MOTT MACDONALD

PennEast PIPELINE

Horizontal Directional Drill Design Report Interstate 78 Crossing

PennEast Pipeline Project

December 17, 2018

Mott MacDonald
111 Wood Avenue South
Iselin NJ 08830-4112
United States of America

T +1 (800) 832 3272
F +1 (973) 376 1072
mottmac.com

PennEast Pipeline Project
One Meridian Blvd
Suite 2C01
Wyomissing, PA 19610
610-373-7999

Horizontal Directional Drill Design Report Interstate 78 Crossing

PennEast Pipeline Project

December 17, 2018

Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
A	11/09/18	M. Lockwood	G. Duyvestyn	M. Wilcox	Draft for Internal Review
B	12/17/18	M. Lockwood	G. Duyvestyn	M. Wilcox	Issued for PADEP

Document reference: 353754-MM-EN-CO-064 RevB

Information class: Standard

Contents

Tables

Figures

1 Introduction

Mott MacDonald has prepared this Horizontal Directional Drill (HDD) design report at the request of PennEast Pipeline Company, LLC (PennEast), for their proposed trenchless crossing of Interstate 78 (I-78), 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 I-78 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, geophysical investigations were completed by Hager-Richter Geoscience, Inc. (Hager-Richter) and THG Geophysics, Inc (THG) 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 2,285 feet (with a true length of approximately 2,304 feet). The HDD entry point is located approximately 285 feet northwest of I-78 and the HDD exit point is located approximately 404 feet southeast of I-78. An elevation difference of approximately 111 feet exists between HDD entry and exit locations, with the HDD entry location at the lower elevation. The minimum depth of cover beneath I-78 is approximately 99 feet.

The pipe staging area for the drag section is located on the south side of the crossing. It is envisioned that the pipe string will be fabricated into a single section prior to pullback operations.

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 borings completed to support the design of this crossing 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.

The first portion of the alignment, beneath the interstate, is anticipated to pass through soils and into dolomite of the Leithsville formation which is anticipated to have a pinnacled top of rock profile and a potential for dissolution voids. South of the interstate the alignment is likely to encounter the relativity thin Hardystone Quartzite before passing in to the Precambrian gneisses for the southern portion of the alignment.

2.1 Subsurface Investigations

A total of eight (8) borings, designated as B-28, B-29, B-30, B-I78-1, B-I78-1A, B-I78-2, B-I78-3, and B-I78-4 were completed as part of the geotechnical investigation program to support the evaluation and design of the I-78 crossing. Boring B-I78-1 was abandoned and Borehole B-I78-1A was added to the program due to the core barrel turning a hard angle in B-I78-1 which prevented advancement of the borehole. Boring B-30 was also terminated approximately 21 feet before reaching the proposed depth due to a piece of wireline that broke off within the borehole. More detailed discussions can be found in the site-specific GDR.

A geophysical investigation program was also completed to support the design of the pipeline alignment. The geophysical surveys were used to locate potential Karst features and evaluate complex geological trends. Along the northwest side of the proposed alignment, Hager-Richter performed geophysical surveys using Electrical Resistivity Imaging (ERI). On the southeast side of the proposed alignment, THG completed geophysical surveys using a combination of ERI, Microgravity (MG), and Multichannel Analysis of Seismic Waves (MASW). More detailed discussions can be found in the site-specific GDR.

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

2.2 Geotechnical Observations

2.2.1 Geotechnical Observations West Side of Interstate 78

The HDD installation on the west side of I-78 is anticipated to encounter soil materials consisting of (based on Boring B-28):

- Silty sand from the ground surface to a depth of 2.0 feet (from Elev. 472 to 470 feet).
- A boulder to a depth of 4.5 feet (to Elev. 467.5 feet).
- Very soft (weight of hammer) clay with sand and gravel to a depth of 8.5 feet (to Elev. 463.5 feet). Grain size distribution tests indicate gravel percentages up to 11.6 percent of the soil particles.
- Medium dense clayey sand with gravel to a depth of 13.5 feet (to Elev. 458.5 feet). Grain size distribution tests indicate gravel percentages up to 28.1 percent of the soil particles.
- Stiff to very stiff clay with sand and gravel to a depth of 23.5 feet (to Elev. 448.5 feet). Grain size distribution tests indicate gravel percentages up to 14 percent of the soil particles.

- Medium dense clayey sand with decomposed rock fragments to a depth of 28.5 feet (to Elev. 443.5 feet). Grain size distribution tests indicate gravel percentages up to 22 percent of the soil particles.
- Medium stiff to very stiff sandy lean clay with decomposed rock fragments to the termination depth of 62 feet (to Elev. 410 feet). Grain size distribution tests indicate gravel percentages up to 6.6 percent of the soil particles.

2.2.2 Geotechnical Observations East Side of Interstate 78

The HDD installation on the east side of I-78 and west side of Redington Road is anticipated to encounter soil materials consisting of (based on Boring B-I78-1):

- Stiff clay with decomposed rock fragments from the ground surface to a depth of 8.5 feet (from Elev. 527 to 518.5 feet).
- Soft to hard silt with decomposed rock fragments to a depth of 38.5 feet (to Elev. 488.5 feet).
- Very stiff clay with decomposed rock fragments to a depth of 43.5 feet (to Elev. 483.5 feet).
- Very stiff silt with decomposed rock fragments to a depth of 48.5 feet (to Elev. 478.5 feet).
- Stiff to very stiff clay with decomposed rock fragments to a depth of 68.5 feet (to Elev. 458.5 feet).
- Very stiff silt with decomposed rock fragments to a depth of 78.5 feet (to Elev.448.5 feet).
- Very stiff clay with decomposed rock fragments to a depth of 88.5 feet (to Elev. 438.5 feet).
- Very dense decomposed rock fragments with silt to a depth of 100.0 feet (to Elev. 427 feet).
- Fresh and strong to very strong dolomite to a depth of 135.0 feet (to Elev. 392 feet). RQD values ranging between 43 and 97 percent (average 81 percent).
- Void encountered to a termination depth of 140 feet (to Elev. 387 feet). Borehole was abandoned and grouted.

Based on Boring B-I78-1A, anticipated soils include:

- Stiff clay with gravel and sand from the ground surface to a depth of 8.5 feet (from Elev. 530 to 521.5 feet).
- Stiff to very stiff silt with decomposed rock fragments to a depth of 28.5 feet (to Elev. 501.5 feet).
- Stiff to very stiff clay with decomposed rock fragments to a depth of 43.5 feet (to Elev. 486.5 feet).
- Hard silt with decomposed rock fragments to a depth of 53.5 feet (to Elev. 476.5 feet).
- Very stiff clay with decomposed rock fragments to a depth of 58.5 feet (to Elev. 471.5 feet).
- Hard to very stiff silt with decomposed rock fragments to a depth of 68.5 feet (to Elev. 461.5 feet).
- Hard to very stiff clay with decomposed rock fragments to a depth of 100.0 feet (to Elev. 430 feet).
- Highly weathered to fresh and weak to very strong dolomite to a termination depth of 160.0 feet (to Elev. 370 feet). RQD values ranging between 43 and 100 percent (average 74 percent). Recovery values ranging between 88 and 100 percent (average 95 percent). Two (2) voids were identified within the layer ranging between 1.0 and 2.5 feet.

2.2.3 Geotechnical Observations East of Redington Road

The HDD installation on the east side of Redington Road is anticipated to encounter soil materials consisting of (based on Boring B-I78-3):

- Very loose silty sand with trace clay from the ground surface to a depth of 3.5 feet (from Elev. 555 to 551.5 feet).
- Loose sand with little clay to a depth of 8.5 feet (to Elev. 546.5 feet).

- Medium dense sand with trace clay to a depth of 13.5 feet (to Elev. 541.5 feet).
- Medium stiff silt with some clay to a depth of 18.5 feet (to Elev. 536.5 feet).
- Soft to hard silty clay with trace sand to a depth of 43.5 feet (to Elev. 511.5 feet).
- Dense sand with some silt to a depth of 48.5 feet (to Elev. 506.5 feet).
- Dense to very dense sand to a depth of 78.5 feet (to Elev. 476.5 feet). Rig chatter was observed throughout this layer, and gravel sized weathered gneiss was occasionally observed within the tip of the split spoon.
- Very dense silty sand with some clay to a depth of 90.0 feet (to Elev. 465 feet).
- Completely weathered to slightly weathered and extremely weak to strong gneiss to a depth of 140 feet (to Elev. 415 feet). RQD values ranging between 0 and 80 percent (average 31 percent). Recovery values ranging between 28 and 98 percent (average 65 percent).
- No rock coring recovery to a depth of 155 feet (to Elev. 400 feet).
- Completely weathered to highly weathered and very weak to weak gneiss to a depth of 170 feet (to Elev. 385 feet). RQD values throughout layer were 0 percent, with recovery values ranging between 35 and 55 percent (average 44 percent).
- Void encountered from a depth of 170 to 172 feet (Elev. 385 to 387 feet).
- Completely weathered to moderately weathered and very weak to medium strong Quartzite to a depth of 200 feet (to Elev. 355 feet). RQD values ranging between 0 and 45 percent (average 18 percent). Recovery values ranging 15 to 73 percent (average 48 percent).
- Void encountered from a depth of 200 to 204 feet (Elev. 355 to 351 feet). No rock core recovery after void to a depth of 205 feet (to Elev. 350 feet). Possible that area is highly weathered rock.
- Completely weathered to fresh and medium strong to strong quartzite to a termination depth of 225.0 feet (to Elev. 330 feet). RQD values ranging between 7 and 85 percent (average 34 percent). Recovery values ranging between 32 and 100 percent (average 74 percent).

Based on Boring B-29, anticipated soils include:

- Hard to very stiff clay with sand and trace gravel from the ground surface to a depth of 18.5 feet (from Elev. 564 to 545.5 feet).
- Dense sand to a depth of 23.5 feet (to Elev. 540.5 feet).
- Stiff to very stiff clay with sand and gravel to a depth of 38.5 feet (to Elev. 525.5 feet).
- Very dense sand with gravel to a depth of 43.5 feet (to Elev. 520.5 feet).
- Very stiff silt with gravel to a depth of 49 feet (to Elev. 515 feet).
- Extremely weathered to moderately weathered and extremely weak to medium strong gneiss to a depth of 160 feet (to Elev. 404 feet). RQD values ranging between 0 and 35 percent (average 9 percent). Recovery values ranging between 0 and 70 percent (average 29 percent). Four (4) area of no rock core recovery.
- Moderately weathered and very weak quartzite to a depth of 180.0 feet (to Elev. 384 feet). RQD values ranging between 0 and 17 percent (average 6 percent). Recovery values ranging between 30 and 68 percent (average 48 percent).

Based on Boring B-I78-2, anticipated soils include:

- Very stiff silt with decomposed rock fragments from the ground surface to a depth of 10 feet (from Elev. 596 to 586 feet).
- Very dense decomposed rock fragments with sandy clay and sandy silt to a depth of 18.5 feet (to Elev. 577.5 feet).
- Hard to very stiff silt with decomposed rock fragments to a depth of 28.5 feet (to Elev. 567.5 feet).

- Very dense decomposed rock fragments with clayey silt and clayey sand to a depth of 38.5 feet (to Elev. 557.5 feet).
- Hard sandy silt with decomposed rock fragments to a depth of 45 feet (to Elev. 551 feet).
- Highly weathered to fresh and weak to very strong gneiss to a depth of 200 feet (to Elev. 396 feet). RQD values ranging from 0 to 97 percent (average 54 percent). Recovery values ranging from 0 to 100 percent (average 87 percent). One (1) area of no rock recovery.

2.2.4 Geotechnical Observations West of Lower Saucon Road

The HDD installation near Lower Saucon Road is anticipated to encounter soil materials consisting of (based on Boring B-I78-4):

- Medium dense silty sand with little gravel from the ground surface to a depth of 3.5 feet (from Elev. 616 to 612.5 feet).
- Medium stiff silt with some clay and trace sand to a depth of 8.5 feet (to Elev. 607.5 feet).
- Medium stiff sandy silt with some clay to a depth of 13.5 feet (to Elev. 602.5 feet).
- Medium dense sandy gravel with little clay to a depth of 18.5 feet (to Elev. 597.5 feet).
- Very dense gravel with some sand to a depth of 23.5 feet (to Elev. 592.5 feet).
- Very dense clayey sand with some gravel to a depth of 28.5 feet (to Elev. 587.5 feet).
- Very dense gravel with some sand to a depth of 32 feet (to Elev. 584 feet).
- Moderately weathered to slightly weathered and weak gneiss to a depth of 43 feet (to Elev. 573 feet). RQD values ranging between 30 to 58 percent (average 47 percent).
- Moderately weathered to slightly weathered and strong granite to a depth of 45.7 feet (to Elev. 570.3 feet).
- Moderately weathered and medium strong gneiss to a depth of 50 feet (to Elev. 566 feet). RQD value of 20 percent.
- Slightly weathered and strong granite to a depth of 58.5 feet (to Elev. 557.5 feet). RQD values ranging between 67 to 77 percent (average 72 percent).
- Highly weathered to fresh and very weak to very strong gneiss to a depth of 250 feet (to Elev. 366 feet). RQD values ranging between 0 and 100 percent (average 87 percent). Recovery values ranging between 65 to 100 percent (average 99 percent).

Based on Boring B-30, anticipated soils include:

- Medium dense and well graded gravel with silt from the ground surface to a depth of 3.5 feet (from Elev. 601.7 to 598.2 feet).
- Hard to very stiff silt with sand to a depth of 38.5 feet (to Elev. 563.2 feet).
- Very dense decomposed rock fragments to a depth of 50 feet (to Elev. 551.7 feet).
- Fresh and medium strong to very strong granitic gneiss to a depth of 85.0 feet (to Elev. 516.7 feet). RQD values ranging between 13 and 93 percent (average 67 percent).
- Fresh and very strong Marble to a depth of 90.0 feet (to Elev. 511.7 feet). RQD value of 100 percent.
- Fresh and very strong pegmatitic granite to a depth of 100.0 feet (to Elev. 501.7 feet). RQD values ranging between 83 and 100 percent (average 92 percent).
- Slightly weathered to fresh and very strong granite to a depth of 135.0 feet (to Elev. 466.7 feet). RQD values ranging between 38 and 75 percent (average 56 percent).
- Fresh and very strong pegmatitic granite to a depth of 150.0 feet (to Elev. 451.7 feet). RQD values ranging between 53 and 93 percent (average 75 percent).

- Fresh and very strong granite to a termination depth of 154.1 feet (to Elev. 447.6 feet).

Along the proposed HDD alignment, the bedrock on the east side of Interstate 78 appears to be of very poor to good quality depending on the strata, with an overall poor quality of the rock mass. The core recovery values on the east side for all strata ranged from 0 to 100 percent with an average value of 76.5 percent.

The dolomite RQD values ranged from 43 to 100 percent with an average value of 76.3 percent. Laboratory testing of the Dolomite from borings B-I78-1 and B-I78-1A indicate a Uniaxial Compressive Strength (UCS) range from 7,849 to 20,216 psi with an average of 13,425 psi. The axial point load UCS ranged from 7,255 to 32,277 psi with an average of 20,553 psi. The diametral point load UCS ranged from 18,960 to 30,336 psi with an average of 23,595 psi. The splitting tensile strength ranged from 1,323 psi to 2,022 psi with an average of 1,675 psi.

The quartzite RQD values ranged from 0 to 17 percent with an average value of 6 percent. Laboratory testing of the Dolomite from borings B-29 indicate a UCS of 2,889 psi, an axial point load UCS of 8,833 psi, and a diametral point load UCS of 1,156 psi.

The gneiss RQD values ranged from 0 to 97 percent with an average value of 39.2 percent. Laboratory testing of the gneiss from borings B-29 and B-I78-2 indicate a UCS range from 3,300 to 8,243 psi with an average of 6,048 psi. The axial point load UCS ranged from 1,236 to 30,394 psi with an average of 15,815 psi. The diametral point load UCS ranged from 1,156 to 40,532 psi with an average of 18,408 psi. The splitting tensile strength ranged from 1,463 to 2,965 psi with an average of 1,714 psi.

2.3 Geophysical Observations

Hager-Richter performed geophysical surveys using Electrical Resistivity Imaging (ERI) to locate potential karst features and evaluate complex geological trends which may affect the construction of the proposed pipeline. Hager-Richter collected geophysical information along the property northwest of the proposed I-78 crossing. A Karst Investigation memo for the PennEast Pipeline Project dated September 23, 2015, identifies segments where these geophysical investigations were conducted within the identified property. The results of this geophysical survey depicted possible clay pockets and extensive fill along the current alignment of the proposed pipeline. Hager-Richter's results are shown on the proposed plan and profile located in Appendix A.

On the southeast side of the proposed alignment, THG completed geophysical surveys using a combination of ERI, Microgravity (MG), and Multichannel Analysis of Seismic Waves (MASW). THG's survey along southeast portions of the proposed pipeline alignment identified and confirmed locations of folding, faulting, and complex lithological sequencing. More detailed discussions can be found in THG's Geophysical Evaluation report provided in the site-specific GDR.

2.4 Karst Formations and Abandoned Mines

On the northwest side of I-78, 20 karst features, described as surface depressions, were identified within 0.5 miles of the proposed HDD alignment. Southeast of I-78 a total of six (6) surface depressions have been identified. No former mines have been mapped in the area of the I-78 Crossing.

Voids ranging from 1 to 4-foot thick were encountered between the depths of 125 and 139.5 feet BGS within boring B-I78-1 and B-I78-1A located on the southeast side of I-78.

3 Interstate 78 Crossing

3.1 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 I-78 Crossing, the entry and exit angles have been set at 10° 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 crossing eliminating the risks associated with horizontal curvature.

The proposed vertical curve radius of 3,600 feet shown in Appendix A consistent with the HDD industry standard of 1,200 times the 36-inch outer diameter of the pipe (1200 X 36 inches = 43,200 inches or 3,600 feet). This radius has been taken as the design radius for the crossing.

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:

- Anticipated geotechnical materials,
- Presence of preferential flow pathways,
- Historical land use,
- Design bending radius,
- 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. For this installation, the HDD is anticipated to be within the bedrock prior to crossing under Interstate 78.

The proposed HDD installation crosses beneath surface features including Interstate 78, Redington Road, and Lower Saucon Road. From a northwest to southeast orientation, the following minimum depths of cover are noted:

- Interstate 78: approximately 99 feet.
- Redington Road: approximately 137 feet.
- Lower Saucon Road: approximately 122 feet.

3.1.4 Bore Diameter

The diameter of the HDD bore must 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 HDD industry standard for the final bore diameter is generally 12 inches larger than the outer diameter of the product pipe. 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 from which the downhole probe can 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.

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 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 to avoid the risks associated with laying a surface coil across Interstate 78. 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 northwest side of the crossing has been established at 325 feet by 250 feet, and the staging area for the southeast side of the crossing has been established at approximately 330 feet by 250 feet. A proposed wareyard is located adjacent to the northwest staging area location, possibly allowing for more workspace area to be utilized. These workspace areas are 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 at least 50 feet wide by the length of the pipe string is also required for welding sections of the pipe string. The proposed staging area for the drag section is located on the southeast side of the crossing. The available length of the staging area is greater than the approximate 2,400 feet required, allowing for the fabrication of the product pipe into a single pipe string. The narrowest width of the proposed pipe staging area is 75 feet.

The temporary work space established for the Interstate 78 is sufficient for HDD operations.

3.4 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 contractor will be required to haul and store water on site for 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 spoils 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 three (3), the estimated total water usage (assuming no loss in circulation) is approximately 777,422 gallons (103,926 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).

3.5 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 is not expected to be suitable for permanent disposal of fluids 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 fluids and processed spoil per the local, state, and federal guidelines.

Disposal volumes of excess fluids and spoil are estimated at approximately 520,400 gallons (2,575 yd^3) and 41,500 ft^3 (1,540 yd^3), respectively. During pullback operations, the estimated displaced fluid volume is approximately 28,418 gallons (141 yd^3).

3.6 Schedule

The duration of the HDD installation is conservatively estimated to take a total of 69 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	5
Pilot Bore Drilling	14
Reaming	40
Swab Pass	1
Product Pipe Pullback	1
Rig Down and Demobilization	5
Total Number of Shifts	69

4 HDD Engineering Evaluation

4.1 Pipeline Properties

The pipeline properties used for the evaluation of the I-78 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 Installation 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. This ultimate minimum bending radius is based on allowing the pipe to experience a maximum shear stress of 45 percent of the specified minimum yield strength (SMYS).

The minimum allowable bending radius is the minimum radius that the HDD contractor is permitted to steer 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 for a 3-joint average radius.

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 I-78 profile has been established at 3,600 feet, which is consistent with the HDD industry standard of 1,200 times the outer diameter of the NPS 36 pipe (1200 X 36 inches = 43,200 inches or 3,600 feet).

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 bore geometry. 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 applicable portions of 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 3-joint average allowable bending radius of 2,600 feet (the minimum allowable bend radius provided to the HDD contractor), respectively. 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 anticipated operating stresses within the 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	55,554	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 the 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 were 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 where water is added to the pipe during pullback, as the estimated installation loads are significantly 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.

Table 4: Summary of Anticipated Pullback Loads

Drilling Fluid Weight (ppg)	Product Pipe Buoyancy Condition	Estimated Pullback Force (lbs)
10 (Case 1)	Empty	525,461
10 (Case 2)	Full	258,732
11 (Case 3)	Empty	610,570
11 (Case 4)	Full	223,090
12 (Case 5)	Empty	695,286
12 (Case 6)	Full	210,732

Results of the corresponding installation stresses (based on the design bending radius of 3,600 feet) are summarized below 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)	6,229 psi (8.9%)	3,067 psi (4.4%)	7,238 psi (10.4%)	2,645 psi (3.8%)	8,242 psi (11.8%)	2,498 psi (3.6%)
Maximum Bending Stress (Percent of Allowable)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)
Maximum Hoop Stress (Percent of Allowable)	772 psi (1.1%)	128 psi (0.2%)	849 psi (1.2%)	205 psi (0.3%)	926 psi (1.3%)	282 psi (0.4%)
Maximum Unity Check – Tensile and Bending	0.38	0.33	0.40	0.32	0.42	0.32
Maximum Unity Check – Tensile, Bending, and Hoop	0.22	0.08	0.25	0.08	0.28	0.09

As observed in Table 5, 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 quartzite and dolomite bedrock materials as weak soils, and the gneiss as moderately strong soil. This conservative approach has been used by Mott MacDonald to successfully complete several HDD installations in similar bedrock materials. However, it is important to note that the presence of open preferential flow pathways within the bedrock mass may lead to drilling fluid losses at fluid pressures below predicted allowable values.

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.

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)	10.5 ppg (1.26)
Yield Point	21 lb/100 ft^2
Plastic Viscosity	13 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, 8, and 9 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, sandy clay overlying bedrock comprised of dolomite, quartzite, and gneiss. For this evaluation, it has also been assumed that the drilling rig will be set up on the northwest side of the crossing to complete the pilot bore.

Table 7: Material Property Assumptions for the Sandy Clay Soils

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	115 lb/ft^3 / 125 lb/ft^3
Effective Cohesion	2000 psf
Internal Friction Angle	0°
Young's Modulus	360,274 psf
Poisson's Ratio	0.30

Table 8: Material Property Assumptions for the Weak Bedrock Soils

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	18°
Young's Modulus	626,563 psf
Poisson's Ratio	0.30

Table 9: Material Property Assumptions for the Medium Strong Bedrock Soils

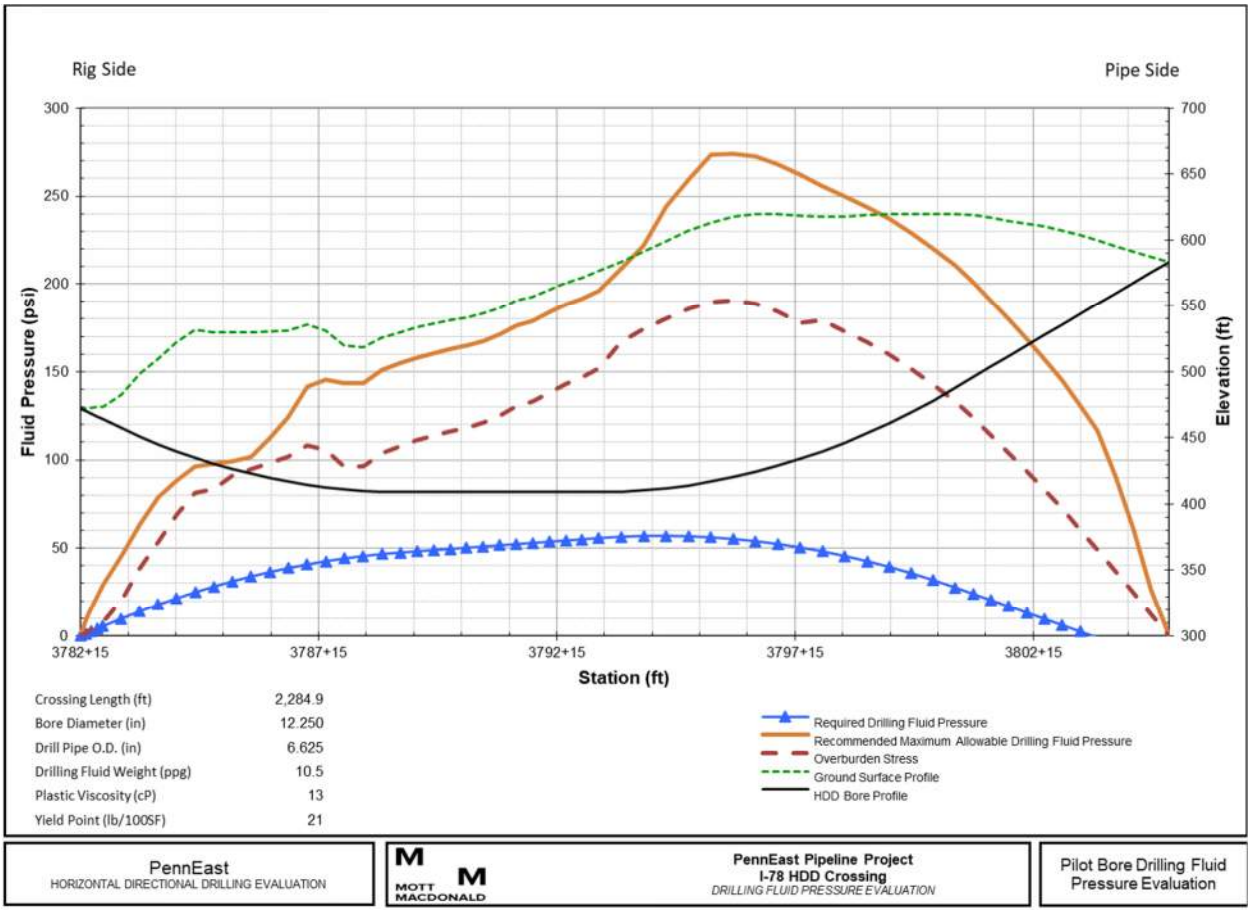
Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	140 lb/ft^3 / 145 lb/ft^3
Effective Cohesion	0 psf
Internal Friction Angle	26°
Young's Modulus	939,844 psf
Poisson's Ratio	0.30

The results of the preliminary hydraulic fracture evaluation for the proposed crossing are provided in Figure 1 below 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 below the allowable bore pressure for the installation. Hence, the risk of a hydraulic fracture or inadvertent return is relatively low for this crossing. The zero-pressure noted at approximate stationing 3803+13 in the Figure 1 reflects the area where the drill bit is advanced above the elevation of the drill rig, where the fluids will tend to flow back towards the rig under the presence of gravity with no induced drilling fluid pressure.

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. Use of 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 I-78 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 10 below. This database is used to 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 required pipe 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-practice for the HDD industry.

Table 10: State of the HDD Industry

	Installation Length												
Product Pipe Diameter	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 10 above, several HDD installations have been successfully completed at a diameter of NPS 36 for lengths considerably longer than the horizontal installation length of approximately 2,285 feet, with a true pipe length of approximately 2,304 feet, required for this crossing. Therefore, from a constructability standpoint, the I-78 Crossing falls within the zone of typical experience of what has been accomplished to date within the HDD industry.

5.3 Geotechnical Risk Discussions

5.3.1 Soil Materials

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 by using 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, 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. Grain size distribution tests conducted on soil samples from Boring B-28 indicate gravel percentages ranging from 6.6 percent to 28.1 percent, which are not anticipated to increase risks associated with the installation.

Soils with high percentages of clay particles can increase the risk to an HDD installation. The higher the clay content, the more difficult it is to remove the soil particles from the drilling fluids. This results in an increase in drilling fluid weight and viscosity which will increase the minimum pressure required to induce drilling fluid flow. Clay materials are also known to “ball-up” or plug the fluid ports and cutting edges of the drill bit. Additional equipment, such as a centrifuge, may be required at the separation plant in order to remove these clay particles. Specialized additives to the drilling fluids may also be required in order to neutralize the effects of the clay content on the drilling fluids. The use of such equipment and additives should be left to the Contractor to suit their means and methods and should be included as part of the Contractors plan of work.

5.3.2 Bedrock Materials

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 I-78 Crossing, the bedrock exhibits a wide range of ratings, with an average of 49 percent overall, and several areas below 25 percent. These areas of lower rock quality significantly increase the risks associated with this installation. Boring B-178-1, Boring B-178-1A, and Boring B-29 indicated bedrock materials containing several voids, as well as RQD values ranging from 0 to 25 percent.

In the vicinity of Redington Road, gneiss bedrock is anticipated. Based on the completed geotechnical program, this material is highly weathered, shattered, fractured, and jointed such that the RQD ratings range from 0 to 50 percent, with the majority of the readings being 0 to 15 percent. This material presents a significant challenge to an HDD installation strategy. Repeated grouting episodes may be required to

support the geotechnical materials through this bedrock mass. Excessive damage to hole openers and downhole tooling, raveling and an inability to maintain bore stability, and difficulty removing cuttings may occur within this section of the installation. Areas of high torque and/or pull force may occur within this area.

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.

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 7,849 psi to 20,216 psi, with an average of 13,425 psi. The quartzite bedrock was considerably weaker, with laboratory tests indicating an unconfined compressive strength of 2,889 psi. The laboratory tests completed for the gneiss bedrock indicate unconfined compressive strengths ranging from 3,300 psi to 8,243 psi, with an average of 6,048 psi.

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

5.3.3 Crossing-Specific Risk Discussions

An HDD alignment may need to transition through soil, then bedrock, back into soil and then back into bedrock due to the pinnacled carbonate bedrock surface beneath the interstate. While the pilot bore can be completed through these materials, successive reaming passes may create a ledge effect where the heavy hole opener/reamer assembly down cuts in the softer soil materials as it transitions from soil to bedrock, and bedrock back into soil. This down cutting can create a lip or ledge that can lead to misalignments of the soil and bedrock portions of the bore. These misalignments significantly increase risks associated with twist-offs of larger reaming assemblies, loss of hole opener components (arms/cones of hole opener) or during product pipe installation. Ledge formation and bore misalignment can also lead to excessive damage to the product pipe coatings and presents a risk to the HDD installation. The HDD Contractor will need to modify their workplan and procedures to minimize the risk of forming a lip at the soil/bedrock interface.

The alignment transitions from carbonate rock in the north of the alignment, through a quartzite band and into a gneiss material in the south. The design process has considered the variability on rock conditions along the alignment profile and tooling is available to accommodate the change of conditions across the alignment.

The alignment crosses fault zones within formations and at the contract between formations, these include the Hellertown fault zone and the Colesville fault. Fault zones can represent fractured planes and potentially higher weathering grade than the adjacent rock.

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 then 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 HDD contractor should monitor and record their downhole drilling fluid pressures within the annular space of the bore as

close to the drill bit as possible. This monitoring should also accompany monitoring of drilling fluid returns at all times during the installation.

Karst features have been identified within the borings completed for the geotechnical and geophysical investigations along the HDD alignment. Also, due to the pinnacled nature of the carbonate bedrock, depths to bedrock may vary significantly. Dissolution fractures, voids and highly weathered sections of dolomite were encountered during the subsurface investigation. Therefore, possible voids and other karst formations may be encountered during HDD construction. The HDD Contractor will need to consider possibility of encountering these features in their workplan. These features pose a risk for drilling fluid losses and an inability to maintain design line and grade/loss of downhole tooling. Mott MacDonald recommends discussing this issue with the respective HDD contractor and request a contingency plan from the contractor to deal with this potential condition if it is encountered. Grouting will likely be required to seal preferential flow pathways to maintain drilling fluid flow through the bedrock materials.

The exit location is approximately 111 feet higher than the elevation of the entry location which will result in approximately 537 feet of dry hole above the rig elevation. Once the bore is advanced above the elevation of the drilling rig it will be difficult to maintain a column of drilling fluid within the portion of the bore above the elevation of the HDD entry location. Lack of a full column of drilling fluid to support the portion of the bore above the elevation of the drilling rig can lead to instability and raveling of the bore. Risks of an unsupported bore in the site soils and poor-quality bedrock present a significant raveling or bore instability risk. The HDD contractor will need to pay attention to the swab pass to determine if any debris has accumulated within the bore.

With the elevation difference, the HDD Contractor will need to be prepared for flushing events that may occur during the drilling process where uncontrolled flow of fluids flow out of the bore towards the HDD entry location. The HDD Contractor must be prepared to contain and capture these fluids at the entry location. This can easily be accomplished with mud pumps, mud lines, and several storage tanks on this side of the crossing.

The elevation difference also presents challenges to steering and production. When the drill bit is advanced to elevations above that of the drilling rig, it becomes more and more difficult for the rig to overcome the weight of the downhole tooling and exert pressure on the face of the drill bit. This results in a reduction in drilling production and increasing difficulties with exerting the force on the bit necessary to induce a steering correction.

6 Summary

An HDD construction approach for the I-78 Crossing is deemed feasible, based on known site conditions. However, the HDD crossing carries a medium to high installation risk due primarily to the very poor-quality bedrock located beneath I-78, the presence of boulders beneath I-78, presence of voids in the bedrock, and the elevation difference between the entry and exit, as mentioned in the previous section. Of the risks evaluated based on the available information, contingency plans should be developed with the HDD contractor to address the risks identified in this report. Based on the required installation length and diameter, the HDD contracting community in North America has successfully completed several HDD installations of similar and greater installation lengths.

If an attempted HDD installation is unsuccessful, the proposed HDD alignment could be modified using the same general location to accommodate an additional HDD attempt, depending on the condition and cause contributing to 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.

