

Champlain Hudson Power Express - Package 6 Crossing #96.XX- C1 - New Baltimore Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/13/23

<u>C</u> - Allowable Mud Pressures:

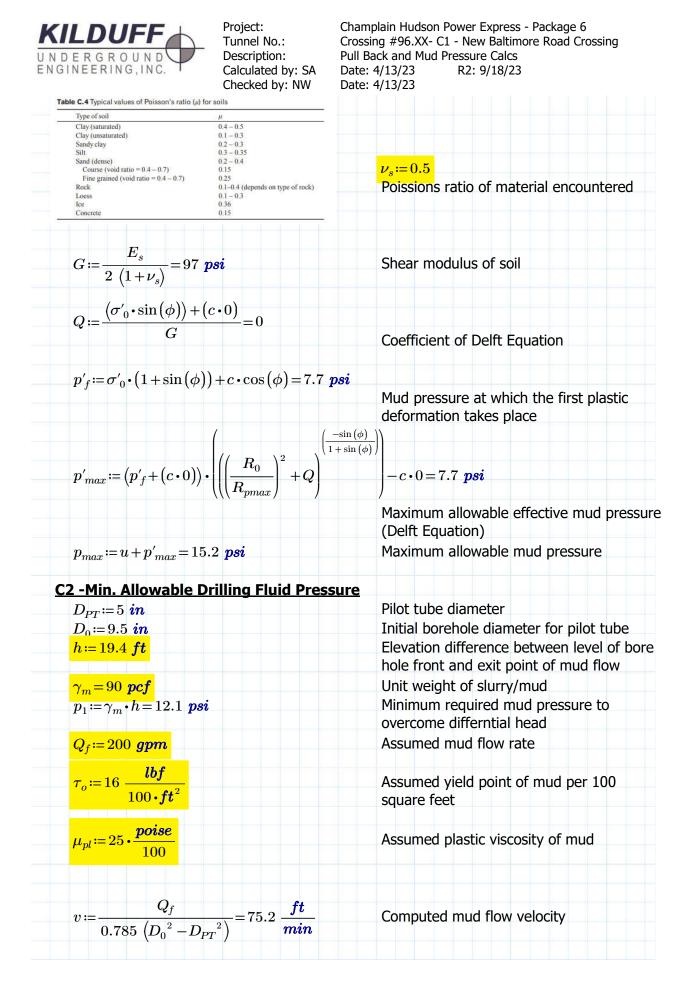
<u>C1 -</u>	Max.	Allowable	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

$H_w \coloneqq 17.4 \cdot ft$	Depth of the bore below groundwater elevation
$H_c \coloneqq 17.4 \ ft$	Vertical separation distance between critic structure and pipe (Stream S-22; ~6+50)
$\gamma \coloneqq 100 \ pcf$	Assumed unit weight very soft clay
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma_w^{\gamma_w} = \gamma_w = 37.6 \ pcf$	Effective unit weight
$u := \gamma_w \cdot H_w = 8 psi$	Initial pore water pressure
$\phi \coloneqq 0 \ deg$	Assumed friction Angle
c:=450 psf =3.13 psi	Assumed cohesion of encountered materia
$R_0 := \frac{D_{rod}}{2} = 1.75$ in	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 9 \ \mathbf{ft}$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
Table C.2 Typical values of modulus of elasticity (E_s) for different type Type of Soil E_s (N/mm ²)	s of soils
Clay Very soft 2–15	
Soft 5–25	
Medium 15–50	F = 2 $N = 200$ mm
Hard 50–100	$E_s \coloneqq 2 \frac{N}{mm^2} \equiv 290 \ psi$
Sandy 25-250 Glacial till	
Loose 10–153	Assumed modulus of elasticity
Dense 144-720	Assumed modulus of clustery
Very dense 478-1,440	
Loess 1457	
Sand Silty 721	
Loose 10-24	
Dense 48-81	
Sand and gravel	
Loose 48–148 Dense 96–192	
Shale 144–14,400	
Silt 2-20	



KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #96.XX- C1 - New Baltimore Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/13/23
$L_{structure} \coloneqq 650 \ ft$		Length to sturcture
$p_{2} := L_{structure} \cdot \left(\left(\frac{\mu_{1}}{(D_{0} - p_{1})} \right) + p_{2} = 14.1 \right) + p_{2} = 14.1 \right)$		Length to sturcture $\left(\frac{D_{D_{PT}}}{D_{PT}}\right) = 1.9 \ psi$ Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure
$check \coloneqq$ if $(p_{max} > p_{min})$	$_{n_{\cdot}},$ "okay", "not ok	xay") = "okay"



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D1.1 - Overburden Pressure (Considering D	eformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 79.8 \ ft$	Depth of cover
$\phi = 0 \ deg$	Friction angle of soil
$B := D_r = 18$ in	"Silo" width, conservative value =
$\langle \rangle^2$	reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 21 \ psi P_E = 3000 \ g$	<i>psf</i> Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
	(Table X1.1 ASTM F 1962)
$E_{short} = 0.26$ mai	Variable in earth load deflection equation
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ \textbf{psi}$	
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 2.8\%$	Pipe deflection to diameter as per
k_{short}	PPI Equ. 10 (Chp 12, p 437, PPI Handboo
D1.3 Earth Load Deflection (Long Term)	
	Apparent modulus of elasticity for PE4710
$E_{long} \coloneqq 28200 \bullet psi$	Base Temperature of 73 Fahrenheit at 50
	years of sustained loading (Table X1.1
E_{long}	ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$12 \cdot (DR_1 - 1)$	Dipo deflection to dispectance and
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 5.7\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)
$\Delta y_{ELD_long} = \frac{1}{k} = 0.1\%$	111 Equ. 10 (Crip 12, p 137)



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D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194 \ in$	Thickness of casing pipe
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$	Assumed unit weight of fluid in
43	borehole (Slurry unit weight)
$I \coloneqq \frac{\iota}{1} = 0.14 \frac{\iota}{1}$	Moment of inertia of pipe wall cross
12 in $(D_{\star})^4$	section
$0.1169 \cdot \gamma_m \cdot \left \frac{D_1}{2} \right $	Pipe ring deflection to buoyant force
$\Delta u_{1} = (2) = 0.1\%$	ASTM F 1962 (Eq. X2.6, p.6)
$\gamma_m = 90 \text{ pcf}$ $I \coloneqq \frac{t^3}{12} = 0.14 \frac{in^4}{in}$ $\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\%$	····· ··· (
D2.1 Buoyant Deflection (Long Term)	
Please note that long term buoyant deflectio	n was assumed negibile, since grout is
assumed to be cured after a 1-week period f	
<u> 3 - Reissner Effect Deflection (Short Terr</u>	m)
<u>D3.1 - Reissner Effect Deflection (Short Term</u>	-
	1)
D3.1 Reissner Enect Denection (Short Term	<u>n)</u>
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at
$\mu_{short} = 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
	Poisson's Ratio for PE pipe material at
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} = 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect
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$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect
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$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect
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$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect)) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect)) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnn Effect)) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature



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<u> D4 - Net Ring</u>	Deflection	
$\Delta y_{lim} \coloneqq 7.5\%$	6	Deflection limit for DR 9 non pressuriz pipe (Table 2 , p. 437, PPI Handbook
<u>D4.1 - Net S</u>	Short Term	
Δy_{short_net} :=	$\Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{F}$	$R_{a_{short}} = 2.8\%$ Percent ring deflection in sho term analysis
$Check := \mathbf{if} \left(A \right)$	$\Delta y_{short_net} {<} \Delta y_{lim},$ "okay", "r	not okay") = "okay"
<u>D4.2 - Net I</u>	Long Term	
Δy_{long_net} := .	$\Delta y_{ELD_long} + \Delta y_{R_long} = 5.7\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if}(\mathbf{z})$	$\Delta y_{long_net} {<} \Delta y_{lim},$ "okay", "n	ot okay") = "okay"



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D5.1 - Unconstrained Ring Buckling, Levy	<u>y's Equation (Short Term-During Pull)</u>
Note that constraining the pipe will incre	ase the pipe's buckling strength, therefore
considering an unconstrained condition v	vill produce a conservative value.
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$E_{short} = 57500 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg.
% Deflection	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
0 2 4 6 8 10 12	
0.0	
0.2	Ovality compensation factor, Figure
to 0.4	3 (PPI Chp. 12). Calculated
0.6	deflection limit in section D4.1
0.8	$f_{o \ short} \coloneqq 0.80$
$P_{UC \ short} \coloneqq \left(\frac{2 \cdot E_{short}}{2}\right) \cdot \left(\frac{1}{2}\right)^3 \cdot \frac{f_o}{2}$	$\frac{-short}{N} = 102.4 \ psi$ Allowable unconstrained buckling pressure
$\left(1-\mu_{short}^2\right)\left(DR_1-1\right)$	N buckling pressure
$H = 16.8 \ ft$	Elevation difference between the lowest
	point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 10.5 \ psi$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 10.5 \ psi$	Net external loading with open borehole
$Check \coloneqq if (P_{UC_short} > P_{net}, "okay", "not$	tokay") = "okay"
D5.2 - Unconstrained Ring Buckling, Levy	<u>r's Equation (Long Term)</u>
Note that constraining the pipe will incre considering an unconstrained condition v	
Note that constraining the pipe will increase considering an unconstrained condition v $N \coloneqq 2.0$	
considering an unconstrained condition v	vill produce a conservative value.

