MOTT MACDONALD

PennEast PIPELINE

HDD Design Report
Delaware River HDD Crossing

PennEast Pipeline Project

December 17, 2018

PennEast Pipeline Project
353754-MM-EN-CO-057 RevD

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1 Introduction

Mott MacDonald has prepared this HDD design report at the request of PennEast Pipeline Company, LLC (PennEast), for their proposed HDD crossing of the Delaware River, part of the larger PennEast Pipeline Project. The proposed Project consists of 115 miles of 36-inch diameter (NPS 36) high pressure, natural gas pipeline from Luzerne County, Pennsylvania to Mercer County, New Jersey.

Specifically, this report summarizes Mott MacDonald's evaluation of the design elements and risk discussions (as determined in the information provided), and presents recommendations for enhancing the success of the Delaware River HDD Crossing.

The drawings and design elements have been prepared and evaluated with the aid of a completed geotechnical subsurface investigation performed by Mott MacDonald, and laboratory assessment and testing analysis completed by Craig Test Boring Co., Inc (CTB). The soil and rock samples were obtained during the geotechnical investigation program, and sent to CTB laboratory for testing. Additionally, a geophysical investigation was completed by Hager-Richter Geoscience, Inc. (Hager-Richter), to supplement the geotechnical borings. Discussions on the geotechnical aspects in this design report have been extracted from the information presented in the site specific Geological Data Report (GDR).

1.1 Crossing Description

The proposed plan and profile is provided in Appendix A. The horizontal length of the proposed HDD is approximately 2,836 feet (with a true length of approximately 2,863 feet). The eastern HDD entry point is located approximately 125 feet east of County Road 627, and the western HDD entry point is located approximately 950 feet west of Pennsylvania State Route 611. An elevation difference of approximately 2 feet exists between the east and west HDD entry locations, with the east HDD entry location being excavated to the lower elevation. To provide sufficient depth beneath the County Road 627, a small excavation is proposed to lower the starting elevation of the HDD bore. This excavation is also necessary to allow for the HDD installation to avoid bedrock materials with lower rock quality designations (RQD) below the horizontal tangent of the HDD profile.

The pipe staging area for the drag section is located on the west side of the crossing. It is envisioned that, due to limited workspace, this pipe string will be fabricated into three sections prior to pullback operations.

This crossing has been designed using the Drill and Intersect method to complete the pilot bore phase of the installation. To accommodate the drill and intersect method, a flat horizontal tangent of 456 feet has been incorporated into the design profile between STA 4097+59 and 4102+15.

2 Anticipated Geotechnical Conditions

The following discussions on the anticipated geotechnical conditions are based on the information provided by the site-specific geotechnical and geophysical investigation programs. Borehole logs for completed borings to support the design of the crossings by HDD methods are provided in Appendix B.

The objective of these discussions is to provide an explanation of the various construction risks identified in subsequent sections related to the geotechnical conditions.

2.1 Subsurface Investigations

A total of six (6) borings, designated as B-DEL-1, B-31, B-32, B-32A, B-33, and B-34, were completed as part of the geotechnical investigation program to support the evaluation and design of the Delaware River HDD Crossing. Due to difficult drilling conditions, Boring B-32 was abandoned and borehole B-32A was added to the program, offset approximately 10 feet from Boring B-32. More detailed discussions can be found in the site-specific GDR.

A geophysical investigation program was also completed to support the design of the Delaware River HDD Crossing and obtain geotechnical information between the borehole locations. Electrical Resistivity Imaging (ERI) was used to determine the depth and orientation of the bedrock surface beneath the Delaware River, and to determine the location and directionality of an existing thrust fault within the Delaware River. Additionally, a boring designated as B-HR-4 was completed to evaluate the presence of a potential Karst feature located approximately 1,200 feet northwest of B-DEL-1. This boring indicated a 5.0-foot thick Karst feature between an elevation of 212 and 217 feet (between depths of 30 and 35 feet below ground surface). More detailed discussions can be found in the GDR.

A summary of the subsurface materials encountered at the site is provided below.

2.2 Geotechnical Observations

The HDD entry location is anticipated to encounter soils over carbonate rock of the Allentown formation. The drill will then transition into the carbonate Leitsville formation before crossing beneath the river. At some point beneath the river the alignment is likely to encounter the Hardystone Quartzite before entering into Precambrian granite and gneiss materials for the southern section of the drill.

The elevation of rock head is seen to be highly variable with deep soils seen in B-32A and B-34.

2.2.1 Geotechnical Observations on the Pennsylvania (west) side

The HDD installation on the Pennsylvania side of the Delaware River is anticipated to encounter soils overlying bedrock materials. Based on Boring B-DEL-1, the site soils are anticipated to include the following:

- Very loose silty sand from the ground surface to a depth of 3.5 feet (from Elev. 166 to 162.5 feet).
- Medium stiff clay with sand to a depth of 8.5 feet (to Elev. 157.5 feet).
- Medium dense sand with gravel to a depth of 13.5 feet (to Elev. 152.5 feet).
- Very dense silty gravel with sand to a depth of 23.5 feet (to Elev. 142.5 feet). Grain size distribution tests indicate gravel percentages up to 64 percent of the soil particles.
- Medium dense silty brown sand with gravel to a depth of 28.5 feet (to Elev. 137.5 feet).
- Very dense, weathered dolomite fragments to a depth of 40.5 feet (to Elev. 125.5 feet). Area of no recovery from depth of 35 feet to 37 feet.

- Highly weathered to moderately weathered, weak to medium strong dolomite to a depth of 52 feet (to Elev. 114 feet). Highly fractured zones encountered near the top of the layer. RQD values ranged between 10 and 40 percent (avg. 25 percent). Recovery values ranged between 60 and 83 percent (avg. 72 percent).
- Slightly weathered, weak siltstone to a depth of 56.9 feet (to Elev. 109.1 feet). RQD value of 43 percent and recovery value of 93 percent.
- Highly weathered to moderately weathered, weak dolomite to a depth of 110 feet (to Elev. 56 feet). RQD values ranged between 0 and 73 percent (avg. 33 percent). Recovery values ranged between 47 and 100 percent (avg. 82 percent).
- Slightly weathered, medium strong dolomite to a termination depth of 120 feet (to Elev. 46 feet). RQD values ranged between 70 and 77 percent (avg. 74 percent) and recovery values of 100 percent.

In the vicinity of Boring B-31, the geotechnical materials are anticipated to include the following:

- Soft clayey silt with sand from the ground surface to a depth of 3.5 feet (from Elev. 152 to 148.5 feet).
- Loose sand to a depth of 8.5 feet (to Elev. 143.5 feet).
- Loose gravel with sand to a depth of 13.5 feet (to Elev. 138.5 feet).
- Very dense gravel with sand to a depth of 18.5 feet (to Elev. 133.5 feet).
- Medium dense silty gravel with sand to a depth of 23.5 feet (to Elev. 128.5 feet).
- Dense clayey sand with gravel to a depth of 28.5 feet (to Elev. 123.5 feet).
- Dense gravel with sand to a depth of 33.5 feet (to Elev. 118.5 feet).
- Very dense silty sand with gravel to a depth of 40 feet (to Elev. 112 feet).
- Moderately weathered to slightly weathered, weak to medium strong dolomite to a depth of 105 feet (to Elev. 47 feet). RQD values ranged between 38 and 100 percent (avg. 68 percent). Recovery values ranged between 88 and 100 percent (avg. 98 percent).
- Highly weathered to moderately weathered, very weak to weak dolomite to a depth of 135 feet (to Elev. 17 feet). Encountered many planar fragments at 75 – 80 degree angles near the bottom of the layer. RQD values ranged between 0 and 75 percent (avg. 31 percent). Recovery values ranged between 58 and 100 percent (avg. 75 percent).
- Moderately weathered, very weak siltstone to a depth of 140 feet (to Elev. 12 feet). Encountered planar fragments at 75 – 80 degree angles. RQD value of 17 percent and recovery value of 100 percent.
- Highly weathered to slightly weathered, very weak to weak dolomite to a termination depth of 165 feet (to Elev. -13 feet). Encountered few areas of missing rock and highly fractured zones. RQD values ranged between 10 and 32 percent (avg. 16 percent). Recovery values ranged between 22 and 100 percent (avg. 62 percent).

In the vicinity of Boring B-32, the geotechnical materials are anticipated to include the following:

- Fill described as loose to medium dense gravel from the ground surface to a depth of 18.5 feet (from Elev. 150 to 131.5 feet).
- Loose sand with silt to a depth of 23.5 feet (to Elev. 126.5 feet).
- Medium dense gravel to a depth of 31 feet (to Elev. 119 feet).
- Medium dense to very dense sand with silt and gravel to a depth of 47.5 feet (to Elev. 102.5 feet).
- Very dense gravelly sand with silt to a depth of 53.5 feet (to Elev. 96.5 feet).
- Medium stiff clayey silt to a depth of 63.5 feet (to Elev. 86.5 feet).
- Medium dense to very dense gravelly sand with silt to a depth of 73.5 feet (to Elev. 76.5 feet).
- Very dense rock fragments to a depth of 78.5 feet (to Elev. 71.5 feet). Encountered 18-inch boulder within layer.

- Stiff to very stiff clayey silt with rock fragments to a depth of 93.5 feet (to Elev. 56.5 feet).
- Medium dense decomposed rock fragments with silty sand to a termination depth of 97 feet (to Elev. 53 feet).

In the vicinity of Boring B-32A, the geotechnical materials are anticipated to include the following:

- Fill described as loose to medium dense gravel from the ground surface to a depth of 32.5 feet (from Elev. 150 to 118 feet).
- Dense gravelly sand with silt to a depth of 45 feet (to Elev. 105 feet).
- Very stiff clayey silt with sand and gravel to a depth of 85 feet (to Elev. 65 feet).
- Medium dense to very dense decomposed rock fragments to a depth of 103.5 feet (to Elev. 46.5 feet).
- Hard to very stiff clayey silt with gravel to a depth of 135 feet (to Elev. 15 feet).
- Slightly weathered, weak to medium strong dolomite with chert to a termination depth of 150 feet (to Elev. 0 feet). RQD values ranged between 23 and 88 percent (avg. 60 percent). Recovery values ranged between 42 and 92 percent (avg. 72 percent).

Along the proposed HDD alignment, the bedrock on the west side of the Delaware River appears to be of very poor to very good quality. RQD values range from 0 to 100 percent with an average value of 44.3 percent. The core recovery values on the west side ranged from 22 to 100 percent with an average value of 83.7 percent.

Laboratory testing of the Dolomite from boring B-31 indicate a Uniaxial Compressive Strength (UCS) range from 6,260 to 6,395 psi with an average of 6,328 psi. The axial point load UCS ranged from 11,593 to 20,931 psi with an average of 18,069 psi. The diametral point load UCS from boring B-31 and B-Del-1 ranged from 1,524 to 14,341 psi with an average of 7,536 psi. The splitting tensile strength ranged from 1,191 psi to 1,866 psi with an average of 1,497 psi.

Laboratory testing of the gneiss from boring B-33 indicate a UCS range from 7,101 to 44,290 psi with an average of 17,551 psi. The axial point load UCS ranged from 23,284 to 36,335 psi with an average of 30,851 psi. The diametral point load UCS ranged from 12,010 to 39,543 psi with an average of 31,577 psi. The splitting tensile strength ranged from 2,155 psi to 2,907 psi with an average of 2,561 psi.

2.2.2 Geotechnical Observations on New Jersey (east) side

The HDD installation on the New Jersey side of the Delaware River is anticipated to encounter soils overlying bedrock materials. Based on Boring B-34, the site soils are anticipated to include the following:

- Topsoil to a depth of 1 feet (from Elev. 160 to 159 feet).
- Soft to medium stiff silt to a depth of 8.5 feet (to Elev. 151.5 feet)
- Medium dense sand with trace silt to a depth of 21 feet (to Elev. 139 feet)
- Medium stiff silt to a depth of 26.5 feet (to Elev. 133.5 feet)
- Weathered Quartzite fragments (gravel) to a depth of 35 feet (to Elev. 125 feet). A possible boulder was noted between 30 and 35 feet.
- Medium dense sand with trace silt to a depth of 36 feet (to Elev. 124 feet)
- Medium dense silty gravel with trace sand to a depth of 38.5 feet (to Elev. 121.5 feet)
- Hard sandy silt with gravel to a depth of 46 feet (to Elev. 114 feet).
- Decomposed rock fragments were noted from 41 - 43.5 feet.
- Various thicknesses of dense sand, hard clay, stiff silt, hard gravelly silt to the termination depth of 110 feet (to Elev. 50 feet). Gravels were noted to be up to 18 percent of the soil, based on grain size distribution tests.

Based on Boring B-33, the site soils are anticipated to include the following:

- Topsoil to a depth of 0.5 feet (from Elev. 150 to 149.5 feet).
- Very dense gravel with silt and sand to a depth of 4 feet (to Elev. 146.0 feet).
- Slightly weathered to fresh and strong to very strong Granitic Gneiss to a depth of 112 feet (to Elev. 38 feet). RQD values ranging between 15 and 100 percent (average 78 percent). Recovery values ranging between 44 and 100 percent (average 93 percent).
- Fresh and medium strong to strong Granitic Gneiss to a termination depth of 165 feet (to Elev. -15 feet). RQD values ranging between 50 and 98 percent (average 80 percent). Recovery values ranging between 88 and 100 percent (average 97 percent).

The bedrock materials are anticipated to include predominantly slightly fresh, medium strong to strong granitic gneiss, based on information collected from Boring B-33. The granitic gneiss appears to be of very poor to good quality, with RQD values ranging from 15 to 100 percent, and an average value of 78.3 percent. The core recovery values on the east side ranged from 44 to 100 percent, with an average value of 94.1 percent.

2.3 Geophysical Observations

A geophysical survey was conducted by Hager-Richter between July 26 and August 11, 2016, to collect ERI data across the Delaware River. It was originally planned to collect data along transects perpendicular to the river. However, the swift current and depth of the river prohibited effectively laying a straight line across the river. Therefore, the survey data was collected across eight (8) transects parallel to the flow of the river and the supposed fault line.

Interpretations of the survey results by Hager-Richter appear to indicate that the thrust fault exists just west of the centerline of the Delaware River at the crossing location. The bedrock surface appears to be relatively level beginning at approximate Elev. 100. Resistivity patterns indicate different materials on either side of the apparent thrust fault consistent with the materials encountered in the geotechnical borings.

3 Delaware River Crossing

3.1 HDD Bore Geometry and Alignment Considerations

3.1.1 Entry and Exit Angles

HDD operations are typically designed with entry angles between 8° and 16°, although steeper entry angles have been used where insufficient setback distance or steeply sloping ground exists for a given alignment. Exit angles are typically lower than the entry angle, as consideration must be given to the pipe diameter, the equipment necessary to transition the pipe into the bore, and the stresses induced as the pipe is forced over the break-over location as it enters the HDD bore.

For the Delaware River Crossing, the east entry and west entry angles have been set at 13° and 12°, respectively, relative to the horizontal.

3.1.2 Vertical and Horizontal Curvature

Vertical curvature is inherent to all HDD installations. The need for horizontal curvature is dependent on the restrictions specific to a single crossing. While horizontal curvature is feasible, it greatly increases the complexity of the scope of design and construction when required. It also increases the stress, and therefore the risk, to the pipe and the overall installation. Steering in both planes is not a standard industry practice, and can lead to complex radii and a reduction in the overall bending radius that the pipe will be subjected to. A straight alignment has been selected for this HDD crossing, thereby eliminating the risks associated with horizontal curvature.

The proposed vertical curve radius of 4,300 feet shown in Appendix A is slightly higher than the HDD industry standard of 1,200 times the 36-inch outer diameter of the pipe. This radius has been taken as the design radius for the crossing to avoid a section of bedrock materials with low RQD ratings beneath the horizontal section of the bore.

3.1.3 HDD Installation Depth

The depth of cover for a given HDD installation is dependent on several factors, including but not limited to:

- The anticipated geotechnical materials,
- The presence of preferential flow pathways,
- The design bending radius,
- The presence of existing utilities and/or structures, and
- Installation length.

Of these, the most important factors are the properties of the overlying geotechnical material, and the resistance these materials provide against the required installation-induced bore fluid pressures necessary to remove the cuttings.

Another important factor in establishing the proper installation depth is the ability to maintain bore stability over the course of the installation. This is accomplished by placing the HDD bore through geotechnical materials that are favorable to HDD operations.

As shown in Appendix A, the minimum depth of cover beneath the bottom of the Delaware River is approximately 114 feet.

3.1.4 Bore Diameter

The diameter of the HDD bore needs to be greater than the outer diameter of the pipe. This larger bore is required to facilitate the flow of drilling fluids around the pipe, reduce the frictional force acting on the pipe as it is installed, and to help the pipe negotiate curves in the alignment.

The acceptable industry standard for the final bore diameter is generally 1.5 times larger than the pipe outer diameter for small diameter pipe (less than 24 inches), and 12 inches larger than the outer diameter for large diameter installations. However, the actual diameter of the bore is typically dependent upon the geotechnical conditions and the required bore geometry. Hence, it may be necessary to increase the diameter beyond the typical industry standard to facilitate the installation process. To increase the likelihood of success, it is highly recommended that the final bore diameter be selected by the HDD Contractor, based on their experiences with similar geotechnical materials, pipe diameters, and installation lengths, and to suit their means and methods.

Based on typical HDD industry standards, the anticipated bore diameter for the NPS 36 pipe is 48 inches.

3.2 Line and Grade Accuracy

The horizontal and vertical position of the bottom hole assembly is tracked using a downhole survey tool, consisting of a probe that utilizes Earth's gravitational and magnetic fields. These tools have a nominal accuracy of approximately:

- Inclination: ± 0.1°
- Azimuth: ± 0.3° to 0.5°
- Tool-face: ± 0.1°

The accuracy of these tools can be enhanced by using a surface wire/coil loop established over the alignment. Inducing an electrical current through the wire creates a localized magnetic field that the probe can then use to determine its location relative to the surveyed coil and magnetic field.

These enhanced guidance systems include TruTracker and ParaTrack systems. The TruTracker guidance system relies on a closed loop surveyed wire layout that is at least as wide as the depth of the HDD installation. For highways and water body crossings, individual coils are often established on each side of the crossing feature. A ParaTrack system relies on a single wire placed directly over the HDD alignment centerline, with a return wire offset several hundred feet from the alignment to form a closed loop system. When augmented with a surface coil, the lateral and vertical position of the survey probe is plus or minus two (2) percent of the depth separating the location of the probe and the surface coil. Greater inaccuracies may occur if site constraints prevent the use of an energized wire grid on the ground surface.

Fiber-optic gyroscopic guidance systems have also been used to track downhole tooling. This type of system relies on an inertial measurement unit to calculate the position of the bottom hole assembly and is not affected by magnetic interference. This tool is very effective in accurately locating the surface tool position during pilot bore drilling.

With all of these methods, survey readings can be taken at the end of each drilled joint or every half of a joint. Stand-alone surveys can be completed where the surface coils are established. Here the inaccuracy is a function of the specific depth of cover at the location in question. Where the surface coils cannot be established, such as across a highway or beneath a river, the position of the bottom hole assembly is determined based on the calculated position of the previous measurement. In this manner, any inaccuracy built into the measured position is additive as the drill length increases. However, as the bottom hole assembly re-encounters the surface coil on the opposite side of the highway or river, the inaccuracy is once again a function of a stand-alone measurement based on the specific depth of cover at the location in question.

Mott MacDonald recommends the use of a gyroscopic guidance system for the Delaware River crossing to mitigate concerns associated with laying a surface coil along the proposed alignment and across the waterway. If a ParaTrack system is proposed by the HDD Contractor, the HDD Contractor must assure adequate coverage of surveying with no gaps in coverage with a surface coil and/or beacon.

3.3 Required Workspace and Staging Areas

For the proposed HDD installation, the staging area for the east side of the crossing has been established at 230 feet by 280 feet, and the staging area for the west side of the crossing has been established at 250 feet by 250 feet (to accommodate use of the drill and intersect strategy). This area is required to stage equipment necessary for the installation, which includes the drill rig, stacks of drill pipe, operator control cabin, tooling trailers, crane or excavator, separation plant, mud tanks, mud pumps, Baker storage tanks, office trailer, and support trailers.

In addition to the entry and exit staging areas, a staging area of 75 feet wide by the length of the pipe string (greater width is required where multiple drag sections are required) is also required for welding sections of the pipe string, and preferably the entire pipe string when possible, prior to installation. The proposed staging area for the drag section is located on the west side of the crossing. The available length of the staging area is approximately 1,325 feet, resulting in the need for fabricating the pipe string into three (3) drag sections and the need for two (2) intermediate welds during pullback operations. The HDD Contractor will need to minimize delays during intermediate welding operations. To accommodate fabricating three (3) pipe strings, the staging width has been increased to 125 feet.

The temporary work space established for the Delaware River Crossing is sufficient for HDD operations.

3.4 Requirement for Temporary Surface Casing

During the geotechnical investigation, layers of gravel and isolated boulders were observed extending to various depths on both sides of the Delaware River. The gravels were observed to a depth of approximately 23.5 feet below ground surface on the west side of the crossing. These soils represent a significant risk to the overall bore stability, raveling of gravel into the bore, potential damage to the pipe string, and increased pullback loads/stresses. To support these soils and mitigate the risks associated with such deposits, a temporary conductor casing is recommended on the west side of the HDD installation. The approximate casing length required on the west side of the proposed HDD installation is 120 to 140 feet, depending on where the soil/bedrock interface is encountered with the HDD alignment and the extent of the decomposed dolomite layer above the soil/bedrock interface.

Soils containing gravels were also noted on the east side of the river to a depth of approximately 38 feet below ground surface near Boring B-34. To mitigate the presence of this material, approximately 200 feet of casing pipe is required on this side of the HDD installation.

The minimum conductor casing diameter is recommended to be 56 inches to allow for the free passage of the 48-inch reamer assembly. Any required casing pipe shall be removed once pullback operations have been completed.

The requirement for temporary conductor casings on each end of the proposed HDD installation will require a drill and intersect installation strategy for this crossing. This method involves drilling independent pilot bores from each side of the installation meeting within a target intersection location along the alignment. For the proposed profile, the intersection location is envisioned to occur along the 456-foot long horizontal tangent between STA 4097+59 and 4102+15.

3.5 Drilling Fluid Make-Up Water and Source

HDD operations require a continuous source of water to support construction activities. It is typical for contractors to make use of an onsite source or have water delivered from a nearby source. In each case, the contractor should verify that the water source is suitable for HDD operations or treat it (filtration, pH, etc.) so that it is suitable for use.

For the proposed crossing, the Delaware River has been identified as a potential source of fresh water to support construction activities. Estimates of fresh water requirements is a function of maintaining drilling fluid flow within the bore during the HDD installation, and water requirements to adjust for hole volume, minor losses to processed spoil and surrounding geotechnical materials, wash water, etc. Daily fresh water usage typically ranges from 2,650 to 5,300 ft^3, depending on the process and storage capabilities of the Contractor.

Total fresh water requirements can be estimated as a function of the final reamed diameter. Factors of between two (2) and seven (7) times the final reamed diameter have been used to estimate the fresh water requirements necessary to support HDD operations. Based on a factor of five (5), the estimated total water usage (assuming no loss in circulation) is approximately 1,500,000 gallons (200,000 ft^3). This volume estimate assumes good HDD industry practices and procedures are followed, and that no significant fluid losses occur during the installation. This volume also includes fresh water required for buoyancy control during the HDD installation (estimated at approximately 100,000 gallons).

3.6 Disposal of Excess Drilling Fluid and Processed Spoils

Excess drilling fluids and processed spoils will need to be disposed of during the installation. The direct area around the HDD is not expected to be suitable for permanent disposal of drilling fluid or processed solids (based on local, state, and federal regulations). Local temporary storage will be required either in above ground tanks or a lined burrow pit. A suitable offsite disposal site should be located for disposal of drilling fluid and processed spoil per the local, state, and federal guidelines.

Disposal volumes of excess drilling fluid and spoil are estimated at approximately 727,225 gallons (3,600 yd^3) and 50,860 ft^3 (1,885 yd^3) respectively. During pullback operations, the estimated displaced fluid volume is approximately 149,800 gallons (750 yd^3).

3.7 Schedule

The duration of the HDD installation is conservatively estimated to take a total of 161 shifts (Table 1). This estimate is based on a 12-hour shift, regardless of whether 24-hour operations are conducted to complete the crossing. No provisions have been included for pad construction and erection and tear-down of a shelter (if used) in these durations. In addition, no contingency has been provided for weather or more difficult drilling conditions.

Table 1: Estimated schedule duration for the HDD Crossing

Activity	Duration (shifts)
Mobilization	3
Rig Up / Equipment Setup	6
Casing Installation	15
Pilot Bore Drilling	30
Reaming	94
Swab Pass	2
Product Pip Pullback	3
Casing Removal	3
Rig Down and Demobilization	5
Total Number of Shifts	**161**

4 HDD Engineering Evaluation

4.1 Pipeline Properties

The pipeline properties used for the evaluation of the Delaware River Crossing have been provided by PennEast, and are summarized in Table 2 below:

Table 2: Pipeline properties and input parameters for the HDD evaluation

Evaluation Parameter	Value
Pipe Size	NPS 36
Outer Diameter	36 in
Wall Thickness	0.762 in
Pipe Grade	X-70
Maximum Allowable Operating Pressure	1,480 psig
Minimum Operating Temperature	45°F
Maximum Operating Temperature	120°F
Poisson's Ratio	0.30
Elastic Modulus	29,200,000 psi
Coefficient of Thermal Expansion	6.5 x 10^{-6} in/in/°F
Design Factor	0.5

4.2 Design and Minimum Allowable Bend Radii

The minimum ultimate bend radius is a function of the maximum allowable operating pressure, pipe diameter, wall thickness, design factor, location factor, and specified minimum yield strength of the pipe material. Determination of the ultimate minimum bend radius is based on determining the hoop and longitudinal stresses under operating pressure and then determining the available magnitude of stress that the product pipe can accommodate in an alignment bend/curve.

The minimum ultimate bending radius evaluation is completed in accordance with:

- ASCE Manual of Practice No. 108 Pipeline Design for Installation by Horizontal Directional Drilling
- 49 CFR 192 Transportation of Natural and Other Gas by Pipeline- Minimum Federal Safety Standards
- ASME B31.8 Gas Transmission Distribution and Piping Systems
- ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

Using the pipe properties presented in Table 2, the ultimate minimum bending radius is calculated for the pipe and pressure conditions. This radius represents the lowest radius that could be drilled without overstressing the pipe for the identified pipe properties and in-service loading. Based on the pipe properties provided in Table 2 and a design factor of 0.5, the ultimate minimum bending radius is approximately 2,500 feet.

The minimum allowable bending radius is the minimum radius that the HDD contractor is permitted to drill during their pilot bore to maintain the design alignment and profile. This radius is established above the calculated ultimate minimum bending radius to not overstress the pipe during the HDD installation process, and sufficiently below the design radius provided on the construction drawings. Based on an ultimate minimum bending radius of 2,500 feet, the minimum allowable bending radius has been established at 2,600 feet.

The design radius is the radius selected to develop the HDD plan and profile. This radius is greater than the minimum allowable bending radius given to the HDD contractor to complete the construction of the crossing. The design bending radius for developing the Delaware River profile has been established at 4,300 feet, which is slightly lower than the HDD industry standard of 1,200 times the outer diameter of the NPS 36 pipe.

4.3 Operating Stress Evaluation

Evaluation of operating loads for pipelines installed by HDD methods is generally similar to the evaluation for pipelines installed by open-cut construction methods. The main difference between the two scenarios is that the condition of elastic bending (as a result of the curved HDD alignment profile) must be considered for the HDD installation. Elastic bending stresses occur as the pipe takes on the final shape of the HDD bore. As a rule, the bending stresses induced are not a critical stress condition on their own, but must be considered in a combined loading condition with other stress conditions such as hoop stress and longitudinal stress.

An operating stress evaluation has been completed in compliance with the American Society of Mechanical Engineers B31.4 and B31.8. The input parameters for this analysis are provided in Table 2. The results of the evaluation are provided in Table 3 below, and are based on the minimum allowable bending radius of 2,600 feet (based on the allowable bend radius provided to the HDD contractor). As observed in Table 3, the operating stresses are below the maximum allowable limits. Hence, the pipe properties (wall thickness and grade) are sufficient to meet the operating stresses within the HDD alignment.

Table 3: Summary of operating stress evaluation

Stress Condition	Estimated Stress (psi)	Percent of SMYS[1] (%)	Maximum Allowable Percent of SMYS[1] (%)
Longitudinal Bending Stress	16,846	24.1	--
Hoop Stress	34,961	49.9	50[2]
Longitudinal Tensile Stress from Hoop Stress	10,488	15.0	--
Longitudinal Stress from Thermal Expansion	-14,235	20.3	90[3]
Net Longitudinal Stress (Compression Side of the Curve)	-20,593	29.4	90[4]
Net Longitudinal Stress (Tension Side of the Curve)	13,099	18.7	90[4]
Maximum Shear Stress	27,777	39.7	45
Combined Biaxial Stress	55,553	79.4	90[4]

Notes: [1] Specified Minimum Yield Stress
[2] Limited by design factor
[3] Limited by ASME B31.4
[4] Limited by ASME B31.8

4.4 HDD Installation Load and Stress Evaluation

A total of six (6) pull load evaluations were completed for the HDD bore profile. These calculations are based on the installation load calculation method provided in American Society of Civil Engineer MREP 108 (2015), and the Pipeline Research Committee at the American Gas Association publication, entitled "Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide."

The pull load evaluation includes assumptions for final bore diameter, soil, and pipe roller friction coefficients, drilling fluid yield point, plastic viscosity, drilling fluid pumping rate, and other installation parameters such as buoyancy control measures (i.e. whether or not the pipe will be filled with water during pullback operations). In addition, the evaluation accounts for the capstan effect induced by curves in the alignment, fluidic drag, buoyancy of the pipe string within the bore, and the weight of the tail string at start-up and throughout the installation process.

Six (6) installation evaluations have been completed to investigate the effects of varying mud weights and buoyancy control measures during the installation of the pipe. The six (6) scenarios evaluated include:

- Case 1: Drilling Fluid Weight — 10 ppg (Specific Gravity of 1.20)
  Pipe — No buoyancy control (pipe empty of water)
- Case 2: Drilling Fluid Weight — 10 ppg (Specific Gravity of 1.20)
  Pipe — Full buoyancy control (pipe full of water)
- Case 3: Drilling Fluid Weight — 11 ppg (Specific Gravity of 1.32)
  Pipe — No buoyancy control (pipe empty of water)
- Case 4: Drilling Fluid Weight — 11 ppg (Specific Gravity of 1.32)
  Pipe — Full buoyancy control (pipe full of water)
- Case 5: Drilling Fluid Weight — 12 ppg (Specific Gravity of 1.44)
  Pipe — No buoyancy control (pipe empty of water)
- Case 6: Drilling Fluid Weight — 12 ppg (Specific Gravity of 1.44)
  Pipe — Full buoyancy control (pipe full of water)

A summary of the maximum anticipated pull load for each case scenario is provided in Table 4 below. Detailed calculations are provided in Appendix C. The anticipated installation loads shown in Table 4 are well below the ultimate allowable load of the pipe of approximately 3,542,953 lbs, based on a tensile stress equivalent to 60 percent of the yield stress for the given wall thickness and pipe grade provided in Table 2. It is important to note the difference in pull loads when buoyancy control measures are implemented and water is added to the pipe during pullback, as the estimated installation loads are typically lower when buoyancy control measures are used. Mott MacDonald recommends the use of buoyancy control measures to lower the overall installation loads and stresses for this installation.

A start-up factor of 1.5 has been applied to the estimated pullback forces to replicate the higher installation loads observed during stoppages and recommencing of pullback operations. This is referred to as the initial start-up pullback force in Table 4.