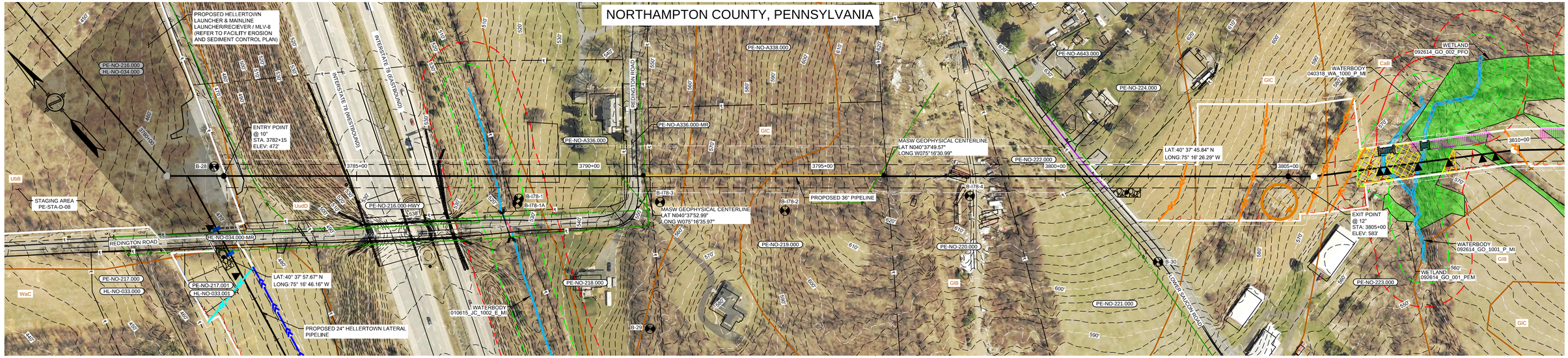
7 Limitations

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 I-78 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



CROSSING SPECIFIC HDD NOTES:

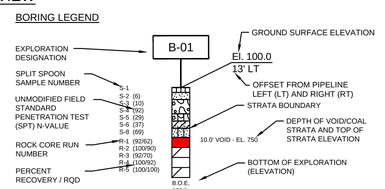
1. ALL DIMENSIONS AND ELEVATIONS ARE IN FEET, UNLESS OTHERWISE SPCIFIED.
2. ALL CHAINAGES ARE HORIZONTAL.
3. CONTRACTOR SHALL DETERMINE FINAL LOCATIONS AND DIMENSIONS OF ALL MUD PITS NECESSARY TO ACCOMMODATE THEIR MEANS AND METHODS.
4. CONTRACTOR TO STAGE ALL PERSONNEL AND EQUIPMENT WITHIN THE PERMITTED 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.
8. 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. HDD CONTRACTOR SHALL COMPLETE DRILLING OPERATIONS FROM THE NORTH SIDE OF THE CROSSING AND MOBILIZE THE DRILL RIG TO THE SOUTH SIDE OF THE CROSSING PRIOR TO PULLBACK OPERATIONS.
12. 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.
13. 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.
14. 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 increase 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 (deeper) 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.

15. CROSS SECTIONS PRESENTS SUMMARY BOREHOLE LOG GRAPHICS, SEE FULL BOREHOLE LOG FOR DETAILS.
16. SUMMARY GEOPHYSICAL PROFILE DISPLAYED. SEE FULL REPORT FOR DETAILS.

INTERSTATE 78 HDD PLAN VIEW
SCALE: 1" = 100'

BORING LEGEND



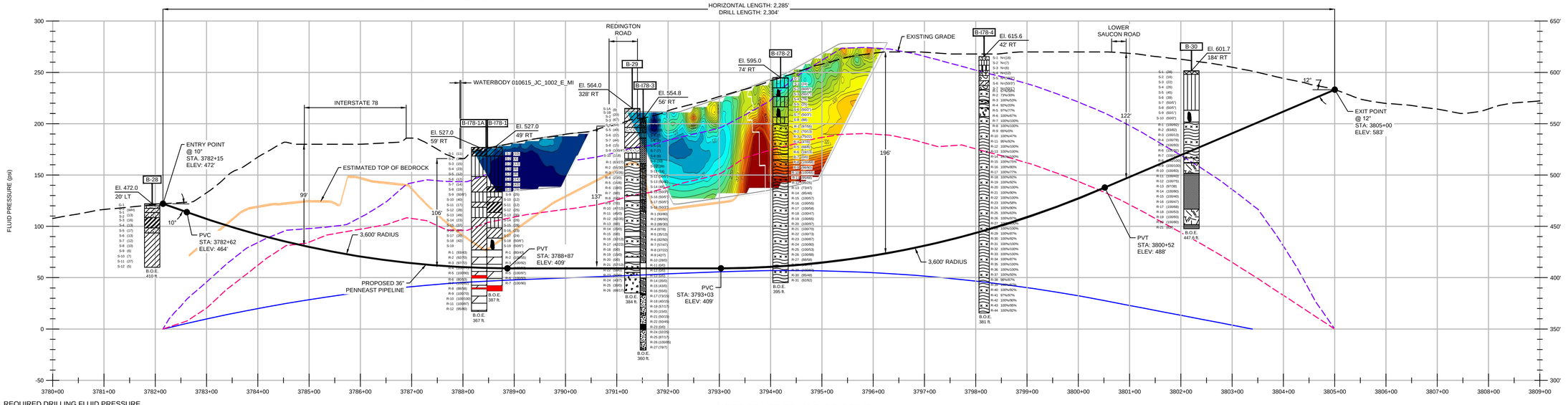
GEOTECHNICAL NOTE: MASW GEOPHYSICS CONDUCTED OFF CENTERLINE.

Resistivity (Ohm-m)

SOIL AND ROCK STRATAGRAPHIC LEGEND:

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

GRAPHIC SCALE
100' 50' 0' 100'



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

INTERSTATE 78 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
000-03-01-144	ALIGNMENT SHEET
000-03-01-145	ALIGNMENT SHEET
000-03-01-229	ALIGNMENT SHEET

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
INTERSTATE 78 HDD
NORTHAMPTON COUNTY, PENNSYLVANIA

SCALE	DRAWING NO.	REVISION
AS SHOWN	000-03-07-006	A

G:\PENNEAST\353754_PENNEAST_PIPELINE_EPC\MDATAPROD_STATE_PERMIT\WORK\PAIDRAFTING\EROSION_SEDIMENT_CONTROL_PLAN\HDD_DETAILS\000-03-07-006.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)		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		
	SM	Silty sands, sand-silt mixtures			
	SC	Clayey sands, sand-clay mixtures			

Infilling

Description	Symbol
Clay	Cl
Silt	SI
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

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

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

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.

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

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

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-28**
Page **1** of **3**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 8, 2016 at 8:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 8, 2016 at 12:00 pm

Elevation: 470 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Off Redington Rd. **Coord.:** **N:** 40.633122 **E:** -75.279075 **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
470	G-1 0.0'- 2.0'				SM	0.1 1" ASPHALT Reddish brown Silty SAND (SM)	-	-	-	-	Hand Augered to 2 feet BGS.
	G-2 2.0'- 4.0'					2.0 BOULDER, Drill and wash to 5 feet	-	-	-	-	
						4.5					
5	S-1 5.0'- 7.0'	6	WH		CL	Very soft, Reddish brown Lean CLAY with Sand and Gravel, moist (CL)	N	M	M	N	Installed Casing to 10 feet BGS.
						8.5					
10 460	S-2 10.0'- 12.0'	14	5 8 5 8		SC	Medium dense, Brown Clayey SAND with Gravel, wet (SC)	N	L	H	N	Installed Casing to 15 feet BGS.
						13.5					
15	S-3 15.0'- 17.0'	18	2 8 8 8		CH	Very Stiff, Brownish yellow Lean CLAY with Sand and Gravel, wet (CH)	N	M	H	N	Installed Casing to 20 feet BGS.

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-28**

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-28**
Page **2** of **3**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	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*
450	S-4 20.0'-22.0'	24	4 5 8 11		CH	Stiff, Brownish yellow Lean CLAY with Sand, trace Gravel, wet (CH)	N	M	H	N	
						23.5					
25	S-5 25.0'-27.0'	15	5 9 8 9		SC	Medium dense, Brownish yellow Clayey SAND with Decomposed Rock fragments and Sand, wet (SC)	N	H	M	N	
						28.5					
30 440	S-6 30.0'-32.0'	17	5 5 8 8		CL	Stiff, Reddish brown Sandy Lean CLAY with Decomposed Rock fragments, wet (CL)	N	M	M	N	
35	S-7 35.0'-37.0'	24	4 5 7 6		CL	Stiff, Reddish brown Sandy Lean CLAY with Decomposed Rock fragments, wet (CL)	N	L	H	N	
40 430	S-8 40.0'-42.0'	24	3 3 7 8		CL	Stiff, Brownish yellow Sandy Lean CLAY with Decomposed Rock fragments, wet (CL)	N	H	H	N	
45	S-9 45.0'-47.0'	24	4 3 3 2		CL	Medium Stiff, Reddish brown Lean CLAY with Decomposed Rock fragments, wet (CL)	N	H	H	N	

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-28**

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-28**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	**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*
50 420	S-10 50.0'-52.0'	19	1 3 4 5		CL	Medium Stiff, Reddish brown Lean CLAY with Sand and Decomposed Rock fragments, wet (CL)	N	H	H	N	
55	S-11 55.0'-57.0'	8	12 14 13 10		CL	Very Stiff, Brownish Yellow Lean CLAY with Decomposed Rock fragments, wet (CL)	N	L	M	N	
60 410	S-12 60.0'-62.0'	24	2 2 3 7		CL	Medium Stiff, Brownish Yellow Lean CLAY with Decomposed Rock fragments, wet (CL)	R	L	H	N	
						62.0 End of Boring at 62 feet BGS. Borehole grouted with cement and bentonite hole plug.					
65											
70 400											
75											

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-28**

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-29**
Page **1** of **3**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Rhan Flatin
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 30, 2015 at 10:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	July 2, 2015 at 1:00 pm

Elevation: 585 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.:** **N:** 40.6306972 **E:** -75.2774167 **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-1A				ML	0.5 Top 6" - Soft, Dark brown SILT, trace Gravel, moist (ML)	N	L	M	N	PP = 1.25 tsf.
	0.0'- 0.5'	13	1		CL	Stiff, Brownish yellow Lean CLAY, trace Sand, trace Gravel, dry (CL)	N	M	M	L	PP = 2.0 tsf.
	S-1B 0.5'- 2.0'		3 6 5								
5 580	S-2 5.0'- 7.0'	7	23 14 6 8		CL	Very stiff, Yellowish red Gravelly Lean CLAY, trace sand, dry (CL)	N	M	M	N	PP = 0.75 tsf.
10	S-3 10.0'- 12.0'	16	27 33 34 25		CL	Hard, Brown Sandy Lean CLAY, trace gravel, dry (CL)	N	H	M	M	PP = N/A.
15 570	S-4 15.0'- 17.0'	18	18 22 42 53		CL	Hard, Brown Lean CLAY with sand, trace silt, trace gravel, dry (CL)	N	M	L	M	PP = N/A.
						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
SS Split Spoon Sample
G Geoprobe

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-29**

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-29**
Page **2** of **3**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	**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-5 20.0'-22.0'	13	22 19 30 31		SP	Dense, Light brown SAND, fine, trace Clay, dry (SP)	-	-	-	-	
						23.5					
25 560	S-6 25.0'-27.0'	1	11 10 12 13		CL	Very stiff, Brown, CLAY, trace gravel, moist (CL)	N	L	M	N	PP = 0.75 N/A.
30	S-7 30.0'-32.0'	19	11 14 30 37		CL	Very stiff, Brown Lean CLAY with sand, trace gravel, dry (CL)	N	M	L	M	PP = N/A.
35 550	S-8 35.0'-37.0'	17	9 6 9 11		CL	Stiff, Brown, Sandy Lean CLAY with gravel, dry (CL)	N	M	L	M	PP = N/A.
						38.5					
40	S-9 40.0'-42.0'	4	100/4"		SP	Very dense, Light brown SAND with gravel, trace silt, trace clay, dry (SP)	-	-	-	-	
						43.5					
45 540	S-10 45.0'-47.0'	13	36 56 62 38		ML	Very stiff, Brown Sandy SILT with gravel, dry (ML)	N	L	L	L	PP = N/A.

NOTES:

PROJECT NO.: **353754** BORING NO.: **B-29**

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-29**
Page **3** of **3**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	**Visual - Manual Identification & Description*** (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
						49.0 Top of Rock at 49 feet BGS. See Rock Coring Log.					
50											
55 530											
60											
65 520											
70											
75 510											

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-29**

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-29**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Rhan Flatin
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 30, 2015 at 10:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	July 2, 2015 at 1:00 pm

Elevation: 585 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** **Coord.: N:** 40.6306972 **E:** -75.2774167

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 **Drilling Method:** Wireline

Rig Make & Model: CME-750X

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								
	4.00	50.0							GNEISS, Olive gray, medium grained, moderately weathered, medium strong, very close to close spaced discontinuities	50.30	J	43	U,Sm	DS	PO	Fe	No loss of water from 50' to 180'.
										50.87	J	2	U,R	DS	T	Fe	
	2.25								51.2' - 52.3' highly weathered zone								
	3.00		R-1	38 63%	16 27%	R3	M		52.55' - 53.15' Quartz								
	3.00																
	3.75	55.0															
55 530	1.50	55.0							GNEISS, Olive gray, medium grained, moderately weathered, medium strong, very close to close spaced discontinuities 55.0' - 55.5' Quartz								
	2.50								56.35' - 56.95' Quartz fragments with concentrations of Mica Schist or Feldspar	56.35	J	50	U,Sm	DS	T	Fe	
	3.25		R-2	33 55%	18 30%	R3	M										
	4.50																
	4.50	60.0															
60	3.25	60.0							GNEISS, Olive gray, medium grained, moderately weathered, medium strong, very close to moderately spaced discontinuities								
	3.00									61.20	J	25	U,R	DS	T	Fe	
										61.50	J	65	U,R	DS	PO	Fe	
	3.00		R-3	42 70%	21 35%	R3	M										
	4.00									63.00	J	65	S,R	DS	PO	Fe	
	3.50	65.0															
65 520	1.75	65.0							GNEISS, Olive gray, medium grained, highly weathered, weak, very close to close spaced discontinuities	65.30	J	25	S,R	DS	PO	CL	Soft silty Clay, brown, fine, covering most of core.
										65.60	J	45	S,R	DS	PO	CL	
	2.00																
	1.50		R-4	14 23%	0 0%	R2	H										
	1.50																
	1.25	70.0															

Water Level Data

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

Notes:

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
	1.25	70.0							GNEISS, Olive gray, medium grained, highly weathered, weak, close spaced discontinuities, Hornblend minerals present	70.50	J	15	U,R	DS	PO	Fe	
	1.25																
	0.50		R-5	10 16%	5 8%	R2	H										
	0.50																
	0.50	75.0															
75 510	1.00	75.0							GNEISS, Light brown, medium grained, highly weathered, weak, very close spaced discontinuities. Core has less Hornblende, more Feldspar	75.55	J	7	U,R	DS	PO	Fe	
	1.50																
	1.25		R-6	11 18%	0 0%	R2	H										
	1.50																
	1.25	80.0															
80	1.00	80.0							GNEISS, Light brown, medium grained, highly weathered, weak, exrememly close spaced discontinuities								
	1.75																
	1.25		R-7	6 9%	0 0%	R2	H										
	1.75																
	2.00	85.0							85.0								
85 500	1.75	85.0							No Recovery								
	1.25																
	1.25		R-8	0 0%	0 0%												
	1.00																
	1.00	90.0							90.0								
90	1.00	90.0							GNEISS, Olive gray, medium grained, highly weathered, weak, extremely close spaced discontinuities								
	2.50																
	2.75		R-9	4 7%	0 0%	R2	H										
	2.75																
	3.00	95.0															
95 490		95.0															

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-29**

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
	5.50								GNEISS, Olive gray, medium grained, highly weathered, weak, extremely close to close spaced discontinuities								
	3.50																
	2.75		R-10	28 47%	8 13%	R2	H			96.80	J	36	S,R	FR	T	N	
	2.50																
	2.75	100.0															
100	2.50	100.0							GNEISS, Reddish brown, medium grained, highly weathered, weak, very close to close spaced discontinuities								
	3.50																
	4.50		R-11	27 45%	0 0%	R2	H										Increased drill speed.
	3.00																Decreased drill speed.
	3.00	105.0															
105 480	3.00	105.0							GNEISS, Reddish brown, medium grained, completely weathered, extremely weak, extrememly close to moderately spaced discontinuities								
	3.50																
	2.50		R-12	37 62%	21 35%	R0	C			106.75	J	10	U,R	DS	PO	N	
	4.50																
	3.00	110.0															
110	3.00	110.0							GNEISS, Olive gray, medium grained, highly weathered, weak, extremely close spaced discontinuities. Fragments only								No joints.
	3.00																
	3.25		R-13	5 8%	0 0%	R2	H										
	2.50																
	2.25	115.0															
115 470	3.50	115.0							GNEISS, Olive gray, medium grained, highly weathered, weak, extremely close to very close spaced discontinuities								No joints.
	2.30																
	3.00		R-14	12 20%	0 0%	R2	H										
		120.0								120.0							
120	2.75	120.0							No Recovery								

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
	2.25																
	3.50		R-15	0 0%	0 0%												
	3.25																
	3.25	125.0							125.0								
125 460	3.50	125.0							GNEISS, Olive gray, medium grained, moderaely weathered, weak, very close to moderately spaced discontinuities 125.0' - 125.2' Gneiss fragments 120.3' - 126.6' Gneiss fragments	125.40 125.55	J J	57 10	U,Sm S,R	DS DS	PO T	N N	Slow drilling.
	4.00																
	2.00		R-16	19 32%	8 13%	R2	M										
	2.50																
	3.00	130.0															
130	2.00	130.0							Gneiss, Olive gray, medium grained, moderately weathered, weak, very close to close spaced discontinuities	130.42 130.55	J J	28 3	U,Sm U,Sm	DS DS	T T	N N	Increased drill speed.
	5.00									131.00 131.35	J J	22 22	S,R U,R	FR DS	PO PO	N N	Decreased drill speed.
	6.00		R-17	25 42%	14 23%	R2	M										
	4.50																
	2.75	135.0							135.0								
135 450	3.00	135.0							No Recovery								
	4.00																
	4.00		R-18	0 0%	0 0%												
	3.00																
	3.50	140.0							140.0								
140	2.50	140.0							GNEISS, Olive gray, medium grained, highly weahered, very weak, no joints One 2" core section and the remainder is fragments								No joints.
	2.50																
	3.00		R-19	9 15%	0 0%	R1	H										
	3.50																
	2.50	145.0							145.0								
145 440	3.75	145.0							No Recovery								
	3.25																Much Sand accumulated in the tub.

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
	3.25																
	4.25		R-20	0 0%	0 0%												
	2.50																
	3.00	150.0							150.0								
150	3.00	150.0							GNEISS, Brown, medium grained, compleely weahered, very weak, very close to close spaced discontinuities 150.4' - 150.8' Medium stiff, SILT, Yellowish red, moist								
	2.50									151.35	J	14	U,Sm	DS	PO	N	
	3.50		R-21	34 57%	8 13%	R1	C		151.75' - 152.85' (end) Rock change to Quartzite, Light brown, course grain, slightly weathered, moderately strong	152.15	J	47	S,R	DS	T	N	
	2.75																
	2.75	155.0															154' - No water return.
155 430	4.50	155.0							GNEISS, Brown, medium grained, completely weathered, very weak, extremely close to close spaced discontinuities	155.42	J	18	S,R	DS	PO	N	No water return at R22. Some water return at 156'.
	2.50									156.41	J	10	U,Sm	DS	PO	N	
	2.50		R-22	30 50%	0 0%	R1	C										
	1.50																
	3.00	160.0							160.0								
160	1.75	160.0							QUARTZITE, Light brown, medium to coarse grained, moderately weathered, very weak, extremely close to close spaced discontinuities								
	1.50									160.95	J	15	S,R	DS	T	N	
	1.25		R-23	30 50%	0 0%	R1	H			161.77	J	25	U,Sm	DS	PO	N	
	1.25																
	1.50	165.0															
165 420	2.50	165.0							QUARTZITE, Light brown, medium to coarse grained, moderately weathered, very weak, extremely close to close spaced discontinuities								
	1.50																
	2.00		R-24	26 43%	4 7%	R1	H			167.30	J	26	U,Sm	DS	T	Fe	
	2.00																
	2.00	170.0															
170	2.50	170.0							QUARTZITE, Light brown, medium to coarse grained, moderately weathered, very weak, extremely close to close spaced discontinuities								
	2.50									170.90 171.05 171.11 171.13	J J J J	44 10 40 31	U,Sm S,R S,R U,Sm	DS DS DS DS	PO T PO T	Fe Fe N Fe	

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-29**
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	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.25		R-25	18 30%	0 0%	R1	H										
	2.25																
	3.00	175.0															
175 410	2.25	175.0							QUARTZITE, Light brown, medium to coarse grained, moderately weathered, very weak, extremely close to close spaced discontinuities								
	2.25																
	2.00		R-26	41 68%	10 17%	R1	H			177.15	J	11	S,R	DS	T	N	
										177.50	J	8	U,R	DS	T	N	
	2.00																
	2.50	180.0							180.0								
180									End of Boring at 180 feet BGS. Borehole grouted wih cement and bentonite hole plug.								
185 400																	
190																	
195 390																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-29**

Figure B-29.1
B-29 Box 1 Run 1-5 Dry

Figure B-29.2
B-29 Box 1 Run 1-5 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-29

Figure B-29.3
B-29 Box 2 Run 10-19 Dry

Figure B-29.4
B-29 Box 2 Run 10-19 Wet

MOTT MACDONALD	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-29

Boring #	Run	Depth		Rec		RQD	
				"	%	"	%
B-29	R-20	145	150	0	0	0	0
B-29	R-21	150	155	34	57	8	13
B-29	R-22	155	160	30	50	0	0
B-29	R-23	160	165	26	43	5	8
B-29	R-24	165	170	26	43	4	6.6

Boring #	Run	Depth		Rec		RQD	
				"	%	"	%
B-29	B-25	170	175	18	30	0	0
B-29	B-26	175	180	41	68	10	17

Figure B-29.5
B-29 Box 3 Run 20-26 Dry

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-30**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	December 19, 2016 at 9:45 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	December 27, 2016 at 11:00 am

Elevation: 601.7 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Lower Saucon Road **Coord.:** **N:** 40.629525 **E:** -75.274147 **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'	18	27 17 11 7		FILL	0.3 4" - ASPHALT	-	-	-	-	Casing installed to 4 feet BGS.
600					FILL	Medium dense, Yellowish red well graded GRAVEL with Silt, dry (FILL)					Mottled soil from 0.3-30 feet BGS.
						3.5					
5	S-2 5.0'- 7.0'	17	7 7 9 9		ML	Very stiff, Yellowish red SILT with Sand, dry (ML)	-	-	-	-	PP= N/A TV= N/A
10	S-3 10.0'- 12.0'	14	9 9 13 15		ML	Very stiff, Yellowish red SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A
590											
15	S-4 15.0'- 17.0'	19	13 11 15 15		ML	Very stiff, Yellowish red SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
12/21/16	9:00	-		105.0	38.2
12/22/16	9:00	-		125.0	38.4

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-30**

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-30**

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'	19	15 18 27 22		ML	Hard, Yellowish red SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A
580											
25	S-6 25.0'-27.0'	21	9 15 24 34		ML	Hard, Light brown SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A
30	S-7 30.0'-32.0'	16	19 29 50/5"		ML	Hard, Light brown SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A
570											
35	S-8 35.0'-37.0'	14	20 50/5"		ML	Hard, Light brown SILT with Sand, moist (ML)	-	-	-	-	PP= N/A TV= N/A Silt is highly decomposed material. Rig Chatter.
						38.5					
40	S-9 40.0'-42.0'	1	50/1"			Very dense, dark gray DECOMPOSED ROCK fragments, moist	-	-	-	-	
560											
45	S-10 45.0'-47.0'	0	50/0"			No Recovery	-	-	-	-	Rig Chatter. Advanced through with roller bit to 50 feet BGS.

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-30**

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-30**
Page **3** of **3**

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						50.0 Top of Rock at 50 feet BGS. See Rock Coring Log.					
550											
55											
60											
540											
65											
70											
530											
75											

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-30**

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-30**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	December 19, 2016 at 9:45 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	December 27, 2016 at 11:00 am

Elevation: 601.7 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Lower Saucon Road **Coord.: N:** 40.629525 **E:** -75.274147

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	6
Inside Dia. (in.)	4	2.0	1.875

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 (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	2.50	50.0							Granitic GNEISS, Greenish gray, medium to very fine grained, fresh, medium strong, close spaced discontinuities	50.40	MB	-	-	-	-	-	
										50.70	J	60	P,R	FR	PO	N	
	2.50																
550																	
	2.50		R-1	60 100%	55 92%	R3	FR										
	2.50									53.50	J	50	X,R	DS	PO	N	
										53.80	J	30	P,R	DS	PO	Sa	
	2.50	55.0								54.60	MB	-	-	-	-	-	
55		55.0							Granitic GNEISS, Greenish gray, medium to very fine grained, fresh, strong, extremely close to wide spaced discontinuities								
	2.50																
	2.50		R-2	56 93%	49 82%	R4	FR										
	2.50								58.4' - 58.6' Fractured zone								
	2.50	60.0								59.30	J	40	P,R	FR	T	N	
										59.60	MB	-	-	-	-	-	
60		60.0							Granitic GNEISS, Greenish gray, medium to very fine grained, slightly weathered, medium strong, extremely close to close spaced discontinuities 60' - 63.2' Highly Fractured zone with Calcite infill								
	2.50																
	2.50																
540																	
	2.50		R-3	60 100%	8 13%	R3	SL										
	2.50									63.40	J	40	P,Sm	DS	PO	Ca	
	2.50	65.0								64.40	J	60	P,R	FR	T	N	
65		65.0							Granitic GNEISS, Greenish gray, medium to very fine grained, fresh, strong, extremely close to close spaced discontinuities	64.80	MB	-	-	-	-	-	
	2.00									65.30	J	30	P,Sm	FR	T	N	
										65.70	J	60	P,R	FR	T	Ca	
	2.00									66.40	J	-	X,R	FR	O	N	
	2.00		R-4	60 100%	47 78%	R4	FR		66.9' - 67.2' Highly Fractured zone	67.50	J	50	U,Sm	FR	T	N	
	2.00								68.1' - 68.4' Highly Fractured zone								
	2.00	70.0								69.30	J	50	P,R	FR	T	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
12/21/16	9:00	-		105.0	38.2
12/22/16	9:00	-		125.0	38.4

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 Type	Dip	Rgh	Wea	Aper	Infill	Remarks
		70.0							Granitic GNEISS, Greenish gray, medium to very fine grained, fresh, very strong, extremely close to close spaced discontinuities	69.80	MB	-	-	-	-	-	
	2.50									70.50	J	30	P,R	FR	PO	N	
	2.50																
530																	
	2.50		R-5	60 100%	56 93%	R5	FR			71.90	J	50	P,R	FR	T	N	
										72.60	J	40	P,R	DS	PO	Ca	
										73.10	J	40	P,R	DS	PO	Ca	
	2.50									73.40	J	40	P,R	FR	O	N	
	2.50									74.40	MB	-	-	-	-	-	
		75.0								74.50	MB	-	-	-	-	-	
75										74.60	MB	-	-	-	-	-	
		75.0							Granitic GNEISS, Greenish gray, medium to very fine grained, fresh, very strong, extremely close to close spaced discontinuities								
	3.00																
	3.00									76.30	J	40	P,R	FR	PO	N	
										77.00	J	30	P,R	FR	PO	N	
	3.00		R-6	60 100%	55 92%	R5	FR			77.10	J	50	P,R	FR	T	N	
										77.60	J	70	P,R	FR	T	N	
	3.00																
	3.00									79.10	MB	-	-	-	-	-	
		80.0															
80																	
		80.0							Granitic GNEISS, Greenish gray, coarse to fine grained, fresh, very strong, extremely close to close spaced discontinuities 80' - 81' Highly Fractured zone								
	3.00																
	3.00									81.20	J	50	P,R	FR	PO	N	
520									81.6' - 83.5' Highly Fractured zone with Vertical Fractures								
	3.00		R-7	60 100%	16 27%	R5	FR										
	3.00																
										84.10	J	40	P,R	FR	PO	N	
	3.00									84.40	MB	-	-	-	-	-	
		85.0							85.0								
85																	
		85.0							MARBLE, Greenish gray, coarse grained, fresh, very strong, close to wide spaced discontinuities								
	3.50									85.80	J	40	P,R	FR	PO	N	
	3.50																
										86.80	J	50	P,Sm	FR	PO	N	
	3.50		R-8	60 100%	60 100%	R5	FR										
	3.50																
	3.50																
		90.0							90.0								
90																	
		90.0							Pegmatitic GRANITE with interbedded Marble, coarse grained, fresh, very strong, close to wide spaced discontinuities								
	5.00																
	5.00																
510																	
	5.00		R-9	60 100%	60 100%	R5	FR			91.90	J	40	P,R	FR	PO	N	
	5.00																
	5.00																
		95.0								94.60	MB	-	-	-	-	-	
95																	
		95.0															

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
	8.00								Pegmatitic GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities	95.30	MB	-	-	-	-	-	
										95.60	MB	-	-	-	-	-	
	8.00																
										96.60	J	60	P,R	FR	T	N	
	8.00		R-10	60 100%	50 83%	R5	FR										
										97.80	J	60	P,R	FR	PO	N	
	8.00																
	13.00									99.20	J	40	P,R	FR	T	N	
100		100.0							100.0								
		100.0								99.80	MB	-	-	-	-	-	Changed core bit at 100 feet BGS.
	3.00								GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities 100' - 101.1' Highly Fractured zone								
	3.50									101.50	J	40	P,Sm	FR	T	N	
500									102' - 102.6' Highly Fractured zone								
	5.00		R-11	60 100%	26 43%	R5	FR										
	10.00									103.40	J	40	P,R	FR	T	N	
										103.60	J	40	P,Sm	FR	T	N	
	15.00	105.0															
105		105.0							GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities 105' - 105.5 Highly Fractured zone								Roller bit down to 105 feet. Hard bit used.
	3.00																
	3.00									106.50	J	30	P,R	FR	PO	N	
	4.00		R-12	60 100%	45 75%	R5	FR			107.20	J	30	P,R	FR	PO	N	
										108.00	J	30	P,R	FR	PO	N	
	3.50									108.50	J	30	P,R	FR	PO	N	
										108.60	MB	-	-	-	-	-	
	3.50									109.30	J	30	P,R	FR	T	N	Rig chatter at 109 feet BGS.
		110.0								109.60	MB	-	-	-	-	-	Rig chatter at 109.5 feet BGS.
110		110.0							GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities 110' - 110.6' Highly Fractured zone								Rig chatter at 109.8 feet BGS.
	5.00																
	5.00																
490																	
	5.00		R-13	58 97%	23 38%	R5	FR		112.3' - 112.5' Highly Fractured zone								
	5.00									113.20	J	20	P,R	FR	T	N	
									113.8' - 115' Highly Fractured zone								
	5.00	115.0															
115		115.0							GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities	115.20	MB	-	-	-	-	-	
	5.00									115.90	J	30	P,R	FR	T	N	
	5.00									116.70	J	50	P,R	DS	T	Fe	
										116.90	J	50	P,R	DS	T	Fe	
	5.00		R-14	60 100%	48 80%	R5	FR										
	5.00									118.00	J	30	P,R	FR	T	N	
	5.00									118.90	J	40	P,R	FR	PO	N	
										119.00	MB	-	-	-	-	-	
		120.0															
120		120.0							GRANITE, Greenish gray, coarse grained, slightly weathered, very strong, extremely close to close spaced discontinuities	120.10	MB	-	-	-	-	-	
	5.00																

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-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 (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
										120.70	J	40	P,R	FR	PO	N	
	5.00									121.30	J	30	U,R	FR	T	N	No water return at 121 feet BGS. Losing water with little return from 121 to 125 feet BGS.
480																	
	5.00		R-15	60 100%	24 40%	R5	SL		122' - 125' Highly Fractured zone with Serpentine interbedding								
	5.00																
	5.00	125.0															
125																	
	5.00	125.0							GRANITE, Greenish gray, coarse grained, slightly weathered, very strong, extremely close to close spaced disconinuities 125' - 125.8' Highly Fractured zone 127.4' - 127.8' Highly Fractured zone								Loss of water at 125.5 feet BGS.
	5.00																
	5.00		R-16	60 100%	28 47%	R5	SL										
	5.00																
	5.00	130.0															
130																	
	6.00	130.0							GRANITE, Greenish gray, coarse grained, slightly weathered, very strong, extremely close to close spaced discontinuities	130.50	J	20	P,R	FR	PO	N	
										131.00	J	-	X,R	FR	PO	N	
	6.00								131.4' - 131.6' Epidote Band								
470									131.8' - 133.3' Highly Fractured zone								
	6.00		R-17	60 100%	41 68%	R5	SL										
	6.00																
	6.00	135.0															
135									135.0								
	6.00	135.0							Pegmatitic GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities								
	6.00									136.10	J	30	P,R	FR	T	N	
	6.00		R-18	60 100%	32 53%	R5	FR			137.20	J	40	P,R	FR	T	N	
										138.00	J	60	P,R	FR	T	N	
	6.00																
	6.00								138.6' - 140' Highly Fractured zone								
	6.00	140.0															
140																	
	6.00	140.0							Pegmatitic GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities								
										140.90	J	10	P,R	FR	T	N	
	6.00									141.20	J	40	P,R	FR	T	N	
460																	
	6.00		R-19	60 100%	56 93%	R5	FR		141.8' - 141.9' Epidote Band 141.8' - 141.9' Highly Fractured zone 142.3' - 142.4' Epidote Band 142.5' - 143.3' Epidote Band	142.30	J	20	P,R	FR	T	N	
										143.00	B	20	P,Sm	FR	PO	N	
	6.00									143.50	J	10	P,R	FR	O	N	
									143.8' - 144' Epidote Band	144.00	J	20	P,R	FR	O	N	
	6.00	145.0															
145																	
	5.50	145.0								145.30	J	60	P,R	FR	PO	N	
										145.80	J	30	P,R	FR	T	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-30**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-30**
Page **5** of **5**

