ATLANTIC COAST PIPELINE, LLC
ATLANTIC COAST PIPELINE

Construction, Operations, and Maintenance Plans

ATTACHMENT O

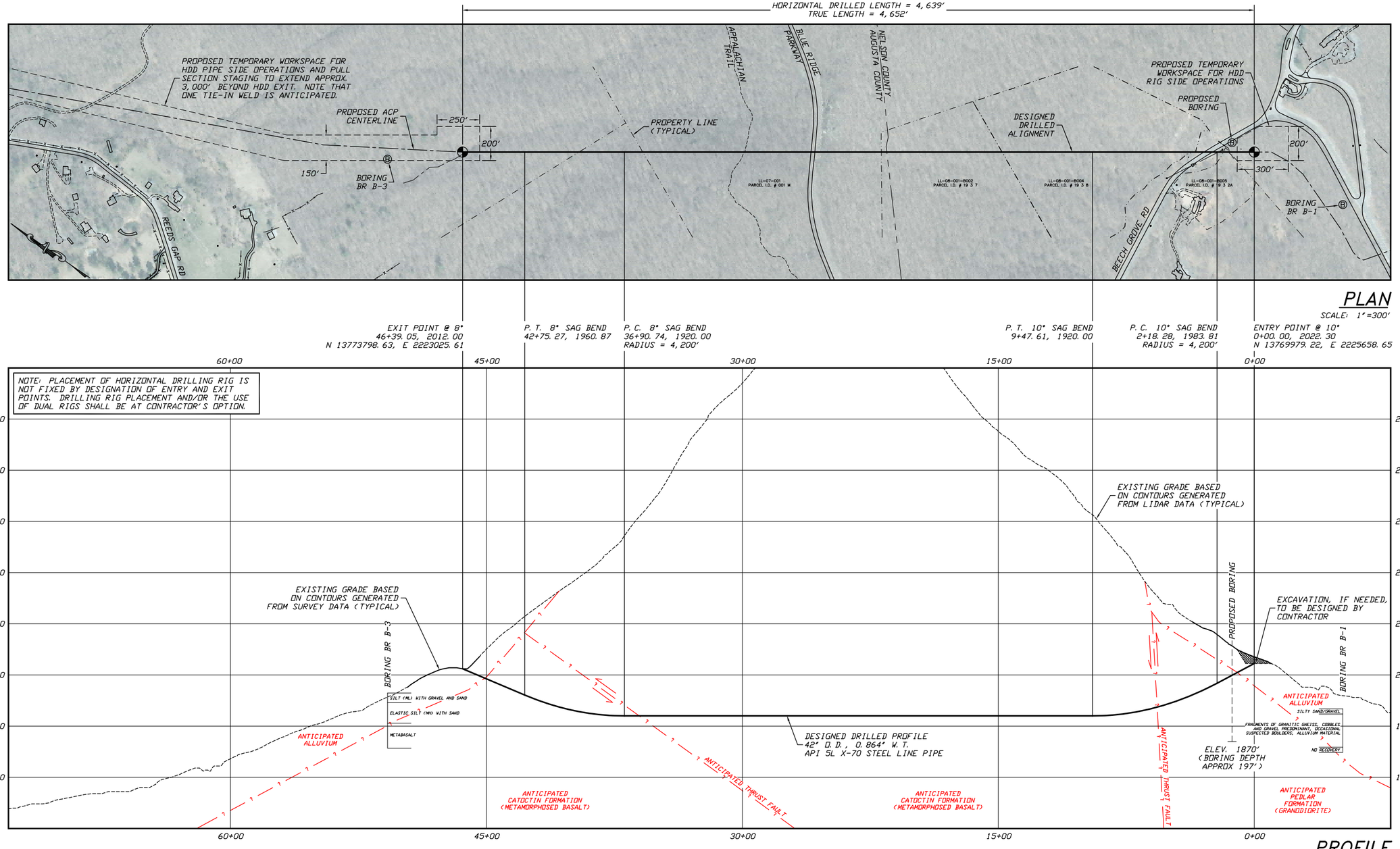
Appalachian National Scenic Trail HDD Plan and Profile Drawings

