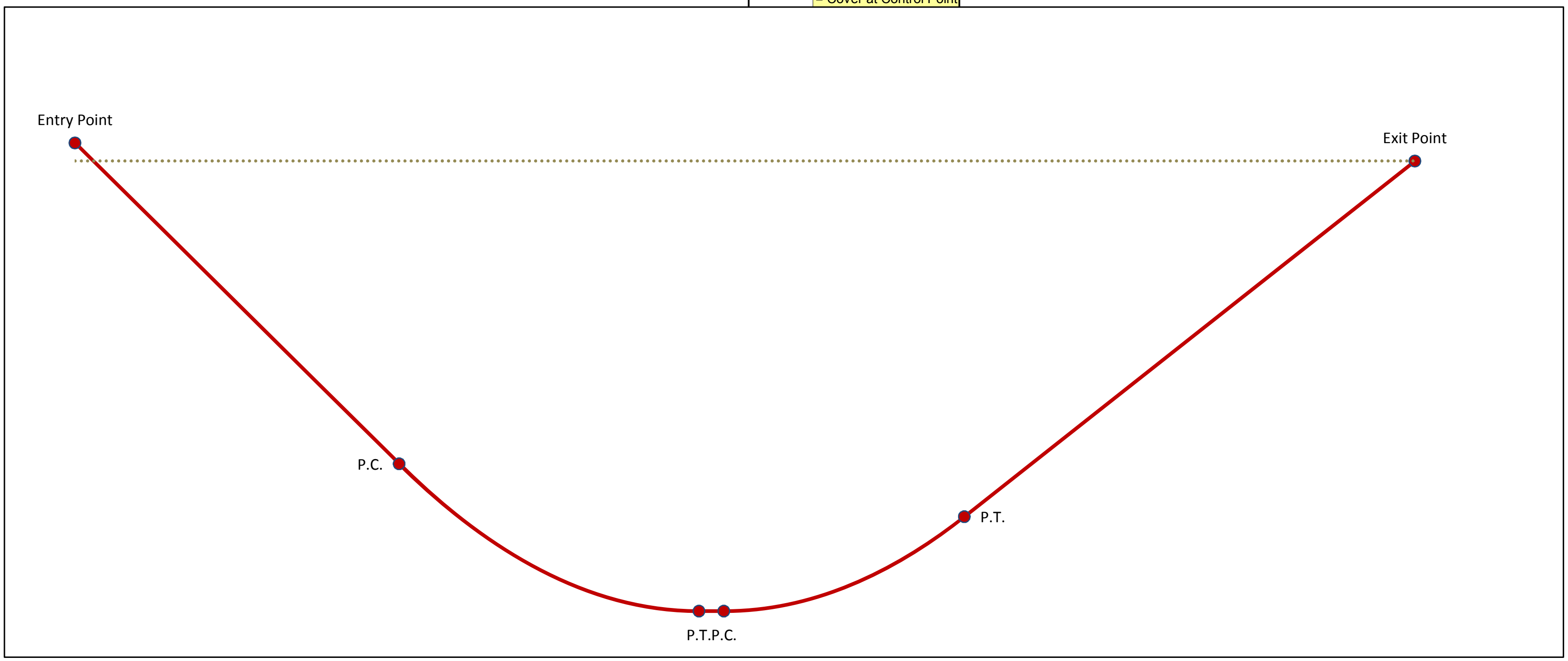
## Fishing Creek P1 Installation Stress Analysis (worst-case).xlsm

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

| | | 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

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 = | 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 | º | | | |

| | | |
|---|---|---|
| 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 | º | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, α = | -4.0 | º | 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** |

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

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

## 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

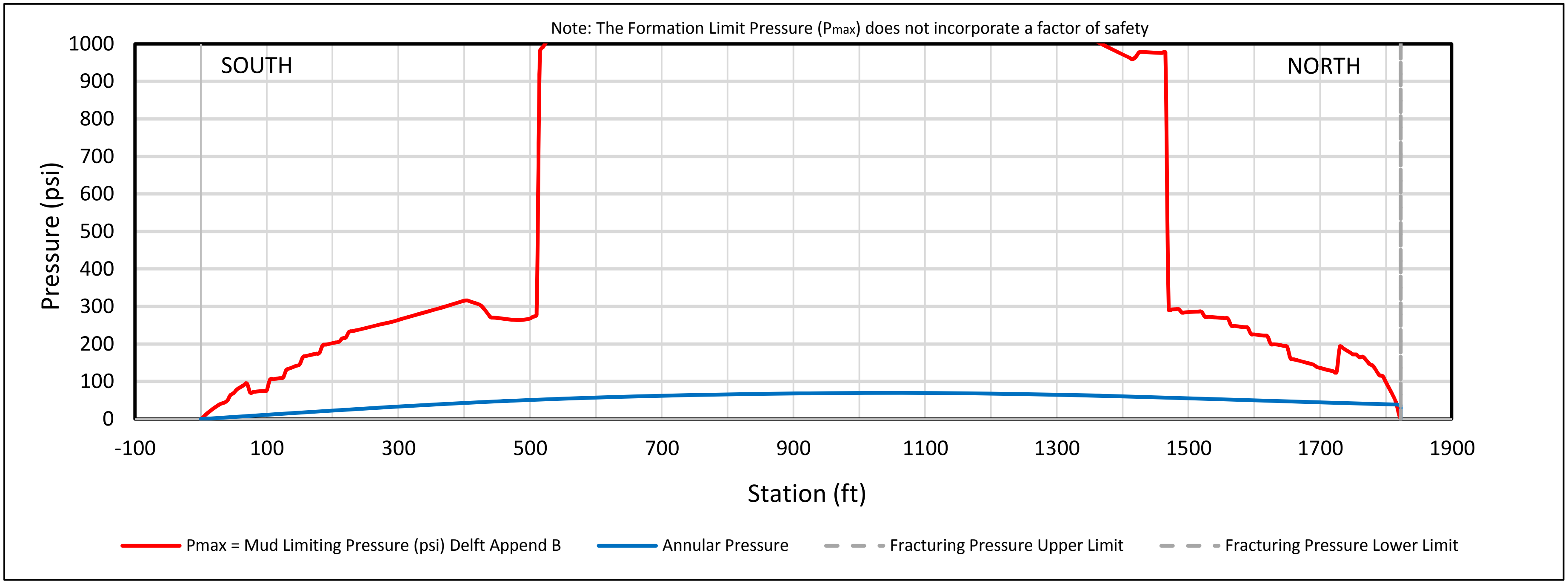
Axial Segment Weight = $W_e$ L sinθ = -28,225 lb

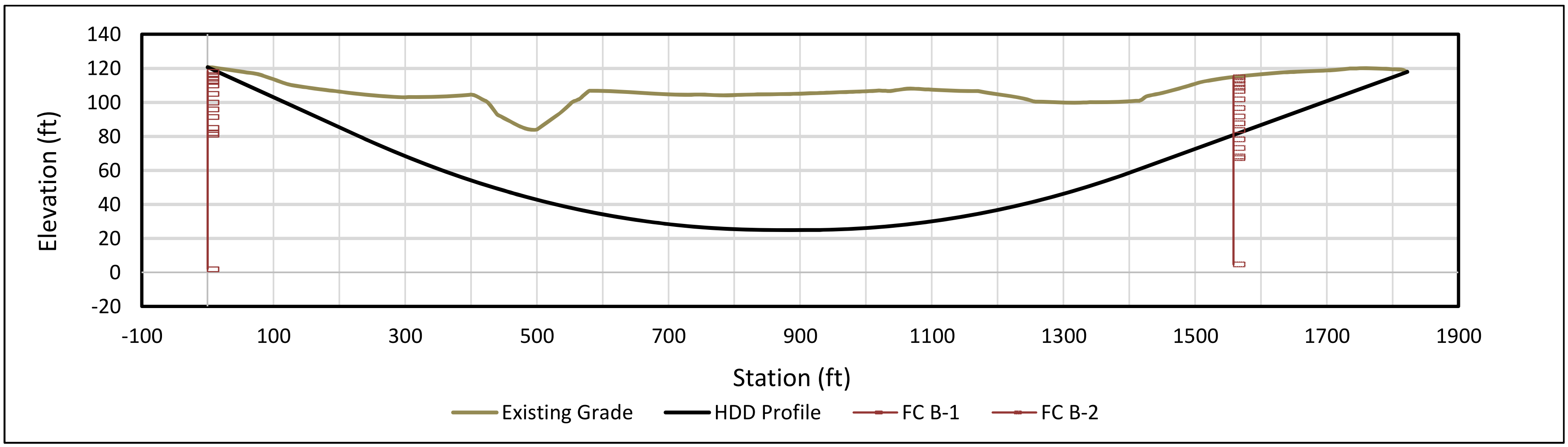
Negative value indicates axial weight applied in direction of installation

**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 |




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

Date: 9/26/2016 Revision: 0

J.D.Hair&Associates, Inc.

# 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)


## PLAN

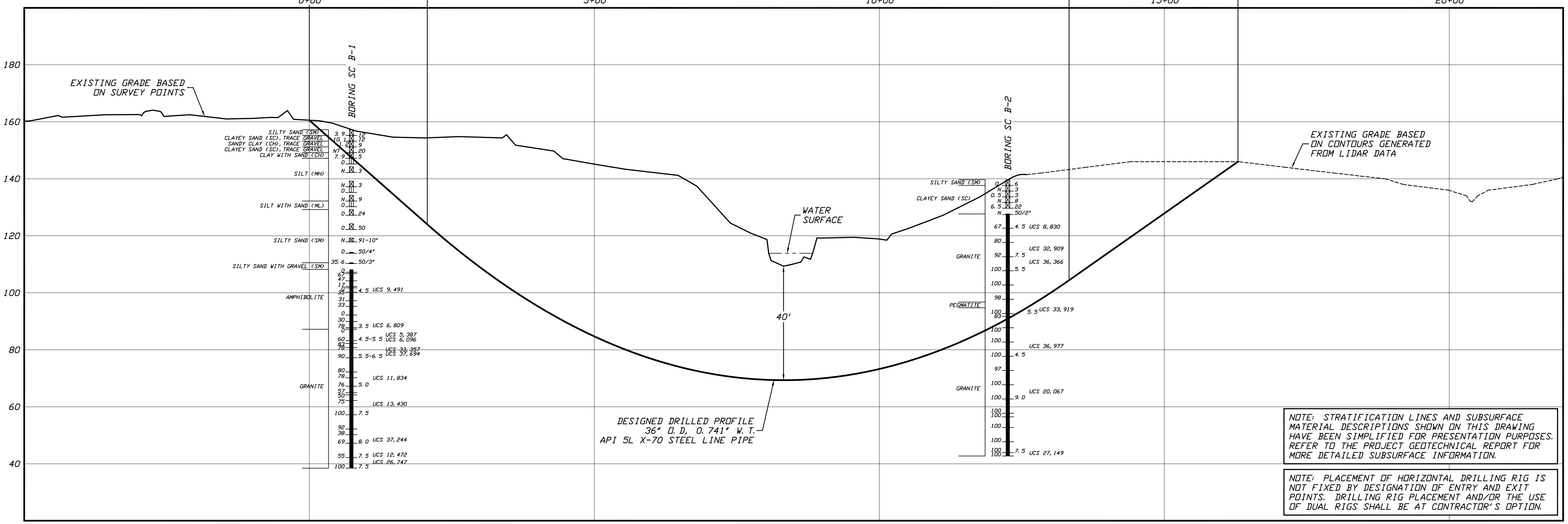
SCALE: 1"=100'

ENTRY POINT @ 10°
0+00.00, 160.54
N 13111039.76, E 2565805.53

P.C. 18° SAG BEND
2+07.05, 124.03
RADIUS = 3,600'

P.T. 18° SAG BEND
13+33.21, 104.37

EXIT POINT @ 8°
16+29.43, 146.00
N 13111938.79, E 2567164.50




## 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

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

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

| 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 | |

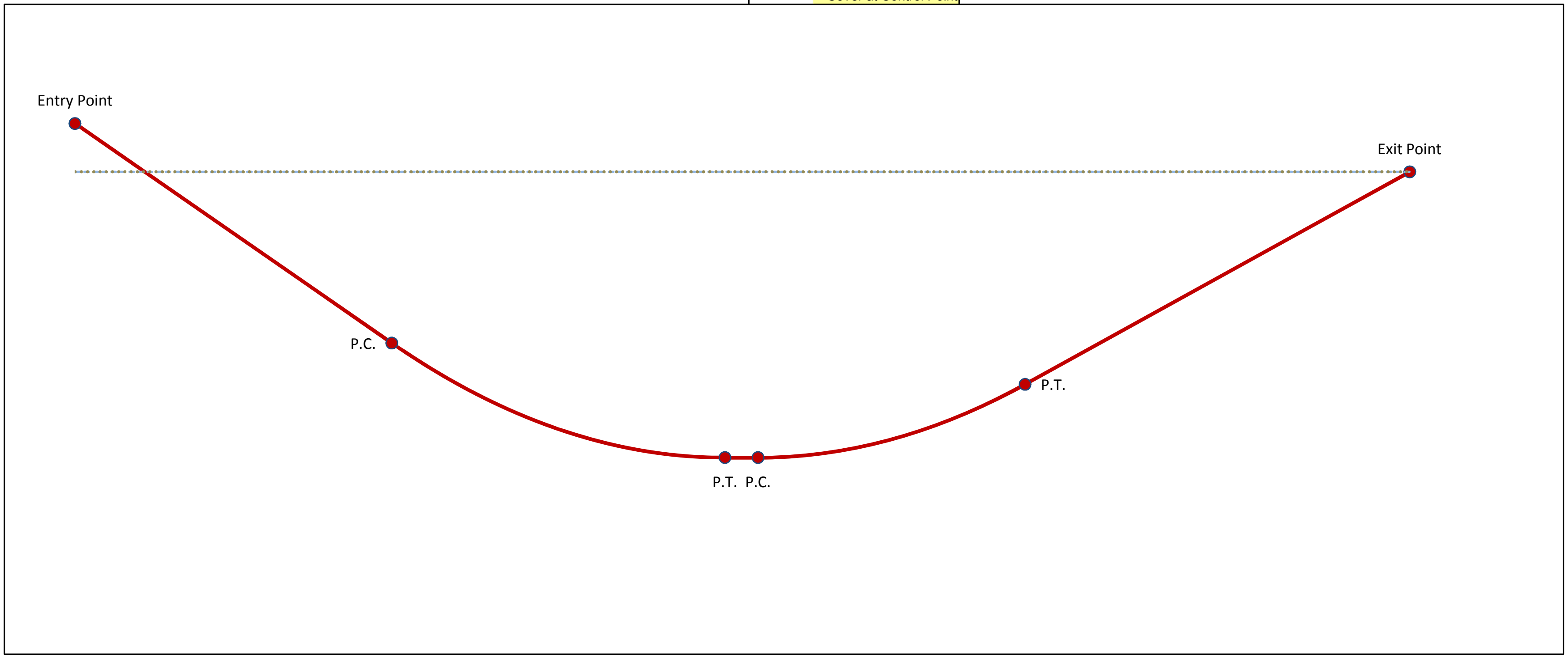
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,517 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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 | |



## 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** |

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

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

## 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 μ N = | 4,495 | lb | | | |
| Fluidic Drag = 12 π D L $C_d$ = | 14,212 | lb | | | |
| Axial Segment Weight = $W_e$ L sinθ = | 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 μ cosθ = | 5,952 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 13,652 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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 |

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

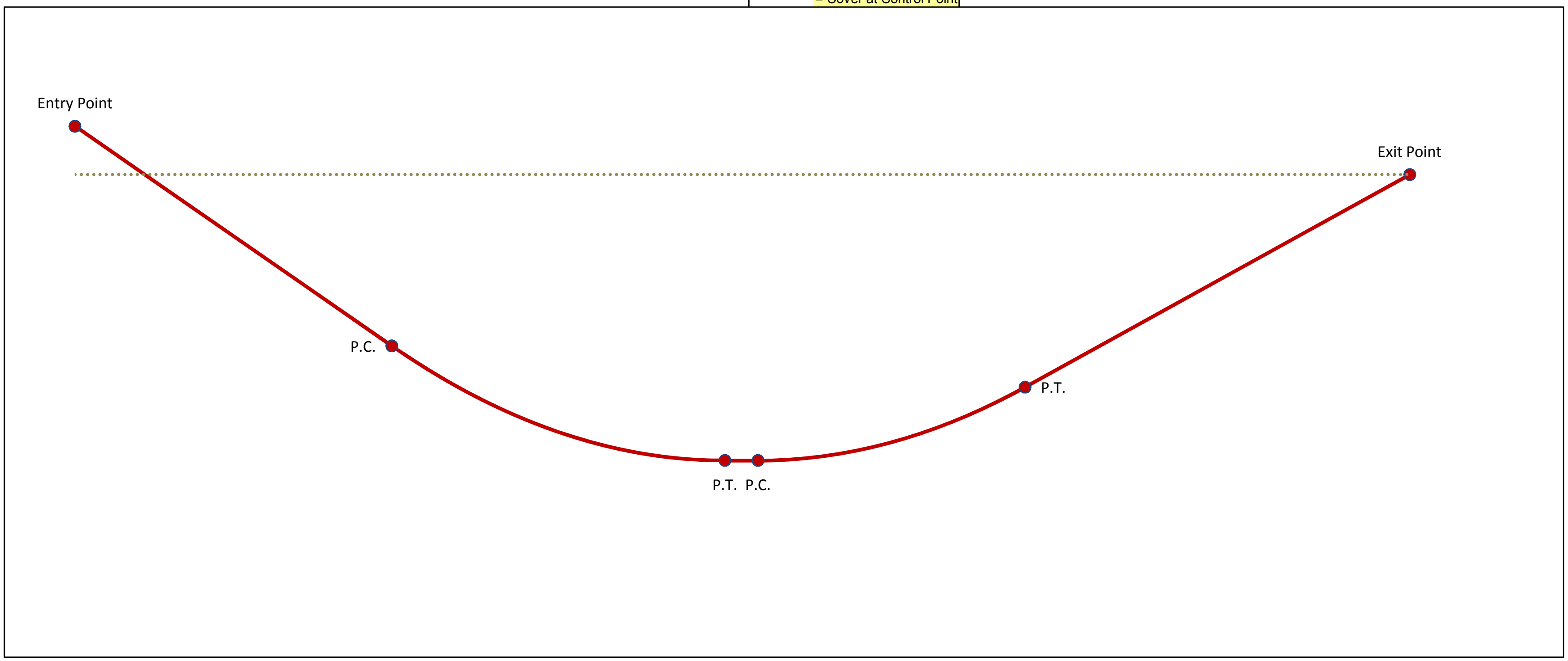
J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

| Project Information | | | | |
|---|---|---|---|---|
| Project : | Dominion Atlantic Coast Pipeline | | User : | JSP |
| Crossing : | 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**
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 | | | | 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**

11:26 AM10/10/2016

# Swift Creek R0 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 = | 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

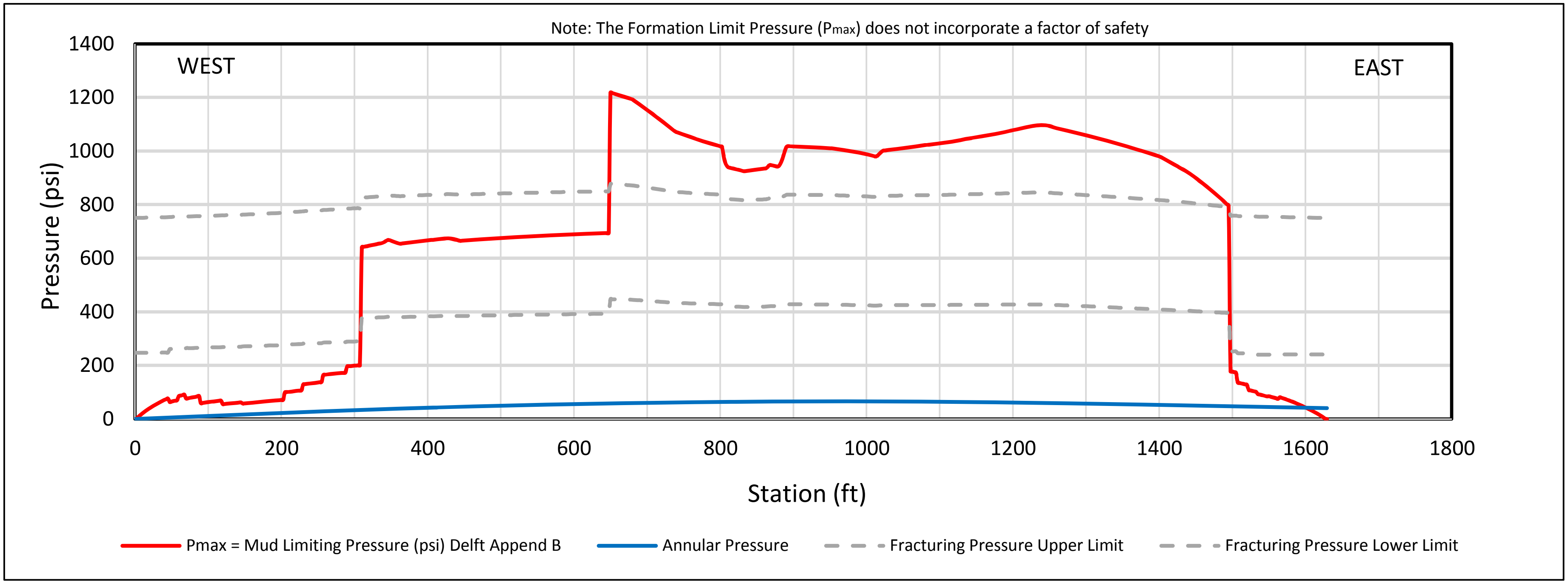
Fluidic Drag = $12 \pi D L C_d$ = 13,652 lb

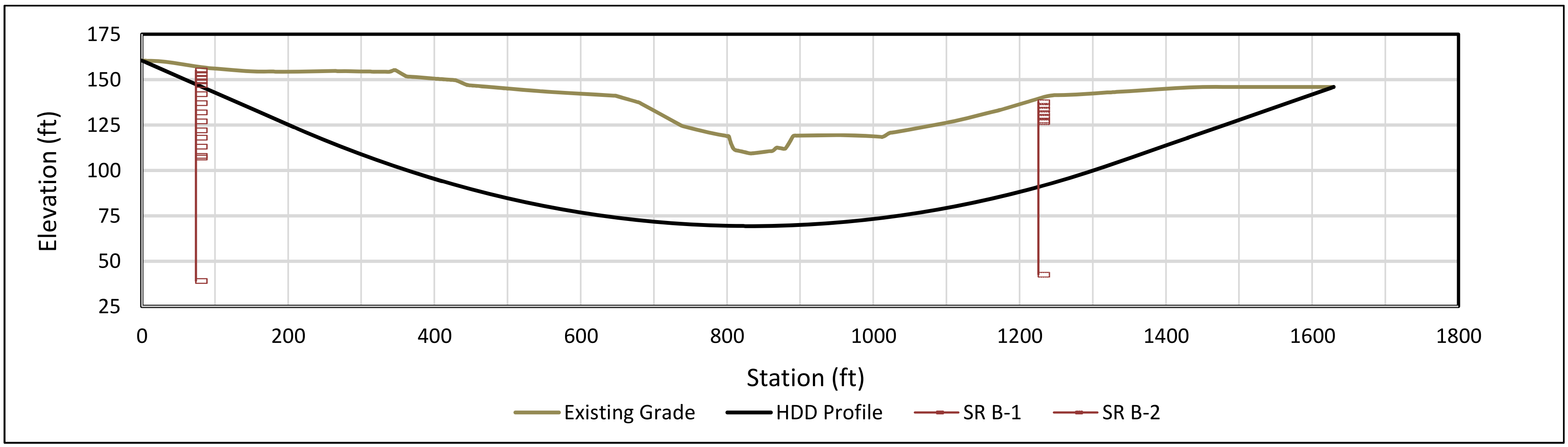
Axial Segment Weight = $W_e L \sin\theta$ = -24,834 lb — Negative value indicates axial weight applied in direction of installation

**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.

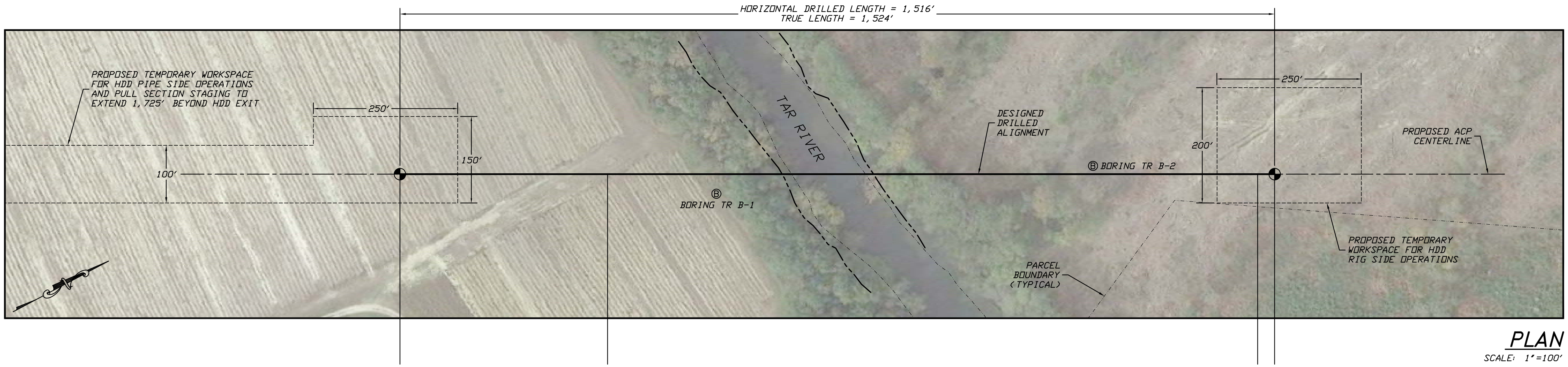
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
SWIFT CREEK CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