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #96.XX- C1 - New Baltimore Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/13/23
$E_{long} \!=\! 28200 \; psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2} \right)$	$\left(\frac{1}{DR_1 - 1} \right)^3 \cdot \frac{f_o}{d}$	$\frac{1}{N} = 31.1 \ psi$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 7.54$	psi	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := if (P_{UC_long} >$	P "okay" "no	(a + a + a + a + a + a + a + a + a + a +
	<u>I _{net}, Okay , IIC</u>	tokay) – Okay



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill

96.A & 96.B



Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

ning Parameters of Horizontal Direction D ₁ := 10.75 <i>in</i>	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$D_{rod} \coloneqq 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 := 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 \coloneqq \boldsymbol{\pi} \cdot D_1 = 33.8 \ \boldsymbol{in}$	Pipe circumference of pipe 1
$C_1 \coloneqq \pi \cdot D_1 = 00.0 \text{ in}$ $C_2 \coloneqq \pi \cdot D_2 = 7.5 \text{ in}$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
drill rig B	A a
	Janahounna fannannan
H	
pipe exit C	В
· · · · · · · · · · · · · · · · · · ·	· · · · · · · · · · · · · · · · · · ·
L_4 L_3	
L ₄ L ₃	
L ₄ L ₃	
-	
• L _{bore}	
Illustration 1 - Schematic of I	Drive Cross-section
L_{bore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians)
$\begin{array}{c} L_{\text{bore}} \\ Illustration \ 1 - \ \text{Schematic of I} \\ \alpha \coloneqq 10 \\ \beta \coloneqq 14 \\ \beta \coloneqq \alpha_{in} \coloneqq \alpha = 0.1745 \\ \beta_{exit} \coloneqq \beta = 0.2443 \\ rad \end{array}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$\alpha := 10 \circ \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor
$\begin{array}{c} \textbf{L}_{\text{tore}} \\ \textbf{Illustration 1 - Schematic of I} \\ \alpha \coloneqq 10 \\ \beta \coloneqq 14 \\ \beta \coloneqq 14 \\ \textbf{D}_r \coloneqq 18 \cdot \textbf{in} \end{array}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
L_{bore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 79.95 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface
$\alpha := 10 \circ \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
L_{tore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 79.95 \ ft$ $L_{total} := 1498.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
L_{tore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 79.95 \ ft$ $L_{total} := 1498.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 637.7 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
L_{tore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 79.95 \ ft$ $L_{total} := 1498.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 637.7 \ ft$ $L_3 := 560.8 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section
L_{tore} Illustration 1 - Schematic of I $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 79.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 79.95 \ ft$ $L_{total} := 1498.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 637.7 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1

	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Cros Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b = 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w \coloneqq 62.4 \ pcf $		Unit weight of water
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 70 \ pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$ $\gamma_c \coloneqq 1.0$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
Axial Bending Stress	<u>:</u>	
$R_{avg._in}$:=1000 ft		Radius of curvature at the entry, provided by Contractor
$R_{avg._out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg._in} + R_{avg._on}}{2}$	$\frac{t}{t} = 1000 \; ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 35$	50 ft	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq ext{if} \left(R_{avg._in} > ight)$	<i>m</i> "oltort" "not	(alter ?) = (alter ?)

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \coloneqq e_a \cdot E_{12hr} = 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

<u>1 - Empty Pipe</u>	
B1.1 - Effective Weight of Empty Pipe:	
$w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - \left(D_{2} - T_{p1} \right)^{2} \right) + \left(D_{p1}^{2} - \left(D_{p1} - T_{p1} \right)^{2} \right) \right) + \left(D_{p1}^{2} - \left(D_{p1} - T_{p1} \right)^{2}$	$\left(-T_{p2} ight)^{2} ight)\!\!\left)\!\cdot\! ho_{w}\!\cdot\!\gamma_{a}\!=\!8.3\;plf$
B1.2 - Upward Buoyant Force:	Effective weight
$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 38 pl$	f Upward buoyant force of empty pipe
B1.3 - Hydrokinetic Pressure:	
$\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796$	<i>bf</i> Hydrokinetic force
B1.4 - Pullback Force Point A:	
$T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) =$	1390 <i>lbf</i>
<i>u</i> (<i>u u</i> (1 2 3 ±//	Pullback force when pipe enters the grou
<u>B1.5 - Pullback Force Point B:</u>	
$T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_b \cdot H_$	$v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot lpha_{in})} = 11727 \ lbf$
	Pullback force increase with depth
B1.6 - Pullback Force Point C:	
$T_c \coloneqq T_b + \left(v_b \cdot w_b \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_3 \right)$	$_{3} \cdot e^{(v_a \cdot \alpha_{in})} = 17619 \ lbf$
B1.7 - Pullback Force at D:	
$T := o^{(v_b \cdot \beta_{exit})} (T + a + av_b) + I = av_b + H$	$= - e^{(v_a \cdot lpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot lpha_{in})})) = 19125 \ lbf$
$I_d := e^{-\frac{1}{c}} \cdot \left(I_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max}\right)$	$-e^{-e^{-i}}\left(\left(u_a\cdot u_a\cdot L_4\cdot e^{-i}\right)\right)=19123 \ ioj$
B1.8 - Maximum Pullback Force - Empty P	ipe:
$P_{max_empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 1$	19921 <i>lbf</i>
$= max_empty \qquad = = (-a, -b, -c, -a) = -$	Maximum Pullback Force
2 - Filled Dipe with Water	
<u>2 - Filled Pipe with Water</u> B2.1 - Upward Buoyant Force:	
	$(2,1)^2$
$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \cdot \boldsymbol{D}_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{D}\right)\right)\right)$	$\left \frac{2}{R_1} \right \left -w_a = 12 \ \boldsymbol{plf} \right $
	Upward buoyant force of pipe filled with

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1390 \ lbf$ Pullback force enter ground



Project:

Tunnel No.:

Description:

Calculated by: DA

Checked by: NW

Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

	- Pullback Force Point B:
$+v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 5464 \ lbf$ force increase and decrease with	$c_{cd} := e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot w_{bfilled} \cdot L_2 + v_b \cdot w_{bf$
$\cdot e^{(v_a \cdot \alpha_{in})} = 6991 \ lbf$	$\boldsymbol{w}_{d} \coloneqq \boldsymbol{T}_{bfilled} + \left(\boldsymbol{v}_{b} \boldsymbol{\cdot} \left \boldsymbol{w}_{bfilled} \right \boldsymbol{\cdot} \boldsymbol{L}_{3} \right) - \boldsymbol{e}^{\left(\boldsymbol{v}_{b} \boldsymbol{\cdot} \boldsymbol{\alpha}_{inj} \right)}$
	- Pullback Force at D:
$_{u} \cdot w_{a} \cdot L_{4} \cdot e^{\langle v_{a} \cdot \alpha_{in} \rangle})) = 8413 \ lbf$	$e_{d} \coloneqq e^{\langle v_{b} \cdot \beta_{exil} \rangle} \cdot (T_{cfilled} + v_{b} \cdot w_{bfilled} \cdot L_{4})$
· · · · · · · · · · · · · · · · · · ·	- Maximum Pullback Force - Filled Pipe
n Pullback Force	$\coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$
<u>:k:</u>	<u>fe Pull Strength / Ultimate Tensile</u>
	Safe Pullback Check
ctional area of Pipe 1	$\frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$
ctional area of Pipe 2	$\frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) \!=\! 0.8 \boldsymbol{in}^2$
forces acting on Pipe 1 (Empty)	$=\frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 19148 \ lbf$
forces acting on Pipe 2 (Empty)	$=\frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 773 \ lbf$
forces acting on Pipe 1 (Ballast)	$=\frac{A_1 \cdot P_{max}}{A_1 + A_2} = 8086 \ lbf$
forces acting on Pipe 2 (Ballast)	$=\frac{A_2 \cdot P_{max}}{A_1 + A_2} = 326 \ lbf$
back forces Pipe 1 (Table %, PPI)	:=41214 <i>lbf</i>
back forces Pipe 2 (Table %, PPI)	₂:=1683 <i>lbf</i>
	$k \coloneqq \mathbf{if} \left(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''} \right)$
	$\mathbf{c} \coloneqq \mathbf{if} \left(P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay''} \right)$
	$k \coloneqq \mathbf{if}(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay''})$
	$\mathbf{c} \coloneqq \mathbf{if} \left(P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay''} \right)$



Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

C - Allowable Mud Pressures:

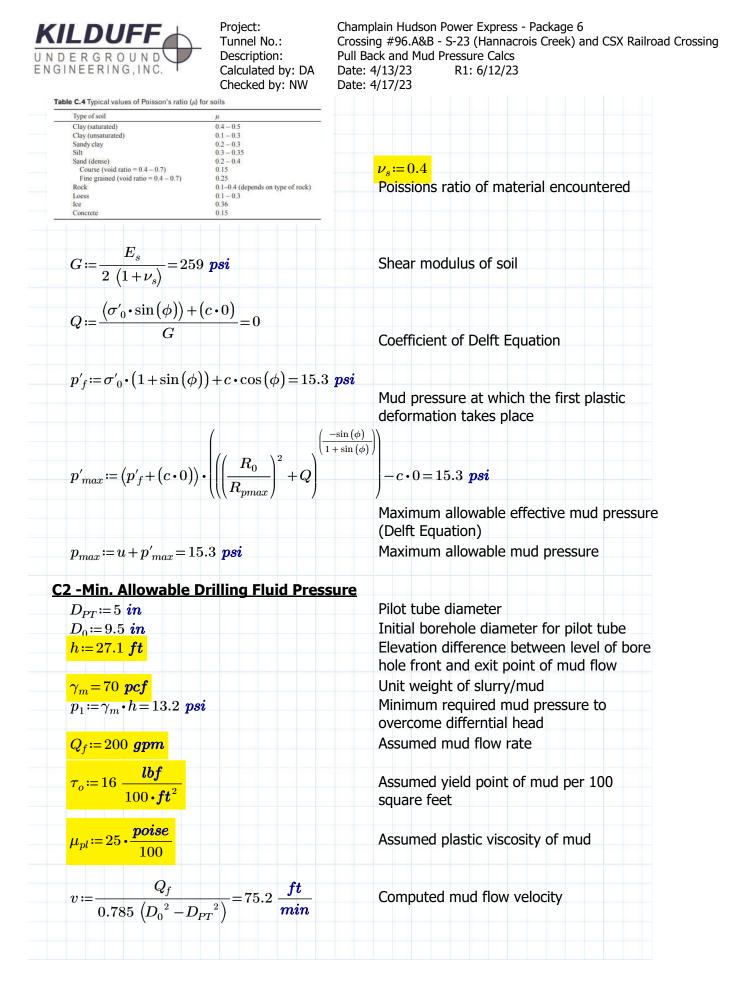
<u>C1 -</u>	Max.	Allow	able	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