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
	5.50																
	5.50								Pegmatitic GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities 146.4' - 146.9' Highly Fractured zone								
	5.50		R-20	60 100%	48 80%	R5	FR			147.30	J	20	P,R	-	-	-	
	5.50								148.5' - 149.1' Highly Fractured zone								
	5.50								149.5' - 150' Highly Fractured zone								
150		150.0							150.0								
	6.00	150.0							GRANITE, Greenish gray, coarse grained, fresh, very strong, extremely close to close spaced discontinuities 150.6' - 151.6' Vertical Fracturing								Rig chatter. Attempted to pull inner barrel at 153 feet. Wireline barrel snapped. See daily logs. Drill stem retrieved. Drill and wash to 153 feet.
	6.00																
450																	
	6.00		R-21	49 82%	-- --	R5	FR		152.3' - 153' Highly Fractured zone								
	7.00																
									154.0								
									End of Boring at 154 .1 feet BGS. Borehole was grouted with bentonite and cement hole plug.								Water loss at 154 feet BGS. 35 feet casing installed. Core bit/barrel was eaten up by pieces of wireline in the hole. Borehole abandoned at 154.1 feet BGS.
		155.0															
155																	
160																	
440																	
165																	
170																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-30**

Figure B-30.1
B-30 Box 1 Runs 1-4 Dry

Figure B-30.2
B-30 Box 1 Runs 1-4 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-30

Figure B-30.3
B-30 Box 2 Runs 5-8 Dry

Figure B-30.4
B-30 Box 2 Runs 5-8 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-30

Figure B-30.5
B-30 Box 3 Runs 9-12 Dry

Figure B-30.6
B-30 Box 3 Runs 9-12 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-30

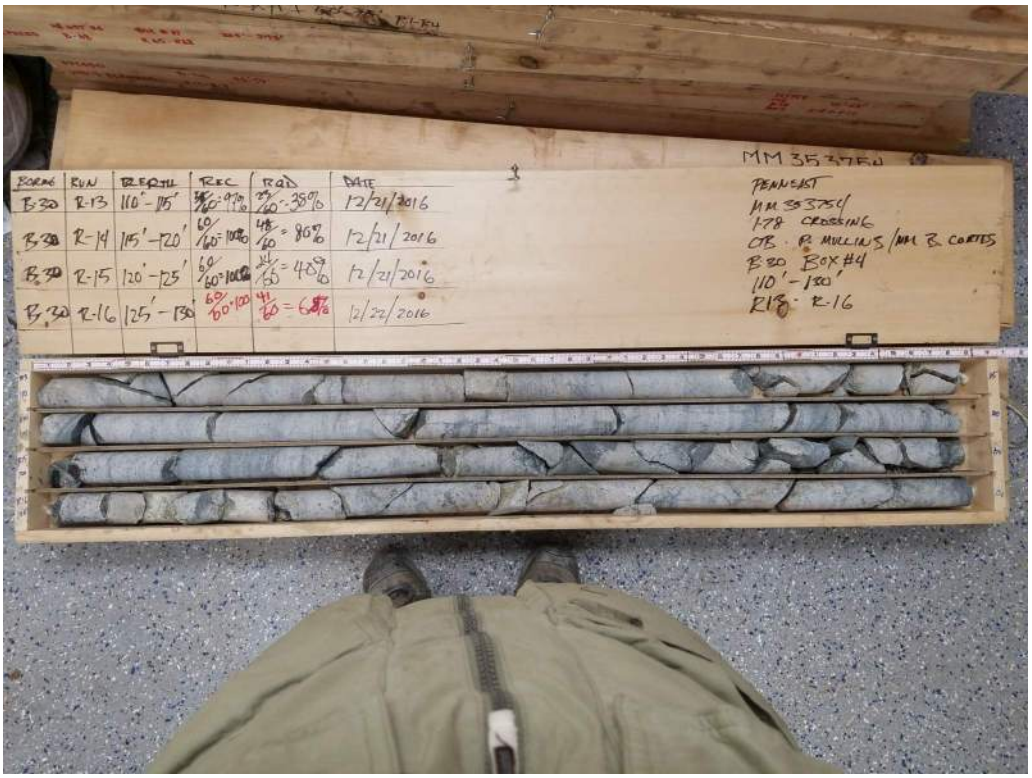


Figure B-30.7
B-30 Box 4 Runs 13-16 Dry

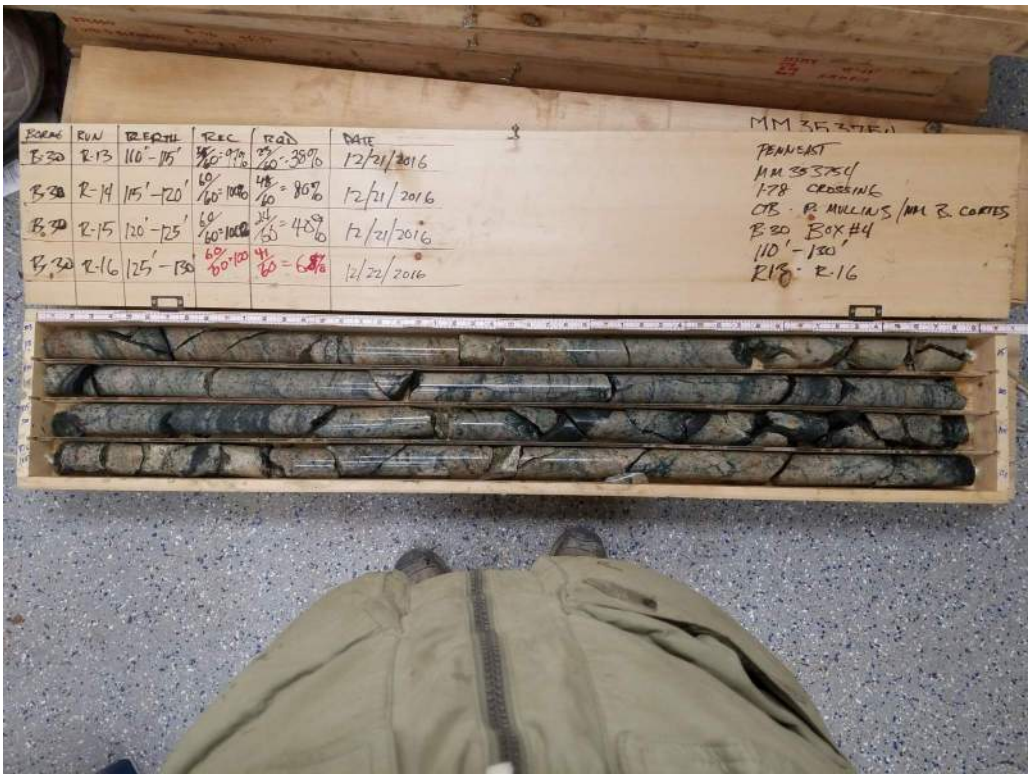


Figure B-30.8
B-30 Box 4 Runs 13-16 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-30

Figure B-30.9
B-30 Box 5 Runs 17-20 Dry

Figure B-30.10
B-30 Box 5 Runs 17-20 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-30

Figure B-30.11
B-30 Box 6 Runs 21-24 Dry

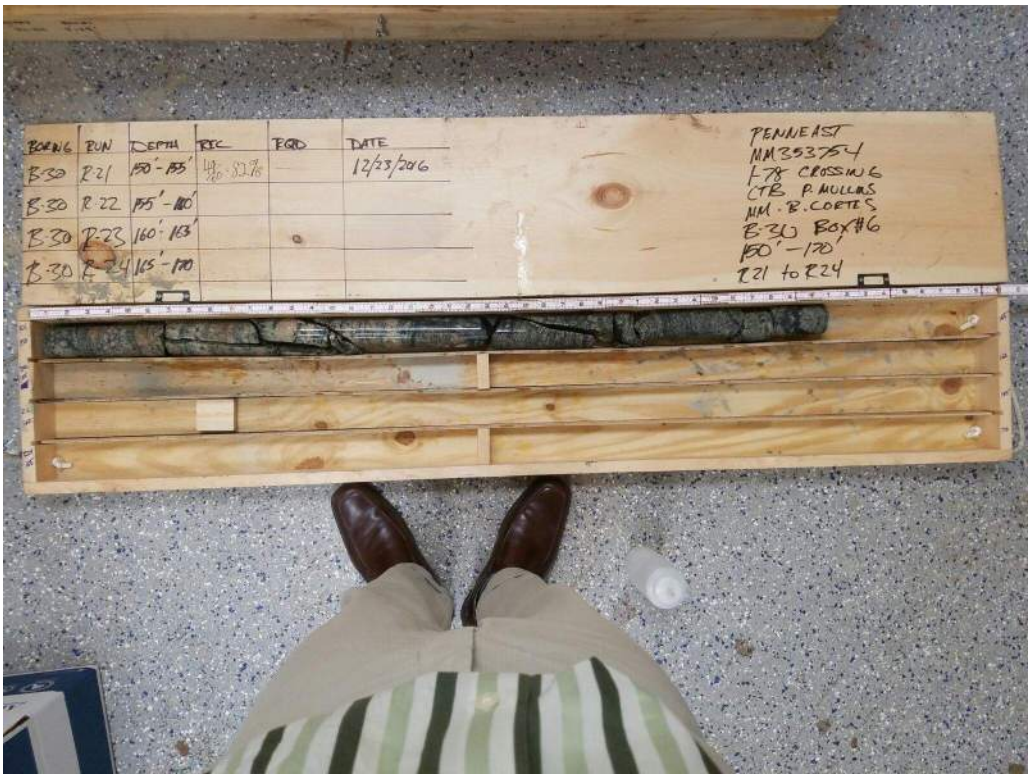


Figure B-30.12
B-30 Box 6 Runs 21-24 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-30

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-I78-1**
Page **1** of **4**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 17, 2016 at 7:30 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 21, 2016 at 9:00 am

Elevation: 530 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Off Redington Rd. **Coord.:** **N:** 40.631756 **E:** -75.277489 **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
530	G 0.0'- 2.0'				CL	0.2 TOPSOIL Yellowish red CLAY, Moist (CL)	-	M	L	-	Hand Augered to 5 feet BGS. Installed casing to 4 feet BGS.
5	S-1 5.0'- 7.0'	17	2 5 5 7		CL	Stiff, Brownish yellow CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	
						8.5					
10 520	S-2 10.0'- 12.0'	24	1 2 2 5		ML	Soft, Brown SILT with Decomposed Rock fragments, moist (ML)	-	M	L	-	Installed casing to 10 feet BGS.
15	S-3 15.0'- 17.0'	18	6 6 7 9		ML	Stiff, Brownish yellow SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	Installed casing to 15 feet BGS.

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-I78-1**

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.

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	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*
510	S-4 20.0'-22.0'	20	2 3 5 6		ML	Medium stiff, Brown SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	
25	S-5 25.0'-27.0'	20	5 5 3 9		ML	Medium stiff, Brown SILT with Clay, moist (ML)	-	L	NP	-	
30 500	S-6 30.0'-32.0'	24	7 7 7 8		ML	Stiff, Brown SILT with Decomposed Rock fragments, moist (ML)	-	L	NP	-	
35	S-7 35.0'-37.0'	18	16 23 20 17		ML	Hard, Brown SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	
						38.5					
40 490	S-8 40.0'-42.0'	27	8 14 15 10		CH	Very stiff, Brown Lean CLAY with Decomposed Rock fragments, moist (CH)	-	M	H	-	
						43.5					
45	S-9 45.0'-47.0'	19	7 9 16 16		ML	Very stiff, Brown SILT with Decomposed Rock fragments, wet (ML)	-	L	L	-	

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 / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description* (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
						48.5					
50 480	S-10 50.0'-52.0'	24	5 5 7 10		CL	Stiff, Brown Lean CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	
						53.5					
55	S-11 55.0'-57.0'	24	10 6 6 20		CH	Stiff, Brown Lean CLAY with Decomposed Rock fragments, wet (CH)	-	M	H	-	
60 470	S-12 60.0'-62.0'	24	9 10 15 19		CH	Very stiff, Brown Lean CLAY with Decomposed Rock fragments, wet (CH)	-	M	H	-	
						63.5					
65	S-13 65.0'-67.0'	24	7 11 19 16		CL	Very stiff, Brown Lean CLAY with Decomposed Rock fragments, wet (CL)	-	L	M	-	
						68.5					
70 460	S-14 70.0'-72.0'	14	4 6 20 30		ML	Very stiff, Brown SILT with Decomposed Rock fragments, wet (ML)	-	M	L	-	
75	S-15	24	10		ML	Very stiff, Brownish yellow SILT with Decomposed Rock fragments (ML)	-	M	L	-	

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-I78-1**

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

SOIL BORING LOG
(continued)

BORING NO.: **B-I78-1**
Page **4** of **4**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	**Visual - Manual Identification & Description*** (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
	75.0'-77.0'		9 19 17								
						78.5					
80 450	S-16 80.0'-82.0'	24	22 13 10 9		CL	Very stiff, Reddish brown Lean CLAY with Decomposed Rock fragments, wet (CL)	-	M	M	-	
85	S-17 85.0'-87.0'	24	10 9 15 50/5"		CL	Very stiff, Brown to reddish brown Lean CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	
						88.5					
90 440	S-18 90.0'-92.0'	6	50/6"			Very dense, Gray DECOMPOSED ROCK fragments with Silt, moist	-	-	-	-	
95	S-19 95.0'-97.0'	17	5 6 50/6"			Very dense, Gray to brown DECOMPOSED ROCK fragments with Sandy Silt, wet	-	-	-	-	
						100.0					
100 430						Top of Rock at 100 feet BGS. See Rock Coring Log.					

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-I78-1**

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-I78-1**
Page **1** of **2**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 17, 2016 at 7:30 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 21, 2016 at 9:00 am

Elevation: 530 ft. | **Vertical Datum:** NAVD 1988 | **Boring Location:** Off Redington Rd. | **Coord.: N:** 40.631756 **E:** -75.277489

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
430									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	8.0	100.0							DOLOMITE, Gray, fine grained, fresh, strong, extremely close to close spaced discontinuities								Approximately 700 Gallons of water lost in 8 minutes.
									Calcite veins and Dolomite mineral present.	100.70	J	0	X,R	FR	O	N	
										100.90	J	50	P,R	FR	PO	N	
	3.0									101.20	J	0	X,R	FR	O	N	
	3.0		R-1	48 80%	26 43%	R4	FR										
										102.80	J	40	P,R	FR	T	N	
	3.0									103.40	J	40	P,Sm	DS	PO	CA	
										103.80	J	40	P,R	DG	O	N	
	3.0	105.0															
105																	
	3.5	105.0							DOLOMITE, Gray, fine grained, slightly weathered, very strong, extremely close to moderately spaced discontinuities								
	3.5								Calcite veins present.								
	3.5		R-2	60 100%	33 55%	R5	SL										
	4.5								108.9'-110' Highly fractured zone								Mechanical Breaks.
	3.5	110.0															
110 420																	
	5.0	110.0							DOLOMITE, Gray, very fine grained, fresh, very strong, close to moderately spaced discontinuities 110.5-110.8' Highly fractured zone, possible MB. Calcite veins present.								
	5.0																
										111.80	J	60	P,R	FR	PO	N	
	5.0		R-3	60 100%	55 92%	R5	FR										
	4.5									113.50	J	30	P,R	FR	PO	N	
										114.00	MB						
	7.0	115.0															
115																	
	4.0	115.0							DOLOMITE, Gray, very fine grained, fresh, very strong, wide spaced discontinuities Calcite veins present.								
	4.5																
	5.5		R-4	60 100%	58 97%	R5	FR										
	6.0																
	4.5	120.0								119.50	J	30	P,Sm	DS	VT	CA	

Water Level Data

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

Notes:

MOTT MACDONALD

CORE BORING LOG
(continued)

BORING NO.: **B-I78-1**
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 Type	Dip	Rgh	Wea	Aper	Infill	Remarks
410																	
	4.5	120.0							DOLOMITE, Gray, very fine grained, fresh, very strong, moderate to wide spaced discontinuities Calcite veins present.	120.20	MB						Used up to 1,650 Gallons of water for R3/R4.
										120.80	MB						
	4.5									121.20	J	70	P,R	DS	T	CA	
	5.0		R-5	60 100%	58 97%	R5	FR										
										122.70	V	40	P,R	DS	VT	CA	
	4.5																
	5.0	125.0															
125																	
	5.0	125.0							DOLOMITE, Gray, very fine grained, slightly weathered, very strong, extremely close to moderately spaced discontinuities Calcite veins present.	125.80	V	60	P,R	DS	T	CA	
	5.0									126.60	V	10	P,Sm	DS	VT	CA	
	5.0		R-6	60 100%	56 93%	R5	SL		127.3'-128.3' Highly fractured								
	5.0																
	5.0	130.0								129.00	MB						
										129.60	MB						
130 400																	
	8.5	130.0							DOLOMITE, Gray, very fine to fine grained, fresh, very strong, close to moderately spaced discontinuities								Used up to 1,650 Gallons of water for R5/R6.
										130.90	J	10	P,R	DS	T	N	
	8.5									131.70	J	30	P,R	DS	VT	CA	
	8		R-7	60 100%	54 90%	R5	FR										
										132.90	MB						
	7																
	7.5																
		135.0							135.0	134.70	MB						
135																	
		135.0							VOID from 135' to 139.5'.								Attempted to core, but no recovery at 140 feet BGS. Used up to 1,000 Gallons of water from R-5 to 140 feet BGS.
			R-	-- --	-- --												
		140.0							140.0								
140 390									Boring abandoned at 140 feet BGS. Borehole grouted with cement and bentonite hole plug Boring was offset as B-I78-1A.								
145																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-I78-1**

Figure B-I78-1.1
B-178-1: Box 1 Runs 1-4 (Dry)

Figure B-I78-1.2
B-178-1: Box 1 Runs 1-4 (Wet)

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-1

Figure B-I78-1.3
B-178-1: Box 2 Runs 5-7 (Dry)

Figure B-I78-1.4
B-178-1: Box 2 Runs 5-7 (Wet)

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-1

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-I78-1A**
Page **1** of **4**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 22, 2016 at 8:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 24, 2016 at 1:00 pm

Elevation: 530 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Off Redington Road **Coord.:** **N:** 40.631762 **E:** -75.277525 **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
530	G 0.0'- 2.0'				CH	0.2 2" TOPSOIL Yellowish red Fat CLAY with roots, moist (CH)	-	-	H	-	Hand Auger to 5 feet BGS
5	S-1 5.0'- 7.0'	13	4 5 6 5		CH	Stiff, Yellowish red Fat CLAY with Gravel and Sand, wet (CH)	-	M	H	-	Installed 4" casing to 5 feet BGS
						8.5					
10 520	S-2 10.0'- 12.0'	14	8 8 11 9		ML	Very stiff, Light brown SILT with Clay and Decomposed Rock fragments, moist (ML)	-	M	NP	-	Installed 4" casing to 10 feet BGS
15	S-3 15.0'- 17.0'	23	4 4 11 12		ML	Very stiff, Light brown SILT with Decomposed Rock fragments, moist (ML)	-	M	NP	-	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/23/16	7:00	-	100.0	100.0	56.9
3/24/16	7:00	-	100.0	140.0	115.3

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-I78-1A**

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-I78-1A**
Page **2** of **4**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	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*
510	S-4 20.0'-22.0'	22	11 12 11 12		ML	Very stiff, Light brown SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	
25	S-5 25.0'-27.0'	24	2 3 9 10		ML	Stiff, Light brown SILT, moist (ML)	-	-	NP	-	Potentially residual soil.
						28.5					
30 500	S-6 30.0'-32.0'	22	5 5 7 9		CL	Stiff, Brown Lean CLAY with Sand, moist (CL)	-	M	M	-	
35	S-7 35.0'-37.0'	24	8 7 7 12		CL	Stiff, Brown Lean CLAY with Sand and Decomposed Rock fragments, moist (CL)	-	M	M	-	
40 490	S-8 40.0'-42.0'	22	8 9 10 15		CL	Very stiff, Brown to dark brown Lean CLAY with Sand and Decomposed Rock fragments, moist to wet (CL)	-	M	M	-	Possible Groundwater encountered at 40 feet BGS.
						43.5					
45	S-9 45.0'-47.0'	12	34 50/6"		ML	Hard, Light brown Sandy SILT with Decomposed Rock fragments, wet (ML)	-	-	NP	-	Possible Boulder.

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-I78-1A**

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 / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	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*
50 480	S-10 50.0'-52.0'	23	16 20 20 21		ML	Hard, Light brown SILT with Sand and Decomposed Rock fragments, wet (ML)	-	M	L	-	
						53.5					
55	S-11 55.0'-57.0'	23	9 6 11 18		CL	Very stiff, Reddish brown Lean CLAY with Decomposed Rock fragments, wet (CL)	-	M	M	-	
						58.5					
60 470	S-12 60.0'-62.0'	24	7 12 16 21		ML	Very stiff, Brown SILT, moist (ML)	-	H	L	-	
65	S-13 65.0'-67.0'	16	20 25 24 16		ML	Hard, Brownish yellow Sandy SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	
						68.5					
70 460	S-14 70.0'-72.0'	24	7 11 12 21		CL	Very stiff, Yellowish red Lean CLAY with Sand and Decomposed Rock fragments, moist (CL)	-	H	M	-	
75	S-15	24	11		CL	Hard, Brown Lean CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	

SOIL BORING LOG
(continued)

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description* (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
	75.0'-77.0'		17 20 23								
80 450	S-16 80.0'-82.0'	24	12 11 16 16		CL	Very stiff, Brown Lean CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	
85	S-17 85.0'-87.0'	7	11 12 14 13		CL	Very stiff, Brown Lean CLAY with Decomposed Rock fragments, moist (CL)	-	M	M	-	
90 440	S-18 90.0'-92.0'	17	49 26 16 15		CL	Hard, Brownish red Lean CLAY with Decomposed Rock fragments, moist (CL)	-	H	M	-	
95	S-19 95.0'-97.0'		0			No Recovery	-	-	-	-	
100 430	S 100.0'-102.0'					100.0 Top of Rock at 100 feet BGS. See Rock Coring Log.	-	-	-	-	

NOTES:

PROJECT NO.: 353754

BORING NO.: B-I78-1A

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-I78-1A**
Page **1** of **3**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 22, 2016 at 8:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 24, 2016 at 1:00 pm

Elevation: 530 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Off Redington Road **Coord.: N:** 40.631762 **E:** -75.277525

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								
430	2.50	100.0							DOLOMITE, Gray, very fine grained, highly weathered, weak, extremely close to moderately spaced discontinuities 100'-101.3' Highly Fractured zone								Extremely Decomposed.
	2.00																
	3.00		R-1	56 93%	26 43%	R2	H		102.1'-103.1' Highly Fractured zone								
	3.50																
	3.50	105.0								104.10	J	10	S,R	DS	PO	Ca	
105	2.50	105.0							DOLOMITE, Gray, very fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities 105'-106' Highly Fractured zone								Losing small amount of water.
	3.50																
	4.00		R-2	55 92%	42 70%	R3	SL			107.80	J	30	P,R	DS	T	Ca	
	4.00																
	4.00	110.0															
110 420	4.00	110.0							DOLOMITE, Gray, very fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities								Losing small amount of water.
	4.00									111.40	J		X,R	DS	O	Ca	
	4.00		R-3	58 97%	43 72%	R3	SL		112.2'-112.8' Highly Fractured zone								
	4.50								113.4'-113.9' Highly Fractured zone								
	4.50	115.0							114.6-115' Highly Fractured zone								
115	3.00	115.0							DOLOMITE, Gray, very fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities 115'-115.5' Highly Fractured zone								
	4.00									116.00 116.30	J J	40 50	P,R P,R	DS DS	T T	Ca Fe	
	4.00		R-4	60 100%	46 77%	R3	SL		117.6'-117.9' Highly Fractured zone								
	4.50									118.30	J	30	P,R	DS	T	Ca	
	4.50	120.0								119.00 119.40	MB MB						

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/23/16	7:00	-	100.0	100.0	56.9
3/24/16	7:00	-	100.0	140.0	115.3

Notes:

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-I78-1A**
Page **2** of **3**

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
410		120.0							DOLOMITE, Gray, very fine grained, fresh, very strong, close to moderately spaced discontinuities Calcite veins and vugs								
	4.00									120.90	V	5	P,R	DS	VT	Ca	
	5.00																
	5.00		R-5	60 100%	54 90%	R5	FR			122.40	J	60	P,R	DS	T	Fe	
	5.00									123.30	J	70	P,Sm	DS	T	Fe	
	6.00									124.10	J	35	P,Sm	DS	T	Ca	
		125.0							125.0	124.60	J	55	U,Sm	DS	T	Fe	
125									VOID								No Return.
									127.5								
	8.00	127.5							DOLOMITE, Gray, very fine grained, fresh, very strong, extremely close to close spaced discontinuities Calcite veins and vugs 128'-128.5' Highly Fractured zone								
	8.00		R-6	24 80%	16 53%	R5	FR			128.90	J	30	P,R	DS	T	Fe	
		130.0								129.40	J	20	P,R	DS	VT	Fe	
130 400		130.0							DOLOMITE, Gray, very fine grained, slightly weathered, very strong, extremely close to close spaced discontinuities								
	4.50									130.40	J	5	P,R	DS	T	Fe	
										130.80	MB						
	4.50									131.00	J		X,R	DS	O	Fe	
										131.90	J	50	P,R	DS	PO	N	
	5.00		R-7	60 100%	49 82%	R5	SL			132.40	J	50	P,R	FR	T	N	
										132.90	J	50	P,R	DS	T	Fe	
	3.00								133.1'-133.7' Highly Fractured zone								
	5.00									134.30	J	20	P,R	DS	T	CL	
		135.0															
135		135.0							DOLOMITE, Gray, very fine grained, moderately weathered, very strong, extremely close to close spaced discontinuities 135'-137.4' Highly Fractured zone								
	5.00																
	5.00																
									137.0								
	7.00		R-8	53 88%	35 58%	R5	M		137'-138' VOID	137.60	MB						
									138.0								
	5.00									138.00	J	30	P,R	DG	PO	N	
	8.00	140.0															
140 390		140.0							DOLOMITE, Gray, very fine grained, slightly weathered, medium strong, extremely close to close spaced discontinuities 140.3'-140.9' Highly Fractured zone								
	6.00																
	5.50																
	4.50		R-9	60 100%	42 70%	R3	SL			142.20	J	50	P,R	FR	PO	Fe	
										142.70	J	50	P,R	FR	PO	Fe	
										143.00	MB						
	6.50									143.70	J	50	P,R	DS	O	SD	
	7.50	145.0															
145		145.0							144.9'-145' Highly Fractured zone DOLOMITE, Gray, very fine grained, fresh, medium								

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-I78-1A**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-I78-1A**
Page **3** of **3**

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
	5.00								strong, wide spaced discontinuities								
	6.00																
	6.00		R-10	60 100%	60 100%	R3	FR										
	5.00									148.20	J	30	P,Sm	FR	VT	N	
										148.40	MB						
										148.70	MB						
	6.00	150.0															
150 380		150.0							DOLOMITE, Gray, very fine grained, fresh, strong, close to wide spaced discontinuities								
	5.00									150.30	MB						
	5.00																
	5.00		R-11	60 100%	52 87%	R4	FR										
										152.70	J	20	P,R	FR	O	N	
	5.00									153.30	V	50	P,Sm	FR	VT	Ca	
	6.00	155.0															
155		155.0							DOLOMITE, Gray, very fine grained, fresh, very strong, close to wide spaced discontinuities								
	5.00																
	5.00																
	5.00		R-12	57 95%	48 80%	R5	FR										
	6.00																
	5.00	160.0															
160 370		160.0							160.0 End of Boring at 145 feet BGS. Borehole grouted with cement and bentonite hole plug.								
165																	
170 360																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-I78-1A**

Figure B-I78-1A.1
B-I78-1A Box 1 Runs 1-4 Dry

Figure B-I78-1A.2
B-I78-1A Box 1 Runs 1-4 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-1A

Figure B-I78-1A.3
B-I78-1A Box 2 Runs 5-8 Dry

Figure B-I78-1A.4
B-I78-1A Box 2 Runs 5-8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-1A

Figure B-I78-1A.5
B-I78-1A Box 3 Runs 9-12 Dry

Figure B-I78-1A.6
B-I78-1A Box 3 Runs 9-12 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-1A

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-I78-2**
Page **1** of **2**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 10, 2016 at 7:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 16, 2016 at 12:00 pm

Elevation: 610 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** East of Redington Rd. **Coord.:** **N:** 40.630672 **E:** -75.276028 **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
610	G-1 0.0'- 2.0'				ML	0.5 Yellowish red SILT with Decomposed Rock fragments and Roots, moist (ML)	N	-	NP	N	
5	S-1 5.0'- 7.0'	17	12 12 12 50/1"		ML	Very stiff, Yellowish red Sandy SILT with Decomposed Rock fragments, dry (ML)	-	-	NP	-	Installed Casing to 10'.
10 600	S-2 10.0'- 12.0'	8	15 60/0"			10.0 Very dense, DECOMPOSED ROCK fragments with Sandy Silt, moist	-	-	-	-	
15	S-3 15.0'- 17.0'	8	31 50/1"			Very dense, DECOMPOSED ROCK fragments with Sandy Clay, wet	-	-	-	-	Possible Groundwater at 15'.
						18.5					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/10/16	7:40	-		100.0	74.5

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-I78-2**

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-I78-2**
Page **2** of **2**

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec / Pen. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description* (density/consistency, color, Group Name & Symbol, maximum particle size, structure, odor, moisture, optional descriptions, geologic interpretation)	Field Tests: Dilatancy	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks*
590	S-4 20.0'-22.0'	18	14 38 40 35		ML	Hard, Gray SILT with Decomposed Rock fragments, moist (ML)	-	-	NP	-	
25	S-5 25.0'-27.0'	15	10 13 12 8		ML	Very stiff, Gray SILT with Decomposed Rock fragments, wet (ML)	-	L	L	-	
						28.5					
30 580	S-6 30.0'-32.0'	2	50/2"			Very dense, DECOMPOSED ROCK fragments with Clayey Silt, wet	-	-	-	-	
35	S-7 35.0'-37.0'	3	50/3"			Very dense, DECOMPOSED ROCK fragments with Clayey Sand, moist	-	-	-	-	
						38.5					
40 570	S-8 40.0'-42.0'		45 46 42 47		ML	Hard, Gray to reddish brown Sandy SILT with Decomposed Rock fragments, moist (ML)	-	-	-	-	
45						45.0 Top of Rock at 45 feet BGS. See Rock Coring Log.					

NOTES:

PROJECT NO.: **353754**

BORING NO.: **B-I78-2**

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-I78-2**
Page **1** of **7**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate-78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Bernard Cortes
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 10, 2016 at 7:00 am
Driller/Helper:	Paul Mullins /Nick Beehler	**Date/Time Finished:**	March 16, 2016 at 12:00 pm

Elevation: 610 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** East of Redington Rd. **Coord.: N:** 40.630672 **E:** -75.276028

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								
	3.50	45.0							GNEISS, Gray, fine to coarse grained, highly weathered, very strong, extremely close to moderately spaced discontinuities								Losing Water.
	1.50								46'-47.8' Highly Fractured zone 47'-50' Greenish Gray								
	1.50		R-1	58 97%	33 55%	R5	H										
	1.50									48.10	J	50	P,R	DG	O	N	
	2.00	50.0							48.8'-50' Highly Fractured zone								
50 560	1.15	50.0							GNEISS, Gray, fine to very coarse grained, moderately weathered, very strong, extremely close to close spaced discontinuities 50'-50.9' Highly Fractured zone								
	3.00								51.3'-52' Highly Fractured zone								
	3.00		R-2	42 70%	8 13%	R5	M		52.3'-52.6' Highly Fractured zone								
	3.50																
	2.50	55.0															
55	2.00	55.0							GNEISS, Gray, fine to coarse grained, moderately weathered, very strong, extremely close to close spaced discontinuities 55'-55.3' Silt Pocket 55.3'-57.5' Highly Fractured zone								No water return.
	5.00																
	2.00		R-3	45 75%	13 22%	R5	M										
	2.50																
	2.00	60.0															
60 550	3.50	60.0							GNEISS, Brown, fine to very coarse grained, highly weathered, weak to strong, extremely close spaced discontinuities 60'-62.3' Highly Fractured zone								No water return.
	3.50																
	3.50		R-4	28 47%	0 0%	R2	H										
	3.50																
	3.50	65.0															

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/10/16	7:40	-		100.0	74.5

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	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.50	65.0							GNEISS, Gray, fine to coarse grained, moderately to highly weathered, medium strong to strong 65'-68.8' Highly Fractured zone								No water return.
	3.50																
	3.50		R-5	41 68%	5 8%	R3	H										
	3.50																
	3.50	70.0															
70 540		70.0															No water return.
	3.00								GNEISS, Gray green, fine to medium grained, highly weathered, weak to strong, extremely close to close spaced discontinuities								
	3.50																
	3.50		R-6	11 18%	8 13%	R2	H										
	3.50																
	3.50	75.0															
75		75.0							75.0 No Recovery								
	3.50																
	3.00																
	3.00		R-7	0 0%	0 0%												
	3.50																
	3.50	80.0															
80 530		80.0							80.0 GNEISS, Light gray to green, very fine to coarse grained, moderately weathered, strong, extremely close to close spaced discontinuities 80'-82' Highly Fractured zone								
	10.00																
	6.00																
	5.00		R-8	60 100%	41 68%	R4	M			82.60	J	40	P,R	DG	O	CL	
	4.00									83.40	FJ	70	P,R	DG	O	CL	
	6.00									83.90	FJ	10	P,R	DG	O	CL	
		85.0															
85		85.0							GNEISS, Green gray, medium to coarse grained, slightly weathered, strong, moderately spaced discontinuities								No water return.
	3.50									85.60	FJ	5	P,R	DS	PO	N	
	4.50									86.40	J	80	P,R	DS	PO	N	
	6.00		R-9	59 98%	54 90%	R4	SL										
	5.00									87.90	FJ	10	P,R	DS	PO	N	
	5.00									88.90	J	60	P,R	DS	PO	N	
		90.0															
90 520		90.0							GNEISS, Gray green, medium to coarse grained, slightly weathered, strong, moderate to very close								No water return. Hard drilling.