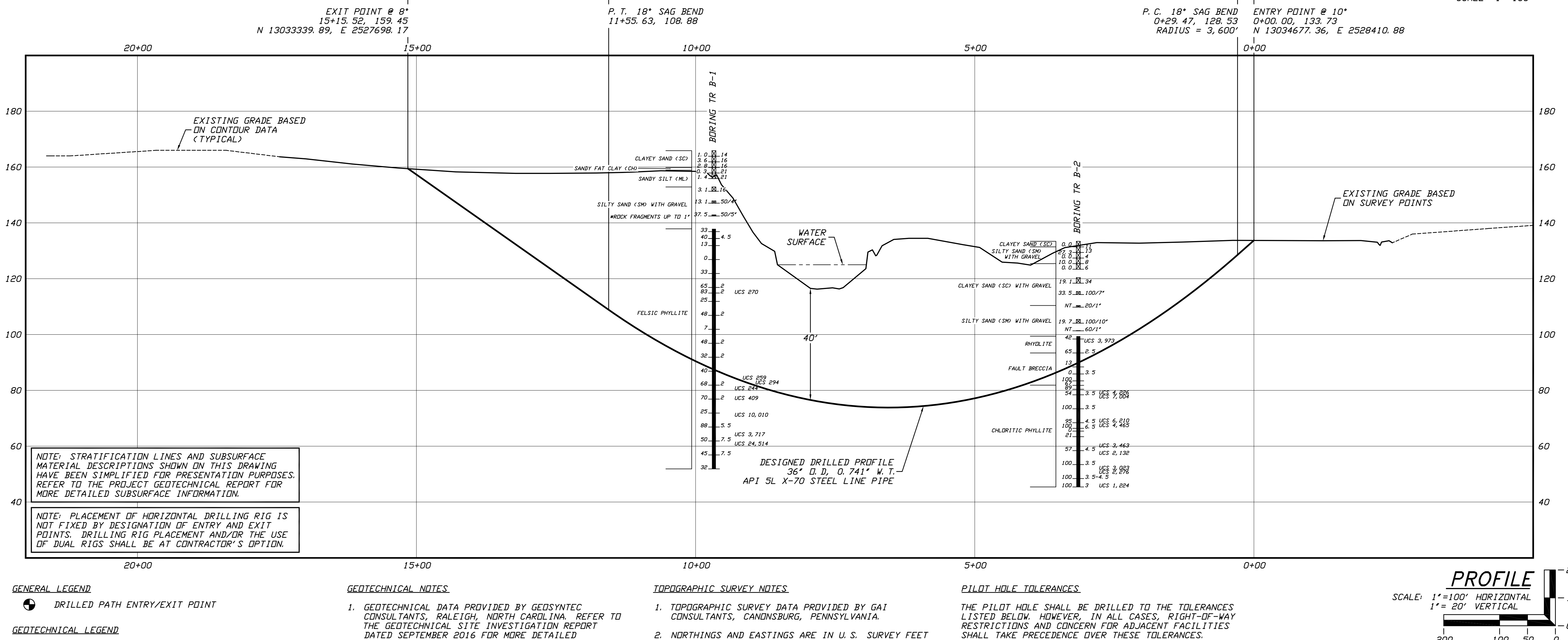
Date: 9/23/2016 Revision: 0

# 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)




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

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

| 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 | |

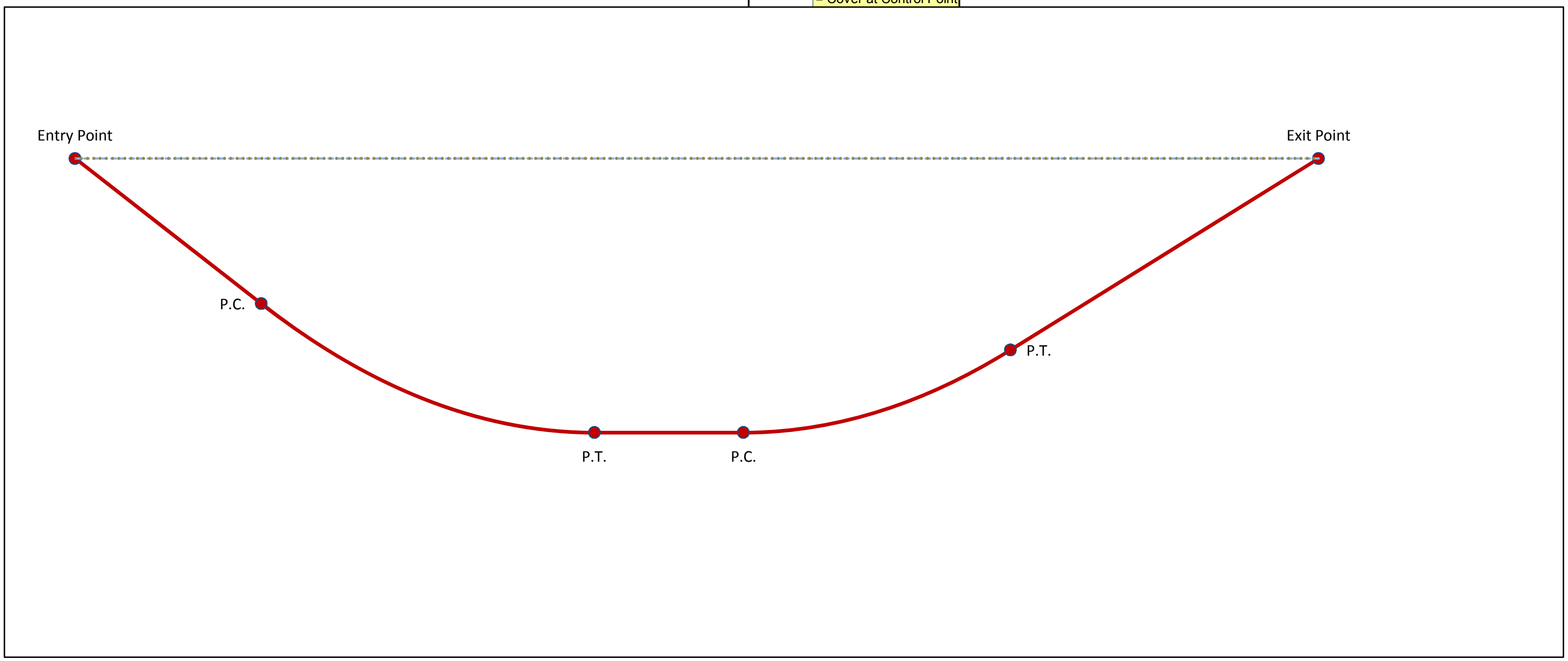
## Tar River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm

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 |
|---|---|



# Tar River R0 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 = | 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

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

| 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 | |

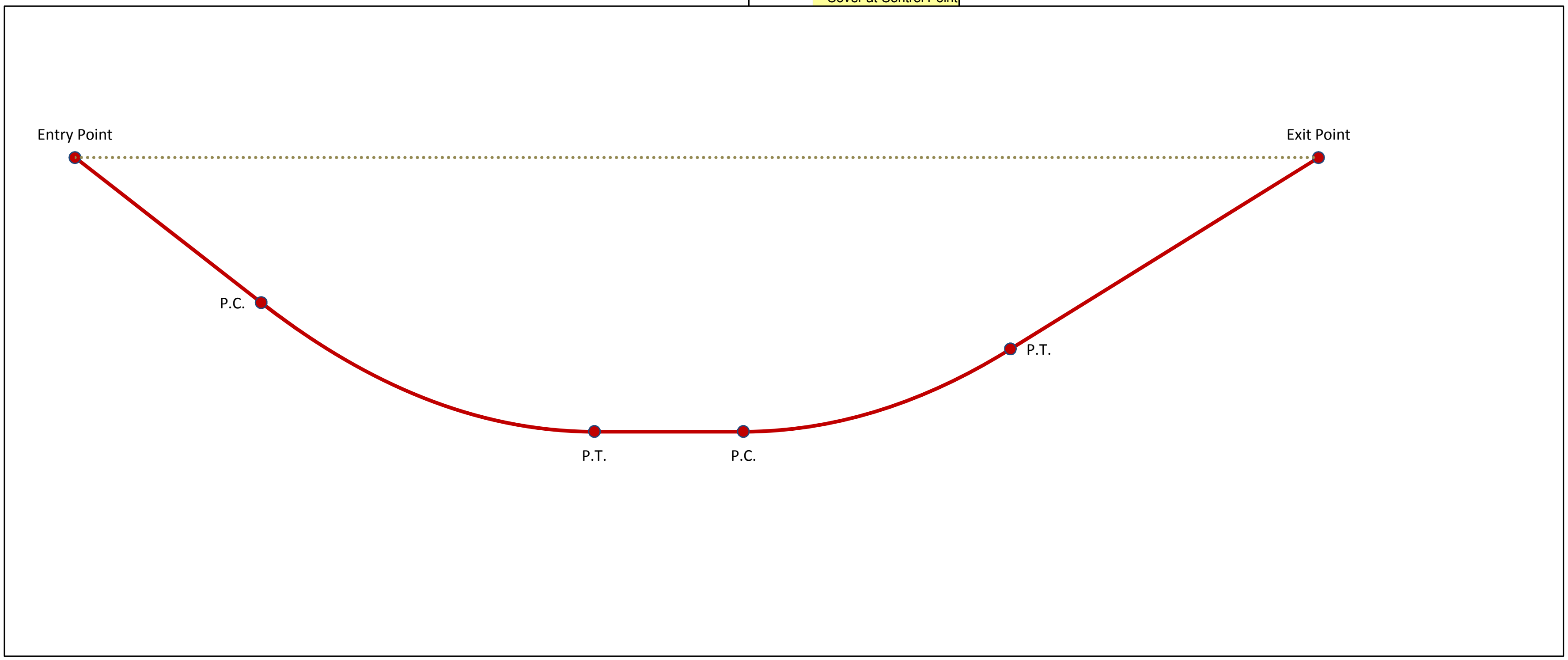
## Tar River R0 Installation Stress Analysis (worst-case).xlsm

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 | | | | 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

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 = | 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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -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** |

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

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

## 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

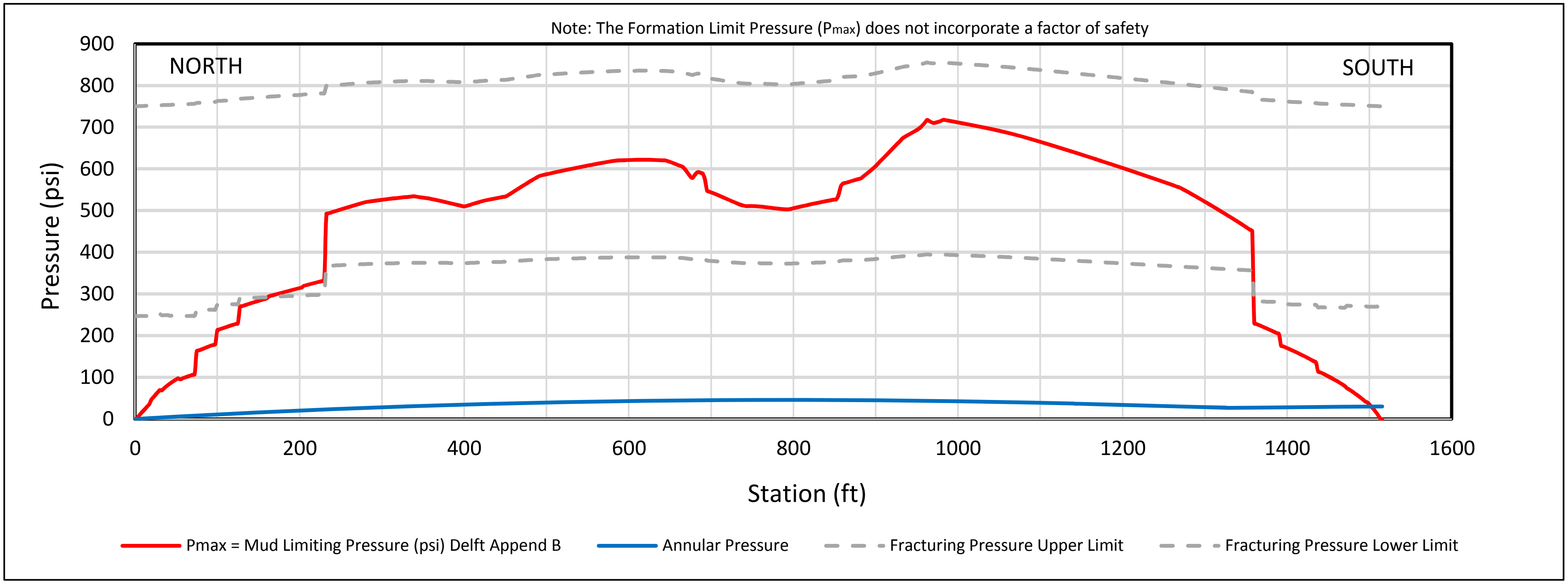
Fluidic Drag = $12 \pi D L C_d$ = 8,024 lb

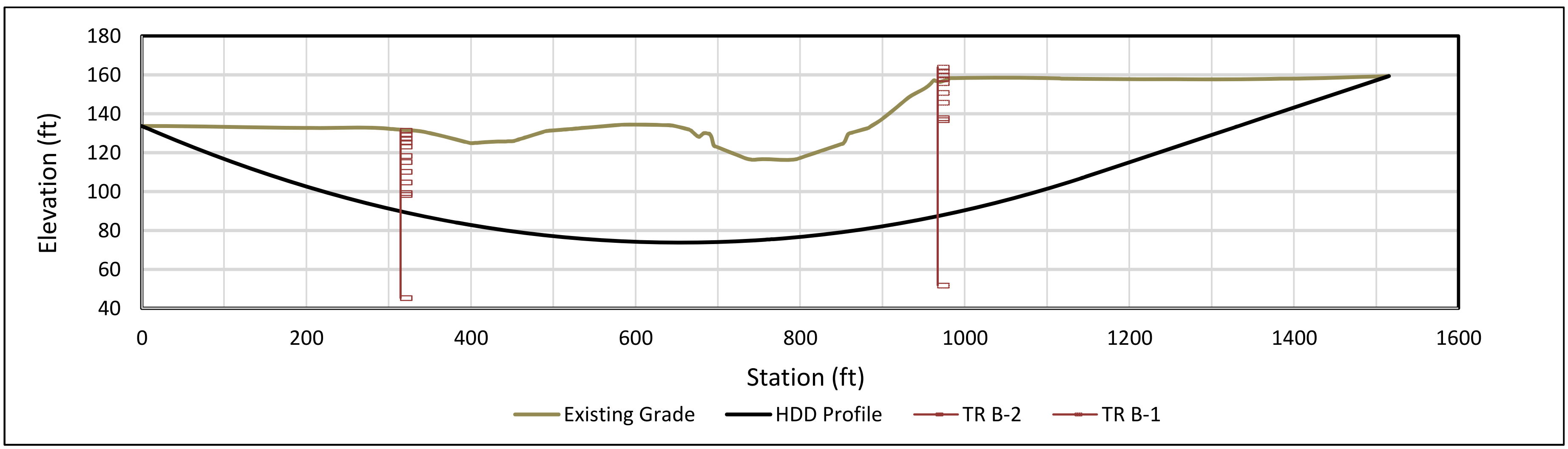
Axial Segment Weight = $W_e L \sin\theta$ = -14,597 lb — Negative value indicates axial weight applied in direction of installation

**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.

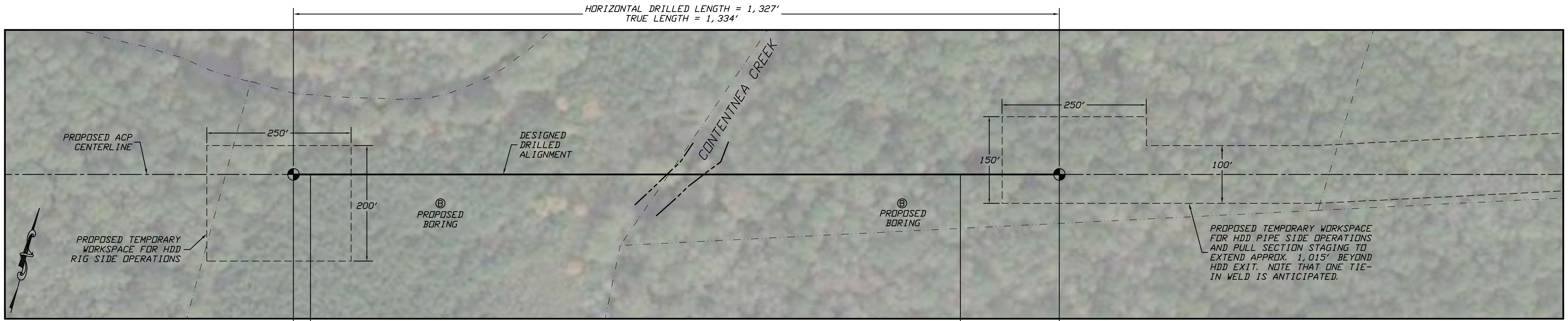
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
TAR RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 9/23/2016 Revision: 0

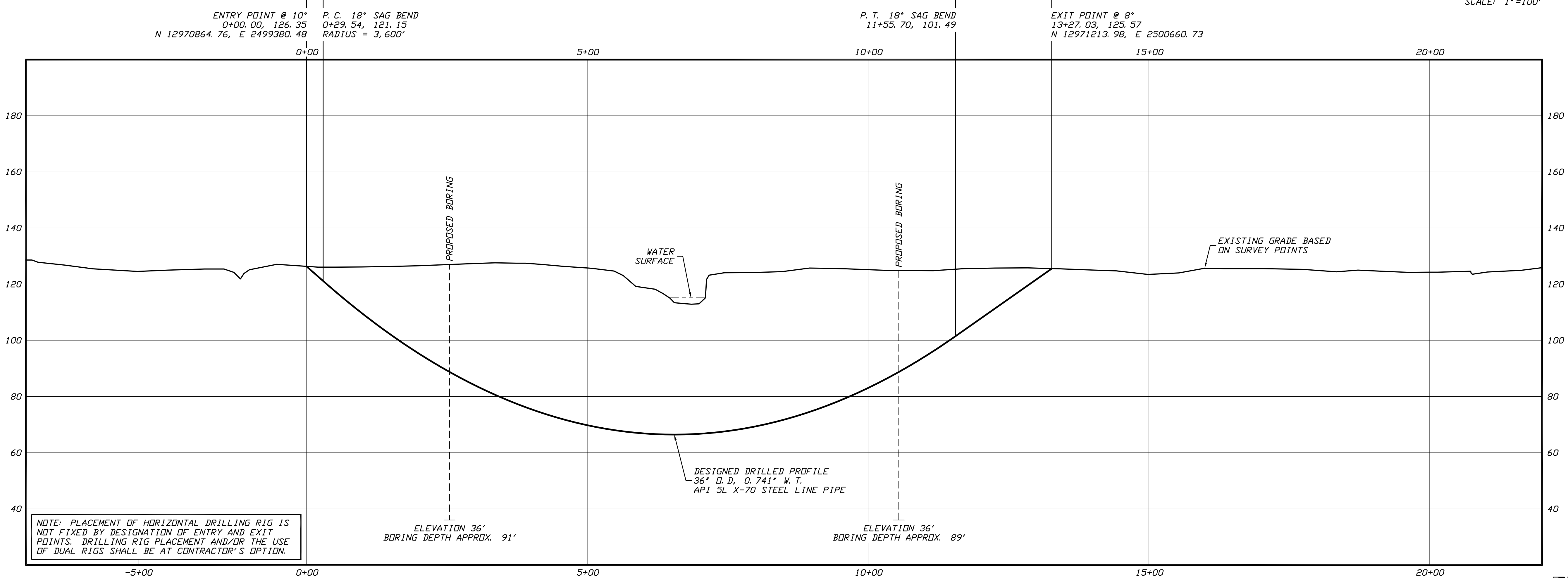
# Contentnea Creek

**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

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

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

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

| 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 | |

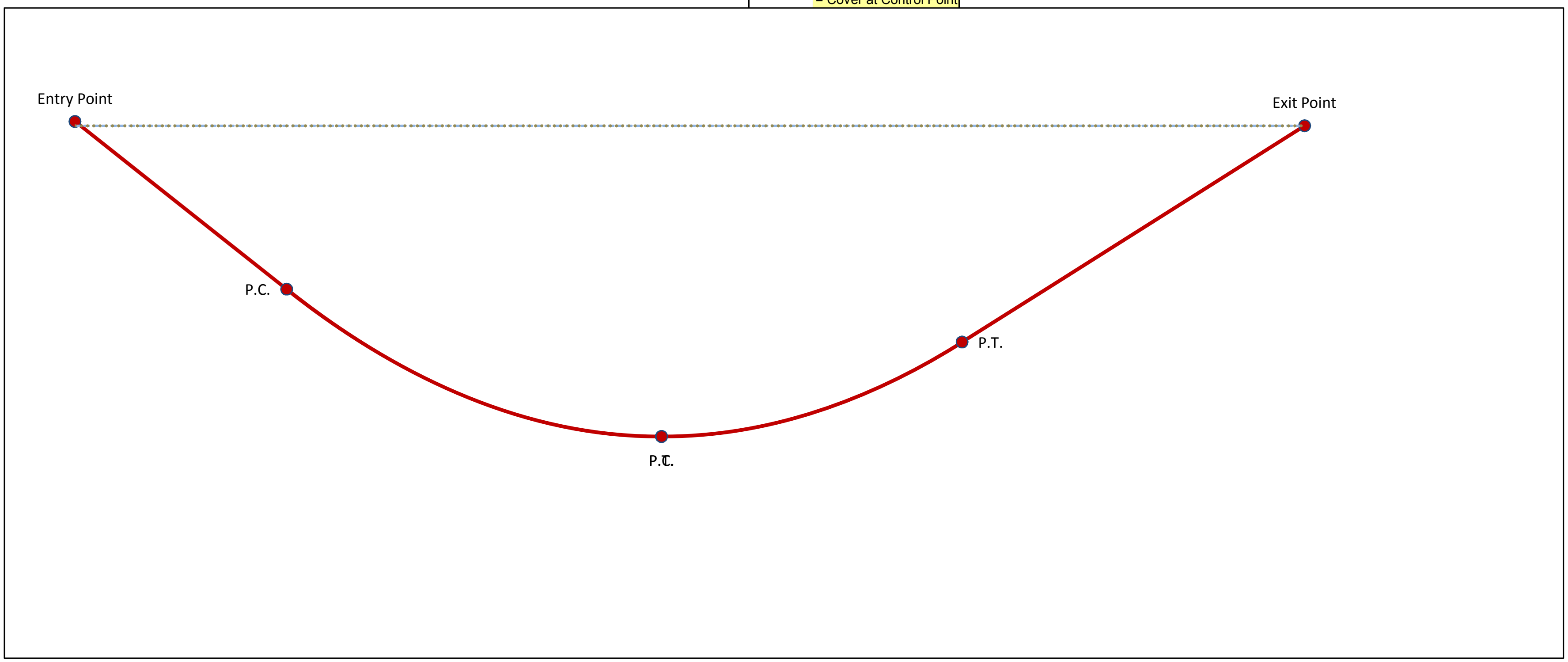
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,517 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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 | |




Step 2, Drilled Path Input

11:44 AM10/10/2016

# Contentnea Creek P2 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 = | 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

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

## 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

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

| 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 | | |

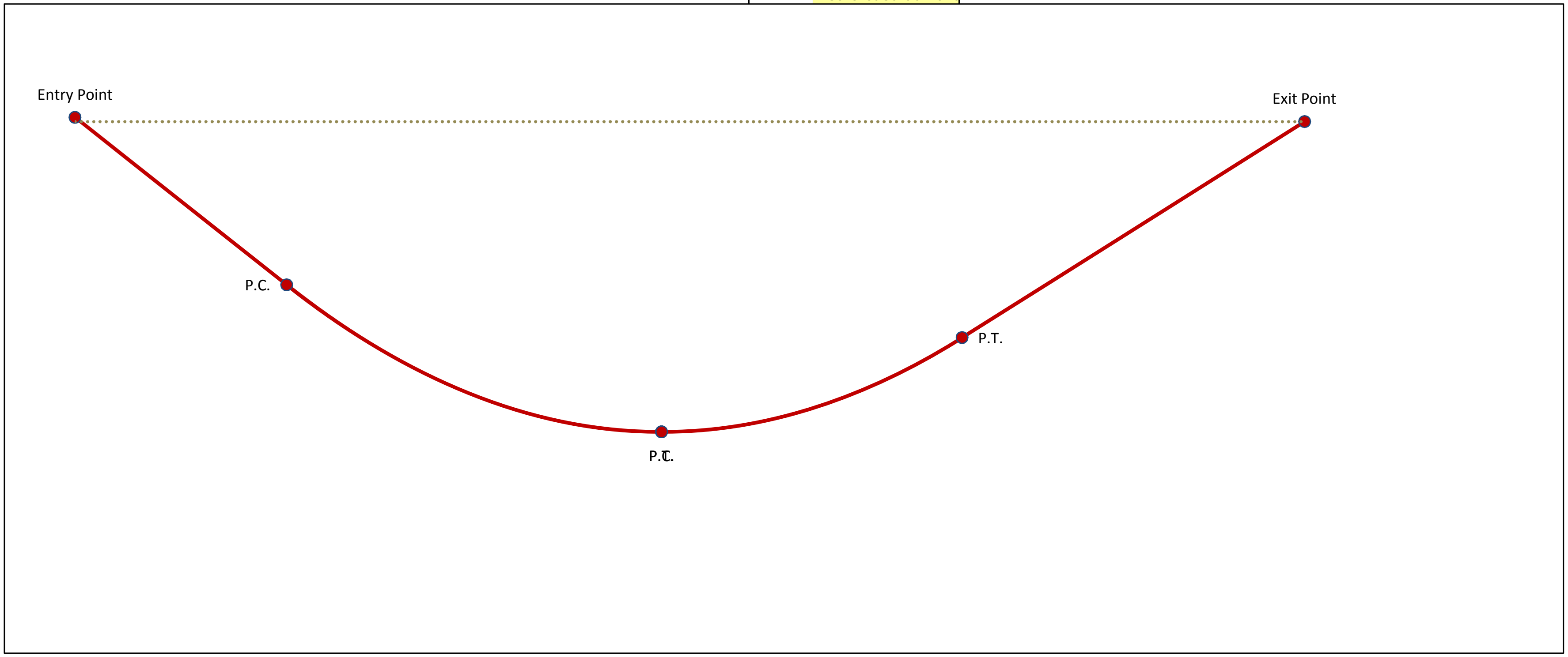
| Line Pipe Properties | | | |
|---|---|---|---|
| Pipe Outside Diameter = | 36.000 | in | |
| Wall Thickness = | 0.741 | in | |
| Specified Minimum Yield Strength = | 70,000 | psi | |
| Young's Modulus = | 2.9E+07 | psi | |
| Moment of Inertia = | 12755.22 | $in^4$ | |
| Pipe Face Surface Area = | 82.08 | $in^2$ | |
| 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

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 | | | | 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 | |




**Step 2, Drilled Path Input**

# Contentnea Creek P2 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 = | 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 μ cosθ = | 40,602 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 13,046 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) = | 102,264 | lb |
| Bending Frictional Drag = 2 μ N = | 61,359 | 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 =** | **81,037** | **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 μ = | 39 | 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 =** | **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(α/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 μ 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**