$H_w \coloneqq 0 \cdot ft$ $H_c \coloneqq 17.5 ft$ $\gamma \coloneqq 100 pcf$ $\gamma_w \coloneqq 62.4 pcf$	Depth of the bore below groundwater elevation Vertical separation distance between critica structure and pipe Assumed unit weight very soft clay
$\gamma \coloneqq 100 \ pcf$	structure and pipe
	Assumed unit weight very soft clay
$\gamma_{u} := 62.4 \ pcf$	
	Unit weight of water
$\gamma' = \gamma - \gamma_w = 37.6 \ pcf$	Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 0 \ psi$	Initial pore water pressure
$\frac{\phi := 0}{\phi} \frac{\phi = 0}{\phi} \phi$	Assumed friction Angle
<i>c</i> ≔ 450 <i>psf</i> = 3.13 <i>psi</i>	Assumed cohesion of encountered materia
$R_0 := \frac{D_{rod}}{2} = 1.75$ in	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 9 ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\sigma'_{0} \coloneqq \left(\left(\gamma \cdot \left(H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$	2 <i>psi</i> Initial effective stress
Table C.2 Typical values of modulus of elasticity (E_s) for different typ Type of Soil E_s (N/mm ²)	es of soils
Table C.2 Typical values of modulus of elasticity (E_S) for different type Type of Soil E_s (N/mm ²) Clay	es of soils
Type of Soil E _y (N/mm ²) Clay Very soft 2–15	es of soils
Type of Soil E_s (N/mm ²) Clay	
Type of Soil E_s (N/mm ²) Clay 2–15 Very soft 5–25 Medium 15–50 Hard 50–100	
Type of Soil $E_{\rm g}$ (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250	$E_s := 5 \frac{N}{mm^2} = 725 psi$
Type of Soil E_{ν} (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till 50–100	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
Type of Soil $E_{\rm g}$ (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250	
$\begin{tabular}{ c c c c c } \hline Type of Soil & E_s (N/mm^2) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
$\begin{tabular}{ c c c c c } \hline Type of Soil & E_{*} (N/mm^{2}) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ Loess & 14-57 \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
$\begin{tabular}{ c c c c c } \hline Type of Soil & E_s (N/mm^2) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
$\begin{tabular}{ c c c c c } \hline Type of Soil & E_{v} (N/mm^{2}) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ Loess & 14-57 \\ Sand & & \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
$\begin{tabular}{ c c c c } \hline Type of Soil & E_s (N/mm^2) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ Loess & 14-57 \\ Sand & & \\ Silty & 7-21 \\ Loose & 10-24 \\ Dense & 48-81 \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
Type of Soil E_{ν} (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand 501 Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel 50	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
$\begin{tabular}{ c c c c } \hline Type of Soil & E_s (N/mm^2) \\ \hline Clay & & & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ Loess & 14-57 \\ Sand & & \\ Silty & 7-21 \\ Loose & 10-24 \\ Dense & 48-81 \\ \hline \end{tabular}$	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 \ psi$
Type of Soil E_{ν} (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till 10–153 Loose 10–153 Dense 144–720 Very dense 478–1,440 Looss 14–57 Sand 10–24 Dense 10–24 Dense 48–81 Sand and gravel 10–24 Loose 48–81	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 psi$



Champlain Hudson Power Express - Package 6 Project: KILDUF Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Tunnel No.: Pull Back and Mud Pressure Calcs Description: UNDERGROUND ENGINEERING, INC. Calculated by: DA Date: 4/13/23 R1: 6/12/23 Checked by: NW Date: 4/17/23 $L_{structure} \coloneqq 125 \ ft$ Length to sturcture $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)} \right)$ =0.4 **psi** Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure $p_{min.} \coloneqq p_1 + p_2 = 13.5 \ psi$ $check := if(p_{max} > p_{min.}, "okay", "not okay") = "okay"$



Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

D1.1 - Overburden Pressure (Considering E	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 79.2 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value =
$\left(\begin{array}{c} 1 \end{array} \right)^2$	reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{m} \cdot \tan\left(\frac{\phi}{\phi}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 21 \ psi \ P_E = 2978$	<i>psf</i> Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	PE4710, Base Temperature of 73 deg.
	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 2.8\%$	Pipe deflection to diameter as per
31011	PPI Equ. 10 (Chp 12, p 437, PPI Handbool
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 5.6\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)



Project:

Tunnel No.:

Description:

Calculated by: DA

Checked by: NW

Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194 \ in$	Thickness of casing pipe
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
$\gamma_m = 70 \ pcf$	Assumed unit weight of fluid in
t^3 in ⁴	borehole (Slurry unit weight)
$I := \frac{1}{12} = 0.14 \frac{i}{in}$	Moment of inertia of pipe wall cross
$(D_1)^4$	section
$0.1169 \cdot \gamma_m \cdot \left(\frac{1}{2} \right)$	Pipe ring deflection to buoyant force
$\gamma_{m} = 70 \text{ pcf}$ $I \coloneqq \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)^{4}$ $\Delta y_{bouyant} \coloneqq \frac{E_{short} \cdot I}{E_{short}} = 0.0$	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (Long Term)	
Please note that long term buoyant deflection	on was assumed negibile, since grout is
assumed to be cured after a 1-week period	
<u> 3 - Reissner Effect Deflection (Short Ter</u>	m)
3 - Reissner Effect Deflection (Short Ter D3.1 - Reissner Effect Deflection (Short Terr	-
3 - Reissner Effect Deflection (Short Ter D3.1 - Reissner Effect Deflection (Short Terr	-
D3.1 - Reissner Effect Deflection (Short Terr	<u>n)</u>
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} := 0.35$	-
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} := 0.35$	<u>n)</u> Poisson's Ratio for PE pipe material a
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Terr}$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n)
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Terr})$ $\mu_{long} \coloneqq 0.45$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Terr $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Terr $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2) Radius of curvature
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Terr $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Terr $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Terr})$ $\mu_{long} \coloneqq 0.45$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnr Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2) Radius of curvature

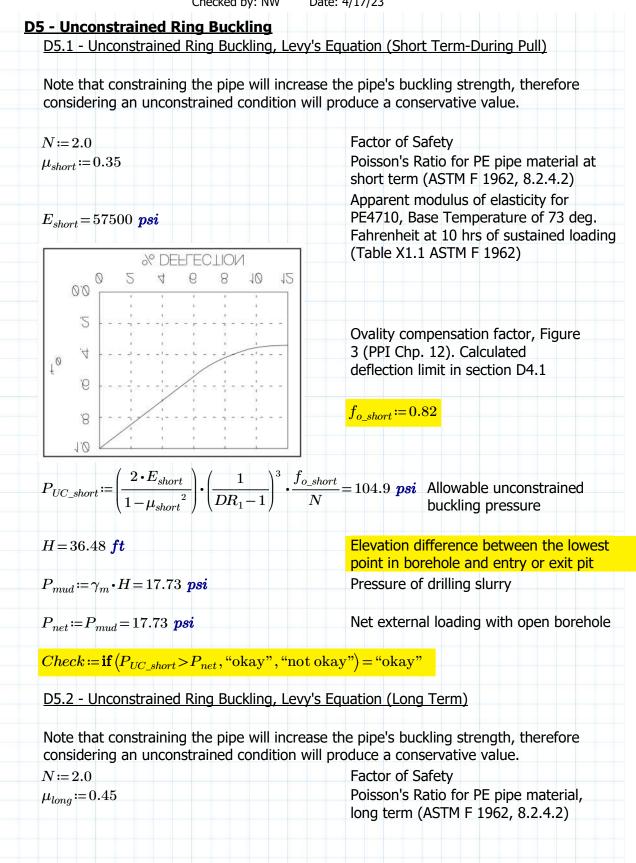


Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

D4 - Net Ring Deflection	
$\Delta y_{lim} \coloneqq 7.5\%$	Deflection limit for DR 9 non pressurized pipe (Table 2 , p. 437, PPI Handbook)
D4.1 - Net Short Term	
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y$	$P_{R_short} = 2.8\%$ Percent ring deflection in short term analysis
$Check\!\coloneqq\!\mathbf{if}\left(\! \varDelta y_{short_net} \!<\! \varDelta y_{lim}, \text{``okay''}, \text{``}\right.$	not okay") = "okay"
D4.2 - Net Long Term	
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{R_long} = 5.6\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``n} \right)$	not okay") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23



	Tunnel No.:CrDescription:PuCalculated by: DADa	hamplain Hudson Power Express - Package 6 rossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing III Back and Mud Pressure Calcs ate: 4/13/23 R1: 6/12/23 ate: 4/17/23
$E_{long} {=} 28200~{psi}$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$(2 \cdot E_{long})$) $(1)^3 f_{o_long}$	9 01 1
$P_{UC_long} \coloneqq \left(\frac{1}{1 - \mu_{long}^2} \right)^2$	$\left \cdot \left(\frac{DR_1 - 1}{DR_1 - 1} \right) \right \cdot \frac{1}{N}$	^g =31.1 psi Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ ps_w$	<i>i</i>	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := \mathbf{if} \left\langle P_{UC_long} \right\rangle$	P_{net} , "okay", "not ol	kay") = "okay"

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Champlain Hudson Power Express - Package 6 Crossing #96.A&B - S-23 (Hannacrois Creek) and CSX Railroad Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill



Champlain Hudson Power Express - Package 6 Crossing #97- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

	ional Drilling :
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$D_{rod} := 3.5 in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_{1}}{DR_{1}} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_{2}}{DR_{2}} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
	pipeandy
drill rig B	A a
	- running tunning tu
H,	
pipe exit C	B
	· · · · · · · · · · · · · · · · · · ·
L ₄ L ₃	· L ₂ L ₁
Loore	1
Illustration 1 - Schematic of	Drive Cross-section
$\alpha := 8^{\circ}$ $\alpha_{in} := \alpha = 0.1396 \ rad$	
616	Borehole entry angle (degrees, radians)
$\beta \coloneqq 8$ $\beta_{exit} \coloneqq \beta = 0.1396 \ rad$	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$ \begin{array}{c} \beta \coloneqq 8 & \beta_{exit} \coloneqq \beta \equiv 0.1396 \ \textbf{rad} \\ D_r \coloneqq 18 \cdot \textbf{in} \\ H_{max} \coloneqq 23.6 \ \textbf{ft} \end{array} $	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
$ \begin{array}{c} \beta \coloneqq 8 & \circ \\ B_{exit} \coloneqq \beta \equiv 0.1396 \ rad \\ D_r \coloneqq 18 \cdot in \end{array} $	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
$ \begin{array}{c} \beta \coloneqq 8 & \beta_{exit} \coloneqq \beta \equiv 0.1396 \ \textbf{rad} \\ D_r \coloneqq 18 \cdot \textbf{in} \\ H_{max} \coloneqq 23.6 \ \textbf{ft} \end{array} $	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
$\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 445.0 \text{ ft}$ $L_1 := 150 \text{ ft}$	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
$\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 445.0 \text{ ft}$	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
$\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 445.0 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 185.5 \text{ ft}$	 Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 445.0 \text{ ft}$ $L_1 := 150 \text{ ft}$	 Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #97- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ ho_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b \! \coloneqq \! \frac{\gamma_m}{\rho_w} \! = \! 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
<u>A - Axial Bending Stress</u>	<u>:</u>	
$R_{avg._in}$:=1000 ft		Radius of curvature at the entry, provided by Contractor
$R_{avg_out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$ \qquad \qquad$	$\frac{t}{t} = 1000 \ ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 35$	50 f t	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq$ if $\left(R_{avg._in} > \right)$	r _{rod} , "okay", "not	cokay") = "okay"
$Check \coloneqq \mathbf{if} \left(R_{avg._out} > \right)$	r_{rod} , "okay", "no	ot okay") = "okay"