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
	5.50								spaced discontinuities								
	6.00									91.10	S	40	P,R	DS	T	N	
	7.00		R-10	60 100%	39 65%	R4	SL		91.6'-92.8' Highly Fractured zone								
	6.00								93.5'-94.1' Highly Fractured zone								
	7.00	95.0															
95	8.00	95.0							GNEISS, Gray green, medium to coarse grained, slightly weathered, close to moderately spaced discontinuities	95.50	J	50	P,R	DS	PO	N	No water return.
	6.00																
	6.00		R-11	57 95%	41 68%	R4	SL			97.30	J	30	P,R	DS	T	N	
	4.00								98.5'-100' Highly Fractured zone								No water return.
	4.50	100.0															
100 510	10.00	100.0							GNEISS, Gray green, medium to coarse grained, highly to slightly weathered, weak to strong, very close to close spaced discontinuities Highly weathered zones are clay rich 100'-101.5' Highly Fractured Zone								No water return.
	4.00																
	5.00		R-12	57 95%	15 25%	R4	M		102.3'-104' Highly Fractured zone								
	4.00																
	4.00	105.0															
105	4.00	105.0							GNEISS, Gray green, fine to coarse grained, moderately weathered, moderate to extremely close spaced discontinuities 105'-105.4' Highly Fractured zone								No water return.
	3.00									106.00	FJ	50	P,R	DS	PO	N	
										106.40	B	20	P,R	DS	T	N	
	4.00		R-13	44 73%	28 47%	R4	M		107.5'-110' Highly Fractured zone								
	4.00																108' Rock is weak.
	4.00	110.0															
110 500	5.00	110.0							GNEISS, Gray green, fine to coarse grained, moderate to slightly weathered, weak to strong, very close to moderately spaced discontinuities								No water return.
	5.00									110.90	FJ	50	P,R	DS	O	N	
										111.20	FJ	50	P,R	DS	PO	N	
	4.00		R-14	57 95%	29 48%	R4	SL			111.80	FJ	40	P,R	DG	O	N	
	4.00									113.00	J	80	P,R	DS	T	N	
										113.50	FJ	40	P,R	DG	O	N	
	4.00	115.0							114'-115' Highly Fractured zone								
115	3.00	115.0							GNEISS, Gray, fine to coarse grained, slightly weathered, strong, extremely close to moderately spaced discontinuities 115'-116' Highly Fractured zone								No water return.

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
	3.00									116.40	J	40	P,R	DS	PO	N	
	3.00		R-15	60 100%	34 57%	R4	SL		117'-118' Highly Fractured zone								
	3.00																
	3.00	120.0								119.00	FJ	45	P,R	DG	PO	SD	
120 490	3.00	120.0							GNEISS, Gray, fine to coarse grained, slightly to moderately weathered, strong to weak, extremely close to moderately spaced discontinuities								No water return.
	2.00									121.10	FJ	10	P,R	DG	O	N	
										121.50	FJ	30	P,R	DS	PO	N	
	2.00		R-16	60 100%	33 55%	R4	SL		122'-123.4' Highly Fractured zone								
	2.00																
	2.00									123.80	J	30	P,R	DS	PO	N	
	2.00	125.0							124.3'-124.6' Highly Fractured zone								
125	3.00	125.0							GNEISS, Gray, fine to coarse grained, slightly to moderately weathered, medium strong to strong, extremely close to moderately spaced discontinuities								No water return.
	3.00								126'-127' Highly Fractured zone								
	3.00		R-17	60 100%	35 58%	R4	SL			127.80	J	40	P,R	DS	PO	N	
	3.00																
	3.00	130.0								128.80	FJ	40	P,R	DS	PO	N	
130 480	3.00	130.0							GNEISS, Gray, fine to coarse grained, slightly weathered, strong, close to moderately spaced discontinuities 130'-132.3 Highly Fractured zone								No water return.
	3.00																
	4.00		R-18	60 100%	28 47%	R4	SL		132.3'-133.8' Highly Fractured zone								
	3.00																
	3.00	135.0															
135	3.50	135.0							GNEISS, Gray to gray green, fine to coarse grained, slightly weathered, strong, close to moderately spaced discontinuities								No water return.
	3.50									136.00	FJ	20	P,R	DG	PO	N	
										136.10	FJ	60	P,R	DG	O	N	
	3.50									136.60	FJ	60	P,R	DS	T	N	
	3.50		R-19	60 100%	39 65%	R4	SL		138.2'-139' Highly Fractured zone								
	3.50																
	3.50	140.0															
140 470	3.00	140.0							GNEISS, Gray, fine to coarse grained, slightly weathered, strong, medium spaced discontinuities								No water return.
	3.00																

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
	3.00									141.50	FJ	30	P,R	DS	PO	N	
	3.50		R-20	60 100%	58 97%	R4	SL			142.00	J	40	P,R	DS	T	N	
	3.00									143.00	FJ	30	P,R	DS	T	QZ	
	3.00									143.80	J	0	P,R	DS	PO	N	
		145.0								144.30	FJ	50	P,R	DS	T	N	
145		145.0							GNEISS, Gray, fine to medium grained, moderate to slightly weathered, strong, extremely close spaced discontinuities 145.5'-147' Highly Fractured zone								No water return all day.
	3.00																
	3.00																
	3.00		R-21	60 100%	42 70%	R4	SL			148.00	J	20	P,R	DS	T	N	
	3.00									148.60	FJ	70	P,R	DS	T	N	
	2.50																
150 460		150.0								149.80	FJ	10	P,R	DS	T	N	No water return.
	6.00	150.0							GNEISS, Gray, fine to medium grained, slightly weathered, medium strong, extremely close to wide spaced discontinuities	150.60	FJ	30	P,R	DS	T	N	
	5.00									151.30	J	0	P,R	FR	T	N	
	5.50		R-22	60 100%	44 73%	R3	SL			151.90	S	50	P,K	DS	T	L	
	3.00								152.8'-155' Highly Fractured zone								
	3.00	155.0															
155		155.0							GNEISS, Gray, fine to medium grained, fresh, medium strong, extremely close spaced discontinuities 155'-156' Highly Fractured zone								No water return.
	3.00																
	2.50									156.30	J	20	P,Sm	FR	T	N	
										156.70	J	30	P,R	FR	T	N	
	2.50		R-23	60 100%	52 87%	R3	FR			157.00	FJ	40	P,Sm	FR	T	N	
	2.50									158.00	J	20	P,R	DG	O	N	
	2.50									159.20	MB						
		160.0								159.70	MB						
160 450	5.00	160.0							GNEISS, Gray, fine to medium grained, fresh, medium strong, extremely close to moderately spaced discontinuities 160.8'-162.3' Highly Fractured zone								
	5.00																
	5.00		R-24	60 100%	48 80%	R3	FR			162.50	Sty	30	P,Sm	FR	T	N	
	10.00									163.50	FJ	0	P,R	FR	O	N	
	4.00	165.0															
165		165.0							GNEISS, Dark gray, fine to coarse grained, slightly weathered, very strong, extremely close to moderately spaced discontinuities 165'-167.7' Highly Fractured zone	164.80	MB						No water return.
	1.00																
	2.00																

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
	2.00		R-25	60 100%	32 53%	R5	SL										
	2.00								168.2'-168.7' Highly Fractured zone								
	2.300	170.0															
170 440	2.50	170.0							GNEISS, Dark gray, fine to coarse grained, fresh, strong, extremely close to moderately spaced discontinuities	169.90	MB						No water return.
										170.60	J	60	P,R	FR	T	N	
	2.50									171.20	FJ	0	X,R	FR	T	N	
	2.50								171.8'-172.5' Highly Fractured zone								
	2.50		R-26	60 100%	53 88%	R4	FR										
	2.50									173.10	V	70	P,Sm	DS	T	Ca	
	2.50	175.0															
175		175.0							GNEISS, Greenish gray, fine to coarse grained, moderately weathered, strong, extremely close to close spaced discontinuities								No water return.
	2.50								175'-175.4' Highly Fractured zone	175.90	FJ	40	P,R	DG	T	Fe	
	5.00									176.40	FJ	50	P,Sm	DS	T	Fe	
	2.50		R-27	53 88%	35 58%	R4	M		176.9'-177.9' Highly Fractured zone								
	5.00									178.30	J	40	P,Sm	DS	T	N	
										178.60	J	40	P,Sm	FR	PO	Sa	
	10.00	180.0								178.80	MB						
180 430	5.00	180.0							Granitic GNEISS, Greenish gray, medium to coarse grained, fresh, very strong, extremely close to moderately spaced discontinuities								No water return. Loss 550 gallons of water per foot.
										180.80	J	70	P,Sm	DS	T	N	
	4.00								181.4'-182.2' Highly Fractured zone								
	4.00		R-28	54 90%	46 77%	R5	FR										
										182.60	J	40	P,Sm	FR	T	N	
	4.00																
	4.00	185.0								184.60	J		X,R	DS	T	N	
185	5.00	185.0							Granitic GNEISS, Greenish gray, medium to coarse grained, slightly weathered, very strong, extremely close to moderately spaced discontinuities	185.30	MB						No water returns.
	11.50																Loss 550 gallons of water per foot.
	10.00		R-29	60 100%	36 60%	R5	SL										
										188.00	J	40	P,Sm	FR	T	N	
	11.00																
										188.90	J	40	P,R	DG	PO	ST	
	7.50	190.0								189.40	J	60	U,R	DS	PO	ST	
190 420	10.00	190.0							GNEISS, Greenish gray, fine to coarse grained, moderately weathered, very strong, extremely close to moderately spaced discontinuities								Loss 550 gallons of water per foot.
	15.00								190.6'-192' Highly Fractured zone								
	15.00		R-30	57	29	R5	M										

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-I78-2**
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
	15.00			95%	48%				192.6'-193.4' Highly Fractured zone								
	15.00									193.80	J	40	P,Sm	FR	T	N	
	6.00	195.0															
195		195.0							Granitic GNEISS, Light gray, medium to coarse grained, fresh, extremely strong, moderately spaced discontinuities								Loss 550 gallons of water per foot.
	5.00																
	7.00									196.60	MB						
	7.00		R-31	55 92%	55 92%	R6	FR			197.60	J	50	P,Sm	FR	VT	N	
	16.00																
	30.00									199.20	J	20	P,R	FR	T	N	
		200.0							200.0								
200 410									End of Boring at 200 feet BGS. Borehole grouted with cement and bentonite hole plug Boring was terminated due to collasped borehole.								
205																	
210 400																	
215																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-I78-2**

Figure B-I78-2.1
B-I78-2 Box 1 Runs 1-4 Dry

Figure B-I78-2.2
B-I78-2 Box 1 Runs 1-4 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-2

Figure B-I78-2.3
B-I78-2 Box 2 Runs 5-8 Dry

Figure B-I78-2.4
B-I78-2 Box 2 Runs 5-8 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-2

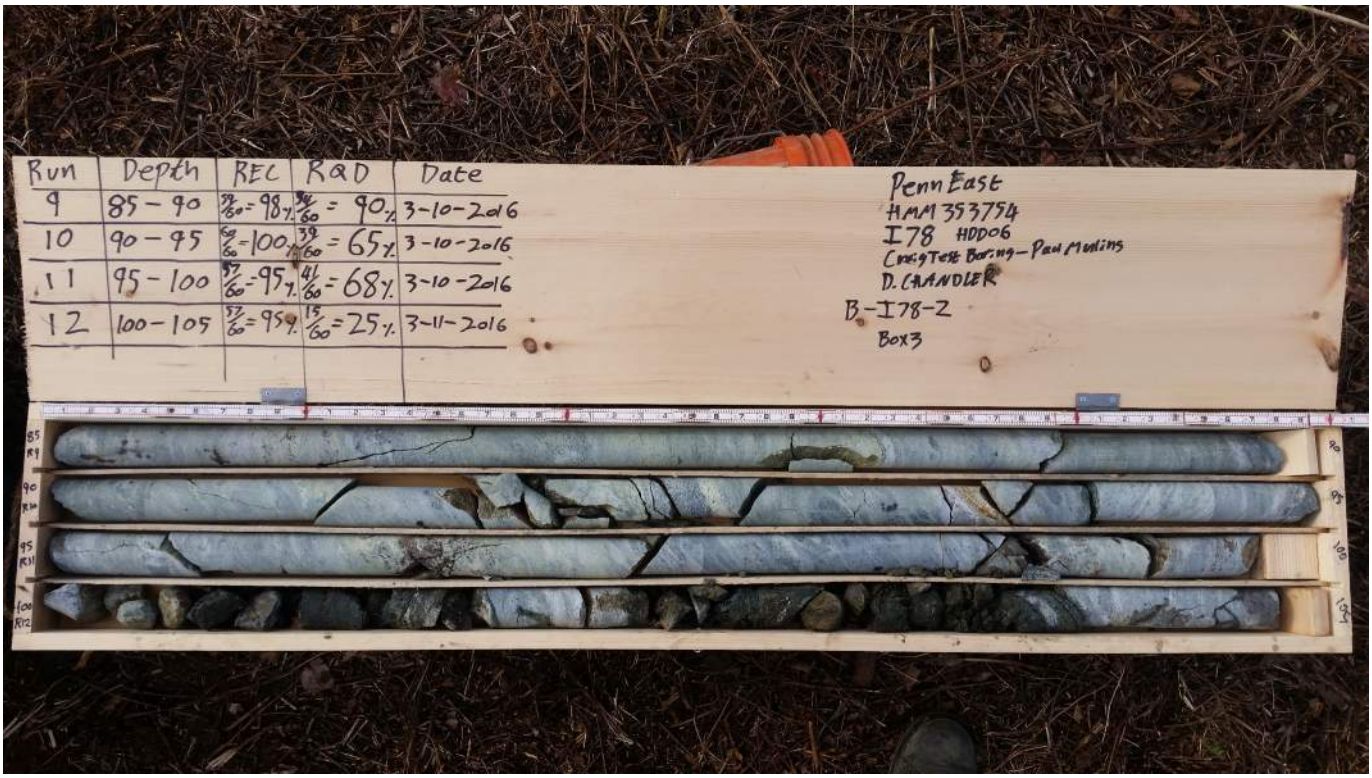


Figure B-I78-2.5
B-I78-2 Box 3 Runs 9-12 Dry

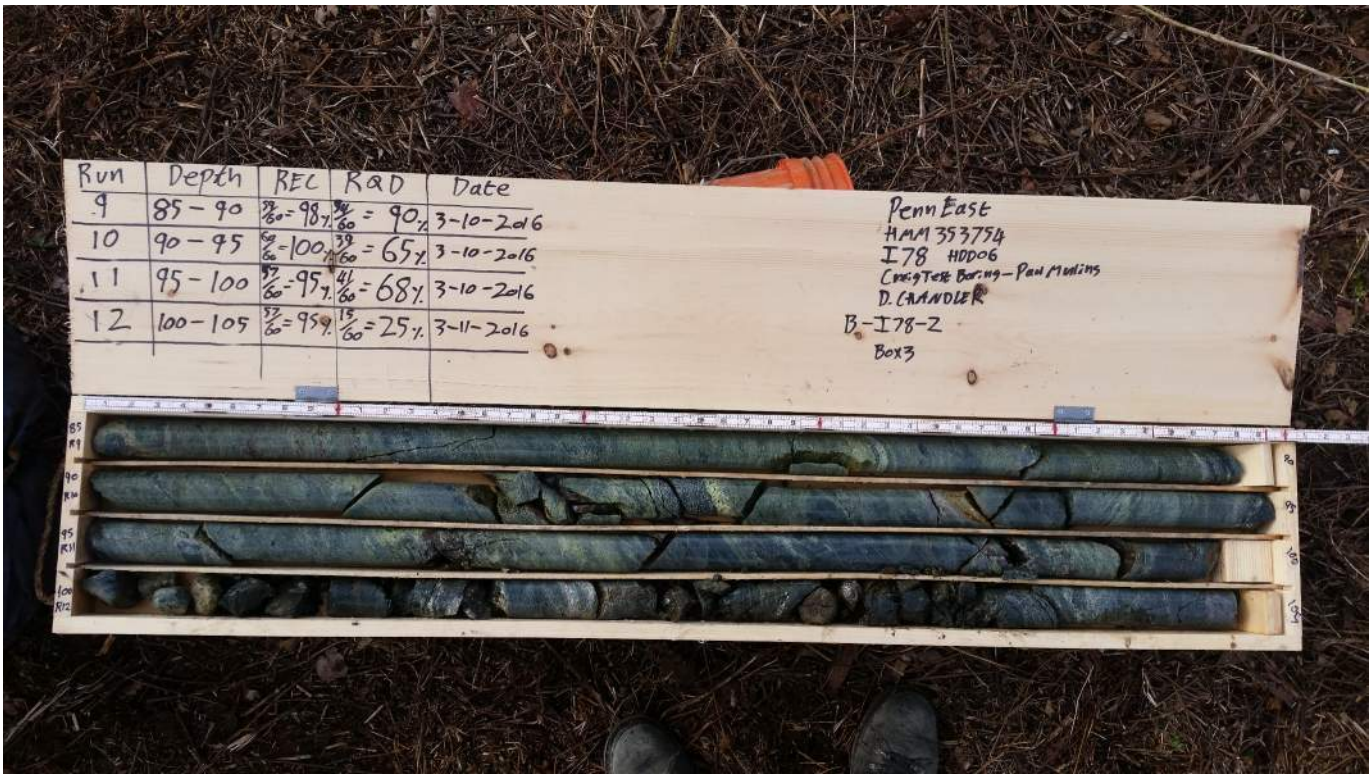


Figure B-I78-2.6
B-I78-2 Box 3 Runs 9-12 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-2

Figure B-I78-2.7
B-I78-2 Box 4 Runs 13-16 Dry

Figure B-I78-2.8
B-I78-2 Box 4 Runs 13-16 Wet

Figure B-I78-2.9
B-I78-2 Box 5 Runs 17-20 Dry

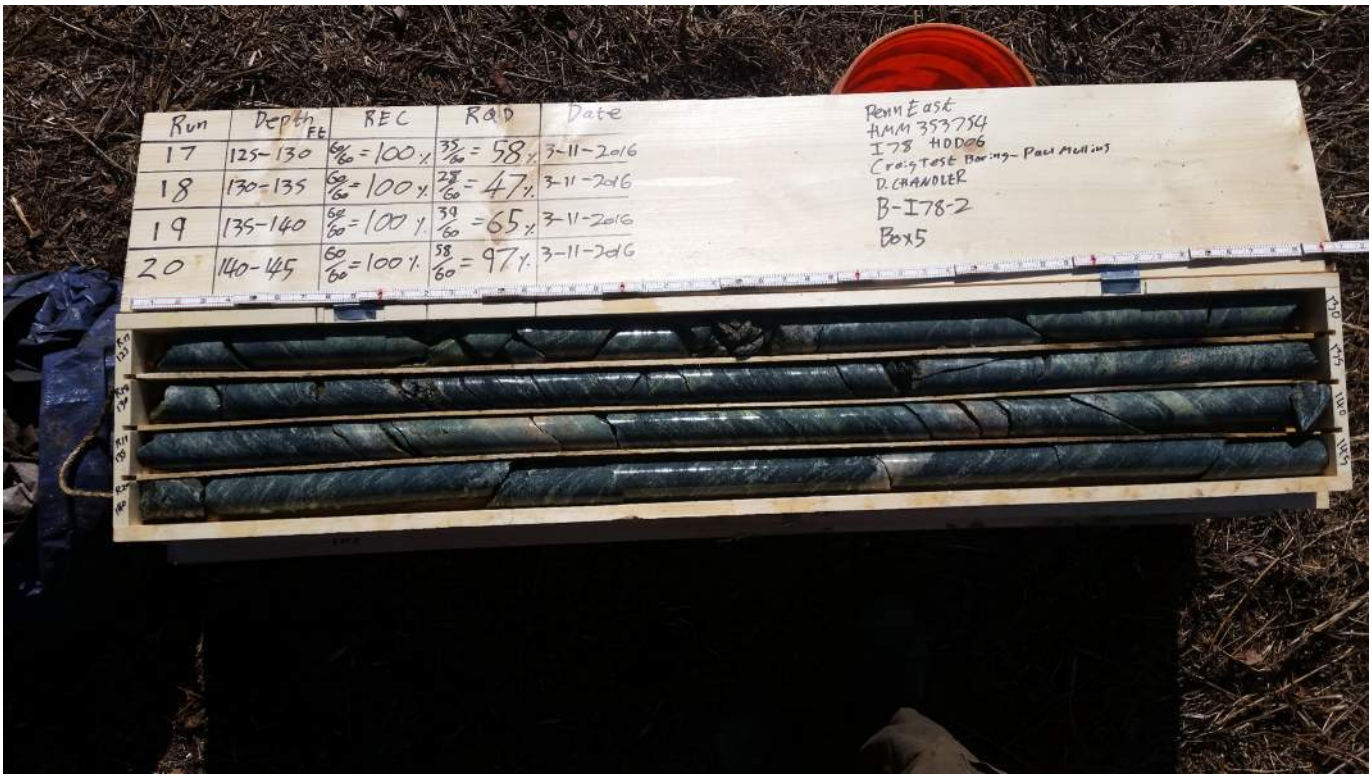


Figure B-I78-2.10
B-I78-2 Box 5 Runs 17-20 Wet

Figure B-I78-2.11
B-I78-2 Box 6 Runs 21-24 Dry

Figure B-I78-2.12
B-I78-2 Box 6 Runs 21-24 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-2

Figure B-I78-2.13
B-I78-2 Box 7 Runs 25-28 Dry

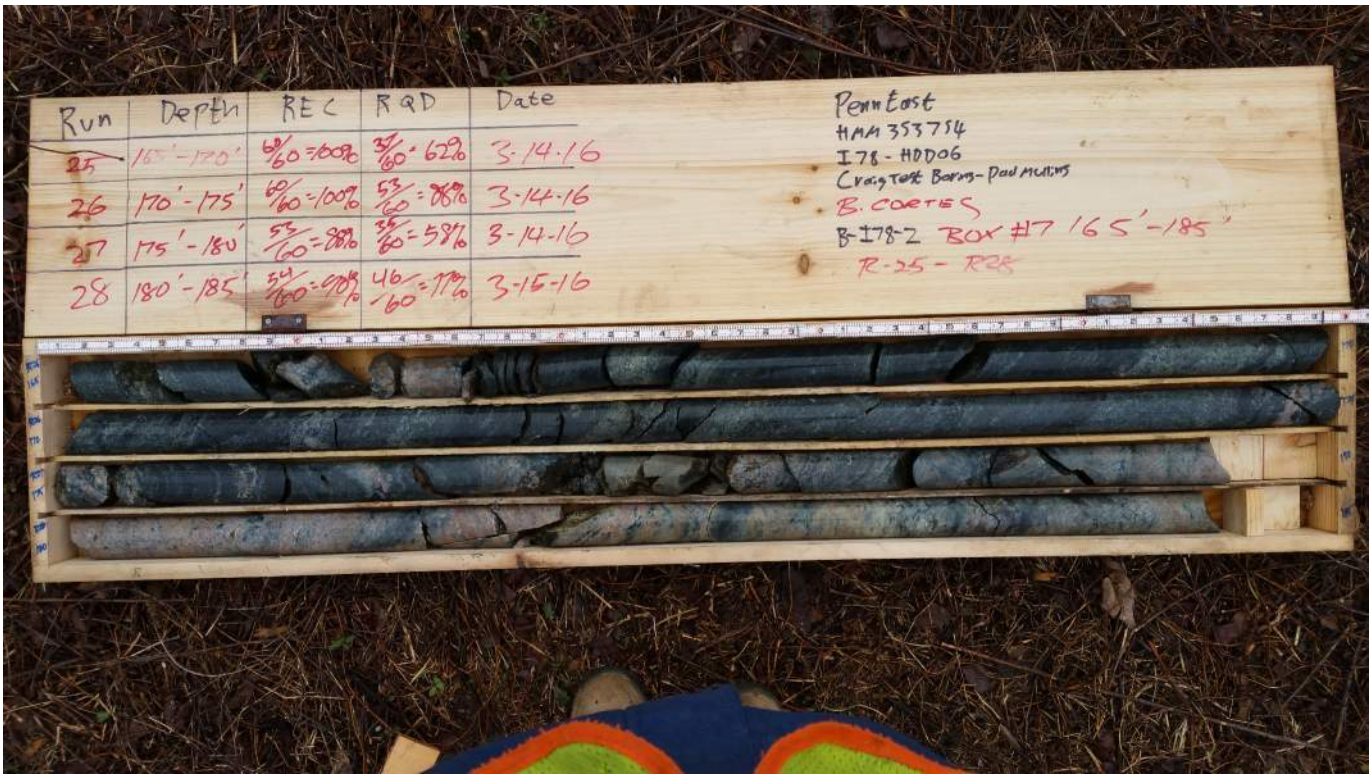


Figure B-I78-2.14
B-I78-2 Box 7 Runs 25-28 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-2

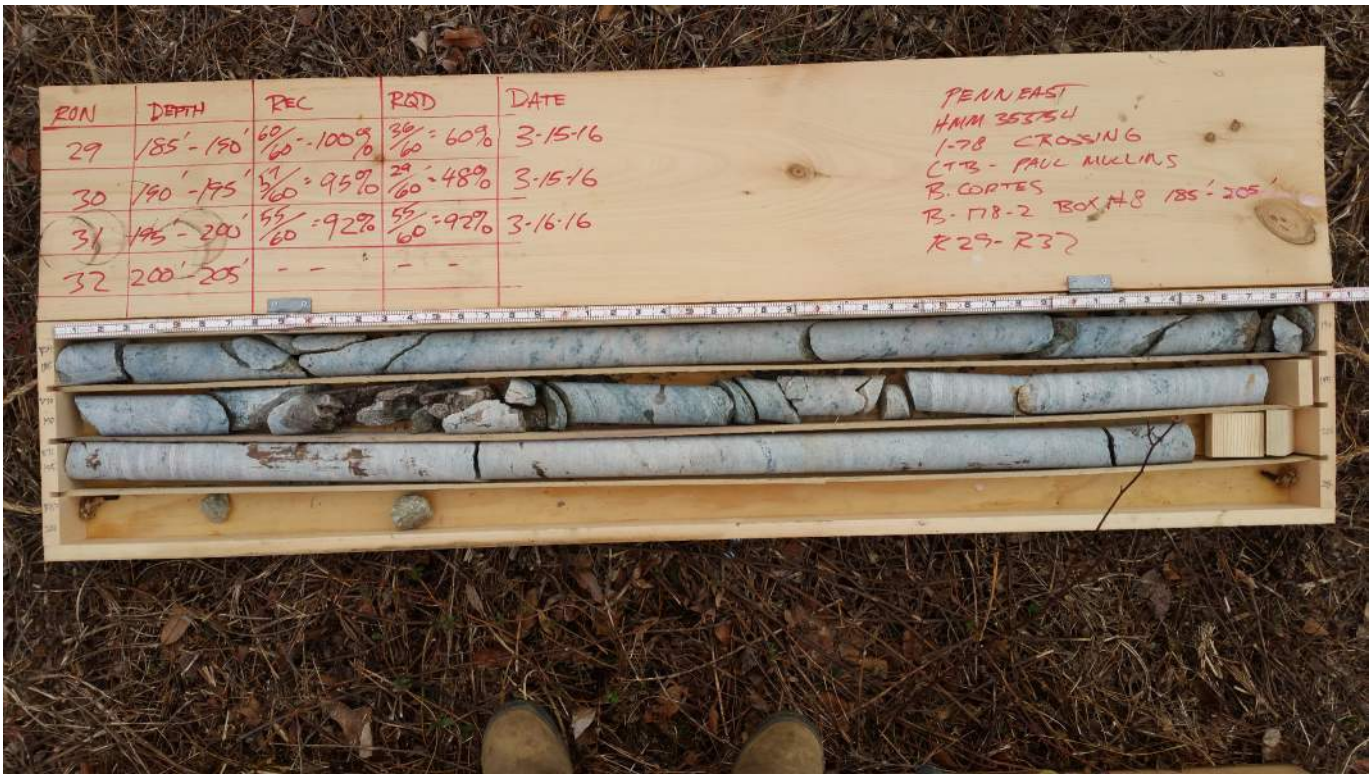


Figure B-I78-2.15
B-I78-2 Box 8 Runs 29-31 Dry

Figure B-I78-2.16
B-I78-2 Box 8 Runs 29-31 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-2

MOTT MACDONALD

SOIL BORING LOG

BORING NO.: **B-I78-3**
Page **1** of **4**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	B. Kalpouzos, C. Guilcapi
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 9, 2018 at 10:40 am
Driller/Helper:	Paul Mullins /Dalton Lentes	**Date/Time Finished:**	June 12, 2018 at 11:15 am

Elevation: 555 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** East of Redington Rd. **Coord.:** **N:** 40.6312034 **E:** -75.2766996 **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'	8	2 2 2 4		SM	Very loose, Brownish yellow Silty SAND, trace Clay, dry (SM)	-	-	-	-	Advanced 4-inch casing to 5 feet BGS.
						3.5					
5 550	S-2 5.0'- 7.0'	10	8 5 4 3		SC	Loose, Brownish yellow Clayey SAND, dry (SC)	-	-	-	-	
						8.5					
10	S-3 10.0'- 12.0'	15	3 8 11 9		SP	Medium dense, Brownish yellow SAND, trace Clay, moist (SP)	-	-	-	-	
						13.5					
15 540	S-4 15.0'- 17.0'	17	2 3 4 5		ML	Medium stiff, Brown Clayey SILT, wet (ML)	S	L	M	L	
						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 Grab Sample

Notes:

PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

Boring No.: **B-I78-3**

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
	S-5 20.0'-22.0'	22	3 3 6 6		CL-ML	Stiff, Brown Silty CLAY, wet (CL-ML)	S	L	M	L	PP = 1.5 tsf. TV = 1.25 tsf.
25 530	S-6 25.0'-27.0'	24	3 1 2 3		CL-ML	Soft, Dark brown Silty CLAY, wet (CL-ML)	R	L	M	L	PP = 1.0 tsf. TV = 1.0 tsf.
30	S-7 30.0'-32.0'	20	WOH 3 4 4		CL-ML	Medium stiff, Dark brown Silty CLAY, wet (CL-ML)	R	L	H	L	PP = 1.5 tsf. TV = 1.0 tsf.
35 520	S-8 35.0'-37.0'	24	2 4 2 5		CL-ML	Medium stiff, Dark brown Silty CLAY, wet (CL-ML)	R	L	M	L	PP = N/A. TV = N/A.
40	S-9 40.0'-42.0'	22	8 11 22 19		CL-ML	Hard, Brownish yellow Silty CLAY, trace Sand, wet (CL-ML)	N	H	NP	M	PP = N/A. TV = N/A.
						43.5					
45 510	S-10 45.0'-47.0'	15	17 13 26 34		SM	Dense, Brown SAND, some Silt, dry (SM)	-	-	-	-	Rig chatter from 47 to 50 feet BGS.

NOTES: PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

PROJECT NO.: **353754**

BORING NO.: **B-I78-3**

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
						48.5					
50	S-11 50.0'-52.0'	19	16 24 50 50/3"		SP	Very dense, Brown SAND, dry (SP)	-	-	-	-	Rig chatter from 52 to 55 feet BGS.
55 500	S-12 55.0'-57.0'	5	50/5"		SP	Very dense, Brown SAND, dry (SP)	-	-	-	-	Weathered Gneiss in tip of spoon, gravel sized. Rig chatter from 57 to 60 feet BGS.
60	S-13 60.0'-62.0'	0	50/3"		SP	No Recovery	-	-	-	-	Rig chatter from 62 to 65 feet BGS.
65 490	S-14 65.0'-67.0'	19	36 26 22 50/4"		SP	Dense, Brown SAND, dry (SP)	-	-	-	-	Weathered Gneiss in tip of spoon, gravel sized. Rig chatter from 67 to 70 feet BGS.
70	S-15 70.0'-72.0'	16	29 29 50/3"		SP	Very dense, Brown SAND, dry (SP)	-	-	-	-	Rig chatter from 72 to 75 feet BGS.

NOTES: PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

PROJECT NO.: 353754

BORING NO.: B-I78-3

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-I78-3**
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
75 480	S-16 75.0'-77.0'	5	50/5"		SP	Very dense, Brown SAND, dry (SP)	-	-	-	-	
						78.5					
80	S-17 80.0'-82.0'	13	25 50/5"		SM	Very dense, Brownish yellow Silty SAND with Clay, dry (SM)	-	-	-	-	Rig chatter from 82 to 85 feet BGS.
85 470	S-18 85.0'-87.0'	3	50/3"		SM	Very dense, Brown Silty SAND, dry (SM)	-	-	-	-	
90						90.0 Top of Rock at 90 feet BGS. See Rock Coring Log.					
95 460											
100											

NOTES: PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

PROJECT NO.: **353754**

BORING NO.: **B-I78-3**

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-I78-3**
Page **1** of **6**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	B. Kalpouzos, C. Guilcapi
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 9, 2018 at 10:40 am
Driller/Helper:	Paul Mullins /Dalton Lentes	**Date/Time Finished:**	June 12, 2018 at 11:15 am

Elevation: 555 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** East of Redington Rd. **Coord.: N:** 40.6312034 **E:** -75.2766996

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)						
	0.90	90.0							GNEISS, Olive gray, medium grained, slightly weathered, strong, close to moderately spaced discontinuities	90.30	J	60	U,R	DS	T	N	
	5.50									91.20	J	50	U,R	DS	T	N	
	4.00		R-1	56 93%	48 80%	R4	SL			92.30	J	50	U,R	DS	T	N	
	5.00									93.20	J	40	U,R	DS	T	N	
										93.65	J	40	U,R	DS	PO	N	
	5.50	95.0								94.30	J	30	P,R	DS	T	N	
95 460	3.45	95.0							GNEISS, Olive gray, coarse to medium grained, moderately weathered, strong, very close to moderately spaced discontinuities	95.50	J	30	U,R	DS	O	CL	
	4.50								96.1'-97.0' Fractured zone 97.7'-98.9' Fractured zone								
	3.75		R-2	59 98%	30 50%	R4	M			97.20	J	80	S,R	DS	T	N	
	4.25																
	5.25	100.0								99.30	J	20	U,R	DS	T	N	
100	4.50	100.0							GNEISS, Olive gray, coarse to medium grained, highly weathered, strong, extremely close to close spaced discontinuities								
									100.9'-101.6' Fractured zone	100.90	J	40	U,R	DS	T	N	
	4.00								102.3'-104.4' Fractured zone	101.50	J	20	S,R	DG	W	N	
	3.00		R-3	53 88%	18 30%	R4	H			102.20	J	60	U,R	DG	W	N	
	3.25																
	3.00	105.0															
105 450	2.50	105.0							GNEISS, Olive gray, coarse to fine grained, highly weathered, strong, extremely close to close spaced discontinuities								
	3.00								105.3'-108.1' Fractured zone 108.7'-109.5' Fractured zone								
	4.00		R-4	52 87%	5 8%	R4	H										
	4.50									108.20	J	0	P,R	DS	PO	N	
	4.00	110.0															

Water Level Data

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

Notes:

Groundwater was not encountered.