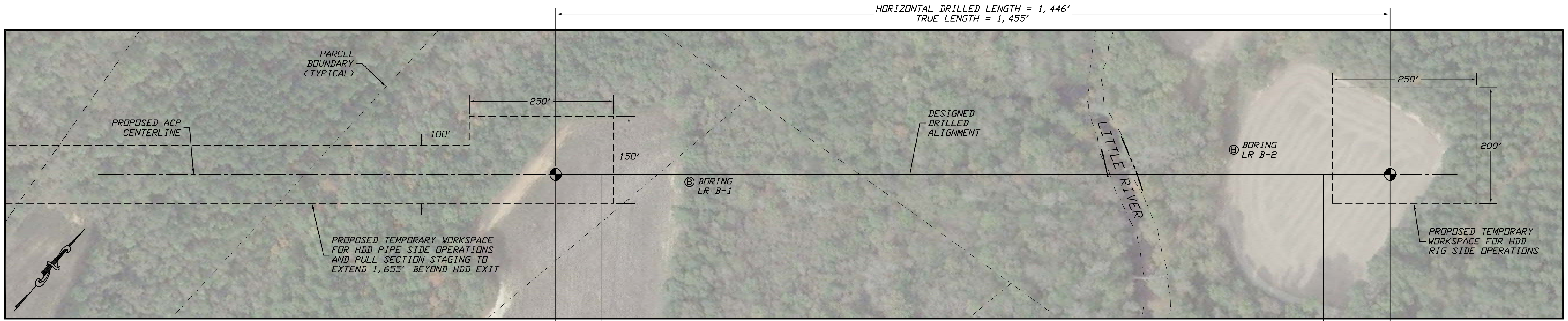
## Summary of Calculated Stress vs. Allowable Stress

| | 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

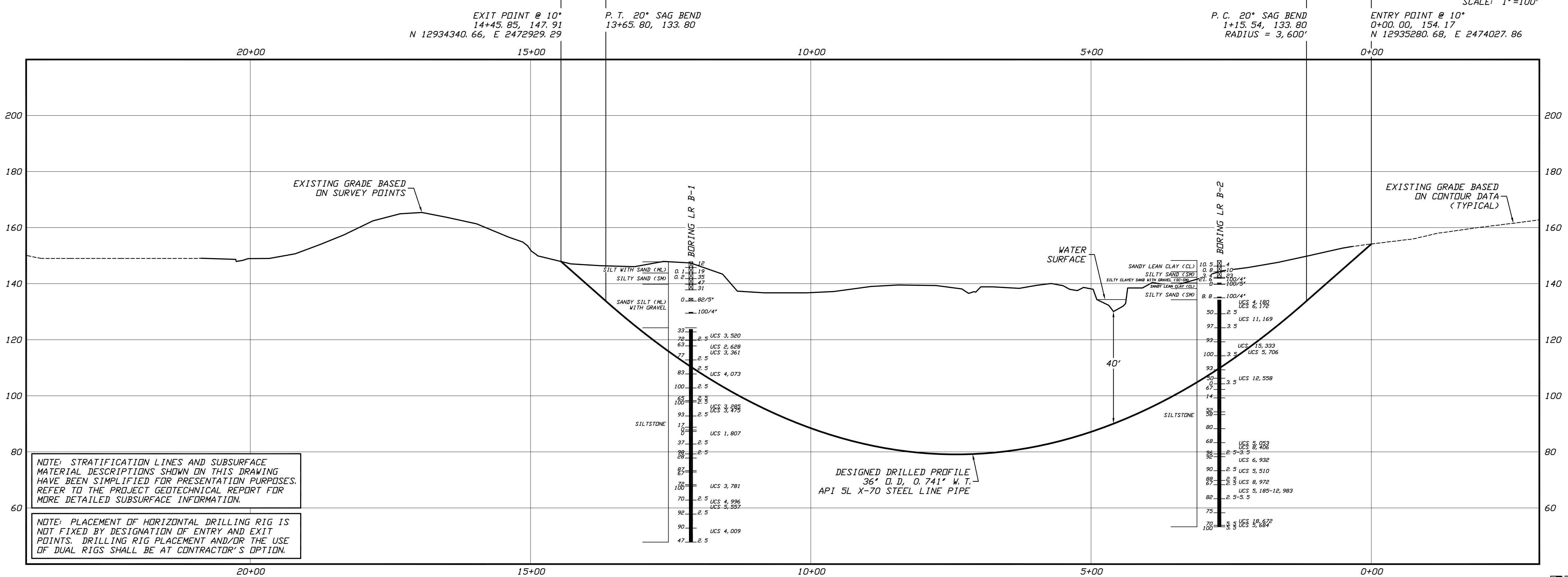
**Supporting Information**

- 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

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

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

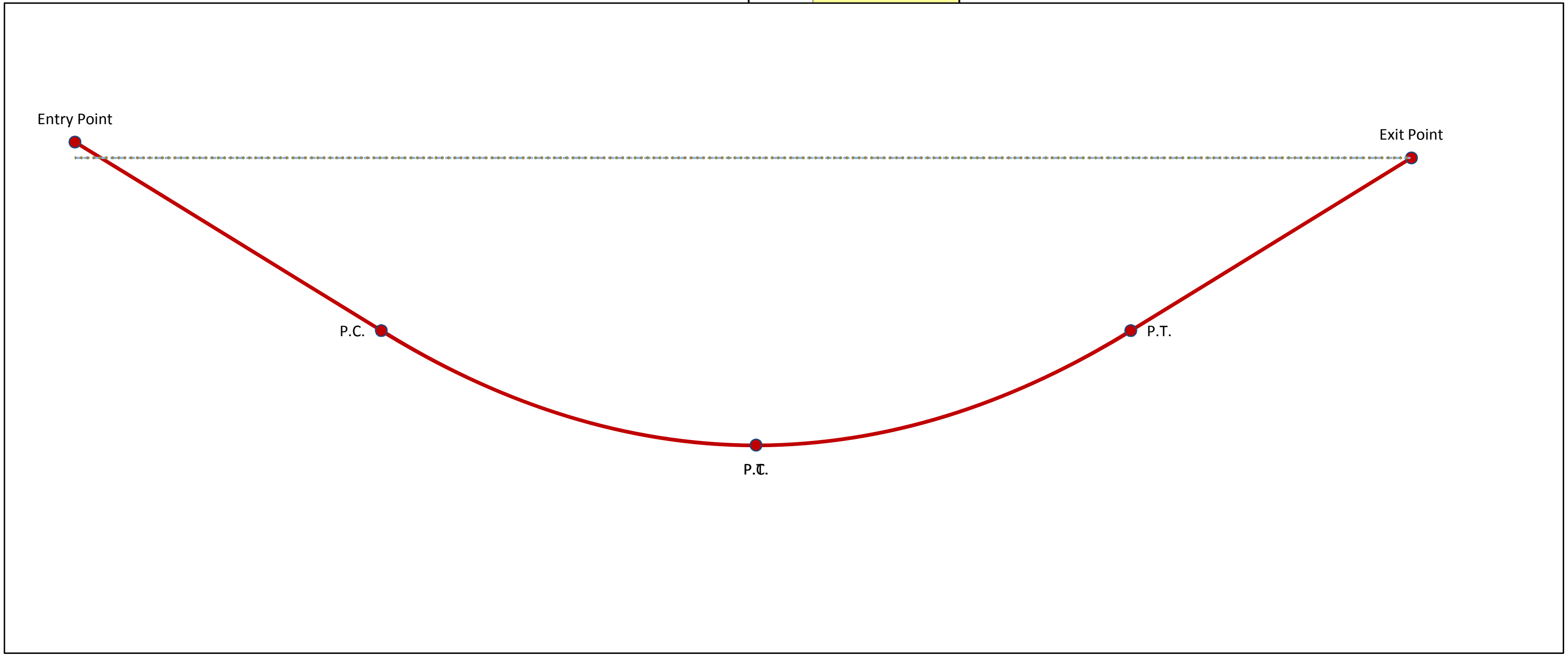
| Project Information | | | |
|---|---|---|---|
| Project : | Dominion Atlantic Coast Pipeline | User : | ACM |
| Crossing : | 36" Little River Crossing | Date : | 9/29/2016 |
| Comments : | Installation stress analysis based on worst-case drilled path per tolerances (40' longer and 22' deeper than design 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**
J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

| | | 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 | |



# Little River R0 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 = | 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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -10.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -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

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

| 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 | |

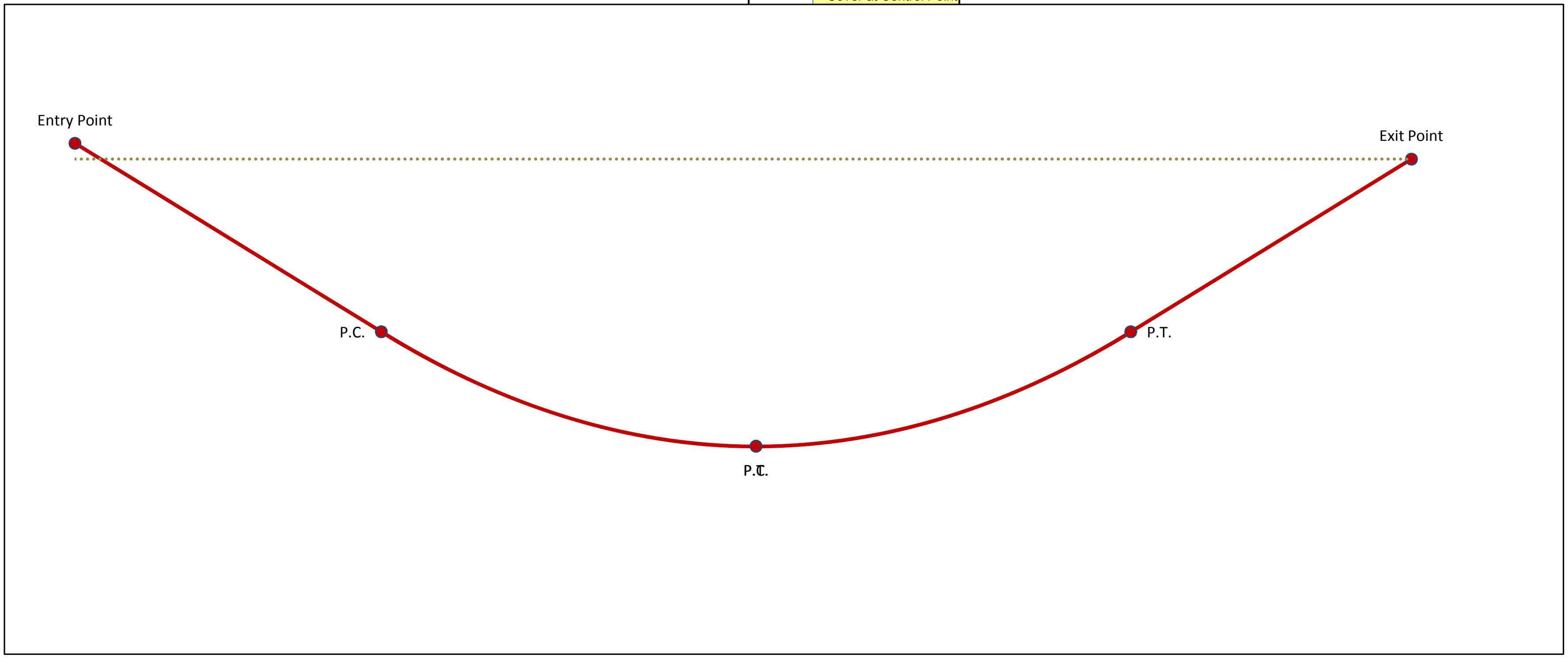
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,517 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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

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

| | | 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

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 = | 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
Segment Angle with Horizontal, θ = 10.0 °
Deflection Angle, α = 5.0 °

Average Tension, T = 200,598 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

$j = [(E I) / T]^{1/2}$ = 1,358

$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = 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
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 = 36,302 lb

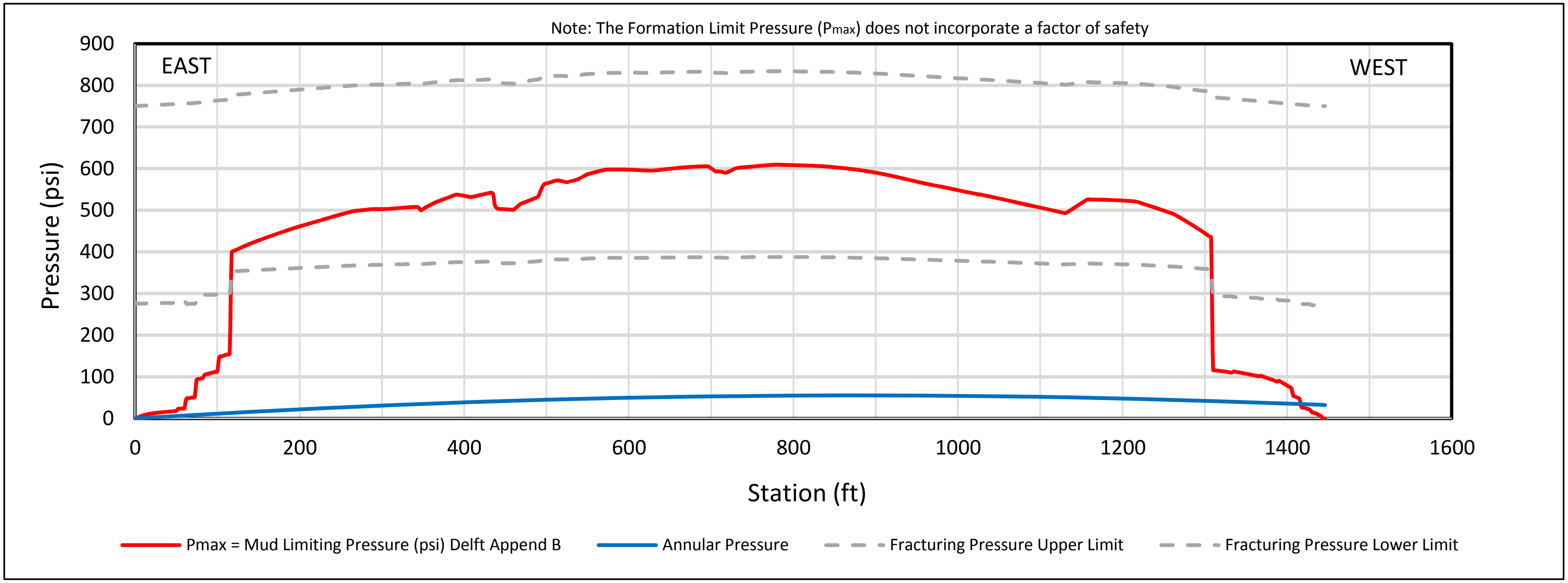
Fluidic Drag = 12 π D L $C_d$ = 11,729 lb

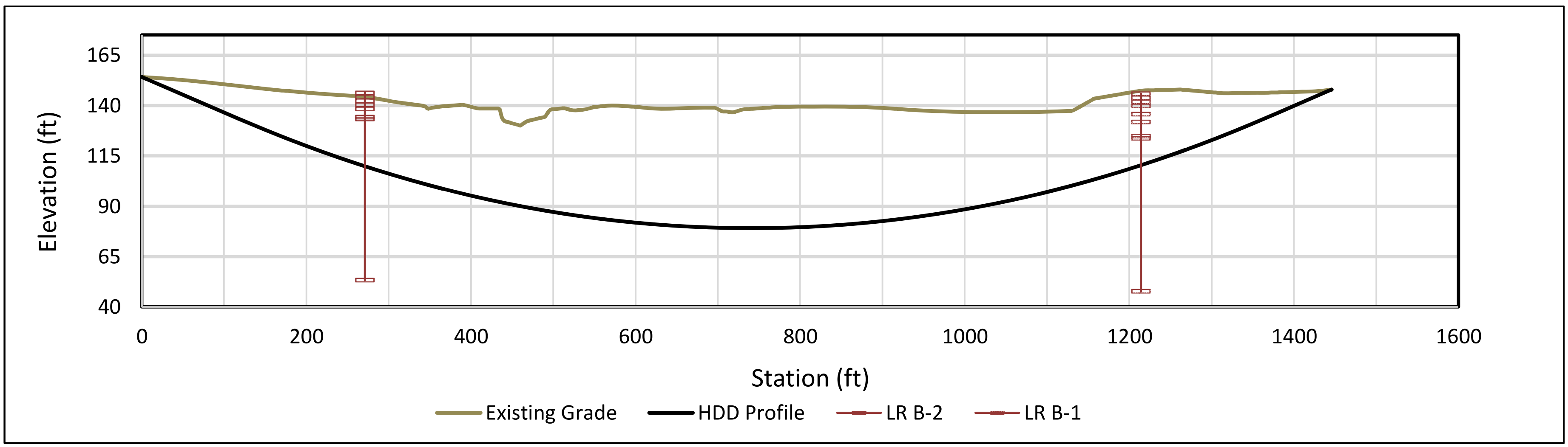
Axial Segment Weight = $W_e$ L sinθ = -21,337 lb — Negative value indicates axial weight applied in direction of installation

**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 |




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

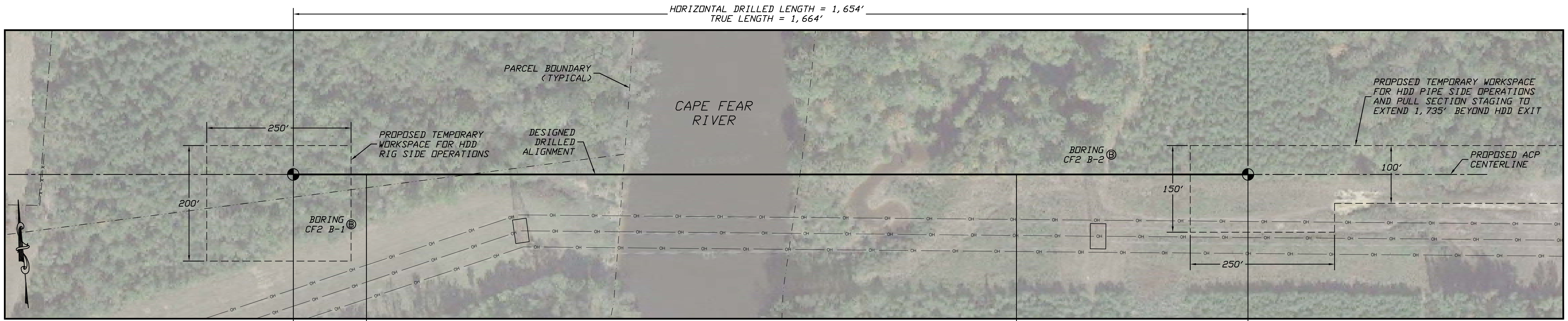
J.D.Hair&Associates, Inc.

Date: 9/26/2016 Revision: 0

# Cape Fear River

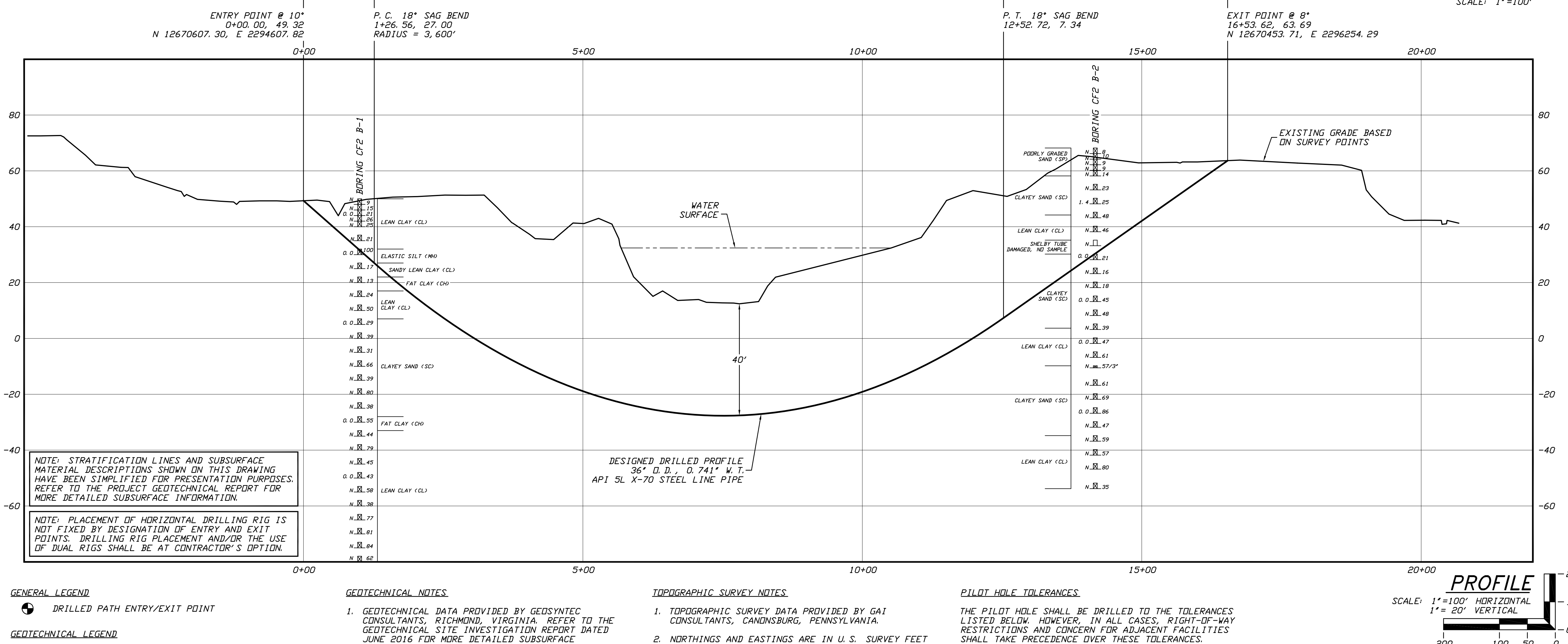
**Supporting Information**

- 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)




## 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

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

| 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 | |

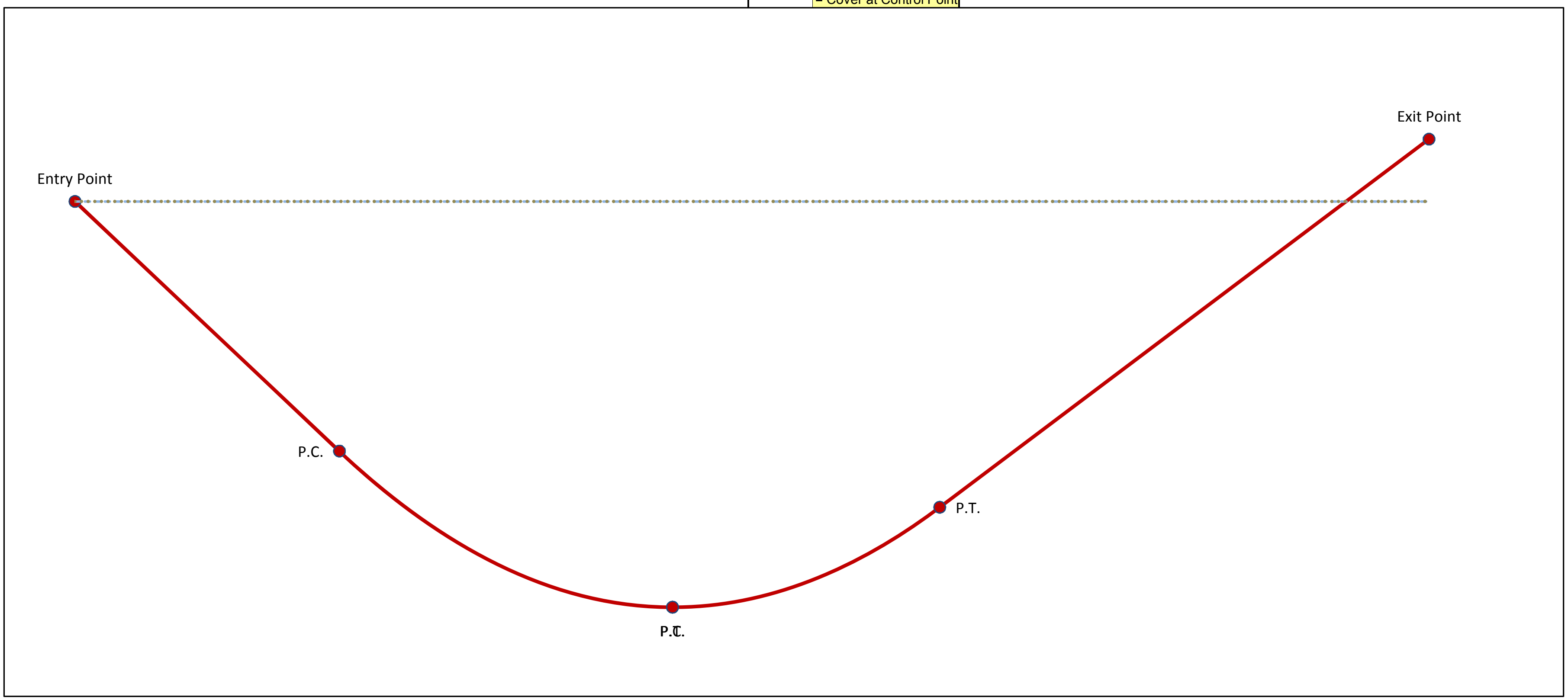
**Cape Fear River R0 Installation Stress Analysis (worst-case) - with buoyancy.xlsm**

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 |
|---|---|




**Step 2, Drilled Path Input**

# Cape Fear River R0 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, $D$ = | 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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, $R$ = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -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 | Average Tension, T = | 53,408 | 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 | $j = [(E\ I) / T]^{1/2}$ = | 2,632 | |
| $Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ = | 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 | Effective Weight, $W_e = W + W_b - W_m$ = | 50.1 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e\ L\ \mu \cos\theta$ = | 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 |

| 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 | |

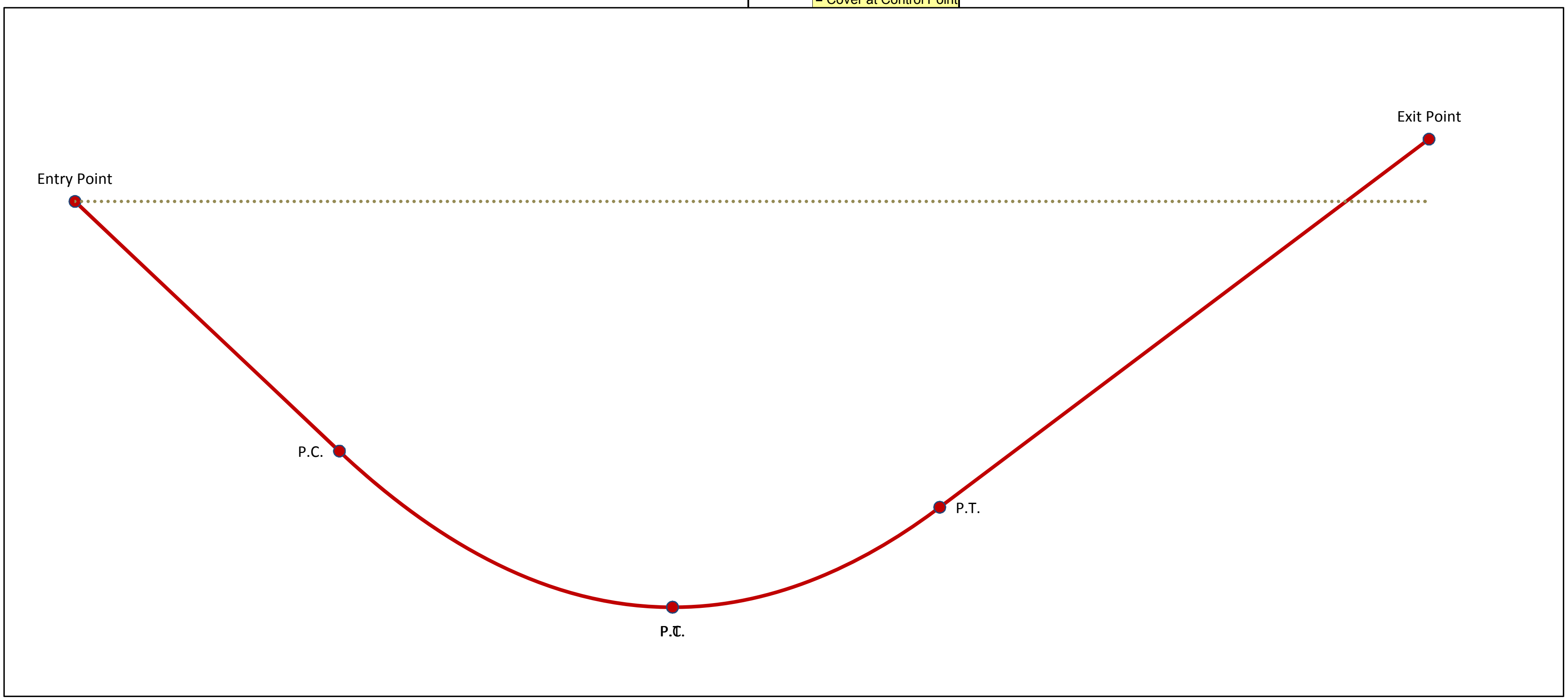
## Cape Fear River R0 Installation Stress Analysis (worst-case).xlsm