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
E _{12hr} := 57500 • psi	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \coloneqq e_a \cdot E_{12hr} = 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



Champlain Hudson Power Express - Package 6 Crossing #97- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

B1.1 - Effective Weight of Empty Pipe: $w_{a} := \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p_{1}} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p_{2}} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \text{ plf}$ B1.2 - Upward Buoyant Force: Effective weight $w_{b} := \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2 \text{ plf}$ Upward buoyant force of empty pipe B1.3 - Hydrokinetic Pressure: $\Delta T := \Delta P \cdot \left(\frac{\pi}{8} \right) \left(D_{r}^{2} - \left(D_{1}^{2} + D_{2}^{2} \right) \right) = 796 \text{ lbf}$ Hydrokinetic force B1.4 - Pullback Force Point A: $T_{a} := e^{v_{a} \cdot \alpha_{w}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3} + L_{4} \right) \right) = 500 \text{ lbf}$ Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{w}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{w})} \right) = 4591 \text{ lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_{c} := T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3} \right) - e^{(v_{b} \cdot \alpha_{w})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{w})} \right) = 5434 \text{ lbf}$ B1.7 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{w})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \right) \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{w})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{w})} \right) \right) = 7452 \text{ lbf}$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max \left(T_{a}, T_{b}, T_{c}, T_{d} \right) + \Delta T = 8248 \text{ lbf}$ Maximum Pullback Force E2 - Filled Pipe with Water B2.1 - Upward Buoyant Force: $w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2} \right)}{4} \right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 24.6 \text{ plf}$	<u>1 - Empty Pipe</u>	
B1.2 - Upward Buoyant Force:Effective weight $w_b := \left(\frac{\pi \cdot (D_1^2 + D_2^2)}{4}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf$ Upward buoyant force of empty pipeB1.3 - Hydrokinetic Pressure: $\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) (D_r^2 - (D_1^2 + D_2^2)) = 796 \ lbf$ Hydrokinetic forceB1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_m} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 500 \ lbf$ Pullback force when pipe enters the groB1.5 - Pullback Force Point B: $T_b := e^{v_a \cdot \alpha_m} (T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_m)}) = 4591 \ lbf$ $T_b := e^{v_a \cdot \alpha_m} (T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_m)}) = 4591 \ lbf$ B1.6 - Pullback Force Point C: $T_c := T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_m)} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_m)}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_d := e^{(v_b \cdot \beta_{em})} \cdot (T_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_m)} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_m)})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max(T_a, T_b, T_c, T_d) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	B1.1 - Effective weight of Empty Pipe:	
$w_{b} := \left(\frac{\pi \cdot (D_{1}^{2} + D_{2}^{2})}{4}\right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2 \ plf $ Upward buoyant force of empty pipe B1.3 - Hydrokinetic Pressure: $\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_{r}^{2} - (D_{1}^{2} + D_{2}^{2})\right) = 796 \ lbf $ Hydrokinetic force B1.4 - Pullback Force Point A: $T_{a} := e^{v_{a} \cdot \alpha_{m}} \cdot \left(v_{a} \cdot w_{a} \cdot (L_{1} + L_{2} + L_{3} + L_{4})\right) = 500 \ lbf $ Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{m}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{m})}\right) = 4591 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_{c} := T_{b} + (v_{b} \cdot w_{b} \cdot L_{3}) - e^{(v_{b} \cdot \alpha_{m})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{m})}\right) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{stal})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{m})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{m})}\right)\right) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max \left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	$w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p1} \right)^{2} \right) \right)$	$\leftT_{p2} ight angle ^{2} ight) angle oldsymbol{\cdot} ho_{w}oldsymbol{\cdot} \gamma_{a} ightarrow 8.3 ~ plf$
B1.3 - Hydrokinetic Pressure: $\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf$ Hydrokinetic force B1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_m} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4\right)\right) = 500 \ lbf$ Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_b := e^{v_b \cdot \alpha_m} \left(T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_m)}\right) = 4591 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c := T_b + \left(v_b \cdot w_b \cdot L_3\right) - e^{(v_b \cdot \alpha_m)} \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_m)}\right) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_d := e^{(v_b \cdot \beta_{em})} \cdot \left(T_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_m)} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_m)}\right)\right) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max \left(T_a, T_b, T_c, T_d\right) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	B1.2 - Upward Buoyant Force:	Effective weight
$\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf \ \text{Hydrokinetic force}$ $B1.4 - \text{Pullback Force Point A:}$ $T_a := e^{v_a \cdot a_m} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4\right)\right) = 500 \ lbf \ Pullback force when pipe enters the groen between the probability of the second seco$	$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2 \text{ g}$	<i>plf</i> Upward buoyant force of empty pipe
B1.4 - Pullback Force Point A: $T_{a} := e^{v_{a} \cdot \alpha_{m}} \cdot (v_{a} \cdot w_{a} \cdot (L_{1} + L_{2} + L_{3} + L_{4})) = 500 \ lbf$ Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{m}} (T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{m})}) = 4591 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_{c} := T_{b} + (v_{b} \cdot w_{b} \cdot L_{3}) - e^{(v_{b} \cdot \alpha_{m})} \cdot (v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{m})}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{crit})} \cdot (T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{m})} \cdot (v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{m})})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	B1.3 - Hydrokinetic Pressure:	
$\begin{split} T_{a} &:= e^{v_{a} \cdot \alpha_{m}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3} + L_{4}\right)\right) = 500 \ \textit{lbf} \\ & Pullback force when pipe enters the grown of the set of $	$\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796$	<i>lbf</i> Hydrokinetic force
Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{in}} (T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})}) = 4591 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_{c} := T_{b} + (v_{b} \cdot w_{b} \cdot L_{3}) - e^{(v_{b} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{in})}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{cail})} \cdot (T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	B1.4 - Pullback Force Point A:	
Pullback force when pipe enters the gro B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 4591 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_{c} := T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3}\right) - e^{(v_{b} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{cxtl})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{m})}\right)\right) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max\left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	$T := e^{v_a \cdot \alpha_{in}} (a a (T + T + T + T))$	500 lbf
$\begin{array}{l} \underline{B1.5 - Pullback \ Force \ Point \ B:} \\ T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 4591 \ lbf \\ Pullback \ force \ increase \ with \ depth \\ \underline{B1.6 - Pullback \ Force \ Point \ C:} \\ T_{c} \coloneqq T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3}\right) - e^{(v_{b} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 5434 \ lbf \\ \underline{B1.7 - Pullback \ Force \ at \ D:} \\ T_{d} \coloneqq e^{(v_{b} \cdot \beta_{cxil})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) = 7452 \ lbf \\ \underline{B1.8 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \\ P_{max_empty} \coloneqq \max \left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf \\ Maximum \ Pullback \ Force \\ \underline{2 - Filled \ Pipe \ with \ Water} \\ \underline{B2.1 - Upward \ Buoyant \ Force:} \end{array}$	$L_a := e^{-1} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 5$	
Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c := T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_d := e^{(v_b \cdot \beta_{exil})} \cdot (T_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max (T_a, T_b, T_c, T_d) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	B1.5 - Pullback Force Point B:	
Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c := T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_d := e^{(v_b \cdot \beta_{exil})} \cdot (T_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} := \max (T_a, T_b, T_c, T_d) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:		$I = (v_{\cdot}, \alpha_{\cdot}) $ Apple $I = 0$
B1.6 - Pullback Force Point C: $T_{c} \coloneqq T_{b} + (v_{b} \cdot w_{b} \cdot L_{3}) - e^{(v_{b} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{in})}) = 5434 \ lbf$ B1.7 - Pullback Force at D: $T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exil})} \cdot (T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})})) = 7452 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} \coloneqq \max (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf$ Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	$T_b \coloneqq e^{-v} w_b \cdot L_2 + w_b \cdot H_{max} - v$	
$\begin{array}{l} \underline{B1.7 - Pullback \ Force \ at \ D:} \\ T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) = 7452 \ lbf \\ \underline{B1.8 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \\ P_{max_empty} \coloneqq \max \left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf \\ Maximum \ Pullback \ Force \\ \underline{P_{max_empty}} \coloneqq \max \left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf \\ \underline{B1.1 - Upward \ Buoyant \ Force} \\ \underline{P_{max_empty}} = \sum_{(x_{a}, x_{b}, x_{c}, $	B1.6 - Pullback Force Point C:	
$\begin{array}{l} \underline{B1.7 - Pullback \ Force \ at \ D:} \\ T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) = 7452 \ lbf \\ \underline{B1.8 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \\ P_{max_empty} \coloneqq \max \left(T_{a}, T_{b}, T_{c}, T_{d}\right) + \Delta T = 8248 \ lbf \\ Maximum \ Pullback \ Force \\ \underline{2 - Filled \ Pipe \ with \ Water} \\ \underline{B2.1 - Upward \ Buoyant \ Force:} \end{array}$		
$T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot (T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})})) = 7452 \ lbf$ $\underline{B1.8 - Maximum Pullback Force - Empty Pipe:}_{P_{max_empty} \coloneqq max} (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf_{Maximum Pullback Force}$ $\underline{P_{max_empty} \coloneqq max} (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf_{Maximum Pullback Force}$	$T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3)$	$(\cdot e^{(v_a \cdot \alpha_{in})}) = 5434 \ lbf$
$T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot (T_{c} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})})) = 7452 \ lbf$ $\underline{B1.8 - Maximum Pullback Force - Empty Pipe:}_{P_{max_empty} \coloneqq max} (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf_{Maximum Pullback Force}$ $\underline{P_{max_empty} \coloneqq max} (T_{a}, T_{b}, T_{c}, T_{d}) + \Delta T = 8248 \ lbf_{Maximum Pullback Force}$	B1.7 - Pullback Force at D:	
B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} \coloneqq max (T_a, T_b, T_c, T_d) + \Delta T = 8248$ <i>Ibf</i> Maximum Pullback Force 2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:		
$P_{max_empty} \coloneqq \max (T_a, T_b, T_c, T_d) + \Delta T = 8248 \ lbf$ Maximum Pullback Force $\frac{2 - Filled Pipe with Water}{B2.1 - Upward Buoyant Force}$	$T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max}\right)$	$-e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 7452 \ lbf$
$P_{max_empty} \coloneqq \max (T_a, T_b, T_c, T_d) + \Delta T = 8248 \ lbf$ Maximum Pullback Force $\frac{2 - Filled Pipe with Water}{B2.1 - Upward Buoyant Force}$	R1 8 - Maximum Pullback Force - Empty Pi	no:
2 - Filled Pipe with Water Maximum Pullback Force B2.1 - Upward Buoyant Force: Description	DI.0 - Maximum Pulback Force - Empty Pi	<u>pe.</u>
2 - Filled Pipe with Water B2.1 - Upward Buoyant Force:	$P_{max_empty} \coloneqq \max \left(T_a, T_b, T_c, T_d \right) + \Delta T = 8$	3248 <i>lbf</i>
B2.1 - Upward Buoyant Force:		Maximum Pullback Force
B2.1 - Upward Buoyant Force:	2 - Filled Pine with Water	
$w_{bfilled} \coloneqq \left(\frac{(\gamma \cdot D_1)}{4}\right) \cdot \rho_w \cdot \left(\gamma_b - \gamma_c \cdot \left(1 - \left(\frac{2}{DR_1}\right)\right)\right) - w_a = 24.6 \ plf$		$(2 \times 1)^2$
	$w_{bfilled} \coloneqq \left(\frac{\gamma \cdot \nu_1}{4}\right) \cdot \rho_w \cdot \left(\gamma_b - \gamma_c \cdot \left(1 - \left(\frac{2}{D}\right)\right)\right)$	$\left -w_a = 24.6 \ plf \right $
Unward buoyant force of pino filled with		Upward buoyant force of pipe filled with v