Previously filed with FERC on August 1, 2016 (Accession No. 20160801-5228)

Blue Ridge Parkway

Supporting Information

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



PLAN

SCALE: 1"=300'

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

P.T. 8° SAG BEND
42+75.27, 1960.87

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

P.T. 10° SAG BEND
9+47.61, 1920.00

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

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

PROFILE

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

100 50 0
600 300 150 0

GENERAL LEGEND

- DRILLED PATH ENTRY/EXIT POINT
- Ⓑ BORING LOCATION

GEOTECHNICAL NOTES

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

TOPOGRAPHIC SURVEY NOTES

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

DRILLED PATH NOTES

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

PILOT HOLE TOLERANCES

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

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

PROTECTION OF EXISTING FACILITIES

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

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

ATLANTIC COAST PIPELINE PROJECT

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

LOCATION: AUGUSTA COUNTY & NELSON COUNTY, VIRGINIA					
DRAWN	DATE	CHECKED	APPROVED	SCALE	DRAWING LABEL
KMN	05/19/16	DMP	JSP	SHOWN FOR D-SIZED PLOT	BR PARKWAY 1

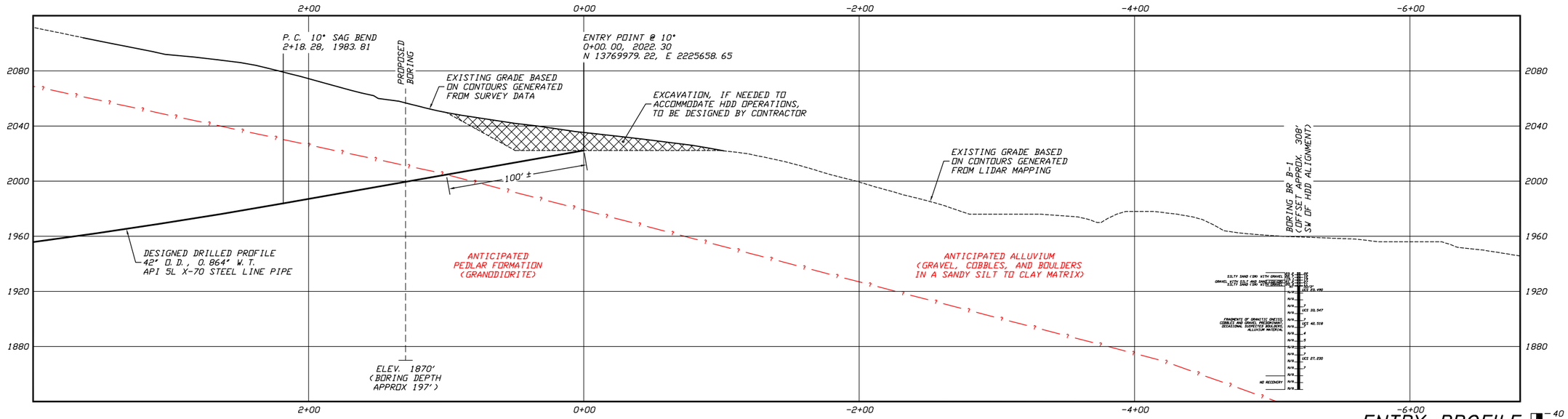
REVISION 0

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

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

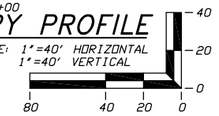
PROJECT NO.
Dominion\1508

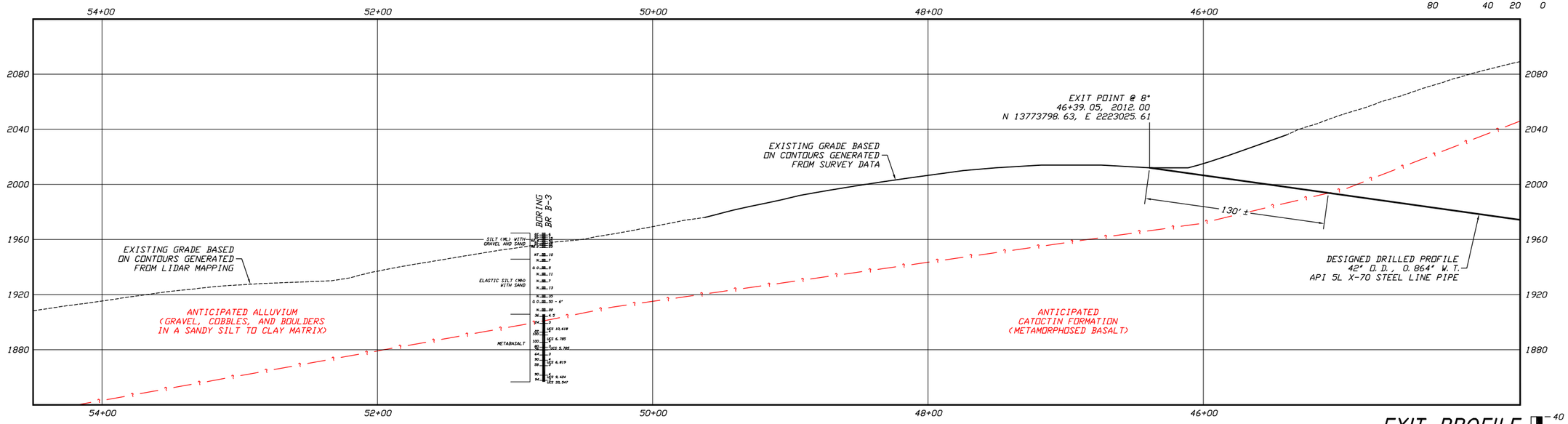
MILE POST
AP1-158



ENTRY PROFILE

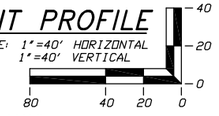
SCALE: 1"=40' HORIZONTAL
1"=40' VERTICAL





EXIT PROFILE

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



GENERAL LEGEND

DRILLED PATH ENTRY/EXIT POINT

GEOTECHNICAL LEGEND

SPLIT SPOON SAMPLE

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

CORE BARREL SAMPLE

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

GEOTECHNICAL NOTES

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

GEOTECHNICAL NOTES (CONTINUED)

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

TOPOGRAPHIC SURVEY NOTES

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

DRILLED PATH NOTES

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

PROTECTION OF EXISTING FACILITIES

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

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

ATLANTIC COAST PIPELINE PROJECT

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

LOCATION: AUGUSTA COUNTY & NELSON COUNTY, VIRGINIA

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

NO.	DATE	REVISION DESCRIPTION	BY	CHK'D	APP.