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 | | | | 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



# Cape Fear River R0 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 = | 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, $\mu$ = | 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, $\theta$ = | 8.0 | ° | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e\ L\ \mu \cos\theta$ = | 65,261 | lb |
| Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = | 20,969 | lb |
| Axial Segment Weight = $W_e\ L \sin\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 2,400 | ft |
| Deflection Angle, $\alpha$ = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -355.4 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R\ [1 - \cos(\alpha/2)]$ = | 5.85 | ft | $j = [(E\ I) / T]^{1/2}$ = | 1,528 | |
| $Y = [18\ (L)^2] - [(j)^2\ (1 - \cosh(U/2)^{-1}]$ = | 8.5E+05 | | $X = (3\ L) - [\ (j / 2) \tanh(U/2)\ ]$ = | 343.81 | |
| $U = (12\ L) / j$ = | 2.63 | | $N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ = | 105,786 | lb |
| Bending Frictional Drag = $2\ \mu\ N$ = | 63,472 | 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 =** | **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 = $W_e\ L\ \mu$ = | 4 | 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 =** | **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** | | | |

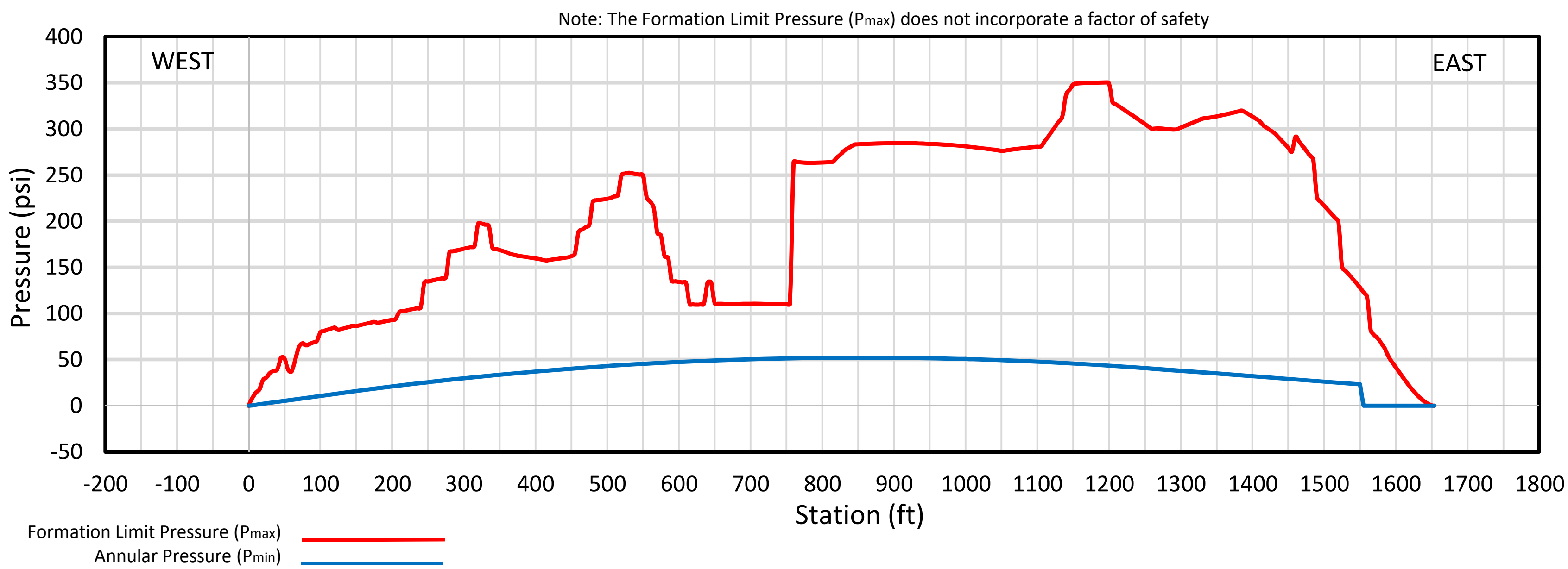
## Entry Tangent - Summary of Pulling Load Calculations

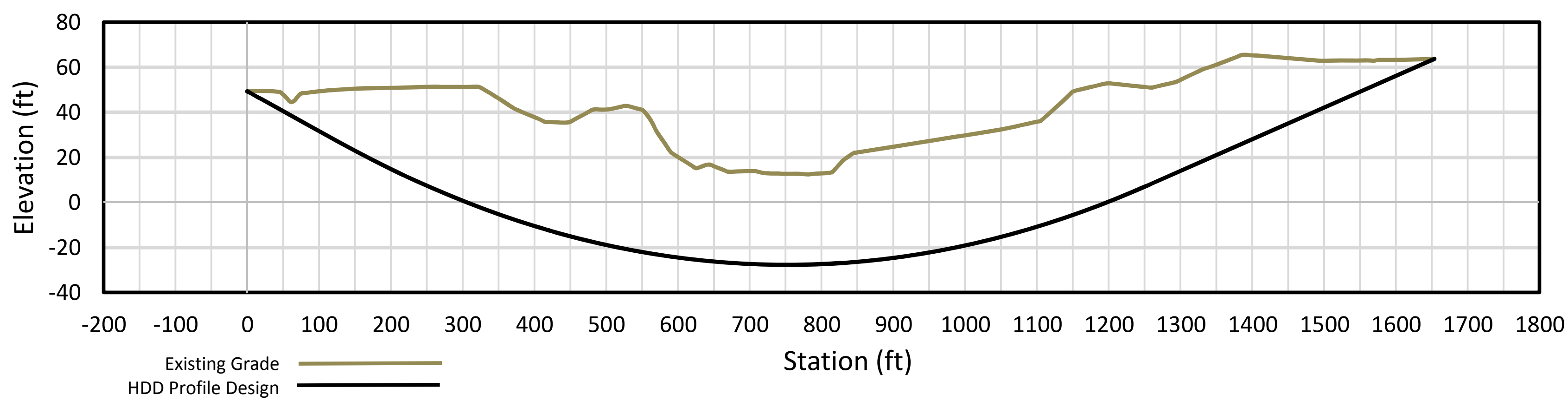
| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 335.9 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -355.4 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| 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

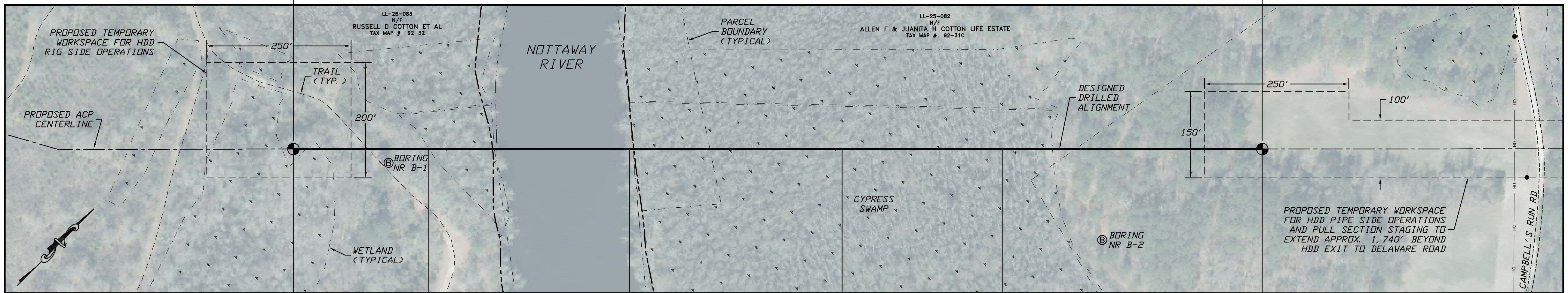
Revision: 0

# Nottaway River

**Supporting Information**

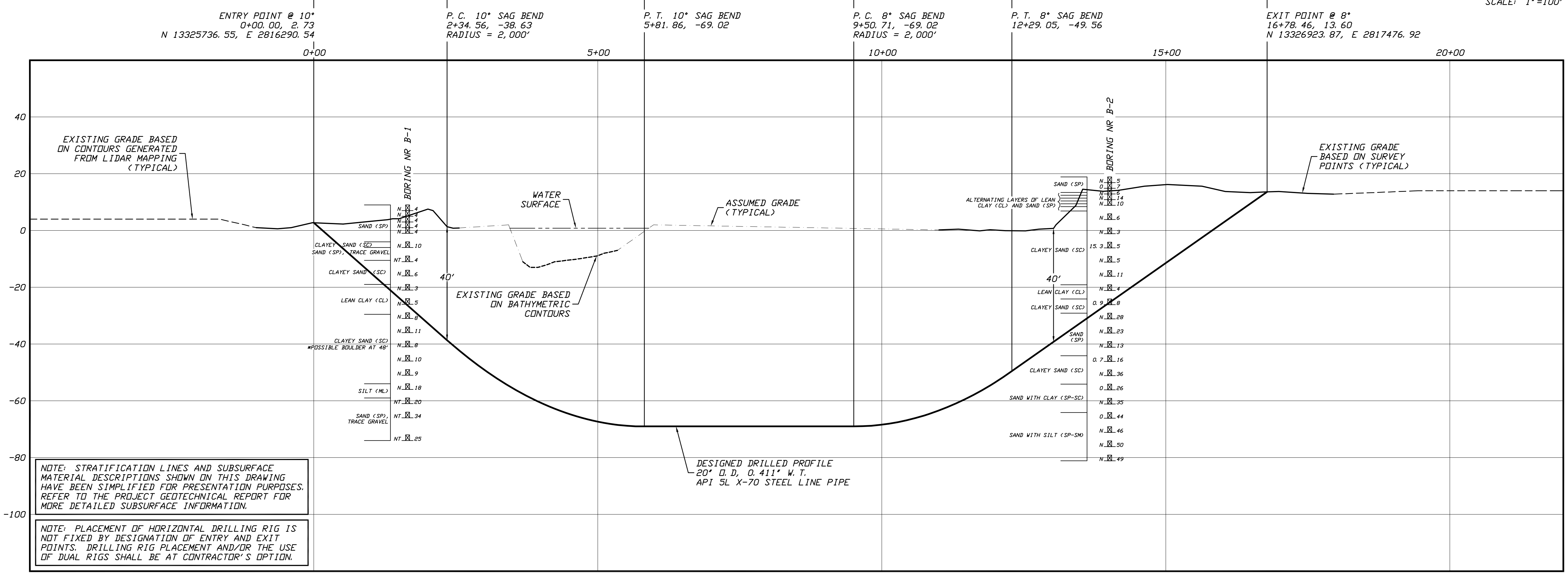
- Plan & profile drawing presenting HDD crossing design (1 page, 11x17)
- Installation stress analysis, without buoyancy control (4 pages)
- Hydrofracture evaluation (1 page)

HORIZONTAL DRILLED LENGTH = 1,678'
TRUE LENGTH = 1,689'




PLAN

SCALE: 1"=100'




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"=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 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 |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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 | |

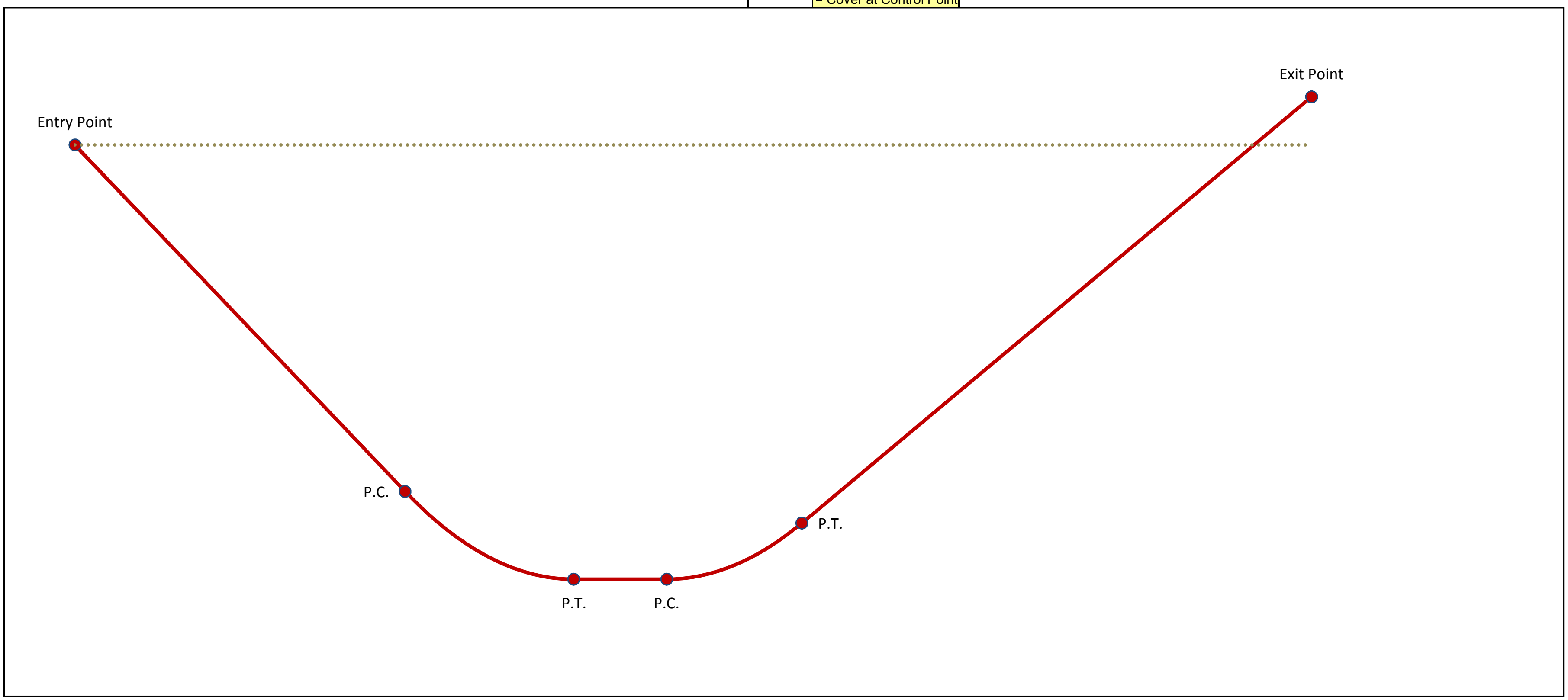
# Nottaway River R0 Installation Stress Analysis (worst-case).xlsm

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

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, $\mu$ = | 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, $\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 1,350 | ft |
| Deflection Angle, $\alpha$ = | -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** |

## 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 = 83,129 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

$j = [(E\,I) / T]^{1/2}$ = 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
Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e\,L\,\mu \cos\theta$ = 15,120 lb

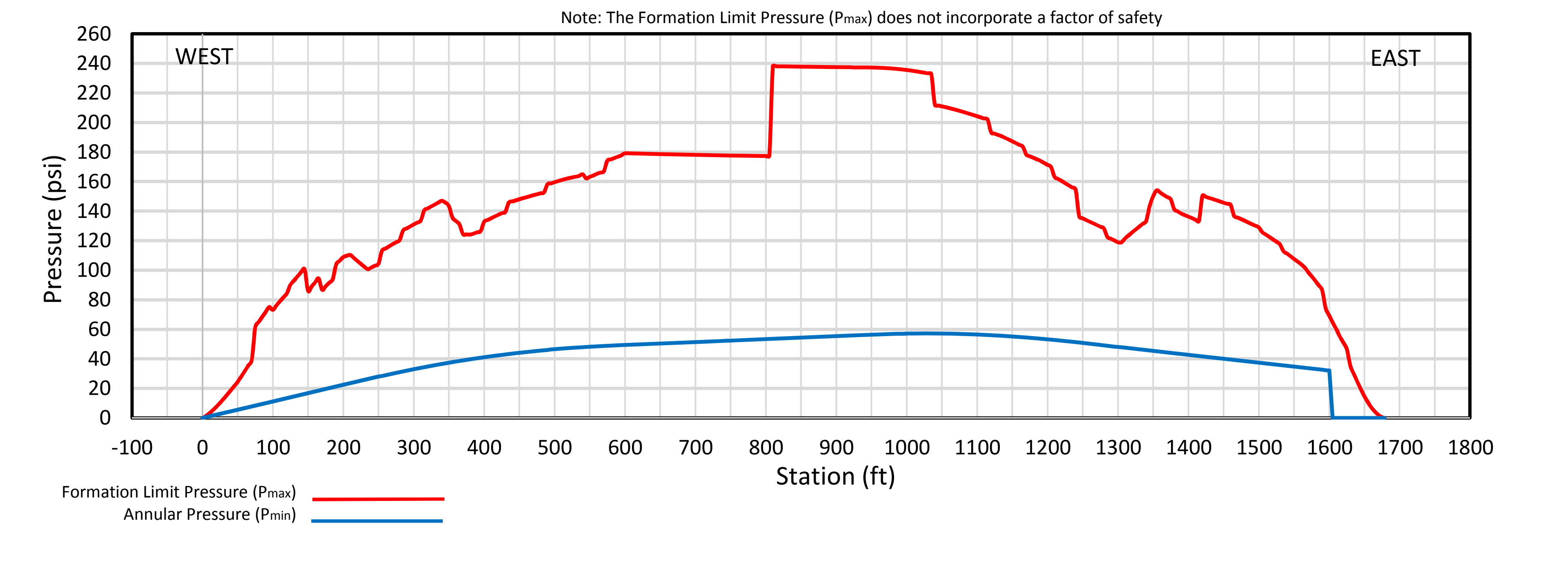
Fluidic Drag = $12\,\pi\,D\,L\,C_d$ = 8,783 lb

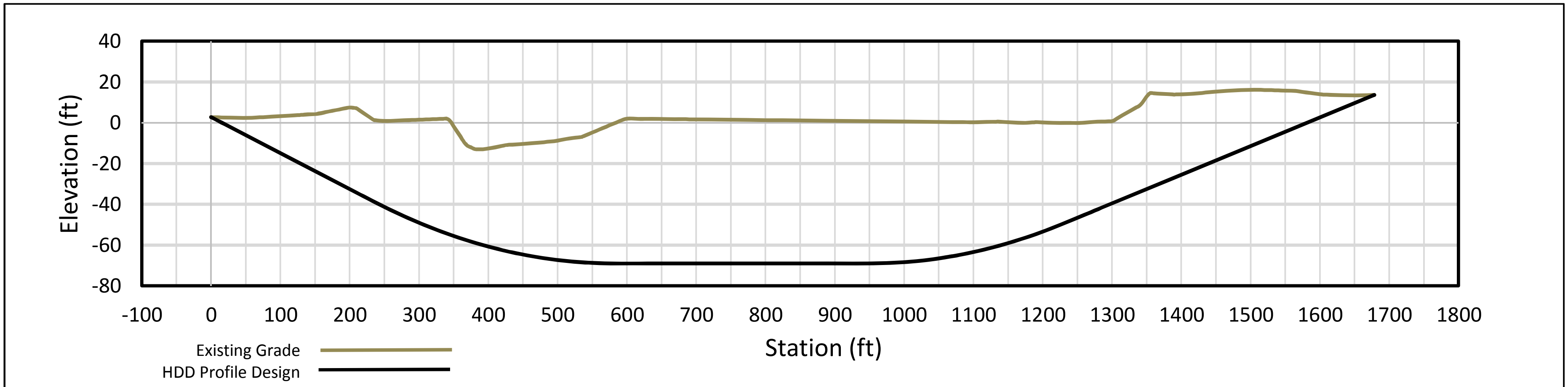
Axial Segment Weight = $W_e\,L \sin\theta$ = -8,887 lb — Negative value indicates axial weight applied in direction of installation

**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 |




J.D.Hair&Associates, Inc.

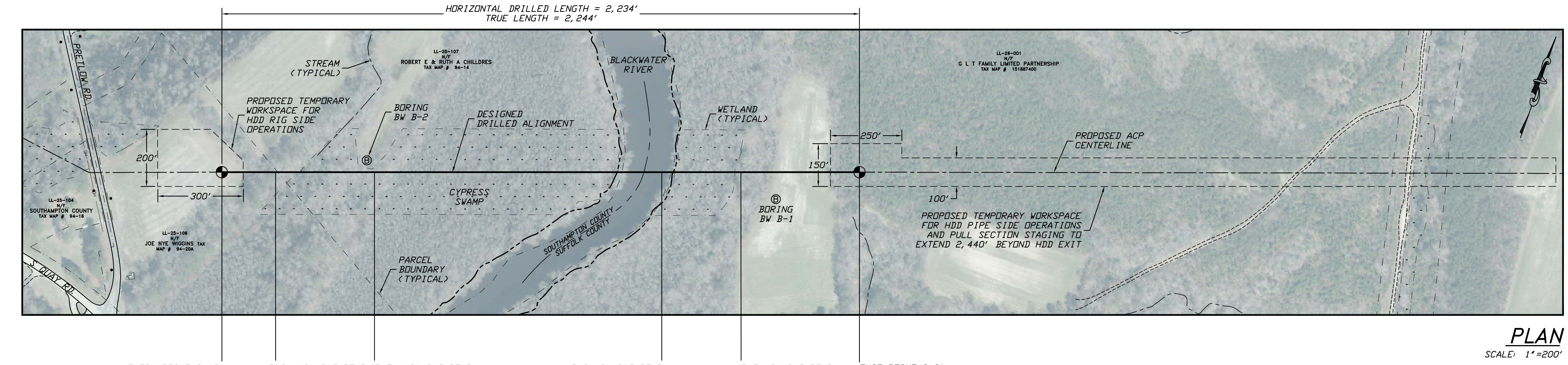
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH NOTTAWAY RIVER CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

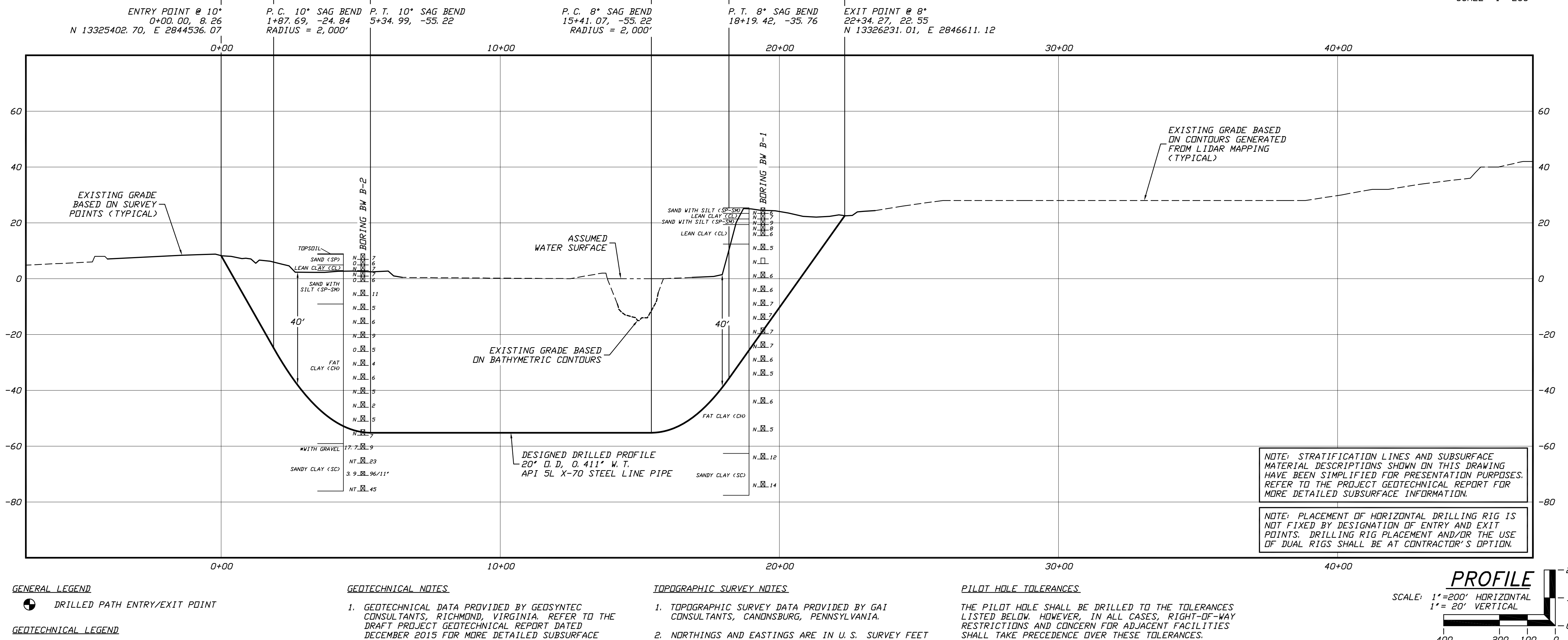
Date: 7/12/2016 Revision: 1

# 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.
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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.