Table 4: Summary of anticipated pullback loads

Drilling Fluid Weight (ppg)	Product Pipe Buoyancy Condition	Estimated Pullback Force (lbs)	Initial Start-Up Force String 1 (lbs)	Initial Start-Up Force String 2 (lbs)	Initial Start-Up Force String 3 (lbs)
10 (Case 1)	Empty	487,716	18,084	170,415	469,513
10 (Case 2)	Full	278,750	18,084	138,372	277,740
11 (Case 3)	Empty	564,254	18,084	178,335	524,490
11 (Case 4)	Full	232,700	18,084	137,021	250,100
12 (Case 5)	Empty	642,908	18,084	186,256	582,637
12 (Case 6)	Full	210,918	18,084	135,670	222,901

Results of the corresponding installation stresses (based on the design bending radius of 4,300 feet) are summarized in Table 5.

Table 5: Summary of installation stress evaluation

Stress Condition	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Maximum Tensile Stress (Percent of Allowable)	5,782 psi (8.3%)	3,304 psi (4.7%)	6,689 psi (9.6%)	2,965 psi (4.2%)	7,621 psi (10.9%)	2,642 psi (3.8%)
Maximum Bending Stress (Percent of Allowable)	10,116 psi (14.5%)	10,116 psi (14.5%)	10,116 psi (14.5%)	10,116 psi (14.5%)	10,116 psi (14.5%)	10,116 psi (14.5%)
Maximum Hoop Stress (Percent of Allowable)	1,966 psi (2.8%)	326 psi (0.5%)	2,163 psi (3.1%)	523 psi (0.8%)	2,359 psi (3.4%)	719 psi (1.0%)
Maximum Unity Check – Tensile and Bending	0.33	0.28	0.34	0.28	0.36	0.27
Maximum Unity Check – Tensile, Bending, and Hoop	0.17	0.06	0.19	0.06	0.21	0.07

As observed in this Table, the results of the HDD installation stress evaluation are within the allowable limits for all cases.

4.5 Hydraulic Fracture Evaluation

The hydraulic fracture evaluation for this crossing has been completed in general accordance with the Delft Geotechnics Method outlined in Appendix B of the Army Corps of Engineers 1998 Report CPAR-GL-98 and 2002 Report ERDC/GSL TR-02-9 (Guidelines for Installation of Utilities Beneath Corp of Engineers Levees Using Horizontal Directional Drilling). This method is used to estimate the maximum effective pressure (i.e. drilling fluid pressure) that can be induced during an HDD operation within a particular soil horizon. This pressure is then compared with the fluid pressure required to induce slurry flow within the HDD bore to determine the potential for a hydraulic fracture for a given HDD alignment. The required fluid pressure for an HDD installation is governed by the drilling fluid weight (commonly referred to as the mud weight), installation length and depth, and drilling fluid flow properties (plastic viscosity, yield point, etc.).

The hydraulic fracture evaluation method described above and used in the HDD industry was developed for soil installations. Currently, no accepted method is available to model/predict the maximum allowable

drilling fluid pressure within bedrock materials. While bedrock tensile strength and unconfined compressive strength evaluations have been used to estimate the allowable drilling fluid pressure within bedrock materials, these methods tend to provide results that are not considered suitably conservative and greatly over-predict the true maximum allowable drilling fluid pressures. These over-predictions are a result of laboratory testing on sound or high quality bedrock samples that are not representative of the strengths of the weaker bedrock materials that contain natural fractures/joints that are washed out or impacted by the geotechnical coring process. Hence, for bedrock hydraulic fracture evaluation, Mott MacDonald has elected to model the dolomite and gneiss bedrock materials as strong soils. This conservative approach has been used by Mott MacDonald to successfully complete several HDD installations in similar bedrock materials.

The Delft Geotechnics Method assumes a uniform column of soil above any point of interest along the alignment. Where an increased risk of hydraulic fracture is identified, it does not necessarily mean that a hydraulic fracture will occur. A proper HDD execution plan, based on HDD industry standard construction practices, can reduce the risk of a hydraulic fracture from occurring.

In order to complete the hydraulic fracture evaluation, it is necessary to make several assumptions relative to the bore diameter, drilling fluid pumping rate, and drilling fluid properties. Parameters used in Mott MacDonald's evaluation are provided in Table 6 below. These parameters have been selected based on Mott MacDonald's experience in drilling within similar anticipated geotechnical materials.

Table 6: Assumptions used for hydraulic fracture evaluation

Evaluation Parameter	Value
Pilot Bore Diameter	12-¼ in
Drill Pipe Diameter	6-⅝ in
Drilling Fluid Pumping Rate	600 gal/min
Drilling Fluid Weight (Specific Gravity)	11 ppg (1.32)
Yield Point	24 lb./100 ft^2
Plastic Viscosity	16 cP

In addition to the assumptions provided in Table 6, assumptions are also required for the anticipated soil formation(s) and their properties including, but not limited to, geotechnical material strength, unit weight, cohesion, friction angle, and shear modulus. These assumptions are provided in Tables 7 through 11 for the varied subsurface materials that are anticipated for this crossing. For this evaluation, Mott MacDonald assumes that the encountered subsurface material will be similar to that described in Section 2.0, namely, a mixture of silt, sand, and gravel overlying dolomite and gneiss bedrock. For this evaluation, it has also been assumed that the Drill and Intersect method will be used to complete the pilot bore.

Table 7: Material property assumptions for the silt and sand

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	125 lb./ft^3 / 135 lb./ft^3
Effective Cohesion	0 psf
Internal Friction Angle	30°
Young's Modulus	522,136 psf
Poisson's Ratio	0.33

Table 8: Material property assumptions for the silty clay

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	120 lb./ft^3 / 135 lb./ft^3
Effective Cohesion	2,600 psf
Internal Friction Angle	0°
Young's Modulus	730,990 psf
Poisson's Ratio	0.35

Table 9: Material property assumptions for the sand and gravel

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	130 lb./ft^3 / 135 lb./ft^3
Effective Cohesion	0 psf
Internal Friction Angle	31°
Young's Modulus	835,417 psf
Poisson's Ratio	0.33

Table 10: Material property assumptions for the gneiss bedrock

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	135 lb./ft^3 / 140 lb./ft^3
Effective Cohesion	2,000 psf
Internal Friction Angle	28°
Young's Modulus	960,730 psf
Poisson's Ratio	0.33

Table 11: Material property assumptions for the dolomite bedrock

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	130 lb./ft^3 / 135 lb./ft^3
Effective Cohesion	2,000 psf
Internal Friction Angle	28°
Young's Modulus	898,073 psf
Poisson's Ratio	0.33

The results of the preliminary hydraulic fracture evaluation for the proposed crossing are provided in Figure 1 for the pilot bore phase of the installation process. More detailed results are provided in Appendix D. A safety factor has been incorporated into the hydraulic fracture evaluation for the allowable bore pressure within the bedrock, to account for assumptions incorporated into the design and heterogeneity of the geotechnical materials. The graph also displays the total soil/bedrock overburden stress representing the equivalent unit weight of the overlying soil without consideration of any soil strength. Mott MacDonald recommends holding discussions with the HDD contactor if the actual bore pressures trend higher than those values estimated in Appendix D during actual construction, especially if the observed bore pressures spike during the installation.

As shown in the graph, the required bore pressure to facilitate the installation process is well below the allowable bore pressure for the installation.

Once the pilot bore is completed, the hydraulic fracture risk associated with the reaming, swab, and pullback phase of the installation typically decreases, assuming the bore is reamed to its full extent and a subsequent swab pass is completed through the bore prior to installing the pipe. However, it is important to note that although the hydraulic fracture potential is significantly reduced, a hydraulic fracture event may still occur during the reaming pass if the bore becomes plugged or blocked such that the required drilling fluid pressure increases in magnitude to the point where it exceeds the estimated allowable mud pressure for the overlying soils. HDD industry standard construction practices, such as pumping sufficient drilling fluids, maintaining drilling fluid returns, monitoring and maintaining drilling fluid and returning slurry properties, etc., should reduce any potential loss of drilling fluids.

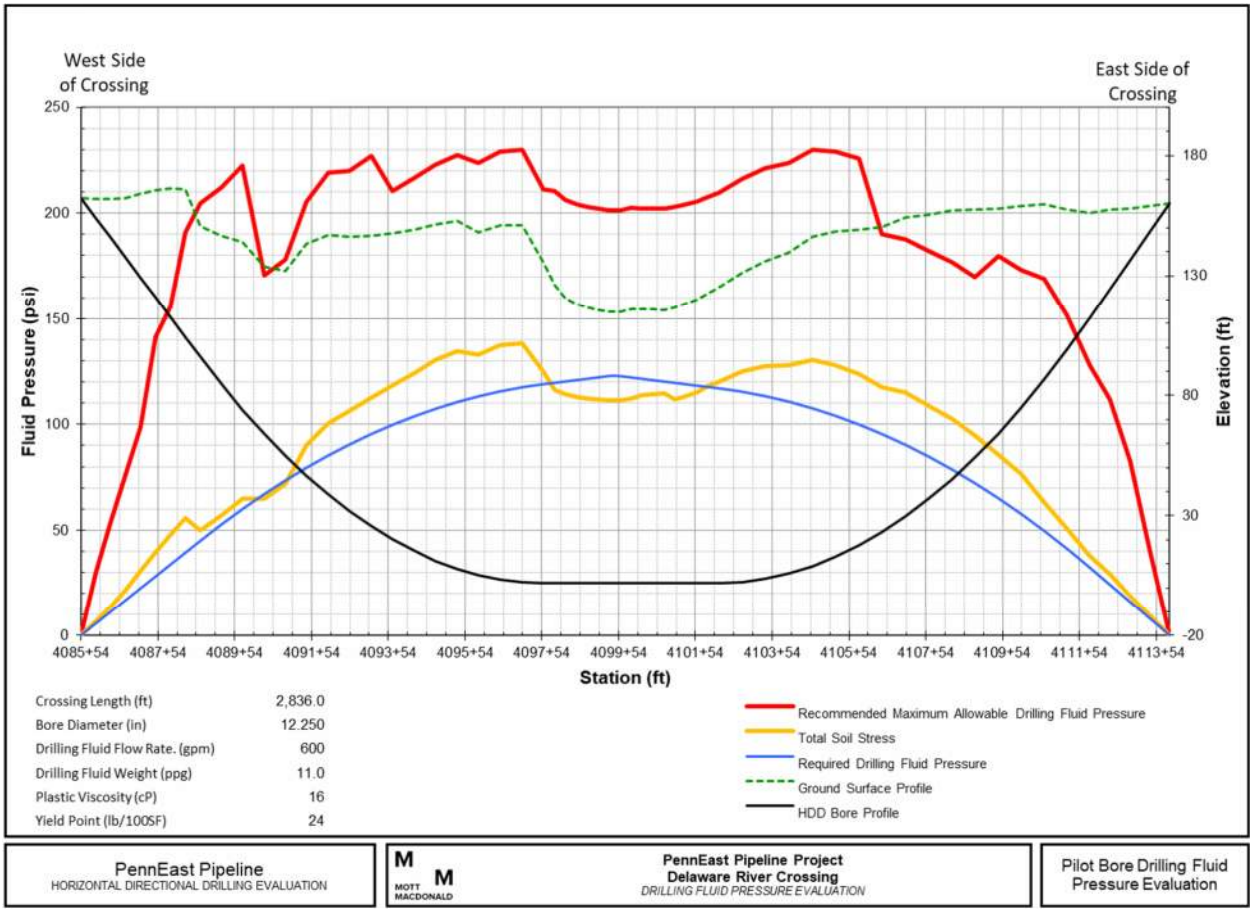


Figure 1: Calculated, recommended, and allowable drilling fluid pressures

5 HDD Risk Discussions

5.1 HDD Risk Characterization

Risk identification and mitigation is paramount to successfully completing the Delaware River Crossing. Discussions of the general risks associated with these crossings are presented below.

5.2 HDD Industry – State of Practice

Mott MacDonald maintains an up-to-date database of successfully completed HDD installations based on pipeline diameter and installation length, as shown in Table 12 below. This database is used to quickly and uniquely assess the achievable installation length for a given pipeline diameter. The green shaded cells indicate the common range of HDD industry experience/capability, and was established with the requirement that several contractors have successfully completed similar installation lengths at the specific diameter. The yellow shaded cells identify the installation lengths and diameters that are considered feasible with an experienced contractor in favorable ground conditions. The red shaded cells are considered to be at the limits of, or beyond, the current state-of-the-practice for the HDD industry.

Table 12: State of the HDD Industry

Product Pipe Diameter	Installation Length												
	1,000 m	1,200 m	1,400 m	1,600 m	1,800 m	2,000 m	2,200 m	2,400 m	2,600 m	2,800 m	3,000 m	3,500 m	3,750 m
	3,281 ft	3,937 ft	4,593 ft	5,249 ft	5,905 ft	6,562 ft	7,218 ft	7,874 ft	8,530 ft	9,186 ft	9,842 ft	11,483 ft	12,303 ft
200 mm (8 inch)	16	9	14	4	5	10	5	0	0	0	1	0	1
250 mm (10 inch)	9	9	4	11	1	0	3	1	0	0	0	0	0
300 mm (12 inch)	14	10	9	4	3	1	0	1	1	0	0	1	0
350 mm (14 inch)	3	5	3	0	1	0	0	0	0	0	0	0	0
400 mm (16 inch)	9	4	4	6	4	1	3	0	0	0	2	0	0
450 mm (18 inch)	0	0	0	2	0	0	0	0	0	0	0	0	1
500 mm (20 inch)	8	10	9	1	0	1	2	1	0	0	0	0	0
600 mm (24 inch)	29	30	9	12	9	4	1	2	0	0	1	0	0
750 mm (30 inch)	23	10	10	11	8	3	1	3	0	0	1	0	0
900 mm (36 inch)	23	21	21	6	2	1	2	0	1	0	0	0	0
1050 mm (42 inch)	29	21	11	5	1	1	0	0	0	0	0	0	0
1200 mm (48 inch)	1	2	1	0	0	0	0	0	0	0	0	0	0

Colour Coding:

- Within typical capabilities of industry. Multiple experienced contractors.
- Zone of limited industry application. Considered feasible with an experienced contractor and favourable ground conditions.
- Exceeds current capabilities of industry. Considered risky even with an experienced contractor and favourable ground conditions.

NOTE: Current State of the HDD Industry shown above is based solely on the reported installation lengths and diameters. Site-specific geotechnical and installation based risks have not been considered in developing this chart.

It is very important to note that the state of the HDD industry shown above includes crossings with similar elevations between HDD entry/exit locations and the crossing feature, good soils/bedrock materials, and adequate staging area for fabricating the pipe string. These completed projects mostly reflect those with low risk profiles (especially for larger and longer HDD installations). As such, when comparing a specific crossing to those completed projects within the HDD industry, the site-specific geotechnical and crossing risks need to be thoroughly considered and evaluated to verify the completed project listings are comparable and deemed to be adequate. If the current proposed crossing carries a low risk profile, then the comparison can serve as a guide to what has been successfully completed within the HDD industry. However, if the current proposed crossing carries a high risk profile, then the comparison to the completed projects may not be applicable.

As observed in Table 12, several HDD installations have been successfully completed at a diameter of NPS 36 for lengths considerably longer than the horizontal installation length of approximately 2,836 feet,

with a true pipe length of approximately 2,863 feet, required for the Delaware River crossing. Therefore, from a constructability standpoint, the Delaware River Crossing falls within the zone of typical experience of what has been accomplished to date within the HDD industry.

5.3 Geotechnical Risk Discussions

Sands, silts, and clays typically present no significant challenge to an HDD installation. These materials are often described as good to excellent materials in terms of feasibility. However, when these soils exist in a soft or loose state, they may not provide sufficient strength to resist the required fluid pressures necessary to complete an HDD installation. Within these materials, the required drilling fluid pressures can exceed their strength, resulting in the formation of a hydraulic fracture through the overlying soils and ponding of drilling fluids at the ground surface. This risk can only be mitigated by placing the HDD bore within more favorable geotechnical materials that provide greater resistance to induced drilling fluid pressures, or through the use of conductor casings to provide an open pathway for drilling fluid flow.

Soils containing gravels and larger size particles (cobbles) range from marginally acceptable to unacceptable in terms of feasibility, depending upon the percentage of gravels by weight and particle size. Only those particles that can be suspended within the drilling fluid can be removed from the bore. Generally speaking, gravel-sized particles less than approximately 0.5 to 0.75 inches can be removed from the bore, provided good HDD practices are followed. Particles greater in size typically cannot be suspended by the drilling fluid and tend to settle out and accumulate along the bottom of the bore. The risks associated with accumulation of larger particles within the bore increase with greater bore diameter, due to the greater exposed soil materials in the crown of a larger bore.

To mitigate risks associated with the anticipated soils, temporary conductor casings have been incorporated into the design of the profile on each end of the installation.

Controlling and maintaining fluid flow within the bore is critical to the success of an HDD installation. Installation risks significantly increase when slurry circulation is not maintained within the HDD bore. The flow of drilling fluid follows the path of least resistance. As long as the bore is located within favorable geotechnical materials at a sufficient installation depth and properly drilled by the HDD contractor, a stable flow pathway can be created between the drill bit and the HDD entry or exit locations, and maintaining drilling fluid flow within the bore should not be an issue. As observed in the hydraulic fracture evaluation, loss of drilling fluids through the overlying soil is not anticipated for this crossing.

The drill and intersect method was chosen to mitigate risks associated with the geotechnical data provided during the investigation, such as drilling through cobbles and gravel at the entry and exit points, and hydraulic fracture through the overburden materials above the alignment. However, drill and intersect method provides an added level of complexity and technical proficiency to the drilling process. Mott MacDonald recommends that an intersection plan be discussed with the contractor and that they demonstrate that they are technically proficient using the drill and intersect method.

Bedrock can be highly variable and can be classified as being excellent to unacceptable with respect to HDD feasibility. Competent bedrock is well suited for HDD as the bore tends to remain open for extended periods of time. However, heavily weathered, jointed, fractured or fissured bedrock can present challenges with respect to bore stability. In fact, poor quality bedrock can present the same challenges as coarse granular (gravel) deposits where fracturing and jointing is extensive and present an unacceptable risk in terms of constructability to an HDD installation. The risk associated with these materials arises from the inability to support and maintain stability within the bore.

This risk increases with RQD ratings below 60 percent. For the Delaware River Crossing, the bedrock exhibits a wide range of ratings, with an average of 64.4 percent overall, and several isolated areas below 60 percent. The areas of lower rock quality are not anticipated to significantly increase risks associated with this installation.

Karst features have been identified within 0.5 miles of the HDD alignment on the Pennsylvania side. The potential for Karst features in dolomite formations should also be considered with respect to drilling fluid management and steering control. These features pose a risk for significant drilling fluid losses and an inability to maintain design line and grade/loss of downhole tooling. As stated earlier, Mott MacDonald recommends that this issue be discussed with the respective HDD contractor and requests that a contingency plan be provided by the contractor to deal with this potential condition if it is encountered.

The strength of the bedrock can impact construction duration, with higher strength leading to more frequent trips out of the bore to replace worn tooling. The laboratory tests completed to date on the dolomite bedrock indicate unconfined compressive strengths ranging from 11,593 to 20,931 psi, with an average value of 18,070 psi. The unconfined compressive strength of the chert bedrock ranged from 23,284 to 39,543 psi, with an average value of 30,677 psi. The unconfined compressive strength of the granitic gneiss bedrock ranged from 31,152 to 33,531 psi, with an average value of 32,093 psi.

High angle fractures were observed throughout the geotechnical borings. The presence of these fractures increases the risk to bore stability, as the vertical and intersecting fracture planes will be less likely to bridge the crown of the bore and maintain an open annular space for fluid flow. Bore collapse that occurs during the pilot bore and reaming phases of the installation can lead to spikes in drilling fluid pressure, lost circulation and hydraulic fracture, increased force on the downhole tooling, decreased steering control, and loss or damage of downhole tooling. A swab pass is recommended to determine the condition of each bore prior to pullback operations. If areas of higher drill rig effort (torque or thrust/pullback) are experienced, the HDD Contractor should complete additional passes with a hole opener to clear the bore of any debris within the bore.

Preferential flow pathways may occur where heavily weathered, jointed, fractured or fissured bedrock exists. If interconnected, preferential flow pathways may exist for drilling fluid losses into the rock mass or upwards towards the ground surface. Fortunately, the presence of the drilling fluid slurry within the bore often is capable of sealing fractures and/or joints as drilling fluids migrate into these features, resulting in low potential for inadvertent returns of drilling fluids at the ground surface.

Based on the anticipated geotechnical materials, the HDD installation has been designed within favorable geotechnical materials to the extent possible.

5.4 Crossing-Specific Risk Discussions

The length of the pipe staging area for the proposed crossing is insufficient to fabricate the pipe into a single string prior to pullback operations, and intermediate welds will be required. Intermediate welds will require stoppage of pullback operations each time a new pipe segment is welded on. These stoppages represent a significant risk to the installation because the bore is required to remain open much longer than would be required for the installation of a single pipe string. Stoppages for the intermediate welds also provide downtime, while welding occurs, that allows the drilling fluids to “gel” and making it harder to resume pullback operations due to the increased friction between the gelled fluids and the pipe. Start-up loads will increase each time pullback operations are resumed. In some cases, the gel strength of the fluids is too great and the resulting loads lead to damage to the pipe, or the pipe may become stuck at its current position in the bore. This risk increases with each additional intermediate weld. Prior to pullback operations, a swab pass should be completed to gauge whether the bore has been conditioned to accept the pipe.

Areas of high torque and/or pull force should be re-reamed to lower the drill rig effort to pass tools through this portion of the bore. The pipe should be installed with the shortest sections of pipe first and the longest pipe section last to decrease the startup loads on the pipe required to resume drilling operations.

The geological conditions encountered by this HDD installation will vary considerably along the alignment and each condition has an associated risk profile.

At the western end of the crossing, with in the carbonate Allentown and Leitsville formations, there is potential for karst features to be encountered which included pinnacled rock head and dissolution features within the formations and a potential for high strength chert layers.

In the central area of the crossing the alignment will transition out of the carbonates, across the Muscenetcong Fault before entering into Precambrian granite and gneiss materials. At this fault location there is an increased probability of fractured rock and potentially higher weathering grades. A secondary risk item within the central crossing location is the unknown top of rock profile; previous channel erosion elevations may have deepened the top of rock to lower elevations than observed in B-32A.

The Eastern end of the profile may transition out of the Precambrian bedrock into deep soils stratum. B-34 did not hit bedrock and was drilled to 110ft through thick silt and clay materials with occasional sand and gravel layers which is consistent with river alluvial deposits.

6 Summary

For the Delaware River Crossing, geotechnical risks have been acknowledged, but no fatal deterrents have been identified within the alignment. Based on the required installation length and diameter, the HDD contracting community in North America has successfully completed a large number of HDD installations of similar lengths.

While not anticipated, if an attempted HDD installation is unsuccessful, the proposed HDD alignment could be modified using the same HDD entry/exit locations to accommodate an additional HDD attempt, depending on the condition that resulted in the HDD failure. Prior to attempting a second HDD crossing, a risk mitigation workshop should be held with all parties to determine the cause of the initial failure and any mitigation measures that could be adopted to reduce the risk(s) during the second HDD attempt.

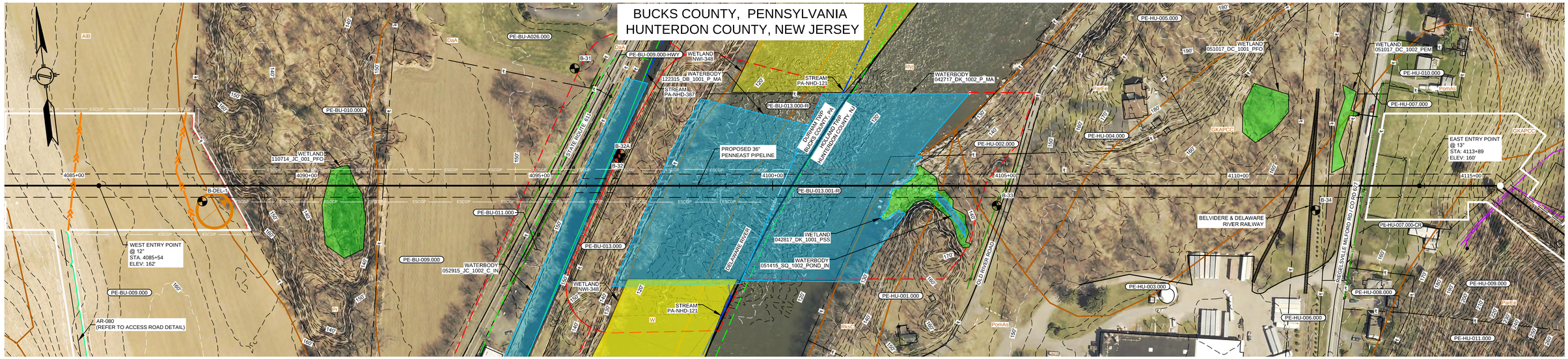
7 Limitations

This report is intended to be used in its entirety. The data, interpretations, conclusions, and recommendations contained within this report are provided for informational purposes for PennEast, and pertain specifically to the Delaware River Crossing. The data and conclusions presented herein do not and should not be applied to any other project site or HDD installation. Interpretations of the subsurface conditions are based on the information obtained from the geotechnical borings. The subsurface conditions presented between the geotechnical borings are interpretations and may vary from the actual conditions encountered.

It is recommended that Mott MacDonald provide construction monitoring services to verify the subsurface conditions encountered during construction, provide field design services, and evaluate contractor performance in accordance with the contract and the approved contractor supplied work plan.

Appendix A

HDD Plan and Profile



DELAWARE RIVER HDD PLAN VIEW
SCALE: 1" = 100'

GRAPHIC SCALE
100' 50' 0' 100'

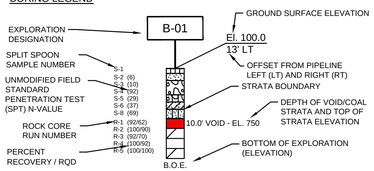
CROSSING SPECIFIC HDD NOTES:

1. ALL DIMENSIONS AND ELEVATIONS ARE IN FEET, UNLESS OTHERWISE SPECIFIED.
2. ALL CHAINAGES ARE HORIZONTAL.
3. CONTRACTOR SHALL DETERMINE FINAL LOCATIONS AND DIMENSIONS OF ALL MUD PITS NECESSARY TO ACCOMMODATE THEIR MEANS AND METHODS.
4. CONTRACTOR TO STAGE ALL PERSONNEL AND EQUIPMENT WITHIN THE PERMITTED LIMIT OF DISTURBANCE AS DEPICTED ON THIS DRAWING, UNLESS OTHERWISE AUTHORIZED BY THE CLIENT.
5. CONTRACTOR SHALL DETERMINE DIAMETER, GRADE, WALL THICKNESS AND ADDITIONAL LENGTH OF TEMPORARY CONDUCTOR CASINGS IF DEEMED NECESSARY BY THE CONTRACTOR. ANY INSTALLED TEMPORARY CONDUCTOR CASING SHALL BE FULLY REMOVED UPON COMPLETION OF PULLBACK OPERATIONS.
6. THE MINIMUM ALLOWABLE DRILLING RADIUS SHALL BE 2,600 FEET BASED ON A 3-JOINT AVERAGE.
7. EXISTING UTILITY LOCATIONS AND DEPTHS, INCLUDING PRIVATE SERVICES, ARE APPROXIMATE AND SHALL BE FIELD VERIFIED BY THE CONTRACTOR PRIOR TO ANY CONSTRUCTION OPERATIONS. PENNSYLVANIA LAW REQUIRES AT LEAST 48 HOURS AND NO MORE THAN TEN (10) WORKING DAYS NOTICE BEFORE EXCAVATION OR DEMOLITION.
8. HDD OPERATIONS SHALL BE CONDUCTED IN ACCORDANCE WITH ALL PERMIT REQUIREMENTS.
9. DOWNHOLE ANNULAR DRILLING FLUID PRESSURES SHALL BE MONITORED AT ALL TIMES DURING THE PILOT BORE DRILLING PROCESS. LOCATION OF MONITORING SHALL BE AS CLOSE TO THE DRILL BIT AS POSSIBLE.
10. HDD CONTRACTOR SHALL BE PREPARED TO PUMP A CEMENT GROUT DOWNHOLE TO HELP SEAL LARGE PREFERENTIAL FLOW PATHWAYS AND RESTORE DRILLING FLUID FLOW WITHIN THE HDD BORE IN THE EVENT KARST FEATURES ARE ENCOUNTERED AND EXCESSIVE DRILLING FLUID LOSSES OCCUR.
11. PILOT BORE SHALL BE CONTINUOUSLY TRACKED AT ALL TIMES. CONTRACTOR SHALL USE A GYROSCOPIC GUIDANCE SYSTEM TO COMPLETE THE PILOT BORE INSTALLATION. NO BLIND SECTIONS SHALL BE PERMITTED, EVEN WHEN THE DRILL BIT IS UNDER WATER.
12. IF THE CONTRACTOR ENCOUNTERS AN OBSTRUCTION THAT PREVENTS THE INSTALLATION ACCORDING TO THE PROJECT SPECIFICATIONS, THE CONTRACTOR SHALL PLACE A CEMENT BASED GROUT WITHIN THE BORE. WORK SHALL NOT RESUME UNTIL REVISED PLANS AND PROCEDURES HAVE BEEN SUBMITTED TO AND ACCEPTED BY THE OWNER.
13. PILOT BORE DRILLING TOLERANCES SHALL BE AS FOLLOWS:

Item	Tolerance
Pilot entry angle	Increase angle up to 1° (steeper), but no decrease in angle allowed.
Pilot entry location	As staked by Owner. No changes without Owner approval.
Pilot exit angle	Decrease angle up to 2° (flatter), but no increases in exit angle allowed.
Pilot exit location	Up to ten (10) feet shorter or longer.
Pilot depth	Up to three (3) feet shallower depth allowed. Up to ten (10) feet increase in pipe design depth (cover) allowed.
Pilot alignment	Up to ten (10) feet left or right of the Owner survey centerline but not within five (5) feet of the right-of-way/easement boundary or any below-grade utility or structure.

14. CROSS SECTIONS PRESENTS SUMMARY BOREHOLE LOG GRAPHICS, SEE FULL BOREHOLE LOG FOR DETAILS.
15. SUMMARY GEOPHYSICAL PROFILE DISPLAYED, SEE FULL REPORT FOR DETAILS. ANY INTERPRETATION DISPLAYED UPON GEOPHYSICAL PROFILES WAS PERFORMED BY GEOPHYSICAL SUBCONSULTANT.

BORING LEGEND

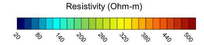


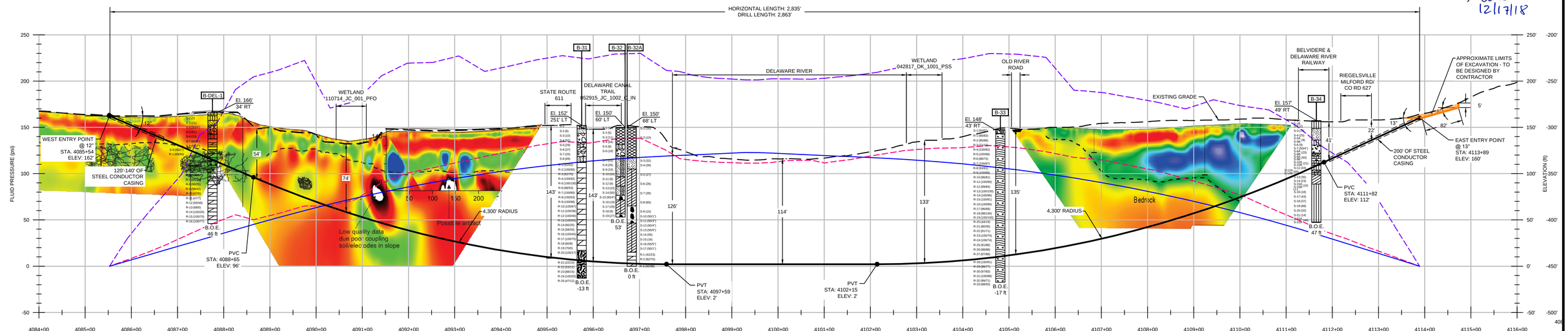
SOIL AND ROCK STRATAGRAPHIC LEGEND:

ASPHALT	SM	BOULDERS
CL	SC	CH
ML	SP	FILL
DECOMPOSED ROCK	TOPSOIL	GNEISS
QUARTZITE	MARBLE	PEGMATITE
GRANOFELS	DOLOMITE	VOID

GEOTECHNICAL NOTE: MASW GEOPHYSICS CONDUCTED OFF CENTERLINE.