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Tulsa, Oklahoma 74114

PROJECT NO.
Dominion\1508

MILE POST
AP1-158

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

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

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

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

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

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

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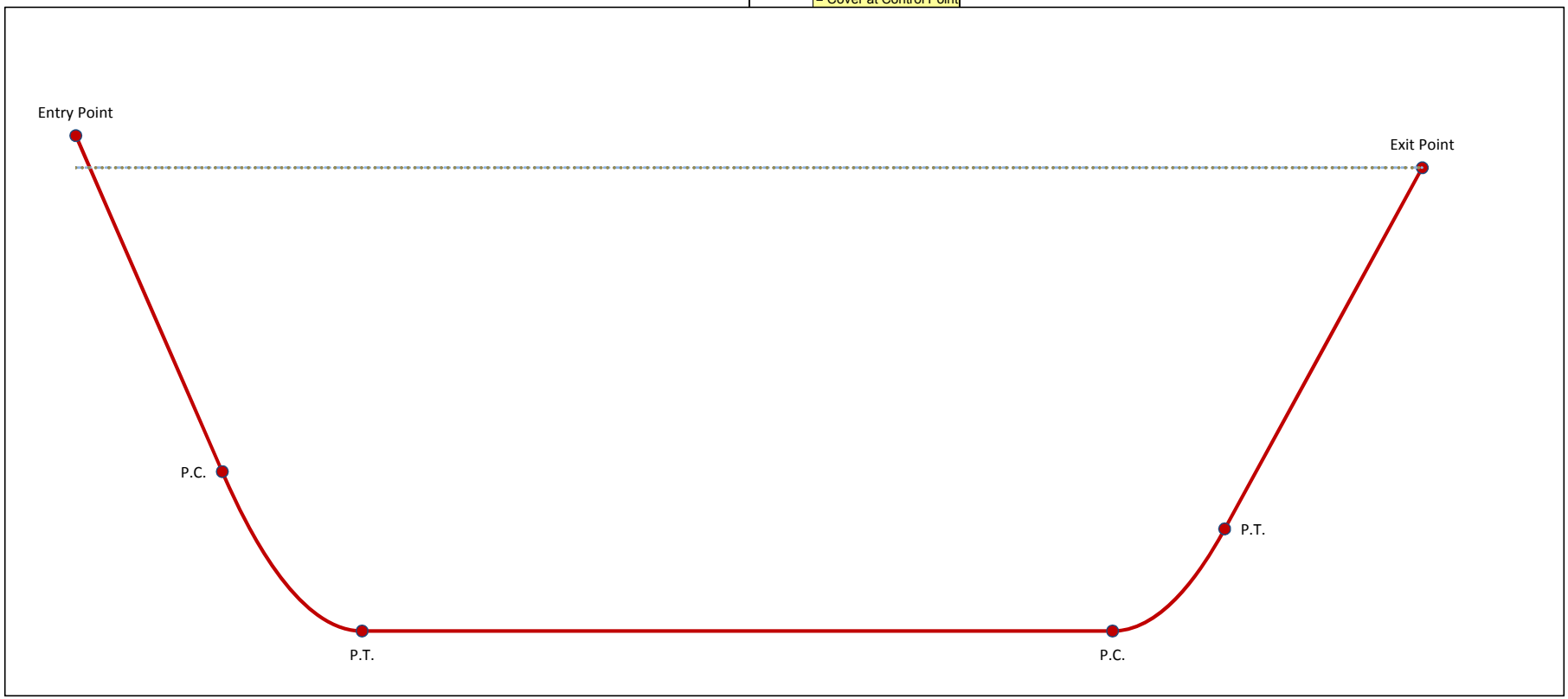
		Station	Elevation	Angle	Radius	Length	Average Tension	Total Pull
Entry Point		-10.00	2022.30	10.00				286,742
Entry Tangent						516.92		
Entry Sag Bend	PC	499.06	1932.54					249,800
	PI	740.31	1890.00	10.00	2800	488.69	231,351	
	PT	985.28	1890.00				0	212,902
Bottom Tangent				0.00		2607.73		
Exit Sag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

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

= Cover at Control Point



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

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Pipe and Installation Properties

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

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

Exit Tangent - Summary of Pulling Load Calculations

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

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

Exit Sag Bend - Summary of Pulling Load Calculations

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

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

Bottom Tangent - Summary of Pulling Load Calculations

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

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

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

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Entry Sag Bend - Summary of Pulling Load Calculations