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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 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 |

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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 | |

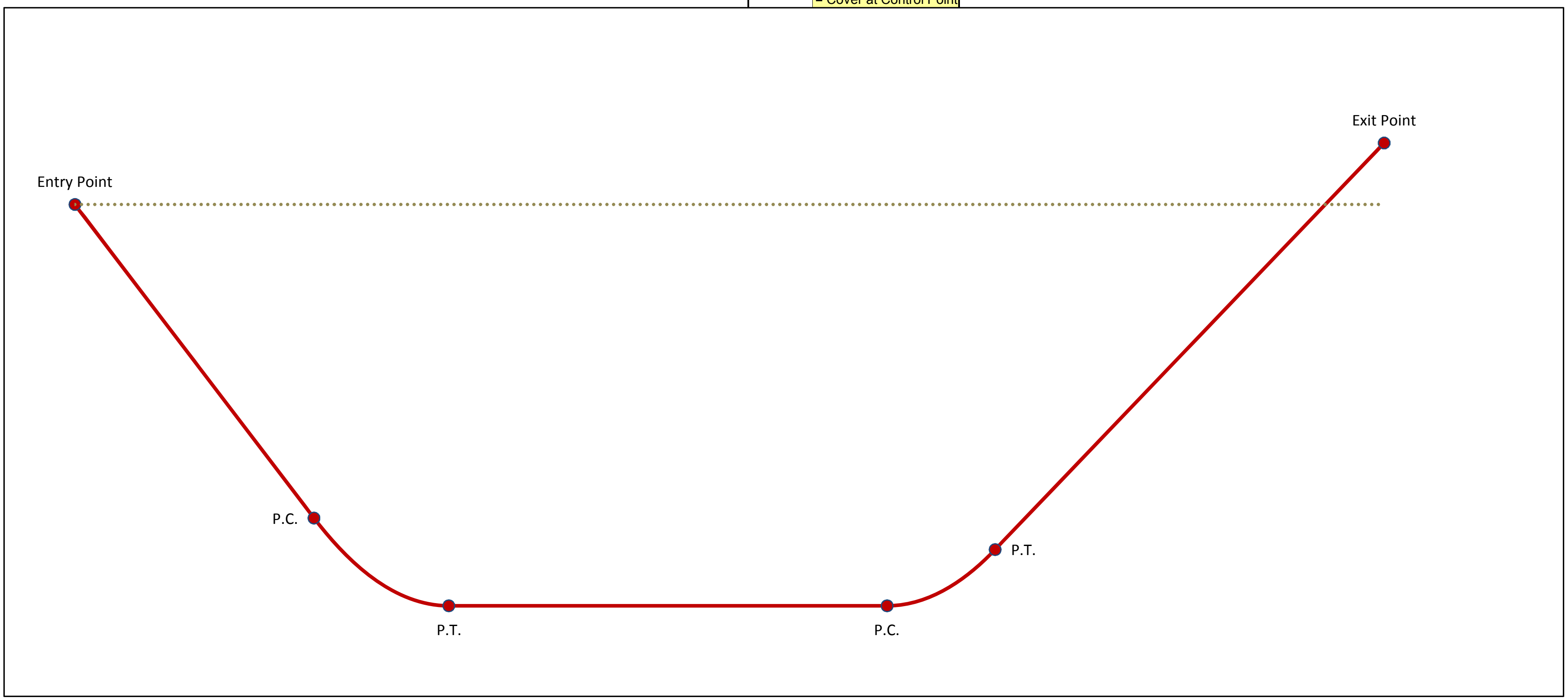
## Blackwater River R1 Installation Stress Analysis (worst-case).xlsm

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

| | | 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



# Blackwater River 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 = | 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 μ cosθ = | 22,268 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 12,863 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) | 23,074 | lb |
| Bending Frictional Drag = 2 μ N = | 13,844 | 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 =** | **18,842** | **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 μ = | 25,075 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 14,344 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 0 | lb |
| **Pulling Load on Bottom Tangent =** | **39,418** | **lb** |
| **Total Pulling Load =** | **103,822** | **lb** |

# Blackwater River R1 Installation Stress Analysis (worst-case).xlsm

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

## Entry Sag Bend - Summary of Pulling Load Calculations

Segment Length, L = 235.6 ft

Segment Angle with Horizontal, $\theta$ = 10.0 °

Deflection Angle, $\alpha$ = 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, $\theta$ = 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

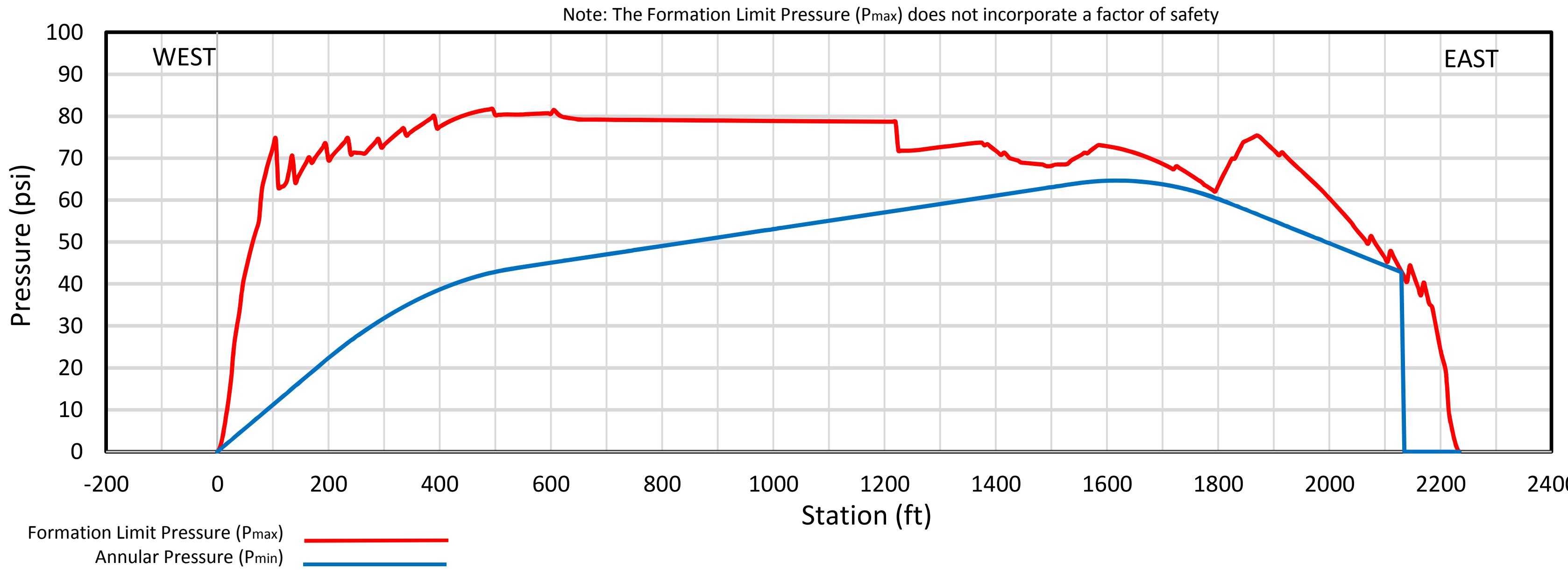
Negative value indicates axial weight applied in direction of installation

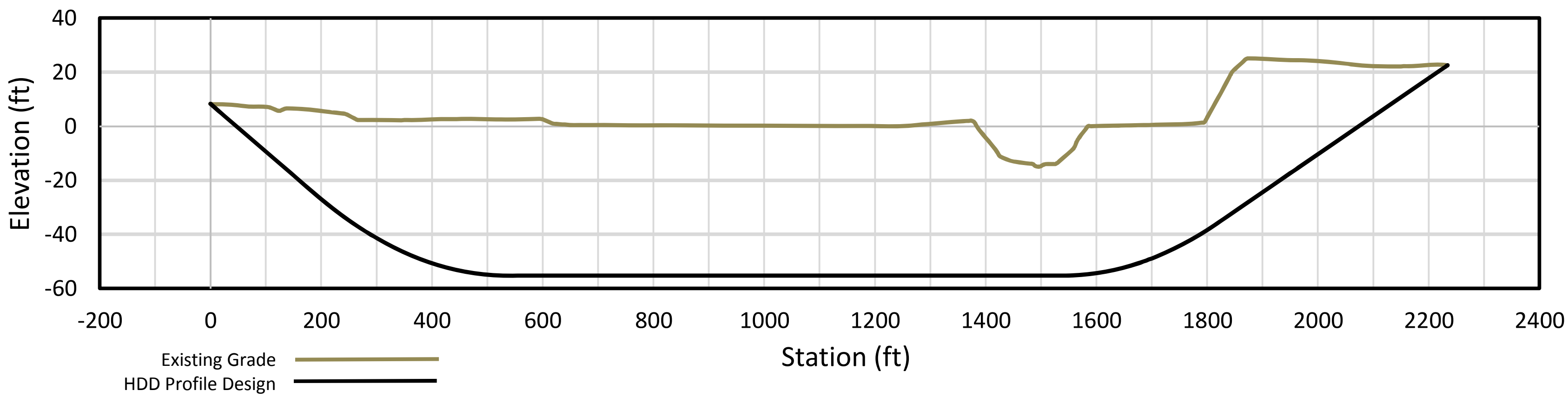
**Pulling Load on Entry Tangent = 13,589 lb**

**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

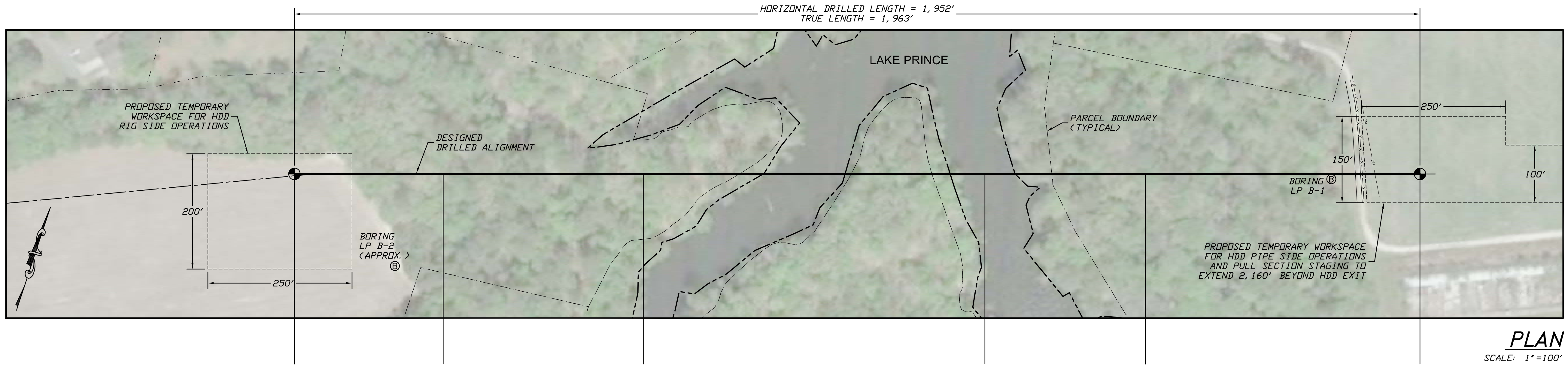
Date: 1/12/2016 Revision: 1

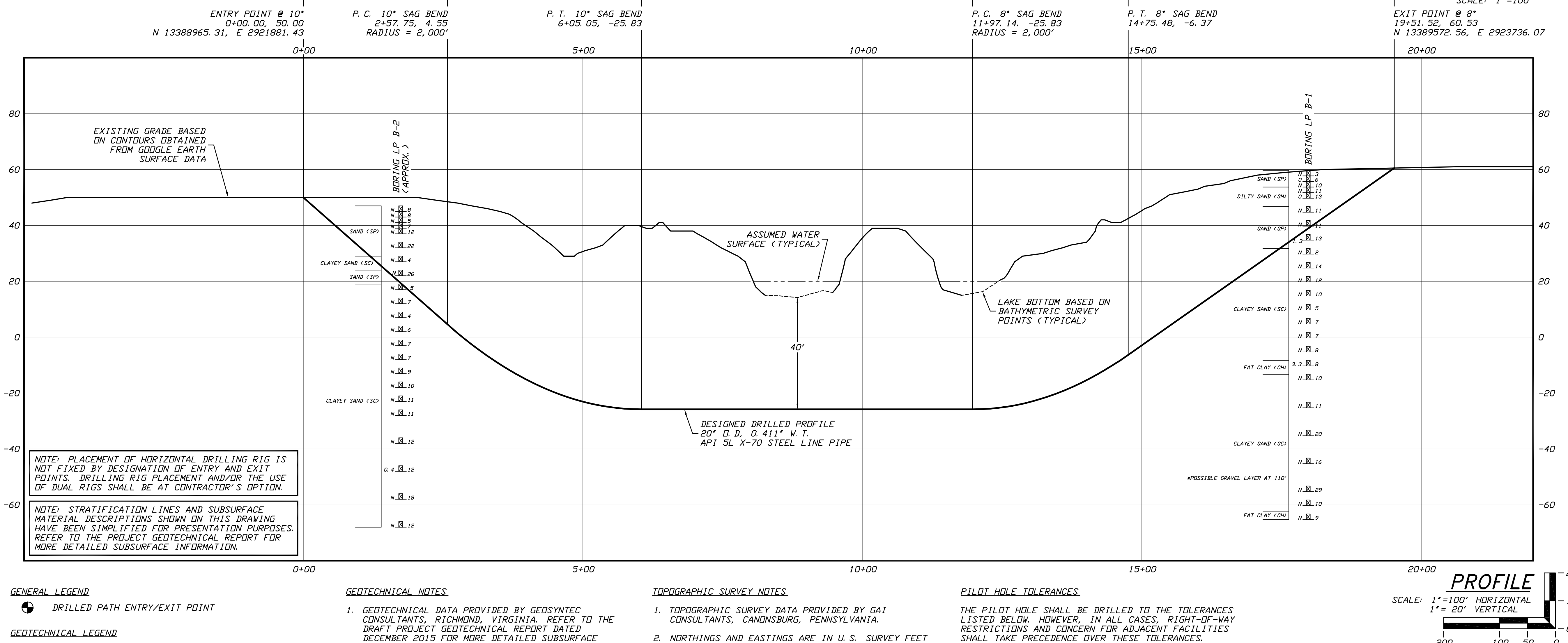
J.D.Hair&Associates, Inc.

# Lake Prince

**Supporting Information**

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




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.

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.

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

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

| 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 | |

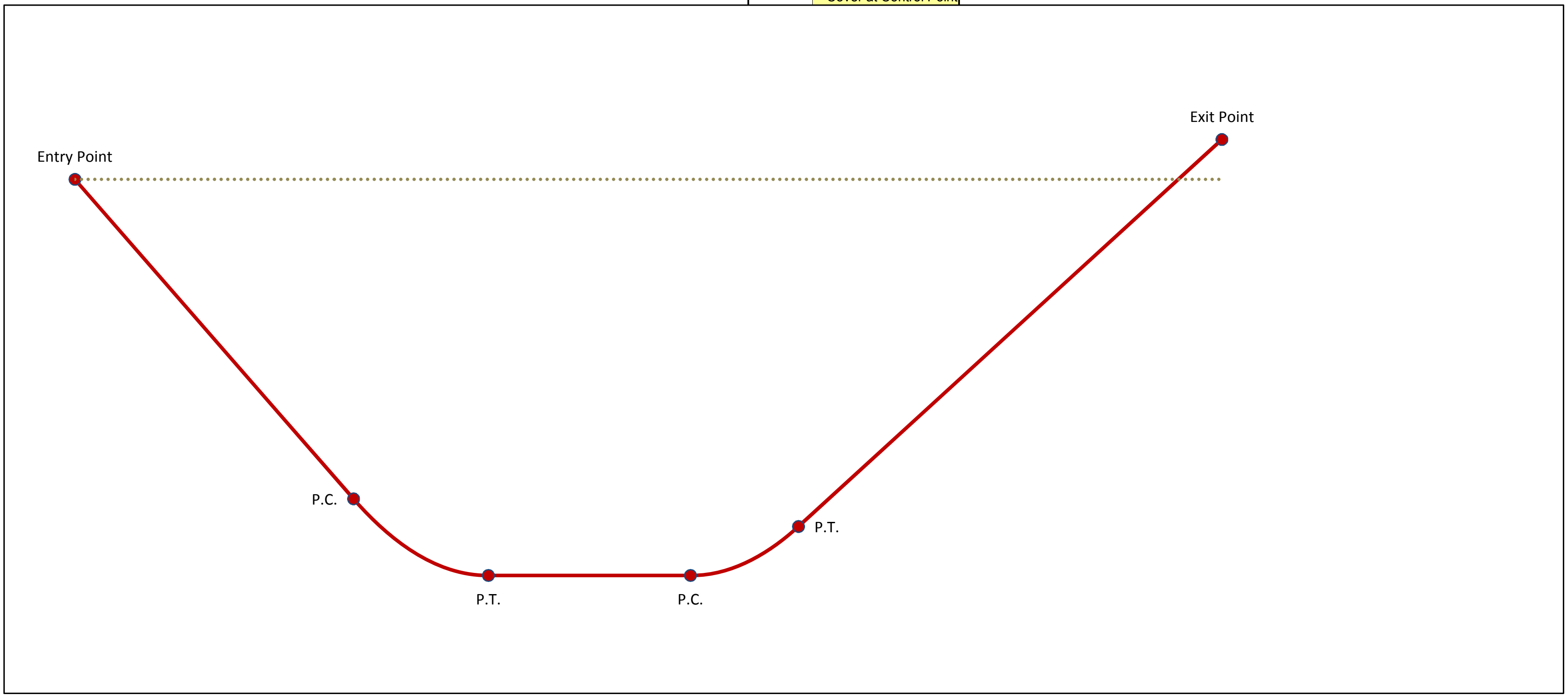
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,493 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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

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

| | | 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 | |



# Lake Prince R0 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 = | 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** | | | |

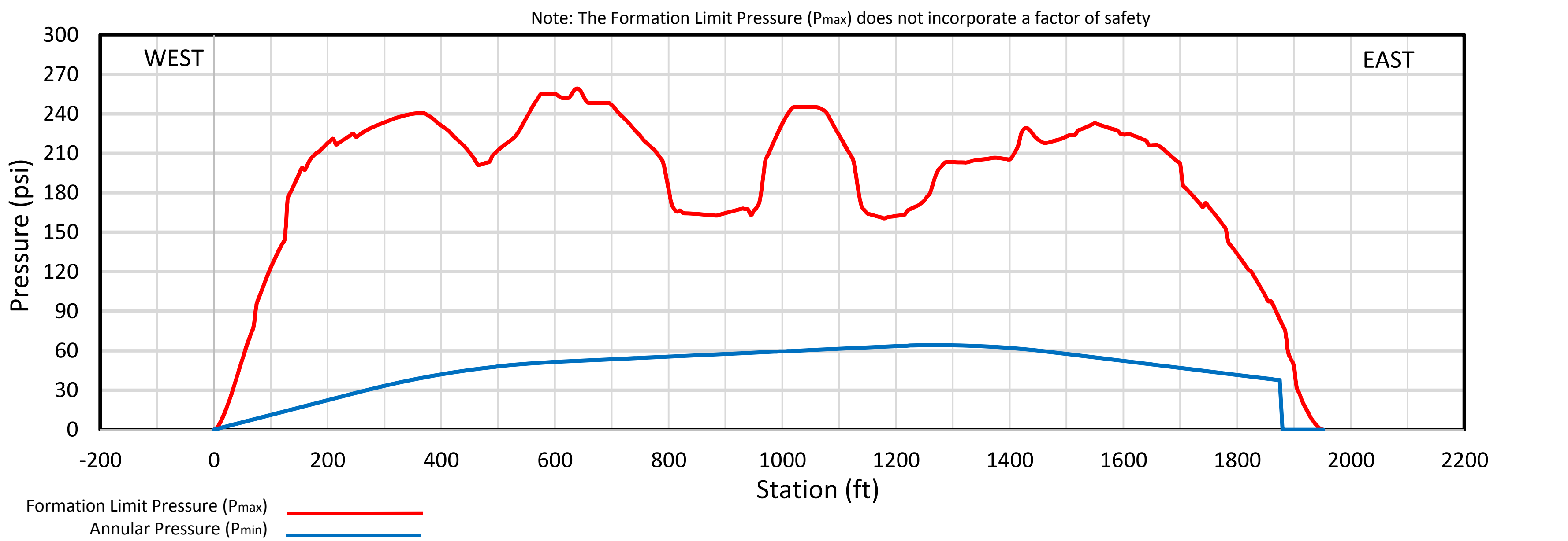
## Entry Tangent - Summary of Pulling Load Calculations

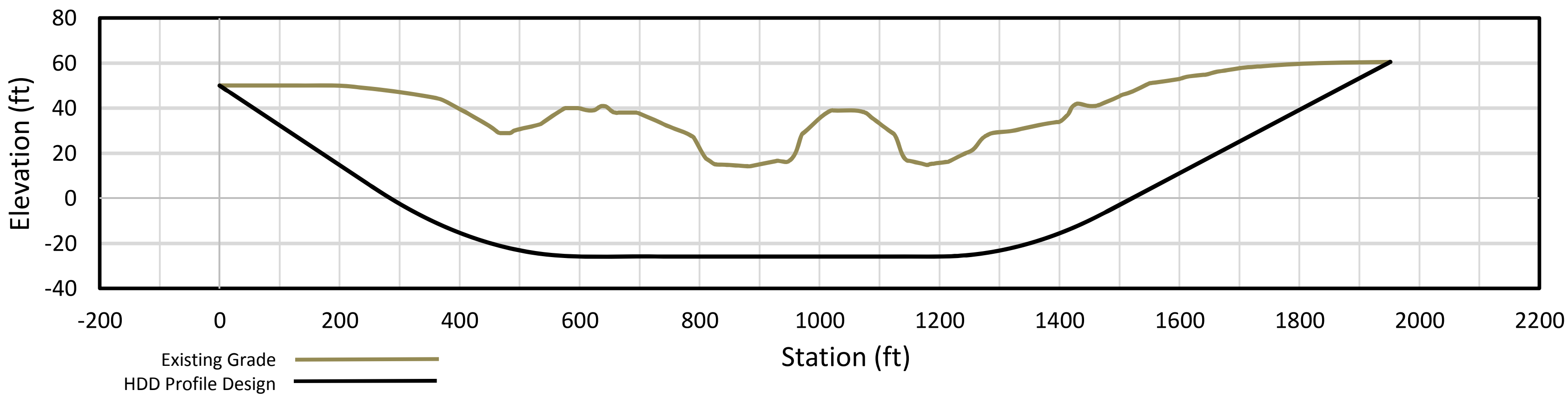
| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 491.3 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| 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.

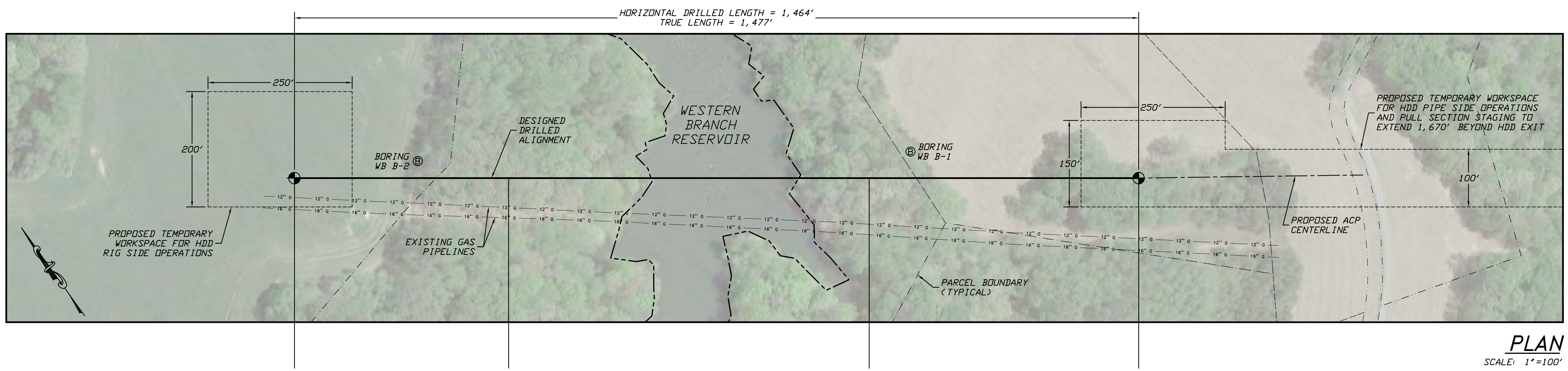
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH LAKE PRINCE CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