Resistivity (Ohm-m)





REQUIRED DRILLING FLUID PRESSURE
RECOMMENDED MAXIMUM ALLOWABLE DRILLING FLUID PRESSURE
OVERBURDEN STRESS
HDD BORE PROFILE
GROUND SURFACE PROFILE

DELAWARE RIVER HDD PROFILE
HORIZONTAL SCALE: 1" = 100'
VERTICAL SCALE: 1" = 50'

GRAPHIC SCALE
HORIZ SCALE: 100' 50' 0' 100'
VERT SCALE: 50' 25' 0' 50'

NOTES:
1. THE CONTOURS AND IMAGERY SHOWN WERE PROVIDED BY PICTOMETRY, 2015. ADDITIONAL CONTOURS AND IMAGERY SUPPLEMENTED FROM PASDA.
2. EXISTING FEATURE SURVEYED PERFORMED BY MOTT MACDONALD 2015 THRU 2018. ADDITIONAL FEATURES DIGITIZED FROM IMAGERY. ALL LOCATIONS ARE APPROXIMATE AND SHALL BE VERIFIED BY CONTRACTOR.
3. PROPERTY LINES DEPICTED ON THIS PLAN ARE BASED ON GIS TAX MAP DATA AND RECTIFIED PROPERTY LINES AND ARE NOT THE RESULT OF A BOUNDARY SURVEY.
4. WATERBODY INFORMATION PROVIDED BY AECOM 2015 THRU 2018.

REFERENCE DRAWINGS

DWG. NO.	TITLE
000-03-01-155	ALIGNMENT SHEET
000-03-01-156	ALIGNMENT SHEET
000-03-03-056	ACCESS ROAD DETAIL

REVISIONS

	REVISIONS	DATE	DRAWN	CK	APPR
A	ISSUED FOR PADEP	10/2018	JL (MM)	AJD (MM)	MJD (MM)

APPROVALS

DRAWN BY	DATE
RJP (MM)	10/15/2018
CHECKED BY	DATE
CAF (MM)	10/15/2018
ENG. APPROVAL	DATE
MDN (MM)	10/15/2018
P.M. APPROVAL	DATE
MAW (MM)	10/15/2018

CLIENT APPROVAL

DATE

PREPARED FOR
PennEast PIPELINE

PENNEAST PIPELINE PROJECT
SOIL EROSION AND SEDIMENT CONTROL PLAN
PROPOSED 36" PIPELINE
HDD EXHIBIT PLAN AND PROFILE
DELAWARE RIVER HDD
BUCKS COUNTY, PENNSYLVANIA
HUNTERDON COUNTY, NEW JERSEY

SCALE	DRAWING NO.	REVISION
AS SHOWN	000-03-07-007	A

G:\PENNEAST\353754_PENNEAST_PIPELINE_EPC\MIDATA\PROD_STATE_PERMIT\WORK\PAD\DRAFTING\EROSION_SEDIMENT_CONTROL_PLAN\HDD_DETAILS\000-03-07-007.DWG DUM64749

Appendix B

Geotechnical Boring Logs

MOTT MACDONALD

SOIL/ROCK BORING LOG LEGEND

USCS Group Symbol

UNIFIED SOIL CLASSIFICATION SYSTEM AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)			FINE-GRAINED SOILS (more than 50% of material is smaller than No. 200 sieve size.)		
Gravels More than 50% of coarse fraction larger than N.4 sieve size	Clean Gravels (Less than 5% fines)		**SILTS AND CLAYS** Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey of clayey fine sands or clayey silts with slight plasticity
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines		OL	Organic silts and organic silty clays of low plasticity
	Gravels with fines (more than 12% fines)		**SILTS AND CLAYS** Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	GM	Silty gravels, gravel-sand-silt mixtures		CH	Inorganic clays of high plasticity, fats clays
	GC	Clayey gravels, gravel-sand-clay mixtures		OH	Organic clays of medium to high plasticity, organic silts
Sands More than 50% of coarse fraction larger than N.4 sieve size	Clean Sands (Less than 5% fines)		**HIGHLY ORGANIC SOILS**	PT	Peat and other highly organic soils
	SW	Well-graded sands, gravelly sands, little or no fines	Determine percentages of sand and Gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:		
	SP	Poorly-graded sands, gravelly sands, little or no fines			
	Sands with fines (More than 12% fines)				
	SM	Silty sands, sand-silt mixtures	Less than 5 percent ……GW, GP, SW, SP More than 12 percent ……GM, GC, SM, SC 5 to 12 percent ……Borderline cases requiring dual symbols		
	SC	Clayey sands, sand-clay mixtures			

Minor Components

Description	Criteria
20 – 30%	some
10 – 20%	little
1 – 10%	trace

Infilling

Description	Symbol
Clay	CL
Silt	ML
Sand	SD
Calcite	CA
Carbonate	C
Dolomite	DO
Gypsum/Tale	GY
Hematite	HE
Limonite	L
Quartz	QZ
Chlorite	CH
Pyrite	PY
Iron Oxide Staining	FE
Stylolite	ST
Not Determined	X
None	N
Healed	H

Weathering of Rock Mass

Description	Symbol	Criteria	Grade
Fresh (Unweathered)	FR	No visible sign of rock material weathering, except slight discoloration on major discontinuity surfaces.	I
Slightly Weathered	SL	Discoloration indicates weathering of rock material and discontinuity surfaces. All rock material may be discolored by weathering and may be somewhat weaker than externally than in its fresh condition.	II
Moderately Weathered	M	Less than half of the rock material is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly Weathered	H	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	IV
Completely Weathered	C	All rock material is decomposed and/or disintegrated to soil. The original mass structure remains largely intact.	V
Residual Soil	RS	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

Discontinuity Spacing

Description	Symbol	Spacing (in.)
Extremely Close	EC	< 0.75
Very Close	VC	0.75 – 2.5
Close	C	2.5 – 8.0
Moderate	M	8 – 24
Wide	W	24 – 80
Very Wide	VW	80 – 240
Extremely Wide	EW	> 240

Spacing Type

Description	Symbol	Spacing (in.)
Joint	J	A natural fracture along which no displacement has occurred. May occur in parallel groups called sets.
Shear	S	A natural fracture along which differential movement has occurred. May be slickensided or striated.
Fault	F	A natural fracture along which displacement has occurred. Usually lined with gouge and slickensides.
Vein	V	A thin, sheet-like igneous intrusion into a fissure.
Bedding Joint	B	Joints that occur along bedding planes.
Foliation Joint	FJ	Joints that occur parallel to the foliation of a rock mass.
Shear Zone	SZ	Zone of fractured rock and gouge bordering the displacement plane.

Field Strength

Description	Criteria	Grade	Approx. Range of Uniaxial Compressive Strength (psi)
Extremely Weak	Indented by thumbnail.	R0	40 – 150
Very Weak	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife.	R1	150 – 700
Weak	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer.	R2	700 – 4,000
Medium Strong	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer.	R3	4,000 – 7,000
Strong	Specimen requires more than one blow of geological hammer to fracture it.	R4	7,000 – 15,000
Very Strong	Specimen requires many blows of geological hammer to fracture it.	R5	15,000 – 36,000
Extremely Strong	Specimen can only be chipped with geological hammer.	R6	>36,000

Roughness

Intermediate Scale	Symbol	Small Scale	Symbol
Stepped	S	Rough	R
Undulating	U	Smooth	Sm
Planar	P	Slickensided	K
Not Determined	X	Wavy	Wa
		Not Determined	X

Weathering/Alteration of Discontinuity Surfaces

Description	Symbol	Criteria
Fresh	FR	No visible sign of weathering on the rock discontinuity surfaces.
Discolored	DS	Discoloration of rock material discontinuity surfaces. Degree of discoloration and specific discolored mineral constituents (if applicable) indicated.
Disintegrated	DG	Discontinuity surface rock material is weathered to a soil with the rock material fabric intact. Rock material is friable, but the mineral grains are not decomposed.
Decomposed	DE	Discontinuity surface rock material is weathered to a soil with the rock material fabric intact and with some or all mineral grains decomposed.

Aperture

Description	Symbol	Aperture (in.)	
Very Tight	VT	< 0.004	"Closed" Features
Tight*	T	0.004 – 0.010	
Partly Open	PO	0.01 – 0.02	
Open**	O	0.02 – 0.10	"Gapped" Features
Moderately Wide	MW	0.1 – 0.4	
Wide	W	> 0.4	
Very Wide	VW	0.4 – 4.0	"Open" Features
Extremely Wide	EW	4.0 – 40.0	
Cavernous	CA	> 40	

MOTT MACDONALD

BOREHOLE LOG GRAPHIC LEGEND

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Manager:**	Vatsal Shah
Client:	PennEast Pipeline	**Project Director:**	Michael Wilcox

Soil Log Graphic Legend


CH: USCS High Plasticity Clay


CL: USCS Low Plasticity Clay


CL-ML: USCS Low Plasticity Silty Clay


DECOMPOSED ROCK: Decomposed Rock


DOLOMITE: Dolomite


FILL: Miscellaneous and Manmade Fill


GM: USCS Silty Gravel


GP: USCS Poorly-graded Gravel


GP-GM: USCS Poorly-graded Gravel with Silt


GRAVEL-STONE: Gravel or Crushed Stone


ML: USCS Silt


QUARTZITE: Quartz and Quartzite


SC: USCS Sandy Clay to Clayey Sand


SM: USCS Silty Sand


SP: USCS Poorly-graded Sand


SP-SM: USCS Poorly-graded Sand with Silt


SW-SM: USCS Well-graded Sand with Silt


TOPSOIL: Topsoil


VOID: Underground Void

Rock Log Graphic Legend


DOLEMITE - OBSELETE: USE DOLOMITE


DOLOMITE - Dolomite


GNEISS - Gneiss


LIMESTONE - Limestone


SILTSTONE - Siltstone

▽ Ground Water Level
(Note that due to drilling process disturbance the ground water levels obtained during drilling are not as representative as those obtained from monitoring wells)

This legend reports all soil and rock graphics which have been used in the logs of this project only.

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-DEL-1**
Page **1** of **2**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	TJ Liveston
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 29, 2016 at 8:15 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 30, 2016 at 3:00 pm

Elevation: 166 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** In the farm field **Coord.:** **N:** 40.5843 **E:** -75.1978 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-750X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ _____

Drilling Fluid: ☐ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size: **Casing Advance**: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	10	1 2 1 2		SM	Very loose, Brown Silty SAND with Topsoil, moist (SM)	-	-	-	-	
						3.5					
5 160	S-2 5.0'- 7.0'	12	6 3 4 4		CL	Medium stiff, Red brown CLAY with sand, moist (CL)	-	-	-	-	Boulder at 8.5'.
						8.5					
10	S-3 10.0'- 12.0'	10	7 9 12 12		SP	Medium dense, Brown SAND with Gravel and Silt, moist (SP)	-	-	-	-	
						13.5					
15 150	S-4 15.0'- 17.0'	5	12 29 50/4"		GM	Very dense, Brown Silty GRAVEL with Sand, moist (GM)	-	-	-	-	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/30/16	7:00	0:00	40.0	60.0	37.5

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-DEL-1**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

SOIL BORING LOG
(continued)

BORING NO.: **B-DEL-1**
Page **2** of **2**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-5 20.0'-22.0'	10	17 35 26 15		GM	Very dense, Red brown Silty GRAVEL with Sand, moist (GM)	-	-	-	-	
						23.5					
25	S-6 25.0'-27.0'	16	14 10 13 17		SM	Medium dense, Brown Silty SAND with Gravel, moist (GM)	-	-	-	-	
140						28.5					
30	S-7 30.0'-32.0'	3	50/3"			Very dense, Weathered DOLOMITE Fragments	-	-	-	-	
35						35.0					
	S-8 35.0'-37.0'	0	50/2"			No recovery	-	-	-	-	
130						37.0					
▽	38.0'-'						-	-	-	-	Drill rig chattering at 38'
40	S-9 40.0'-42.0'	11	50/1"			Very dense, Weathered DOLOMITE Fragments	-	-	-	-	
						40.5 Top of Rock at 40 feet BGS. See Rock Coring Log.					
45											
120											

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: **353754**

BORING NO.: **B-DEL-1**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-DEL-1**
Page **1** of **4**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	TJ Liveston
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 29, 2016 at 8:15 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 30, 2016 at 3:00 pm

Elevation: 166 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** In the farm field **Coord.: N:** 40.5843 **E:** -75.1978

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983 **Rig Make & Model:** CME-750X **Drilling Method:** Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS		(See Legend for Rock Description System)						
	4.50	40.0							DOLOMITE, Gray tan, fine grained, moderately weathered, medium strong, extremely close to close spaced discontinuities	40.11	J	5	S,Sm	DS	PO	Sa	
									40.8' - 41.1' Highly Fractured zone								
	4.50									41.25	J	15	S,Sm	FR	T	N	
									41.7' - 42.2' Highly Fractured zone								
	4.50		R-1	50 83%	24 40%	R3	M			42.60	J	30	S,Sm	DS	T	Fe	
	4.50								42.9' - 43.75' Highly Fractured zone								
	4.50	45.0															
45	4.00	45.0							DOLOMITE, Gray tan, fine grained, highly weathered, weak, extremely close to close spaced discontinuities								
120									45' - 46.8' Highly Fractured zone								
	4.00																
	4.00		R-2	36 60%	6 10%	R2	H		47.3' - 48' Highly Fractured zone								
	4.00																
	4.00	50.0															
50	5.40	50.0							DOLOMITE, Gray tan, fine grained, slightly weathered, weak, very close to close spaced discontinuities	50.15	J	0	S,Sm	DS	T	Fe	
										50.30	J	0	S,Sm	DS	T	Fe	
										50.85	J	10	S,Sm	DE	O	Fgmts	
	5.40									51.10	J	40	U,Sm	FR	T	N	
										51.60	J	35	S,Sm	DS	T	Fe	
									52.0 51.8' - 52.1' Highly Fractured zone								
	5.40		R-3	56 93%	26 43%	R2	SL		SILTSTONE, Gray, fine grained, slightly weathered, weak, very close to close spaced discontinuities, pyrite present	52.70	J	45	S,Sm	FR	-	N	
										52.95	J	45	U,Sm	FR	T	N	
	5.40								53.1' - 53.2' Highly Fractured zone								
										53.85	J	50	S,Sm	DG	O	Fgmts	
	5.40									54.10	J	30	P,Sm	FR	T	N	
		55.0															
55	5.20	55.0							SILTSTONE, Gray, fine grained, slightly weathered, weak, very close to moderately spaced discontinuities, pyrite present								
110										55.70	J	40	S,Sm	DS	T	Fe	
										55.85	J	0	S,Sm	DG	PO	Fe	
	5.20									56.05	J	60	S,Sm	DS	T	Fe	
										56.20	J	30	U,Sm	DS	T	Fe	
									56.9								
	5.20		R-4	60 100%	32 53%	R2	SL		DOLOMITE, Gray tan, fine grained, slightly weathered, weak, close spaced discontinuities	56.85	J	45	S,Sm	DG	PO	Fgmts	
										57.10	J	0	S,Sm	DG	PO	Fe	
										57.60	J	10	S,Sm	DS	T	Fe	
	5.20								58' - 59' Highly Fractured zone								
	5.20																
	5.20	60.0								59.35	J	10	S,Sm	DG	O	Fgmts	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/30/16	7:00	0:00	40.0	60.0	37.5

Notes:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	5.60	60.0							DOLOMITE, Gray tan, fine grained, slightly weathered, weak, extremely close to moderately spaced discontinuities, vugs present								
									60' - 60.25' Highly Fractured zone	60.65	J	30	S,Sm	DG	O	Fgmts	
	5.60									61.20	J	0	S,Sm	DG	O	Fgmts	
										62.00	J	0	U,Sm	DG	PO	Fgmts	
	5.60		R-5	56 93%	44 73%	R2	SL			62.35	J	30	S,Sm	DS	PO	Fe	
										62.70	J	50	S,Sm	DS	PO	Fgmts	
										63.05	J	40	P,Sm	DS	T	Fe	
	5.60									63.45	J	5	U,Sm	DS	T	Fe	
	5.60	65.0							64.5' - 64.7' Highly Fractured zone	64.30	J	60	S,Sm	FR	T	N	
65	5.20	65.0							DOLOMITE, Gray tan, fine grained, slightly weathered, weak, extremely close to moderately spaced discontinuities, vugs present								
									65.4' - 65.65' Highly Fractured zone	65.90	J	50	S,Sm	DS	T	Fe	
100										66.05	J	50	S,Sm	DS	T	Fe	
	5.20									66.50	J	10	S,Sm	DS	T	Fe	
	5.20		R-6	60 100%	40 67%	R2	SL			67.65	J	5	S,Sm	DS	PO	Fe	
										68.05	J	60	S,Sm	DS	T	Fgmts	
	5.20									68.20	J	5	S,Sm	DS	VT	Fe	
										68.50	J	5	U,Sm	DS	T	Fe	
	5.20	70.0								69.35	J	20	U,Sm	DS	T	Fe	
70		70.0								69.70	J	50	S,Sm	FR	PO	N	
	5.40								DOLOMITE, Gray tan, fine grained, moderately weathered, very close to close spaced discontintuities, weak	69.90	J	30	S,Sm	DS	PO	Fe	
									70' - 70.4' Highly Fractured zone	71.00	J	5	S,R	DS	O	Fgmts	
	5.40									71.20	J	60	S,R	DG	O	Fgmts	
										71.90	J	60	S,R	DG	O	Fgmts	
	5.40		R-7	39 65%	18 30%	R2	M			72.10	J	60	S,R	DG	O	Fgmts	
										72.20	J	30	S,R	DG	O	Fgmts	
										72.60	J	10	S,R	DG	O	Fgmts	
	5.40								72.8' - 73.25' Highly Fractured zone								
	5.40	75.0															
75		75.0															
	5.20								DOLOMITE, Gray tan, fine grained, moderately weathered, weak, very close to close spaced discontinuites								
									75'-75.2' Highly Fractured zone	75.85	J	60	U,Sm	DS	PO	Fe	
90										76.00	J	65	U,Sm	DS	PO	Fe	
	5.20									76.10	J	65	U,Sm	DS	PO	Fe	
										76.20	J	65	U,Sm	DS	PO	Fe	
										76.60	J	65	U,Sm	DS	T	Fe	
										76.70	J	60	U,Sm	DS	O	Fe	
	5.20		R-8	54 90%	15 25%	R2	M			76.90	J	45	S,Sm	DG	O	Fgmts	
										77.20	J	45	S,Sm	DS	O	Fe	
									77.4' - 77.6' Highly Fractured zone	77.25	J	10	U,Sm	DS	PO	Fe	
										77.95	J	15	S,Sm	DG	O	Res	
	5.20									78.10	J	0	S,Sm	DG	O	Fgmts	
									78.4' - 79.5' Highly Fractured zone								
	5.20																
	5.20	80.0															
80		80.0															
	4.90								DOLOMITE, Gray tan, fine grained, slightly weathered, weak, very close to close spaced discontinuities, vugs present	80.30	J	60	S,Sm	DS	PO	Fgmts	
									80'-80.2' Highly Fractured zone	80.70	J	45	S,Sm	DS	PO	Fe	
										81.00	J	30	U,Sm	DS	T	Fe	
	4.90									81.60	J	45	S,Sm	DS	T	Fe	
	4.90		R-9	59 98%	25 42%	R2	SL		82.3' - 82.7' Highly Fractured zone								
										83.00	J	50	U,Sm	DS	T	ML	
	4.90									83.15	J	10	S,Sm	FR	T	N	
										83.75	J	30	S,Sm	DE	O	Res	
	4.90									84.10	J	5	U,Sm	DS	O	Fe	
		85.0							84.3' - 84.55' Highly Fractured zone								

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.60	85.0							DOLOMITE, Gray tan, fine grained, highly weathered, weak, extremely close to very close spaced discontinuities, vugs present 85' - 85.7' Highly Fractured zone								
80	3.60									86.00 86.10	J J	20 20	S,Sm S,Sm	DS DG	O O	Fe Fgmts	
									86.25' - 86.4' Highly Fractured zone 86.7' - 87.3' Highly Fractured zone								
	3.60		R-10	28 47%	0 0%	R2	H										
	3.60																
	3.60	90.0															
90	3.20	90.0							DOLOMITE, Gray, fine grained, highly weathered, weak, extremely close to close spaced discontinuities, vugs present 90' - 92' Highly Fractured zone								
	3.20																
	3.20		R-11	28 47%	4 7%	R2	H										
	3.20																
	3.20	95.0															
95	5.60	95.0							DOLOMITE, Gray, fine grained, slightly weathered, weak, very close to close spaced discontinuities, vugs present 95.15' - 95.45' Highly Fractured zone	95.80	J	10	U,Sm	DS	T	Fe	
70	5.60									96.20 96.30 96.50	J J J	45 20 5	S,Sm S,Sm S,Sm	FR FR FR	T T T	N N N	
	5.60		R-12	56 93%	29 48%	R2	SL		97.6' - 98.4' Highly Fractured zone	97.20	J	45	P,Sm	FR	T	N	
	5.60																
	5.60	100.0							99.25' - 99.67' Highly Fractured zone	99.00	J	60	S,Sm	DS	PO	Fe	
100	4.30	100.0							DOLOMITE, Gray, fine grained, moderately weathered, weak, extremely close to close spaced discontinuities, vugs present Occasional Calcite veins 100' - 103.4' Highly Fractured zone								
	4.30																
	4.30		R-13	41 68%	0 0%	R2	M										
	3.70																
	3.70	105.0															
105	4.60	105.0							DOLOMITE, Gray, fine grained, slightly weathered, weak, very close to close spaced discontinuities, vugs present	105.20	J	20	S,Sm	DS	PO	Fe	
60	4.60								106.35' - 106.95' Highly Fractured zone	106.10 106.40 106.60	J J J	0 0 60	S,Sm S,Sm P,R	FR FR DS	T T PO	N N Fe	
	4.60		R-14	60 100%	12 20%	R2	SL		107.1' - 107.5' Highly Fractured zone 108' - 109.5' Highly Fractured zone								
	4.60																
	4.60	110.0															

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-DEL-1**
Page **4** of **4**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
		110.0							DOLOMITE, Gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities, vugs present	109.80	J	858	S,Sm	DS	PO	Fe	
	4.60								110' - 110.8' Vertical fractures	110.60	J	36	S,Sm	DS	PO	Fe	
	4.60									111.30	J	0	S,Sm	DS	PO	Fgmts	
										111.65	J	15	S,Sm	FR	PO	Fgmts	
										111.90	J	0	S,Sm	DG	PO	Fgmts	
	4.60		R-15	60 100%	42 70%	R3	SL			112.15	J	20	S,Sm	FR	T	N	
										112.40	J	0	S,Sm	DS	PO	Fgmts	
										112.56	J	15	S,Sm	FR	T	N	
	4.60									113.40	J	15	S,Sm	FR	T	N	
										113.56	J	0	S,Sm	FR	T	N	
	4.60									113.70	J	5	S,Sm	DS	T	ML	
		115.0															
115		115.0							DOLOMITE, Gray, fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities, vugs present								
	4.90									115.50	J	5	U,Sm	FR	T	N	
50										115.60	J	5	U,Sm	DS	PO	Res	
	4.90									115.70	J	5	S,Sm	FR	T	N	
										116.80	J	5	S,Sm	FR	PO	Fgmts	
	4.90		R-16	60 100%	46 77%	R3	SL										
									117.95' - 118.2' Highly Fractured zone	117.80	J	10	S,Sm	FR	T	N	
	4.90																
										118.60	J	10	S,Sm	FR	PO	Fgmts	
									119' - 119.4' Highly Fractured zone								
	4.9																
		120.0							120.0								
120		120.0							End of Boring at 145 feet BGS. Borehole grouted with cement and bentonite hole plug.								
125																	
40																	
130																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-DEL-1**

Figure B-DEL-1.1
B-Del-1 Box 1 Runs 1-4 Dry

Figure B-DEL-1.2
B-Del-1 Box 1 Runs 1-4 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-DEL-1

Figure B-DEL-1.3
B-Del-1 Box 2 Runs 5-8 Dry

Figure B-DEL-1.4
B-Del-1 Box 2 Runs 5-8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-DEL-1

Figure B-DEL-1.5
B-Del-1 Box 3 Runs 9-12 Dry

Figure B-DEL-1.6
B-Del-1 Box 3 Runs 9-12 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-DEL-1

Figure B-DEL-1.7
B-Del-1 Box 4 Runs 13-16 Dry

Figure B-DEL-1.8
B-Del-1 Box 4 Runs 13-16 Wet

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-31**
Page **1** of **2**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Rhan Flatin
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	July 15, 2015 at 9:20 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	July 17, 2015 at 9:00 am

Elevation: 152 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.584814 **E:** -75.194819 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-750X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type
☐ Safety
☐ Doughnut
☑ Automatic
☐ _____

Drilling Fluid
☐ Bentonite
☐ Polymer
☑ Water
☐ None

Drill Rod Size:

Casing Advance
Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 1.0'	5	1 1			0.2 2" TOPSOIL	-	-	-	-	
150	1.0'- 2.0'		2 3		CL-ML	2"- 5" Soft, Dark brown Clayey SILT with Sand, moist (CL-ML)	N	L	L	N	PP = 1.5 tsf. TV = 1.0 tsf.
						3.5					
5	S-2 5.0'- 7.0'	13	5 3 3 3		SP	Loose, Yellowish red SAND, moist (SP)	N	-	NP	N	PP = 0.75 tsf. TV = 0.5 tsf.
						8.5					
10	S-3 10.0'- 12.0'	3	9 6 4 3		GP	Loose, GRAVEL with Sand (GP)	N	-	NP	N	
140											
15	S-4 15.0'- 17.0'	6	47 68 24 26		GP	Very dense, GRAVEL with Sand (GP)	N	-	NP	N	
						18.5					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:
PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-31**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD

SOIL BORING LOG
(continued)

BORING NO.: **B-31**
Page **2** of **2**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-5 20.0'-22.0'	11	20 15 14 14		GM	Medium dense, Brownish yellow Silty GRAVEL with Sand (GM)	N	-	NP	N	
130						23.5					
25	S-6 25.0'-27.0'	13	23 18 19 19		SC	Dense, Brownish yellow Clayey SAND with Gravel (SC)	N	-	NP	N	
						28.5					
30	S-7 30.0'-32.0'	3	14 18 15 14		GP	Dense, GRAVEL with Sand (GP)	N	-	NP	N	
120						33.5					
35	S-8 35.0'-37.0'	6	15 45 24 29		SM	Very dense, Brownish yelllow Silty SAND with Gravel (SM)	N	-	NP	N	
40						40.0 Top of Rock at 40 feet BGS. See Rock Coring Log.					
110											
45											

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: **353754**

BORING NO.: **B-31**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-31**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Rhan Flatin
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	July 15, 2015 at 9:20 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	July 17, 2015 at 9:00 am

Elevation: 152 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.: N:** 40.584814 **E:** -75.194819

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983 **Rig Make & Model:** CME-750X **Drilling Method:** Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS		(See Legend for Rock Description System)						
		40.0							DOLOMITE with Clay, Gray, fine to medium grain, moderately weathered, weak, close to moderately spaced discontinuities								
	1.25									40.54	J	53	S,R	DS	T	CL	
										40.95	J	30	S,R	DS	PO	CL	
	1.25																
110										41.75	J	83	U,Sm	DS	T	CL	
	1.25		R-1	55 92%	37 62%	R2	M			42.60	J	85	P,Sm	DS	T	Py	
									43' - 43.4' Highly fractured zone								
	0.75																
	1.25									44.30	J	87	P,Sm	DS	T	Py	
		45.0								44.60	J	12	S,R	DS	PO	CL	
45		45.0							DOLOMITE with Clay, Gray, fine to medium grain, moderately weathered, weak, close to moderately spaced discontinuities								Frequent highly weathered, fractured, and weak clay veins.
	1.25																
	1.25																
										46.80	J	80	P,Sm	DS	T	N	
	1.75		R-2	60 100%	54 90%	R2	M										
	1.75																
										48.90	J	40	S,R	DS	PO	N	
	1.25	50.0															
50		50.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, weak, close to moderately spaced discontinuities 50' - 51.9' Mostly Clay, highly weathered, very weak								
	0.75																
	1.00																
100										51.77	J	12	S,R	DS	PO	N	
	1.00		R-3	55 92%	42 70%	R2	M			52.70	J	24	S,R	DS	PO	CL	
	1.25																
										53.80	J	85	P,R	DS	T	CL	
	1.25	55.0															
55		55.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, close to moderately spaced discontinuities								Small decline in water return.
	1.50									55.47	J	28	U,R	DS	T	Ca	
	1.50									56.20	J	37	U,R	DS	T	Ca	
										56.70	J	47	U,R	DS	T	Ca	
	2.00		R-4	60 100%	55 92%	R3	SL			57.10	J	53	U,R	DS	T	Ca	
										57.75	J	47	U,Sm	DS	T	Ca	
	2.00									58.35	J	15	U,R	DS	PO	Ca	Frequent precense of thin Calcite veins, generally within bedding plane.
										58.85	J	45	U,R	DS	PO	Ca	
	2.50	60.0								59.30	J	35	S,R	DS	PO	Ca	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.00	60.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, close to moderately spaced discontinuities	60.35	J	30	S,R	DS	PO	N	
	2.25									61.30	J	73	U,R	DS	PO	Ca	
90	2.25		R-5	60 100%	60 100%	R3	SL										
	2.25									62.98	J	16	S,R	DS	PO	Ca	
	2.25	65.0															
65	2.00	65.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, close to moderately spaced discontinuities								Frequent Calcite veins.
	2.00									65.70	J	18	S,R	DS	PO	Ca	
	2.00									66.50	J	74	P,Sm	DS	T	N	Long Clay vein
	2.00		R-6	53 88%	32 53%	R3	SL			67.10	J	40	S,R	DS	PO	Ca	
	2.00									68.20	J	42	S,R	DG	PO	CL	
	2.50	70.0								68.90	J	10	S,R	DS	PO	CL	
70	2.00	70.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium srong, close to wide spaced discontinuities								
	2.25																
80	2.00		R-7	60 100%	48 80%	R3	SL			72.40	J	73	U,R	DS	PO	Fe	
	2.00																
	2.25	75.0															
75	1.75	75.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, very close to moderately spaced discontinuities								
	2.25									76.30	J	72	P,Sm	DS	PO	CL	
										76.47	J	35	S,R	DS	PO	CL	
										76.81	J	40	S,R	DS	PO	CL	
	2.00		R-8	60 100%	38 63%	R3	SL			77.55	J	57	U,Sm	DS	PO	CL	
	2.00									78.50	J	72	P,Sm	FR	T	N	
										78.75	J	27	U,R	FR	T	N	
										78.90	J	73	P,Sm	FR	T	N	
	2.25	80.0								79.17	J	30	S,R	FR	T	N	
80	2.25	80.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, very close to moderate discontinuities								
	2.00									81.45	J	40	S,R	DS	PO	Fe	
70	2.25		R-9	60 100%	41 68%	R3	SL			82.36	J	8	S,R	FR	T	CL	
	2.25									83.55	J	34	U,Sm	FR	T	N	
										83.70	J	29	S,R	FR	T	N	
	2.25	85.0															