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 (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
	3.00	110.0							GNEISS, Dark brown, fine to medium grained, highly weathered, weak, very close to close spaced discontinuities	110.50	J	0	S,R	DS	W	N	
	3.50								110'-110.4' Fractured zone	111.10	J	30	S,R	DS	W	N	
									111.1'-111.4' Fractured zone	111.40	J	0	S,R	DS	W	N	
	2.00		R-5	21 35%	8 13%	R2	H		111.6'-111.8' Fractured zone	111.60	J	0	S,R	DS	W	N	
	2.00																
	2.00	115.0															
115 440	1.00	115.0							GNEISS, Olive gray, coarse grained, moderately weathered, strong, extremely close to moderately spaced discontinuities	115.10	J	30	P,R	DS	PO	N	Difficult drilling at 117 feet BGS. No water return.
	2.00								116'-117.4' Fractured zone	116.00	J	70	S,R	DS	VW	N	
	2.00		R-6	49 82%	30 50%	R4	M			117.40	J	40	U,R	DS	W	N	
	1.50									118.40	J	50	S,R	DS	O	N	
										118.50	J	60	U,R	DS	PO	N	
	4.50	120.0															
120	3.00	120.0							GNEISS, Olive gray, coarse grained, slightly weathered, strong, very close to moderately spaced discontinuities								
	2.50									121.20	J	20	U,R	DS	W	N	
										121.30	J	70	S,R	DS	W	N	
										121.60	J	70	S,R	DS	T	N	
	2.00		R-7	34 57%	28 47%	R4	SL			122.00	J	20	U,R	DS	PO	N	
										122.40	J	0	U,R	DS	PO	N	
	2.00																
	3.00	125.0															
125 430	2.00	125.0							GNEISS, Brown, medium to fine grained, completely weathered, extremely weak, close spaced discontinuities								
										125.90	J	0	S,R	DE	PO	CL	
	2.00									126.00	J	0	U,R	DE	O	CL	
										126.60	J	30	S,R	DE	PO	CL	
	3.00		R-8	22 37%	13 22%	R0	C										
	2.50																
	5.00	130.0															
130	3.00	130.0							GNEISS, Olive gray, coarse to medium grained, moderately weathered, strong, extremely close to close spaced discontinuities	130.30	J	40	P,R	DS	PO	N	
										130.60	J	60	S,R	DS	PO	N	
	4.00																
	4.00		R-9	25 42%	4 7%	R4	M										
	3.00																
	3.00	135.0															

NOTES: Groundwater was not encountered.

PROJECT NO.: **353754**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-I78-3**
Page **3** 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
420	2.00	135.0							GNEISS, Olive gray, coarse to fine grained, moderately weathered, strong, extremely close to very close spaced discontinuities	135.50	J	50	U,R	DS	W	N	
										135.70	J	40	P,R	DS	VW	N	
	4.00								136'-136.4' Fracture zone	136.00	J	60	S,R	DS	W	N	
	6.00		R-10	17 28%	0 0%	R4	M										
	7.00																
	5.50	140.0							140.0								
140	1.00	140.0							NO RECOVERY								Highly weathered rock zone.
	0.13																
	0.13		R-11	0 0%	0 0%	-	-										
	0.13																
	0.25	145.0															
145 410	0.50	145.0							NO RECOVERY								Highly weathered rock zone.
	0.25																
	0.10		R-12	0 0%	0 0%	-	-										
	0.50																
	0.75	150.0															
150	0.75	150.0							NO RECOVERY								Highly weathered rock zone.
	0.75																
	0.60		R-13	0 0%	0 0%	-	-										
	0.60																
	1.50	155.0							155.0								
155 400	2.00	155.0							GNEISS, Olive gray, coarse to fine grained, completely weathered, weak, very close to close spaced discontinuities								
	2.00																
	1.00		R-14	21 35%	0 0%	R0	C										
	1.50																
	2.50	160.0															

NOTES: Groundwater was not encountered.

PROJECT NO.: **353754**

Boring No.: **B-I78-3**

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
	1.25	160.0							GNEISS, Olive gray, coarse to fine grained, completely weathered, very weak, very close to close spaced discontinuities								
	1.25																
	1.50		R-15	26 43%	0 0%	R0	C										
	2.00																
	2.00	165.0															
165 390	3.00	165.0							GNEISS, Olive gray to yellowish red, coarse to fine grained, highly weathered, weak, very close to close spaced discontinuities								
	4.00																
	4.00		R-16	33 55%	0 0%	R1	H										
	4.00																
	4.00	170.0							170.0								
170	0.25	170.0							QUARTZITE, Yellowish red, coarse to fine grained, moderately weathered, medium strong, very close to close spaced discontinuities								Loss of water from 170 to 172 feet BGS.
	0.25								171.0 170'-172' Void zone 172'-172.9' Fractured zone	171.40 171.60	J J	60 45	U,R U,R	DS DS	T T	Fe Fe	
	4.00		R-17	44 73%	9 15%	R3	M										
	4.00									173.40	J	70	U,R	DS	T	Fe	
	4.00	175.0															
175 380	1.00	175.0							QUARTZITE, Yellowish red, coarse to fine grained, moderately weathered, medium strong, very close to close spaced discontinuities 175'-176' Fractured zone	176.20 176.60	J J	75 60	S,R U,R	DS DS	PO PO	Fe Fe	
	1.00																
	2.25		R-18	24 40%	9 15%	R3	M										
	5.00																
	5.00	180.0															
180	3.50	180.0							QUARTZITE, Yellowish red, coarse to fine grained, moderately weathered, medium strong, very close to close spaced discontinuities								
	4.00																
	4.50		R-19	34 57%	10 17%	R3	M			181.90 182.10	J J	60 60	U,R U,R	DS DS	PO PO	Fe Fe	
	5.50																
	5.50	185.0															

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
370	1.75	185.0							QUARTZITE, Yellowish red, coarse to fine grained, completely weathered, very weak, very close spaced discontinuities								Loss of water from 185 to 190 feet BGS.
	1.50																
	1.50		R-20	9 15%	0 0%	R0	C										
	1.50																
	1.00	190.0															
190	2.00	190.0							QUARTZITE, Gray, coarse to fine grained, moderately weathered, medium strong, very close to close spaced discontinuities								Soft drilling from 190 to 192 feet BGS.
	2.00									191.20	J	50	U,R	DS	PO	N	
										191.60	J	50	U,R	DS	PO	N	
	2.00		R-21	30 50%	9 15%	R3	M			192.00	J	50	S,R	DS	O	N	
	2.00																
	1.00	195.0															
195 360	2.00	195.0							QUARTZITE, Gray, coarse to fine grained, moderately weathered, medium strong, close to moderately spaced discontinuities	195.70	J	40	U,Sm	DS	PO	N	Rods dropped from 198.5 to 200 feet BGS.
										195.90	J	20	S,R	DS	O	N	
	2.50									196.60	J	20	S,R	DS	O	N	
	2.50		R-22	30 50%	27 45%	R3	M			197.00	J	15	S,R	DS	PO	N	
	2.50																
	0.25	200.0															
200	0.00	200.0							200.0 200' to 204' Void zone.								Rods dropped from 200 to 204 feet BGS.
	0.00																
	0.00		R-23	0 0%	0 0%	-	-										
	0.00																
	1.50	205.0							204.0 Possible highly weathered rock. 205.0								
205 350	4.50	205.0							QUARTZITE, Gray, coarse to fine grained, moderately weathered, medium strong, close spaced discontinuities								
	0.00									206.00	J	40	S,R	DS	O	N	
	1.00		R-24	19 32%	15 25%	R3	M										
	0.25																
	4.25	210.0															

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-I78-3**
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
	3.50	210.0							QUARTZITE, Gray, coarse to fine grained, moderately weathered, medium strong, very close to close spaced discontinuities								
									210'-211' Highly Fractured zone								
	4.50									211.20	J	45	S,R	DS	PO	N	
									213.4'-214.4' Highly Fractured zone	211.60	J	20	U,Sm	DS	O	N	
	5.75		R-25	52 87%	10 17%	R3	M										
										212.80	J	25	U,Sm	DS	PO	N	
	5.75																
	5.00	215.0															
215 340		215.0							QUARTZITE, Gray, coarse to fine grained, fresh, strong, close to moderately spaced discontinuities								
	3.50																
									215'-215.6' Fractured zone								
	4.50									216.40	J	20	U,R	DS	PO	N	
										216.80	J	50	S,R	DS	PO	Fe	
	4.75		R-26	60 100%	51 85%	R2	FR			217.50	J	30	U,R	DS	PO	Fe	
	5.25									218.20	J	30	U,R	DS	PO	N	
										218.60	J	15	U,R	DS	PO	N	
										219.00	J	10	U,R	DS	PO	N	
	5.50	220.0								219.50	J	10	U,R	DS	T	N	
220		220.0							QUARTZITE, Gray, coarse to fine grained, completely weathered, medium strong, very close to close spaced discontinuities								
	1.50																
	1.00																
	1.00		R-27	47 78%	4 7%	R3	C										
	1.00																
	2.00	225.0															
225 330									225.0 End of Boring at 225 feet BGS. Borehole grouted with cement and Bentonite hole plug.								
230																	

NOTES: Groundwater was not encountered.

PROJECT NO.: **353754**

Boring No.: **B-I78-3**

Figure B-I78-3.1
B-I78-3 Box 1 Runs 1-4 Dry

Figure B-I78-3.2
B-I78-3 Box 1 Runs 1-4 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-3

Figure B-I78-3.3
B-I78-3 Box 2 Runs 5-8 Dry

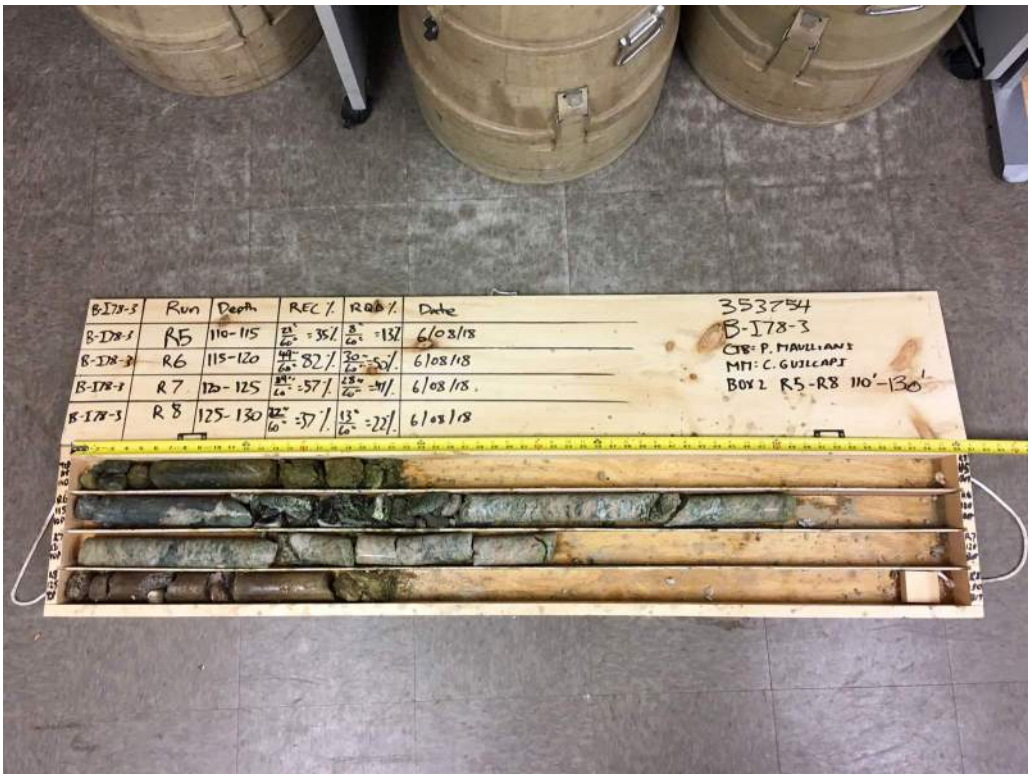


Figure B-I78-3.4
B-I78-3 Box 2 Runs 5-8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-3

Figure B-I78-3.5
B-I78-3 Box 3 Runs 9-12 Dry

Figure B-I78-3.6
B-I78-3 Box 3 Runs 9-12 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-3

Figure B-I78-3.7
B-I78-3 Box 4 Runs 13-16 Dry

Figure B-I78-3.8
B-I78-3 Box 4 Runs 13-16 Wet

Figure B-I78-3.9
B-I78-3 Box 5 Runs 17-20 Dry

Figure B-I78-3.10
B-I78-3 Box 5 Runs 17-20 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-3

Figure B-I78-3.11
B-I78-3 Box 6 Runs 21-24 Dry

Figure B-I78-3.12
B-I78-3 Box 6 Runs 21-24 Wet

Figure B-I78-3.13
B-I78-3 Box 7 Runs 25-27 Dry

Figure B-I78-3.14
B-I78-3 Box 7 Runs 25-27 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-3

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-I78-4**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	B. Kalpouzos, C. Guilcapi
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 13, 2018 at 8:00 am
Driller/Helper:	Paul Mullins /Dalton Lentes	**Date/Time Finished:**	June 19, 2018 at 1:00 pm

Elevation: 616 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** West of Lower Saucon Road **Coord.:** **N:** 40.6300057 **E:** -75.2748901 **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'	18	8 8 8 8		SM	Medium dense, Brownish yellow Silty SAND with Gravel, dry (SM)	-	-	-	-	Installed casing to 5 feet BGS.
						3.5					
5 610	S-2 5.0'- 7.0'	20	4 3 4 4		ML	Medium stiff, Brownish yellow Clayey SILT, trace Sand, moist (ML)	-	-	-	-	
						8.5					
10	S-3 10.0'- 12.0'	12	2 2 4 3		MH	Medium stiff, Reddish brown Sandy SILT with Clay, moist (MH)	-	-	-	-	
						13.5					
15 600	S-4 15.0'- 17.0'	17	3 6 6 6		GM	Medium stiff, Brownish Yellow Sandy GRAVEL with Clay, moist (GM)	-	-	-	-	
						18.5					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
6/15/18	7:00	-		125.0	37.2
6/18/18	7:00	-		170.0	44.3
6/19/18	7:00	-		215.0	41

Sample Type

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

Notes:

PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

Boring No.: **B-I78-4**

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.

MOTT MACDONALD M M

SOIL BORING LOG
(continued)

BORING NO.: **B-I78-4**
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	Field Tests: Toughness	Field Tests: Plasticity	Field Tests: Dry Strength	Remarks
	S-5 20.0'-22.0'	2	50/2"		GP	Very dense, Light brown Sandy GRAVEL, wet (GP)	-	-	-	-	
						23.5					
25	S-6 25.0'-27.0'	8	32 50/3"		SC	Very dense, Brown Clayey SAND with Gravel, dry (SC)	-	-	-	-	
590						28.5					
30	S-7 30.0'-32.0'	1	50/1"		GP	Very dense, Greenish gray Sandy GRAVEL, moist (GP)	-	-	-	-	
						32.0					
						Top of Rock at 32 feet BGS. See Rock Coring Log.					
35											
580											
40											
45											
570											

NOTES: PP = Pocket Penetrometer
TV = Torvane

Groundwater was not encountered.

PROJECT NO.: **353754**

BORING NO.: **B-I78-4**

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-I78-4**
Page **1** of **9**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Interstate 78 Crossing, Hellertown, PA	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	B. Kalpouzos, C. Guilcapi
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	June 13, 2018 at 8:00 am
Driller/Helper:	Paul Mullins /Dalton Lentes	**Date/Time Finished:**	June 19, 2018 at 1:00 pm

Elevation: 616 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** West of Lower Saucon Road **Coord.: N:** 40.6300057 **E:** -75.2748901

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)						
	4.25	32.0							GNEISS, Olive gray, coarse grained, moderately weathered, weak, very close to close spaced discontinuities	32.50	J	0	U,R	DS	PO	N	Drilling was done at 750 PSI. Water return to tub.
	10.0		R-1	24 67%	21 58%	R2	M			33.10	J	0	U,R	DS	T	N	
										33.60	J	10	P,R	DS	O	N	
	2.50	35.0															
35																	
	3.00	35.0							GNEISS, Olive gray, coarse grained, moderately weathered, weak, very close to close spaced discontinuities								
580																	
	2.50								35' - 35.6' Highly Fractured zone	36.10	J	5	U,R	DS	O	Fe	
									36.4' - 37.3' Fractured zone								
	3.25		R-2	44 73%	18 30%	R2	M		35.5' - 38.4' Fractured zone								
	5.25																
	5.40	40.0															
40																	
	6.50	40.0							GNEISS, Olive gray, coarse grained, slightly weathered, weak, very close to close spaced discontinuities								Brief loss of water from 44 to 45 feet BGS.
									40' - 40.5' Fractured zone	41.00	J	20	U,R	DS	T	N	
	4.00									41.20	J	40	U,R	DS	T	Ca	
	3.75		R-3	60 100%	32 53%	R2	SL										
									43.0								
	9.00								GRANITE, Greenish gray to olive gray, medium to coarse grained, slightly weathered, strong, close to moderately spaced discontinuities								
									42' - 43' Fractured zone								
	9.20	45.0							44.5' - 45' Fractured zone								
45																	
	1.80	45.0							GRANITE, Greenish gray to olive gray, coarse grained, moderately weathered, strong, very close to close spaced discontinuities								
									45.7								
570									GNEISS, Olive gray, coarse grained, moderately weathered, medium strong, very close to close spaced discontinuities								
	2.00																
									45' - 46' Highly Fractured zone								
	2.75		R-4	55 92%	12 20%	R4	M		46' - 47.4' Fractured zone	47.10	J	15	U,R	DS	O	N	
										48.00	J	10	U,R	DS	O	N	
	4.00									48.60	J	60	U,R	FR	PO	N	
										49.10	J	20	U,R	DS	O	N	
	5.00	50.0															
50									50.0								
	2.75	50.0							GRANITE, Greenish gray, medium to coarse grained, slightly weathered, strong, close to moderately spaced discontinuities								
	3.75									51.20	J	10	U,R	DS	PO	N	
										51.30	J	10	U,R	DS	PO	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
6/15/18	7:00	-		125.0	37.2
6/18/18	7:00	-		170.0	44.3
6/19/18	7:00	-		215.0	41.0

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 Type	Dip	Rgh	Wea	Aper	Infill	Remarks
										52.00	J	10	U,R	DS	PO	N	
	4.25		R-5	58 97%	46 77%	R4	SL			52.30	J	10	U,R	DS	PO	Ca	
	5.75									53.30	J	60	U,R	DS	PO	N	
	7.75	55.0															
55	4.00	55.0							GRANITE, Greenish gray, medium to coarse grained, slightly weathered, strong, close to moderately spaced discontinuities	55.40	J	10	U,R	DS	PO	N	
560	3.00									56.50	J	15	U,R	DS	PO	N	
	3.75		R-6	60 100%	40 67%	R4	SL										
	2.25								58.5	58.30	J	10	P,R	DS	PO	N	
	2.25	60.0							GNEISS with interbedded Granite, Olive green, coarse grained, slightly weathered, weak, close to moderately spaced discontinuities								
60	3.00	60.0							GNEISS, Olive gray, coarse grained, fresh, medium strong, moderately spaced discontinuities								No water briefly at 60 feet BGS. Rig chatter at 64 - 65 feet BGS.
	3.00									61.30	J	10	U,R	DS	PO	N	
	3.50		R-7	60 100%	60 100%	R3	FR										
	3.50									63.50	J	45	U,R	DS	PO	N	
	3.75	65.0								64.70	J	5	U,R	DS	PO	N	
65	4.00	65.0							GNEISS, Olive gray, coarse grained, fresh, weak, wide spaced discontinuities								
550	3.25																
	3.50		R-8	60 100%	60 100%	R2	FR										
	3.50																
	3.75	70.0															
70	2.00	70.0							GNEISS, Olive gray to brownish yellow, coarse grained, highly weathered, very weak, very close spaced discontinuities								Brief water loss at 75 feet BGS.
	1.50								70' - 72' Highly Fractured zone 72' - 72.8' Fractured zone								
	2.25		R-9	39 65%	0 0%	R1	H										
	2.00																
	3.25	75.0															
75	3.00	75.0							GNEISS, Olive gray, coarse grained, fresh, weak, close to moderately spaced discontinuities 75' - 77.7' Vertical Fracture with calcite infilling								Drilling was done at 800 PSI.
540	3.25																

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
	2.75		R-10	60 100%	28 47%	R2	FR										
	3.75																
	4.00	80.0								79.60	J	15	U,R	FR	PO	N	
80	80.0								GNEISS, Olive gray, coarse grained, fresh, strong, wide spaced discontinuities								
	4.25																
	4.00																
	4.00		R-11	57 95%	55 92%	R4	FR										
	3.75																
	3.75	85.0								84.60	J	30	U,R	FR	O	Ca	
85	85.0								GNEISS with interbedded Granite, Olive gray, coarse grained, fresh, medium strong, very wide spaced discontinuities								Brief water loss at 86 feet BGS.
	3.50																
530	3.00																
	3.50		R-12	60 100%	60 100%	R3	FR										
	4.00																
	4.00	90.0															
90	90.0								Granitic GNEISS, Olive gray, coarse grained, fresh, strong, wide spaced discontinuities								
	4.50																
	4.00																
	5.25		R-13	60 100%	60 100%	R4	FR										
	6.75																
	7.75	95.0								94.30	J	50	U,R	FR	VT	Ca	
95	95.0								Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, wide spaced discontinuities								
	8.50																
520	9.75																
	11.25		R-14	60 100%	60 100%	R5	FR										
	12.25									97.80	J	20	U,R	FR	T	N	
	16.75	100.0								99.50	J	20	U,R	FR	T	N	
100	100.0								Granitic GNEISS, Olive gray, coarse grained, slightly weathered, very strong, moderate spaced discontinuities								
	22.25																
	13.00								100.8'-101.6' 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 (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	6.5		R-15	60 100%	45 75%	R5	SL										
	7.25									103.60	J	70	U,R	FR	T	N	
	8.25	105.0															
105	5.50	105.0							Granitic GNEISS, Olive gray, coarse grained, slightly weathered, strong, moderately spaced discontinuities								
510	5.25																
	5.50		R-16	60 100%	48 80%	R4	SL			107.50	J	70	U,R	FR	T	N	
	8.00									108.40	J	40	U,R	FR	T	N	
										108.80	J	40	U,R	FR	T	N	
	6.25	110.0															
110	5.25	110.0							Granitic GNEISS, Olive gray, coarse grained, slightly weathered, medium strong, close to moderately spaced discontinuities								
									112.9'-113.5' Fractured zone								
	3.50									111.40	J	60	U,R	FR	VT	N	
	3.75		R-17	60 100%	46 77%	R3	SL			112.40	J	20	U,R	FR	T	N	
	3.75																
	3.30	115.0								114.20	J	20	U,R	FR	VT	N	
										114.60	J	20	U,R	FR	T	N	
115	5.50	115.0							Granitic GNEISS, Olive gray, coarse grained, fresh, strong, moderate to close spaced discontinuities								
500	6.25																
	6.50		R-18	60 100%	55 92%	R4	FR										
	9.25																
	11.25	120.0								119.10	J	30	U,R	FR	PO	N	
										119.40	J	20	U,R	FR	PO	N	
120	6.00	120.0							Granitic GNEISS, Olive gray, coarse grained, fresh, strong, moderate to close spaced discontinuities								
	6.25																
	6.50		R-19	60 100%	55 92%	R4	FR			122.10	J	20	U,R	FR	PO	N	
										122.50	J	13	U,R	FR	PO	N	
										123.00	J	30	U,R	FR	PO	N	
	8.00									123.40	J	20	U,R	FR	T	N	
	8.00	125.0								124.60	J	20	U,R	FR	PO	N	
125	8.00	125.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to moderately spaced discontinuities	125.50	J	15	U,R	FR	T	N	
490	6.00									126.30	J	10	U,R	FR	VT	N	

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
	5.75		R-20	60 100%	60 100%	R5	FR			126.80	J	10	U,R	FR	VT	N	
										127.70	J	60	P,R	FR	PO	N	
	5.75									128.50	J	5	U,R	FR	VT	N	
	5.00	130.0								129.30	J	20	U,R	FR	T	N	
130		130.0							Granitic GNEISS, Olive gray, coarse grained, fresh, strong, very close to moderately spaced discontinuities								
	4.75									130.80	J	60	U,R	FR	PO	N	
	4.50									131.80	J	70	U,R	FR	T	N	
	5.00		R-21	60 100%	54 90%	R4	FR			133.00	J	60	S,R	DS	O	N	
	6.00									134.50	J	15	U,R	FR	PO	N	
	6.50	135.0															
135		135.0							Granitic GNEISS with interbedded Granite, Olive gray, coarse grained, fresh, very strong, close to moderately spaced discontinuities								
	7.50									136.10	J	5	U,R	FR	T	N	
480	8.00									138.40	J	35	U,R	FR	PO	N	
	11.75		R-22	60 100%	60 100%	R5	FR			139.40	J	50	U,R	FR	O	N	
	10.00																
	17.00	140.0															
140		140.0							Granitic GNEISS, Olive gray, coarse grained, fresh, strong, close to moderately spaced discontinuities								
	5.50									141.60	J	5	U,R	DS	W	N	
	5.50									142.00	J	10	U,R	FR	PO	N	
	5.00		R-23	60 100%	35 58%	R4	FR			142.50	J	60	U,R	FR	PO	N	
	4.50									143.50	J	55	U,R	FR	O	N	
	5.25									144.00	J	45	U,R	FR	T	N	
		145.0								144.60	J	50	U,R	DS	O	N	
145		145.0							Granitic GNEISS, Olive gray, coarse grained, fresh, strong, close to moderately spaced discontinuities								
	5.00									145.20	J	0	U,R	DS	O	N	
470	7.00									148.10	J	65	U,R	DS	O	N	
	7.25		R-24	60 100%	54 90%	R4	FR			149.40	J	15	U,R	DS	O	N	
	8.00																
	8.00	150.0															
150		150.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to moderately spaced discontinuities								
	5.00								154' - 155' Fractured zone	150.50	J	5	U,R	FR	O	N	
	5.00																

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
	6.25		R-25	60 100%	38 63%	R5	FR										
										152.90	J	20	P,R	FR	O	N	
	6.50									153.20	J	10	U,R	FR	O	N	
	6.50	155.0															
155	5.50	155.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, wide spaced discontinuities								
460	5.50									156.60	J	15	U,R	FR	PO	N	
	5.75		R-26	60 100%	58 97%	R5	FR										
	5.25																
	5.75	160.0															
160	4.50	160.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to moderately spaced discontinuities								
	4.50									161.80	J	25	U,R	FR	PO	N	
	4.75		R-27	60 100%	60 100%	R5	FR			162.70	J	0	U,R	FR	T	N	
	4.75																
	5.50	165.0								164.10	J	10	U,R	FR	T	N	
165	3.00	165.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to wide spaced discontinuities								
450	5.00																
	5.50		R-28	60 100%	60 100%	R5	FR			167.10	J	15	U,R	FR	PO	N	
	5.50																
	6.50	170.0															
170	3.50	170.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to wide spaced discontinuities								
	5.50																
	5.50		R-29	60 100%	52 87%	R5	FR			173.10	J	72	U,R	FR	T	N	
	6.00																
	5.50	175.0								173.80	J	10	U,R	FR	VT	N	
175	4.00	175.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to wide spaced discontinuities								
440	3.00									175.60	J	50	P,R	FR	VT	N	

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
	3.00		R-30	60 100%	55 92%	R5	FR										
	4.00																
	5.00	180.0								178.80	J	30	U,R	FR	PO	N	
180		180.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, wide spaced discontinuities								
	4.50																
	3.25																
	4.50		R-31	60 100%	60 100%	R5	FR										
	2.50									183.20	J	60	P,R	FR	T	N	
	3.75	185.0															
185		185.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to wide spaced discontinuities								
	4.00																
430	4.50																
	4.75		R-32	60 100%	60 100%	R5	FR										
	4.50																
	4.50	190.0															
190		190.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to wide spaced discontinuities								
	3.50																
	5.00																
	4.00		R-33	60 100%	60 100%	R5	FR			192.10	J	20	P,R	FR	T	N	
	6.00																
	6.00	195.0															
195		195.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to moderately spaced discontinuities								
	2.00									195.80	J	65	P,R	FR	T	N	
420	3.00									196.60	J	20	U,R	FR	T	N	
	4.00		R-34	60 100%	52 87%	R5	FR			197.60	J	60	P,R	FR	T	N	
	4.75									198.70	J	70	U,R	FR	T	N	
	13.00	200.0															
200		200.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, wide spaced discontinuities								
	9.00																
	11.00									201.30	J	70	P,R	FR	T	N	

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
	16.50		R-35	60 100%	60 100%	R5	FR										
	21.50																
	34.00	205.0															
205	3.75	205.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to moderately spaced discontinuities	205.60	J	20	P,R	FR	PO	N	
410	4.00																
	4.00		R-36	60 100%	60 100%	R5	FR			207.30	J	90	S,R	FR	T	N	
	4.00																
	5.00	210.0															
210	3.50	210.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to moderately spaced discontinuities	210.60	J	20	P,R	FR	PO	N	
	2.75								210.6' - 211.4' Fracture zone								
	3.00		R-37	60 100%	30 50%	R5	FR										
	2.50									213.60	J	70	U,R	FR	PO	N	
	5.50	215.0															
215	4.50	215.0							Granitic GNEISS, Olive gray to reddish brown, coarse grained, fresh, very strong, close to wide spaced discontinuities								
400	4.00									216.60	J	70	U,R	FR	PO	N	
	4.50		R-38	59 98%	52 87%	R5	FR			217.40	J	60	U,R	FR	O	N	
	4.50									218.70	J	20	U,R	FR	PO	N	
	6.00	220.0															
220	5.50	220.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to wide spaced discontinuities	220.70	J	10	P,R	FR	PO	N	
	7.50																
	10.00		R-39	60 100%	52 87%	R5	FR			222.50	J	10	P,R	FR	O	N	
	11.00																
	12.00	225.0								224.00	J	20	U,R	FR	O	N	
										224.60	J	10	U,R	FR	O	N	
225	4.00	225.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to close spaced discontinuities								
390	3.00									226.00	J	10	U,R	FR	T	N	

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
	4.00		R-40	60 100%	55 92%	R5	FR										
	4.00									228.10	J	20	U,R	FR	T	N	
	4.50	230.0								229.50	J	20	U,R	FR	PO	N	
230	4.00	230.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, wide spaced discontinuities								
	5.00																
	5.50		R-41	58 97%	58 97%	R5	FR			232.00	J	10	U,R	FR	PO	N	
	9.00																
	20.00	235.0															
235	6.00	235.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, close to moderately spaced discontinuities								
380	3.00									236.10	J	10	U,R	FR	T	N	
										236.80	J	10	P,R	FR	T	N	
	3.00		R-42	60 100%	54 90%	R5	FR			238.00	J	10	P,R	FR	T	N	
	4.00																
	5.00	240.0								239.20	J	10	U,R	FR	T	N	
240	8.50	240.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to moderately spaced discontinuities	239.70	J	20	P,R	FR	T	N	Drill bit was changed at 243 feet BGS.
										240.80	J	20	U,R	FR	PO	N	
	13.00									241.40	J	10	U,R	FR	T	N	
	33.00		R-43	60 100%	57 95%	R5	FR			242.80	J	30	U,R	FR	T	N	
	4.50																
	9.75	245.0								244.50	J	10	S,R	FR	T	N	
245	4.00	245.0							Granitic GNEISS, Olive gray, coarse grained, fresh, very strong, very close to moderately spaced discontinuities	245.40	J	20	U,R	FR	PO	N	
370										245.85	J	10	U,R	FR	T	N	
	3.00									246.30	J	30	U,R	FR	T	N	
										246.80	J	10	S,R	FR	PO	N	
	3.00		R-44	60 100%	55 92%	R5	FR			247.60	J	10	P,R	FR	PO	N	
	9.00									248.70	J	10	U,R	FR	PO	N	
	7.00	250.0															
250									250.0 End of Boring at 250 feet BGS. Borehole grouted with cement and bentonite hole plug.								