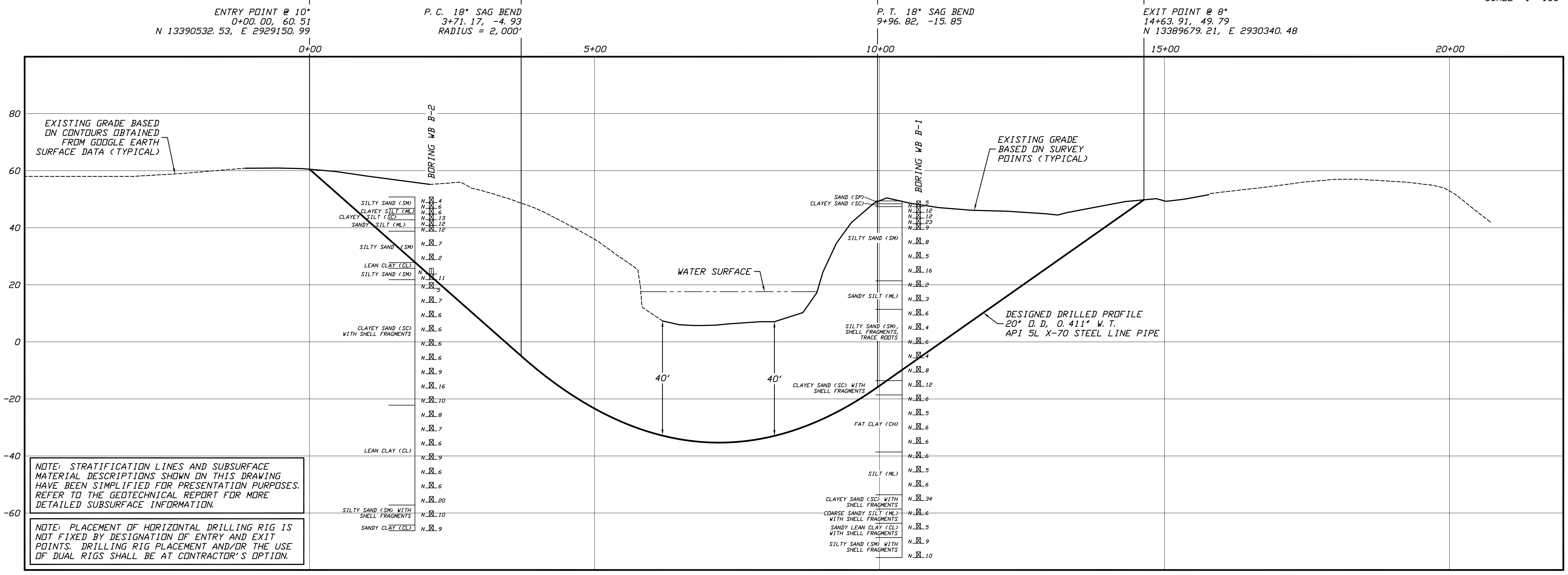
Date: 7/12/2016 Revision: 0

# 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)




## 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

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 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 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

| 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 | |

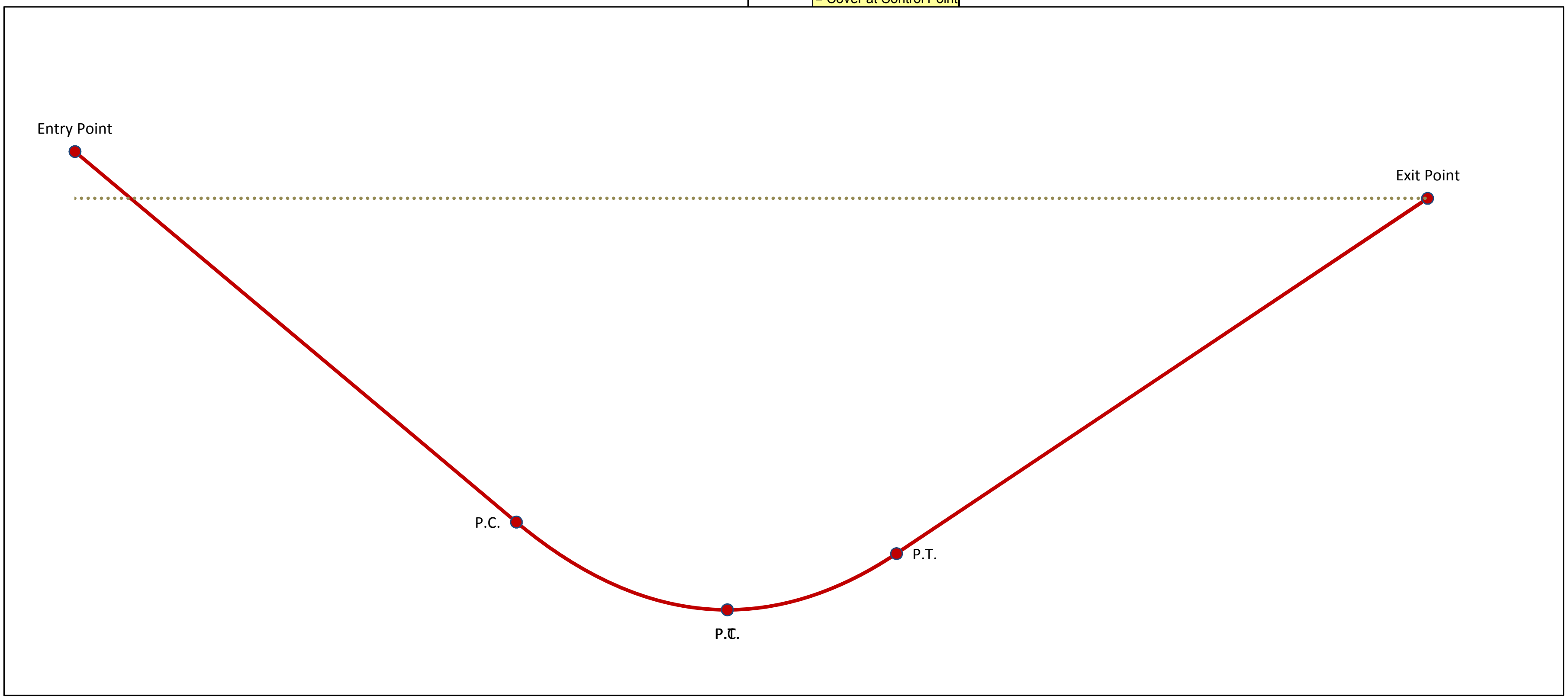
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,493 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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

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

| | | 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**

3:26 PM7/27/2016

# Western Branch Reservoir 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 = | 596.5 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |
| Exit Angle, θ = | 8.0 | ° | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e\, L\, \mu \cos\theta$ = | 19,464 | lb |
| Fluidic Drag = $12\, \pi\, D\, L\, C_d$ = | 11,243 | lb |
| Axial Segment Weight = $W_e\, L \sin\theta$ = | 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 = $2\, \mu\, N$ = | 13,563 | 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 =** | **18,560** | **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 = $W_e\, L\, \mu$ = | 3 | lb |
| Fluidic Drag = $12\, \pi\, D\, L\, C_d$ = | 2 | lb |
| Axial Segment Weight = $W_e\, L \sin\theta$ = | 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** | | | |

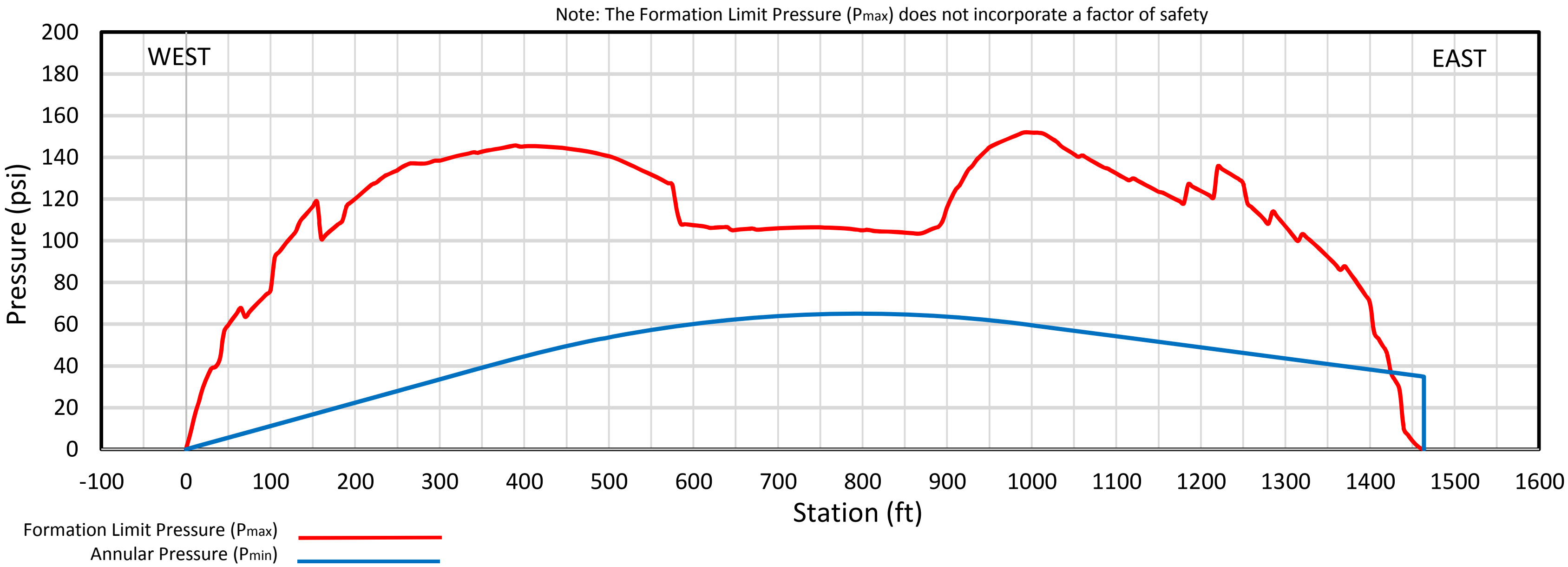
## Entry Tangent - Summary of Pulling Load Calculations

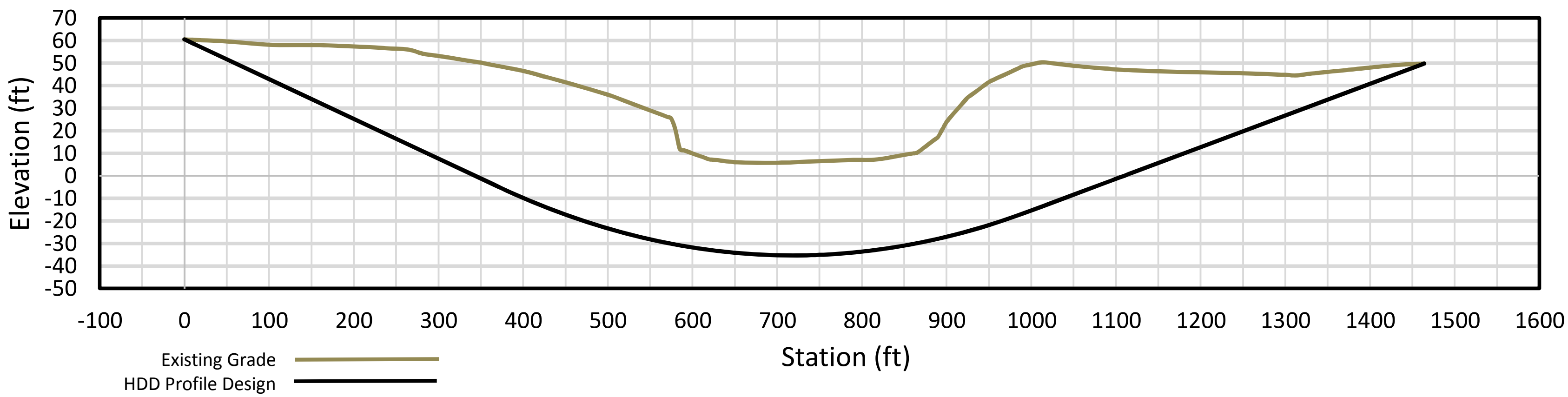
| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 498.4 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| 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

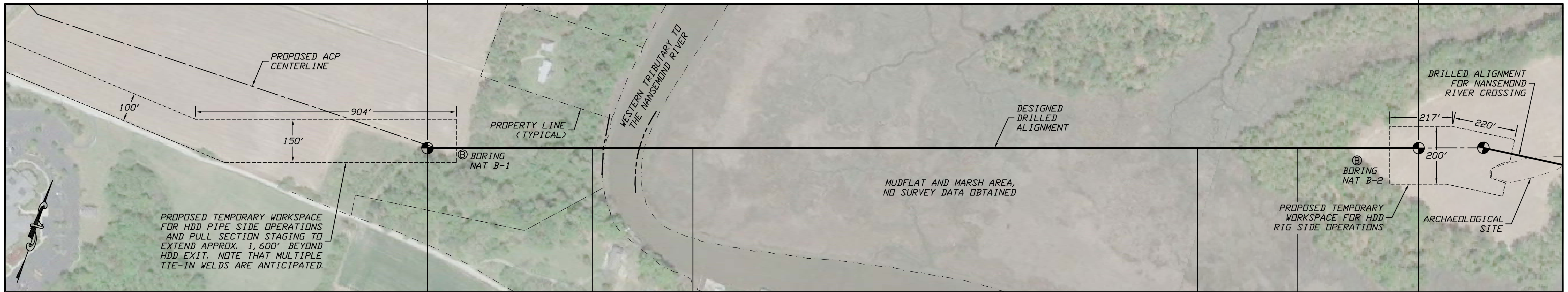
J.D.Hair&Associates, Inc.

# Nansemond River Tributary

**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 = 3, 435'
TRUE LENGTH = 3, 454'




## PLAN

SCALE: 1"=200'

EXIT POINT @ 10°
34+35. 33, 48. 41
N 13388704. 69, E 2934780. 08

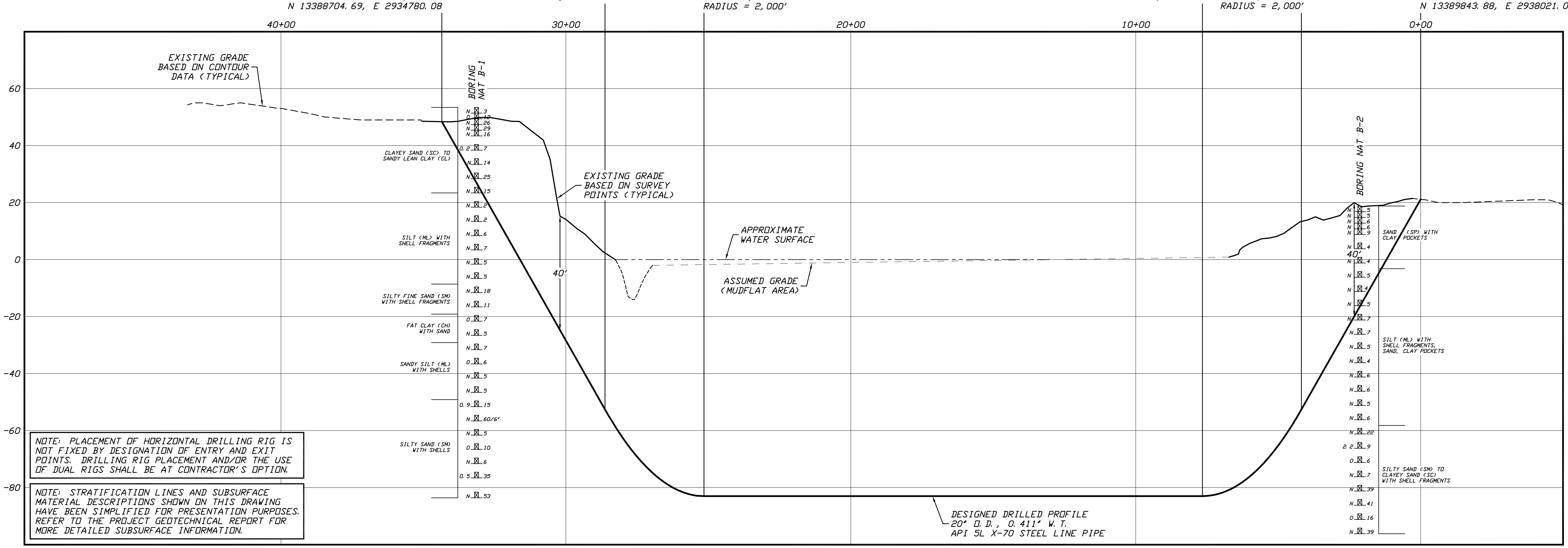
P. T. 10° SAG BEND
28+62. 40, -52. 62

P. C. 10° SAG BEND
25+15. 11, -83. 00
RADIUS = 2,000'

P. T. 10° SAG BEND
7+65. 73, -83. 00

P. C. 10° SAG BEND
4+18. 43, -52. 62
RADIUS = 2,000'

ENTRY POINT @ 10°
0+00. 00, 21. 16
N 13389843. 88, E 2938021. 03




## PROFILE

SCALE: 1"=200' HORIZONTAL
1"= 20' 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

GEOTECHNICAL NOTES

1. GEOTECHNICAL DATA PROVIDED BY GEOSYNTEC CONSULTANTS, RICHMOND, VIRGINIA. REFER TO THE PROJECT GEOTECHNICAL REPORT DATED MARCH 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.
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TOPOGRAPHIC SURVEY NOTES

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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 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 |

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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 | |

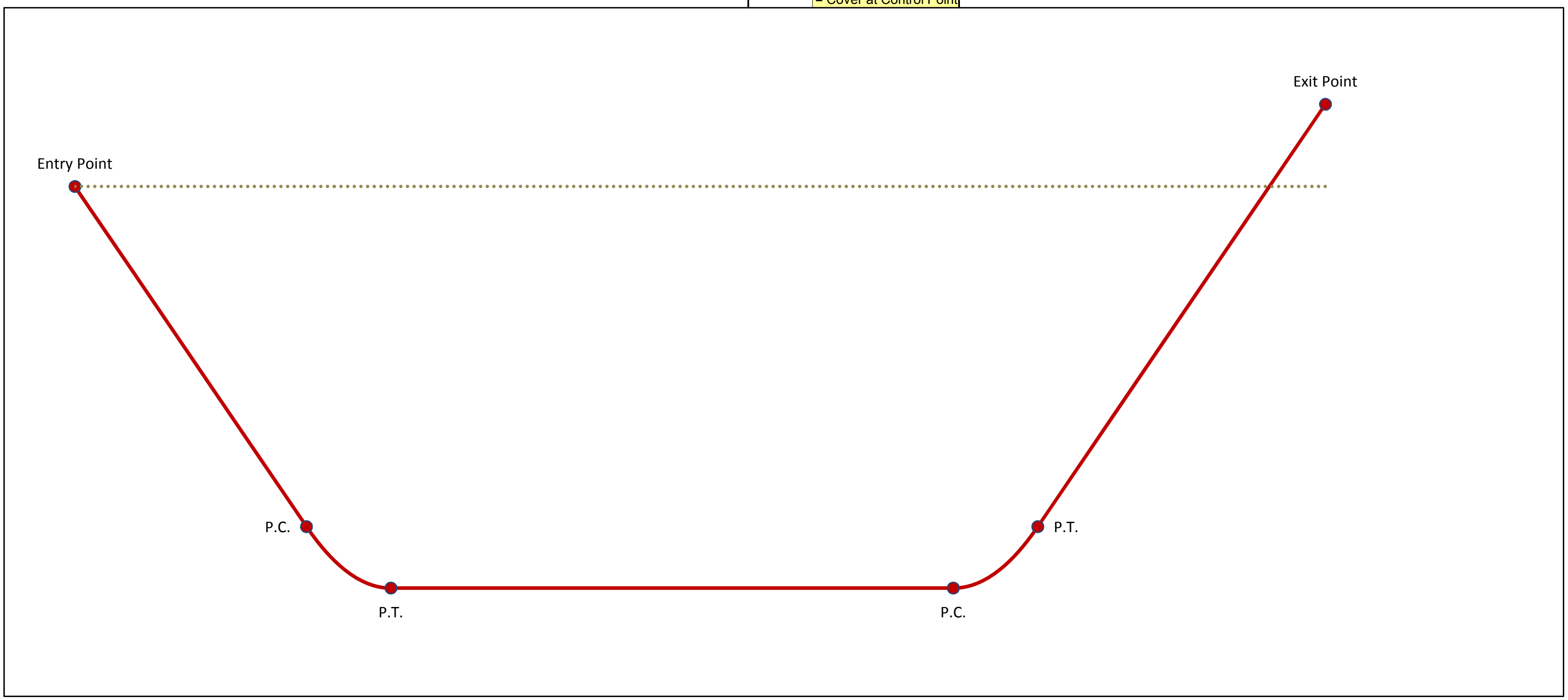
## Nansemond Tributary R1 Installation Stress Analysis (worst-case).xlsm

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 |
|---|---|



# 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, $\mu$ = | 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, $\theta$ = | 10.0 | ° | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e\ L\ \mu\ \cos\theta$ = | 26,342 | lb |
| Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = | 15,301 | lb |
| Axial Segment Weight = $W_e\ L\ \sin\theta$ = | 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, $\theta$ = | -10.0 | ° | Radius of Curvature, R = | 1,350 | ft |
| Deflection Angle, $\alpha$ = | -5.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R\ [1 - \cos(\alpha/2)]$ = | 5.14 | ft | $j = [(E\ I) / T]^{1/2}$ = | 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 | | $N = [(T\ h) - W_e \cos\theta\ (Y/144)] / (X / 12)$ | 27,440 | lb |
| Bending Frictional Drag = $2\ \mu\ N$ = | 16,464 | lb | | | |
| Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = | 4,441 | lb | | | |
| Axial Segment Weight = $W_e\ L\ \sin\theta$ = | 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 = $W_e\ L\ \mu$ = | 51,507 | lb |
| Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = | 29,464 | lb |
| Axial Segment Weight = $W_e\ L\ \sin\theta$ = | 0 | lb |
| **Pulling Load on Bottom Tangent =** | **80,971** | **lb** |
| **Total Pulling Load =** | **161,257** | **lb** |

# Nansemond Tributary R1 Installation Stress Analysis (worst-case).xlsm

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

## 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 = 173,618 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

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

Entry Angle, θ = 10.0 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e L \mu \cos\theta$ = 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

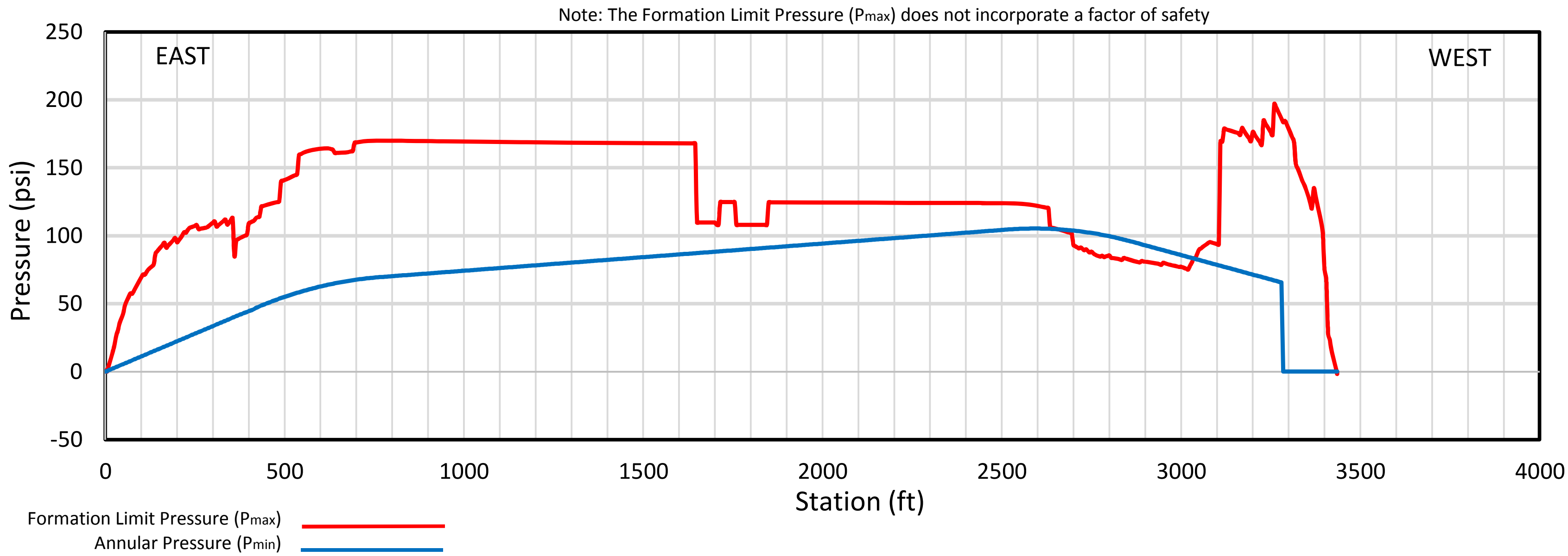
Negative value indicates axial weight applied in direction of installation

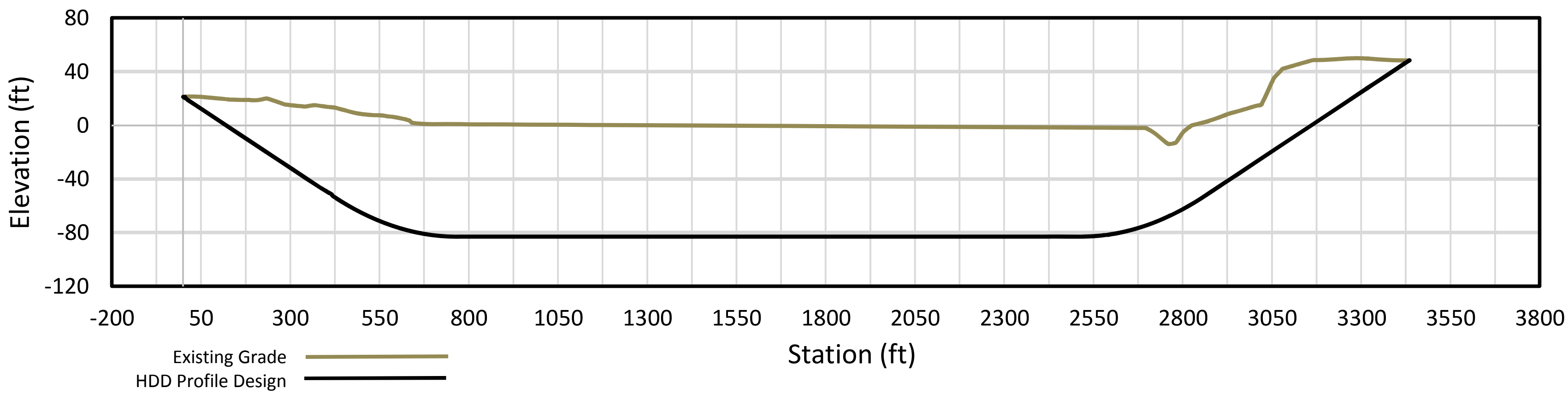
**Pulling Load on Entry Tangent = 21,074 lb**

**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 |




J.D.Hair&Associates, Inc.