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.75	85.0							DOLOMITE, Gray, fine to medium grain, slightly weathered, medium strong, close to moderately spaced discontinuities								
	2.00									86.10	J	15	S,R	DS	PO	N	
										86.48	J	11	U,Sm	DS	T	N	
										86.60	J	33	S,R	DS	T	CL	
	2.50		R-10	60 100%	40 67%	R3	SL			86.90	J	75	P,Sm	DS	PO	CL	
	2.75									88.08	J	30	U,R	DS	PO	CL	
										88.70	J	17	S,R	FR	PO	N	
	2.25	90.0								89.00	J	65	U,Sm	FR	T	N	
90		90.0							DOLOMITE, Dark gray, fine grain, slightly weathered, medium strong, extremely close to moderately spaced discontinuities								Presence of Calcite veins.
	2.25									90.50	J	71	P,Sm	DS	T	CL	
									91.9' - 95.0' Highly fractured zone	91.10	J	20	S,R	DS	PO	CL	
	2.25									91.65	J	24	U,R	DS	PO	N	
60																	
	2.50		R-11	60 100%	23 38%	R3	SL			92.20	J	13	S,R	FR	PO	Ca	
										92.60	J	25	S,R	FR	T	Ca	
	2.75																
	2.75	95.0															
95		95.0							DOLOMITE, Dark gray, fine grain, slightly weathered, medium strong, very close to moderately spaced discontinuities								Numerous fine Calcite veins.
	2.25																
	2.00									96.60	J	80	P,Sm	DS	T	N	
	2.00		R-12	60 100%	24 40%	R3	SL										
										98.00	J	65	U,R	FR	T	N	
	2.25									98.12	J	50	S,R	FR	T	Ca	
										98.60	J	72	P,Sm	FR	PO	CL	
	2.50	100.0								98.88	J	40	U,R	FR	T	Ca	
										99.00	J	70	P,Sm	FR	T	N	
100		100.0							DOLOMITE with Clay, Brown, fine to medium grain, slightly weathered, weak, very close to moderately spaced discontinuities								
	1.75									101.00	J	52	U,R	FR	T	N	
	2.25									101.40	J	35	S,R	DS	PO	Ca	
50																	
	2.25		R-13	60 100%	33 55%	R2	SL										
	2.50									103.23	J	30	S,R	DS	PO	CL	
	2.50	105.0								104.20	J	70	P,Sm	DS	T	Ca	
105		105.0							DOLOMITE wih Clay, Brown, fine to medium grain, moderately weathered, very weak, extremely close to moderately spaced discontinuities 105' - 105.4' Planar, banded	105.00							Water return, but gradually dropping. Used up to 2,000 Gallons of water.
	1.50									105.15	J	66	P,Sm	DS	T	N	
										105.65	J	70	P,Sm	DS	T	Ca	
	1.75																
	1.75		R-14	36 60%	15 25%	R1	M			107.00	J	68	P,Sm	DS	T	Ca	
	2.00																
	2.00	110.0															

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.00	110.0							110' - 112.1' DOLOMITE, Brown, fine to medium grain, highly weathered, very weak, very close to close discontinuities	110.30	J	65	U,Sm	DS	T	N	
										110.35	J	14	U,R	DS	T	N	
	1.75									111.17	J	35	U,R	DS	PO	Ca	
										111.60	J	45	U,R	DS	PO	Ca	
40	1.50		R-15	35 58%	20 33%	R1	H										
	1.50																
	1.50	115.0															
115	2.00	115.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, weak, extremely close to moderately spaced discontinuities	115.50	J	63	P,Sm	DS	T	Ca	
	2.00									116.75	J	70	P,Sm	FR	T	N	
	2.25		R-16	60 100%	27 45%	R2	M										
	1.75									118.20	J	72	P,Sm	FR	T	Py	
										118.90	J	68	P,Sm	FR	T	N	
	1.75	120.0															
120	2.00	120.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, weak, very close to moderately spaced discontinuities 120' - 122' Numerous Clay veins								
	2.00																
30	2.50		R-17	60 100%	45 75%	R2	M			122.83	J	24	S,Sm	FR	T	Ca	
	2.75																
	3.00	125.0								124.10	J	24	S,Sm	FR	T	N	
										124.40	J	77	P,Sm	FR	T	GY	
125	2.00	125.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, very weak, extremely close to close spaced discontinuities Many planar fragments at 75 - 80 degree angles 127.4' - 129.4' Rock missing								No joints.
	2.25																
	1.00		R-18	36 60%	5 8%	R1	M										
	0.75																
	1.50	130.0															
130	1.50	130.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, very weak, extremely close to close spaced discontinuities Many planar fragments at 75 - 80 degree angles	131.00	J	64	P,Sm	FR	T	GY	
	2.00									131.10	J	20	S,R	FR	T	N	
										131.50	J	76	P,Sm	FR	T	GY	
20	2.00		R-19	42 70%	0 0%	R1	M			132.30	J	75	P,Sm	FR	T	GY	
	2.25																
	1.75	135.0							135.0								

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.50	135.0							SILTSTONE, Gray, fine to medium grain, moderately weathered, very weak, extremely close to moderately spaced discontinuities, planar fragments at 70 - 80 degree angles	135.30	J	76	P,Sm	FR	T	Ca	
										135.85	J	65	S,R	FR	PO	Ca	
	1.50																
	1.50		R-20	60 100%	10 17%	R1	M			137.30	J	76	P,Sm	FR	T	GY	
	1.50																
	1.50	140.0							140.0								
140	1.50	140.0							DOLOMITE, Gray, fine to medium grain, highly weathered, very weak, very close to moderate spaced discontinuities								
									140' - 141' Highly fractured zone	140.90	J	72	P,Sm	DS	PO	CL	
	1.00								141' - 145' Rock missing								
10	1.00		R-21	13 22%	6 10%	R1	H										
	0.75																
	0.75	145.0															
145	1.00	145.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, weak, extremely close to close spaced discontinuities								No joints.
	0.75								145' - 146.2' Highly fractured zone 146.2' - 148.3' Rock missing								
	0.75		R-22	32 53%	7 12%	R1	H										
	1.50	148.0							148.3' - 150' Clay, Quartz, Sand, and possibly Actinolite present								
	1.50	150.0															
150	1.50	150.0							DOLOMITE, Gray, fine to medium grain, moderately weathered, weak, very close to close spaced discontinuities								
	1.50								Clay, Quartz, Sand, and possibly Oolitic Limestone present								
0	1.50		R-23	53 88%	9 15%	R2	M										
	2.00																
	2.00	155.0								154.30	J	75	P,Sm	DS	PO		
155	2.00	155.0							ARGILLACEOUS DOLOMITE, Gray, fine to medium grain, slightly weathered, weak, very close to moderately spaced discontinuities								
	2.00									156.30	J	75	S,R	DS	PO	Ca	
										156.50	J	75	P,Sm	FR	T	Ca	
	2.25		R-24	60 100%	19 32%	R2	SL			157.20	J	75	P,Sm	DS	PO	Ca	
										157.45	J	60	S,R	FR	T	N	
	2.25																
	2.50	160.0															

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-31**
Page **6** of **6**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.50	160.0							DOLIMITE, Gray, fine to medium grain, highly weathered, very weak, extremely close to close spaced discontinuities								No joints.
	3.00								162.3' - 165' Rock missing								
-10	1.50		R-25	28 47%	7 12%	R1	H										
	1.25																
	1.50	165.0							165.0								
165									End of Boring at 165 feet BGS. Borehole grouted with cement and bentonite hole plug.								
170																	
-20																	
175																	
180																	
-30																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-31**

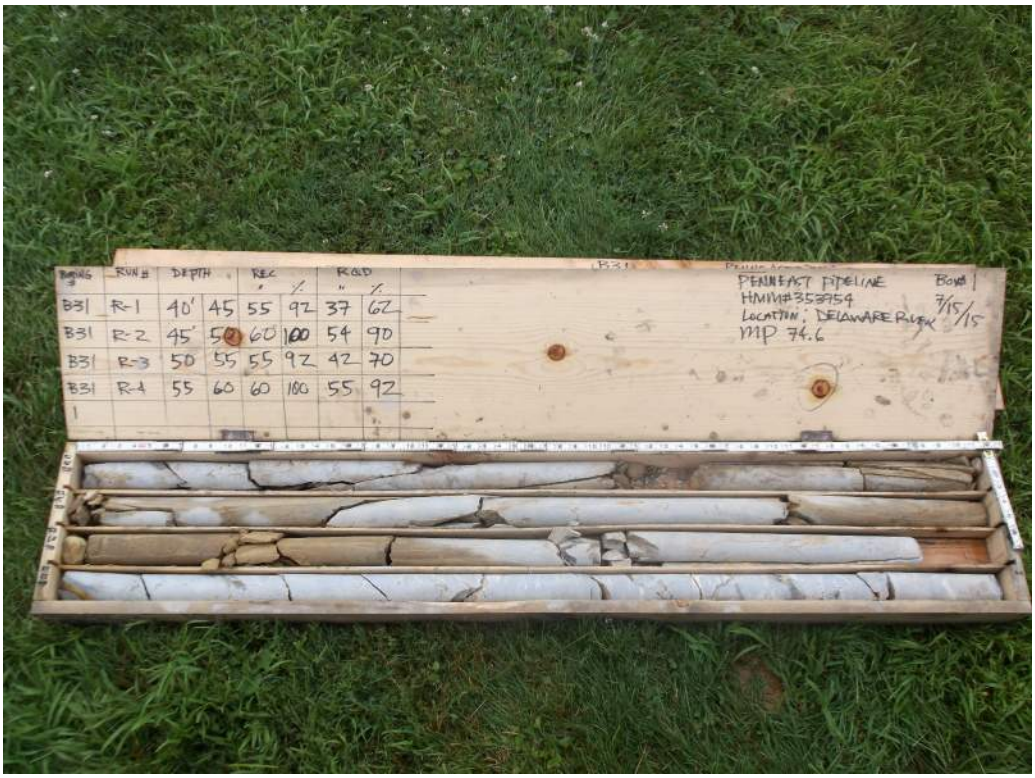


Figure B-31.1
B-31 Box 1 Run 1-4 Dry

Figure B-31.2
B-31 Box 1 Run 1-4 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-31

Figure B-31.3
B-31 Box 2 Run 5-8 Dry

Figure B-31.4
B-31 Box 2 Run 5-8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-31

Figure B-31.5
B-31 Box 3 Run 9-12 Dry

Figure B-31.6
B-31 Box 3 Run 9-12 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-31

Figure B-31.7
B-31 Box 4 Run 13-16 Dry

Figure B-31.8
B-31 Box 4 Run 13-16 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-31

Figure B-31.9
B-31 Box 5 Run 17-20 Dry

Figure B-31.10
B-31 Box 5 Run 17-20 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-31

Figure B-31.11
B-31 Box 6 Run 21-23 Dry

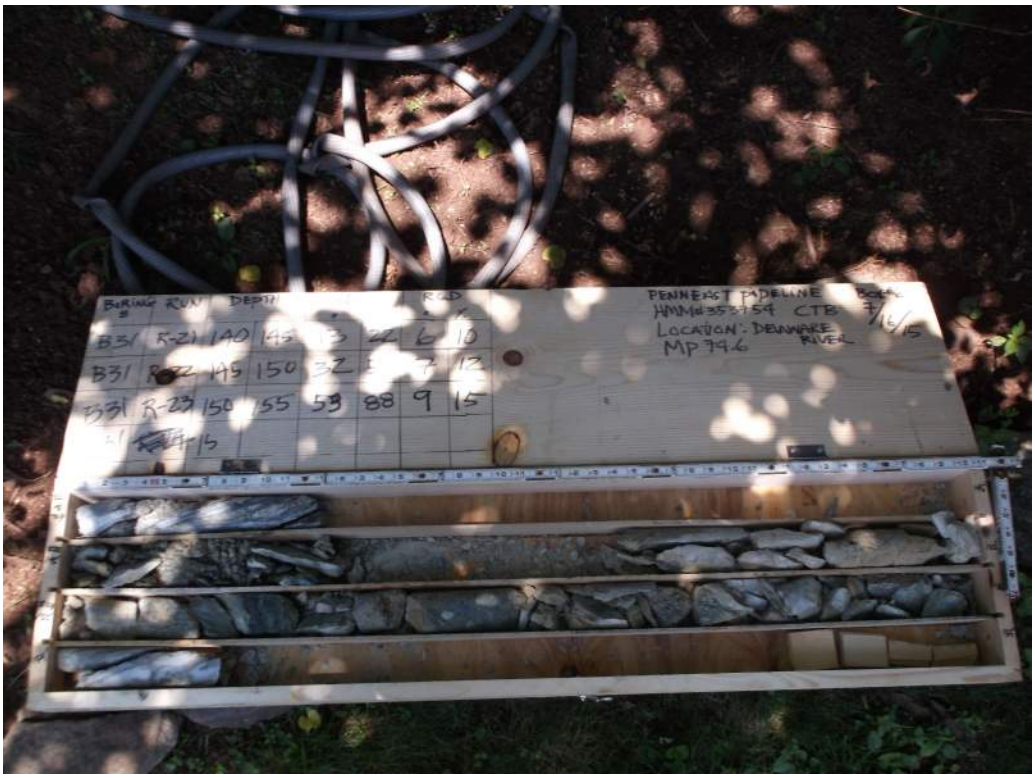


Figure B-31.12
B-31 Box 6 Run 21-23 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-31

Figure B-31.13
B-31 Box 7 Run 24-25 Dry

Figure B-31.14
B-31 Box 7 Run 24-25 Wet

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-32**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Chris Brillante
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	October 12, 2015 at 8:30 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	October 13, 2015 at 3:00 pm

Elevation: 150 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.584261 **E:** -75.1945667

Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-750X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ _____

Drilling Fluid: ☐ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size:

Casing Advance: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
150	S-1 0.0'- 2.0'	14	2 7 10 10			0.5 Top (6") - TOPSOIL	N	-	NP	N	
					FILL	Bottom (8") - Medium dense, Gray GRAVEL, dry (FILL)					
5	S-2 5.0'- 7.0'	6	6 2 3 4		FILL	Loose, Gray GRAVEL, dry (FILL)	N	-	NP	N	
10 140	S-3 10.0'- 12.0'	3	8 4 7 8		FILL	Medium dense, Gray GRAVEL, dry (FILL)	N	-	NP	N	
15	S-4 15.0'- 17.0'	6	15 34 20 13			Very dense, Gray ROCK fragments, dry (FILL)	N	-	NP	N	
						18.5					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-32**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
130	S-5 20.0'-22.0'	12	2 3 5 5		SM	Loose, Brown SAND with Silt, moist (SM)	N	-	NP	N	
						23.5					
25	S-6 25.0'-27.0'	3	8 10 8 8		GP	Medium dense, Gray GRAVEL, trace Sand, moist (GP)	N	-	NP	N	
30 120	30.0'-30.0'						-	-	-	-	5-foot casing broke off, but was recovered. No SPT can be taken.
						31.0					
35	S-7 35.0'-37.0'	14	21 28 25 31		SP-SM	Very dense, Brown SAND with Silt and Gravel, moist (SP-SM)	N	-	NP	N	
40 110	S-8 40.0'-42.0'	12	17 12 14 12		SP-SM	Medium dense, Brown SAND with Silt and Gravel, moist (SP-SM)	N	-	NP	N	
45	S-9 45.0'-47.0'	0	4 4 6 8			No Recovery	-	-	-	-	

NOTES:

PROJECT NO.: 353754

BORING NO.: B-32

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
50 100	S-10 50.0'-52.0'	12	38 14 40 50/0"		SP-SM	Very dense, Light brown Gravelly SAND with Silt, moist (SP-SM)	N	-	NP	N	Split Spoon bouncing (refusal).
						53.5					
55	S-11 55.0'-57.0'	16	4 4 4 4		CL-ML	Medium stiff, Brown Clayey SILT, trace Sand, wet (CL-ML)	N	L	M	L	PP = 0.5 tsf. TV = 1.5 tsf.
60 90	S-12 60.0'-62.0'	20	4 4 4 8		CL-ML	Medium stiff, Brown Clayey SILT with Gravel, trace Sand, wet (CL-ML)	N	L	M	L	PP = 0.5 tsf. TV = 1.0 tsf.
						63.5					
65	S-13 65.0'-67.0'	3	42 7 16 10		SP-SM	Medium dense, Brown SAND with Silt and Gravel, moist (SP-SM)	N	-	NP	N	
70 80	S-14 70.0'-72.0'	6	26 26 24 30		SP-SM	Very dense, Light brown Gravelly SAND with Silt, moist (SP-SM)	N	-	NP	N	
						73.5					
75	S-15	2	50/4"			Very dense, Gray ROCK fragments, moist	N	-	NP	N	Casing installed at 75 feet BGS.

NOTES:

PROJECT NO.: 353754 | BORING NO.: B-32

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

SOIL BORING LOG
(continued)

BORING NO.: **B-32**
Page **4** of **4**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	75.0'-77.0'					18-inch BOULDER					Split Spoon bouncing (refusal).
						78.5					
80 70	S-16 80.0'-82.0'	20	5 6 13 16		CL-ML	Very stiff, Brown Clayey SILT with Rock fragments, moist (CL-ML)	N	L	L	L	
85	S-17 85.0'-87.0'	18	12 14 15 18		CL-ML	Very stiff, Brown Clayey SILT with Rock fragments, moist (CL-ML)	N	L	L	L	
90 60	S-18 90.0'-92.0'	18	9 5 4 3		CL-ML	Stiff, Brown Clayey SILT, trace Rock fragments, moist (CL-ML)	N	L	L	L	
						93.5					
95	S-19 95.0'-97.0'	8	14 7 20 21			Medium dense, Light brown DECOMPOSED ROCK fragments with Silty Sand, moist	N	-	NP	N	All casing was recovered except the 5-foot casing lost at 75 feet BGS.
						97.0					
						Borehole was abandoned at 97 feet BGS due to loss of casing at 75 feet. Borehole grouted with bentonite and hole plug.					
100 50											

NOTES:

PROJECT NO.: **353754** BORING NO.: **B-32**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-32A**
Page **1** of **6**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Chris Brillante
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	October 14, 2015 at 7:45 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	October 16, 2015 at 10:00 am

Elevation: 150 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.584283 **E:** -75.194547 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-750X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ _____

Drilling Fluid: ☐ Bentonite ☑ Polymer ☑ Water ☐ None

Drill Rod Size:

Casing Advance: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
150	S-1 0.0'- 2.0'	10	3 7 9 13		FILL	0.3 Top (4") - TOPSOIL Bottom (6") - Medium dense, Gray GRAVEL, dry (FILL)	N	-	NP	N	
5											
10 140	S-2 10.0'- 12.0'	14	1 4 6 6		FILL	Loose, Gray GRAVEL, dry (FILL)	N	-	NP	N	3-inch Split Spoon used.
15											

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-32A**

Field Test Legend:
Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
130	20.0'-20.0'						-	-	-	-	Advanced casing to more stable soil. Loose, gravely soil causing casing to slip.
25											
30 120											
						32.5					
35	S-3 35.0'-37.0'	14	35 16 16 38		SP	Dense, Brown Gravelly SAND with Silt, moist (SP)	N	-	NP	N	
40 110	S-4 40.0'-42.0'	12	20 22 17 30		SP	Dense, Brown Gravelly SAND with Silt, moist (SP)	N	-	NP	N	
45						45.0					

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: **353754**

BORING NO.: **B-32A**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
50 100	S-5 50.0'-52.0'	16	8 10 17 20		CL-ML	Very stiff, Brown Clayey SILT with Sand, moist (CL-ML)	R	L	L	L	
55											
60 90	S-6 60.0'-62.0'	8	60 19 7 5		CL-ML	Very stiff, Brown Clayey SILT with Sand and Gravel, moist (CL-ML)	R	L	M	L	
65											
70 80	S-7 70.0'-72.0'	6	24 22 17 31		CL-ML	Very stiff, Brown Clayey SILT with Gravel, trace Sand, moist (CL-ML)	N	L	M	L	

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: 353754

BORING NO.: B-32A

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
75											
80 70	S-8 80.0'- 82.0'	19	24 14 46 38		CL-ML	Very stiff, Brown Clayey SILT with Gravel and Decomposed Rock Fragments and Sand, moist (CL-ML)	N	L	L	L	
85						85.0					
90 60	S-9 90.0'- 92.0'	16	2 3 12 13			Medium dense, Light brown DECOMPOSED ROCK fragments with Silt and Sand, moist	N	-	NP	N	
95	S-10 95.0'- 97.0'	1	50/1"			Very dense, Light brown DECOMPOSED ROCK fragments, moist	N	-	NP	N	Split Spoon bouncing (refusal).
100 50	S-11 100.0'-	1	50/3"			Very dense, Gray DECOMPOSED ROCK fragments, moist	N	-	NP	N	Split Spoon bouncing (refusal).

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: 353754

BORING NO.: B-32A

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	102.0'										
						103.5					
105	S-12 105.0'-107.0'	14	18 10 50/4"		CL-ML	Hard, Brown Clayey SILT, trace Gravel, wet (CL-ML)	R	L	M	L	Split Spoon bouncing (refusal).
110 40	S-13 110.0'-112.0'	0	50/0"			No Recovery	-	-	-	-	Split Spoon bouncing (refusal).
115	S-14 115.0'-117.0'	6	49 35 20 7		CL-ML	Hard, Brown Clayey SILT with Gravel and Decomposed Rock fragments, moist (CL-ML)	N	L	L	L	
120 30	S-15 120.0'-122.0'	6	10 2 14 15		CL-ML	Very stiff, Brown Clayey SILT with Gravel, moist (CL-ML)	N	L	M	L	
125	S-16 125.0'-127.0'	4	4 50/5"		CL-ML	Hard, Light gray Clayey SILT with Gravel, wet (CL-ML)	N	L	L	L	Split Spoon bouncing (refusal).

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: 353754

BORING NO.: B-32A

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
130 20	S-17 130.0'-132.0'	0	50/1"			No Recovery	-	-	-	-	Split Spoon bouncing (refusal).
135						135.0 Top of Rock at 135 feet BGS. See Rock Coring Log.					
140 10											
145											
150 0											

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: **353754**

BORING NO.: **B-32A**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD

CORE BORING LOG

BORING NO.: **B-32A**
Page **1** of **1**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Chris Brillante
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	October 14, 2015 at 7:45 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	October 16, 2015 at 10:00 am

Elevation: 150 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.: N:** 40.584283 **E:** -75.194547

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983
Rig Make & Model: CME-750X
Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS		(See Legend for Rock Description System)						
	1:45	135.0							135' - 137.5' - SOFT ZONE DOLOMITE, Gray, fine to medium grained, slightly weathered, weak, extremely close discontinuities								No water return. Used up to 1,125 Gallons of water.
	1:05																
	2:20		R-1	25 42%	14 23%	R2	SL										
	3:30								138.3' - 139.2' - Highly fractured zone	138.00	J	30	P,R	DS	T	N	
	2:30	140.0															
140 10	2:45	140.0							DOLOMITE with Chert, gray, fine grained, slightly weathered, medium strong								Used up to 1,125 Gallons of water. Water truck empty.
	2:30																
	2:50		R-2	49 82%	42 70%	R3	SL										
	3:00																
	3:10	145.0															
145	3:30	145.0							DOLOMITE with Chert, gray, fine grained, slightly weathered, medium strong, extremely close discontinuities								Used up to 1,125 Gallons of water.
	3:50																
	4:20		R-3	55 92%	53 88%	R3	SL										
	4:30																
	4:25	150.0							150.0	149.40	J	45	P,R	DS	T	N	Iron staining present. Vugs present.
150 0									End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite hole plug.								

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Figure B-32A.1
B-32A Box 1 Run1-3 Dry

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-33**
Page **1** of **1**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Jonathan Nelson/ Joelle Freeman
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	July 20, 2015 at 10:55 am
Driller/Helper:	Keith Parent /Eric Craig	**Date/Time Finished:**	July 30, 2015 at 3:30 pm

Elevation: 150 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.5837139 **E:** -75.1917056 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-850X

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ _____

Drilling Fluid: ☐ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size:

Casing Advance: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description* (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
150	S-1 0.0'- 2.0'	11	1 50 50/0"		GP-GM	0.5 Top (6") - TOPSOIL Bottom (5") - Very dense, Light gray GRAVEL with Silt and Sand (GP-GM)	-	-	-	-	
						4.0 Top of Rock at 4 feet BGS. See Rock Coring Log.					
5											
10 140											
15											

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
SS Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-33**

Field Test Legend:
Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-33**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Jonathan Nelson/ Joelle Freeman
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	July 20, 2015 at 10:55 am
Driller/Helper:	Keith Parent /Eric Craig	**Date/Time Finished:**	July 30, 2015 at 3:30 pm

Elevation: 150 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.: N:** 40.5837139 **E:** -75.1917056

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983 **Rig Make & Model:** CME-850X **Drilling Method:** Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	1.80	4.0							Granitic GNEISS, Light gray, coarse grain, fresh, strong, moderately spaced discontinuities								
5																	
	2.00																
	2.15		R-1	51 85%	50 83%	R4	FR										
										6.85	J	48	U,R	FR	PO	N	
										6.90	MB						7.8' - 9' Broken to fit into box.
	3.00																
										7.85	J	12	U,R	FR	VT	N	
	2.00									8.25	J	70	U,R	FR	O	N	
		9.0															
	4.70	9.0							Granitic GNEISS, Light gray, coarse grain, fresh, strong, moderately spaced discontinuities	9.00	J	11	U,R	FR	O	N	
10	140																
	3.00									10.00	J	31	U,R	FR	VT	N	
	3.10		R-2	57 95%	53 88%	R4	FR										
										12.00	V	50	P,R	FR	VT	CH	
	2.70									12.45	J	20	U,R	FR	T	N	
										12.80	J	37	U,R	DS	PO	N	
	3.20									12.90	J	38	U,R	DS	PO	N	
		14.0															
	2.15	14.0							Granitic GNEISS, Light gray, coarse grain, slightly weathered, strong, close spaced discontinuities	14.35	MB						Losing some water. Contains some Pyrite.
15										14.70	J	12	U,R	DS	PO	N	
	2.45								15.5' - 19' Highly fractured zone								
	3.00		R-3	43 71%	9 15%	R4	SL										
	7.15																
	3.10																
		19.0															
	3.70	19.0							Granitic GNEISS, Light gray, coarse grain, fresh, strong, close to moderately spaced discontinuities	19.25	V		U,R	DS	PO	N	
20	130																
	2.10									20.65	J		U,R	DS	PO	N	
										21.00	J		U,R	DS	T	N	
	3.20		R-4	60 100%	55 92%	R4	FR										
										21.95	J		U,R	DS	T	N	
	5.70																
										23.00	J		U,R	FR	T	N	
	4.70																
		24.0															Losing a lot of water at 23.5 feet

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
		24.0							Granitic GNEISS, Light gray, medium to coarse grain, slightly weathered, strong, moderately spaced discontinuities								BGS.
	4.30																
25																	
	5.10									25.50	V	87	U,R	DS	VT	CH	
										25.80	J	52	U,R	DS	T	N	
	6.50		R-5	60 100%	41 68%	R4	SL			26.70	J	61	S,R	DS	T	N	
	6.75									27.45	J	86	S,R	DS	PO	N	
	6.60																No water return from 28 to 29 feet BGS
		29.0															
	3.20	29.0							Granitic GNEISS, Light gray, medium to coarse grain, fresh, strong, moderately spaced discontinuities								No water return from 29 to 30 feet BGS.
30	120									29.65	J	53	U,Sm	FR	T	N	Consistent loss of water throughout run.
	7.30									30.55	V	37	U,Sm	FR	T	CH	
	8.15		R-6	53 88%	44 73%	R4	FR										
	7.10									32.55	J	39	U,Sm	FR	T	N	
										32.75	J	26	U,R	DS	T	N	
		34.0															
	9.75	34.0							Granitic GNEISS, Light gray, medium to coarse grain, fresh, strong, close spaced discontinuities	34.55	J	28	U,R	FR	T	N	Loss of water consistent throughout run.
35																	
	10.10									35.40	J	15	U,R	FR	T	N	
	6.50		R-7	60 100%	58 97%	R4	FR			36.10	V	23	U,R	FR	T	QZ	
										36.85	J	45	U,Sm	FR	T	CH	
	6.20									37.40	J	46	U,R	FR	T	N	
	5.90									38.05	J	0	U,R	FR	T	N	
		39.0															
	10.40	39.0							Granitic GNEISS, Light gray to gray, medium to coarse grain, fresh, strong, moderately spaced discontinuities	39.55	J	31	U,R	FR	T	N	Thick Quartz quantitites throughout run.
40	110																
	8.50																
	9.00		R-8	56 93%	55 91%	R4	FR										Loss of water from 41.5 to 42 feet BGS.
	9.00									42.15	J	41	U,R	FR	T	Py	
	9.50																
		44.0															
	12.30	44.0							Granitic GNEISS, Light gray to gray, medium to coarse grain, fresh, strong, moderately spaced discontinuities	44.15	J	45	P,R	FR	T	Py	High Quartz content.
45																	
	16.70									45.15	J	9	P,R	FR	T	N	
	16.50		R-9	60 100%	53 88%	R4	FR			46.25	J	41	U,R	FR	T	N	
										46.75	J	43	U,R	FR	T	N	
	5.50																
	2.40																
		49.0															
		49.0															

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
50	3.00								Granitic GNEISS, Gray to dark gray, medium to coarse grain, fresh, strong, moderately spaced discontinuities	49.80	J	61	U,R	FR	PO	N	
100	3.50									50.20	J	62	P,R	FR	PO	QZ	
	4.25		R-10	58 96%	49 81%	R4	FR										
	4.00									51.95	J	11	X,R	DS	O	N	Mica flakes from 52 to 54 feet BGS.
										52.10	J	9	U,R	DS	O	Py	
	4.10	54.0															
	3.00	54.0							Granitic GNEISS, Light gray, medium to coarse grain, fresh, strong, close to moderately spaced discontinuities								
55										54.70	J	19	U,R	FR	T	Fe	
	3.70									55.30	J	0	P,Sm	DS	O	N	
	7.00		R-11	60 100%	54 90%	R4	FR										
	8.90									57.35	J	36	U,R	FR	VT	N	
	7.10	59.0															
	6.10	59.0							Granitic GNEISS, Light gray to olive gray, medium to coarse grain, fresh, very strong, moderately spaced discontinuities	59.20	J	14	U,R	FR	T	N	
60																	
90	15.10																
	9.25		R-12	59 99%	51 84%	R5	FR			61.05	J	34	S,R	FR	T	Py	
	20.70								62.5' - 63.5' Pegmatitic Granite	62.45	J	9	U,R	FR	T	N	
	39.10	64.0								63.45	J	0	X,R	FR	T	N	
	4.10	64.0							Granitic GNEISS, Greenish gray to olive gray, medium to coarse grain, fresh, strong, wide spaced discontinuities								Had to break rock core to fit into box.
65																	
	4.50									65.80	J	48	S,R	FR	T	N	
	3.90		R-13	60 100%	60 100%	R4	FR			66.70	J	13	U,Sm	FR	T	N	
	4.10																
	5.00	69.0															
	2.10	69.0							Granitic GNEISS, Greenish gray to olive green, medium to coarse grain, fresh, strong, close to moderately spaced discontinuities	69.55	J	53	U,Sm	FR	T	N	Had to break rock core to fit into box.
70																	
80	5.15																
	8.90		R-14	48 100%	46 96%	R4	FR										
	14.00	73.0								71.90	J	64	U,Sm	FR	PO	CH	
										72.35	J	23	U,Sm	FR	PO	N	
	12.25	73.0							Granitic GNEISS, Greenish gray to olive green, medium to coarse grain, fresh, strong, close to moderately spaced discontinuities	72.85	J	38	U,R	FR	T	QZ	
	15.30																