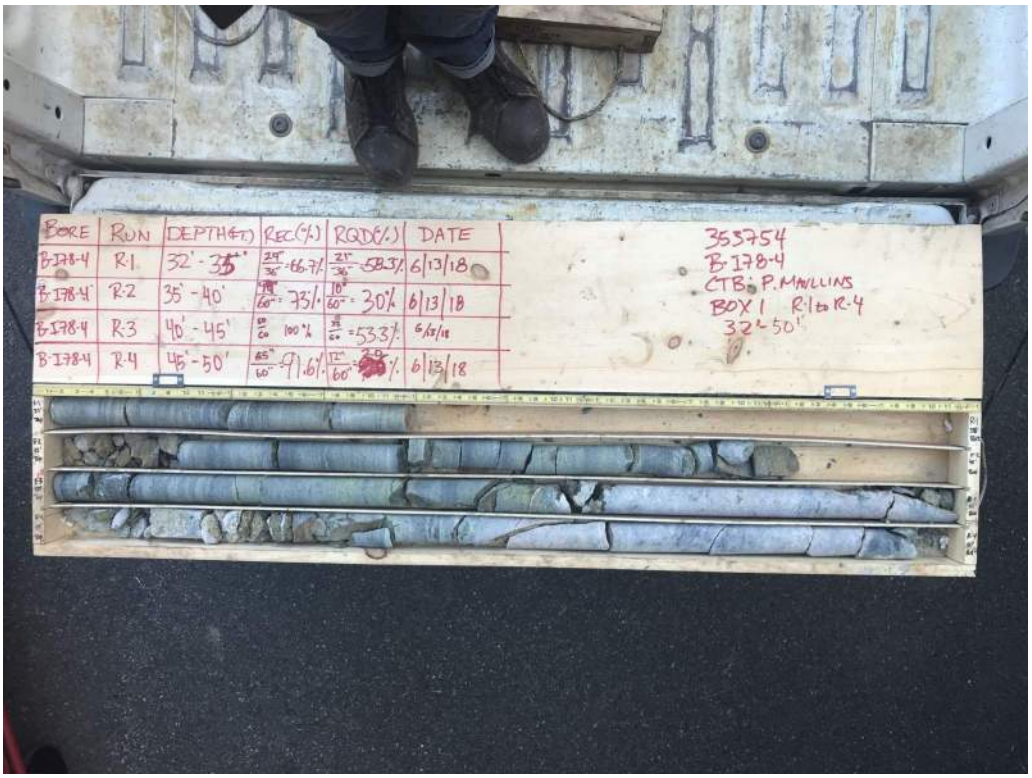


Figure B-I78-4.1
B-I78-4 Box 1 Runs 1-4 Dry

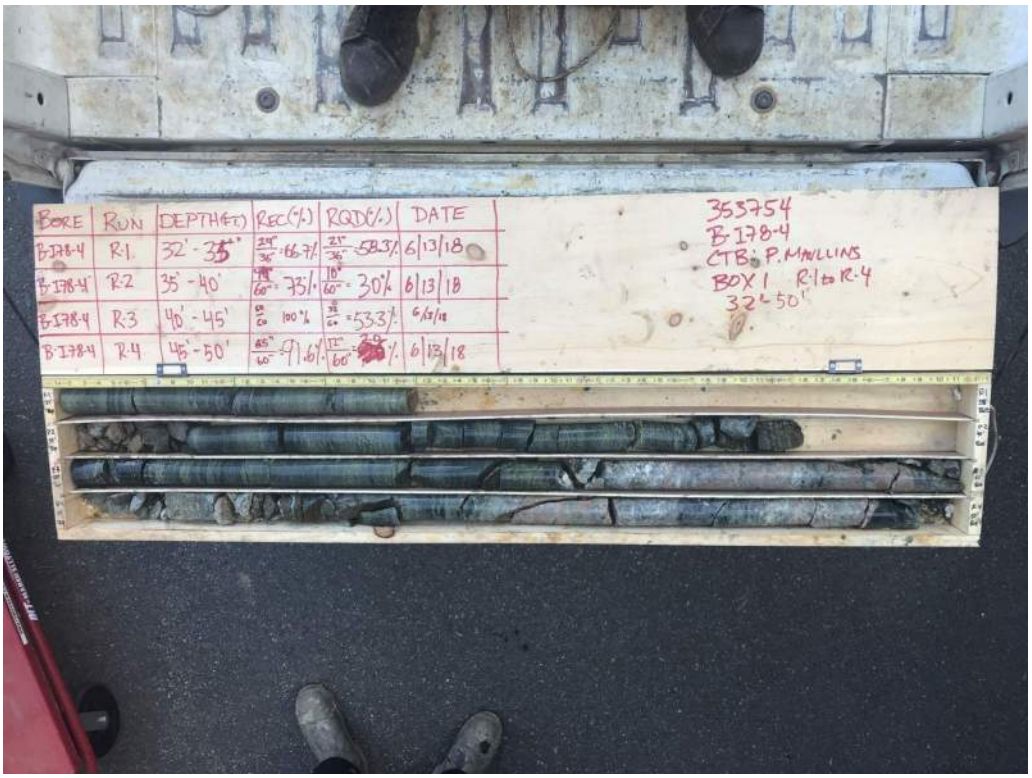


Figure B-I78-4.2
B-I78-4 Box 1 Runs 1-4 Wet

	PennEast Pipeline Project **Rock Core Photographs**	**BORING NO.:** B-I78-4

Figure B-I78-4.3
B-I78-4 Box 2 Runs 5-8 Dry

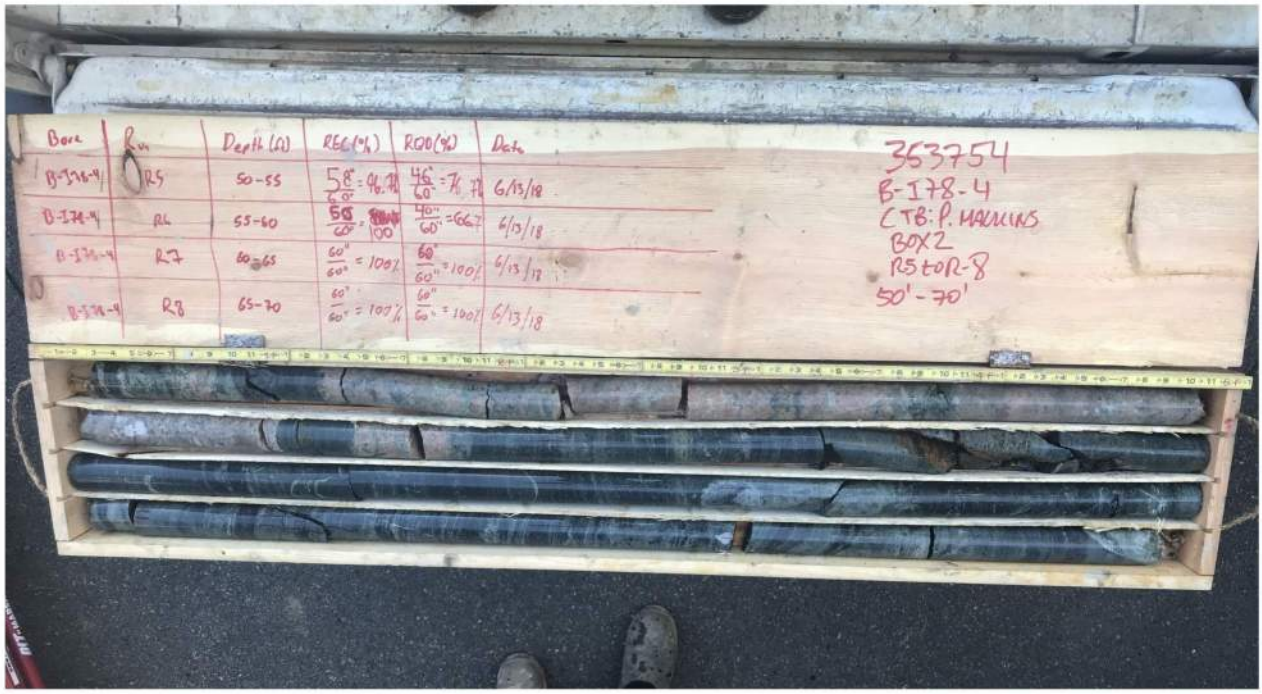


Figure B-I78-4.4
B-I78-4 Box 2 Runs 5-8 Wet

	PennEast Pipeline Project **Rock Core Photographs**	**BORING NO.:** B-I78-4

Figure B-I78-4.5
B-I78-4 Box 3 Runs 9-12 Dry

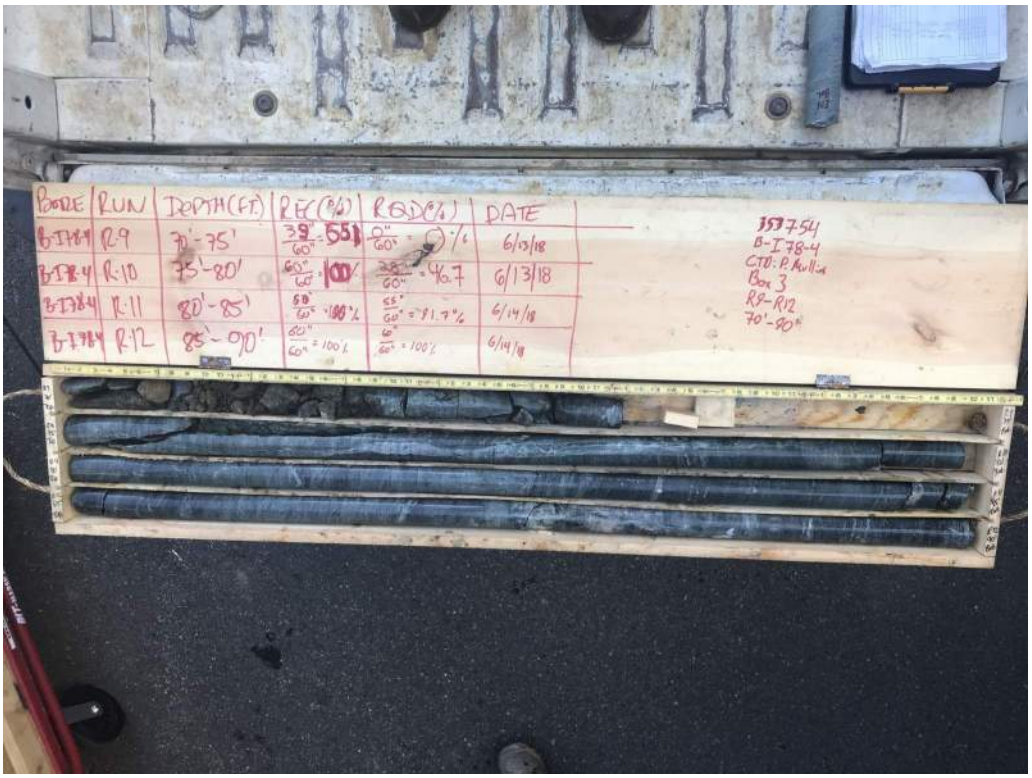


Figure B-I78-4.6
B-I78-4 Box 3 Runs 9-12 Wet

	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-4

Figure B-I78-4.7
B-I78-4 Box 4 Runs 13-16 Dry

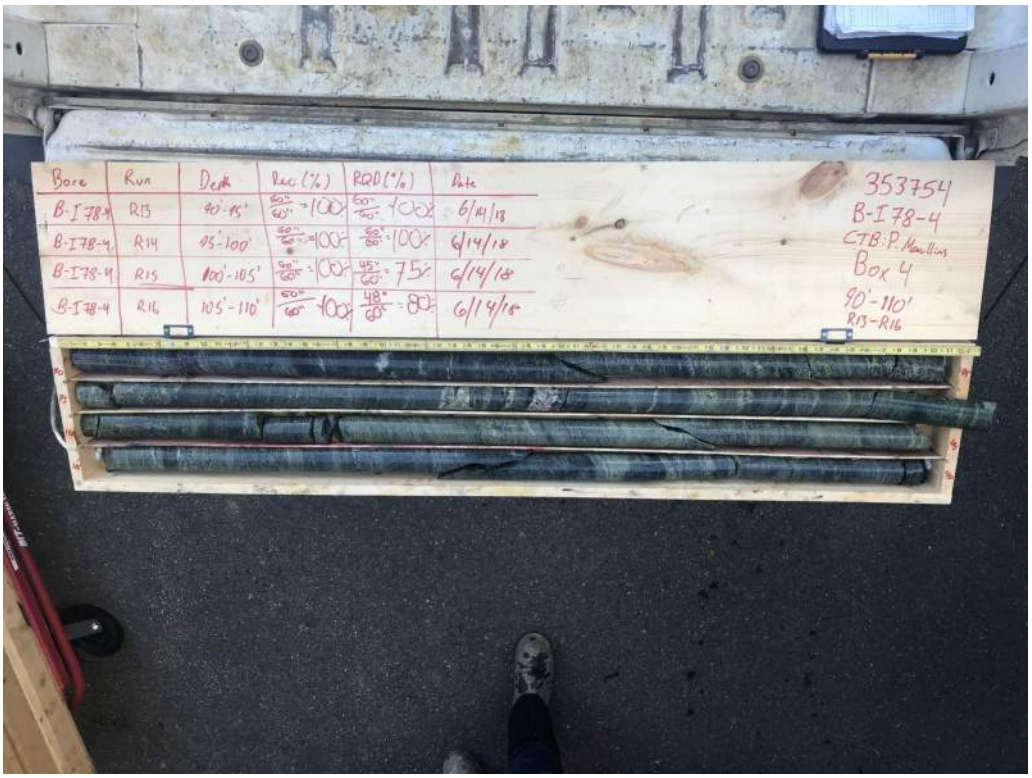


Figure B-I78-4.8
B-I78-4 Box 4 Runs 13-16 Wet

	PennEast Pipeline Project **Rock Core Photographs**	**BORING NO.:** B-I78-4

Figure B-I78-4.9
B-I78-4 Box 5 Runs 17-20 Dry

Figure B-I78-4.10
B-I78-4 Box 5 Runs 17-20 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-4

Figure B-I78-4.11
B-I78-4 Box 6 Runs 21-24 Dry

Figure B-I78-4.12
B-I78-4 Box 6 Runs 21-24 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-I78-4

Figure B-I78-4.13
B-I78-4 Box 7 Runs 25-28 Dry

Figure B-I78-4.14
B-I78-4 Box 7 Runs 25-28 Wet

	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-4

Figure B-I78-4.15
B-I78-4 Box 8 Runs 29-32 Dry

Figure B-I78-4.16
B-I78-4 Box 8 Runs 29-32 Wet

	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-4

Figure B-I78-4.17
B-I78-4 Box 9 Runs 33-36 Dry

Figure B-I78-4.18
B-I78-4 Box 9 Runs 33-36 Wet

	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-I78-4

Figure B-I78-4.19
B-I78-4 Box 10 Runs 37-40 Dry

Figure B-I78-4.20
B-I78-4 Box 10 Runs 37-40 Wet

	PennEast Pipeline Project **Rock Core Photographs**	**BORING NO.:** B-I78-4

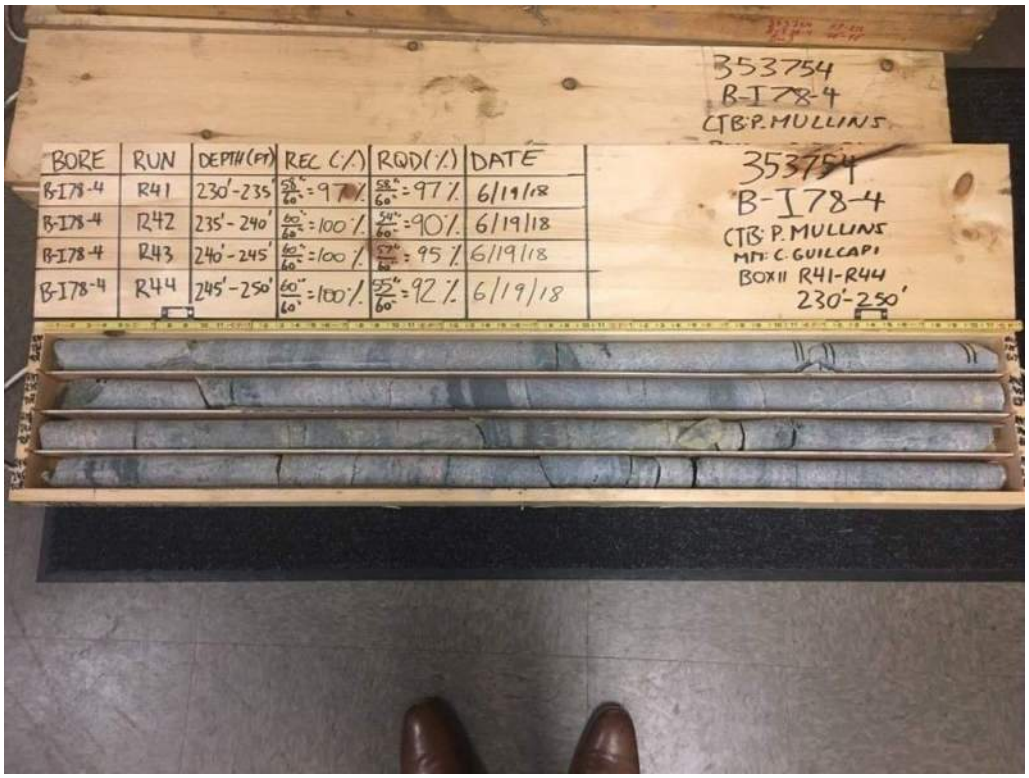


Figure B-I78-4.21
B-I78-4 Box 11 Runs 41-44 Dry

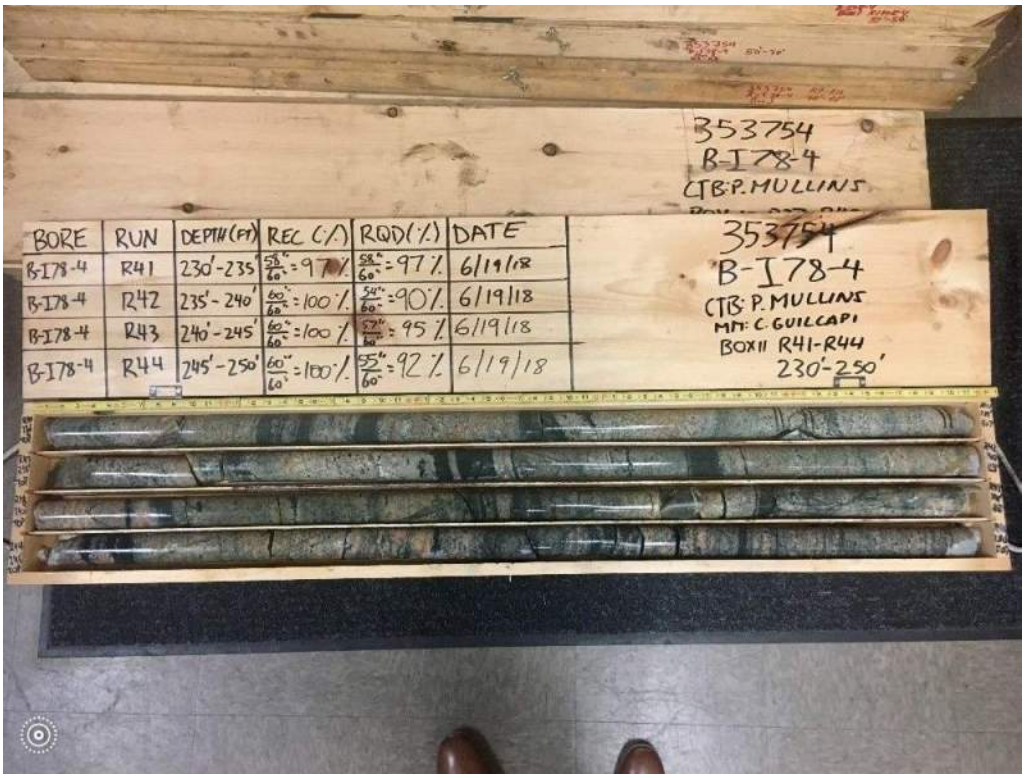


Figure B-I78-4.22
B-I78-4 Box 11 Runs 41-44 Wet

Appendix C

Installation Load and Stress Evaluation

MOTT MACDONALD

Project Name:	PennEast Pipeline	**By:**	M. Lockwood
Project No:	353754	**Checked:**	G. Duyvestyn
HDD Name:	Interstate 78	**Owner:**	PennEast Pipeline
Location:	Mercer County, NJ	**Date:**	10/18/2018

Horizontal Directional Drilling
Minimum Radius Calculations - MAOP Based

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

Project Name: PennEast Pipeline | **By:** M. Lockwood
Project No: 353754 | **Checked:** G. Duyvestyn
HDD Name: Interstate 78 | **Owner:** PennEast Pipeline
Location: Mercer County, NJ | **Date:** 10/18/2018

Horizontal Directional Drilling
Operating Stress Analysis - MAOP Based

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	
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
Temperature Derating Factor	1	

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		55,554	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: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	175,724 lb	**87.9** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	178,908 lb	**89.5** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	184,124 lb	**92.1** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	189,339 lb	**94.7** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	194,555 lb	**97.3** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	199,771 lb	**99.9** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	204,987 lb	**102.5** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	210,203 lb	**105.1** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	215,419 lb	**107.7** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	220,635 lb	**110.3** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	225,851 lb	**112.9** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	231,066 lb	**115.5** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	282,817 lb	**141.4** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	300,131 lb	**150.1** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	293,259 lb	**146.6** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	294,499 lb	**147.2** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	298,900 lb	**149.4** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	304,801 lb	**152.4** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	311,484 lb	**155.7** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	318,583 lb	**159.3** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	325,893 lb	**162.9** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	333,292 lb	**166.6** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	340,700 lb	**170.3** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	348,068 lb	**174.0** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	355,361 lb	**177.7** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	362,559 lb	**181.3** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	369,646 lb	**184.8** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	376,612 lb	**188.3** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	379,703 lb	**189.9** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	382,793 lb	**191.4** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	385,884 lb	**192.9** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	388,974 lb	**194.5** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	392,065 lb	**196.0** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	395,155 lb	**197.6** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	398,245 lb	**199.1** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	401,336 lb	**200.7** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	404,426 lb	**202.2** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	407,517 lb	**203.8** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	410,607 lb	**205.3** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	413,698 lb	**206.8** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	475,198 lb	**237.6** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	487,923 lb	**244.0** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	475,403 lb	**237.7** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	472,631 lb	**236.3** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	473,674 lb	**236.8** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	476,545 lb	**238.3** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	480,388 lb	**240.2** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	484,772 lb	**242.4** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	489,458 lb	**244.7** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	494,301 lb	**247.2** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	499,215 lb	**249.6** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	504,136 lb	**252.1** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	509,030 lb	**254.5** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	513,871 lb	**256.9** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	518,642 lb	**259.3** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	523,331 lb	**261.7** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	523,863 lb	**261.9** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	524,396 lb	**262.2** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	524,928 lb	**262.5** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	525,461 lb	**262.7** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,083	14.36	2.98%	0	0.00	0.00%	97.5	0.67	0.14%	0.04	Yes	0.00	Yes
2,121	14.62	3.03%	0	0.00	0.00%	194.9	1.34	0.28%	0.04	Yes	0.00	Yes
2,183	15.05	3.12%	0	0.00	0.00%	-1,070.8	-7.38	-1.53%	0.04	Yes	0.00	Yes
2,245	15.48	3.21%	0	0.00	0.00%	-973.4	-6.71	-1.39%	0.04	Yes	0.01	Yes
2,306	15.90	3.29%	0	0.00	0.00%	-875.9	-6.04	-1.25%	0.04	Yes	0.01	Yes
2,368	16.33	3.38%	0	0.00	0.00%	-778.5	-5.37	-1.11%	0.04	Yes	0.01	Yes
2,430	16.75	3.47%	0	0.00	0.00%	-681.0	-4.70	-0.97%	0.04	Yes	0.01	Yes
2,492	17.18	3.56%	0	0.00	0.00%	-583.5	-4.02	-0.83%	0.04	Yes	0.01	Yes
2,554	17.61	3.65%	0	0.00	0.00%	-486.1	-3.35	-0.69%	0.05	Yes	0.02	Yes
2,616	18.03	3.74%	0	0.00	0.00%	-388.6	-2.68	-0.56%	0.05	Yes	0.02	Yes
2,677	18.46	3.82%	0	0.00	0.00%	-291.1	-2.01	-0.42%	0.05	Yes	0.02	Yes
2,739	18.89	3.91%	0	0.00	0.00%	-193.7	-1.34	-0.28%	0.05	Yes	0.03	Yes
3,353	23.12	4.79%	12,167	83.89	17.38%	-77.2	-0.53	-0.11%	0.33	Yes	0.13	Yes
3,558	24.53	5.08%	12,167	83.89	17.38%	31.9	0.22	0.05%	0.34	Yes	0.13	Yes
3,476	23.97	4.97%	12,167	83.89	17.38%	133.6	0.92	0.19%	0.33	Yes	0.14	Yes
3,491	24.07	4.99%	12,167	83.89	17.38%	227.8	1.57	0.33%	0.33	Yes	0.15	Yes
3,543	24.43	5.06%	12,167	83.89	17.38%	314.5	2.17	0.45%	0.34	Yes	0.15	Yes
3,613	24.91	5.16%	12,167	83.89	17.38%	393.7	2.71	0.56%	0.34	Yes	0.16	Yes
3,692	25.46	5.27%	12,167	83.89	17.38%	465.4	3.21	0.66%	0.34	Yes	0.17	Yes
3,777	26.04	5.40%	12,167	83.89	17.38%	529.6	3.65	0.76%	0.34	Yes	0.17	Yes
3,863	26.64	5.52%	12,167	83.89	17.38%	586.3	4.04	0.84%	0.34	Yes	0.18	Yes
3,951	27.24	5.64%	12,167	83.89	17.38%	635.4	4.38	0.91%	0.34	Yes	0.18	Yes
4,039	27.85	5.77%	12,167	83.89	17.38%	677.0	4.67	0.97%	0.34	Yes	0.19	Yes
4,126	28.45	5.89%	12,167	83.89	17.38%	711.1	4.90	1.02%	0.35	Yes	0.19	Yes
4,213	29.05	6.02%	12,167	83.89	17.38%	737.6	5.09	1.05%	0.35	Yes	0.19	Yes
4,298	29.63	6.14%	12,167	83.89	17.38%	756.5	5.22	1.08%	0.35	Yes	0.20	Yes
4,382	30.21	6.26%	12,167	83.89	17.38%	767.8	5.29	1.10%	0.35	Yes	0.20	Yes
4,465	30.78	6.38%	12,167	83.89	17.38%	771.6	5.32	1.10%	0.35	Yes	0.20	Yes
4,501	31.03	6.43%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,538	31.29	6.48%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,574	31.54	6.53%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,611	31.79	6.59%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,648	32.05	6.64%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,684	32.30	6.69%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,721	32.55	6.74%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,758	32.80	6.80%	0	0.00	0.00%	771.6	5.32	1.10%	0.08	Yes	0.09	Yes
4,794	33.06	6.85%	0	0.00	0.00%	771.6	5.32	1.10%	0.09	Yes	0.09	Yes
4,831	33.31	6.90%	0	0.00	0.00%	771.6	5.32	1.10%	0.09	Yes	0.09	Yes
4,868	33.56	6.95%	0	0.00	0.00%	771.6	5.32	1.10%	0.09	Yes	0.09	Yes
4,904	33.81	7.01%	0	0.00	0.00%	771.6	5.32	1.10%	0.09	Yes	0.09	Yes
5,633	38.84	8.05%	12,167	83.89	17.38%	769.0	5.30	1.10%	0.37	Yes	0.22	Yes
5,784	39.88	8.26%	12,167	83.89	17.38%	761.1	5.25	1.09%	0.38	Yes	0.22	Yes
5,636	38.86	8.05%	12,167	83.89	17.38%	748.0	5.16	1.07%	0.37	Yes	0.21	Yes
5,603	38.63	8.00%	12,167	83.89	17.38%	729.6	5.03	1.04%	0.37	Yes	0.21	Yes
5,615	38.72	8.02%	12,167	83.89	17.38%	705.9	4.87	1.01%	0.37	Yes	0.21	Yes
5,649	38.95	8.07%	12,167	83.89	17.38%	677.0	4.67	0.97%	0.37	Yes	0.21	Yes
5,695	39.26	8.14%	12,167	83.89	17.38%	642.9	4.43	0.92%	0.37	Yes	0.21	Yes
5,747	39.62	8.21%	12,167	83.89	17.38%	603.5	4.16	0.86%	0.37	Yes	0.20	Yes
5,802	40.01	8.29%	12,167	83.89	17.38%	558.9	3.85	0.80%	0.38	Yes	0.20	Yes
5,860	40.40	8.37%	12,167	83.89	17.38%	509.1	3.51	0.73%	0.38	Yes	0.20	Yes
5,918	40.80	8.45%	12,167	83.89	17.38%	454.0	3.13	0.65%	0.38	Yes	0.19	Yes
5,976	41.21	8.54%	12,167	83.89	17.38%	393.7	2.71	0.56%	0.38	Yes	0.19	Yes
6,034	41.61	8.62%	12,167	83.89	17.38%	328.2	2.26	0.47%	0.38	Yes	0.19	Yes
6,092	42.00	8.70%	12,167	83.89	17.38%	257.5	1.78	0.37%	0.38	Yes	0.18	Yes
6,148	42.39	8.78%	12,167	83.89	17.38%	181.6	1.25	0.26%	0.38	Yes	0.18	Yes
6,204	42.77	8.86%	12,167	83.89	17.38%	100.5	0.69	0.14%	0.38	Yes	0.17	Yes
6,210	42.82	8.87%	0	0.00	0.00%	75.4	0.52	0.11%	0.11	Yes	0.06	Yes
6,216	42.86	8.88%	0	0.00	0.00%	50.3	0.35	0.07%	0.11	Yes	0.05	Yes
6,223	42.90	8.89%	0	0.00	0.00%	25.1	0.17	0.04%	0.11	Yes	0.05	Yes
6,229	42.95	8.90%	0	0.00	0.00%	0.0	0.00	0.00%	0.11	Yes	0.05	Yes

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

Ground Elevation at Pipe Entry	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	525,461	lb	262.7 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		
6,229	42.9	8.90%	12,167	83.9	17.38%	772	5.3	1.10%	0.38	0.22

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	2.92E+07	psi
	201327	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	525,461	lb
	2,337	kN
Factor of Safety	6.7	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	1,050,922	lb
	4,675	kN
Factor of Safety	3.4	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

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

Calculated by: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	171,627 lb	**85.8** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	170,714 lb	**85.4** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	171,170 lb	**85.6** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	171,625 lb	**85.8** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	172,081 lb	**86.0** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	172,537 lb	**86.3** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	172,993 lb	**86.5** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	173,449 lb	**86.7** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	173,905 lb	**87.0** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	174,361 lb	**87.2** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	174,817 lb	**87.4** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	175,273 lb	**87.6** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	221,094 lb	**110.5** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	211,200 lb	**105.6** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	187,935 lb	**94.0** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	172,934 lb	**86.5** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	161,270 lb	**80.6** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	161,985 lb	**81.0** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	165,078 lb	**82.5** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	167,655 lb	**83.8** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	169,906 lb	**85.0** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	171,947 lb	**86.0** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	173,850 lb	**86.9** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	175,664 lb	**87.8** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	177,423 lb	**88.7** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	179,151 lb	**89.6** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	180,865 lb	**90.4** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	182,580 lb	**91.3** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	184,234 lb	**92.1** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	185,888 lb	**92.9** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	187,542 lb	**93.8** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	189,196 lb	**94.6** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	190,849 lb	**95.4** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	192,503 lb	**96.3** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	194,157 lb	**97.1** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	195,811 lb	**97.9** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	197,465 lb	**98.7** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	199,119 lb	**99.6** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	200,773 lb	**100.4** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	202,427 lb	**101.2** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	258,732 lb	**129.4** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	253,116 lb	**126.6** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	229,028 lb	**114.5** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	214,850 lb	**107.4** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	204,671 lb	**102.3** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	196,521 lb	**98.3** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	197,714 lb	**98.9** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	201,671 lb	**100.8** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	205,188 lb	**102.6** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	208,406 lb	**104.2** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	211,413 lb	**105.7** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	214,286 lb	**107.1** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	217,007 lb	**108.5** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	219,665 lb	**109.8** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	222,260 lb	**111.1** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	224,810 lb	**112.4** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	225,690 lb	**112.8** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	226,571 lb	**113.3** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	227,451 lb	**113.7** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	228,331 lb	**114.2** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,035	14.03	2.91%	0	0.00	0.00%	16.2	0.11	0.02%	0.04	Yes	0.00	Yes
2,024	13.95	2.89%	0	0.00	0.00%	32.3	0.22	0.05%	0.04	Yes	0.00	Yes
2,029	13.99	2.90%	0	0.00	0.00%	-177.5	-1.22	-0.25%	0.04	Yes	0.00	Yes
2,035	14.03	2.91%	0	0.00	0.00%	-161.4	-1.11	-0.23%	0.04	Yes	0.00	Yes
2,040	14.06	2.91%	0	0.00	0.00%	-145.2	-1.00	-0.21%	0.04	Yes	0.00	Yes
2,045	14.10	2.92%	0	0.00	0.00%	-129.0	-0.89	-0.18%	0.04	Yes	0.00	Yes
2,051	14.14	2.93%	0	0.00	0.00%	-112.9	-0.78	-0.16%	0.04	Yes	0.00	Yes
2,056	14.18	2.94%	0	0.00	0.00%	-96.7	-0.67	-0.14%	0.04	Yes	0.00	Yes
2,062	14.21	2.95%	0	0.00	0.00%	-80.6	-0.56	-0.12%	0.04	Yes	0.00	Yes
2,067	14.25	2.95%	0	0.00	0.00%	-64.4	-0.44	-0.09%	0.04	Yes	0.00	Yes
2,072	14.29	2.96%	0	0.00	0.00%	-48.3	-0.33	-0.07%	0.04	Yes	0.00	Yes
2,078	14.33	2.97%	0	0.00	0.00%	-32.1	-0.22	-0.05%	0.04	Yes	0.00	Yes
2,621	18.07	3.74%	12,167	83.89	17.38%	-12.8	-0.09	-0.02%	0.32	Yes	0.07	Yes
2,504	17.26	3.58%	12,167	83.89	17.38%	5.3	0.04	0.01%	0.32	Yes	0.07	Yes
2,228	15.36	3.18%	12,167	83.89	17.38%	22.1	0.15	0.03%	0.31	Yes	0.07	Yes
2,050	14.13	2.93%	12,167	83.89	17.38%	37.8	0.26	0.05%	0.31	Yes	0.07	Yes
1,912	13.18	2.73%	12,167	83.89	17.38%	52.1	0.36	0.07%	0.31	Yes	0.07	Yes
1,920	13.24	2.74%	12,167	83.89	17.38%	65.3	0.45	0.09%	0.31	Yes	0.07	Yes
1,957	13.49	2.80%	12,167	83.89	17.38%	77.2	0.53	0.11%	0.31	Yes	0.07	Yes
1,987	13.70	2.84%	12,167	83.89	17.38%	87.8	0.61	0.13%	0.31	Yes	0.07	Yes
2,014	13.89	2.88%	12,167	83.89	17.38%	97.2	0.67	0.14%	0.31	Yes	0.07	Yes
2,038	14.05	2.91%	12,167	83.89	17.38%	105.3	0.73	0.15%	0.31	Yes	0.07	Yes
2,061	14.21	2.94%	12,167	83.89	17.38%	112.2	0.77	0.16%	0.31	Yes	0.07	Yes
2,082	14.36	2.97%	12,167	83.89	17.38%	117.9	0.81	0.17%	0.31	Yes	0.07	Yes
2,103	14.50	3.00%	12,167	83.89	17.38%	122.3	0.84	0.17%	0.31	Yes	0.07	Yes
2,124	14.64	3.03%	12,167	83.89	17.38%	125.4	0.86	0.18%	0.31	Yes	0.07	Yes
2,144	14.78	3.06%	12,167	83.89	17.38%	127.3	0.88	0.18%	0.31	Yes	0.07	Yes
2,164	14.92	3.09%	12,167	83.89	17.38%	127.9	0.88	0.18%	0.31	Yes	0.07	Yes
2,184	15.06	3.12%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,204	15.19	3.15%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,223	15.33	3.18%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,243	15.46	3.20%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,262	15.60	3.23%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,282	15.73	3.26%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,302	15.87	3.29%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,321	16.00	3.32%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,341	16.14	3.34%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,360	16.27	3.37%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,380	16.41	3.40%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
2,400	16.55	3.43%	0	0.00	0.00%	127.9	0.88	0.18%	0.04	Yes	0.00	Yes
3,067	21.15	4.38%	12,167	83.89	17.38%	127.5	0.88	0.18%	0.33	Yes	0.08	Yes
3,001	20.69	4.29%	12,167	83.89	17.38%	126.2	0.87	0.18%	0.33	Yes	0.08	Yes
2,715	18.72	3.88%	12,167	83.89	17.38%	124.0	0.85	0.18%	0.32	Yes	0.08	Yes
2,547	17.56	3.64%	12,167	83.89	17.38%	120.9	0.83	0.17%	0.32	Yes	0.08	Yes
2,426	16.73	3.47%	12,167	83.89	17.38%	117.0	0.81	0.17%	0.32	Yes	0.08	Yes
2,330	16.06	3.33%	12,167	83.89	17.38%	112.2	0.77	0.16%	0.31	Yes	0.07	Yes
2,344	16.16	3.35%	12,167	83.89	17.38%	106.6	0.73	0.15%	0.31	Yes	0.07	Yes
2,391	16.48	3.42%	12,167	83.89	17.38%	100.0	0.69	0.14%	0.31	Yes	0.07	Yes
2,432	16.77	3.47%	12,167	83.89	17.38%	92.7	0.64	0.13%	0.32	Yes	0.07	Yes
2,471	17.03	3.53%	12,167	83.89	17.38%	84.4	0.58	0.12%	0.32	Yes	0.07	Yes
2,506	17.28	3.58%	12,167	83.89	17.38%	75.3	0.52	0.11%	0.32	Yes	0.07	Yes
2,540	17.51	3.63%	12,167	83.89	17.38%	65.3	0.45	0.09%	0.32	Yes	0.07	Yes
2,573	17.74	3.68%	12,167	83.89	17.38%	54.4	0.38	0.08%	0.32	Yes	0.08	Yes
2,604	17.95	3.72%	12,167	83.89	17.38%	42.7	0.29	0.06%	0.32	Yes	0.08	Yes
2,635	18.17	3.76%	12,167	83.89	17.38%	30.1	0.21	0.04%	0.32	Yes	0.08	Yes
2,666	18.37	3.81%	12,167	83.89	17.38%	16.7	0.11	0.02%	0.32	Yes	0.07	Yes
2,675	18.45	3.82%	0	0.00	0.00%	12.5	0.09	0.02%	0.05	Yes	0.00	Yes
2,686	18.52	3.84%	0	0.00	0.00%	8.3	0.06	0.01%	0.05	Yes	0.00	Yes
2,696	18.59	3.85%	0	0.00	0.00%	4.2	0.03	0.01%	0.05	Yes	0.00	Yes
2,707	18.66	3.87%	0	0.00	0.00%	0.0	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	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	258,732	lb	129.4 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		
3,067	21.1	4.38%	12,167	83.9	17.38%	128	0.9	0.18%	0.33	0.08