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B2.3 - Pullback Force Point B:	
$T_{bfilled} := e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot \left w_{bfilled} \right \cdot L_2 + \frac{1}{2} \right)$ B2.4 - Pullback Force Point C:	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot lpha_{in})} = 2721$ Pullback force increase and decrease depth
$T_{cfilled} \coloneqq T_{bfilled} + (v_b \cdot w_{bfilled} \cdot L_3) - e^{(v_b \cdot lpha_{ib})}$	$^{n} \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 3100 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot (T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_4$	$-e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 4606 \ lb$
<u>B2.6 - Maximum Pullback Force - Filled Pip</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}, T_{$	$l) = 4606 \ lbf$ Maximum Pullback Force
3 - Safe Pull Strength / Ultimate Tensil B3.1 Safe Pullback Check	<u>e Load Check:</u>
$A_1 := \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 \coloneqq \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 7928 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Em
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 320 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Em
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 4427 \ lbf$	Pullback forces acting on Pipe 1 (Bal
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 179 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Bal
<i>P</i> _{SPF1} :=41214 <i>lbf</i>	Safe pullback forces Pipe 1 (Table % p. 448, PPI)
<i>P</i> _{<i>SPF</i>2} :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq if(P_{SPF1} > P_{11}, "okay", "not okay$	
$check \coloneqq if(P_{SPF2} > P_{21}, "okay", "not okay)$	
$check \coloneqq if (P_{SPF1} > P_{12}, "okay", "not okay check \coloneqq if (P_{SPF2} > P_{22}, "okay", "not okay $	



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<u>C - Allowable Mud Pressures:</u>

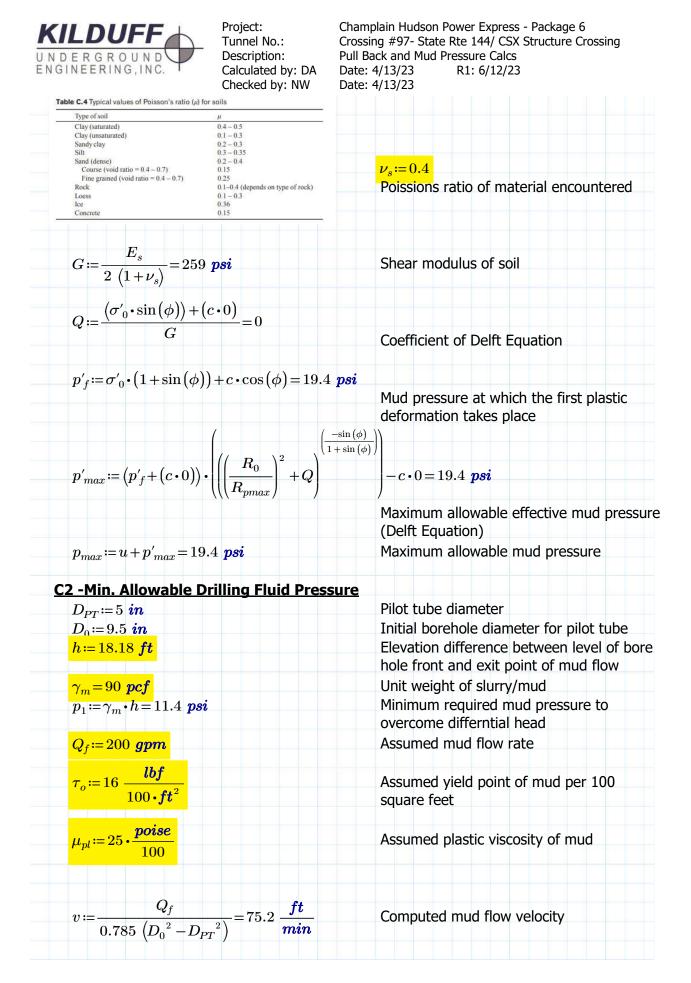
<u>C1 -</u>	Max.	Allowable	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

 Depth of the bore below groundwater elevation Vertical separation distance between critica structure and pipe (State Rte 144, ~2+00) Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material
structure and pipe (State Rte 144, ~2+00) Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle
Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle
Effective unit weight Initial pore water pressure Assumed friction Angle
Effective unit weight Initial pore water pressure Assumed friction Angle
Initial pore water pressure Assumed friction Angle
Initial pore water pressure Assumed friction Angle
Assumed cohesion of encountered materia
Initial radius of the borehole
Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$E_s \coloneqq 5 \frac{N}{mm^2} = 725 psi$
$E_s \coloneqq 5 \xrightarrow{2} = 725 \text{ pst}$
mm
Assumed modulus of elasticity
Assumed modulus of elasticity



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$L_{structure} \coloneqq 200 \; ft$		Length to sturcture
$p_2 \coloneqq L_{structure} \cdot \left(\left(- \frac{\mu}{2} \right) \right)$	$\left(\frac{u_{pl} \cdot v}{2}\right) + \left(\frac{\tau_{c}}{D}\right)$	Length to sturcture $\left(\frac{D_{PT}}{D_{PT}}\right) = 0.6 \ psi$
$\bigcup (D_0$	$(D_{PT})^2$	(\mathcal{D}_{PT})) Minimum required mud pressure to create
$p_{min} \coloneqq p_1 + p_2 = 12 \ p$	ei.	flow inside the borehole Minimum required mud pressure
$p_{min.} - p_1 + p_2 - 12 p$	51	Filmman required mad pressure
$check \coloneqq \mathbf{if} \left(p_{max} > p_m \right)$	_{in.} , "okay", "not ok	ay") = "okay"



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	<u>):</u>
	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 23.6 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18 \text{ in}$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	1 Arching factor (Eq. 6, p.432, PPI)
$P_L \approx 300 \ psf$	Live loading for E80 (RR at 23-feet
	depth; use 20-ft to be conservative)
$P_E \coloneqq (k \cdot (\gamma - \gamma_w) \cdot (H_c)) + P_L \equiv 8 psi$ $P_E \equiv 1187 psf$	Effective overburden pressure (psi) Effective overburden pressure (psf)
20 loads due to soil cover > 8-feet.	pected for the crossing. (i.e. no HS
20 loads due to soil cover > 8-feet.	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} = 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg.
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{3} = 9.36 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equation
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.1\%$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equation Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.1\%$ D1.3 Earth Load Deflection (Long Term) $E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equation Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo
20 loads due to soil cover > 8-feet. D1.2 Earth Load Deflection (Short Term) $E_{short} \coloneqq 57500 \cdot psi$ $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.1\%$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equation Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo Apparent modulus of elasticity for PE4710 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1



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D2 - Buoyant Deflection
D2.1 Buoyant Deflection (Short Term)
$D_1 = 10.75 \ in$
$t := T_{p1} = 1.194$ in
$E_{short} \!=\! 57500 \mathbf{psi}$
$\gamma_m = 90 \ pcf$
$I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$
$\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\%$

Outside diameter of casing pipe Thickness of casing pipe Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1) Assumed unit weight of fluid in borehole (Slurry unit weight) Moment of inertia of pipe wall cross section Pipe ring deflection to buoyant force ASTM F 1962 (Eq. X2.6, p.6)

D2.1 Buoyant Deflection (Long Term)

Please note that long term buoyant deflection was assumed negibile, since grout is assumed to be cured after a 1-week period from installation/pumping.