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	5.20		R-15	60 100%	55 91%	R4	FR			75.20	J	59	U,R	FR	T	N	
	6.00									76.65	J	18	U,Sm	FR	T	N	
	6.95									77.35	J	29	P,R	FR	T	N	
		78.0								77.70	J	90	X,R	DS	PO	Ca	
		78.0							Granitic GNEISS, Dark gray to greenish gray, medium to coarse grain, fresh, strong, close to moderately spaced discontinuities								
	5.50																
	4.50									79.10	J	33	U,Sm	FR	T	N	
80	70																
	4.20		R-16	60 100%	48 80%	R4	FR			80.10	J	62	U,R	DS	T	Fe	
										80.55	J	59	U,R	FR	PO	Ca	
										81.00	J	0	U,R	FR	PO	Py	
	6.15									81.60	J	11	U,Sm	FR	T	Ca	
	5.35																
		83.0								82.65	J	20	U,Sm	FR	T	Py	
		83.0							Granitic GNEISS, Olive gray to greenish gray, medium to coase grain, fresh, strong, close to moderately spaced discontinuities								
	4.75																
	4.70																
85										84.75	J	12	U,Sm	FR	T	Ca	
										85.05	J	14	U,Sm	FR	T	N	
	5.30		R-17	58 96%	41 68%	R4	FR			85.55	J	48	S,Sm	FR	T	N	
	7.40									86.55	J	44	P,R	FR	PO	N	
										86.90	J	0	U,R	FR	T	N	
	12.50																
		88.0															
		88.0							Granitic GNEISS, Light gray to gray, medium to coarse grain, fresh, strong, wide spaced discontinuities								
	3.60																
	3.50																
90	60																
	3.05		R-18	59 98%	60 100%	R4	FR										
	4.20									91.40	J	14	U,Sm	FR	T	N	
										91.75	J	58	U,R	FR	T	N	
	3.70																
		93.0															
		93.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, strong, moderately spaced discontinuities								
	5.25																
										93.95	J	0	U,R	FR	T	N	
	6.30									94.40	J	0	U,R	FR	T	N	
95			R-19	48 100%	48 100%	R4	FR			95.00	J	0	U,R	FR	T	N	
	10.10																
	10.20																
		97.0															
		97.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, strong, extremely close to close spaced discontinuities 97.15' - 97.5' Highly fractured zone								Possible loss of Rock from 97 to 101 feet BGS.
	1.70									97.15	J	0	U,R	FR	EW	N	
										97.50	J	0	U,R	FR	EW	N	
	2.50																
	3.70		R-20	26 44%	12 19%	R4	FR										
100	50																
	3.70																

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.70									100.50	MB						Rock was stuck inside barrel from 100.5 to 101.1 feet BGS.
	7.75	102.0								101.10	J	5	U,R	FR	T	N	
										101.70	J	0	P,Wa	FR	T	N	
	4.75	102.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, strong, close spaced discontinuities 104.9' - 107' Rock fragments	102.50	J	45	U,R	DS	O	Fe	
	9.80									103.15	J	0	U,R	FR	T	N	
										103.50	J	0	U,R	FR	T	N	
	9.80		R-21	48 80%	21 35%	R4	FR			103.90	J	35	U,R	FR	O	N	
										104.20	J	0	U,R	FR	T	N	
105										104.90	J	0	U,R	FR	T	N	
	12.70																
	16.90	107.0															
	1.10	107.0							Granitic GNEISS, Pinkish gray to light gray, medium to coarse grain, fresh, strong, close spaced discontinuities	107.70	V	54	X,R	FR	O	Ca	0.25" thick crystals.
										107.95	V	33	X,R	FR	O	Ca	
	1.30									108.75	J	20	P,R	FR	T	N	
										109.10	J	45	P,R	DS	T	Fe	
	2.90		R-22	55 91%	43 71%	R4	FR			109.25	J	33	P,Sm	DS	T	Fe	
110	40									110.10	J	28	P,Sm	FR	O	Ca	
	2.35									110.85	J	42	S,R	DS	T	Ca	
	2.30	112.0								111.30	J	71	U,R	DS	T	N	
	1.70	112.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, medium strong, close spaced discontinuities 113.3' - 114.05' Rock fragments, moderately weathered, Chlorite on freshly broken surfaces	112.95	J	58	P,R	DS	T	N	
	2.25									113.30	J	0	U,R	DG	O	N	
										114.05	J	2	U,R	DE	O	N	
	3.25		R-23	60 100%	42 70%	R3	FR			114.50	J	50	U,R	DS	O	Fe	
115										114.75	J	35	U,R	DS	O	Fe	
	2.00									115.05	J	35	U,R	DS	O	N	
										115.20	J	40	U,R	DS	O	N	
	2.20	117.0								116.10	J	25	U,R	DS	O	N	
	3.40	117.0							Granitic GNEISS, Gray to light greenish gray, medium to coarse grain, fresh, strong, very close to wide spaced discontinuities 121.85' - 122' Rock fragments	117.30	J	35	U,R	FR	T	N	
	4.40									117.95	J	14	U,R	FR	T	N	
	5.20		R-24	60 100%	45 74%	R4	FR										
120	30																
	6.00																
										120.90	V	108	U,Sm	DG	T	Ca	
	6.30	122.0								121.20	J	0	U,R	DS	O	N	
										121.55	J	80	S,R	DG	T	CH	
										121.85	J	35	S,R	DS	O	N	
	4.50	122.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, medium strong, close to moderately spaced discontinuities	122.15	J	20	P,Sm	FR	O	N	
	4.30									122.90	J	18	P,Sm	FR	O	N	
										123.40	J	25	P,Sm	DG	T	N	
										123.75	J	5	P,Sm	DS	O	Fe	
	4.50		R-25	55 91%	52 86%	R3	FR			124.20	J	48	P,Sm	DS	T	Fe	124.65' - 126.55' Broken with hammer to fit into box.
125										124.65	J	5	P,Sm	DG	O	N	
	5.70																

NOTES:

PROJECT NO.: **353754**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	8.50	127.0															
	13.9	127.0							Granitic GNEISS, Gray to light pinkish gray, medium to coarse grain, fresh, medium strong, close to moderately spaced discontinuties								
	10.1									128.05	J	12	S,R	FR	T	N	
	14.2		R-26	59 98%	53 88%	R3	FR			129.15	J	15	U,R	FR	T	N	129.6' - 131.55' Broken with hammer to fit into box.
130 20										129.60	J	40	S,Sm	FR	T	N	
	15.1																
	14.5	132.0								131.55	J	40	S,R	DG	T	N	
										131.70	J	40	U,R	FR	O	Fe	
	8.30	132.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, medium strong, very close to wide spaced discontinuities	132.50	J	62	S,R	FR	T	N	
										132.90	J	52	U,R	FR	T	N	
	5.20									133.65	J	28	U,R	FR	T	N	
	5.50		R-27	58 97%	53 88%	R3	FR			134.35	J	45	U,R	DS	O	N	134.6' - 136.7' Broken with hammer to fit into box.
135										134.60	J	32	P,R	DG	T	N	
	4.70																
	4.70	137.0								136.70	J	48	P,Sm	DG	O	CH	
	10.50	137.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, medium strong, close to moderately spaced discontinuities	137.40	J	42	P,R	FR	T	N	
	9.50									138.45	J	38	U,R	DS	T	N	138.45' - 140.4' Broken with hammer to fit into box.
	10.20		R-28	60 100%	55 91%	R3	FR										
140 10																	
	22.20									140.40	J	44	P,Sm	FR	T	N	
	25.50	142.0								141.30	J	32	P,R	FR	T	N	
	10.60	142.0							Granitic GNEISS, Gray to light gray, medium to coarse grain, fresh, medium strong, very close to wide spaced discontinuities 142' - 142.45' Highly fractured zone	142.45	J	10	S,R	FR	O	N	Switched to new diamond bit, improved drilling rate dramatically.
	2.30									143.10	MB						
	2.40		R-29	59 98%	46 77%	R3	FR			144.55	J	26	U,R	DS	T	Ca	
145																	
	2.60									145.65	J	70	P,Sm	DS	T	N	
	2.50	147.0								145.70	J	22	P,R	FR	T	N	
	2.90	147.0							Granitic GNEISS, Gray to light pinkish gray, medium to coarse grain, fresh, medium strong, very close to wide spaced discontinuities 148.2' - 148.5' Rock fragments	147.55	J	72	P,R	FR	T	N	
										147.90	J	32	P,Sm	FR	T	N	
	2.60									148.20	J	50	P,Sm	DG	O	N	
										148.50	J	17	U,R	DS	O	Fe	
										148.85	J	16	P,R	DS	O	N	
	2.50		R-30	58 97%	50 83%	R3	FR			149.30	J	39	P,R	DS	T	Fe	
150 0																	
	2.40																
	4.20																

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-33**
Page **7** of **7**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	4.20	152.0															
	4.50	152.0							Granitic GNEISS, Gray to light pinkish gray, medium to coarse grain, fresh, medium strong, close to wide spaced discontinuities 156.3' - 156.4' Highly fractured zone	152.35	J	24	U,R	FR	O	Ca	Persistent healed joints throughout, easily broken by hand.
	4.20									153.00	J	8	S,R	FR	O	N	
	4.70		R-31	60 100%	59 98%	R3	FR			154.00	J	29	S,R	FR	T	N	
155										154.70	J	40	P,R	FR	T	N	
	5.50																
	5.30	157.0								156.30	J	38	P,R	FR	O	N	
	5.70	157.0							Granitic GNEISS, Gray to light pinkish gray, medium to coarse grain, fresh, medium strong, close to wide spaced discontinuities 158.75' - 159.1' Highly fractured zone	157.70	J	19	P,Sm	DS	O	Fe	Persistent healed joints throughout, easily broken by hand.
	5.20									158.25	J	40	U,R	DS	O	Li	
										158.55	J	70	S,R	DS	O	Fe	
	5.80		R-32	60 99%	43 71%	R3	FR			159.15	J	0	U,Sm	FR	O	N	
160 -10										159.70	J	35	U,R	FR	O	N	
	6.00									160.50	J	34	P,R	DS	T	Ca	
	5.10	162.0								161.00	J	45	U,R	DG	O	Fe	
	4.00	162.0							Granitic GNEISS, Gray to light pinkish gray, medium to coarse grain, fresh, medium strong, close to wide spaced discontinuities	162.30	J	12	U,R	FR	O	N	
										162.35	J	42	P,R	FR	O	N	
	3.60		R-33	32 88%	18 50%	R3	FR			163.45	J	28	U,Sm	FR	O	Ca	
										163.80	J	18	P,R	DG	O	Ca	
	3.90	165.0							165.0	164.35	J	15	U,R	DS	O	Ca	
165									End of Boring at 165 feet BGS. Borehole grouted with cement and bentonite hole plug.								
170 -20																	
175																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-33**

Figure B-33.1
B-33 Box 1 Runs 1-3 Dry

Figure B-33.2
B-33 Box 1 Runs 1-3 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-33

Figure B-33.3
B-33 Box 2 Runs 4-6 Dry

Figure B-33.4
B-33 Box 2 Runs 4-6 Wet

Figure B-33.5
B-33 Box 3 Runs 7-9 Dry A

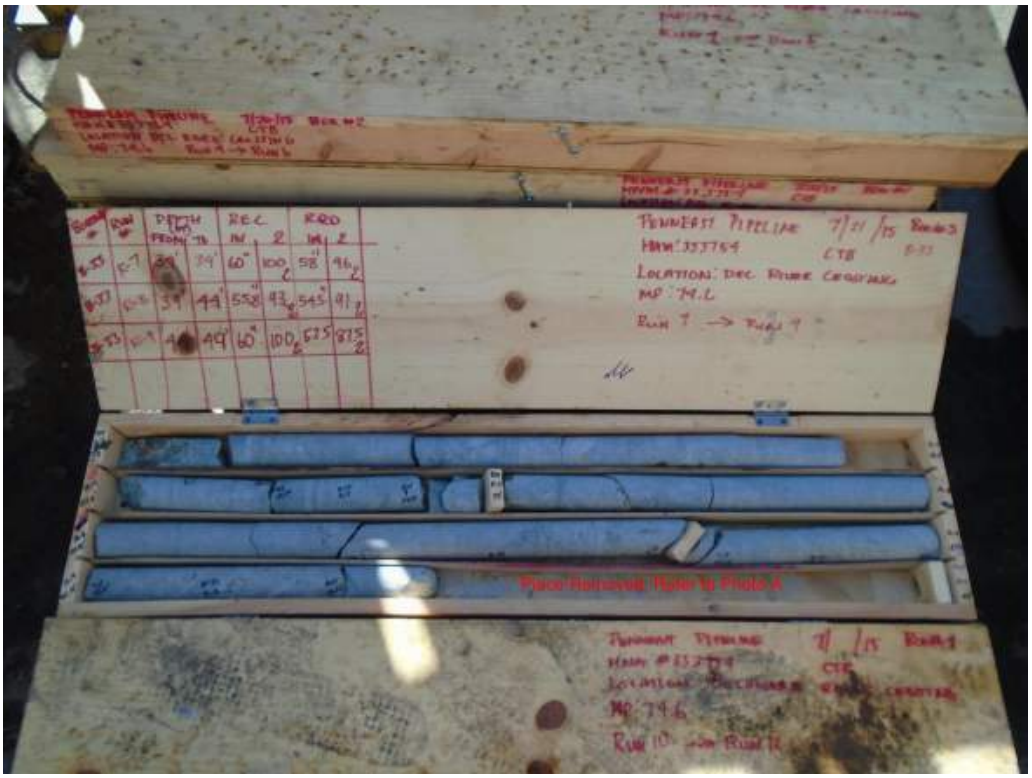


Figure B-33.6
B-33 Box 3 Runs 7-9 Dry B

Figure B-33.7
B-33 Box 3 Runs 7-9 Wet A

Figure B-33.8
B-33 Box 3 Runs 7-9 Wet B

Figure B-33.9
B-33 Box 4 Runs 10-12 Dry

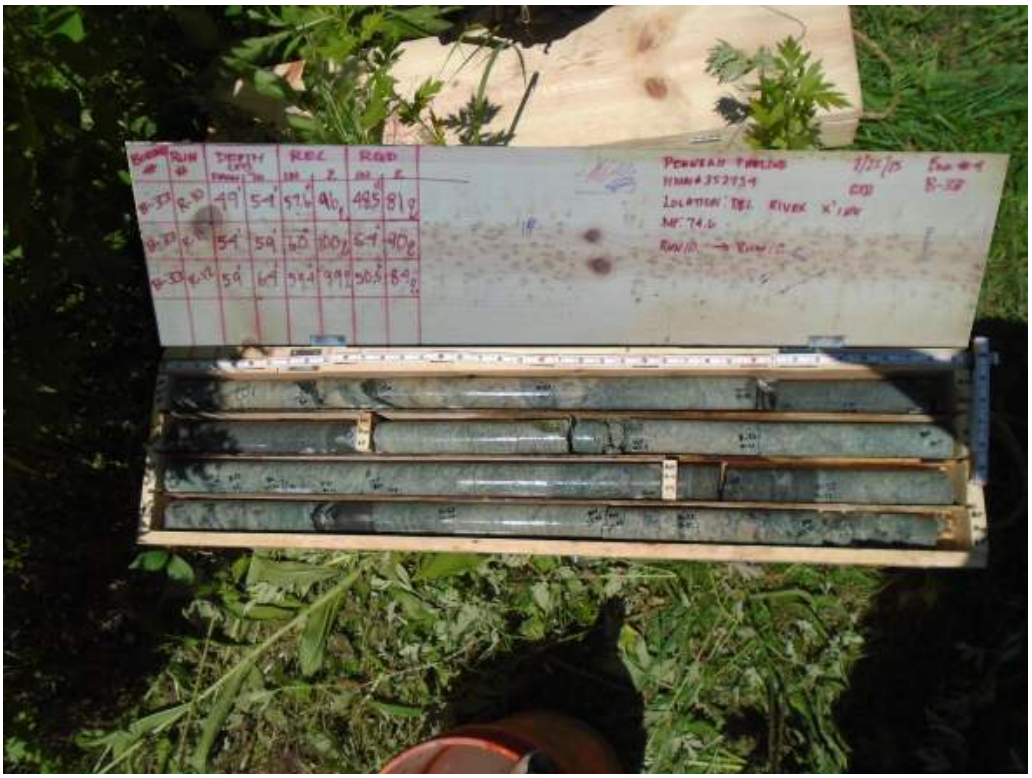


Figure B-33.10
B-33 Box 4 Runs 10-12 Wet

Figure B-33.11
B-33 Box 5 Runs 13-15 Dry

Figure B-33.12
B-33 Box 5 Runs 13-15 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-33

Figure B-33.13
B-33 Box 6 Runs 16-18 Dry

Figure B-33.14
B-33 Box 6 Runs 16-18 Wet

Figure B-33.15
B-33 Box 7 Runs 19-21 Dry

Figure B-33.16
B-33 Box 7 Runs 19-21 Wet

Figure B-33.17
B-33 Box 8 Runs 22-24 Dry

Figure B-33.18
B-33 Box 8 Runs 22-24 Wet

Figure B-33.19
B-33 Box 9 Runs 25-27 Dry

Figure B-33.20
B-33 Box 9 Runs 25-27 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-33

Figure B-33.21
B-33 Box 10 Runs 28-30 Dry

Figure B-33.22
B-33 Box 10 Runs 28-30 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-33

Figure B-33.23
B-33 Box 11 Runs 31-33 Dry

Figure B-33.24
B-33 Box 11 Runs 31-33 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-33

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-34**
Page **1** of **5**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Delaware River Crossing, NJ/ PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Jonathan Nelson
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	July 14, 2015 at 8:00 am
Driller/Helper:	Keith Parent /Eric Craig	**Date/Time Finished:**	July 14, 2015 at 3:30 pm

Elevation: 157 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.583463 **E:** -75.189264 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-75

☑ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐ _____

Drilling Fluid: ☐ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size:

Casing Advance: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1A 0.0'- 1.0'	12	4 4			0.3 4" GRAVEL, Balck asphalt fragments 8" TOPSOIL 1.0	-	-	-	-	
	S-1B 1.0'- 2.0'		2 2		ML	Medium stiff, Yellowish red SILT, dry (ML)	N	-	NP	N	
5 150	S-2 5.0'- 7.0'	21	1 1 1 2		ML	Soft, Yellowish red SILT, wet (ML) 8.5	N	-	NP	N	
10	S-3 10.0'- 12.0'	16	12 10 7 9		SP	Medium dense, Yellowish red SAND, trace Silt, wet (SP)	N	-	NP	N	
15 140	S-4 15.0'- 17.0'	15	16 14 11 13		SP	Medium dense, Dark brown to yellowish red SAND, trace Silt, wet (SP)	N	-	NP	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-34**

Field Test Legend:
Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	S-5A 20.0'- 21.0'	16.5	5 4		SP	Top (12") - Loose, Yellowish red SAND, trace Silt, wet (SP)	N	-	NP	N	20' - 30' Installed 3" casing.
						21.0					
	S-5B 21.0'- 22.0'		5 5		ML	Bottom (3.5") - Medium stiff, Yellowish red SILT, wet (ML)	-	-	-	-	
25	S-6 25.0'- 27.0'	15	2 2 7 25		ML	Top (9") - Medium stiff, Yellowish red SILT with Sand, wet (ML)	N	-	NP	N	
						26.5					
130						Bottom (6") - Weathered QUARTZ fragments					
30	S-7 30.0'- 32.0' 31.0'-'	6	50/4"			QUARTZITE, Gray, fine to medium grain, fresh 30' - 35' Possible Boulder	N	-	NP	N	4" Rock fragments. Refusal at 30.5 feet BGS.
						31.2' to 31.4' - Brownish yellow QUARTZITE fragments	-	-	-	-	5th gear at 30.4 feet BGS. Loss of water at 31 to 35 feet BGS.
						35.0					
35	S-8A 35.0'- 36.0'	23	9 10		SP	Top (12") - Medium dense, Yellowish red SAND, trace Silt, wet (SP)	N	-	NP	N	
						36.0					
	S-8B 36.0'- 37.0'		13 12		GM	Bottom (12") - Medium dense, Brownish yellow Silty GRAVEL, trace Sand, wet (GM)	-	-	-	-	
120						38.5					
40	S-9A 40.0'- 41.0'	16	8 21		ML	Top (10") - Hard, Brownish yellow Sandy SILT with Gravel, dry (ML)	N	-	NP	N	
						41.0					
	S-9B 41.0'- 42.0'		42 49			Bottom (6") - Decomposed Rock fragments	-	-	-	-	
						43.5					
45	S-10A 45.0'- 46.0'	16	12 10		ML	Hard, Brownish yellow SILT with Gravel, moist (ML)	N	-	NP	N	
						46.0					
	S-10B 46.0'- 47.0'		11 17		SM	Medium dense, Brownish yellow Silty SAND, trace Gravel, moist (SM)	-	-	-	-	
110											

NOTES:

PROJECT NO.: 353754 | BORING NO.: B-34

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
						48.5					
50	S-11 50.0'- 52.0'	16	30 15 18 23		ML	Hard, Brownish yellow SILT, trace Gravel (ML)	N	-	NP	N	
						53.5					
					SW-SM	Top (6") - Dense, Brownish yellow SAND with Silt and Gravel, moist (SW-SM)					
55	S-12A 55.0'- 56.0'	21	21 26				N	-	NP	N	
						56.0					
	S-12B 56.0'- 57.0'		29 45		SM	Bottom (15") - Dense, Brownish yellow Silty SAND (SM)	-	-	-	-	
100	57.0'-'						-	-	-	-	
						58.5					
60	S-13 60.0'- 62.0'	21.5	8 10 25 25		CL	Hard, Brownish yellow Lean CLAY, moist (CL)	N	M	M	M	PP = 2.2 tsf. TV = 0.34 tsf.
65	S-14 65.0'- 67.0'	5	8 11 12 24		CL	Very stiff, Brownish yellow Lean CLAY, moist (CL) Gravel wash at top 2"	N	M	M	M	PP = 1.3 tsf. TV = 0.29 tsf.
90											
						68.5					
70	S-15A 70.0'- 71.0'	23	4 5		ML	Top (7") - Stiff, Dark brown SILT with Clay, moist (ML)	N	-	NP	N	
						70.6					
	S-15B 71.0'- 72.0'		5 5			Bottom (14") - Medium dense, Brownish yellow weathered rock fragments with Sand, with Silt, moist	-	-	-	-	
						72.5					
	U-1 73.0'- 75.0'	16	P U S H		ML	Brownish yellow SILT, dry (ML)	-	-	-	-	
75	S-16	20	3		ML	Stiff, Light gray to brown SILT with Sand and Clay, moist (ML)	N	-	NP	N	

NOTES:

PROJECT NO.: 353754 BORING NO.: B-34

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
	75.0'-77.0'		10 8 11								
80											
80	S-17 80.0'-82.0'	19	11 21 22 50/1"		ML	Hard, Brownish yellow Gravelly SILT with Sand, moist (ML)	N	-	NP	N	Decomposed Rock fragments.
85	S-18 85.0'-87.0'	16	25 18 19 14		ML	Hard, Brownish yellow Gravelly SILT, moist (ML)	N	-	NP	N	
70											
90	S-19 90.0'-92.0' 91.0'-'	21.5	29 28 40 50		ML	Hard, Brownish yellow Gravelly SILT, moist (ML)	N -	- -	NP -	N -	 Weathered Rock fragments from 91.7 to 92 feet BGS.
95	S-20 95.0'-97.0'	17	13 9 11 10		ML	Very stiff, Brownish yellow SILT, trace Gravel, trace Sand, moist (ML)	N	-	NP	N	
60											
100	S-21 100.0'-102.0'	10	3 4 10 8		ML	Stiff, Brownish yellow Gravelly SILT with Clay, moist (ML)	N	-	NP	N	No Return. Loss of water 103 to 105 feet BGS.

NOTES:

PROJECT NO.: 353754 | BORING NO.: B-34

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

SOIL BORING LOG
(continued)

BORING NO.: **B-34**
Page **5** of **5**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks*
105						105.0					
	105.0'-'					Possible 3-foot VOID	-	-	-	-	105' - 108' - Split Spoon dropped when attempting to take the SPT sample.
50						108.0					
	S-22A 108.0'-109.0'	23	13 22		ML	Hard, Brown Sandy SILT, wet, Clay pockets (ML)	N	-	NP	N	
	S-22B 109.0'-110.0'		24 17		CH	109.5 Hard, Fat Clay with Decomposed Rock fragments (CH)	N	M	M	N	
110						110.0 End of Boring at 110 feet BGS. Borehole grouted with cement and bentonite hole plug.					
115											
40											
120											
125											
30											
130											

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-34**

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Hatch Mott MacDonald

SOIL BORING LOG

BORING NO.: **B-HR-4**
Page **1** of **1**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Easton Road, Durham, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Chris Brillante
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	September 21, 2015 at 8:30 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	September 22, 2015 at 10:00 am

Elevation: 247 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.58529 **E:** -75.20224 **Horizontal Datum:** NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-750X

☐ Truck ☐ Tripod ☐ Cat-Head
☑ ATV ☐ Geoprobe ☑ Winch
☐ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ _____ ☐ Cutting Head

Hammer Type
☐ Safety
☐ Doughnut
☑ Automatic
☐ _____

Drilling Fluid
☐ Bentonite
☐ Polymer
☑ Water
☐ None

Drill Rod Size:
Casing Advance
Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description* (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	16	4 4 4 3		SM	Loose, Brown Silty SAND, dry (SM)	N	-	NP	N	
	S-2 2.0'- 4.0'	12	5 45 50/3"		SM	Very dense, Brown Silty SAND with Rock Fragments, dry (SM)	N	-	NP	N	
						4.0					
	S-3 4.0'- 6.0'	6	35 50/1"			Gray ROCK FRAGMENTS, trace Silty Sand, moist	N	-	NP	N	
5											
	S-4 6.0'- 8.0'	6	26 50/3"			Gray ROCK FRAGMENTS	N	-	NP	N	
240						8.0					
						Top of rock at 8 feet BGS. See Rock Coring Log.					
10											
15											
230											

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
SS Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-HR-4**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

Hatch Mott MacDonald

CORE BORING LOG

BORING NO.: **B-HR-4**
Page **1** of **2**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Easton Road, Durham, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Chris Brillante
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	September 21, 2015 at 8:30 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	September 22, 2015 at 10:00 am

Elevation: 247 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.: N:** 40.58529 **E:** -75.20224

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983
Rig Make & Model: CME-750X
Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	1:05	8.0	R-1	20 83%	11 46%	R3	SL		DOLOMITE, gray, fine to medium grained, slightly weathered, medium strong, close to very close discontinuities	8.70	J	30	P,R	DS	PO	N	
	1:00	10.0								9.00	J	35	P,R	DS	O	N	
10	1:25	10.0							DOLOMITE, gray, fine to medium grained, slightly weathered, med strong, close to very close discontinuities								Quartz deposits and small vugs present.
	1:25									11.10	J	35	P,R	DS	MW	N	
										11.60	J	5	P,R	DS	MW	N	
	1:45		R-2	38 63%	14 23%	R3	SL		11.9' - 13.2' - Rock Fragments								
	1:35																
	1:40	15.0															
15	1:15	15.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong, close to very close discontinuities	15.40	J	5	P,R	DS	PO	N	Quartz deposits present.
										15.70	J	5	P,R	DS	PO	N	
	1:30																
230	1:25		R-3	21 35%	9 15%	R3	SL										
	1:25																
	1:35	20.0															
20	1:18	20.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong 20.0' - 20.6' - Rock Fragments								
	1:03																
	1:47		R-4	25 42%	13 22%	R3	SL										
	1:40																
	1:43	25.0															
25	1:17	25.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong, close to very close discontinuities	25.40	J	15	P,R	DS	PO	N	
	1:14								26.2' - 26.9' - Rock Fragments								
220	4:00		R-5	36 60%	15 25%	R3	SL		27.1' - 27.6' - Rock Fragments								

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
		-			

Notes:

Hatch Mott MacDonald

CORE BORING LOG
(continued)

BORING NO.: **B-HR-4**
Page **2** of **2**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2:05																
	1:17	30.0							30.0								
30		30.0							30.0' - 31.5' - Rock Fragments 31.5' - 35.0' - VOID/SOFT ZONE								
	0:57																
	0:59																
	0:46		R-6	14 23%	0 0%	R1	M										
	0:41																
	0:38	35.0							35.0								
35		35.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong, close to very close discontinuities 35.0' - 35.4' - Rock Fragments								
	0:29									36.10	J	5	S,R	DS	O	N	
	1:14																
210	1:08		R-7	39 65%	29 48%	R3	SL			37.30	J	30	P,R	DS	O	N	
	1:27								37.8' - 38.1' - Rock Fragments								
	1:18	40.0															
40		40.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong, very close discontinuities								
	1:00									40.30	J	10	P,R	DS	O	N	
	1:03								41.5' - 41.7' - Rock Fragments								
	1:19		R-8	48 80%	37 62%	R3	SL										
	0:52																
	1:50	45.0															
45		45.0							DOLOMITE, light brown, fine to medium grained, slightly weathered, medium strong, very close discontinuities								
	2:03																
	2:08								46.5' - 46.8' - Rock Fragments	46.10	J	35	P,R	DS	T	N	
200	1:57		R-9	58 97%	52 87%	R3	SL										
	1:42																
	2:27	50.0							50.0								
50									End of Boring at 50 feet BGS. Borehole grouted with cement and bentonite hole plug.								