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	2.92E+07	psi
	201327	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	258,732	lb
	1,151	kN
Factor of Safety	13.7	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	517,464	lb
	2,302	kN
Factor of Safety	6.8	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

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

Calculated by: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	176,737 lb	**88.4** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	180,933 lb	**90.5** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	187,606 lb	**93.8** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	194,279 lb	**97.1** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	200,952 lb	**100.5** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	207,626 lb	**103.8** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	214,299 lb	**107.1** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	220,972 lb	**110.5** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	227,645 lb	**113.8** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	234,318 lb	**117.2** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	240,991 lb	**120.5** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	247,664 lb	**123.8** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	299,810 lb	**149.9** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	321,212 lb	**160.6** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	316,554 lb	**158.3** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	319,982 lb	**160.0** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	326,538 lb	**163.3** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	334,559 lb	**167.3** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	343,320 lb	**171.7** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	352,453 lb	**176.2** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	361,754 lb	**180.9** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	371,097 lb	**185.5** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	380,405 lb	**190.2** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	389,630 lb	**194.8** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	398,739 lb	**199.4** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	407,713 lb	**203.9** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	416,538 lb	**208.3** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	425,208 lb	**212.6** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	429,261 lb	**214.6** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	433,315 lb	**216.7** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	437,369 lb	**218.7** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	441,423 lb	**220.7** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	445,476 lb	**222.7** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	449,530 lb	**224.8** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	453,584 lb	**226.8** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	457,638 lb	**228.8** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	461,692 lb	**230.8** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	465,745 lb	**232.9** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	469,799 lb	**234.9** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	473,853 lb	**236.9** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	535,756 lb	**267.9** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	551,599 lb	**275.8** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	540,805 lb	**270.4** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	539,726 lb	**269.9** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	542,425 lb	**271.2** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	546,910 lb	**273.5** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	552,323 lb	**276.2** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	558,233 lb	**279.1** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	564,400 lb	**282.2** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	570,682 lb	**285.3** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	576,993 lb	**288.5** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	583,275 lb	**291.6** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	589,495 lb	**294.7** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	595,628 lb	**297.8** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	601,661 lb	**300.8** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	607,583 lb	**303.8** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	608,329 lb	**304.2** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	609,076 lb	**304.5** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	609,823 lb	**304.9** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	610,570 lb	**305.3** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,095	14.45	2.99%	0	0.00	0.00%	107.2	0.74	0.15%	0.04	Yes	0.00	Yes
2,145	14.79	3.06%	0	0.00	0.00%	214.4	1.48	0.31%	0.04	Yes	0.00	Yes
2,224	15.33	3.18%	0	0.00	0.00%	-1,177.9	-8.12	-1.68%	0.04	Yes	0.00	Yes
2,303	15.88	3.29%	0	0.00	0.00%	-1,070.7	-7.38	-1.53%	0.04	Yes	0.01	Yes
2,382	16.42	3.40%	0	0.00	0.00%	-963.5	-6.64	-1.38%	0.04	Yes	0.01	Yes
2,461	16.97	3.52%	0	0.00	0.00%	-856.3	-5.90	-1.22%	0.04	Yes	0.01	Yes
2,540	17.52	3.63%	0	0.00	0.00%	-749.1	-5.16	-1.07%	0.05	Yes	0.01	Yes
2,620	18.06	3.74%	0	0.00	0.00%	-641.9	-4.43	-0.92%	0.05	Yes	0.02	Yes
2,699	18.61	3.86%	0	0.00	0.00%	-534.7	-3.69	-0.76%	0.05	Yes	0.02	Yes
2,778	19.15	3.97%	0	0.00	0.00%	-427.5	-2.95	-0.61%	0.05	Yes	0.02	Yes
2,857	19.70	4.08%	0	0.00	0.00%	-320.3	-2.21	-0.46%	0.05	Yes	0.03	Yes
2,936	20.24	4.19%	0	0.00	0.00%	-213.0	-1.47	-0.30%	0.05	Yes	0.03	Yes
3,554	24.50	5.08%	12,167	83.89	17.38%	-84.9	-0.59	-0.12%	0.34	Yes	0.14	Yes
3,808	26.25	5.44%	12,167	83.89	17.38%	35.1	0.24	0.05%	0.34	Yes	0.15	Yes
3,753	25.87	5.36%	12,167	83.89	17.38%	146.9	1.01	0.21%	0.34	Yes	0.15	Yes
3,793	26.15	5.42%	12,167	83.89	17.38%	250.5	1.73	0.36%	0.34	Yes	0.16	Yes
3,871	26.69	5.53%	12,167	83.89	17.38%	345.9	2.39	0.49%	0.34	Yes	0.17	Yes
3,966	27.34	5.67%	12,167	83.89	17.38%	433.1	2.99	0.62%	0.34	Yes	0.18	Yes
4,070	28.06	5.81%	12,167	83.89	17.38%	512.0	3.53	0.73%	0.34	Yes	0.19	Yes
4,178	28.81	5.97%	12,167	83.89	17.38%	582.6	4.02	0.83%	0.35	Yes	0.19	Yes
4,288	29.57	6.13%	12,167	83.89	17.38%	644.9	4.45	0.92%	0.35	Yes	0.20	Yes
4,399	30.33	6.28%	12,167	83.89	17.38%	699.0	4.82	1.00%	0.35	Yes	0.21	Yes
4,510	31.09	6.44%	12,167	83.89	17.38%	744.7	5.13	1.06%	0.35	Yes	0.21	Yes
4,619	31.85	6.60%	12,167	83.89	17.38%	782.2	5.39	1.12%	0.35	Yes	0.22	Yes
4,727	32.59	6.75%	12,167	83.89	17.38%	811.3	5.59	1.16%	0.36	Yes	0.22	Yes
4,833	33.32	6.90%	12,167	83.89	17.38%	832.1	5.74	1.19%	0.36	Yes	0.22	Yes
4,938	34.05	7.05%	12,167	83.89	17.38%	844.6	5.82	1.21%	0.36	Yes	0.23	Yes
5,041	34.75	7.20%	12,167	83.89	17.38%	848.8	5.85	1.21%	0.36	Yes	0.23	Yes
5,089	35.09	7.27%	0	0.00	0.00%	848.8	5.85	1.21%	0.09	Yes	0.11	Yes
5,137	35.42	7.34%	0	0.00	0.00%	848.8	5.85	1.21%	0.09	Yes	0.11	Yes
5,185	35.75	7.41%	0	0.00	0.00%	848.8	5.85	1.21%	0.09	Yes	0.11	Yes
5,233	36.08	7.48%	0	0.00	0.00%	848.8	5.85	1.21%	0.09	Yes	0.11	Yes
5,281	36.41	7.54%	0	0.00	0.00%	848.8	5.85	1.21%	0.09	Yes	0.11	Yes
5,329	36.74	7.61%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,377	37.07	7.68%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,425	37.40	7.75%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,473	37.74	7.82%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,521	38.07	7.89%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,569	38.40	7.96%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
5,617	38.73	8.02%	0	0.00	0.00%	848.8	5.85	1.21%	0.10	Yes	0.11	Yes
6,351	43.79	9.07%	12,167	83.89	17.38%	845.9	5.83	1.21%	0.39	Yes	0.25	Yes
6,539	45.08	9.34%	12,167	83.89	17.38%	837.2	5.77	1.20%	0.39	Yes	0.25	Yes
6,411	44.20	9.16%	12,167	83.89	17.38%	822.8	5.67	1.18%	0.39	Yes	0.24	Yes
6,398	44.11	9.14%	12,167	83.89	17.38%	802.5	5.53	1.15%	0.39	Yes	0.24	Yes
6,430	44.33	9.19%	12,167	83.89	17.38%	776.5	5.35	1.11%	0.39	Yes	0.24	Yes
6,483	44.70	9.26%	12,167	83.89	17.38%	744.7	5.13	1.06%	0.39	Yes	0.24	Yes
6,548	45.14	9.35%	12,167	83.89	17.38%	707.2	4.88	1.01%	0.39	Yes	0.24	Yes
6,618	45.63	9.45%	12,167	83.89	17.38%	663.9	4.58	0.95%	0.39	Yes	0.23	Yes
6,691	46.13	9.56%	12,167	83.89	17.38%	614.8	4.24	0.88%	0.39	Yes	0.23	Yes
6,765	46.64	9.66%	12,167	83.89	17.38%	560.0	3.86	0.80%	0.39	Yes	0.23	Yes
6,840	47.16	9.77%	12,167	83.89	17.38%	499.4	3.44	0.71%	0.39	Yes	0.22	Yes
6,914	47.67	9.88%	12,167	83.89	17.38%	433.1	2.99	0.62%	0.40	Yes	0.22	Yes
6,988	48.18	9.98%	12,167	83.89	17.38%	361.0	2.49	0.52%	0.40	Yes	0.21	Yes
7,061	48.68	10.09%	12,167	83.89	17.38%	283.3	1.95	0.40%	0.40	Yes	0.21	Yes
7,132	49.18	10.19%	12,167	83.89	17.38%	199.8	1.38	0.29%	0.40	Yes	0.20	Yes
7,203	49.66	10.29%	12,167	83.89	17.38%	110.6	0.76	0.16%	0.40	Yes	0.20	Yes
7,211	49.72	10.30%	0	0.00	0.00%	82.9	0.57	0.12%	0.13	Yes	0.07	Yes
7,220	49.78	10.31%	0	0.00	0.00%	55.3	0.38	0.08%	0.13	Yes	0.07	Yes
7,229	49.84	10.33%	0	0.00	0.00%	27.6	0.19	0.04%	0.13	Yes	0.07	Yes
7,238	49.90	10.34%	0	0.00	0.00%	0.0	0.00	0.00%	0.13	Yes	0.07	Yes

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

Ground Elevation at Pipe Entry	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	610,570	lb	305.3 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		
7,238	49.9	10.34%	12,167	83.9	17.38%	849	5.9	1.21%	0.40	0.25

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	2.92E+07	psi
	201327	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	610,570	lb
	2,716	kN
Factor of Safety	5.8	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	1,221,139	lb
	5,432	kN
Factor of Safety	2.9	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

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

Calculated by: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	171,454 lb	**85.7** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	170,368 lb	**85.2** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	170,207 lb	**85.1** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	170,045 lb	**85.0** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	169,884 lb	**84.9** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	169,723 lb	**84.9** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	169,561 lb	**84.8** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	169,400 lb	**84.7** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	169,238 lb	**84.6** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	169,077 lb	**84.5** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	168,916 lb	**84.5** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	168,754 lb	**84.4** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	215,913 lb	**108.0** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	208,784 lb	**104.4** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	187,548 lb	**93.8** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	174,558 lb	**87.3** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	164,886 lb	**82.4** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	156,892 lb	**78.4** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	150,830 lb	**75.4** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	152,238 lb	**76.1** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	153,310 lb	**76.7** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	154,162 lb	**77.1** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	154,867 lb	**77.4** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	155,474 lb	**77.7** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	156,016 lb	**78.0** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	156,517 lb	**78.3** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	156,996 lb	**78.5** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	157,465 lb	**78.7** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	158,155 lb	**79.1** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	158,846 lb	**79.4** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	159,536 lb	**79.8** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	160,227 lb	**80.1** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	160,918 lb	**80.5** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	161,608 lb	**80.8** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	162,299 lb	**81.1** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	162,990 lb	**81.5** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	163,680 lb	**81.8** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	164,371 lb	**82.2** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	165,061 lb	**82.5** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	165,752 lb	**82.9** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	223,090 lb	**111.5** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	218,630 lb	**109.3** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	195,608 lb	**97.8** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	182,477 lb	**91.2** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	173,321 lb	**86.7** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	166,173 lb	**83.1** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	160,186 lb	**80.1** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	155,782 lb	**77.9** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	158,123 lb	**79.1** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	160,161 lb	**80.1** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	161,986 lb	**81.0** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	163,656 lb	**81.8** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	165,212 lb	**82.6** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	166,683 lb	**83.3** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	168,090 lb	**84.0** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	169,449 lb	**84.7** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	169,898 lb	**84.9** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	170,348 lb	**85.2** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	170,798 lb	**85.4** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	171,247 lb	**85.6** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,033	14.01	2.90%	0	0.00	0.00%	25.9	0.18	0.04%	0.04	Yes	0.00	Yes
2,020	13.92	2.89%	0	0.00	0.00%	51.8	0.36	0.07%	0.04	Yes	0.00	Yes
2,018	13.91	2.88%	0	0.00	0.00%	-284.6	-1.96	-0.41%	0.04	Yes	0.00	Yes
2,016	13.90	2.88%	0	0.00	0.00%	-258.7	-1.78	-0.37%	0.04	Yes	0.00	Yes
2,014	13.89	2.88%	0	0.00	0.00%	-232.8	-1.61	-0.33%	0.04	Yes	0.00	Yes
2,012	13.87	2.87%	0	0.00	0.00%	-206.9	-1.43	-0.30%	0.04	Yes	0.00	Yes
2,010	13.86	2.87%	0	0.00	0.00%	-181.0	-1.25	-0.26%	0.04	Yes	0.00	Yes
2,008	13.85	2.87%	0	0.00	0.00%	-155.1	-1.07	-0.22%	0.04	Yes	0.00	Yes
2,006	13.83	2.87%	0	0.00	0.00%	-129.2	-0.89	-0.18%	0.04	Yes	0.00	Yes
2,004	13.82	2.86%	0	0.00	0.00%	-103.3	-0.71	-0.15%	0.04	Yes	0.00	Yes
2,002	13.81	2.86%	0	0.00	0.00%	-77.4	-0.53	-0.11%	0.04	Yes	0.00	Yes
2,000	13.79	2.86%	0	0.00	0.00%	-51.5	-0.35	-0.07%	0.04	Yes	0.00	Yes
2,560	17.65	3.66%	12,167	83.89	17.38%	-20.5	-0.14	-0.03%	0.32	Yes	0.08	Yes
2,475	17.06	3.54%	12,167	83.89	17.38%	8.5	0.06	0.01%	0.32	Yes	0.08	Yes
2,223	15.33	3.18%	12,167	83.89	17.38%	35.5	0.24	0.05%	0.31	Yes	0.07	Yes
2,069	14.27	2.96%	12,167	83.89	17.38%	60.5	0.42	0.09%	0.31	Yes	0.07	Yes
1,955	13.48	2.79%	12,167	83.89	17.38%	83.6	0.58	0.12%	0.31	Yes	0.07	Yes
1,860	12.82	2.66%	12,167	83.89	17.38%	104.6	0.72	0.15%	0.31	Yes	0.07	Yes
1,788	12.33	2.55%	12,167	83.89	17.38%	123.7	0.85	0.18%	0.30	Yes	0.07	Yes
1,805	12.44	2.58%	12,167	83.89	17.38%	140.8	0.97	0.20%	0.30	Yes	0.07	Yes
1,817	12.53	2.60%	12,167	83.89	17.38%	155.8	1.07	0.22%	0.30	Yes	0.07	Yes
1,828	12.60	2.61%	12,167	83.89	17.38%	168.9	1.16	0.24%	0.30	Yes	0.08	Yes
1,836	12.66	2.62%	12,167	83.89	17.38%	179.9	1.24	0.26%	0.31	Yes	0.08	Yes
1,843	12.71	2.63%	12,167	83.89	17.38%	189.0	1.30	0.27%	0.31	Yes	0.08	Yes
1,849	12.75	2.64%	12,167	83.89	17.38%	196.0	1.35	0.28%	0.31	Yes	0.08	Yes
1,855	12.79	2.65%	12,167	83.89	17.38%	201.1	1.39	0.29%	0.31	Yes	0.08	Yes
1,861	12.83	2.66%	12,167	83.89	17.38%	204.1	1.41	0.29%	0.31	Yes	0.08	Yes
1,867	12.87	2.67%	12,167	83.89	17.38%	205.1	1.41	0.29%	0.31	Yes	0.08	Yes
1,875	12.93	2.68%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,883	12.98	2.69%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,891	13.04	2.70%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,899	13.10	2.71%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,908	13.15	2.73%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,916	13.21	2.74%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,924	13.27	2.75%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,932	13.32	2.76%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,940	13.38	2.77%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,949	13.43	2.78%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,957	13.49	2.80%	0	0.00	0.00%	205.1	1.41	0.29%	0.03	Yes	0.01	Yes
1,965	13.55	2.81%	0	0.00	0.00%	205.1	1.41	0.29%	0.04	Yes	0.01	Yes
2,645	18.23	3.78%	12,167	83.89	17.38%	204.4	1.41	0.29%	0.32	Yes	0.08	Yes
2,592	17.87	3.70%	12,167	83.89	17.38%	202.3	1.39	0.29%	0.32	Yes	0.08	Yes
2,319	15.99	3.31%	12,167	83.89	17.38%	198.8	1.37	0.28%	0.31	Yes	0.08	Yes
2,163	14.91	3.09%	12,167	83.89	17.38%	193.9	1.34	0.28%	0.31	Yes	0.08	Yes
2,055	14.17	2.94%	12,167	83.89	17.38%	187.6	1.29	0.27%	0.31	Yes	0.08	Yes
1,970	13.58	2.81%	12,167	83.89	17.38%	179.9	1.24	0.26%	0.31	Yes	0.08	Yes
1,899	13.09	2.71%	12,167	83.89	17.38%	170.9	1.18	0.24%	0.31	Yes	0.08	Yes
1,847	12.73	2.64%	12,167	83.89	17.38%	160.4	1.11	0.23%	0.31	Yes	0.07	Yes
1,874	12.92	2.68%	12,167	83.89	17.38%	148.5	1.02	0.21%	0.31	Yes	0.07	Yes
1,899	13.09	2.71%	12,167	83.89	17.38%	135.3	0.93	0.19%	0.31	Yes	0.07	Yes
1,920	13.24	2.74%	12,167	83.89	17.38%	120.7	0.83	0.17%	0.31	Yes	0.07	Yes
1,940	13.38	2.77%	12,167	83.89	17.38%	104.6	0.72	0.15%	0.31	Yes	0.07	Yes
1,959	13.50	2.80%	12,167	83.89	17.38%	87.2	0.60	0.12%	0.31	Yes	0.07	Yes
1,976	13.62	2.82%	12,167	83.89	17.38%	68.4	0.47	0.10%	0.31	Yes	0.07	Yes
1,993	13.74	2.85%	12,167	83.89	17.38%	48.3	0.33	0.07%	0.31	Yes	0.07	Yes
2,009	13.85	2.87%	12,167	83.89	17.38%	26.7	0.18	0.04%	0.31	Yes	0.07	Yes
2,014	13.89	2.88%	0	0.00	0.00%	20.0	0.14	0.03%	0.04	Yes	0.00	Yes
2,019	13.92	2.88%	0	0.00	0.00%	13.4	0.09	0.02%	0.04	Yes	0.00	Yes
2,025	13.96	2.89%	0	0.00	0.00%	6.7	0.05	0.01%	0.04	Yes	0.00	Yes
2,030	14.00	2.90%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	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	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	223,090	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		
2,645	18.2	3.78%	12,167	83.9	17.38%	205	1.4	0.29%	0.32	0.08

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	2.92E+07	psi
	201327	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	223,090	lb
	992	kN
Factor of Safety	15.9	
Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	446,180	lb
	1,985	kN
Factor of Safety	7.9	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

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

Calculated by: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	177,749 lb	**88.9** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	182,958 lb	**91.5** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	191,089 lb	**95.5** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	199,219 lb	**99.6** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	207,350 lb	**103.7** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	215,480 lb	**107.7** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	223,610 lb	**111.8** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	231,741 lb	**115.9** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	239,871 lb	**119.9** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	248,002 lb	**124.0** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	256,132 lb	**128.1** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	264,262 lb	**132.1** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	316,804 lb	**158.4** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	342,292 lb	**171.1** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	339,847 lb	**169.9** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	345,458 lb	**172.7** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	354,165 lb	**177.1** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	364,296 lb	**182.1** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	375,125 lb	**187.6** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	386,280 lb	**193.1** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	397,556 lb	**198.8** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	408,827 lb	**204.4** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	420,019 lb	**210.0** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	431,084 lb	**215.5** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	441,991 lb	**221.0** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	452,724 lb	**226.4** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	463,272 lb	**231.6** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	473,630 lb	**236.8** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	478,647 lb	**239.3** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	483,664 lb	**241.8** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	488,681 lb	**244.3** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	493,698 lb	**246.8** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	498,715 lb	**249.4** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	503,733 lb	**251.9** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	508,750 lb	**254.4** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	513,767 lb	**256.9** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	518,784 lb	**259.4** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	523,801 lb	**261.9** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	528,818 lb	**264.4** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	533,835 lb	**266.9** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	596,140 lb	**298.1** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	615,097 lb	**307.5** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	606,024 lb	**303.0** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	606,632 lb	**303.3** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	610,975 lb	**305.5** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	617,060 lb	**308.5** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	624,027 lb	**312.0** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	631,444 lb	**315.7** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	639,072 lb	**319.5** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	646,773 lb	**323.4** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	654,461 lb	**327.2** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	662,085 lb	**331.0** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	669,612 lb	**334.8** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	677,021 lb	**338.5** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	684,301 lb	**342.2** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	691,443 lb	**345.7** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	692,404 lb	**346.2** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	693,365 lb	**346.7** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	694,326 lb	**347.2** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	695,286 lb	**347.6** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,107	14.53	3.01%	0	0.00	0.00%	117.0	0.81	0.17%	0.04	Yes	0.00	Yes
2,169	14.95	3.10%	0	0.00	0.00%	233.9	1.61	0.33%	0.04	Yes	0.00	Yes
2,265	15.62	3.24%	0	0.00	0.00%	-1,285.0	-8.86	-1.84%	0.04	Yes	0.00	Yes
2,362	16.28	3.37%	0	0.00	0.00%	-1,168.1	-8.05	-1.67%	0.04	Yes	0.01	Yes
2,458	16.95	3.51%	0	0.00	0.00%	-1,051.1	-7.25	-1.50%	0.04	Yes	0.01	Yes
2,554	17.61	3.65%	0	0.00	0.00%	-934.1	-6.44	-1.33%	0.05	Yes	0.01	Yes
2,651	18.28	3.79%	0	0.00	0.00%	-817.2	-5.63	-1.17%	0.05	Yes	0.02	Yes
2,747	18.94	3.92%	0	0.00	0.00%	-700.2	-4.83	-1.00%	0.05	Yes	0.02	Yes
2,844	19.61	4.06%	0	0.00	0.00%	-583.3	-4.02	-0.83%	0.05	Yes	0.02	Yes
2,940	20.27	4.20%	0	0.00	0.00%	-466.3	-3.22	-0.67%	0.05	Yes	0.03	Yes
3,036	20.93	4.34%	0	0.00	0.00%	-349.4	-2.41	-0.50%	0.05	Yes	0.03	Yes
3,133	21.60	4.48%	0	0.00	0.00%	-232.4	-1.60	-0.33%	0.06	Yes	0.04	Yes
3,756	25.89	5.37%	12,167	83.89	17.38%	-92.6	-0.64	-0.13%	0.34	Yes	0.15	Yes
4,058	27.98	5.80%	12,167	83.89	17.38%	38.3	0.26	0.05%	0.34	Yes	0.16	Yes
4,029	27.78	5.76%	12,167	83.89	17.38%	160.3	1.11	0.23%	0.34	Yes	0.17	Yes
4,095	28.24	5.85%	12,167	83.89	17.38%	273.3	1.88	0.39%	0.35	Yes	0.18	Yes
4,198	28.95	6.00%	12,167	83.89	17.38%	377.4	2.60	0.54%	0.35	Yes	0.19	Yes
4,319	29.78	6.17%	12,167	83.89	17.38%	472.4	3.26	0.67%	0.35	Yes	0.20	Yes
4,447	30.66	6.35%	12,167	83.89	17.38%	558.5	3.85	0.80%	0.35	Yes	0.21	Yes
4,579	31.57	6.54%	12,167	83.89	17.38%	635.6	4.38	0.91%	0.35	Yes	0.21	Yes
4,713	32.49	6.73%	12,167	83.89	17.38%	703.6	4.85	1.01%	0.36	Yes	0.22	Yes
4,846	33.42	6.92%	12,167	83.89	17.38%	762.5	5.26	1.09%	0.36	Yes	0.23	Yes
4,979	34.33	7.11%	12,167	83.89	17.38%	812.4	5.60	1.16%	0.36	Yes	0.24	Yes
5,110	35.23	7.30%	12,167	83.89	17.38%	853.3	5.88	1.22%	0.36	Yes	0.24	Yes
5,240	36.13	7.49%	12,167	83.89	17.38%	885.1	6.10	1.26%	0.37	Yes	0.25	Yes
5,367	37.00	7.67%	12,167	83.89	17.38%	907.8	6.26	1.30%	0.37	Yes	0.25	Yes
5,492	37.87	7.85%	12,167	83.89	17.38%	921.4	6.35	1.32%	0.37	Yes	0.26	Yes
5,615	38.71	8.02%	12,167	83.89	17.38%	925.9	6.38	1.32%	0.37	Yes	0.26	Yes
5,674	39.12	8.11%	0	0.00	0.00%	925.9	6.38	1.32%	0.10	Yes	0.13	Yes
5,734	39.53	8.19%	0	0.00	0.00%	925.9	6.38	1.32%	0.10	Yes	0.13	Yes
5,793	39.94	8.28%	0	0.00	0.00%	925.9	6.38	1.32%	0.10	Yes	0.13	Yes
5,853	40.35	8.36%	0	0.00	0.00%	925.9	6.38	1.32%	0.10	Yes	0.13	Yes
5,912	40.76	8.45%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.13	Yes
5,972	41.17	8.53%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,031	41.58	8.62%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,090	41.99	8.70%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,150	42.40	8.79%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,209	42.81	8.87%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,269	43.22	8.96%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
6,328	43.63	9.04%	0	0.00	0.00%	925.9	6.38	1.32%	0.11	Yes	0.14	Yes
7,067	48.72	10.10%	12,167	83.89	17.38%	922.8	6.36	1.32%	0.40	Yes	0.28	Yes
7,292	50.27	10.42%	12,167	83.89	17.38%	913.3	6.30	1.30%	0.40	Yes	0.28	Yes
7,184	49.53	10.26%	12,167	83.89	17.38%	897.6	6.19	1.28%	0.40	Yes	0.28	Yes
7,191	49.58	10.27%	12,167	83.89	17.38%	875.5	6.04	1.25%	0.40	Yes	0.28	Yes
7,243	49.94	10.35%	12,167	83.89	17.38%	847.1	5.84	1.21%	0.40	Yes	0.27	Yes
7,315	50.43	10.45%	12,167	83.89	17.38%	812.4	5.60	1.16%	0.40	Yes	0.27	Yes
7,398	51.00	10.57%	12,167	83.89	17.38%	771.5	5.32	1.10%	0.40	Yes	0.27	Yes
7,485	51.61	10.69%	12,167	83.89	17.38%	724.2	4.99	1.03%	0.41	Yes	0.26	Yes
7,576	52.23	10.82%	12,167	83.89	17.38%	670.7	4.62	0.96%	0.41	Yes	0.26	Yes
7,667	52.86	10.95%	12,167	83.89	17.38%	610.9	4.21	0.87%	0.41	Yes	0.26	Yes
7,758	53.49	11.08%	12,167	83.89	17.38%	544.8	3.76	0.78%	0.41	Yes	0.25	Yes
7,849	54.11	11.21%	12,167	83.89	17.38%	472.4	3.26	0.67%	0.41	Yes	0.25	Yes
7,938	54.73	11.34%	12,167	83.89	17.38%	393.9	2.72	0.56%	0.41	Yes	0.24	Yes
8,026	55.34	11.47%	12,167	83.89	17.38%	309.0	2.13	0.44%	0.42	Yes	0.23	Yes
8,112	55.93	11.59%	12,167	83.89	17.38%	217.9	1.50	0.31%	0.42	Yes	0.23	Yes
8,197	56.51	11.71%	12,167	83.89	17.38%	120.6	0.83	0.17%	0.42	Yes	0.22	Yes
8,208	56.59	11.73%	0	0.00	0.00%	90.5	0.62	0.13%	0.15	Yes	0.09	Yes
8,220	56.67	11.74%	0	0.00	0.00%	60.3	0.42	0.09%	0.15	Yes	0.08	Yes
8,231	56.75	11.76%	0	0.00	0.00%	30.2	0.21	0.04%	0.15	Yes	0.08	Yes
8,242	56.83	11.77%	0	0.00	0.00%	0.0	0.00	0.00%	0.15	Yes	0.08	Yes

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

Ground Elevation at Pipe Entry	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	695,286	lb	347.6 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		
8,242	56.8	11.77%	12,167	83.9	17.38%	926	6.4	1.32%	0.42	0.28

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	2.92E+07	psi
	201327	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	695,286	lb
	3,093	kN
Factor of Safety	5.1	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	1,390,573	lb
	6,186	kN
Factor of Safety	2.5	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

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

Calculated by: Matthew Lockwood
Checked by: Glenn Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