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

$h = R [1 - \cos(\alpha/2)]$ =	10.65	ft	$j = [(E I) / T]^{1/2}$ =	1,721	
$Y = [18 (L)^2] - [(j)^2 (1 - \cosh(U/2)^{-1}]$ =	2.4E+06		$X = (3 L) - [(j / 2) \tanh(U/2)]$ =	660.90	
$U = (12 L) / j$ =	3.41		$N = [(T h) - W_e \cos\theta (Y/144)] / (X / 12)$ =	24,431	lb
Bending Frictional Drag = $2 \mu N$ =	14,659	lb			
Fluidic Drag = $12 \pi D L C_d$ =	19,344	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	2,895	lb			
Pulling Load on Entry Sag Bend =	**36,898**	**lb**			
Total Pulling Load =	**249,800**	**lb**			

Entry Tangent - Summary of Pulling Load Calculations

Segment Length, L =	516.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	68.0	lb/ft
Entry Angle, θ =	10.0	º			

Frictional Drag = $W_e L \mu \cos\theta$ =	10,379	lb			
Fluidic Drag = $12 \pi D L C_d$ =	20,462	lb			
Axial Segment Weight = $W_e L \sin\theta$ =	6,101	lb			
Pulling Load on Entry Tangent =	**36,942**	**lb**			
Total Pulling Load =	**286,742**	**lb**			

Summary of Calculated Stress vs. Allowable Stress

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

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

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

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

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

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

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

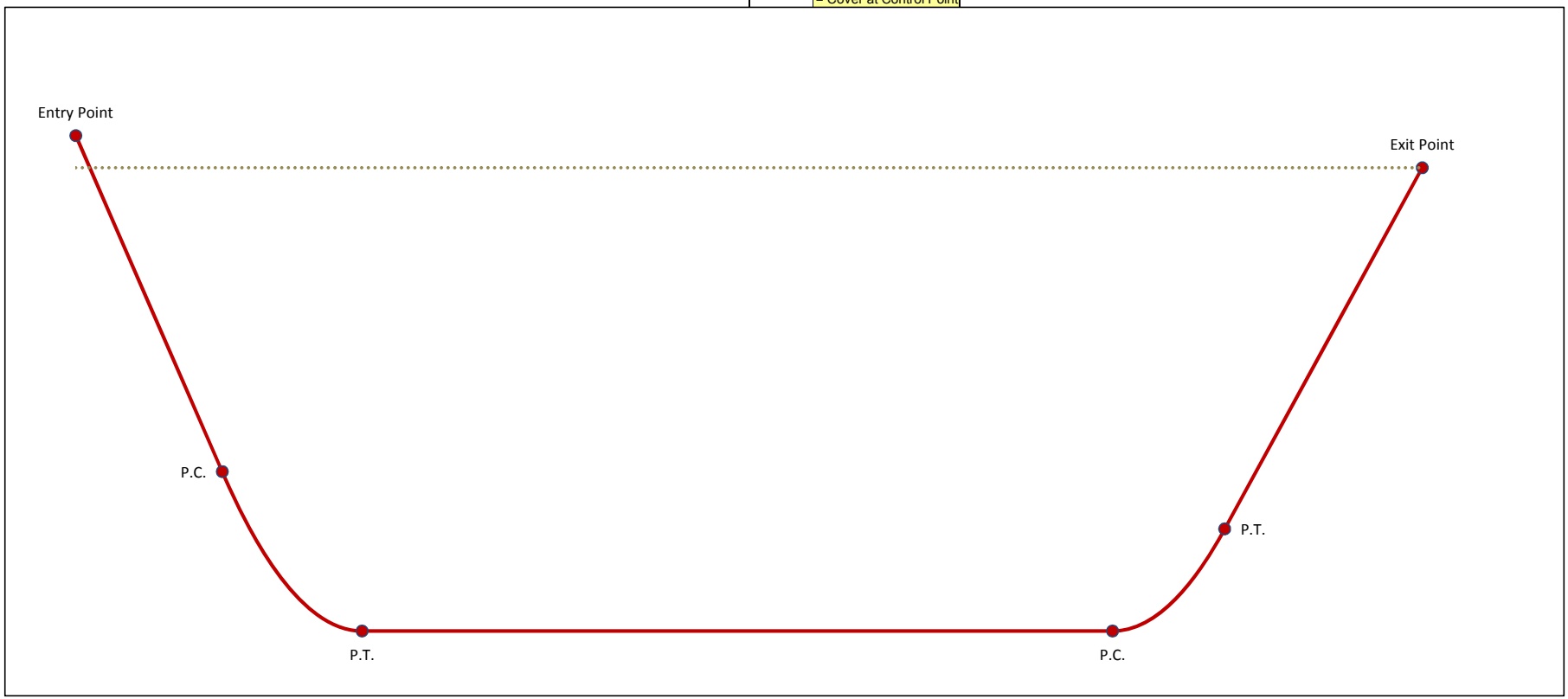
Blue Ridge Parkway R0 Installation Stress Analysis (worst-case).xlsm