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-HR-4**

Figure B-HR-4.1
B-HR-4 Box 1 Runs 1-5 Dry

Figure B-HR-4.2
B-HR-4 Box 1 Runs 1-5 Wet

Hatch Mott MacDonald	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-HR-4

Figure B-HR-4.3
B-HR-4 Box 2 Runs 6-9 Dry

Figure B-HR-4.4
B-HR-4 Box 2 Runs 6-9 Wet

Hatch Mott MacDonald	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-HR-4

Appendix C

Installation Load and Stress Evaluation

MOTT MACDONALD

Horizontal Directional Drilling
Minimum Radius Calculations - MAOP Based

Project Name:	PennEast Pipeline	By:	S. Crouse
Project No:	353754	Checked:	G. Duyvestyn
HDD Name:	Delaware River	Owner:	PennEast Pipeline
Location:	Northampton County, PA/ Hunterdon County, NJ	Date:	10/27/2015

References:

1. ASME/ANSI B31.4 section 402.3.2
2. ASME/ANSI B31.8 section 833.3
3. ASME/ANSI B31.8 section 833.4
4. ASME/ANSI B31.4 section 402.3.1

Design Parameters

Pipe Diameter	36	inches
Wall Thickness	0.762	inches
D/t Ratio	47	
MAOP	1,480	psi
SMYS	70,000	psi
Modulus of Elasticity	2.92E+07	psi
Design Factor	0.5	

Hoop Stress Calculation

Hoop Stress = (MAOP * Pipe Diameter) / (2 * Wall Thickness)
Calculated Hoop Stress 34,961 psi

Longitudinal Stress Calculation

Longitudinal Stress = Hoop Stress / 2
Calculated Longitudinal Stress 17,480 psi

Allowable Stress Calculation

Allowable Stress = Design Factor * SMYS
Calculated Allowable Stress 35,000 psi

Bending Stress Calculation

Bending Stress = Allowable Stress - Longitudinal Stress
Calculated Bending Stress 17,520 psi

Minimum Bend Radius Calculation

Minimum Radius = (Modulus of Elasticity * Pipe Diameter) / (2 * Bending Stress)
Calculated Minimum Radius 2,500 feet

MOTT MACDONALD

Horizontal Directional Drilling
Operating Stress Analysis - MAOP Based

Project Name: PennEast Pipeline
Project No: 353754
HDD Name: Delaware River
Location: Northampton County, PA/ Hunterdon County, NJ

By: S. Crouse
Checked: G. Duyvestyn
Owner: PennEast Pipeline
Date: 10/27/2015

References:

1. ASME/ANSI B31.4 section 402.3.2
2. ASME/ANSI B31.8 section 833.3
3. ASME/ANSI B31.8 section 833.4
4. ASME/ANSI B31.4 section 402.3.1

Design Parameters

Pipe Diameter	36	inches
Wall Thickness	0.762	inches
D/t Ratio	47	
MAOP	1,480	psi
SMYS	70,000	psi
Modulus of Elasticity	2.92E+07	psi
Combined Design Factor	0.5	
Poisson's Ratio	0.30	
Minimum Radius of Curvature	2,500	feet
Radius of Curvature Factor	104%	
Design Minimum Allowable Radius of Curvature	2,600	feet
Coefficient of Thermal Expansion	6.50E-06	in/in/°F
Assumed Installation Temperature	45	°F
Assumed Operating Temperature	120	°F

Longitudinal Stress from Bending

Longitudinal Stress from Bending 16,846 psi
Percent SMYS 24.1%

Hoop Stress

Calculated Hoop Stress 34,961 psi — Should be less than Design Factor x SMYS of 35,000 psi
Percent SMYS 49.9% — Limited by Design Factor according to 49 CFR 192.11

Longitudinal Tensile Stress from Hoop Stress

Longitudinal Tensile Stress from Hoop Stress 10,488 psi
Percent SMYS 15.0%

Longitudinal Stress from Thermal Expansion

Longitudinal Stress from Thermal Expansion -14,235 psi
Percent SMYS 20.3% — Limited by 90% SMYS by ASME/ANSI B31.4 section 402.3.2

Net Longitudinal Stress (Compression Side of Curve)

Net Longitudinal Stress (Compression Side of Curve) -20,593 psi
Percent SMYS 29.4% — Limited by 90% SMYS by ASME/ANSI B31.8 section 833.3

Net Longitudinal Stress Tension Side of Curve)

Net Longitudinal Stress (Tesion Side of Curve) 13,099 psi
Percent SMYS 18.7% — Limited by 90% SMYS by ASME/ANSI B31.8 section 833.3

Maximum Shear Stress

Maximum Shear Stress 27,777 psi
Percent SMYS 39.7% — Limited by 45% SMYS by ASME/ANSI B31.4 section 402.3.1

Combined Biaxial Stress Check

Combined Biaxial Stress Check 55,553 psi
Percent SMYS 79.4% — Limited to 90% SMYS by ASME/ANSI B31.8 section 833.4

MOTT MACDONALD

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

PROJECT: PennEast Pipeline

HDD CROSSING LOCATION: Delaware River

Reference:

1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	21,976	lb	**11.0** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	25,868	lb	**12.9** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	29,759	lb	**14.9** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	33,651	lb	**16.8** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	170,415	lb	**85.2** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	117,502	lb	**58.8** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	121,394	lb	**60.7** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	125,286	lb	**62.6** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	171,595	lb	**85.8** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	158,843	lb	**79.4** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	159,016	lb	**79.5** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	162,298	lb	**81.1** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	166,716	lb	**83.4** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	171,606	lb	**85.8** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	176,679	lb	**88.3** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	181,787	lb	**90.9** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	186,845	lb	**93.4** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	191,801	lb	**95.9** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	196,622	lb	**98.3** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	201,288	lb	**100.6** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	205,783	lb	**102.9** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	210,098	lb	**105.0** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	214,228	lb	**107.1** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	218,168	lb	**109.1** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	219,565	lb	**109.8** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	220,962	lb	**110.5** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	222,359	lb	**111.2** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	223,757	lb	**111.9** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	225,154	lb	**112.6** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	228,101	lb	**114.1** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	231,048	lb	**115.5** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	233,995	lb	**117.0** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	469,513	lb	**234.8** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	315,955	lb	**158.0** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	318,902	lb	**159.5** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	321,849	lb	**160.9** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	324,796	lb	**162.4** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	327,743	lb	**163.9** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	330,690	lb	**165.3** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	333,637	lb	**166.8** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	408,178	lb	**204.1** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	387,234	lb	**193.6** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	387,188	lb	**193.6** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	392,152	lb	**196.1** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	398,921	lb	**199.5** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	406,413	lb	**203.2** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	414,163	lb	**207.1** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	421,943	lb	**211.0** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	429,631	lb	**214.8** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	437,164	lb	**218.6** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	444,507	lb	**222.3** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	451,642	lb	**225.8** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	458,560	lb	**229.3** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	465,258	lb	**232.6** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	471,736	lb	**235.9** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	477,993	lb	**239.0** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	480,423	lb	**240.2** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	482,854	lb	**241.4** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	485,285	lb	**242.6** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	487,716	lb	**243.9** tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
261	1.80	0.37%	0	0.00	0.00%	102	0.70	0.15%	0.00	Yes	0.00	Yes
307	2.11	0.44%	0	0.00	0.00%	203	1.40	0.29%	0.01	Yes	0.00	Yes
353	2.43	0.50%	0	0.00	0.00%	305	2.10	0.44%	0.01	Yes	0.00	Yes
399	2.75	0.57%	0	0.00	0.00%	407	2.80	0.58%	0.01	Yes	0.00	Yes
2,020	13.93	2.89%	0	0.00	0.00%	508	3.50	0.73%	0.04	Yes	0.01	Yes
1,393	9.60	1.99%	0	0.00	0.00%	610	4.20	0.87%	0.02	Yes	0.01	Yes
1,439	9.92	2.06%	0	0.00	0.00%	711	4.91	1.02%	0.03	Yes	0.01	Yes
1,485	10.24	2.12%	0	0.00	0.00%	813	5.61	1.16%	0.03	Yes	0.01	Yes
2,034	14.03	2.91%	10,116	69.75	14.45%	952	6.57	1.36%	0.26	Yes	0.07	Yes
1,883	12.98	2.69%	10,116	69.75	14.45%	1,083	7.46	1.55%	0.26	Yes	0.08	Yes
1,885	13.00	2.69%	10,116	69.75	14.45%	1,204	8.30	1.72%	0.26	Yes	0.09	Yes
1,924	13.27	2.75%	10,116	69.75	14.45%	1,316	9.08	1.88%	0.26	Yes	0.09	Yes
1,976	13.63	2.82%	10,116	69.75	14.45%	1,420	9.79	2.03%	0.26	Yes	0.10	Yes
2,034	14.03	2.91%	10,116	69.75	14.45%	1,515	10.44	2.16%	0.26	Yes	0.11	Yes
2,094	14.44	2.99%	10,116	69.75	14.45%	1,600	11.03	2.29%	0.26	Yes	0.11	Yes
2,155	14.86	3.08%	10,116	69.75	14.45%	1,677	11.56	2.40%	0.27	Yes	0.12	Yes
2,215	15.27	3.16%	10,116	69.75	14.45%	1,745	12.03	2.49%	0.27	Yes	0.12	Yes
2,274	15.68	3.25%	10,116	69.75	14.45%	1,803	12.43	2.58%	0.27	Yes	0.13	Yes
2,331	16.07	3.33%	10,116	69.75	14.45%	1,853	12.78	2.65%	0.27	Yes	0.13	Yes
2,386	16.45	3.41%	10,116	69.75	14.45%	1,894	13.06	2.71%	0.27	Yes	0.14	Yes
2,439	16.82	3.48%	10,116	69.75	14.45%	1,925	13.28	2.75%	0.27	Yes	0.14	Yes
2,491	17.17	3.56%	10,116	69.75	14.45%	1,948	13.43	2.78%	0.27	Yes	0.14	Yes
2,540	17.51	3.63%	10,116	69.75	14.45%	1,962	13.52	2.80%	0.27	Yes	0.14	Yes
2,586	17.83	3.69%	10,116	69.75	14.45%	1,966	13.56	2.81%	0.27	Yes	0.14	Yes
2,603	17.95	3.72%	0	0.00	0.00%	1,966	13.56	2.81%	0.05	Yes	0.07	Yes
2,619	18.06	3.74%	0	0.00	0.00%	1,966	13.56	2.81%	0.05	Yes	0.07	Yes
2,636	18.17	3.77%	0	0.00	0.00%	1,966	13.56	2.81%	0.05	Yes	0.07	Yes
2,653	18.29	3.79%	0	0.00	0.00%	1,966	13.56	2.81%	0.05	Yes	0.07	Yes
2,669	18.40	3.81%	0	0.00	0.00%	1,966	13.56	2.81%	0.05	Yes	0.07	Yes
2,704	18.64	3.86%	0	0.00	0.00%	1,938	13.37	2.77%	0.05	Yes	0.07	Yes
2,739	18.88	3.91%	0	0.00	0.00%	1,938	13.37	2.77%	0.05	Yes	0.07	Yes
2,774	19.13	3.96%	0	0.00	0.00%	1,938	13.37	2.77%	0.05	Yes	0.07	Yes
5,566	38.38	7.95%	0	0.00	0.00%	1,938	13.37	2.77%	0.10	Yes	0.09	Yes
3,745	25.82	5.35%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,780	26.07	5.40%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,815	26.31	5.45%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,850	26.55	5.50%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,885	26.79	5.55%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,920	27.03	5.60%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
3,955	27.27	5.65%	0	0.00	0.00%	1,938	13.37	2.77%	0.07	Yes	0.08	Yes
4,839	33.36	6.91%	10,116	69.75	14.45%	1,933	13.33	2.76%	0.31	Yes	0.17	Yes
4,590	31.65	6.56%	10,116	69.75	14.45%	1,917	13.22	2.74%	0.31	Yes	0.16	Yes
4,590	31.65	6.56%	10,116	69.75	14.45%	1,891	13.04	2.70%	0.31	Yes	0.16	Yes
4,649	32.05	6.64%	10,116	69.75	14.45%	1,854	12.78	2.65%	0.31	Yes	0.16	Yes
4,729	32.61	6.76%	10,116	69.75	14.45%	1,806	12.45	2.58%	0.31	Yes	0.16	Yes
4,818	33.22	6.88%	10,116	69.75	14.45%	1,748	12.05	2.50%	0.31	Yes	0.15	Yes
4,910	33.85	7.01%	10,116	69.75	14.45%	1,679	11.57	2.40%	0.31	Yes	0.15	Yes
5,002	34.49	7.15%	10,116	69.75	14.45%	1,599	11.03	2.28%	0.32	Yes	0.14	Yes
5,093	35.12	7.28%	10,116	69.75	14.45%	1,509	10.41	2.16%	0.32	Yes	0.14	Yes
5,182	35.73	7.40%	10,116	69.75	14.45%	1,409	9.71	2.01%	0.32	Yes	0.13	Yes
5,269	36.33	7.53%	10,116	69.75	14.45%	1,298	8.95	1.85%	0.32	Yes	0.13	Yes
5,354	36.91	7.65%	10,116	69.75	14.45%	1,176	8.11	1.68%	0.32	Yes	0.12	Yes
5,436	37.48	7.77%	10,116	69.75	14.45%	1,044	7.20	1.49%	0.32	Yes	0.11	Yes
5,515	38.03	7.88%	10,116	69.75	14.45%	902	6.22	1.29%	0.33	Yes	0.11	Yes
5,592	38.56	7.99%	10,116	69.75	14.45%	749	5.17	1.07%	0.33	Yes	0.10	Yes
5,666	39.07	8.09%	10,116	69.75	14.45%	586	4.04	0.84%	0.33	Yes	0.10	Yes
5,695	39.27	8.14%	0	0.00	0.00%	440	3.03	0.63%	0.10	Yes	0.02	Yes
5,724	39.47	8.18%	0	0.00	0.00%	293	2.02	0.42%	0.10	Yes	0.01	Yes
5,753	39.66	8.22%	0	0.00	0.00%	147	1.01	0.21%	0.10	Yes	0.01	Yes
5,782	39.86	8.26%	0	0.00	0.00%	0	0.00	0.00%	0.10	Yes	0.01	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Ground Elevation at Pipe Entry	162.37	feet
	49.49	metres
Ground Elevation at Pipe Exit	160.12	feet
	48.81	metres

	TOTAL PULL LOADS		
Maximum Values	487,716	lb	243.9 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
5,782	39.9	8.26%	10,116	69.7	14.45%	1,966	13.6	2.81%	0.33	0.17

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-241.7	lbs/ft
	-360.42	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	487,716	lb
	2,169	kN
Factor of Safety	7.3	

Start-up Load Factor	1.5	
Required Pipe Pull Load	469,513	lb
	2,088	kN
Factor of Safety	7.5	

Soil and Mud Properties

Mud Weight	10	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.199	Specific Gravity
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)
	114.912	dyne/cm^2
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	1.136	m^3/min
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.138	m^3/min
Pipe Pullback Rate	15	feet/min (Based on HDD experience)
	4.57	m/min

MOTT MACDONALD

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

PROJECT: PennEast Pipeline

HDD CROSSING LOCATION: Delaware River

Reference:

1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	17,703	lb	**8.9** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	17,323	lb	**8.7** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	16,942	lb	**8.5** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	16,562	lb	**8.3** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	138,372	lb	**69.2** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	91,868	lb	**45.9** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	91,487	lb	**45.7** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	91,107	lb	**45.6** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	124,274	lb	**62.1** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	98,602	lb	**49.3** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	86,090	lb	**43.0** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	81,298	lb	**40.6** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	83,525	lb	**41.8** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	85,207	lb	**42.6** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	86,620	lb	**43.3** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	87,901	lb	**44.0** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	89,126	lb	**44.6** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	90,339	lb	**45.2** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	91,567	lb	**45.8** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	92,829	lb	**46.4** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	94,137	lb	**47.1** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	95,498	lb	**47.7** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	96,921	lb	**48.5** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	98,409	lb	**49.2** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	99,132	lb	**49.6** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	99,855	lb	**49.9** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	100,578	lb	**50.3** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	101,301	lb	**50.7** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	102,024	lb	**51.0** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	103,791	lb	**51.9** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	105,559	lb	**52.8** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	107,326	lb	**53.7** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	277,740	lb	**138.9** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	186,927	lb	**93.5** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	188,694	lb	**94.3** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	190,462	lb	**95.2** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	192,229	lb	**96.1** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	193,996	lb	**97.0** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	195,763	lb	**97.9** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	197,531	lb	**98.8** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	254,778	lb	**127.4** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	216,807	lb	**108.4** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	200,066	lb	**100.0** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	196,982	lb	**98.5** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	204,068	lb	**102.0** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	210,142	lb	**105.1** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	215,651	lb	**107.8** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	220,815	lb	**110.4** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	225,759	lb	**112.9** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	230,557	lb	**115.3** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	235,259	lb	**117.6** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	239,899	lb	**119.9** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	244,503	lb	**122.3** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	249,089	lb	**124.5** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	253,673	lb	**126.8** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	258,267	lb	**129.1** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	263,388	lb	**131.7** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	268,508	lb	**134.3** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	273,629	lb	**136.8** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	278,750	lb	**139.4** tons

HDD Installation Stress Analysis

Segment Type	Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
	psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
Pipe Entry Location	214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
straight	210	1.45	0.30%	0	0.00	0.00%	17	0.12	0.02%	0.00	Yes	0.00	Yes
straight	205	1.42	0.29%	0	0.00	0.00%	34	0.23	0.05%	0.00	Yes	0.00	Yes
straight	201	1.38	0.29%	0	0.00	0.00%	51	0.35	0.07%	0.00	Yes	0.00	Yes
straight	196	1.35	0.28%	0	0.00	0.00%	67	0.46	0.10%	0.00	Yes	0.00	Yes
straight	1,640	11.31	2.34%	0	0.00	0.00%	84	0.58	0.12%	0.03	Yes	0.00	Yes
straight	1,089	7.51	1.56%	0	0.00	0.00%	101	0.70	0.14%	0.02	Yes	0.00	Yes
straight	1,085	7.48	1.55%	0	0.00	0.00%	118	0.81	0.17%	0.02	Yes	0.00	Yes
straight	1,080	7.45	1.54%	0	0.00	0.00%	135	0.93	0.19%	0.02	Yes	0.00	Yes
curve	1,473	10.16	2.10%	10,116	69.75	14.45%	158	1.09	0.23%	0.25	Yes	0.05	Yes
curve	1,169	8.06	1.67%	10,116	69.75	14.45%	179	1.24	0.26%	0.25	Yes	0.04	Yes
curve	1,021	7.04	1.46%	10,116	69.75	14.45%	200	1.38	0.29%	0.24	Yes	0.04	Yes
curve	964	6.64	1.38%	10,116	69.75	14.45%	218	1.50	0.31%	0.24	Yes	0.04	Yes
curve	990	6.83	1.41%	10,116	69.75	14.45%	235	1.62	0.34%	0.24	Yes	0.04	Yes
curve	1,010	6.96	1.44%	10,116	69.75	14.45%	251	1.73	0.36%	0.24	Yes	0.04	Yes
curve	1,027	7.08	1.47%	10,116	69.75	14.45%	265	1.83	0.38%	0.24	Yes	0.04	Yes
curve	1,042	7.18	1.49%	10,116	69.75	14.45%	278	1.92	0.40%	0.25	Yes	0.04	Yes
curve	1,057	7.28	1.51%	10,116	69.75	14.45%	289	1.99	0.41%	0.25	Yes	0.04	Yes
curve	1,071	7.38	1.53%	10,116	69.75	14.45%	299	2.06	0.43%	0.25	Yes	0.05	Yes
curve	1,085	7.48	1.55%	10,116	69.75	14.45%	307	2.12	0.44%	0.25	Yes	0.05	Yes
curve	1,100	7.59	1.57%	10,116	69.75	14.45%	314	2.16	0.45%	0.25	Yes	0.05	Yes
curve	1,116	7.69	1.59%	10,116	69.75	14.45%	319	2.20	0.46%	0.25	Yes	0.05	Yes
curve	1,132	7.81	1.62%	10,116	69.75	14.45%	323	2.23	0.46%	0.25	Yes	0.05	Yes
curve	1,149	7.92	1.64%	10,116	69.75	14.45%	325	2.24	0.46%	0.25	Yes	0.05	Yes
curve	1,167	8.04	1.67%	10,116	69.75	14.45%	326	2.25	0.47%	0.25	Yes	0.05	Yes
straight	1,175	8.10	1.68%	0	0.00	0.00%	326	2.25	0.47%	0.02	Yes	0.00	Yes
straight	1,184	8.16	1.69%	0	0.00	0.00%	326	2.25	0.47%	0.02	Yes	0.00	Yes
straight	1,192	8.22	1.70%	0	0.00	0.00%	326	2.25	0.47%	0.02	Yes	0.00	Yes
straight	1,201	8.28	1.72%	0	0.00	0.00%	326	2.25	0.47%	0.02	Yes	0.00	Yes
straight	1,209	8.34	1.73%	0	0.00	0.00%	326	2.25	0.47%	0.02	Yes	0.00	Yes
straight	1,230	8.48	1.76%	0	0.00	0.00%	321	2.22	0.46%	0.02	Yes	0.00	Yes
straight	1,251	8.63	1.79%	0	0.00	0.00%	321	2.22	0.46%	0.02	Yes	0.00	Yes
straight	1,272	8.77	1.82%	0	0.00	0.00%	321	2.22	0.46%	0.02	Yes	0.00	Yes
straight	3,292	22.70	4.70%	0	0.00	0.00%	321	2.22	0.46%	0.06	Yes	0.01	Yes
straight	2,216	15.28	3.17%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,237	15.42	3.20%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,258	15.57	3.23%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,279	15.71	3.26%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,300	15.86	3.29%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,321	16.00	3.32%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
straight	2,342	16.14	3.35%	0	0.00	0.00%	321	2.22	0.46%	0.04	Yes	0.00	Yes
curve	3,020	20.82	4.31%	10,116	69.75	14.45%	320	2.21	0.46%	0.28	Yes	0.06	Yes
curve	2,570	17.72	3.67%	10,116	69.75	14.45%	318	2.19	0.45%	0.27	Yes	0.06	Yes
curve	2,372	16.35	3.39%	10,116	69.75	14.45%	313	2.16	0.45%	0.27	Yes	0.06	Yes
curve	2,335	16.10	3.34%	10,116	69.75	14.45%	307	2.12	0.44%	0.27	Yes	0.06	Yes
curve	2,419	16.68	3.46%	10,116	69.75	14.45%	299	2.06	0.43%	0.27	Yes	0.06	Yes
curve	2,491	17.18	3.56%	10,116	69.75	14.45%	290	2.00	0.41%	0.27	Yes	0.06	Yes
curve	2,556	17.63	3.65%	10,116	69.75	14.45%	278	1.92	0.40%	0.27	Yes	0.06	Yes
curve	2,618	18.05	3.74%	10,116	69.75	14.45%	265	1.83	0.38%	0.27	Yes	0.06	Yes
curve	2,676	18.45	3.82%	10,116	69.75	14.45%	250	1.73	0.36%	0.27	Yes	0.06	Yes
curve	2,733	18.84	3.90%	10,116	69.75	14.45%	234	1.61	0.33%	0.28	Yes	0.06	Yes
curve	2,789	19.23	3.98%	10,116	69.75	14.45%	215	1.48	0.31%	0.28	Yes	0.06	Yes
curve	2,844	19.61	4.06%	10,116	69.75	14.45%	195	1.34	0.28%	0.28	Yes	0.06	Yes
curve	2,898	19.98	4.14%	10,116	69.75	14.45%	173	1.19	0.25%	0.28	Yes	0.06	Yes
curve	2,953	20.36	4.22%	10,116	69.75	14.45%	150	1.03	0.21%	0.28	Yes	0.06	Yes
curve	3,007	20.73	4.30%	10,116	69.75	14.45%	124	0.86	0.18%	0.28	Yes	0.06	Yes
curve	3,062	21.11	4.37%	10,116	69.75	14.45%	97	0.67	0.14%	0.28	Yes	0.06	Yes
straight	3,122	21.53	4.46%	0	0.00	0.00%	73	0.50	0.10%	0.06	Yes	0.00	Yes
straight	3,183	21.95	4.55%	0	0.00	0.00%	49	0.33	0.07%	0.06	Yes	0.00	Yes
straight	3,244	22.36	4.63%	0	0.00	0.00%	24	0.17	0.03%	0.06	Yes	0.00	Yes
straight	3,304	22.78	4.72%	0	0.00	0.00%	0	0.00	0.00%	0.06	Yes	0.00	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Ground Elevation at Pipe Entry	162.37	feet
	49.49	metres
Ground Elevation at Pipe Exit	160.12	feet
	48.81	metres

	TOTAL PULL LOADS		
Maximum Values	278,750	lb	139.4 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
3,304	22.8	4.72%	10,116	69.7	14.45%	326	2.2	0.47%	0.28	0.06

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	162.8	lbs/ft
	242.84	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m
Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	278,750	lb
	1,240	kN
Factor of Safety	12.7	
Start-up Load Factor	1.5	
Required Pipe Pull Load	277,740	lb
	1,235	kN
Factor of Safety	12.8	

Soil and Mud Properties

Mud Weight	10	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.199	Specific Gravity
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)
	114.912	dyne/cm^2
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	1.136	m^3/min
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.138	m^3/min
Pipe Pullback Rate	15	feet/min (Based on HDD experience)
	4.57	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline **HDD CROSSING LOCATION: Delaware River**

Reference:
1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	23,032	lb	**11.5** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	27,980	lb	**14.0** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	32,928	lb	**16.5** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	37,875	lb	**18.9** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	178,335	lb	**89.2** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	123,838	lb	**61.9** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	128,786	lb	**64.4** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	133,734	lb	**66.9** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	181,779	lb	**90.9** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	170,734	lb	**85.4** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	172,581	lb	**86.3** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	177,499	lb	**88.7** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	183,514	lb	**91.8** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	189,957	lb	**95.0** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	196,538	lb	**98.3** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	203,105	lb	**101.6** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	209,573	lb	**104.8** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	215,890	lb	**107.9** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	222,022	lb	**111.0** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	227,949	lb	**114.0** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	233,656	lb	**116.8** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	239,135	lb	**119.6** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	244,383	lb	**122.2** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	249,395	lb	**124.7** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	251,244	lb	**125.6** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	253,093	lb	**126.5** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	254,942	lb	**127.5** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	256,792	lb	**128.4** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	258,641	lb	**129.3** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	262,379	lb	**131.2** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	266,117	lb	**133.1** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	269,855	lb	**134.9** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	524,490	lb	**262.2** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	353,398	lb	**176.7** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	357,136	lb	**178.6** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	360,874	lb	**180.4** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	364,612	lb	**182.3** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	368,350	lb	**184.2** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	372,088	lb	**186.0** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	375,826	lb	**187.9** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	452,844	lb	**226.4** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	434,334	lb	**217.2** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	436,659	lb	**218.3** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	443,917	lb	**222.0** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	452,893	lb	**226.4** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	462,502	lb	**231.3** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	472,280	lb	**236.1** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	482,002	lb	**241.0** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	491,557	lb	**245.8** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	500,885	lb	**250.4** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	509,961	lb	**255.0** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	518,770	lb	**259.4** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	527,310	lb	**263.7** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	535,579	lb	**267.8** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	543,580	lb	**271.8** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	551,313	lb	**275.7** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	554,548	lb	**277.3** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	557,784	lb	**278.9** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	561,019	lb	**280.5** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	564,254	lb	**282.1** tons

HDD Installation Stress Analysis

Segment Type	Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
	psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
Pipe Entry Location	214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
straight	273	1.88	0.39%	0	0.00	0.00%	112	0.77	0.16%	0.00	Yes	0.00	Yes
straight	332	2.29	0.47%	0	0.00	0.00%	224	1.54	0.32%	0.01	Yes	0.00	Yes
straight	390	2.69	0.56%	0	0.00	0.00%	335	2.31	0.48%	0.01	Yes	0.00	Yes
straight	449	3.10	0.64%	0	0.00	0.00%	447	3.08	0.64%	0.01	Yes	0.00	Yes
straight	2,114	14.58	3.02%	0	0.00	0.00%	559	3.85	0.80%	0.04	Yes	0.01	Yes
straight	1,468	10.12	2.10%	0	0.00	0.00%	671	4.62	0.96%	0.03	Yes	0.01	Yes
straight	1,527	10.53	2.18%	0	0.00	0.00%	783	5.40	1.12%	0.03	Yes	0.01	Yes
straight	1,585	10.93	2.26%	0	0.00	0.00%	894	6.17	1.28%	0.03	Yes	0.02	Yes
curve	2,155	14.86	3.08%	10,116	69.75	14.45%	1,047	7.22	1.50%	0.27	Yes	0.08	Yes
curve	2,024	13.95	2.89%	10,116	69.75	14.45%	1,191	8.21	1.70%	0.26	Yes	0.09	Yes
curve	2,046	14.11	2.92%	10,116	69.75	14.45%	1,324	9.13	1.89%	0.26	Yes	0.09	Yes
curve	2,104	14.51	3.01%	10,116	69.75	14.45%	1,448	9.98	2.07%	0.26	Yes	0.10	Yes
curve	2,175	15.00	3.11%	10,116	69.75	14.45%	1,562	10.77	2.23%	0.27	Yes	0.11	Yes
curve	2,252	15.53	3.22%	10,116	69.75	14.45%	1,666	11.49	2.38%	0.27	Yes	0.12	Yes
curve	2,330	16.06	3.33%	10,116	69.75	14.45%	1,760	12.14	2.51%	0.27	Yes	0.12	Yes
curve	2,408	16.60	3.44%	10,116	69.75	14.45%	1,845	12.72	2.64%	0.27	Yes	0.13	Yes
curve	2,484	17.13	3.55%	10,116	69.75	14.45%	1,919	13.23	2.74%	0.27	Yes	0.14	Yes
curve	2,559	17.65	3.66%	10,116	69.75	14.45%	1,984	13.68	2.83%	0.27	Yes	0.14	Yes
curve	2,632	18.15	3.76%	10,116	69.75	14.45%	2,038	14.05	2.91%	0.27	Yes	0.15	Yes
curve	2,702	18.63	3.86%	10,116	69.75	14.45%	2,083	14.36	2.98%	0.27	Yes	0.15	Yes
curve	2,770	19.10	3.96%	10,116	69.75	14.45%	2,118	14.60	3.03%	0.28	Yes	0.16	Yes
curve	2,835	19.55	4.05%	10,116	69.75	14.45%	2,143	14.77	3.06%	0.28	Yes	0.16	Yes
curve	2,897	19.97	4.14%	10,116	69.75	14.45%	2,158	14.88	3.08%	0.28	Yes	0.16	Yes
curve	2,956	20.38	4.22%	10,116	69.75	14.45%	2,163	14.91	3.09%	0.28	Yes	0.16	Yes
straight	2,978	20.54	4.25%	0	0.00	0.00%	2,163	14.91	3.09%	0.05	Yes	0.09	Yes
straight	3,000	20.69	4.29%	0	0.00	0.00%	2,163	14.91	3.09%	0.05	Yes	0.09	Yes
straight	3,022	20.84	4.32%	0	0.00	0.00%	2,163	14.91	3.09%	0.05	Yes	0.09	Yes
straight	3,044	20.99	4.35%	0	0.00	0.00%	2,163	14.91	3.09%	0.05	Yes	0.09	Yes
straight	3,066	21.14	4.38%	0	0.00	0.00%	2,163	14.91	3.09%	0.05	Yes	0.09	Yes
straight	3,110	21.45	4.44%	0	0.00	0.00%	2,132	14.70	3.05%	0.06	Yes	0.09	Yes
straight	3,155	21.75	4.51%	0	0.00	0.00%	2,132	14.70	3.05%	0.06	Yes	0.09	Yes
straight	3,199	22.06	4.57%	0	0.00	0.00%	2,132	14.70	3.05%	0.06	Yes	0.09	Yes
straight	6,218	42.87	8.88%	0	0.00	0.00%	2,132	14.70	3.05%	0.11	Yes	0.10	Yes
straight	4,189	28.88	5.98%	0	0.00	0.00%	2,132	14.70	3.05%	0.07	Yes	0.09	Yes
straight	4,234	29.19	6.05%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
straight	4,278	29.50	6.11%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
straight	4,322	29.80	6.17%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
straight	4,367	30.11	6.24%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
straight	4,411	30.41	6.30%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
straight	4,455	30.72	6.36%	0	0.00	0.00%	2,132	14.70	3.05%	0.08	Yes	0.09	Yes
curve	5,368	37.01	7.67%	10,116	69.75	14.45%	2,126	14.66	3.04%	0.32	Yes	0.19	Yes
curve	5,149	35.50	7.36%	10,116	69.75	14.45%	2,109	14.54	3.01%	0.32	Yes	0.19	Yes
curve	5,176	35.69	7.39%	10,116	69.75	14.45%	2,080	14.34	2.97%	0.32	Yes	0.18	Yes
curve	5,262	36.28	7.52%	10,116	69.75	14.45%	2,039	14.06	2.91%	0.32	Yes	0.18	Yes
curve	5,369	37.02	7.67%	10,116	69.75	14.45%	1,986	13.70	2.84%	0.32	Yes	0.18	Yes
curve	5,483	37.80	7.83%	10,116	69.75	14.45%	1,922	13.25	2.75%	0.32	Yes	0.17	Yes
curve	5,599	38.60	8.00%	10,116	69.75	14.45%	1,847	12.73	2.64%	0.33	Yes	0.17	Yes
curve	5,714	39.40	8.16%	10,116	69.75	14.45%	1,759	12.13	2.51%	0.33	Yes	0.16	Yes
curve	5,827	40.18	8.32%	10,116	69.75	14.45%	1,660	11.45	2.37%	0.33	Yes	0.16	Yes
curve	5,938	40.94	8.48%	10,116	69.75	14.45%	1,550	10.69	2.21%	0.33	Yes	0.15	Yes
curve	6,045	41.68	8.64%	10,116	69.75	14.45%	1,428	9.84	2.04%	0.33	Yes	0.14	Yes
curve	6,150	42.40	8.79%	10,116	69.75	14.45%	1,294	8.92	1.85%	0.34	Yes	0.14	Yes
curve	6,251	43.10	8.93%	10,116	69.75	14.45%	1,149	7.92	1.64%	0.34	Yes	0.13	Yes
curve	6,349	43.78	9.07%	10,116	69.75	14.45%	992	6.84	1.42%	0.34	Yes	0.12	Yes
curve	6,444	44.43	9.21%	10,116	69.75	14.45%	824	5.68	1.18%	0.34	Yes	0.11	Yes
curve	6,536	45.06	9.34%	10,116	69.75	14.45%	645	4.45	0.92%	0.34	Yes	0.11	Yes
straight	6,574	45.33	9.39%	0	0.00	0.00%	484	3.33	0.69%	0.12	Yes	0.02	Yes
straight	6,612	45.59	9.45%	0	0.00	0.00%	322	2.22	0.46%	0.12	Yes	0.02	Yes
straight	6,651	45.85	9.50%	0	0.00	0.00%	161	1.11	0.23%	0.12	Yes	0.02	Yes
HDD Rig Location	6,689	46.12	9.56%	0	0.00	0.00%	0	0.00	0.00%	0.12	Yes	0.01	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