HDD CROSSING LOCATION: I-78 HDD Crossing

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		3805+00	115+978	0.0	0.0	583.1	177.7	--	--		172,540 lb	**86.3** tons
straight		3804+63	115+966	38.2	11.6	575.2	175.3	60.0	1524.0	0.3	171,281 lb	**85.6** tons
straight		3804+25	115+955	76.4	23.3	567.2	172.9	60.0	1524.0	0.3	170,023 lb	**85.0** tons
straight		3803+88	115+944	114.6	34.9	559.3	170.5	60.0	1524.0	0.3	169,244 lb	**84.6** tons
straight		3803+51	115+932	152.8	46.6	551.4	168.1	60.0	1524.0	0.3	168,465 lb	**84.2** tons
straight		3803+13	115+921	191.0	58.2	543.4	165.6	60.0	1524.0	0.3	167,686 lb	**83.8** tons
straight		3802+76	115+909	229.2	69.9	535.5	163.2	60.0	1524.0	0.3	166,908 lb	**83.5** tons
straight		3802+38	115+898	267.4	81.5	527.5	160.8	60.0	1524.0	0.3	166,129 lb	**83.1** tons
straight		3802+01	115+887	305.6	93.2	519.6	158.4	60.0	1524.0	0.3	165,350 lb	**82.7** tons
straight		3801+64	115+875	343.8	104.8	511.6	155.9	60.0	1524.0	0.3	164,572 lb	**82.3** tons
straight		3801+26	115+864	382.0	116.4	503.7	153.5	60.0	1524.0	0.3	163,793 lb	**81.9** tons
straight		3800+89	115+853	420.2	128.1	495.8	151.1	60.0	1524.0	0.3	163,014 lb	**81.5** tons
straight		3800+52	115+841	458.4	139.7	487.8	148.7	60.0	1524.0	0.3	162,235 lb	**81.1** tons
curve	vertical	3800+05	115+827	505.6	154.1	478.3	145.8	60.0	1524.0	0.3	210,732 lb	**105.4** tons
curve	vertical	3799+59	115+813	552.7	168.5	469.4	143.1	60.0	1524.0	0.3	206,368 lb	**103.2** tons
curve	vertical	3799+13	115+799	599.8	182.8	461.1	140.6	60.0	1524.0	0.3	187,161 lb	**93.6** tons
curve	vertical	3798+66	115+785	646.9	197.2	453.5	138.2	60.0	1524.0	0.3	176,183 lb	**88.1** tons
curve	vertical	3798+20	115+770	694.1	211.6	446.4	136.1	60.0	1524.0	0.3	168,502 lb	**84.3** tons
curve	vertical	3797+73	115+756	741.2	225.9	439.9	134.1	60.0	1524.0	0.3	162,479 lb	**81.2** tons
curve	vertical	3797+26	115+742	788.3	240.3	434.1	132.3	60.0	1524.0	0.3	157,409 lb	**78.7** tons
curve	vertical	3796+79	115+728	835.4	254.6	428.9	130.7	60.0	1524.0	0.3	152,942 lb	**76.5** tons
curve	vertical	3796+33	115+713	882.6	269.0	424.2	129.3	60.0	1524.0	0.3	148,883 lb	**74.4** tons
curve	vertical	3795+86	115+699	929.7	283.4	420.2	128.1	60.0	1524.0	0.3	145,114 lb	**72.6** tons
curve	vertical	3795+39	115+685	976.8	297.7	416.8	127.1	60.0	1524.0	0.3	141,564 lb	**70.8** tons
curve	vertical	3794+92	115+670	1,023.9	312.1	414.1	126.2	60.0	1524.0	0.3	138,181 lb	**69.1** tons
curve	vertical	3794+44	115+656	1,071.1	326.5	411.9	125.6	60.0	1524.0	0.3	134,932 lb	**67.5** tons
curve	vertical	3793+97	115+642	1,118.2	340.8	410.4	125.1	60.0	1524.0	0.3	133,789 lb	**66.9** tons
curve	vertical	3793+50	115+627	1,165.3	355.2	409.4	124.8	60.0	1524.0	0.3	133,014 lb	**66.5** tons
curve	vertical	3793+03	115+613	1,212.4	369.6	409.1	124.7	60.0	1524.0	0.3	132,218 lb	**66.1** tons
straight		3792+68	115+602	1,247.1	380.1	409.1	124.7	60.0	1524.0	0.3	131,945 lb	**66.0** tons
straight		3792+34	115+592	1,281.8	390.7	409.1	124.7	60.0	1524.0	0.3	131,673 lb	**65.8** tons
straight		3791+99	115+581	1,316.5	401.3	409.1	124.7	60.0	1524.0	0.3	131,400 lb	**65.7** tons
straight		3791+64	115+571	1,351.2	411.9	409.1	124.7	60.0	1524.0	0.3	131,127 lb	**65.6** tons
straight		3791+30	115+560	1,385.9	422.4	409.1	124.7	60.0	1524.0	0.3	130,855 lb	**65.4** tons
straight		3790+95	115+550	1,420.6	433.0	409.1	124.7	60.0	1524.0	0.3	130,582 lb	**65.3** tons
straight		3790+60	115+539	1,455.3	443.6	409.1	124.7	60.0	1524.0	0.3	130,309 lb	**65.2** tons
straight		3790+25	115+528	1,490.1	454.2	409.1	124.7	60.0	1524.0	0.3	130,037 lb	**65.0** tons
straight		3789+91	115+518	1,524.8	464.8	409.1	124.7	60.0	1524.0	0.3	129,764 lb	**64.9** tons
straight		3789+56	115+507	1,559.5	475.3	409.1	124.7	60.0	1524.0	0.3	129,491 lb	**64.7** tons
straight		3789+21	115+497	1,594.2	485.9	409.1	124.7	60.0	1524.0	0.3	129,219 lb	**64.6** tons
straight		3788+87	115+486	1,628.9	496.5	409.1	124.7	60.0	1524.0	0.3	128,946 lb	**64.5** tons
curve	vertical	3788+47	115+474	1,668.1	508.5	409.4	124.8	60.0	1524.0	0.3	187,316 lb	**93.7** tons
curve	vertical	3788+08	115+462	1,707.4	520.4	410.0	125.0	60.0	1524.0	0.3	184,011 lb	**92.0** tons
curve	vertical	3787+69	115+450	1,746.7	532.4	411.1	125.3	60.0	1524.0	0.3	162,056 lb	**81.0** tons
curve	vertical	3787+30	115+438	1,785.9	544.4	412.6	125.8	60.0	1524.0	0.3	149,973 lb	**75.0** tons
curve	vertical	3786+90	115+426	1,825.2	556.3	414.5	126.3	60.0	1524.0	0.3	141,846 lb	**70.9** tons
curve	vertical	3786+51	115+414	1,864.5	568.3	416.8	127.1	60.0	1524.0	0.3	135,703 lb	**67.9** tons
curve	vertical	3786+12	115+402	1,903.8	580.3	419.6	127.9	60.0	1524.0	0.3	130,701 lb	**65.4** tons
curve	vertical	3785+73	115+390	1,943.0	592.2	422.8	128.9	60.0	1524.0	0.3	126,417 lb	**63.2** tons
curve	vertical	3785+34	115+379	1,982.3	604.2	426.5	130.0	60.0	1524.0	0.3	122,617 lb	**61.3** tons
curve	vertical	3784+95	115+367	2,021.6	616.2	430.5	131.2	60.0	1524.0	0.3	119,160 lb	**59.6** tons
curve	vertical	3784+56	115+355	2,060.8	628.2	435.0	132.6	60.0	1524.0	0.3	115,959 lb	**58.0** tons
curve	vertical	3784+17	115+343	2,100.1	640.1	439.9	134.1	60.0	1524.0	0.3	112,953 lb	**56.5** tons
curve	vertical	3783+78	115+331	2,139.4	652.1	445.3	135.7	60.0	1524.0	0.3	113,156 lb	**56.6** tons
curve	vertical	3783+39	115+319	2,178.6	664.1	451.0	137.5	60.0	1524.0	0.3	113,414 lb	**56.7** tons
curve	vertical	3783+00	115+307	2,217.9	676.0	457.2	139.4	60.0	1524.0	0.3	113,605 lb	**56.8** tons
curve	vertical	3782+62	115+296	2,257.2	688.0	463.8	141.4	60.0	1524.0	0.3	113,745 lb	**56.9** tons
straight		3782+50	115+292	2,269.0	691.6	465.9	142.0	60.0	1524.0	0.3	113,764 lb	**56.9** tons
straight		3782+38	115+288	2,280.8	695.2	467.9	142.6	60.0	1524.0	0.3	113,783 lb	**56.9** tons
straight		3782+27	115+285	2,292.6	698.8	470.0	143.3	60.0	1524.0	0.3	113,801 lb	**56.9** tons
HDD Rig Location		3782+15	115+281	2,304.4	702.4	472.0	143.9	60.0	1524.0	0.3	113,820 lb	**56.9** 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				
2,045	14.10	2.92%	0	0.00	0.00%	0.0	0.00	0.00%	0.04	Yes	0.00	Yes
2,030	14.00	2.90%	0	0.00	0.00%	35.6	0.25	0.05%	0.04	Yes	0.00	Yes
2,016	13.90	2.88%	0	0.00	0.00%	71.3	0.49	0.10%	0.04	Yes	0.00	Yes
2,006	13.83	2.87%	0	0.00	0.00%	-391.7	-2.70	-0.56%	0.04	Yes	0.00	Yes
1,997	13.77	2.85%	0	0.00	0.00%	-356.0	-2.45	-0.51%	0.04	Yes	0.00	Yes
1,988	13.71	2.84%	0	0.00	0.00%	-320.4	-2.21	-0.46%	0.04	Yes	0.00	Yes
1,979	13.64	2.83%	0	0.00	0.00%	-284.7	-1.96	-0.41%	0.04	Yes	0.00	Yes
1,969	13.58	2.81%	0	0.00	0.00%	-249.1	-1.72	-0.36%	0.04	Yes	0.00	Yes
1,960	13.51	2.80%	0	0.00	0.00%	-213.4	-1.47	-0.30%	0.04	Yes	0.00	Yes
1,951	13.45	2.79%	0	0.00	0.00%	-177.8	-1.23	-0.25%	0.03	Yes	0.00	Yes
1,942	13.39	2.77%	0	0.00	0.00%	-142.1	-0.98	-0.20%	0.03	Yes	0.00	Yes
1,932	13.32	2.76%	0	0.00	0.00%	-106.5	-0.73	-0.15%	0.03	Yes	0.00	Yes
1,923	13.26	2.75%	0	0.00	0.00%	-70.8	-0.49	-0.10%	0.03	Yes	0.01	Yes
2,498	17.22	3.57%	12,167	83.89	17.38%	-28.2	-0.19	-0.04%	0.32	Yes	0.08	Yes
2,446	16.87	3.49%	12,167	83.89	17.38%	11.7	0.08	0.02%	0.32	Yes	0.08	Yes
2,219	15.30	3.17%	12,167	83.89	17.38%	48.9	0.34	0.07%	0.31	Yes	0.08	Yes
2,089	14.40	2.98%	12,167	83.89	17.38%	83.3	0.57	0.12%	0.31	Yes	0.08	Yes
1,998	13.77	2.85%	12,167	83.89	17.38%	115.0	0.79	0.16%	0.31	Yes	0.08	Yes
1,926	13.28	2.75%	12,167	83.89	17.38%	144.0	0.99	0.21%	0.31	Yes	0.08	Yes
1,866	12.87	2.67%	12,167	83.89	17.38%	170.2	1.17	0.24%	0.31	Yes	0.08	Yes
1,813	12.50	2.59%	12,167	83.89	17.38%	193.7	1.34	0.28%	0.30	Yes	0.08	Yes
1,765	12.17	2.52%	12,167	83.89	17.38%	214.5	1.48	0.31%	0.30	Yes	0.08	Yes
1,720	11.86	2.46%	12,167	83.89	17.38%	232.4	1.60	0.33%	0.30	Yes	0.08	Yes
1,678	11.57	2.40%	12,167	83.89	17.38%	247.6	1.71	0.35%	0.30	Yes	0.08	Yes
1,638	11.29	2.34%	12,167	83.89	17.38%	260.1	1.79	0.37%	0.30	Yes	0.08	Yes
1,600	11.03	2.29%	12,167	83.89	17.38%	269.8	1.86	0.39%	0.30	Yes	0.08	Yes
1,586	10.94	2.27%	12,167	83.89	17.38%	276.7	1.91	0.40%	0.30	Yes	0.08	Yes
1,577	10.87	2.25%	12,167	83.89	17.38%	280.9	1.94	0.40%	0.30	Yes	0.08	Yes
1,567	10.81	2.24%	12,167	83.89	17.38%	282.2	1.95	0.40%	0.30	Yes	0.08	Yes
1,564	10.78	2.23%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,561	10.76	2.23%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,558	10.74	2.23%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,554	10.72	2.22%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,551	10.70	2.22%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,548	10.67	2.21%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,545	10.65	2.21%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,542	10.63	2.20%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,538	10.61	2.20%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,535	10.58	2.19%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,532	10.56	2.19%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
1,529	10.54	2.18%	0	0.00	0.00%	282.2	1.95	0.40%	0.03	Yes	0.01	Yes
2,221	15.31	3.17%	12,167	83.89	17.38%	281.3	1.94	0.40%	0.31	Yes	0.09	Yes
2,181	15.04	3.12%	12,167	83.89	17.38%	278.4	1.92	0.40%	0.31	Yes	0.09	Yes
1,921	13.25	2.74%	12,167	83.89	17.38%	273.6	1.89	0.39%	0.31	Yes	0.08	Yes
1,778	12.26	2.54%	12,167	83.89	17.38%	266.9	1.84	0.38%	0.30	Yes	0.08	Yes
1,682	11.59	2.40%	12,167	83.89	17.38%	258.2	1.78	0.37%	0.30	Yes	0.08	Yes
1,609	11.09	2.30%	12,167	83.89	17.38%	247.6	1.71	0.35%	0.30	Yes	0.08	Yes
1,549	10.68	2.21%	12,167	83.89	17.38%	235.2	1.62	0.34%	0.30	Yes	0.08	Yes
1,499	10.33	2.14%	12,167	83.89	17.38%	220.8	1.52	0.32%	0.30	Yes	0.08	Yes
1,454	10.02	2.08%	12,167	83.89	17.38%	204.4	1.41	0.29%	0.30	Yes	0.08	Yes
1,413	9.74	2.02%	12,167	83.89	17.38%	186.2	1.28	0.27%	0.30	Yes	0.08	Yes
1,375	9.48	1.96%	12,167	83.89	17.38%	166.1	1.14	0.24%	0.30	Yes	0.08	Yes
1,339	9.23	1.91%	12,167	83.89	17.38%	144.0	0.99	0.21%	0.30	Yes	0.07	Yes
1,341	9.25	1.92%	12,167	83.89	17.38%	120.1	0.83	0.17%	0.30	Yes	0.07	Yes
1,344	9.27	1.92%	12,167	83.89	17.38%	94.2	0.65	0.13%	0.30	Yes	0.07	Yes
1,347	9.29	1.92%	12,167	83.89	17.38%	66.4	0.46	0.09%	0.30	Yes	0.07	Yes
1,348	9.30	1.93%	12,167	83.89	17.38%	36.8	0.25	0.05%	0.30	Yes	0.07	Yes
1,349	9.30	1.93%	0	0.00	0.00%	27.6	0.19	0.04%	0.02	Yes	0.01	Yes
1,349	9.30	1.93%	0	0.00	0.00%	18.4	0.13	0.03%	0.02	Yes	0.01	Yes
1,349	9.30	1.93%	0	0.00	0.00%	9.2	0.06	0.01%	0.02	Yes	0.01	Yes
1,349	9.30	1.93%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	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	583.12	feet
	177.74	metres
Ground Elevation at Pipe Exit	472.03	feet
	143.87	metres

	TOTAL PULL LOADS		
Maximum Values	210,732	lb	105.4 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		
2,498	17.2	3.57%	12,167	83.9	17.38%	282	1.9	0.40%	0.32	0.09

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	2.92E+07	psi
	201327	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	210,732	lb
	937	kN
Factor of Safety	16.8	

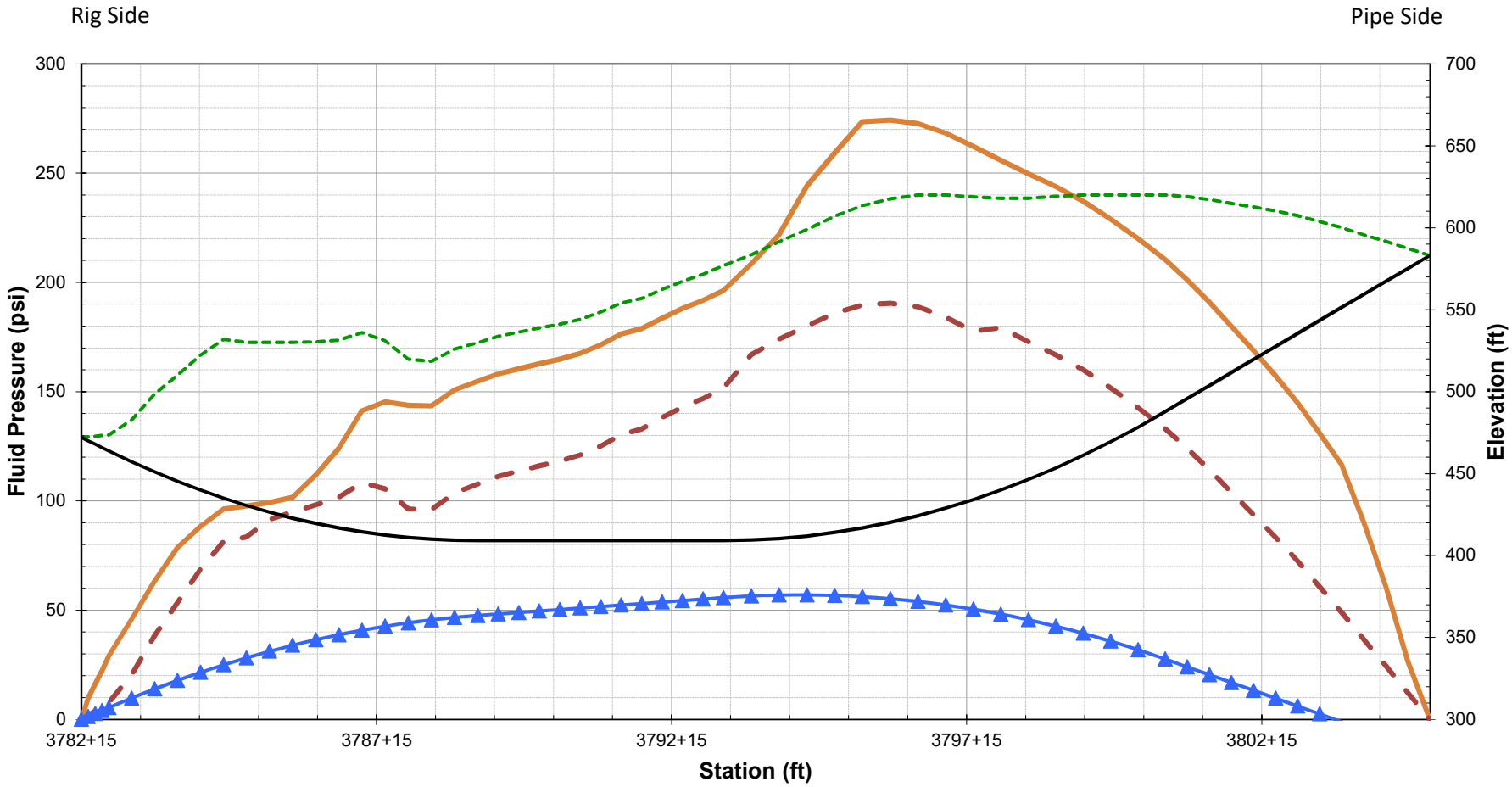
Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	421,463	lb
	1,875	kN
Factor of Safety	8.4	

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)	0.25	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	829	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	3.137	m^3/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

Appendix D

Hydraulic Fracture Evaluation



Crossing Length (ft)	2,284.9
Bore Diameter (in)	12.250
Drill Pipe O.D. (in)	6.625
Drilling Fluid Weight (ppg)	10.5
Plastic Viscosity (cP)	13
Yield Point (lb/100SF)	21

MOTT MACDONALD

Horizontal Directional Drilling
Drilling Fluid Hydraulic Fracture Calculations

Calculated by: M/ Lockwood
Checked by: G. Duyvestyn
Date: 10/18/2018
Project No: 353754

PROJECT: PennEast Pipeline Project

CROSSING LOCATION: I-78 HDD Crossing

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	Soil Type 1	Soil Type 2	Soil Type 3	Soil Type 4	Soil Type 5
c, soil effective cohesion (psf)	2000	0	0		
c, soil effective cohesion (N/m^2 or Pa)	95,761	0	0	0	0
ϕ, soil internal friction angle (deg)	0.0	18.0	26.0		
ϕ, soil internal friction angle (rad)	0.00	0.31	0.45	0.0	0.0
Equivalent 'SPT Blow Count N60 (blows per 12 inch)	12				
E , Young's Modulus based on blow count (lb/ft^2)	360,000	0	0	0	0
E , Young's Modulus (kPa)	17,250	30,000	45,000		
E , Young's Modulus (lb/ft^2)	360,274	626,563	939,844	0	0
ν , Poisson's ratio	0.30	0.30	0.30	0.30	0.30
G, soil shear modulus (ksf)	139	241	361	0	0
G, soil shear modulus (kPa)	6,635	11,538	17,308	0	0
G, soil shear modulus (Pa)	6,634,615	11,538,462	17,307,692	0	0
γ, soil total unit weight (pcf) below water table	125	135	145		
γ, soil total unit weight (kN/m^3) below water table	19.6	21.2	22.8	0.0	0.0
γ, soil total unit weight (pcf) above water table	115	130	140		
γ, soil total unit weight (kN/m^3) above water table	18.1	20.4	22.0	0.0	0.0
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	no	yes or no
Target Drill and Intersect Location		input stationing in feet (do not enter + sign)
	0+000	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	472.0	feet
	143.9	metre
Drill Rig #2 Elevation (Pipe Entry Location)	N/A	feet
	N/A	metre
Recommended Allowable Pressure Factor	2.00	
Total Horizontal Installation Length	2,284.9	feet
	696.5	metre
True Installation Length	2,304.4	feet
	702.4	metre
Pilot Bore Diameter	12.250	inch
	311.15	mm
Drill Pipe Diameter	6.625	inch
	168.28	mm
Yield Point	21	lb/100ft^2
Plastic Viscosity	13	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	0.020	psi per ft of bore
	0.135	kPa per metre of bore
	0.588	psi per 30 ft drill pipe
Drilling Fluid Mud Weight	10.5	ppg
	78.5	lb/ft^3
	1.26	specific gravity

Note: Stationing should be at least every 200 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	Theoretical Unfactored 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	3782+15	115+281	0.0	0.0	472.0	143.9	472.0	143.9	432.0	0.0	0.0	0.0	Type 1	0.0	0.0	0.00	0.0	--	0.00	0.00	--	0.00	0.0	--
	3782+27	115+285	11.8	3.6	470.0	143.3	472.4	144.0	432.4	0.0	2.4	0.7	Type 1	38.9	268.3	0.2	1.6	168.23	1.1	7.7	34.84	1.3	9.3	28.86
	3782+38	115+288	23.6	7.2	467.9	142.6	472.8	144.1	432.8	0.0	4.9	1.5	Type 1	57.3	394.8	0.5	3.2	123.77	2.2	15.4	25.63	2.7	18.6	21.23
	3782+50	115+292	35.4	10.8	465.9	142.0	473.2	144.2	433.2	0.0	7.3	2.2	Type 1	66.7	460.1	0.7	4.8	96.15	3.4	23.1	19.91	4.0	27.9	16.50
	3782+62	115+296	47.2	14.4	463.8	141.4	473.6	144.4	433.6	0.0	9.8	3.0	Type 1	72.7	501.2	0.9	6.4	78.56	4.5	30.8	16.27	5.4	37.2	13.48
	3783+00	115+307	86.4	26.3	457.2	139.4	482.7	147.1	442.7	0.0	25.5	7.8	Type 1	91.7	632.1	1.7	11.7	54.07	8.1	55.7	11.36	9.8	67.3	9.38
	3783+39	115+319	125.7	38.3	451.0	137.5	498.6	152.0	458.6	0.0	47.5	14.5	Type 1	110.8	763.9	2.5	17.0	44.93	11.4	78.9	9.68	13.9	95.9	7.96
	3783+78	115+331	165.0	50.3	445.3	135.7	510.0	155.5	470.0	0.0	64.7	19.7	Type 1	125.9	868.2	3.2	22.3	38.91	14.6	100.6	8.63	17.8	122.9	7.06
	3784+17	115+343	204.3	62.3	439.9	134.1	522.3	159.2	482.3	0.0	82.4	25.1	Type 1	141.3	974.5	4.0	27.6	35.28	17.5	120.7	8.08	21.5	148.3	6.57
	3784+56	115+355	243.5	74.2	435.0	132.6	532.0	162.1	492.0	0.0	96.9	29.5	Type 1	154.0	1061.8	4.8	32.9	32.24	20.2	139.1	7.63	25.0	172.1	6.17
	3784+95	115+367	282.8	86.2	430.5	131.2	530.0	161.5	490.0	0.0	99.5	30.3	Type 1	156.2	1077.1	5.5	38.2	28.16	22.6	156.0	6.90	28.2	194.3	5.54
	3785+34	115+379	322.1	98.2	426.5	130.0	530.0	161.5	490.0	0.0	103.5	31.6	Type 2	277.8	1915.6	6.3	43.6	43.98	24.8	171.3	11.18	31.2	214.8	8.92
	3785+73	115+390	361.3	110.1	422.8	128.9	530.0	161.5	490.0	0.0	107.2	32.7	Type 2	284.6	1962.0	7.1	48.9	40.15	26.8	185.0	10.61	33.9	233.8	8.39
	3786+12	115+402	400.6	122.1	419.6	127.9	530.3	161.6	490.3	0.0	110.7	33.7	Type 2	291.1	2006.8	7.9	54.2	37.04	28.6	197.0	10.19	36.4	251.2	7.99
	3786+51	115+414	439.9	134.1	416.8	127.1	531.3	162.0	491.3	0.0	114.5	34.9	Type 2	298.0	2054.7	8.6	59.5	34.54	30.1	207.5	9.90	38.7	267.0	7.70
	3786+90	115+426	479.1	146.0	414.5	126.3	536.0	163.4	496.0	0.0	121.5	37.0	Type 2	310.8	2142.9	9.4	64.8	33.07	31.4	216.3	9.90	40.8	281.1	7.62
	3787+30	115+438	518.4	158.0	412.6	125.8	531.1	161.9	491.1	0.0	118.5	36.1	Type 2	305.3	2105.1	10.2	70.1	30.03	32.4	223.6	9.41	42.6	293.7	7.17
	3787+69	115+450	557.7	170.0	411.1	125.3	519.8	158.4	479.8	0.0	108.7	33.1	Type 2	287.4	1981.4	10.9	75.4	26.27	33.2	229.2	8.64	44.2	304.6	6.50
	3788+08	115+462	597.0	182.0	410.0	125.0	518.4	158.0	478.4	0.0	108.4	33.0	Type 2	286.9	1978.1	11.7	80.7	24.50	33.8	233.3	8.48	45.5	314.0	6.30
	3788+47	115+474	636.2	193.9	409.4	124.8	525.8	160.3	485.8	0.0	116.5	35.5	Type 2	301.7	2080.0	12.5	86.0	24.18	34.2	235.7	8.83	46.7	321.7	6.47
	3788+87	115+486	675.5	205.9	409.1	124.7	530.0	161.5	490.0	0.0	120.8	36.8	Type 2	309.6	2134.4	13.2	91.3	23.37	34.3	236.5	9.03	47.5	327.8	6.51
	3789+21	115+497	710.2	216.5	409.1	124.7	533.6	162.7	493.6	0.0	124.5	37.9	Type 2	316.2	2180.0	13.9	96.0	22.70	34.3	236.5	9.22	48.2	332.5	6.56
	3789+56	115+507	744.9	227.0	409.1	124.7	536.3	163.5	496.3	0.0	127.2	38.8	Type 2	321.0	2213.5	14.6	100.7	21.97	34.3	236.5	9.36	48.9	337.2	6.56
	3789+91	115+518	779.6	237.6	409.1	124.7	538.8	164.2	498.8	0.0	129.7	39.5	Type 2	325.5	2244.1	15.3	105.4	21.29	34.3	236.5	9.49	49.6	341.9	6.56
	3790+25	115+528	814.3	248.2	409.1	124.7	541.1	164.9	501.1	0.0	132.0	40.2	Type 2	329.7	2273.0	16.0	110.1	20.64	34.3	236.5	9.61	50.3	346.6	6.56
	3790+60	115+539	849.0	258.8	409.1	124.7	544.1	165.8	504.1	0.0	134.9	41.1	Type 2	334.9	2309.3	16.7	114.8	20.11	34.3	236.5	9.77	51.0	351.3	6.57
	3790+95	115+550	883.7	269.4	409.1	124.7	548.6	167.2	508.6	0.0	139.4	42.5	Type 2	342.9	2364.5	17.3	119.5	19.79	34.3	236.5	10.00	51.6	356.0	6.64
	3791+30	115+560	918.4	279.9	409.1	124.7	554.1	168.9	514.1	0.0	145.0	44.2	Type 2	352.7	2431.9	18.0	124.2	19.58	34.3	236.5	10.28	52.3	360.7	6.74
	3791+64	115+571	953.1	290.5	409.1	124.7	556.9	169.7	516.9	0.0	147.8	45.0	Type 2	357.7	2466.0	18.7	128.9	19.13	34.3	236.5	10.43	53.0	365.4	6.75
	3791+99	115+581	987.8	301.1	409.1	124.7	562.4	171.4	522.4	0.0	153.2	46.7	Type 2	367.3	2532.2	19.4	133.6	18.96	34.3	236.5	10.71	53.7	370.1	6.84
	3792+34	115+592	1,022.5	311.7	409.1	124.7	567.4	172.9	527.4	0.0	158.3	48.2	Type 2	376.0	2592.7	20.1	138.3	18.75	34.3	236.5	10.96	54.4	374.8	6.92
	3792+68	115+602	1,057.2	322.2	409.1	124.7	571.7	174.3	531.7	0.0	162.5	49.5	Type 2	383.5	2644.1	20.7	143.0	18.49	34.3	236.5	11.18	55.0	379.5	6.97
	3793+03	115+613	1,091.9	332.8	409.1	124.7	576.9	175.8	536.9	0.0	167.8	51.1	Type 2	392.6	2706.5	21.4	147.7	18.33	34.3	236.5	11.45	55.7	384.1	7.05
	3793+50	115+627	1,139.1	347.2	409.4	124.8	583.5	177.9	543.5	0.0	174.1	53.1	Type 3	604.9	4170.3	22.3	154.0	27.07	34.1	235.3	17.72	56.5	389.4	10.71
	3793+97	115+642	1,186.2	361.6	410.4	125.1	591.5	180.3	551.5	0.0	181.1	55.2	Type 3	621.1	4282.3	23.3	160.4	26.70	33.6	231.8	18.47	56.9	392.3	10.92
	3794+44	115+656	1,233.3	375.9	411.9	125.6	599.0	182.6	559.0	0.0	187.1	57.0	Type 3	634.8	4376.9	24.2	166.8	26.24	32.8	226.0	19.36	57.0	392.8	11.14
	3794+92	115+670	1,280.4	390.3	414.1	126.2	607.0	185.0	567.0	0.0	192.9	58.8	Type 3	648.1	4468.4	25.1	173.2	25.81	31.6	217.9	20.50	56.7	391.1	11.43
	3795+39	115+685	1,327.6	404.6	416.8	127.1	613.5	187.0	573.5	0.0	196.6	59.9	Type 3	656.4	4526.1	26.0	179.5	25.21	30.1	207.5	21.81	56.1	387.0	11.69
	3795+86	115+699	1,374.7	419.0	420.2	128.1	617.7	188.3	577.7	0.0	197.4	60.2	Type 3	658.2	4538.4	27.0	185.9	24.41	28.2	194.7	23.30	55.2	380.6	11.92
	3796+33	115+713	1,421.8	433.4	424.2	129.3	620.0	189.0	580.0	0.0	195.8	59.7	Type 3	654.5	4512.3	27.9	192.3	23.47	26.1	179.7	25.11	53.9	372.0	12.13
	3796+79	115+728	1,468.9	447.7	428.9	130.7	620.0	189.0	580.0	0.0	191.1	58.3	Type 3	644.0	4440.2	28.8	198.6	22.35	23.5	162.3	27.36	52.4	361.0	12.30
	3797+26	115+742	1,516.1	462.1	434.1	132.3	618.8	188.6	578.8	0.0	184.7	56.3	Type 3	629.3	4338.6	29.7	205.0	21.16	20.7	142.6	30.42	50.4	347.7	12.48
	3797+73	115+756	1,563.2	476.5	439.9	134.1	618.0	188.4	578.0	0.0	178.1	54.3	Type 3	614.1	4233.7	30.7	211.4	20.03	17.5	120.7	35.09	48.2	332.1	12.75
	3798+20	115+770	1,610.3	490.8	446.4	136.1	618.0	188.4	578.0	0.0	171.6	52.3	Type 3	599.1	4130.6	31.6	217.8	18.97	14.0	96.4	42.86	45.6	314.1	13.15
	3798+66	115+785	1,657.4	505.2	453.5	138.2	619.1	188.7	579.1	0.0	165.6	50.5	Type 3	585.1	4034.3	32.5	224.1	18.00	10.1	69.8	57.79	42.6	293.9	13.72
	3799+13	115+799	1,704.6	519.6	461.1	140.6	620.0	189.0	580.0	0.0	158.9	48.4	Type 3	569.2	3924.5	33.4	230.5	17.03	5.9	40.9	95.86	39.4	271.5	14.46
	3799+59	115+813	1,751.7	533.9	469.4	143.1	620.0	189.0	580.0	0.0	150.6	45.9	Type 3	549.5	3788.7	34.4	236.9	15.99	1.4	9.8	387.16	35.8	246.7	15.36
	3800+05	115+827	1,798.8	548.3	478.3	145.8	620.0	189.0	580.0	0.0	141.7	43.2	Type 3	528.1	3641.1	35.3	243.3	14.97	-3.4	-23.6	-153.97	31.9	219.6	16.58
	3800+52	115+841	1,845.9	562.6	487.8	148.7	620.0	189.0	580.0	0.0	132.2	40.3	Type 3	504.9	3481.2	36.2	249.6	13.95	-8.6	-59.4	-58.65	27.6	190.3	18.30
	3800+89	115+853	1,884.1	574.3	495.8	151.1	618.9	188.6	578.9	0.0	123.2	37.5	Type 3	482.5	3326.9	37.0	254.8	13.06	-12.9	-89.2	-37.29	24.0	165.6	20.09
	3801+26	115+864	1,922.3	585.9	503.7	153.5	617.2	188.1	577.2	0.0	113.5	34.6	Type 3	458.2	3158.9	37.7	260.0	12.15	-17.3	-119.1	-26.52	20.4	140.9	22.42
	3801+64	115+875	1,960.5	597.6	511.6	155.9	614.8	187.4	574.8	0.0	103.1	31.4	Type 3	431.6	2975.5	38.5	265.1	11.22	-21.6	-149.0	-19.97	16.8	116.2	25.61
	3802+01	115+887	1,998.7	609.2	519.6	158.4	612.7	186.7	572.7	0.0	93.1	28.4	Type 3	405.3	2794.1	39.2	270.3	10.34	-25.9	-178.8	-15.62	13.3	91.5	30.55
	3802+38	115+898	2,036.9	620.9	527.5	160.8	610.2	186.0	570.2	0.0	82.7	25.2	Type 3	377.4	2602.0	40.0	275.5	9.45	-30.3	-208.7	-12.47	9.7	66.8	38.98
	3802+76	115+909	2,075.1	632.5	535.5	163.2	607.4	185.1	567.4	0.0	72.0	21.9	Type 3	347.8	2397.7	40.7	280.6	8.54	-34.6	-238.6	-10.05	6.1	42.1	57.01
	3803+13	115+921	2,113.3	644.2	543.4	165.6	603.7	184.0	563.7	0.0	60.3	18.4	Type 3	314.3	2167.1	41.5	285.8	7.58	-38.9	-268.4	-8.07	2.5	17.4	124.89
	3803+51	115+932	2,151.5	655.8	551.4	168.1	600.0	182.9	560.0	0.0	48.7	14.8	Type 3	279.6	1927.5	42.2	291.0	6.62	-43.3	-298.3	-6.46	-1.1	-7.4	-262.24
	3803+88	115+944	2,189.8	667.4	559.3	170.5	595.6	181.5	555.6	0.0	36.3	11.1	Type 3	234.3	1615.8	42.9	296.1	5.46	-47.6	-328.2	-4.92	-4.6	-32.1	-50.41
	3804+25	115+955	2,228.0	679.1	567.2	172.9	591.6	180.3	551.6	0.0	24.4	7.4	Type 3	170.2	1173.6	43.7	301.3	3.90	-51.9	-358.1	-3.28	-8.2	-56.8	-20.68
	3804+63	115+966	2,266.2	690.7	575.2	175.3	587.3	179.0	547.3	0.0	12.1	3.7	Type 3	80.2	552.8	44.4	306.5	1.80	-56.3	-387.9	-1.42	-11.8	-81.5	-6.79
Pipe Entry Side	3805+00	115+978	2,304.4	702.4	583.1	177.7	583.1	177.7	543.1	0.0	0.0	0.0	Type 3	0.0	0.0	45.2	311.6	--	-60.6	-417.8	--	-15.4	-106.2	--

mottmac.com