D3 - Reissner Effect Deflection (Short Term)

D3.1 - Reissner Effect Deflection (Short Term)

$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	Deflection due to longitudinal bending
$\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect Deflection (Long Term	<u>)</u>
$\mu_{long} \coloneqq 0.45$	Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
R=1000 ft	Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{long}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.000003$	Deflection due to longitudinal bending
$16 \cdot t^2 \cdot R^2$	
$\Delta y_{R_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term



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$\Delta y_{lim} \coloneqq 7.5\%$,)	Deflection limit for DR 9 non press
<u>D4.1 - Net S</u>	Short Term	pipe (Table 2 , p. 437, PPI Handbo
$\Delta y_{short_net} \coloneqq$	$\Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short}$	$p_{ort} = 1.2\%$ Percent ring deflection in term analysis
$\frac{Check := \mathbf{if} \left(\angle \right)}{Check := \mathbf{if} \left(\angle \right)}$	$\Delta y_{short_net} {<} \Delta y_{lim}, { m ``okay"}, { m ``not}$	okay") = "okay"
<u>D4.2 - Net L</u>	ong Term	
Δy_{long_net} := 2	$\Delta y_{ELD_long} + \Delta y_{R_long} = 2.2\%$	Percent ring deflection in long tern analysis (50 years)
Check := if ()	$\Delta y_{long_net} \! < \! \Delta y_{lim}, ext{``okay''}, ext{``not}$	okay'' = "okay"
	$2g_{long_net} < 2g_{lim}, on a g_{i}$	okay) – okay



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DJ.1 - Onconstrained King Buckling, E	evy's Equation (Short Term-During Pull)
Note that constraining the pipe will inc considering an unconstrained conditio	crease the pipe's buckling strength, therefore n will produce a conservative value.
N:=2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$E_{short} = 57500 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
0.0 0 2 4 6 8 10 12 % Deflection	(Table X1.1 ASTM F 1962)
0.2	
fo 0.6 O.6 O.4 O.4	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
1.0 TERM 0.8	$f_{o_short} \coloneqq 0.98$
	f
$P_{UC_short} \coloneqq \left(\frac{1}{1-\mu_{short}}\right) \cdot \left(\frac{1}{DR_1-1}\right) \cdot \left(\frac{1}{DR_$	$\frac{f_{o_short}}{N}$ = 125.4 psi Allowable unconstrained buckling pressure
$P_{UC_short} \coloneqq \left(\frac{1}{1-\mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1}-1}\right) \cdot H = 4.2 \ ft$	Elevation difference between the lowest
(· · · · · · · · · · · · · · · · · · ·	$\frac{50_snort}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry
H=4.2 ft	Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry
$H = 4.2 ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 2.63 psi$	Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole
$H = 4.2 ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 2.63 psi$ $P_{net} \coloneqq P_{mud} = 2.63 psi$	Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole not okay") = "okay"
$H = 4.2 ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 2.63 psi$ $P_{net} \coloneqq P_{mud} = 2.63 psi$ $Check \coloneqq if (P_{UC_short} > P_{net}, \text{``okay''}, \text{``})$ $D5.2 - \text{Unconstrained Ring Buckling, L}$ Note that constraining the pipe will income	Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole not okay") = "okay" evy's Equation (Long Term) crease the pipe's buckling strength, therefore
$H = 4.2 ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 2.63 psi$ $P_{net} \coloneqq P_{mud} = 2.63 psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{``start''} \right)$ $D5.2 - \text{Unconstrained Ring Buckling, Links}$	Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole not okay") = "okay" evy's Equation (Long Term) crease the pipe's buckling strength, therefore

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$E_{long} {=} 28200 \; psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}}\right)^2$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_1}{f_1}$	$\frac{b_long}{N} = 31.1 \text{ psi}$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ ps$	<i>i</i>	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := if (P_{UC_long})$	<u>⊳P "okay" "n</u>	(a + a + a) = (a + a)
	^{>1} _{net} , Okay, II	Stokay) – Okay



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill

97.A



Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

$D_1 := 10.75 \ in$	ional Drilling : Pipe 1 outer diameter		
$D_1 = 10.75 \ in$ $D_2 = 2.375 \ in$	Pipe 2 outer diameter		
$D_{2} = 2.575 \text{ in}$ $D_{rod} = 3.5 \text{ in}$	Assumed drill rod diameter Dimension ratio of Pipe 1		
$\frac{D_{rod} = 3.5 \ th}{DR_1 = 9}$			
$DR_1 = 9$ $DR_2 = 11$	Dimension ratio of Pipe 2		
-			
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1		
$T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2		
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1		
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2		
bore/pipepath	pipe entry		
rillrig B D	A a		
	B		
pipeexit			
	L) L		
	22 21		
- L _{bore}			
4 L _{bor}			
Illustration 1 - Schematic of	Drive Cross-section		
L_{bose} Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians)		
$\begin{array}{c} & \qquad $	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)		
\mathbf{L}_{tose} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 12^{\circ} \qquad \beta_{exit} := \beta = 0.2094 \text{ rad}$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter		
\mathbf{L}_{tore} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 12^{\circ} \qquad \beta_{exit} := \beta = 0.2094 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 60.5 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo		
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$\mathbf{L}_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 12^{\circ} \qquad \beta_{exit} := \beta = 0.2094 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 60.5 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 61.25 \text{ ft}$ $L_{total} := 1770 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing		
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KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ ho_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma_a := 0.965$		Specific gravity of pipe
$\gamma_m := 90 \; pcf$		Assumed unit weight of slurry
$\gamma_b \! \coloneqq \! \frac{\gamma_m}{\rho_w} \! = \! 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
<u>A - Axial Bending Stress</u>	<u>11</u>	
$R_{avg._in}$:= 1000 ft		Radius of curvature at the entry, provided by Contractor
$R_{avg_out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$ \qquad \qquad$	$\frac{dt}{dt} = 1000 \; ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 35$	50 f t	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq$ if $\left(R_{avg._in} > \right)$	r _{rod} , "okay", "not	okay") = "okay"
$Check \coloneqq \mathbf{if} \left(R_{avg_out} \right)$	r_{rod} , "okay", "no	tokay") = "okay"

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \! \coloneqq \! e_a \! \cdot \! E_{12hr} \! = \! 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

B - Site Specific Analyses: Pullback Force: B1 - Empty Pipe B1.1 - Effective Weight of Empty Pipe: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ B1.3 - Hydrokinetic Pressure: $\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf \text{ Hydrokinetic force}$ B1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1619 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 11669 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 23551 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 29676 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 30472 \ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} \boldsymbol{D}_{1}^{-2} \right)}{4} \right) \boldsymbol{\cdot} \rho_{w} \boldsymbol{\cdot} \left(\gamma_{b} - \gamma_{c} \boldsymbol{\cdot} \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 24.6 \ \boldsymbol{plf}$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

$$T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1619 \ \textit{lbf} \quad \text{Pullback force enter ground}$$



Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

B2.3 - Pullback Force Point B:	Jale: 4/13/23
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot w_{bfilled} \cdot L_2 + u_b \cdot w_{bfilled} \right)$	$-w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 7078 \ l_{max}$ Pullback force increase and decrease w
B2.4 - Pullback Force Point C:	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 \right) - e^{\left(v_b \cdot c_b \right)}$	$(\alpha_{in}) \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 12418 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_{cfilled}\right)$	$\left(v_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 16782 \ lb_3$
B2.6 - Maximum Pullback Force - Filled Pi	pe with Water:
$P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$	$_{ed}) = 16782 \ lbf$ Maximum Pullback Force
3 - Safe Pull Strength / Ultimate Tensi	ile Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 := \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 0.8 \ \boldsymbol{in}^2$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 29290 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empt
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 1182 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empt
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 16131 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ballas
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 651 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Ballas
<i>P</i> _{SPF1} :=41214 <i>lbf</i>	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
<i>P</i> _{<i>SPF</i>2} := 1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check := if(P_{SPF1} > P_{11}, "okay", "not okay")$	
$check \coloneqq if(P_{SPF2} > P_{21}, "okay", "not okay")$	
	y") = "okay" y") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

<u>C</u> - Allowable Mud Pressures:

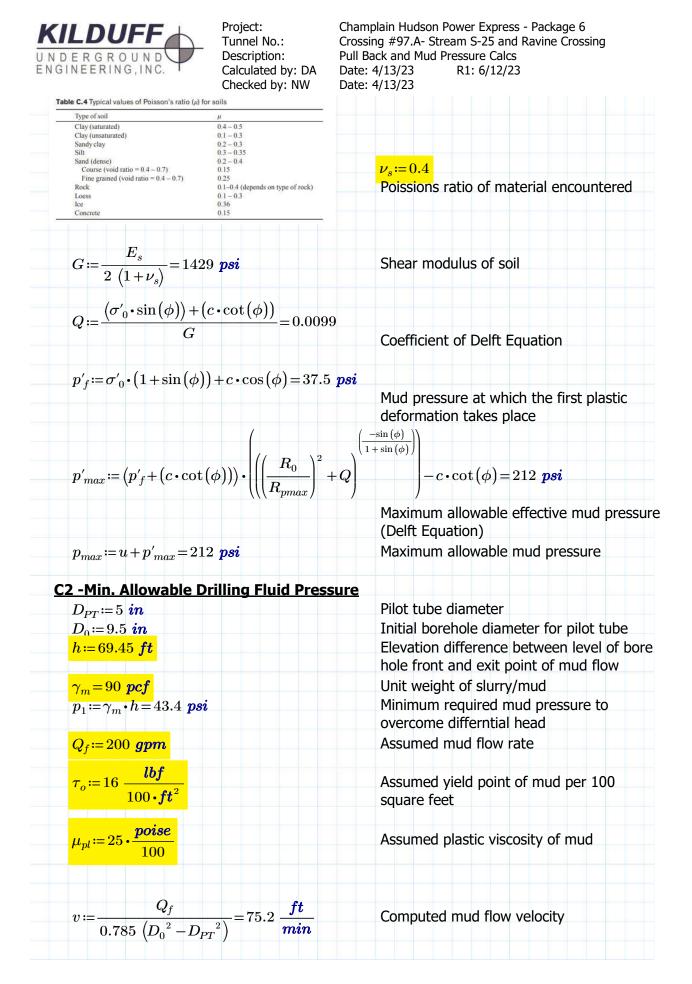
<u>C1 -</u>	Max.	Allowabl	e Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