	Ground Elevation at Pipe Entry		Ground Elevation at Pipe Exit	
	162.37	feet	160.12	feet
	49.49	metres	48.81	metres

	TOTAL PULL LOADS		
Maximum Values	564,254	lb	282.1 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
6,689	46.1	9.56%	10,116	69.7	14.45%	2,163	14.9	3.09%	0.34	0.19

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-294.6	lbs/ft
	-439.27	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	564,254	lb
	2,510	kN
Factor of Safety	6.3	

Start-up Load Factor	1.5	
Required Pipe Pull Load	524,490	lb
	2,333	kN
Factor of Safety	6.8	

Soil and Mud Properties

Mud Weight	11	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.319	Specific Gravity
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)
	114.912	dyne/cm^2
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	1.136	m^3/min
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.138	m^3/min
Pipe Pullback Rate	15	feet/min (Based on HDD experience)
	4.57	m/min

MOTT MACDONALD

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

PROJECT: PennEast Pipeline

HDD CROSSING LOCATION: Delaware River

Reference:

1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	17,523	lb	**8.8** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	16,962	lb	**8.5** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	16,402	lb	**8.2** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	15,841	lb	**7.9** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	137,021	lb	**68.5** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	90,787	lb	**45.4** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	90,226	lb	**45.1** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	89,665	lb	**44.8** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	124,523	lb	**62.3** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	100,512	lb	**50.3** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	89,632	lb	**44.8** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	82,079	lb	**41.0** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	79,296	lb	**39.6** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	80,319	lb	**40.2** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	81,043	lb	**40.5** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	81,606	lb	**40.8** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	82,084	lb	**41.0** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	82,523	lb	**41.3** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	82,950	lb	**41.5** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	83,385	lb	**41.7** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	83,840	lb	**41.9** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	84,325	lb	**42.2** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	84,845	lb	**42.4** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	85,406	lb	**42.7** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	85,677	lb	**42.8** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	85,948	lb	**43.0** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	86,219	lb	**43.1** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	86,491	lb	**43.2** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	86,762	lb	**43.4** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	87,738	lb	**43.9** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	88,714	lb	**44.4** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	89,690	lb	**44.8** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	250,100	lb	**125.0** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	167,709	lb	**83.9** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	168,685	lb	**84.3** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	169,662	lb	**84.8** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	170,638	lb	**85.3** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	171,614	lb	**85.8** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	172,590	lb	**86.3** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	173,566	lb	**86.8** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	232,700	lb	**116.3** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	196,579	lb	**98.3** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	181,649	lb	**90.8** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	172,076	lb	**86.0** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	170,365	lb	**85.2** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	174,469	lb	**87.2** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	178,009	lb	**89.0** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	181,206	lb	**90.6** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	184,185	lb	**92.1** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	187,021	lb	**93.5** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	189,760	lb	**94.9** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	192,435	lb	**96.2** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	195,069	lb	**97.5** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	197,680	lb	**98.8** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	200,280	lb	**100.1** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	202,880	lb	**101.4** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	205,934	lb	**103.0** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	208,987	lb	**104.5** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	212,040	lb	**106.0** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	215,093	lb	**107.5** tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
208	1.43	0.30%	0	0.00	0.00%	27	0.19	0.04%	0.00	Yes	0.00	Yes
201	1.39	0.29%	0	0.00	0.00%	54	0.37	0.08%	0.00	Yes	0.00	Yes
194	1.34	0.28%	0	0.00	0.00%	81	0.56	0.12%	0.00	Yes	0.00	Yes
188	1.29	0.27%	0	0.00	0.00%	108	0.74	0.15%	0.00	Yes	0.00	Yes
1,624	11.20	2.32%	0	0.00	0.00%	135	0.93	0.19%	0.03	Yes	0.00	Yes
1,076	7.42	1.54%	0	0.00	0.00%	162	1.12	0.23%	0.02	Yes	0.00	Yes
1,070	7.37	1.53%	0	0.00	0.00%	189	1.30	0.27%	0.02	Yes	0.00	Yes
1,063	7.33	1.52%	0	0.00	0.00%	216	1.49	0.31%	0.02	Yes	0.00	Yes
1,476	10.18	2.11%	10,116	69.75	14.45%	253	1.74	0.36%	0.25	Yes	0.05	Yes
1,192	8.22	1.70%	10,116	69.75	14.45%	288	1.98	0.41%	0.25	Yes	0.05	Yes
1,063	7.33	1.52%	10,116	69.75	14.45%	320	2.21	0.46%	0.25	Yes	0.05	Yes
973	6.71	1.39%	10,116	69.75	14.45%	350	2.41	0.50%	0.24	Yes	0.05	Yes
940	6.48	1.34%	10,116	69.75	14.45%	377	2.60	0.54%	0.24	Yes	0.05	Yes
952	6.56	1.36%	10,116	69.75	14.45%	403	2.78	0.58%	0.24	Yes	0.05	Yes
961	6.62	1.37%	10,116	69.75	14.45%	425	2.93	0.61%	0.24	Yes	0.05	Yes
967	6.67	1.38%	10,116	69.75	14.45%	446	3.07	0.64%	0.24	Yes	0.05	Yes
973	6.71	1.39%	10,116	69.75	14.45%	464	3.20	0.66%	0.24	Yes	0.05	Yes
978	6.74	1.40%	10,116	69.75	14.45%	479	3.30	0.68%	0.24	Yes	0.05	Yes
983	6.78	1.40%	10,116	69.75	14.45%	493	3.40	0.70%	0.24	Yes	0.05	Yes
988	6.82	1.41%	10,116	69.75	14.45%	503	3.47	0.72%	0.24	Yes	0.05	Yes
994	6.85	1.42%	10,116	69.75	14.45%	512	3.53	0.73%	0.24	Yes	0.05	Yes
1,000	6.89	1.43%	10,116	69.75	14.45%	518	3.57	0.74%	0.24	Yes	0.05	Yes
1,006	6.93	1.44%	10,116	69.75	14.45%	521	3.59	0.74%	0.24	Yes	0.05	Yes
1,012	6.98	1.45%	10,116	69.75	14.45%	523	3.60	0.75%	0.24	Yes	0.05	Yes
1,016	7.00	1.45%	0	0.00	0.00%	523	3.60	0.75%	0.02	Yes	0.01	Yes
1,019	7.02	1.46%	0	0.00	0.00%	523	3.60	0.75%	0.02	Yes	0.01	Yes
1,022	7.05	1.46%	0	0.00	0.00%	523	3.60	0.75%	0.02	Yes	0.01	Yes
1,025	7.07	1.46%	0	0.00	0.00%	523	3.60	0.75%	0.02	Yes	0.01	Yes
1,029	7.09	1.47%	0	0.00	0.00%	523	3.60	0.75%	0.02	Yes	0.01	Yes
1,040	7.17	1.49%	0	0.00	0.00%	515	3.55	0.74%	0.02	Yes	0.01	Yes
1,052	7.25	1.50%	0	0.00	0.00%	515	3.55	0.74%	0.02	Yes	0.01	Yes
1,063	7.33	1.52%	0	0.00	0.00%	515	3.55	0.74%	0.02	Yes	0.01	Yes
2,965	20.44	4.24%	0	0.00	0.00%	515	3.55	0.74%	0.05	Yes	0.01	Yes
1,988	13.71	2.84%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,000	13.79	2.86%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,011	13.87	2.87%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,023	13.95	2.89%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,034	14.03	2.91%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,046	14.11	2.92%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,058	14.19	2.94%	0	0.00	0.00%	515	3.55	0.74%	0.04	Yes	0.01	Yes
2,759	19.02	3.94%	10,116	69.75	14.45%	514	3.54	0.73%	0.28	Yes	0.06	Yes
2,330	16.07	3.33%	10,116	69.75	14.45%	510	3.51	0.73%	0.27	Yes	0.06	Yes
2,153	14.85	3.08%	10,116	69.75	14.45%	503	3.46	0.72%	0.27	Yes	0.06	Yes
2,040	14.06	2.91%	10,116	69.75	14.45%	493	3.40	0.70%	0.26	Yes	0.06	Yes
2,020	13.92	2.89%	10,116	69.75	14.45%	480	3.31	0.69%	0.26	Yes	0.06	Yes
2,068	14.26	2.95%	10,116	69.75	14.45%	464	3.20	0.66%	0.26	Yes	0.06	Yes
2,110	14.55	3.01%	10,116	69.75	14.45%	446	3.08	0.64%	0.26	Yes	0.06	Yes
2,148	14.81	3.07%	10,116	69.75	14.45%	425	2.93	0.61%	0.26	Yes	0.06	Yes
2,183	15.05	3.12%	10,116	69.75	14.45%	401	2.77	0.57%	0.27	Yes	0.06	Yes
2,217	15.29	3.17%	10,116	69.75	14.45%	374	2.58	0.53%	0.27	Yes	0.06	Yes
2,250	15.51	3.21%	10,116	69.75	14.45%	345	2.38	0.49%	0.27	Yes	0.06	Yes
2,281	15.73	3.26%	10,116	69.75	14.45%	313	2.16	0.45%	0.27	Yes	0.06	Yes
2,312	15.94	3.30%	10,116	69.75	14.45%	278	1.91	0.40%	0.27	Yes	0.05	Yes
2,343	16.16	3.35%	10,116	69.75	14.45%	240	1.65	0.34%	0.27	Yes	0.05	Yes
2,374	16.37	3.39%	10,116	69.75	14.45%	199	1.37	0.28%	0.27	Yes	0.05	Yes
2,405	16.58	3.44%	10,116	69.75	14.45%	156	1.07	0.22%	0.27	Yes	0.05	Yes
2,441	16.83	3.49%	0	0.00	0.00%	117	0.81	0.17%	0.04	Yes	0.00	Yes
2,477	17.08	3.54%	0	0.00	0.00%	78	0.54	0.11%	0.04	Yes	0.00	Yes
2,514	17.33	3.59%	0	0.00	0.00%	39	0.27	0.06%	0.04	Yes	0.00	Yes
2,550	17.58	3.64%	0	0.00	0.00%	0	0.00	0.00%	0.05	Yes	0.00	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Ground Elevation at Pipe Entry	162.37	feet	
	49.49	metres	
Ground Elevation at Pipe Exit	160.12	feet	
	48.81	metres	

	TOTAL PULL LOADS		
Maximum Values	232,700	lb	125.0 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
2,965	20.4	4.24%	10,116	69.7	14.45%	523	3.6	0.75%	0.28	0.06

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	110.0	lbs/ft
	163.99	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m
Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	232,700	lb
	1,035	kN
Factor of Safety	15.2	
Start-up Load Factor	1.5	
Required Pipe Pull Load	250,100	lb
	1,112	kN
Factor of Safety	14.2	

Soil and Mud Properties

Mud Weight	11	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)	
	1.319	Specific Gravity	
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)	
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)	
	114.912	dyne/cm^2	
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)	
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)	
	1.136	m^3/min	
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)	
	4.138	m^3/min	
Pipe Pullback Rate	15	feet/min (Based on HDD experience)	
	4.57	m/min	

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline **HDD CROSSING LOCATION: Delaware River**

Reference:
1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	24,088	lb	**12.0** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	30,092	lb	**15.0** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	36,096	lb	**18.0** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	42,100	lb	**21.0** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	186,256	lb	**93.1** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	130,174	lb	**65.1** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	136,178	lb	**68.1** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	142,182	lb	**71.1** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	191,964	lb	**96.0** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	182,625	lb	**91.3** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	186,144	lb	**93.1** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	192,697	lb	**96.3** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	200,305	lb	**100.2** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	208,297	lb	**104.1** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	216,379	lb	**108.2** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	224,398	lb	**112.2** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	232,267	lb	**116.1** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	239,934	lb	**120.0** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	247,365	lb	**123.7** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	254,540	lb	**127.3** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	261,448	lb	**130.7** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	268,080	lb	**134.0** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	274,434	lb	**137.2** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	280,507	lb	**140.3** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	282,809	lb	**141.4** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	285,110	lb	**142.6** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	287,411	lb	**143.7** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	289,713	lb	**144.9** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	294,242	lb	**147.1** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	298,771	lb	**149.4** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	303,300	lb	**151.6** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	307,829	lb	**153.9** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	582,637	lb	**291.3** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	392,954	lb	**196.5** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	397,483	lb	**198.7** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	402,012	lb	**201.0** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	406,541	lb	**203.3** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	411,070	lb	**205.5** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	415,600	lb	**207.8** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	420,129	lb	**210.1** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	499,643	lb	**249.8** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	483,582	lb	**241.8** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	488,288	lb	**244.1** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	497,841	lb	**248.9** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	509,019	lb	**254.5** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	520,735	lb	**260.4** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	532,527	lb	**266.3** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	544,180	lb	**272.1** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	555,590	lb	**277.8** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	566,707	lb	**283.4** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	577,510	lb	**288.8** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	587,993	lb	**294.0** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	598,155	lb	**299.1** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	608,000	lb	**304.0** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	617,530	lb	**308.8** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	626,749	lb	**313.4** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	630,789	lb	**315.4** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	634,829	lb	**317.4** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	638,868	lb	**319.4** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	642,908	lb	**321.5** tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
286	1.97	0.41%	0	0.00	0.00%	122	0.84	0.17%	0.01	Yes	0.00	Yes
357	2.46	0.51%	0	0.00	0.00%	244	1.68	0.35%	0.01	Yes	0.00	Yes
428	2.95	0.61%	0	0.00	0.00%	366	2.52	0.52%	0.01	Yes	0.00	Yes
499	3.44	0.71%	0	0.00	0.00%	488	3.36	0.70%	0.01	Yes	0.00	Yes
2,208	15.22	3.15%	0	0.00	0.00%	610	4.20	0.87%	0.04	Yes	0.01	Yes
1,543	10.64	2.20%	0	0.00	0.00%	732	5.05	1.05%	0.03	Yes	0.01	Yes
1,614	11.13	2.31%	0	0.00	0.00%	854	5.89	1.22%	0.03	Yes	0.01	Yes
1,686	11.62	2.41%	0	0.00	0.00%	976	6.73	1.39%	0.03	Yes	0.02	Yes
2,276	15.69	3.25%	10,116	69.75	14.45%	1,143	7.88	1.63%	0.27	Yes	0.09	Yes
2,165	14.93	3.09%	10,116	69.75	14.45%	1,299	8.96	1.86%	0.27	Yes	0.09	Yes
2,207	15.21	3.15%	10,116	69.75	14.45%	1,445	9.96	2.06%	0.27	Yes	0.10	Yes
2,284	15.75	3.26%	10,116	69.75	14.45%	1,580	10.89	2.26%	0.27	Yes	0.11	Yes
2,375	16.37	3.39%	10,116	69.75	14.45%	1,704	11.75	2.43%	0.27	Yes	0.12	Yes
2,469	17.02	3.53%	10,116	69.75	14.45%	1,818	12.53	2.60%	0.27	Yes	0.13	Yes
2,565	17.69	3.66%	10,116	69.75	14.45%	1,920	13.24	2.74%	0.27	Yes	0.14	Yes
2,660	18.34	3.80%	10,116	69.75	14.45%	2,012	13.88	2.87%	0.27	Yes	0.15	Yes
2,753	18.98	3.93%	10,116	69.75	14.45%	2,094	14.44	2.99%	0.28	Yes	0.15	Yes
2,844	19.61	4.06%	10,116	69.75	14.45%	2,164	14.92	3.09%	0.28	Yes	0.16	Yes
2,932	20.22	4.19%	10,116	69.75	14.45%	2,224	15.33	3.18%	0.28	Yes	0.17	Yes
3,017	20.80	4.31%	10,116	69.75	14.45%	2,273	15.67	3.25%	0.28	Yes	0.17	Yes
3,099	21.37	4.43%	10,116	69.75	14.45%	2,310	15.93	3.30%	0.28	Yes	0.18	Yes
3,178	21.91	4.54%	10,116	69.75	14.45%	2,338	16.12	3.34%	0.28	Yes	0.18	Yes
3,253	22.43	4.65%	10,116	69.75	14.45%	2,354	16.23	3.36%	0.28	Yes	0.18	Yes
3,325	22.93	4.75%	10,116	69.75	14.45%	2,359	16.27	3.37%	0.29	Yes	0.18	Yes
3,353	23.12	4.79%	0	0.00	0.00%	2,359	16.27	3.37%	0.06	Yes	0.10	Yes
3,380	23.30	4.83%	0	0.00	0.00%	2,359	16.27	3.37%	0.06	Yes	0.10	Yes
3,407	23.49	4.87%	0	0.00	0.00%	2,359	16.27	3.37%	0.06	Yes	0.10	Yes
3,434	23.68	4.91%	0	0.00	0.00%	2,359	16.27	3.37%	0.06	Yes	0.10	Yes
3,488	24.05	4.98%	0	0.00	0.00%	2,326	16.04	3.32%	0.06	Yes	0.11	Yes
3,542	24.42	5.06%	0	0.00	0.00%	2,326	16.04	3.32%	0.06	Yes	0.11	Yes
3,595	24.79	5.14%	0	0.00	0.00%	2,326	16.04	3.32%	0.06	Yes	0.11	Yes
3,649	25.16	5.21%	0	0.00	0.00%	2,326	16.04	3.32%	0.07	Yes	0.11	Yes
6,907	47.62	9.87%	0	0.00	0.00%	2,326	16.04	3.32%	0.12	Yes	0.13	Yes
4,658	32.12	6.65%	0	0.00	0.00%	2,326	16.04	3.32%	0.08	Yes	0.11	Yes
4,712	32.49	6.73%	0	0.00	0.00%	2,326	16.04	3.32%	0.08	Yes	0.11	Yes
4,766	32.86	6.81%	0	0.00	0.00%	2,326	16.04	3.32%	0.09	Yes	0.11	Yes
4,819	33.23	6.88%	0	0.00	0.00%	2,326	16.04	3.32%	0.09	Yes	0.11	Yes
4,873	33.60	6.96%	0	0.00	0.00%	2,326	16.04	3.32%	0.09	Yes	0.11	Yes
4,927	33.97	7.04%	0	0.00	0.00%	2,326	16.04	3.32%	0.09	Yes	0.11	Yes
4,980	34.34	7.11%	0	0.00	0.00%	2,326	16.04	3.32%	0.09	Yes	0.11	Yes
5,923	40.84	8.46%	10,116	69.75	14.45%	2,320	15.99	3.31%	0.33	Yes	0.21	Yes
5,733	39.53	8.19%	10,116	69.75	14.45%	2,301	15.86	3.29%	0.33	Yes	0.21	Yes
5,788	39.91	8.27%	10,116	69.75	14.45%	2,269	15.64	3.24%	0.33	Yes	0.21	Yes
5,902	40.69	8.43%	10,116	69.75	14.45%	2,224	15.34	3.18%	0.33	Yes	0.21	Yes
6,034	41.60	8.62%	10,116	69.75	14.45%	2,167	14.94	3.10%	0.33	Yes	0.20	Yes
6,173	42.56	8.82%	10,116	69.75	14.45%	2,097	14.46	3.00%	0.34	Yes	0.20	Yes
6,313	43.53	9.02%	10,116	69.75	14.45%	2,014	13.89	2.88%	0.34	Yes	0.19	Yes
6,451	44.48	9.22%	10,116	69.75	14.45%	1,919	13.23	2.74%	0.34	Yes	0.19	Yes
6,586	45.41	9.41%	10,116	69.75	14.45%	1,811	12.49	2.59%	0.34	Yes	0.18	Yes
6,718	46.32	9.60%	10,116	69.75	14.45%	1,691	11.66	2.42%	0.35	Yes	0.17	Yes
6,846	47.20	9.78%	10,116	69.75	14.45%	1,557	10.74	2.22%	0.35	Yes	0.16	Yes
6,970	48.06	9.96%	10,116	69.75	14.45%	1,412	9.73	2.02%	0.35	Yes	0.15	Yes
7,091	48.89	10.13%	10,116	69.75	14.45%	1,253	8.64	1.79%	0.35	Yes	0.15	Yes
7,208	49.69	10.30%	10,116	69.75	14.45%	1,082	7.46	1.55%	0.36	Yes	0.14	Yes
7,321	50.47	10.46%	10,116	69.75	14.45%	899	6.20	1.28%	0.36	Yes	0.13	Yes
7,430	51.23	10.61%	10,116	69.75	14.45%	703	4.85	1.00%	0.36	Yes	0.12	Yes
7,478	51.56	10.68%	0	0.00	0.00%	528	3.64	0.75%	0.13	Yes	0.03	Yes
7,526	51.89	10.75%	0	0.00	0.00%	352	2.42	0.50%	0.13	Yes	0.02	Yes
7,573	52.22	10.82%	0	0.00	0.00%	176	1.21	0.25%	0.14	Yes	0.02	Yes
7,621	52.55	10.89%	0	0.00	0.00%	0	0.00	0.00%	0.14	Yes	0.02	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Ground Elevation at Pipe Entry	162.37	feet	
	49.49	metres	
Ground Elevation at Pipe Exit	160.12	feet	
	48.81	metres	

	TOTAL PULL LOADS		
Maximum Values	642,908	lb	321.5 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
7,621	52.5	10.89%	10,116	69.7	14.45%	2,359	16.3	3.37%	0.36	0.21

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-347.4	lbs/ft
	-518.11	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	642,908	lb
	2,860	kN
Factor of Safety	5.5	

Start-up Load Factor	1.5	
Required Pipe Pull Load	582,637	lb
	2,592	kN
Factor of Safety	6.1	

Soil and Mud Properties

Mud Weight	12	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.439	Specific Gravity
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)
	114.912	dyne/cm^2
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	1.136	m^3/min
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.138	m^3/min
Pipe Pullback Rate	15	feet/min (Based on HDD experience)
	4.57	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline **HDD CROSSING LOCATION: Delaware River**

Reference:
1. **Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015**
2. **Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005**

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		4085+53	124+528	0.0	0.0	162.4	49.5	--	--		18,084	lb	**9.0** tons
straight		4085+92	124+540	39.8	12.1	154.1	47.0	48.0	1219.2	0.3	17,343	lb	**8.7** tons
straight		4086+31	124+552	79.7	24.3	145.8	44.4	48.0	1219.2	0.3	16,602	lb	**8.3** tons
straight		4086+70	124+564	119.5	36.4	137.5	41.9	48.0	1219.2	0.3	15,861	lb	**7.9** tons
straight		4087+09	124+576	159.4	48.6	129.2	39.4	48.0	1219.2	0.3	15,120	lb	**7.6** tons
straight		4087+48	124+588	199.2	60.7	121.0	36.9	48.0	1219.2	0.3	135,670	lb	**67.8** tons
straight		4087+87	124+600	239.0	72.9	112.7	34.3	48.0	1219.2	0.3	89,706	lb	**44.9** tons
straight		4088+26	124+612	278.9	85.0	104.4	31.8	48.0	1219.2	0.3	88,965	lb	**44.5** tons
straight		4088+65	124+623	318.7	97.1	96.1	29.3	48.0	1219.2	0.3	88,224	lb	**44.1** tons
curve	vertical	4089+20	124+640	375.0	114.3	84.8	25.8	48.0	1219.2	0.3	124,771	lb	**62.4** tons
curve	vertical	4089+75	124+657	431.3	131.5	74.1	22.6	48.0	1219.2	0.3	102,421	lb	**51.2** tons
curve	vertical	4090+30	124+674	487.6	148.6	64.3	19.6	48.0	1219.2	0.3	93,173	lb	**46.6** tons
curve	vertical	4090+86	124+691	543.9	165.8	55.1	16.8	48.0	1219.2	0.3	87,221	lb	**43.6** tons
curve	vertical	4091+42	124+708	600.1	182.9	46.6	14.2	48.0	1219.2	0.3	82,606	lb	**41.3** tons
curve	vertical	4091+97	124+725	656.4	200.1	38.9	11.9	48.0	1219.2	0.3	78,675	lb	**39.3** tons
curve	vertical	4092+53	124+742	712.7	217.2	31.9	9.7	48.0	1219.2	0.3	75,462	lb	**37.7** tons
curve	vertical	4093+09	124+759	769.0	234.4	25.7	7.8	48.0	1219.2	0.3	75,304	lb	**37.7** tons
curve	vertical	4093+65	124+776	825.3	251.6	20.2	6.2	48.0	1219.2	0.3	75,031	lb	**37.5** tons
curve	vertical	4094+21	124+793	881.6	268.7	15.4	4.7	48.0	1219.2	0.3	74,691	lb	**37.3** tons
curve	vertical	4094+77	124+810	937.9	285.9	11.3	3.5	48.0	1219.2	0.3	74,311	lb	**37.2** tons
curve	vertical	4095+34	124+827	994.2	303.0	8.0	2.4	48.0	1219.2	0.3	73,912	lb	**37.0** tons
curve	vertical	4095+90	124+844	1,050.4	320.2	5.5	1.7	48.0	1219.2	0.3	73,506	lb	**36.8** tons
curve	vertical	4096+46	124+862	1,106.7	337.3	3.6	1.1	48.0	1219.2	0.3	73,104	lb	**36.6** tons
curve	vertical	4097+02	124+879	1,163.0	354.5	2.5	0.8	48.0	1219.2	0.3	72,710	lb	**36.4** tons
curve	vertical	4097+59	124+896	1,219.3	371.6	2.1	0.7	48.0	1219.2	0.3	72,332	lb	**36.2** tons
straight		4097+87	124+905	1,247.8	380.3	2.1	0.7	48.0	1219.2	0.3	72,151	lb	**36.1** tons
straight		4098+16	124+913	1,276.3	389.0	2.1	0.7	48.0	1219.2	0.3	71,970	lb	**36.0** tons
straight		4098+44	124+922	1,304.8	397.7	2.1	0.7	48.0	1219.2	0.3	71,789	lb	**35.9** tons
straight		4098+73	124+931	1,333.3	406.4	2.1	0.7	48.0	1219.2	0.3	71,608	lb	**35.8** tons
straight		4099+01	124+939	1,361.8	415.1	2.1	0.7	48.0	1219.2	0.3	71,793	lb	**35.9** tons
straight		4099+30	124+948	1,390.3	423.8	2.1	0.7	48.0	1219.2	0.3	71,978	lb	**36.0** tons
straight		4099+58	124+957	1,418.8	432.5	2.1	0.7	48.0	1219.2	0.3	72,163	lb	**36.1** tons
straight		4099+87	124+965	1,447.3	441.1	2.1	0.7	48.0	1219.2	0.3	72,348	lb	**36.2** tons
straight		4100+15	124+974	1,475.8	449.8	2.1	0.7	48.0	1219.2	0.3	222,901	lb	**111.5** tons
straight		4100+44	124+983	1,504.3	458.5	2.1	0.7	48.0	1219.2	0.3	148,785	lb	**74.4** tons
straight		4100+72	124+991	1,532.8	467.2	2.1	0.7	48.0	1219.2	0.3	148,971	lb	**74.5** tons
straight		4101+01	125+000	1,561.3	475.9	2.1	0.7	48.0	1219.2	0.3	149,156	lb	**74.6** tons
straight		4101+29	125+009	1,589.8	484.6	2.1	0.7	48.0	1219.2	0.3	149,341	lb	**74.7** tons
straight		4101+58	125+018	1,618.3	493.3	2.1	0.7	48.0	1219.2	0.3	149,526	lb	**74.8** tons
straight		4101+86	125+026	1,646.8	501.9	2.1	0.7	48.0	1219.2	0.3	149,711	lb	**74.9** tons
straight		4102+15	125+035	1,675.3	510.6	2.1	0.7	48.0	1219.2	0.3	149,896	lb	**74.9** tons
curve	vertical	4102+76	125+053	1,736.3	529.2	2.6	0.8	48.0	1219.2	0.3	210,918	lb	**105.5** tons
curve	vertical	4103+36	125+072	1,797.2	547.8	3.9	1.2	48.0	1219.2	0.3	176,653	lb	**88.3** tons
curve	vertical	4103+97	125+091	1,858.2	566.4	6.0	1.8	48.0	1219.2	0.3	163,538	lb	**81.8** tons
curve	vertical	4104+58	125+109	1,919.2	585.0	9.1	2.8	48.0	1219.2	0.3	155,739	lb	**77.9** tons
curve	vertical	4105+19	125+128	1,980.2	603.6	12.9	3.9	48.0	1219.2	0.3	150,089	lb	**75.0** tons
curve	vertical	4105+80	125+146	2,041.1	622.1	17.7	5.4	48.0	1219.2	0.3	145,536	lb	**72.8** tons
curve	vertical	4106+41	125+165	2,102.1	640.7	23.3	7.1	48.0	1219.2	0.3	141,628	lb	**70.8** tons
curve	vertical	4107+01	125+183	2,163.1	659.3	29.8	9.1	48.0	1219.2	0.3	141,770	lb	**70.9** tons
curve	vertical	4107+62	125+202	2,224.1	677.9	37.1	11.3	48.0	1219.2	0.3	142,749	lb	**71.4** tons
curve	vertical	4108+22	125+220	2,285.1	696.5	45.3	13.8	48.0	1219.2	0.3	143,581	lb	**71.8** tons
curve	vertical	4108+83	125+239	2,346.0	715.1	54.4	16.6	48.0	1219.2	0.3	144,315	lb	**72.2** tons
curve	vertical	4109+43	125+257	2,407.0	733.7	64.3	19.6	48.0	1219.2	0.3	144,983	lb	**72.5** tons
curve	vertical	4110+03	125+275	2,468.0	752.3	75.0	22.9	48.0	1219.2	0.3	145,605	lb	**72.8** tons
curve	vertical	4110+63	125+293	2,529.0	770.8	86.6	26.4	48.0	1219.2	0.3	146,198	lb	**73.1** tons
curve	vertical	4111+22	125+312	2,589.9	789.4	99.1	30.2	48.0	1219.2	0.3	146,773	lb	**73.4** tons
curve	vertical	4111+82	125+330	2,650.9	808.0	112.4	34.2	48.0	1219.2	0.3	147,339	lb	**73.7** tons
straight		4112+34	125+346	2,704.0	824.2	124.3	37.9	48.0	1219.2	0.3	148,325	lb	**74.2** tons
straight		4112+85	125+361	2,757.1	840.4	136.2	41.5	48.0	1219.2	0.3	149,311	lb	**74.7** tons
straight		4113+37	125+377	2,810.2	856.6	148.2	45.2	48.0	1219.2	0.3	150,297	lb	**75.1** tons
HDD Rig Location		4113+89	125+393	2,863.3	872.7	160.1	48.8	48.0	1219.2	0.3	151,283	lb	**75.6** tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
214	1.48	0.31%	0	0.00	0.00%	0	0.00	0.00%	0.00	Yes	0.00	Yes
206	1.42	0.29%	0	0.00	0.00%	37	0.26	0.05%	0.00	Yes	0.00	Yes
197	1.36	0.28%	0	0.00	0.00%	74	0.51	0.11%	0.00	Yes	0.00	Yes
188	1.30	0.27%	0	0.00	0.00%	112	0.77	0.16%	0.00	Yes	0.00	Yes
179	1.24	0.26%	0	0.00	0.00%	149	1.03	0.21%	0.00	Yes	0.00	Yes
1,608	11.09	2.30%	0	0.00	0.00%	186	1.28	0.27%	0.03	Yes	0.00	Yes
1,063	7.33	1.52%	0	0.00	0.00%	223	1.54	0.32%	0.02	Yes	0.00	Yes
1,055	7.27	1.51%	0	0.00	0.00%	260	1.79	0.37%	0.02	Yes	0.00	Yes
1,046	7.21	1.49%	0	0.00	0.00%	297	2.05	0.42%	0.02	Yes	0.00	Yes
1,479	10.20	2.11%	10,116	69.75	14.45%	348	2.40	0.50%	0.25	Yes	0.05	Yes
1,214	8.37	1.73%	10,116	69.75	14.45%	396	2.73	0.57%	0.25	Yes	0.05	Yes
1,105	7.62	1.58%	10,116	69.75	14.45%	440	3.04	0.63%	0.25	Yes	0.05	Yes
1,034	7.13	1.48%	10,116	69.75	14.45%	482	3.32	0.69%	0.25	Yes	0.05	Yes
979	6.75	1.40%	10,116	69.75	14.45%	519	3.58	0.74%	0.24	Yes	0.05	Yes
933	6.43	1.33%	10,116	69.75	14.45%	554	3.82	0.79%	0.24	Yes	0.05	Yes
895	6.17	1.28%	10,116	69.75	14.45%	585	4.04	0.84%	0.24	Yes	0.05	Yes
893	6.15	1.28%	10,116	69.75	14.45%	613	4.23	0.88%	0.24	Yes	0.05	Yes
889	6.13	1.27%	10,116	69.75	14.45%	638	4.40	0.91%	0.24	Yes	0.05	Yes
885	6.10	1.26%	10,116	69.75	14.45%	660	4.55	0.94%	0.24	Yes	0.05	Yes
881	6.07	1.26%	10,116	69.75	14.45%	678	4.67	0.97%	0.24	Yes	0.05	Yes
876	6.04	1.25%	10,116	69.75	14.45%	693	4.78	0.99%	0.24	Yes	0.05	Yes
871	6.01	1.24%	10,116	69.75	14.45%	704	4.86	1.01%	0.24	Yes	0.06	Yes
867	5.98	1.24%	10,116	69.75	14.45%	713	4.91	1.02%	0.24	Yes	0.06	Yes
862	5.94	1.23%	10,116	69.75	14.45%	717	4.95	1.02%	0.24	Yes	0.06	Yes
857	5.91	1.22%	10,116	69.75	14.45%	719	4.96	1.03%	0.24	Yes	0.06	Yes
855	5.90	1.22%	0	0.00	0.00%	719	4.96	1.03%	0.02	Yes	0.01	Yes
853	5.88	1.22%	0	0.00	0.00%	719	4.96	1.03%	0.02	Yes	0.01	Yes
851	5.87	1.22%	0	0.00	0.00%	719	4.96	1.03%	0.02	Yes	0.01	Yes
849	5.85	1.21%	0	0.00	0.00%	719	4.96	1.03%	0.02	Yes	0.01	Yes
851	5.87	1.22%	0	0.00	0.00%	709	4.89	1.01%	0.02	Yes	0.01	Yes
853	5.88	1.22%	0	0.00	0.00%	709	4.89	1.01%	0.02	Yes	0.01	Yes
855	5.90	1.22%	0	0.00	0.00%	709	4.89	1.01%	0.02	Yes	0.01	Yes
858	5.91	1.23%	0	0.00	0.00%	709	4.89	1.01%	0.02	Yes	0.01	Yes
2,642	18.22	3.77%	0	0.00	0.00%	709	4.89	1.01%	0.05	Yes	0.01	Yes
1,764	12.16	2.52%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,766	12.18	2.52%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,768	12.19	2.53%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,770	12.21	2.53%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,773	12.22	2.53%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,775	12.24	2.54%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
1,777	12.25	2.54%	0	0.00	0.00%	709	4.89	1.01%	0.03	Yes	0.01	Yes
2,500	17.24	3.57%	10,116	69.75	14.45%	707	4.88	1.01%	0.27	Yes	0.07	Yes
2,094	14.44	2.99%	10,116	69.75	14.45%	701	4.84	1.00%	0.26	Yes	0.07	Yes
1,939	13.37	2.77%	10,116	69.75	14.45%	692	4.77	0.99%	0.26	Yes	0.06	Yes
1,846	12.73	2.64%	10,116	69.75	14.45%	678	4.67	0.97%	0.26	Yes	0.06	Yes
1,779	12.27	2.54%	10,116	69.75	14.45%	661	4.55	0.94%	0.26	Yes	0.06	Yes
1,725	11.90	2.46%	10,116	69.75	14.45%	639	4.41	0.91%	0.26	Yes	0.06	Yes
1,679	11.58	2.40%	10,116	69.75	14.45%	614	4.23	0.88%	0.26	Yes	0.06	Yes
1,681	11.59	2.40%	10,116	69.75	14.45%	585	4.03	0.84%	0.26	Yes	0.06	Yes
1,692	11.67	2.42%	10,116	69.75	14.45%	552	3.81	0.79%	0.26	Yes	0.06	Yes
1,702	11.74	2.43%	10,116	69.75	14.45%	515	3.55	0.74%	0.26	Yes	0.06	Yes
1,711	11.80	2.44%	10,116	69.75	14.45%	475	3.27	0.68%	0.26	Yes	0.05	Yes
1,719	11.85	2.46%	10,116	69.75	14.45%	430	2.97	0.61%	0.26	Yes	0.05	Yes
1,726	11.90	2.47%	10,116	69.75	14.45%	382	2.63	0.55%	0.26	Yes	0.05	Yes
1,733	11.95	2.48%	10,116	69.75	14.45%	330	2.27	0.47%	0.26	Yes	0.05	Yes
1,740	12.00	2.49%	10,116	69.75	14.45%	274	1.89	0.39%	0.26	Yes	0.05	Yes
1,747	12.04	2.50%	10,116	69.75	14.45%	214	1.48	0.31%	0.26	Yes	0.05	Yes
1,758	12.12	2.51%	0	0.00	0.00%	161	1.11	0.23%	0.03	Yes	0.00	Yes
1,770	12.20	2.53%	0	0.00	0.00%	107	0.74	0.15%	0.03	Yes	0.00	Yes
1,782	12.28	2.55%	0	0.00	0.00%	54	0.37	0.08%	0.03	Yes	0.00	Yes
1,793	12.36	2.56%	0	0.00	0.00%	0	0.00	0.00%	0.03	Yes	0.00	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Ground Elevation at Pipe Entry	162.37	feet
	49.49	metres
Ground Elevation at Pipe Exit	160.12	feet
	48.81	metres