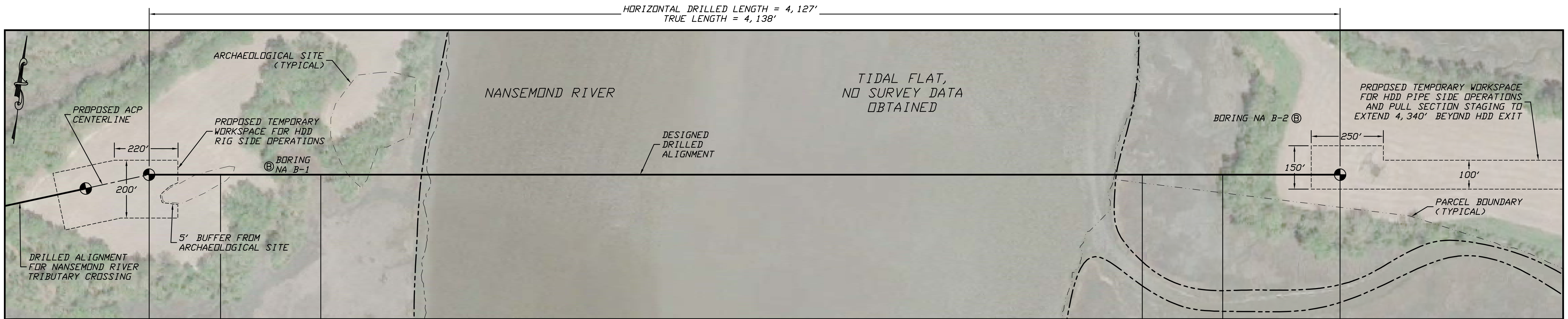
HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
NANSEMOND TRIB. CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

Date: 4/19/2016 Revision: 1

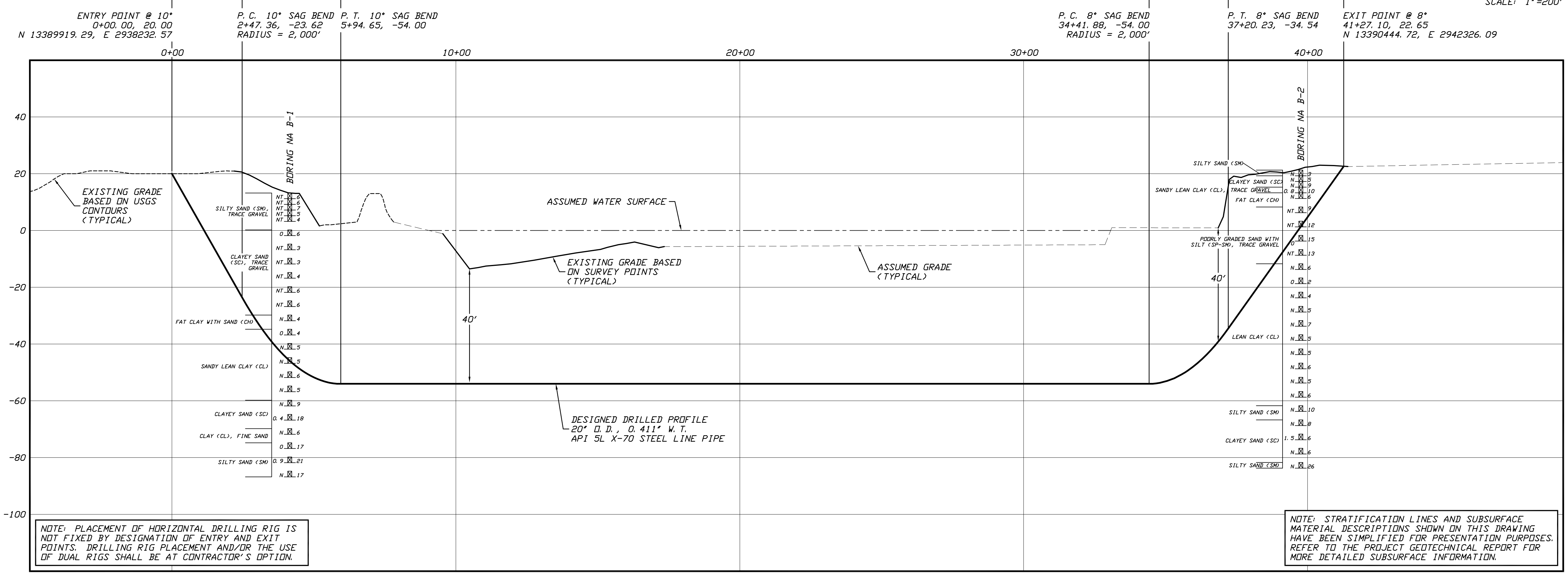
# Nansemond River

**Supporting Information**

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




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 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)

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. |
|---|---|---|---|---|---|

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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 | |

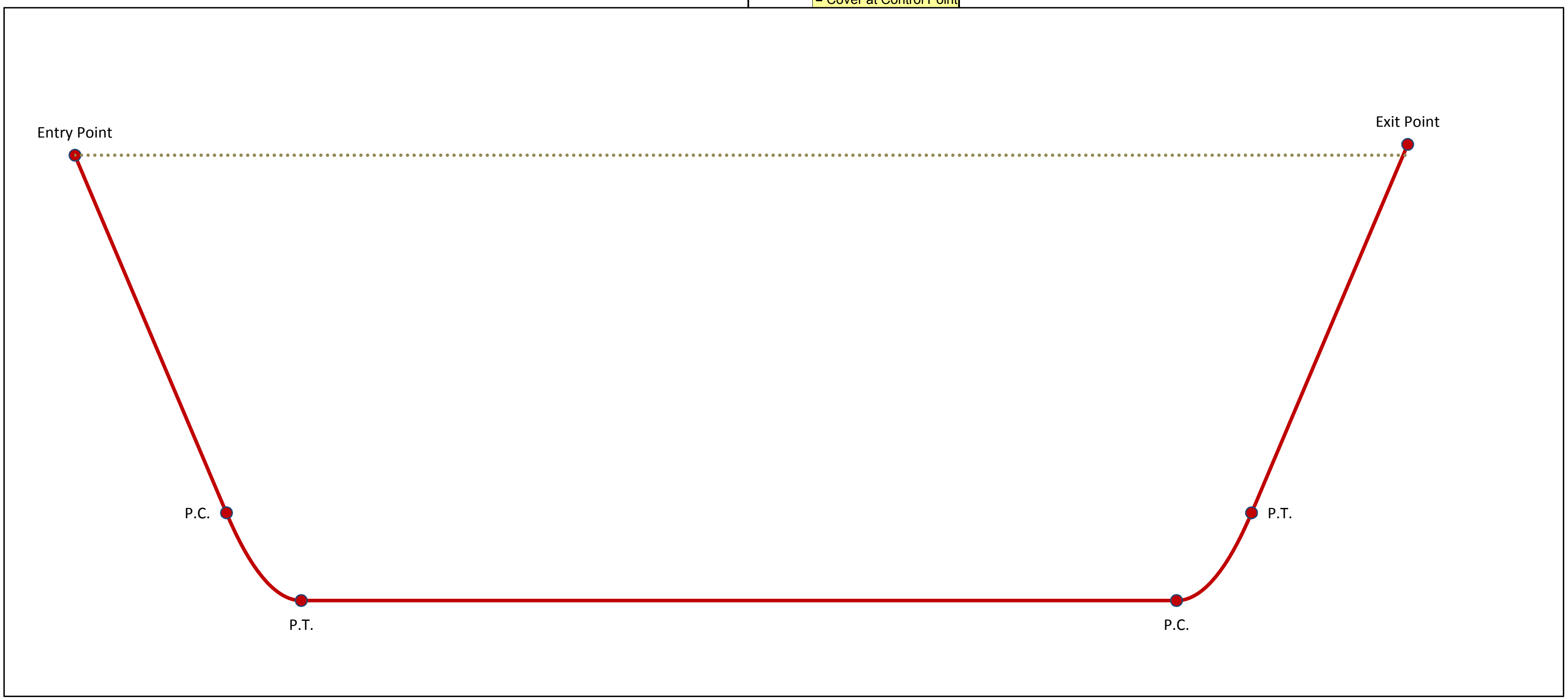
# Nansemond River R0 Installation Stress Analysis (worst-case).xlsm

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

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 = | 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(α/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 μ 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

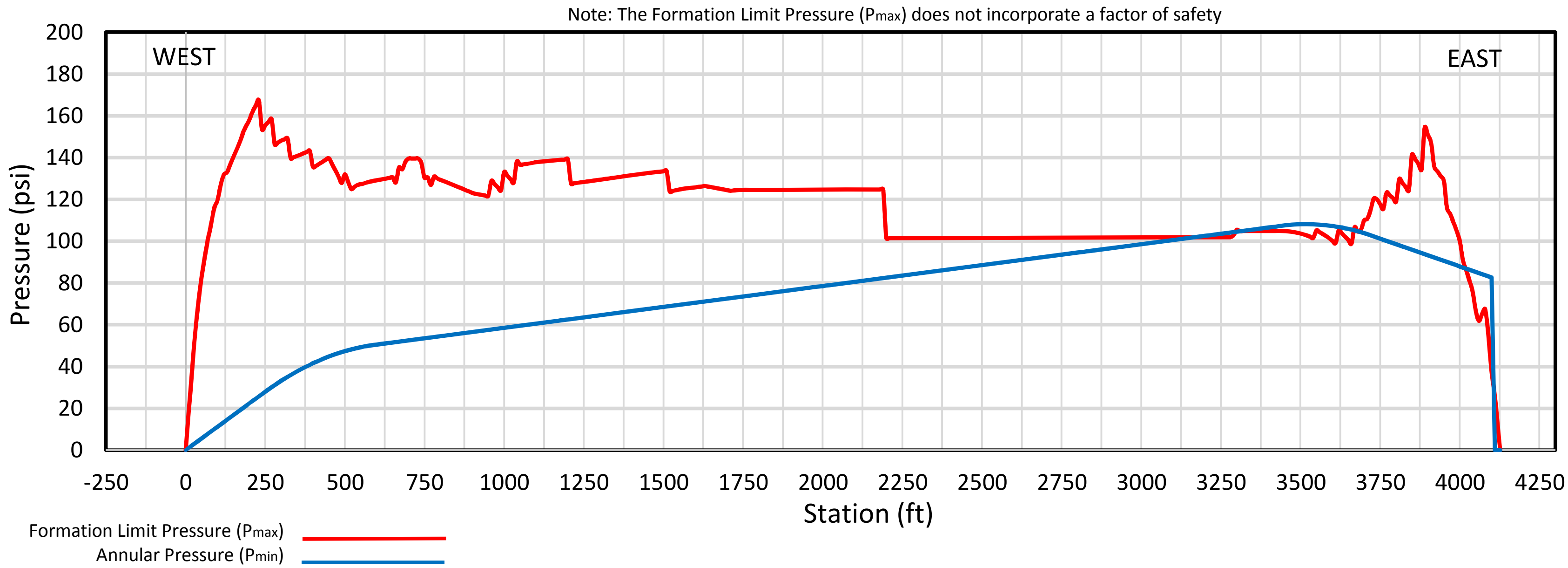
Axial Segment Weight = $W_e\ L \sin\theta$ = -9,171 lb

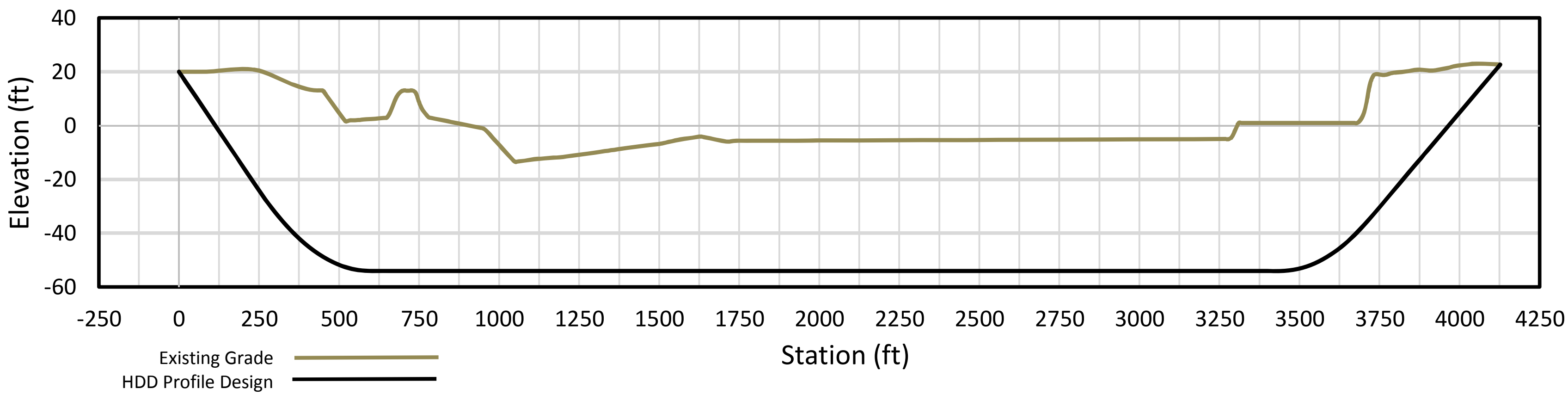
Negative value indicates axial weight applied in direction of installation

**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 |




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

Date: 5/31/2016 Revision: 0

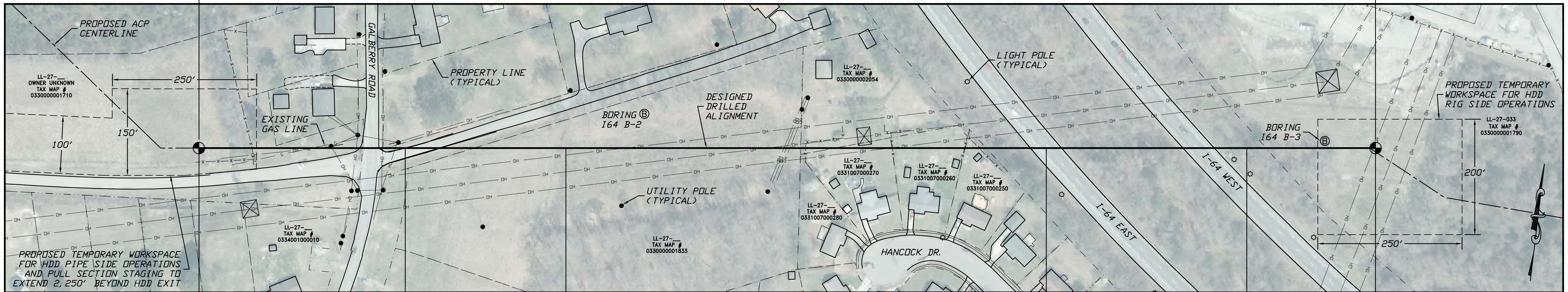
J.D.Hair&Associates, Inc.

# Interstate 64

**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 = 2,039'
TRUE LENGTH = 2,048'




## PLAN
SCALE: 1"=100'

EXIT POINT @ 8°
20+38.42, 10.32
N 13380535.37, E 2998760.33

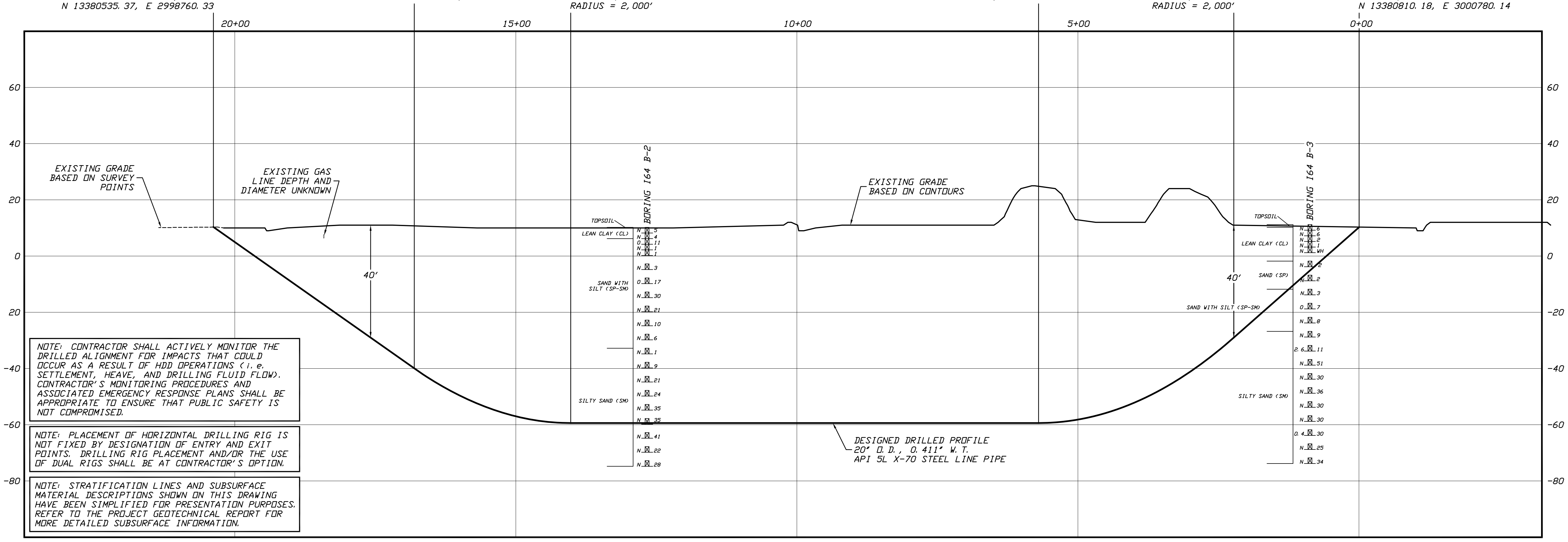
P.T. 8° SAG BEND
16+80.94, -39.32

P.C. 8° SAG BEND
14+02.59, -59.39
RADIUS = 2,000'

P.T. 10° SAG BEND
5+70.25, -59.39

P.C. 10° SAG BEND
2+22.95, -29.00
RADIUS = 2,000'

ENTRY POINT @ 10°
0+00.00, 10.31
N 13380810.18, E 3000780.14




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: 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.

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.

## 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 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 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**

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

| 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 | |

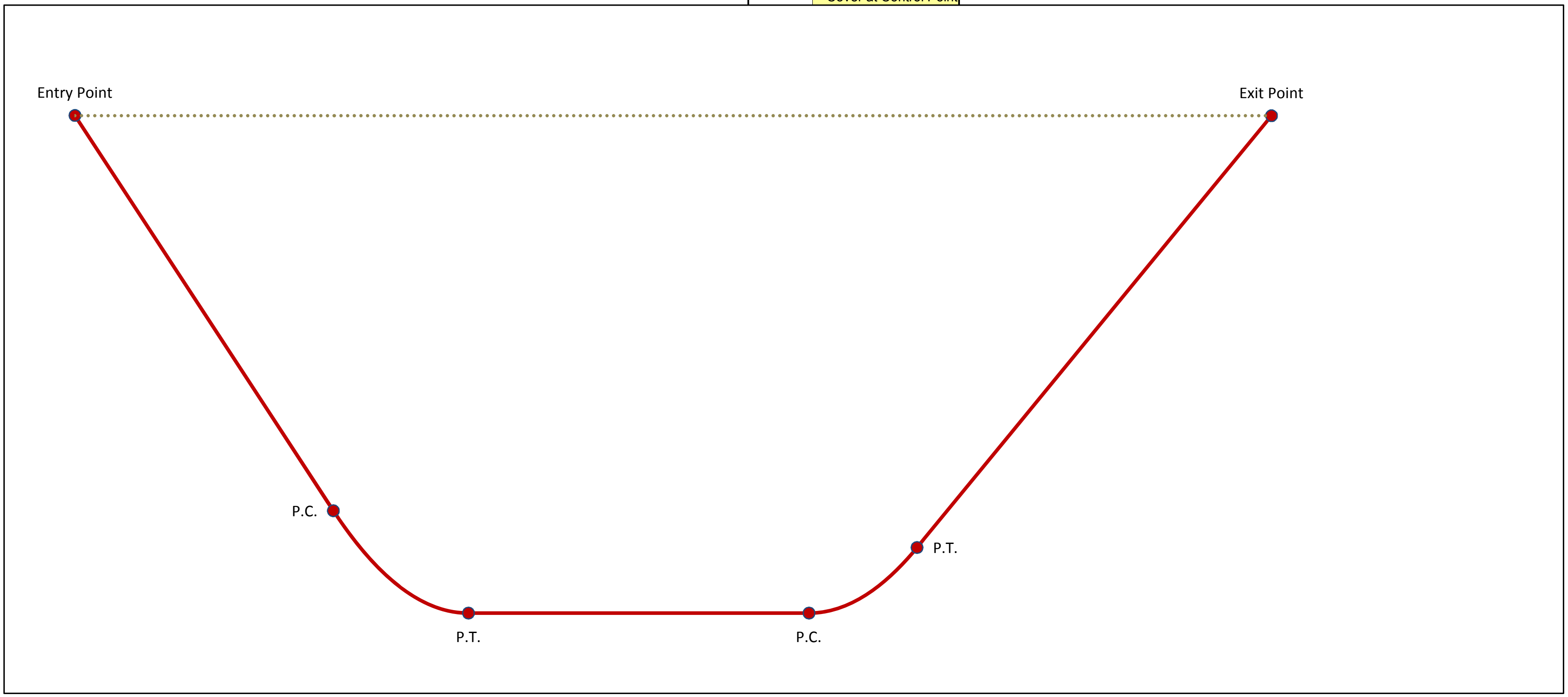
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,493 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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**
J:\Dominion\1508 - Atlantic Coast\Working\Stress Analysis\

| | | 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 |
|---|---|




**Step 2, Drilled Path Input**

# Interstate 64 R0 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, $\mu$ = | 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, $\theta$ = | 8.0 | ° | | | |

| | | |
|---|---|---|
| Frictional Drag = $W_e \, L \, \mu \cos\theta$ = | 20,284 | lb |
| Fluidic Drag = $12 \, \pi \, D \, L \, C_d$ = | 11,717 | lb |
| Axial Segment Weight = $W_e \, L \sin\theta$ = | 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, $\theta$ = | -8.0 | ° | Radius of Curvature, R = | 1,350 | ft |
| Deflection Angle, $\alpha$ = | -4.0 | ° | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |

| | | | | | |
|---|---|---|---|---|---|
| $h = R\,[1 - \cos(\alpha/2)]$ = | 3.29 | ft | $j = [(E\,I) / T]^{1/2}$ = | 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 | | $N = [(T\,h) - W_e \cos\theta\,(Y/144)] / (X/12)$ | 22,742 | lb |
| Bending Frictional Drag = $2\,\mu\,N$ = | 13,645 | 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 =** | **18,643** | **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 = $W_e \, L \, \mu$ = | 19,489 | lb |
| Fluidic Drag = $12 \, \pi \, D \, L \, C_d$ = | 11,148 | lb |
| Axial Segment Weight = $W_e \, L \sin\theta$ = | 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

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

## Entry Sag Bend - Summary of Pulling Load Calculations

| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 235.6 | ft | Average Tension, T = | 101,049 | 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 | $j = [(E\,I)/T]^{1/2}$ = | 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** | | | |

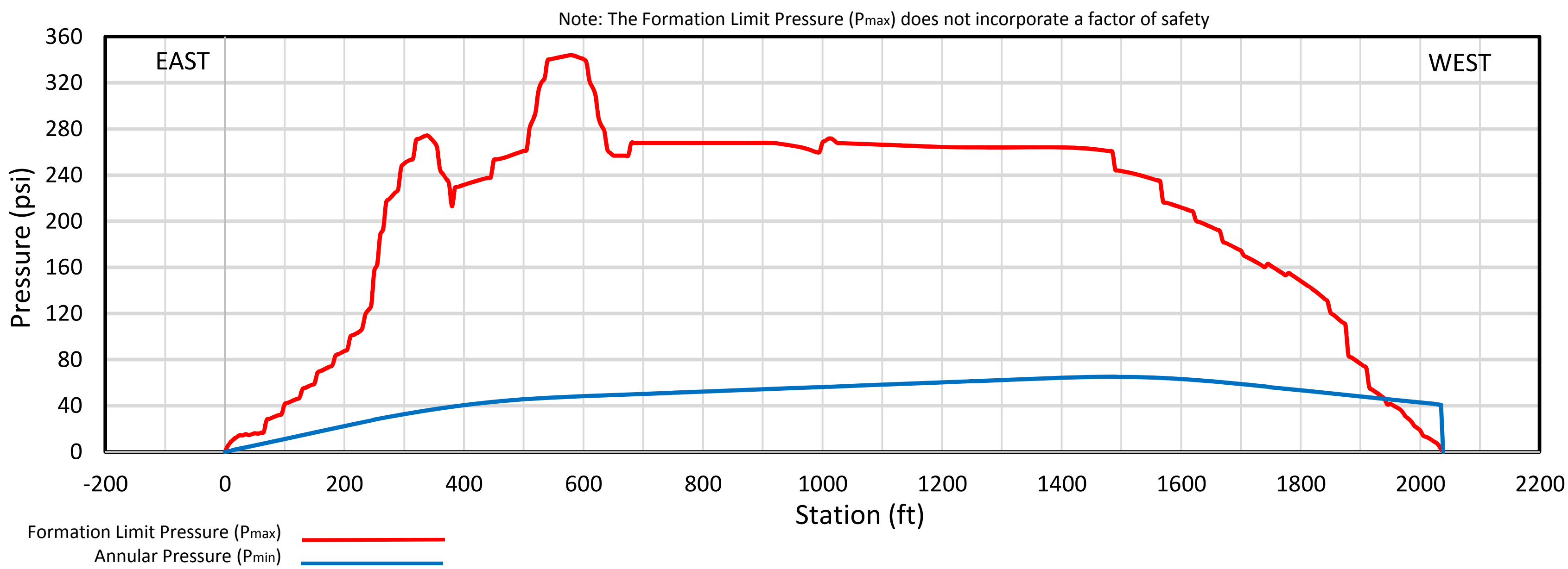
## Entry Tangent - Summary of Pulling Load Calculations

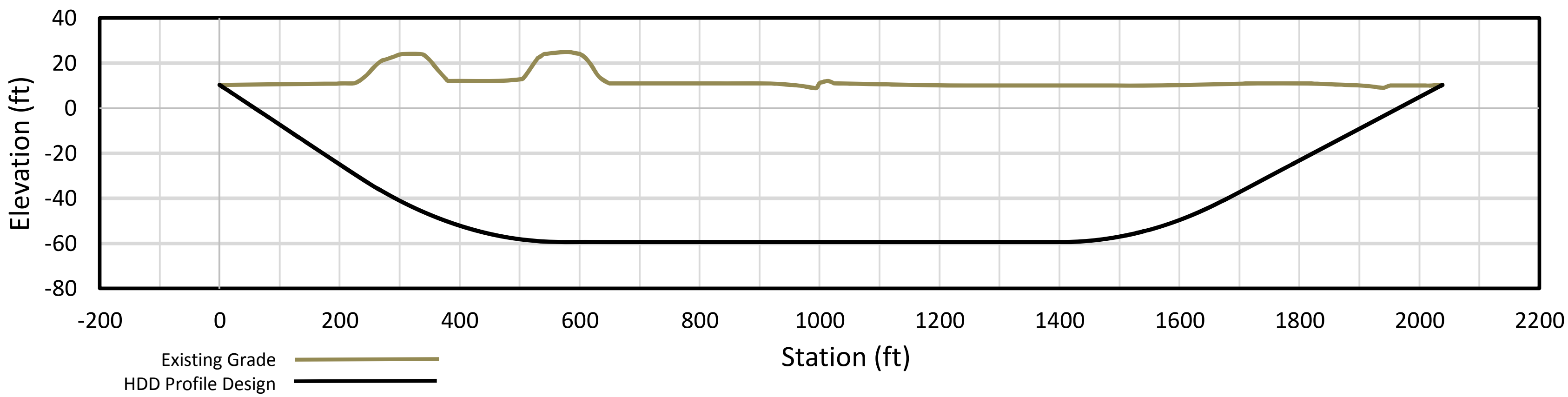
| | | | | | |
|---|---|---|---|---|---|
| Segment Length, L = | 456.0 | ft | Effective Weight, $W_e = W + W_b - W_m$ = | -109.8 | lb/ft |
| Entry Angle, θ = | 10.0 | ° | | | |

| | | | |
|---|---|---|---|
| Frictional Drag = $W_e\,L\,\mu\cos\theta$ = | 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 |




J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH INTERSTATE 64 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