$H_w := 0 \cdot ft$	Depth of the bore below groundwater elevation
H _c ≔24.08 ft	Vertical separation distance between critic structure and pipe (wetlands S37, ~3+79)
γ:=140 pcf	Assumed unit weight interbedded sandstone and shale
$\gamma_m \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 77.6 \ pcf$	Effective unit weight
$u := \gamma_w \cdot H_w = 0 psi$	Initial pore water pressure
$\frac{1}{\phi} = 37 \frac{deg}{deg}$	Assumed friction Angle
$c \coloneqq 0 \ psf = 0 \ psi$	Assumed cohesion of encountered materia
$R_0 := \frac{D_{rod}}{2} = 1.75 \ in$	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{2}{3} \cdot H_c = 16 \ ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\gamma_{0} \coloneqq (\gamma \cdot (H_{c} - H_{w})) + \gamma$	$\gamma' \cdot H_w = 23.4 \ psi$ Initial effective stress
C.2 Typical values of modulus of elasticity	
C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft	(E _s) for different types of soils E _y (N/mm ²) 2-15
C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium	(E _s) for different types of soils E _s (N/mm ²) 2-15 5-25
C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy	(E _s) for different types of soils E _s (N/mm ²) 2-15 5-25
C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose	$ \frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{5-25}} = \frac{1}{27.579} \frac{N}{mm^{2}} = 4000 \text{ psi} $ 10-153 Assumed modulus of elasticity
C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense	$ \underbrace{E_{s} \text{ for different types of soils}}_{E_{s}(N/mm^{2})} = E_{s} := 27.579 \frac{N}{mm^{2}} = 4000 psi$
C.2 Typical values of modulus of elasticity of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess	$ \frac{(E_{s}) \text{ for different types of soils}}{E_{i} (N/mm^{2})} \frac{2-15}{5-25} \frac{5-25}{15-50} \frac{10-153}{25-250} E_{s} := 27.579 \frac{N}{mm^{2}} = 4000 \text{ psi} $
Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{5-25}} = \frac{N}{E_{s} := 27.579} \frac{N}{mm^{2}} = 4000 psi}$ $\frac{10-153}{144-720}$ $\frac{10-153}{478-1,440}$ $\frac{14-57}{14-57}$ Assumed modulus of elasticity
e C.2 Typical values of modulus of elasticity in Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{15-50}} = \frac{1}{E_{s}:=27.579} \frac{N}{mm^{2}} = 4000 psi}$ $\frac{10-153}{144-720}$ Assumed modulus of elasticity $\frac{144-720}{478-1,440}$
e C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty	$ \frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{5-25}} = \frac{N}{E_{s}:=27.579} \frac{N}{mm^{2}} = 4000 \text{ psi}} $ $ \frac{10-153}{144-720} \\ \frac{14-720}{478-1,440} \\ \frac{14-57}{7-21} $
e C.2 Typical values of modulus of elasticity i Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand Silty Loose Dense Sand Silty Loose Dense Sand	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{15-50}} = \frac{1}{27.579} \frac{N}{mm^{2}} = 4000 \text{ psi}}$ $\frac{10-153}{144-720} \text{ Assumed modulus of elasticity}}$ $\frac{144-720}{478-1,440} = \frac{1}{10-24}$
e C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel Loose	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{15-50}} = \frac{N}{mm^{2}} = 4000 \text{ psi}$ $\frac{10-153}{144-720}$ $\frac{10-153}{144-720}$ $\frac{10-153}{144-720}$ $\frac{10-153}{14-57}$ $\frac{10-15}{14-57}$ $10-$
e C.2 Typical values of modulus of elasticity i Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand Silty Loose Dense Sand Silty Loose Dense Sand	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{15-50}} = \frac{1}{27.579} \frac{N}{mm^{2}} = 4000 \text{ psi}}$ $\frac{10-153}{144-720} \text{ Assumed modulus of elasticity}}$ $\frac{144-720}{478-1,440} = \frac{1}{10-24}$
e C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel Loose Sand and gravel Loose Sand and gravel San	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/mm^{2})}{15-50}} = \frac{N}{mm^{2}} = 4000 \text{ psi}$ $\frac{10-153}{14-720} \text{ Assumed modulus of elasticity}}{14-57}$ $\frac{7-21}{10-24}$ $48-148$ $96-192$
e C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand gravel Loose Dense Sand	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/\text{nm}^{2})}{15-50}} = \frac{N}{mn^{2}} = 4000 \text{ psi}$ $\frac{E_{s} := 27.579 \frac{N}{mn^{2}} = 4000 \text{ psi}}{\frac{N}{mn^{2}}} = 4000 \text{ psi}$ $\frac{10-153}{144-720}$ $\frac{14-720}{478-1,440}$ $\frac{14-57}{7-21}$ $\frac{10-24}{48-81}$ $\frac{48-148}{96-192}$ $14-14,400$
e C.2 Typical values of modulus of elasticity of Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand gravel Loose Dense Sand	$\frac{(E_{s}) \text{ for different types of soils}}{\frac{E_{s}(N/\text{nm}^{2})}{15-50}} = \frac{N}{mn^{2}} = 4000 \text{ psi}$ $\frac{E_{s} := 27.579 \frac{N}{mn^{2}} = 4000 \text{ psi}}{\frac{N}{mn^{2}}} = 4000 \text{ psi}$ $\frac{10-153}{144-720}$ $\frac{14-720}{478-1,440}$ $\frac{14-57}{7-21}$ $\frac{10-24}{48-81}$ $\frac{48-148}{96-192}$ $14-14,400$



KILDUFF UNDERGROUND ENGINEERING, INC.	Tunnel No.:CDescription:PCalculated by: DAD	hamplain Hudson Power Express - Package 6 rossing #97.A- Stream S-25 and Ravine Crossing ull Back and Mud Pressure Calcs ate: 4/13/23 R1: 6/12/23 ate: 4/13/23
$egin{aligned} & L_{structure} \coloneqq 200 \; \textit{ft} \ & p_2 \coloneqq L_{structure} \cdot \left(\left(rac{\mu_p}{(D_0 - p_{min.})} ight) + p_2 & = 44 \; \textit{ps} \end{aligned}$		Length to sturcture $\overline{p_{T}}$) = 0.6 <i>psi</i> Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure
$check \coloneqq if(p_{max} > p_{min})$	_{ı.} , "okay" , "not okay	(") = (okay")



Champlain Hudson Power Express - Package 6 Crossing #97.A- Stream S-25 and Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