	TOTAL PULL LOADS		
Maximum Values	210,918	lb	111.5 tons

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
2,642	18.2	3.77%	10,116	69.7	14.45%	719	5.0	1.03%	0.27	0.07

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	57.1	lbs/ft
	85.14	kg/m
Young's Modulus of Elasticity	2.90E+07	psi
	199948	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,600	ft
	792	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	210,918	lb
	938	kN
Factor of Safety	16.8	

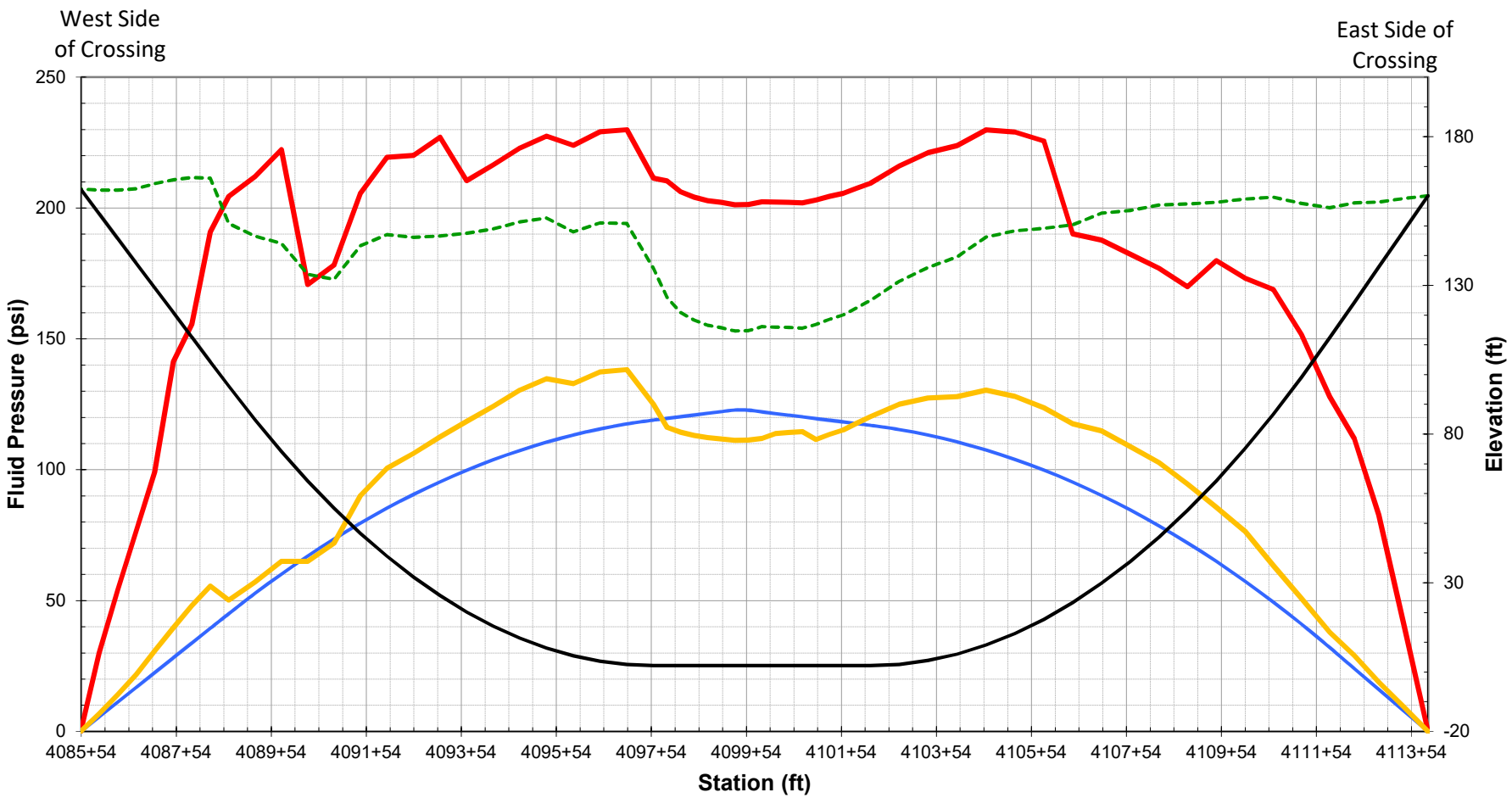
Start-up Load Factor	1.5	
Required Pipe Pull Load	222,901	lb
	992	kN
Factor of Safety	15.9	

Soil and Mud Properties

Mud Weight	12	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)	
	1.439	Specific Gravity	
Friction Coeff. (GS or rollers)	0.2	rollers typically 0.10 to 0.30 (along ground surface is higher range)	
Yield Point	24	lb/100ft^2 (Based on HDD experience from previous installations)	
	114.912	dyne/cm^2	
Plastic Viscosity	16	cP (Based on HDD experience from previous installations)	
Drilling mud pumping rate	300	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)	
	1.136	m^3/min	
Drilling mud pumping rate	1093	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)	
	4.138	m^3/min	
Pipe Pullback Rate	15	feet/min (Based on HDD experience)	
	4.57	m/min	

Appendix D

Hydraulic Fracture Evaluation



Crossing Length (ft)	2,836.0
Bore Diameter (in)	12.250
Drilling Fluid Flow Rate. (gpm)	600
Drilling Fluid Weight (ppg)	11.0
Plastic Viscosity (cP)	16
Yield Point (lb/100SF)	24

- Required Drilling Fluid Pressure
- Recommended Maximum Allowable Drilling Fluid Pressure
- Total Soil Stress
- Ground Surface Profile
- HDD Bore Profile

PennEast Pipeline
HORIZONTAL DIRECTIONAL DRILLING EVALUATION

MOTT MACDONALD

PennEast Pipeline Project
Delaware River Crossing
DRILLING FLUID PRESSURE EVALUATION

Pilot Bore Drilling Fluid Pressure Evaluation

MOTT MACDONALD

Horizontal Directional Drilling
Drilling Fluid Hydraulic Fracture Calculations

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 11/1/2018
Project No: 353754

PROJECT: PennEast Pipeline

CROSSING LOCATION: Delaware River

Reference:
1. Latoore, C.A., Wakeley, L.D., and Conroy, P.J., Guidelines for Installation of Utilities Beneath Corps of Engineers Levees using Horizontal Directional Drilling, June 2002, ERDC/GSL TR-02-9
2. HDD Consortium, Horizontal Directional Drilling Good Practices Guidelines, Third Edition, North American Society of Trenchless Technology, 2008.

Geotechnical Inputs

Note that soil type assumes entire soil layer above the bore consists of the same soil type and properties. Need to input appropriate soil properties into evaluation sheet for soils above the bore.

Only Change cells shaded in green
Changing other cells will interfere with calculations

Soil Properties	silt/sand Soil Type 1	silty clay Soil Type 2	sand/gravel Soil Type 3	gneiss Soil Type 4	dolomite Soil Type 5
c, soil effective cohesion (psf)	0	2,600	0	2,000	2,000
c, soil effective cohesion (N/m^2 or Pa)	0	124,489	0	95,761	95,761
ϕ, soil internal friction angle (deg)	30.0	0.0	31.0	28.0	28.0
ϕ, soil internal friction angle (rad)	0.5	0.0	0.5	0.5	0.5
E , Young's Modulus (kPa)	25,000	35,000	40,000	46,000	43,000
E , Young's Modulus (lb/ft^2)	522,136	730,990	835,417	960,730	898,073
ν , Poisson's ratio	0.33	0.35	0.33	0.33	0.33
G, soil shear modulus (ksf)	196	271	314	361	338
G, soil shear modulus (kPa)	9,398	12,963	15,038	17,293	16,165
G, soil shear modulus (Pa)	9,398,496	12,962,963	15,037,594	17,293,233	16,165,414
γ, soil total unit weight (pcf) below water table	135	135	135	140	135
γ, soil total unit weight (kN/m^3) below water table	21.2	21.2	21.2	22.0	21.2
γ, soil total unit weight (pcf) above water table	125	120	130	135	130
γ, soil total unit weight (kN/m^3) above water table	19.6	18.9	20.4	21.2	20.4
Top Elevation Soil Type encountered (feet)					
Top Elevation Soil Type encountered (metre)					
Bottom Elevation Soil Type encountered (feet)					
Bottom Elevation Soil Type encountered (metre)					

HDD Installation Inputs

Drill and Intersect Used	yes	yes or no
Target Drill and Intersect Location	4099+50	input stationing in feet (do not enter + sign)
	124+954	Stationing in metres
Drill Rig setup on Pipe Side (Single Rig Option Only). **For Drill and Intersect, this must be "no"**	no	yes or no (must be no for direct and interse
Drill Rig #1 Elevation	160.1	feet
	48.8	metre
Drill Rig #2 Elevation (Pipe Entry Location)	162.4	feet
	49.5	metre
Recommended Allowable Pressure Factor	1.50	
Total Horizontal Installation Length	2,836.0	feet
	864.4	metre
True Installation Length	2,863.3	feet
	872.7	metre
Pilot Bore Diameter	12.250	inch
	311.15	mm
Drill Pipe Diameter	6.625	inch
	168.28	mm
Yield Point	24	lb/100ft^2
Plastic Viscosity	16	cP
Drilling Fluid Pumping Rate	600	gal/min
	2.27	m^3/min
Calculated Drilling Fluid Velocity	2.306	ft/sec
	0.703	m/sec
Pressure Required for Bore Slurry Flow	0.022	psi per ft of bore
	0.155	kPa per metre of bore
	0.675	psi per 30 ft drill pipe
Drilling Fluid Mud Weight	11.0	ppg
	82.3	lb/ft^3
	1.32	specific gravity

Note: Stationing should be at least every 100 feet and finer detail where required. Check Start and Stop STA for proper direction.

Type 1 , Type 2, Type 3, Type 4, Type 5 or leave blank

Location	Bore Stationing		Drilled Length wrt Drill Rig(s) and Locations (True Bore Length)		Bore Elevation		Ground Surface Elevation		Water Table Elevation		Depth of Cover		Soil Type	Maximum Allowable Drilling Fluid Pressure		Estimated Bore Fluid Pressure for Drilling Fluid Flow		Factor of Safety	Estimated Hydrostatic Fluid Pressure Within Bore		Factor of Safety	Estimated Bore Fluid Pressure for Drilling Fluid Flow and Hydrostatic Column		Factor of Safety
	feet	metre	feet	metre	feet	metre	feet	metre	feet	metre	feet	metre		psi	kPa	psi	kPa		psi	kPa		psi	kPa	
Pipe Exit Side	4113+89	125+393	0.0	0.0	160.1	48.8	160.1	48.8	128.0	39.0	0.0	0.0	Type 1	0.0	0.0	0.0	0.0	--	0.00	0.00	--	0.00	0.0	--
	4113+37	125+377	53.1	16.2	148.2	45.2	159.2	48.5	128.0	39.0	11.0	3.3	Type 1	70.5	486.0	1.2	8.2	59.01	6.8	47.1	10.33	8.0	55.3	8.79
	4112+85	125+361	106.2	32.4	136.2	41.5	158.0	48.2	128.0	39.0	21.8	6.6	Type 1	140.7	970.2	2.4	16.5	58.90	13.6	94.1	10.31	16.0	110.6	8.77
	4112+34	125+346	159.3	48.5	124.3	37.9	157.7	48.1	128.0	39.0	33.4	10.2	Type 1	190.1	1311.0	3.6	24.7	53.06	20.5	141.2	9.29	24.1	165.9	7.90
	4111+82	125+330	212.4	64.7	112.4	34.2	156.1	47.6	128.0	39.0	43.8	13.3	Type 1	217.4	1499.2	4.8	32.9	45.51	27.3	188.2	7.97	32.1	221.1	6.78
	4111+22	125+312	273.3	83.3	99.1	30.2	157.6	48.0	128.0	39.0	58.5	17.8	Type 1	257.8	1777.8	6.1	42.4	41.93	34.9	240.6	7.39	41.0	283.0	6.28
	4110+63	125+293	334.3	101.9	86.6	26.4	159.7	48.7	128.0	39.0	73.1	22.3	Type 1	295.5	2037.4	7.5	51.9	39.28	42.0	289.6	7.03	49.5	341.5	5.97
	4110+03	125+275	395.3	120.5	75.0	22.9	159.0	48.5	128.0	39.0	84.0	25.6	Type 1	320.6	2210.3	8.9	61.3	36.04	48.6	335.3	6.59	57.5	396.7	5.57
	4109+43	125+257	456.3	139.1	64.3	19.6	157.9	48.1	128.0	39.0	93.7	28.6	Type 1	341.7	2356.0	10.3	70.8	33.29	54.8	377.7	6.24	65.0	448.5	5.25
	4108+83	125+239	517.3	157.7	54.4	16.6	157.4	48.0	128.0	39.0	103.1	31.4	Type 2	195.4	1347.2	11.6	80.2	16.79	60.4	416.7	3.23	72.1	496.9	2.71
	4108+22	125+220	578.2	176.2	45.3	13.8	157.0	47.9	128.0	39.0	111.7	34.1	Type 2	203.6	1403.6	13.0	89.7	15.65	65.6	452.3	3.10	78.6	542.0	2.59
	4107+62	125+202	639.2	194.8	37.1	11.3	155.2	47.3	128.0	39.0	118.1	36.0	Type 2	209.8	1446.4	14.4	99.2	14.59	70.3	484.6	2.98	84.7	583.8	2.48
	4107+01	125+183	700.2	213.4	29.8	9.1	154.3	47.0	128.0	39.0	124.5	37.9	Type 2	215.9	1488.4	15.8	108.6	13.70	74.5	513.5	2.90	90.2	622.1	2.39
	4106+41	125+165	761.2	232.0	23.3	7.1	150.4	45.8	128.0	39.0	127.1	38.7	Type 2	218.7	1507.8	17.1	118.1	12.77	78.2	539.0	2.80	95.3	657.1	2.29
	4105+80	125+146	822.1	250.6	17.7	5.4	149.2	45.5	128.0	39.0	131.5	40.1	Type 4	564.1	3889.3	18.5	127.5	30.50	81.4	561.1	6.93	99.9	688.6	5.65
	4105+19	125+128	883.1	269.2	12.9	3.9	148.4	45.2	128.0	39.0	135.4	41.3	Type 4	572.5	3947.2	19.9	137.0	28.81	84.1	579.8	6.81	104.0	716.8	5.51
	4104+58	125+109	944.1	287.8	9.1	2.8	146.3	44.6	128.0	39.0	137.2	41.8	Type 4	574.6	3961.7	21.2	146.5	27.05	86.3	595.1	6.66	107.6	741.6	5.34
	4103+97	125+091	1,005.1	306.3	6.0	1.8	139.6	42.6	128.0	39.0	133.6	40.7	Type 4	559.7	3859.2	22.6	155.9	24.75	88.0	607.0	6.36	110.7	763.0	5.06
	4103+36	125+072	1,066.0	324.9	3.9	1.2	136.0	41.5	128.0	39.0	132.2	40.3	Type 4	552.9	3811.9	24.0	165.4	23.05	89.3	615.6	6.19	113.3	780.9	4.88
	4102+76	125+053	1,127.0	343.5	2.6	0.8	131.4	40.0	128.0	39.0	128.8	39.3	Type 4	540.3	3725.4	25.4	174.8	21.31	90.0	620.7	6.00	115.4	795.5	4.68
	4102+15	125+035	1,188.0	362.1	2.1	0.7	124.9	38.1	128.0	39.0	122.8	37.4	Type 4	523.7	3610.8	26.7	184.3	19.59	90.3	622.4	5.80	117.0	806.7	4.48
	4101+86	125+026	1,216.5	370.8	2.1	0.7	122.5	37.3	128.0	39.0	120.3	36.7	Type 4	518.8	3577.2	27.4	188.7	18.96	90.3	622.4	5.75	117.6	811.1	4.41
	4101+58	125+018	1,245.0	379.5	2.1	0.7	120.0	36.6	128.0	39.0	117.9	35.9	Type 4	513.9	3543.5	28.0	193.1	18.35	90.3	622.4	5.69	118.3	815.5	4.35
	4101+29	125+009	1,273.5	388.2	2.1	0.7	118.6	36.1	128.0	39.0	116.4	35.5	Type 4	511.1	3523.8	28.7	197.6	17.84	90.3	622.4	5.66	118.9	819.9	4.30
	4101+01	125+000	1,302.0	396.9	2.1	0.7	116.8	35.6	128.0	39.0	114.7	35.0	Type 4	507.5	3499.2	29.3	202.0	17.33	90.3	622.4	5.62	119.6	824.4	4.24
	4100+72	124+991	1,330.5	405.5	2.1	0.7	115.6	35.2	128.0	39.0	113.4	34.6	Type 4	505.0	3482.0	29.9	206.4	16.87	90.3	622.4	5.59	120.2	828.8	4.20
	4100+44	124+983	1,359.0	414.2	2.1	0.7	115.8	35.3	128.0	39.0	113.7	34.6	Type 4	505.5	3485.3	30.6	210.8	16.53	90.3	622.4	5.60	120.8	833.2	4.18
	4100+15	124+974	1,387.5	422.9	2.1	0.7	116.0	35.3	128.0	39.0	113.8	34.7	Type 4	505.8	3487.5	31.2	215.2	16.20	90.3	622.4	5.60	121.5	837.6	4.16
	4099+87	124+965	1,416.0	431.6	2.1	0.7	116.1	35.4	128.0	39.0	114.0	34.7	Type 4	506.1	3489.3	31.9	219.7	15.89	90.3	622.4	5.61	122.1	842.0	4.14
	4099+58	124+957	1,444.5	440.3	2.1	0.7	114.8	35.0	128.0	39.0	112.6	34.3	Type 4	503.4	3470.9	32.5	224.1	15.49	90.3	622.4	5.58	122.8	846.5	4.10
	4099+30	124+948	1,390.3	423.8	2.1	0.7	114.7	35.0	128.0	39.0	112.5	34.3	Type 4	503.2	3469.4	31.3	215.7	16.09	91.6	631.2	5.50	122.8	846.9	4.10
	4099+01	124+939	1,361.8	415.1	2.1	0.7	115.7	35.3	128.0	39.0	113.6	34.6	Type 4	505.3	3484.1	30.6	211.3	16.49	91.6	631.2	5.52	122.2	842.5	4.14
	4098+73	124+931	1,333.3	406.4	2.1	0.7	116.6	35.5	128.0	39.0	114.5	34.9	Type 4	507.1	3496.6	30.0	206.8	16.91	91.6	631.2	5.54	121.6	838.1	4.17
	4098+44	124+922	1,304.8	397.7	2.1	0.7	118.3	36.1	128.0	39.0	116.2	35.4	Type 4	510.5	3519.8	29.4	202.4	17.39	91.6	631.2	5.58	120.9	833.6	4.22
	4098+16	124+913	1,276.3	389.0	2.1	0.7	120.9	36.8	128.0	39.0	118.7	36.2	Type 4	515.7	3555.4	28.7	198.0	17.96	91.6	631.2	5.63	120.3	829.2	4.29
	4097+87	124+905	1,247.8	380.3	2.1	0.7	126.0	38.4	128.0	39.0	123.9	37.8	Type 4	525.9	3625.9	28.1	193.6	18.73	91.6	631.2	5.74	119.6	824.8	4.40
	4097+59	124+896	1,219.3	371.6	2.1	0.7	135.8	41.4	128.0	39.0	133.6	40.7	Type 5	528.7	3644.9	27.4	189.1	19.27	91.6	631.2	5.77	119.0	820.4	4.44
	4097+02	124+879	1,163.0	354.5	2.5	0.8	150.8	46.0	128.0	39.0	148.3	45.2	Type 5	574.8	3963.1	26.2	180.4	21.97	91.3	629.8	6.29	117.5	810.2	4.89
	4096+46	124+862	1,106.7	337.3	3.6	1.1	151.0	46.0	128.0	39.0	147.4	44.9	Type 5	573.0	3950.4	24.9	171.7	23.01	90.7	625.4	6.32	115.6	797.1	4.96
	4095+90	124+844	1,050.4	320.2	5.5	1.7	148.0	45.1	128.0	39.0	142.5	43.4	Type 5	559.8	3859.5	23.6	163.0	23.69	89.7	618.2	6.24	113.3	781.1	4.94
	4095+34	124+827	994.2	303.0	8.0	2.4	152.7	46.5	128.0	39.0	144.6	44.1	Type 5	568.6	3920.5	22.4	154.2	25.42	88.2	608.0	6.45	110.6	762.2	5.14
	4094+77	124+810	937.9	285.9	11.3	3.5	151.4	46.1	128.0	39.0	140.0	42.7	Type 5	557.4	3843.3	21.1	145.5	26.42	86.3	595.0	6.46	107.4	740.5	5.19
	4094+21	124+793	881.6	268.7	15.4	4.7	149.0	45.4	128.0	39.0	133.6	40.7	Type 5	541.2	3731.7	19.8	136.8	27.29	84.0	579.0	6.44	103.8	715.8	5.21
	4093+65	124+776	825.3	251.6	20.2	6.2	147.5	45.0	128.0	39.0	127.4	38.8	Type 5	526.1	3627.3	18.6	128.0	28.33	81.2	560.2	6.48	99.8	688.2	5.27
	4093+09	124+759	769.0	234.4	25.7	7.8	146.6	44.7	128.0	39.0	120.9	36.9	Type 5	511.0	3523.1	17.3	119.3	29.53	78.1	538.4	6.54	95.4	657.7	5.36
	4092+53	124+742	712.7	217.2	31.9	9.7	146.1	44.5	128.0	39.0	114.2	34.8	Type 5	495.3	3415.2	16.0	110.6	30.89	74.5	513.8	6.65	90.6	624.4	5.47
	4091+97	124+725	656.4	200.1	38.9	11.9	147.1	44.8	128.0	39.0	108.2	33.0	Type 5	482.6	3327.6	14.8	101.8	32.68	70.5	486.3	6.84	85.3	588.1	5.66
	4091+42	124+708	600.1	182.9	46.6	14.2	143.3	43.7	128.0	39.0	96.7	29.5	Type 5	452.2	3118.0	13.5	93.1	33.49	66.1	455.9	6.84	79.6	549.0	5.68
	4090+86	124+691	543.9	165.8	55.1	16.8	132.0	40.2	128.0	39.0	76.9	23.4	Type 5	392.2	2704.0	12.2	84.4	32.05	61.3	422.7	6.40	73.5	507.0	5.33
	4090+30	124+674	487.6	148.6	64.3	19.6	133.8	40.8	128.0	39.0	69.5	21.2	Type 5	375.7	2590.3	11.0	75.6	34.25	56.1	386.6	6.70	67.0	462.2	5.60
	4089+75	124+657	431.3	131.5	74.1	22.6	144.2	43.9	128.0	39.0	70.0	21.3	Type 5	389.1	2682.5	9.7	66.9	40.10	50.4	347.6	7.72	60.1	414.5	6.47
	4089+20	124+640	375.0	114.3	84.8	25.8	146.6	44.7	128.0	39.0	61.8	18.8	Type 5	371.1	2558.9	8.4	58.2	43.99	44.3	305.7	8.37	52.8	363.9	7.03
	4088+65	124+623	318.7	97.1	96.1	29.3	150.8	46.0	128.0	39.0	54.7	16.7	Type 5	357.9	2467.6	7.2	49.4	49.91	37.9	261.1	9.45	45.0	310.5	7.95
	4088+26	124+612	278.9	85.0	104.4	31.8	166.0	50.6	128.0	39.0	61.6	18.8	Type 3	334.0	2302.6	6.3	43.3	53.23	33.1	228.4	10.08	39.4	271.7	8.48
	4087+87	124+600	239.0	72.9	112.7	34.3	166.3	50.7	128.0	39.0	53.6	16.3	Type 3	311.2	2145.8	5.4	37.1	57.87	28.4	195.8	10.96	33.8	232.9	9.21
	4087+48	124+588	199.2	60.7	121.0	36.9	165.5	50.4	128.0	39.0	44.5	13.6	Type 3	282.6	1948.6	4.5	30.9	63.06	23.7	163.2	11.94	28.1	194.1	10.04
	4087+09	124+576	159.4	48.6	129.2	39.4	164.2	50.1	128.0	39.0	35.0	10.7	Type 3	247.7	1707.7	3.6	24.7	69.08	18.9	130.5	13.08	22.5	155.2	11.00
	4086+70	124+564	119.5	36.4	137.5	41.9	162.5	49.5	128.0	39.0	24.9	7.6	Type 3	191.4	1320.0	2.7	18.5	71.20	14.2	97.9	13.48	16.9	116.4	11.34
	4086+31	124+552	79.7	24.3	145.8	44.4	162.0	49.4	128.0	39.0	16.2	4.9	Type 1	108.2	746.0	1.8	12.4	60.35	9.5	65.3	11.43	11.3	77.6	9.61
	4085+92	124+540	39.8	12.1	154.1	47.0	162.0	49.4	128.0	39.0	7.9	2.4	Type 1	45.1	311.1	0.9	6.2	50.34	4.7	32.6	9.53	5.6	38.8	8.02
Pipe Entry Side	4085+53	124+528	0.0	0.0	162.4	49.5	162.4	49.5	128.0	39.0	0.0	0.0	Type 1	0.0	0.0	0.0	0.0	--	0.0	0.0	--	0.0	0.0	--

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