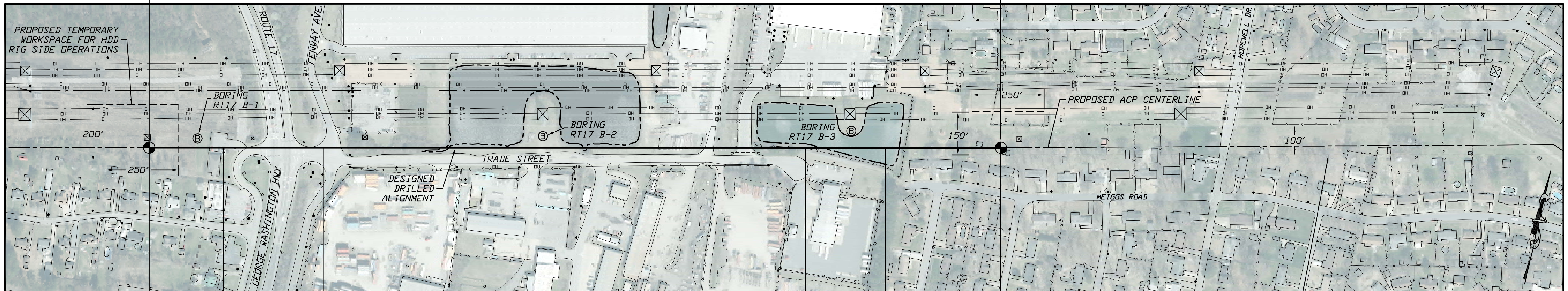
Date: 6/16/2015 | Revision: 0

# 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

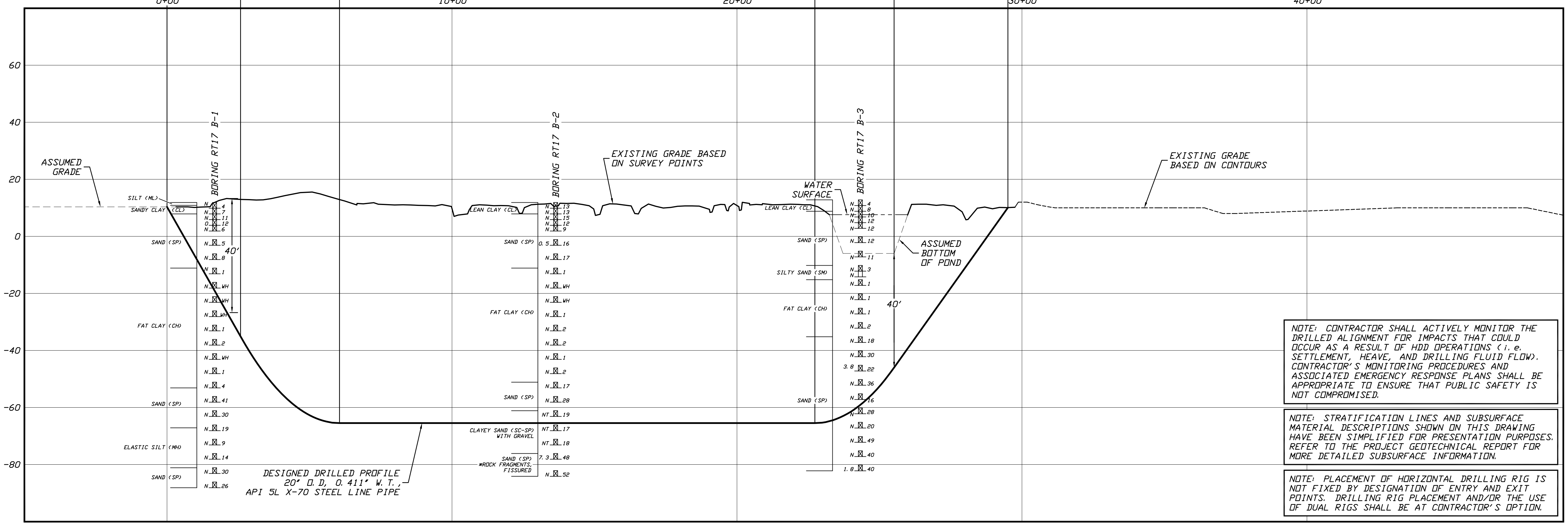
P.C. 10° SAG BEND
2+57.75, -35.08
RADIUS = 2,000'

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

## 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 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. |
|---|---|---|---|---|---|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Consulting Engineer
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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 | |

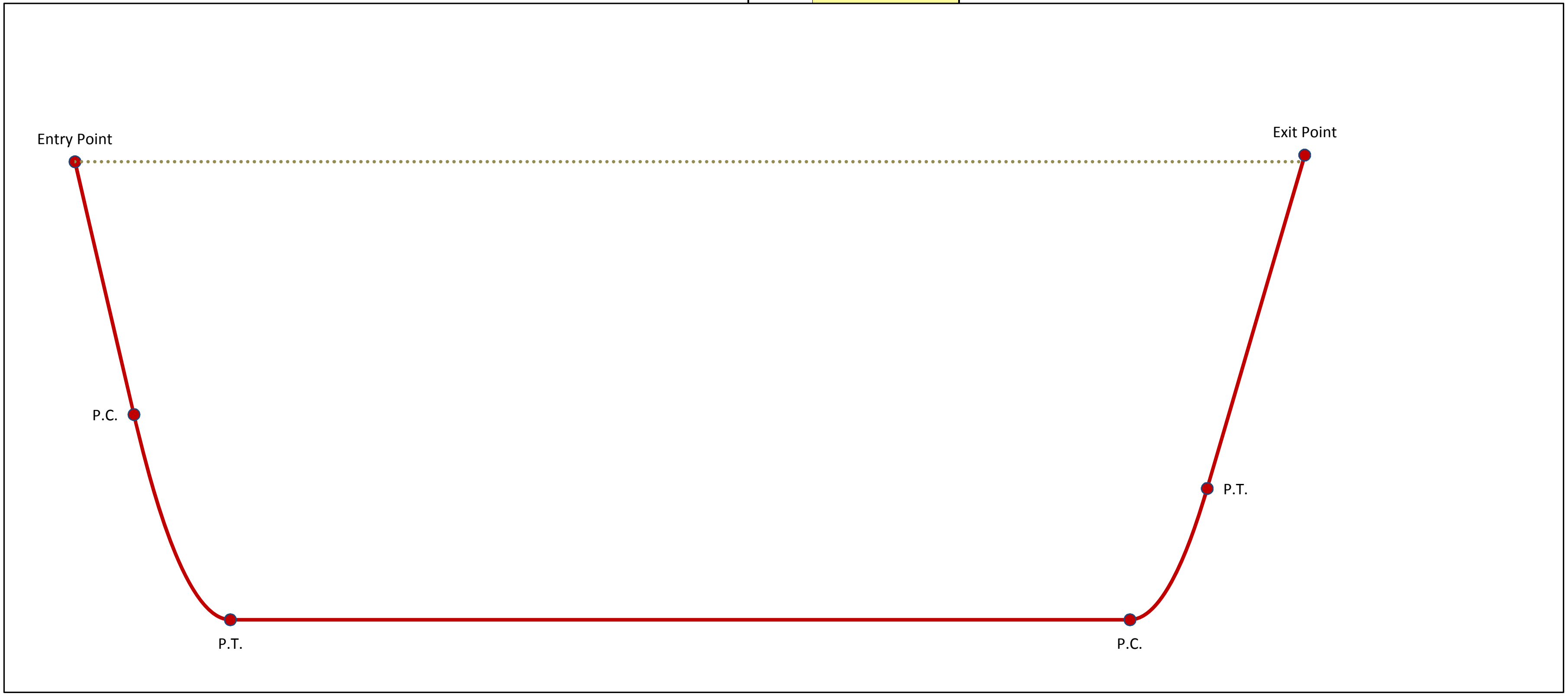
| Installation Stress Limits | | | |
|---|---|---|---|
| Tensile Stress Limit, 90% of SMYS, $F_t$ = | 63,000 | psi | |
| For D/t <= 1,500,000/SMYS, $F_b$ = | 52,500 | psi | No |
| For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, $F_b$ = | 44,493 | psi | No |
| For D/t > 3,000,000/SMYS and <= 300, $F_b$ = | 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

4:21 PM7/27/2016

## 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** |

# Route 17 R0 Installation Stress Analysis (worst-case).xlsm

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

## 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 = 158,638 lb
Radius of Curvature, R = 1,350 ft
Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

$h = R [1 - \cos(\alpha/2)]$ = 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 = $2\ \mu\ N$ = 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 °

Effective Weight, $W_e = W + W_b - W_m$ = -109.8 lb/ft

Frictional Drag = $W_e\ L\ \mu \cos\theta$ = 4,732 lb

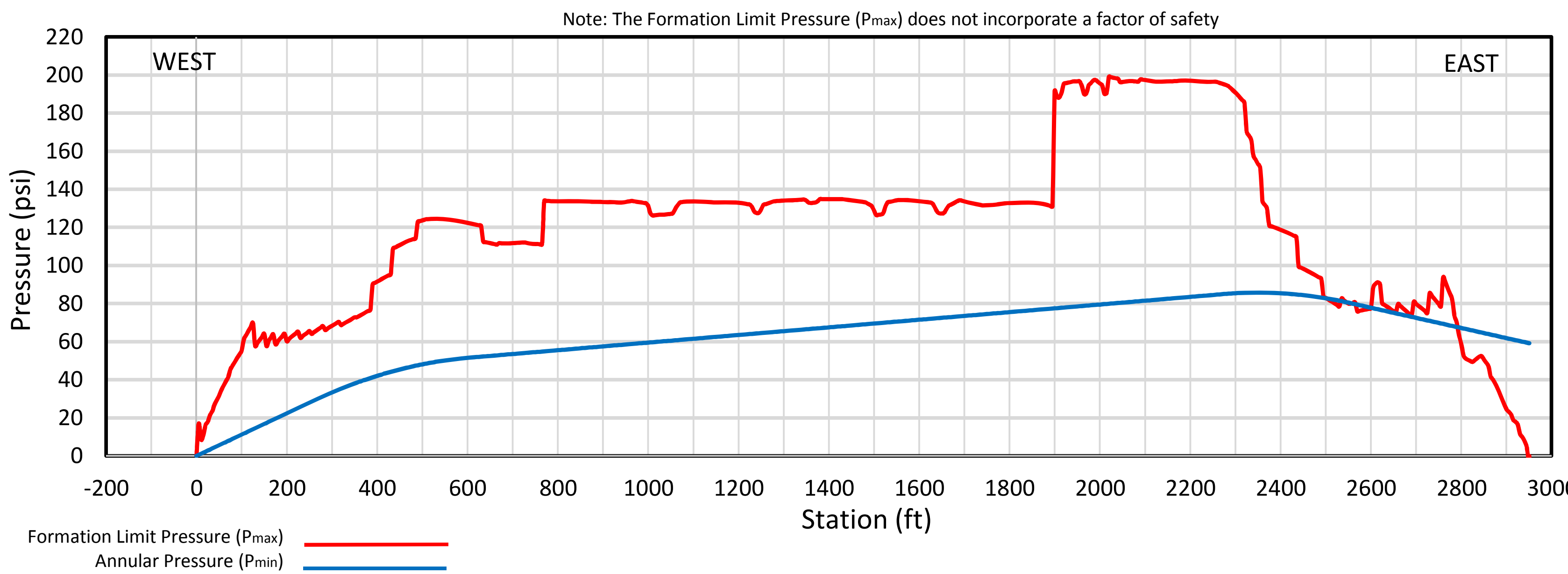
Fluidic Drag = $12\ \pi\ D\ L\ C_d$ = 2,749 lb

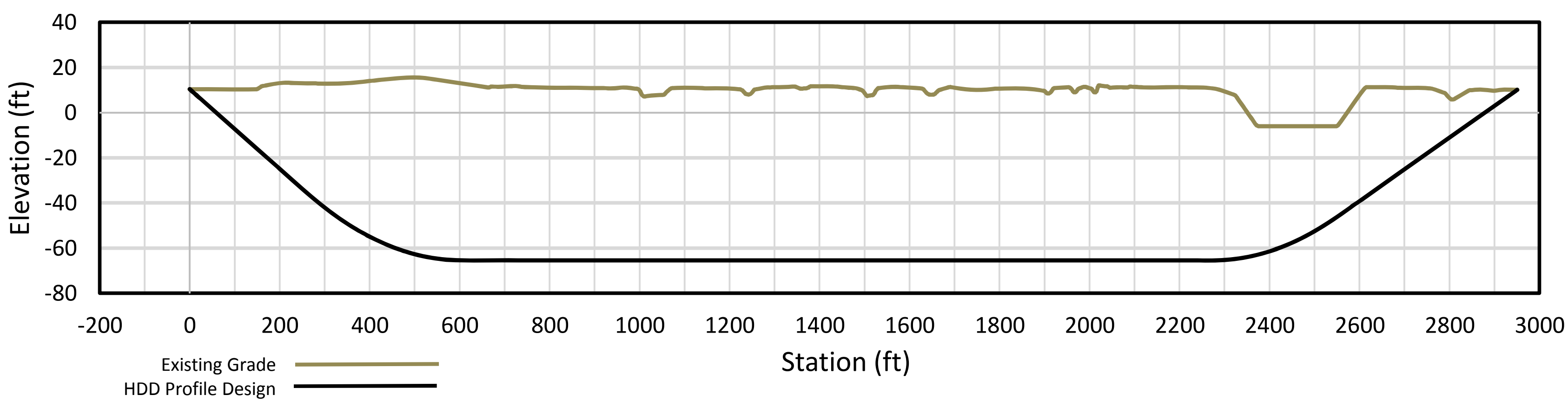
Axial Segment Weight = $W_e\ L \sin\theta$ = -2,781 lb — Negative value indicates axial weight applied in direction of installation

**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 |




J.D.Hair&Associates, Inc.

HYDROFRACTURE EVALUATION
FORMATION LIMIT PRESSURE VS. ANNULAR PRESSURE
20-INCH ROUTE 17 CROSSING
BY HORIZONTAL DIRECTIONAL DRILLING

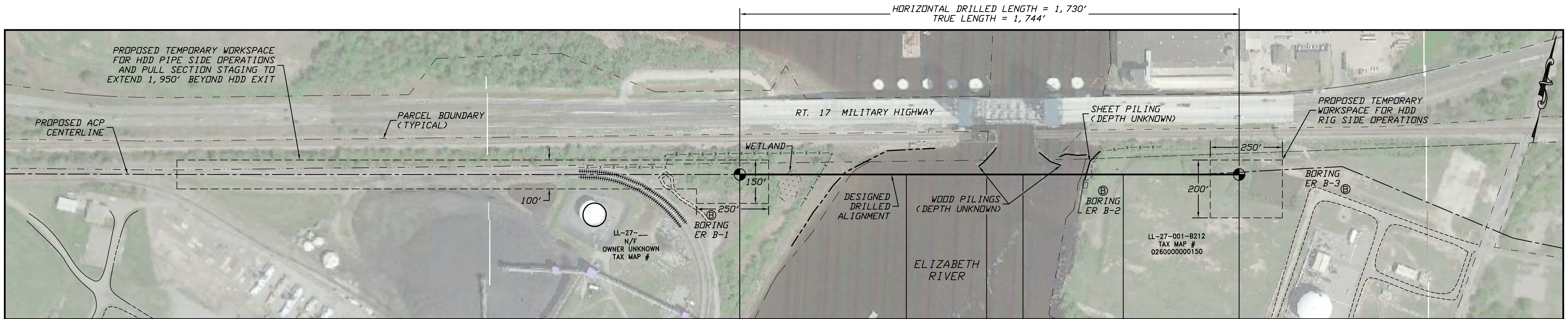
Date: 6/16/2015

Revision: 0

# Elizabeth River

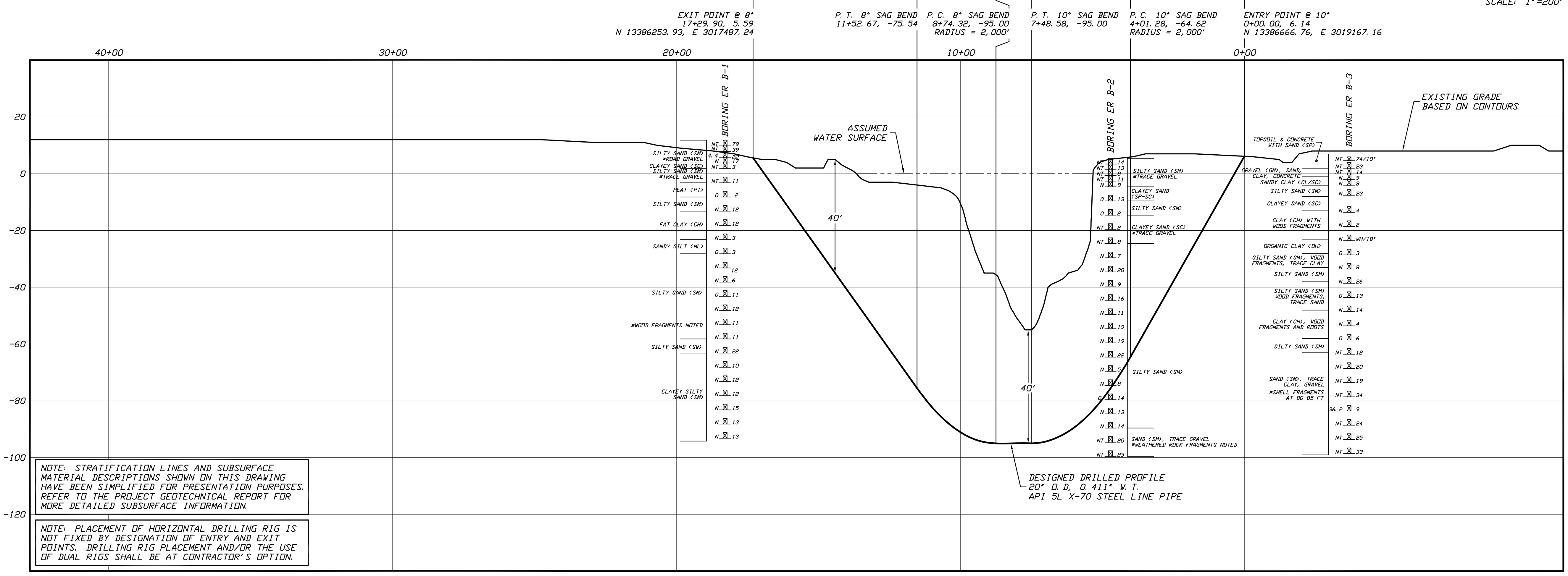
**Supporting Information**

- 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

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PILOT HOLE TOLERANCES

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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. |
|---|---|---|---|---|---|

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PROJECT NO.
Dominion\1508

MILE POST
AP3-082

| 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 | |

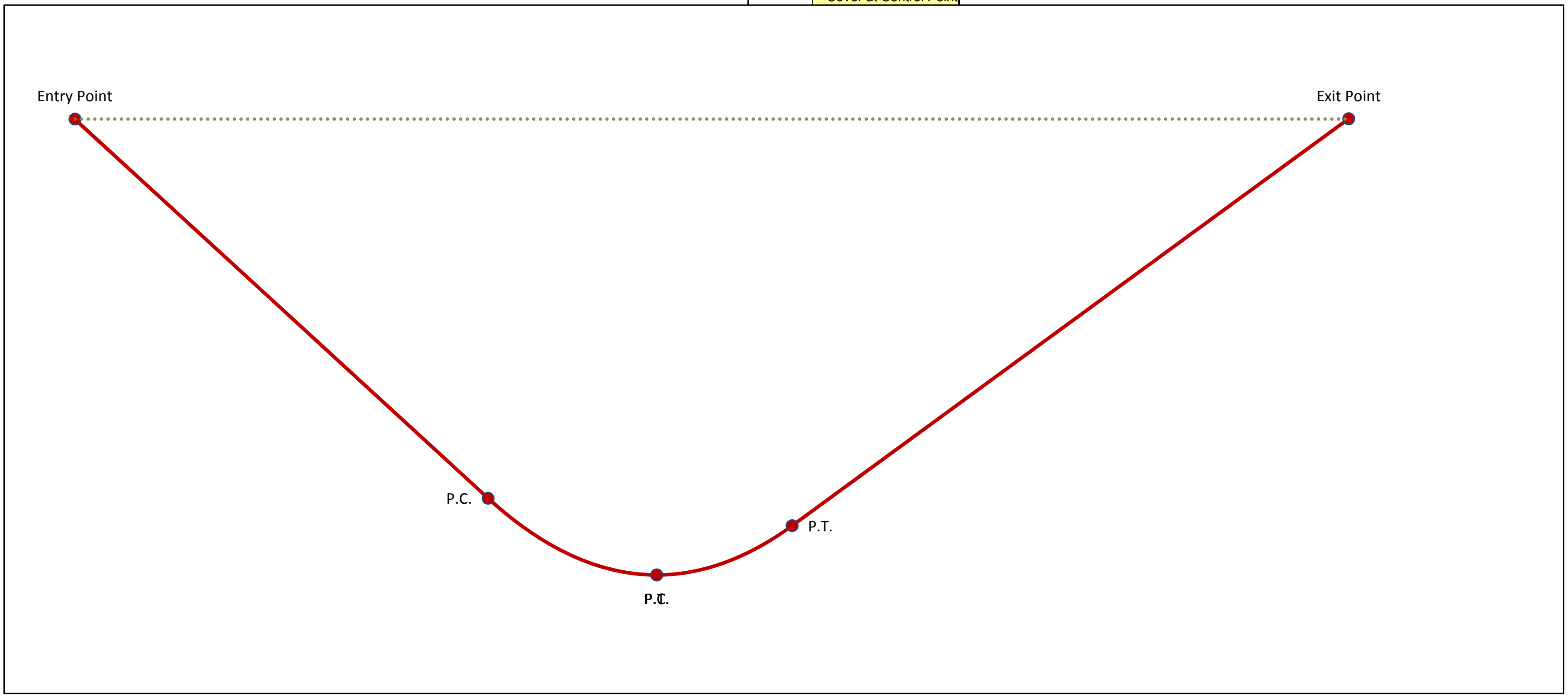
## Elizabeth River R0 Installation Stress Analysis (worst-case).xlsm

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

| | | 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 |
|---|---|



# Elizabeth River R0 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 = | 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 μ cosθ = | 25,485 | lb |
| Fluidic Drag = 12 π D L $C_d$ = | 14,721 | lb |
| Axial Segment Weight = $W_e$ L sinθ = | 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(α/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) - $W_e$ cosθ (Y/144)] / (X / 12) | 23,611 | lb |
| Bending Frictional Drag = 2 μ N = | 14,167 | 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 =** | **19,164** | **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 μ = | 1 | 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 =** | **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

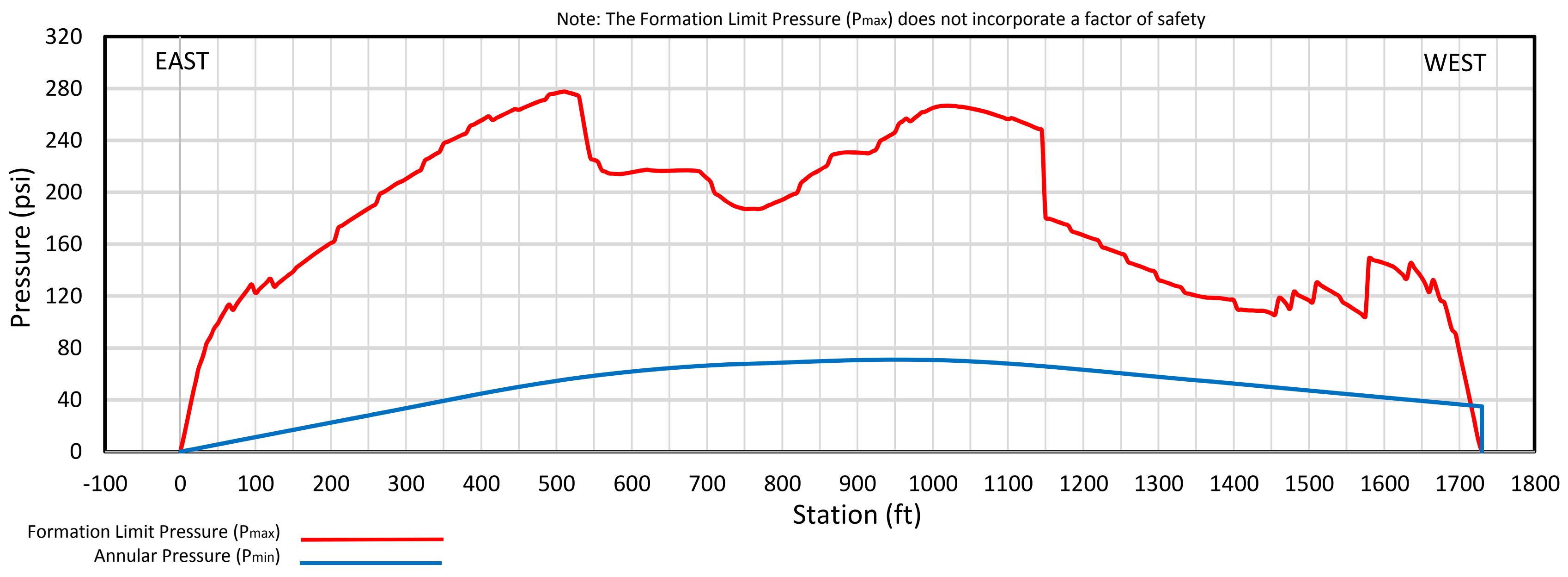
Axial Segment Weight = $W_e L \sin\theta$ = -11,120 lb

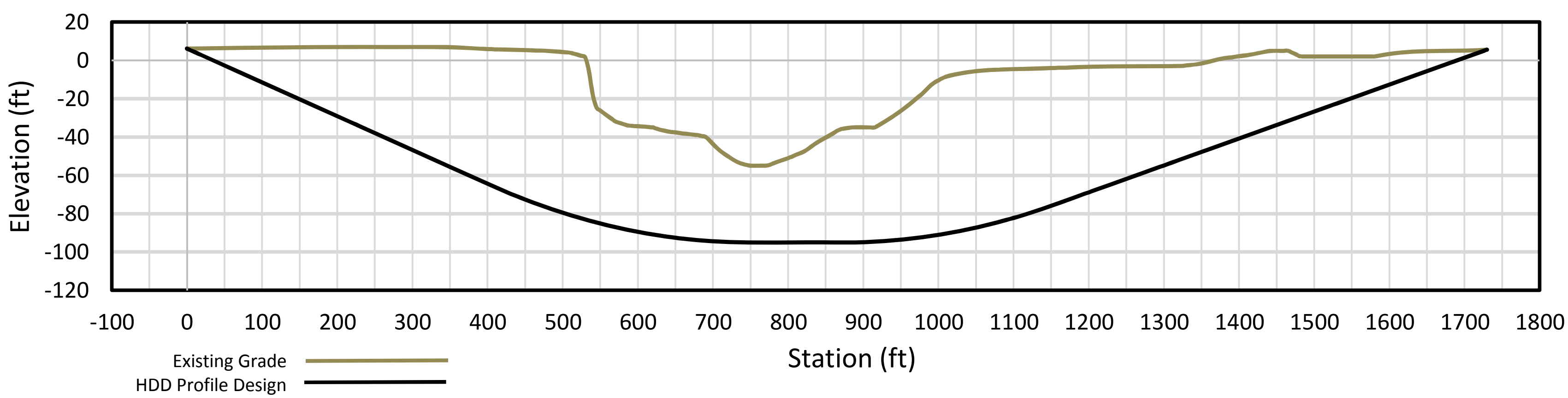
Negative value indicates axial weight applied in direction of installation

**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 |




J.D.Hair&Associates, Inc.

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

Date: 6/16/2015 Revision: 0