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

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

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

= Cover at Control Point



Step 2, Drilled Path Input

11:06 AM7/27/2016

Pipe and Installation Properties

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

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

Exit Tangent - Summary of Pulling Load Calculations

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

Frictional Drag = W_e L μ cosθ =	99,660	lb
Fluidic Drag = 12 π D L C_d =	27,436	lb
Axial Segment Weight = W_e L sinθ =	46,688	lb
Pulling Load on Exit Tangent =	**173,784**	**lb**

Exit Sag Bend - Summary of Pulling Load Calculations

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

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

Bottom Tangent - Summary of Pulling Load Calculations

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

Frictional Drag = W_e L μ =	378,650	lb
Fluidic Drag = 12 π D L C_d =	103,225	lb
Axial Segment Weight = W_e L sinθ =	0	lb
Pulling Load on Bottom Tangent =	**481,875**	**lb**
Total Pulling Load =	**781,730**	**lb**

Entry Sag Bend - Summary of Pulling Load Calculations

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

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

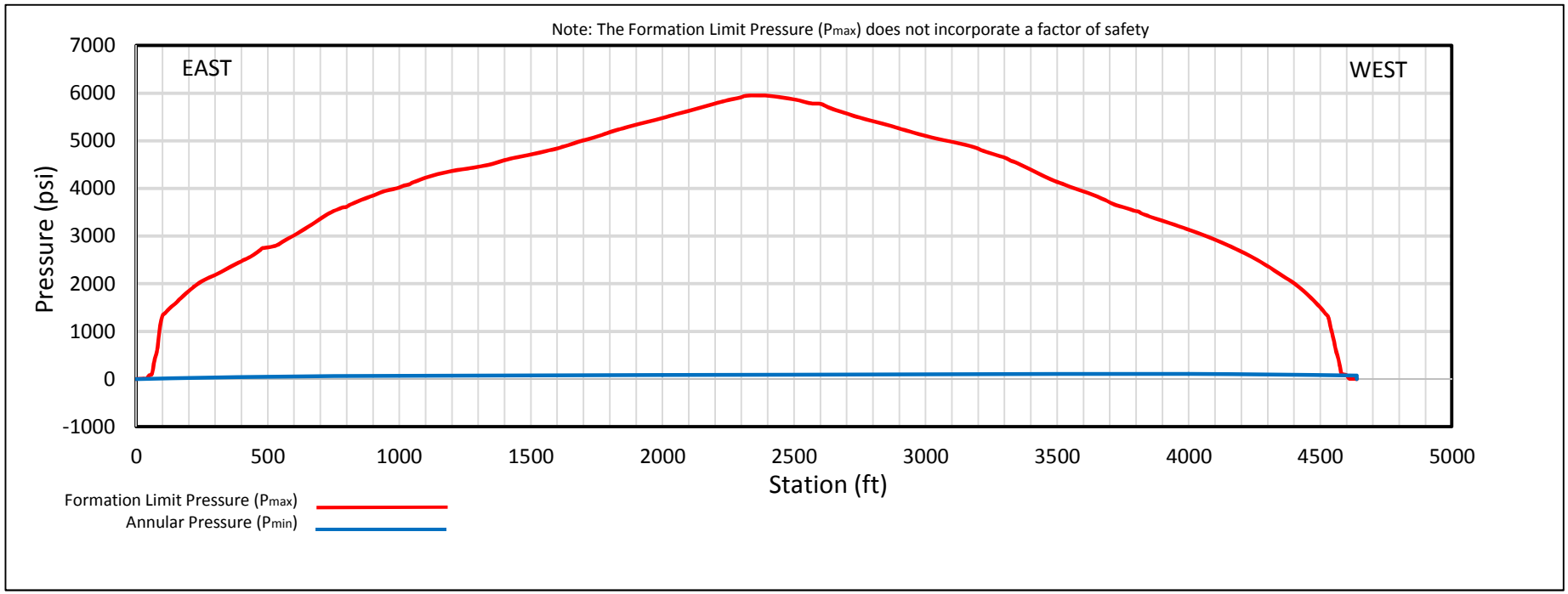
Entry Tangent - Summary of Pulling Load Calculations

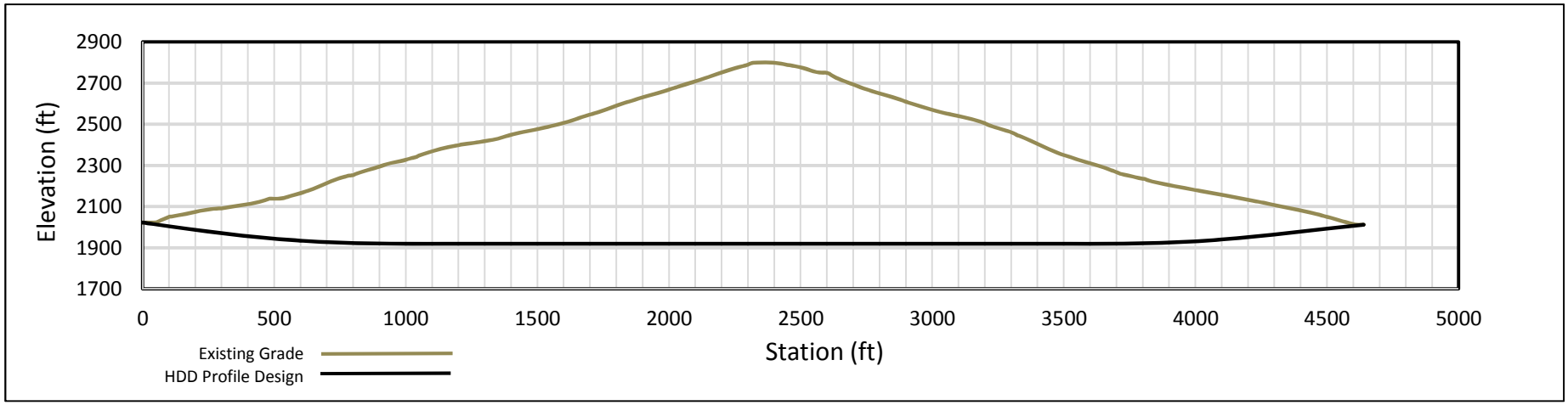
Segment Length, L =	516.9	ft	Effective Weight, $W_e = W + W_b - W_m$ =	-484.0	lb/ft
Entry Angle, θ =	10.0	º			

Frictional Drag = W_e L μ cosθ =	73,917	lb	
Fluidic Drag = 12 π D L C_d =	20,462	lb	
Axial Segment Weight = W_e L sinθ =	-43,445	lb	Negative value indicates axial weight applied in direction of installation
Pulling Load on Entry Tangent =	**50,934**	**lb**	
Total Pulling Load =	**979,838**	**lb**	

Summary of Calculated Stress vs. Allowable Stress

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





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

Date: 7/26/2016 Revision: 0

J.D.Hair&Associates, Inc.