$\gamma = 140 \ pcf$ $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)$ $P_E := k \cdot (\gamma - \gamma_w) \cdot (H_c) = 2 \ psi$ $P_E = 250 \ psf$ Effective overburden pressure D1.2 Earth Load Deflection (Short Term) $E_{short} := \frac{57500 \cdot psi}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ $\Delta y_{ELD_short} := \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handt) D1.3 Earth Load Deflection (Long Term) $E_{long} := 28200 \cdot psi$ $dy_{ELD_short} := \frac{28200 \cdot psi}{k_{short}}$ Unit weight of soil, assumed $dx_{ching} = 28200 \cdot psi$ Unit weight of soil, assumed $dx_{ching} = 0.053$ $dy_{ELD_short} := \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handt) Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)	D1.1 - Overburden Pressure (Considering Defo	rmed Borehole with Arching Mobilized)
$B := D_r = 18 in$ $F := \tan \left(45 - \frac{\phi}{2} \right)^2$ $Y = 140 pcf$ $I = \exp \left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right) \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan \left(\frac{\phi}{2} \right)$ $A rching factor (Eq. 6, p.432, PPI)$ $A rching factor (Eq. 6, p.43, $	$H_c \coloneqq H_{max} = 60.5 \; ft$	Depth of cover
$K := \tan\left(45 - \frac{\phi}{2}\right)^{2}$ Earth pressure coefficient $\gamma = 140 \text{ pcf}$ $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ Arching factor (Eq. 6, p.432, PPI) $2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)$ $P_{E} := k \cdot (\gamma - \gamma_{w}) \cdot (H_{c}) = 2 \text{ psi} P_{E} = 250 \text{ psf}$ Effective overburden pressure D1.2 Earth Load Deflection (Short Term) $E_{short} := 57500 \cdot psi$ $Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $4y_{ELD_short} := \frac{0.0125 \cdot P_{E}}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handt) D1.3 Earth Load Deflection (Long Term) $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $12 \cdot (DR_{1} - 1)^{3} = 4.6 \text{ psi}$ Dine deflection to diameter as per D1.2 Comparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati D1.3 Earth Load Deflection (Long Term) $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati D1.4 CDR_{1} - 1 Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustai$	$\phi = 37 \ deg$	Friction angle of soil
$K := \tan\left(45 - \frac{\phi}{2}\right)^{2}$ Earth pressure coefficient $\gamma = 140 \text{ pcf}$ $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ Arching factor (Eq. 6, p.432, PPI) $2 \cdot \frac{K \cdot H_{c}}{B} \cdot \tan\left(\frac{\phi}{2}\right)$ $P_{E} := k \cdot (\gamma - \gamma_{w}) \cdot (H_{c}) = 2 \text{ psi} P_{E} = 250 \text{ psf}$ Effective overburden pressure D1.2 Earth Load Deflection (Short Term) $E_{short} := 57500 \cdot psi$ $Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $4y_{ELD_short} := \frac{0.0125 \cdot P_{E}}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handt) D1.3 Earth Load Deflection (Long Term) $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $12 \cdot (DR_{1} - 1)^{3} = 4.6 \text{ psi}$ Dine deflection to diameter as per D1.2 Comparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati D1.3 Earth Load Deflection (Long Term) $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)$ Variable in earth load deflection equati $Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati D1.4 CDR_{1} - 1 Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustai$	$B \coloneqq D_r = 18$ in	"Silo" width, conservative value =
$\gamma = 140 \text{ pcf}$ Unit weight of soil, assumed $k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ Arching factor (Eq. 6, p.432, PPI) $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)$ P_E := $k \cdot (\gamma - \gamma_w) \cdot (H_c) = 2 \text{ psi}$ P_E = 250 psf Effective overburden pressure D1.2 Earth Load Deflection (Short Term) $E_{short} := \frac{57500 \cdot psi}{12 \cdot (DR_1 - 1)^3} = 9.36 \text{ psi}$ D1.3 Earth Load Deflection (Long Term) $k_{short} := \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handth D1.3 Earth Load Deflection (Long Term) $k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ Dino deflection to diameter as per Dino deflection to diameter as per Dino deflection equation Dino deflection equation Dino deflection equation Dino deflection to diameter as per Dino deflection equation Dino deflection equation Dino deflection equation Dino deflection to diameter as per Dino deflection equation Dino deflection to diameter as per Dino deflection equation Dinformed equation Dino deflection equation Dino deflection equat	$\left(1\right)^{2}$	reamed hole diameter
$k := \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$ $2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)$ $P_E := k \cdot (\gamma - \gamma_w) \cdot (H_c) = 2 \text{ psi} P_E = 250 \text{ psf}$ Effective overburden pressure D1.2 Earth Load Deflection (Short Term) $E_{short} := 57500 \cdot psi$ $E_{short} := \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \text{ psi}$ $\Delta y_{ELD_short} := \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PI Handt) D1.3 Earth Load Deflection (Long Term) $E_{long} := 28200 \cdot psi$ $k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ Dime deflection to diameter as per Pipe deflectio	$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$P_{E} := k \cdot (\gamma - \gamma_{w}) \cdot (H_{c}) = 2 \text{ psi} P_{E} = 250 \text{ psf}$ Effective overburden pressure $D1.2 \text{ Earth Load Deflection (Short Term)}$ $E_{short} := 57500 \cdot psi$ $k_{short} := \frac{E_{short}}{12 \cdot (DR_{1} - 1)^{3}} = 9.36 \text{ psi}$ $\Delta y_{ELD_short} := \frac{0.0125 \cdot P_{E}}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PFI Equ. 10 (Chp 12, p 437, PFI Handt) $D1.3 \text{ Farth Load Deflection (Long Term)}$ $E_{long} := 28200 \cdot psi$ $k := \frac{E_{long}}{12 \cdot (DR_{1} - 1)^{3}} = 4.6 \text{ psi}$ $12 \cdot (DR_{1} - 1)^{3}$ $= 4.6 \text{ psi}$ Dime deflection to diameter as per PFI Equ. 10 and the presence of	$\gamma = 140 \ pcf$	Unit weight of soil, assumed
$P_{E} := k \cdot (\gamma - \gamma_{w}) \cdot (H_{c}) = 2 \text{ psi} P_{E} = 250 \text{ psf}$ Effective overburden pressure $D1.2 \text{ Earth Load Deflection (Short Term)}$ $E_{short} := 57500 \cdot psi$ $k_{short} := \frac{E_{short}}{12 \cdot (DR_{1} - 1)^{3}} = 9.36 \text{ psi}$ $Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962) Variable in earth load deflection equati \Delta y_{ELD_short} := \frac{0.0125 \cdot P_{E}}{k_{short}} = 0.2\% Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handt D1.3 Earth Load Deflection (Long Term) E_{long} := 28200 \cdot psi k := \frac{E_{long}}{12 \cdot (DR_{1} - 1)^{3}} = 4.6 \text{ psi} Variable in earth load deflection equati Dine deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handter) Dine deflection equati Dine deflection equati Dine deflection equati Dine deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handter) Dine deflection equati Dine deflection equati Dine deflection equati Dine deflection equati Dine deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handter) Dine deflection equati Din$	$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{R}\right)\right)$	
$P_{E} := k \cdot (\gamma - \gamma_{w}) \cdot (H_{c}) = 2 \text{ psi} P_{E} = 250 \text{ psf}$ Effective overburden pressure $D1.2 \text{ Earth Load Deflection (Short Term)}$ $E_{short} := 57500 \cdot psi$ $k_{short} := \frac{E_{short}}{12 \cdot (DR_{1} - 1)^{3}} = 9.36 \text{ psi}$ $\Delta y_{ELD_short} := \frac{0.0125 \cdot P_{E}}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handt) $D1.3 \text{ Earth Load Deflection (Long Term)}$ $k_{i} := \frac{E_{long}}{12 \cdot (DR_{1} - 1)^{3}} = 4.6 \text{ psi}$ $k_{i} := \frac{E_{long}}{12 \cdot (DR_{1} - 1)^{3}} = 4.6 \text{ psi}$ Diameter of the presence of the presenc	$k \coloneqq \frac{\left(\begin{array}{c}B\\2\end{array}\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.053$	Arching factor (Eq. 6, p.432, PPI)
$E_{short} := 57500 \cdot psi$ Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962) $k_{short} := \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ Variable in earth load deflection equati $\Delta y_{ELD_short} := \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI HandhD1.3 Earth Load Deflection (Long Term)Apparent modulus of elasticity for PE47 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) $k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equati		Effective overburden pressure
$E_{short} \coloneqq 57500 \cdot psi$ PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962) $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ Variable in earth load deflection equation $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handle Dase Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 $D1.3$ Earth Load Deflection (Long Term)Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1) $E_{long} \coloneqq 28200 \cdot psi$ Astronometric probability $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equationDiam deflection to diameter as per PPI Equ. 10Variable in earth load deflection equation $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equationDiam deflection to diameter as per PPI Equ. 10Pipe deflection equation $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equation $k \vdash \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equation $k \vdash \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equation $k \vdash \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equation	D1.2 Earth Load Deflection (Short Term)	
shortFahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962) $k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$ Fahrenheit at 10 hrs of sustained loadi (Table X1.1 ASTM F 1962) $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handb D1.3 Earth Load Deflection (Long Term) $D1.3$ Earth Load Deflection (Long Term)Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equati		
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \text{ psi}$ $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ $D1.3 \text{ Earth Load Deflection (Long Term)}$ $E_{long} \coloneqq 28200 \cdot psi$ $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ $12 \cdot (DR_1 - 1)^3 = 4.6 \text{ psi}$ $Diag deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handle Discrete to the second seco$	$E_{short} \coloneqq 57500 \cdot psi$	
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \text{ psi}$ $\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handle D1.3 Earth Load Deflection (Long Term) $E_{long} \coloneqq 28200 \cdot psi$ Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1) ASTM F 1962) $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ Dina deflection to diameter as per PVI Equ. 10 (Chp 12, p 437, PVI Handle Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1) ASTM F 1962) Variable in earth load deflection equati		
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$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.2\%$ Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handle D1.3 Earth Load Deflection (Long Term) $E_{long} \coloneqq 28200 \cdot psi$ Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Dipa deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handle Apparent modulus of elasticity for PE42 Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati	$k_{short} \coloneqq \frac{12 \cdot \left(DR_1 - 1\right)^3}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ psi$	variable in earth load deflection equation
$\frac{D1.3 \text{ Earth Load Deflection (Long Term)}}{E_{long} \coloneqq 28200 \cdot psi}$ $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ $\text{Apparent modulus of elasticity for PE42}$ $\text{Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962)}$ $Variable in earth load deflection equation of the second s$	$0.0125 \cdot P_E = 0.0\%$	Dine deflection to dispector as now
D1.3 Earth Load Deflection (Long Term)Apparent modulus of elasticity for PE42 $E_{long} \coloneqq 28200 \cdot psi$ Apparent modulus of elasticity for PE42 $k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Apparent modulus of elasticity for PE42Disc deflection (Long Term)Apparent modulus of elasticity for PE42Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1)ASTM F 1962)Variable in earth load deflection equationDisc deflection to diameter as per	$\Delta y_{ELD_short} \coloneqq \underbrace{k_{short}}_{k_{short}} \equiv 0.2\%$	
$E_{long} \coloneqq 28200 \cdot psi$ Apparent modulus of elasticity for PE42 $Base Temperature of 73 Fahrenheit atyears of sustained loading (Table X1.1ASTM F 1962)ASTM F 1962)k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psiVariable in earth load deflection equation$		FFI Equ. 10 (Chp 12, p 437, FFI Handboo
$E_{long} := 28200 \cdot psi$ Base Temperature of 73 Fahrenheit at years of sustained loading (Table X1.1 ASTM F 1962) $k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$ Variable in earth load deflection equati		Apparent modulus of elasticity for PE4710
$k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ years of sustained loading (Table X1.1 ASTM F 1962) Variable in earth load deflection equati	$E_{$	•••
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \text{ psi}$ ASTM F 1962) Variable in earth load deflection equation Displayed and the prime deflection is a per-	<i>Ellong</i> - 28200 • ps	· · · · · · · · · · · · · · · · · · ·
	$k = \frac{E_{long}}{-4.6}$ nsi	
	$12 \cdot (DR - 1)^3$ = 1.0 pet	
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 0.5\%$ PPI Equ. 10 (Chp 12, p 437)		Pipe deflection to diameter as per
k k	$\Delta y_{ELD long} \coloneqq \frac{0.0125 \cdot P_E}{=} = 0.5\%$	
	-seeding k	



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D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t = T_{p1} = 1.194$ in	Thickness of casing pipe
<i>p</i> 1	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
~ -00 maf	Assumed unit weight of fluid in
$\gamma_m = 90 \ \mathbf{pcj}$	borehole (Slurry unit weight)
t^{3} of t^{4}	
$I \coloneqq \frac{1}{12} = 0.14 \frac{1}{in}$	Moment of inertia of pipe wall cross
$(D_1)^4$	section
$0.1169 \cdot \gamma_m \cdot (-2)$	Pipe ring deflection to buoyant force
$\Delta y_{bouyant} \coloneqq \frac{\langle 2 \rangle}{E} = 0.1\%$	ASTM F 1962 (Eq. X2.6, p.6)
$\gamma_{m} = 90 \text{ pcf}$ $I \coloneqq \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)^{4}}{E_{short} \cdot I} = 0.1\%$	
D2.1 Buoyant Deflection (Long Term)	
Please note that long term buoyant deflection	
assumed to be cured after a 1-week period f	rom installation/pumping.
- Reissner Effect Deflection (Short Terr	<u>n)</u>
D3.1 - Reissner Effect Deflection (Short Term	-
	1)
	<u>n</u>
	Poisson's Ratio for PE pipe material at
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) \ (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term $\mu_{long} := 0.45$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term $\mu_{long} := 0.45$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{long}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.000003$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect) Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature

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<u>D4 - Net Ring Deflection</u>	
$\Delta y_{lim} = 7.5\%$	Deflection limit for DR 9 non pressurized pipe (Table 2 , p. 437, PPI Handbook)
D4.1 - Net Short Term	
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short}$	$_{hort} = 0.3\%$ Percent ring deflection in short term analysis
$Check \coloneqq \mathbf{if} \left(\Delta y_{short_net} < \Delta y_{lim}, \text{``okay''}, \text{``not} \right)$	tokay") = "okay"
D4.2 - Net Long Term	
$\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \Delta y_{R_long} \! = \! 0.5\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``not} \right)$	okay") = "okay"



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D5.1 - Unconstrained Ring Buckling,	Levy's Equation (Short Term-During Pull)
Note that constraining the pipe will in considering an unconstrained condition	ncrease the pipe's buckling strength, therefore on will produce a conservative value.
N≔2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
0 2 4 6 8 10 12 % Deflection	(Table X1.1 ASTM F 1962)
0.0	
0.2	
fo 0.4	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated
0.6 0F7.5%	deflection limit in section D4.1
ASSUME LONG TERM DEFLECTION AT LIMIT	
1.0 TERM 0.8	$f_{o_short} \coloneqq 0.98$
	$\cdot \frac{f_{o_short}}{N} = 125.4 \ psi$ Allowable unconstrained buckling pressure
$(1-\mu_{short})$ (DR_1-1)	N buckling pressure
$H = 4.2 \ ft$	Elevation difference between the lowest
$P_{mud} \coloneqq \gamma_m \cdot H = 2.63 \ psi$	point in borehole and entry or exit pit Pressure of drilling slurry
$1 mud - 7m^{-11} - 2.00 pst$	
$P_{net} \coloneqq P_{mud} = 2.63 \ psi$	Net external loading with open borehole
$Check \coloneqq if(P_{UC_short} > P_{net}, "okay","$	"not okay") = "okay"
D5.2 - Unconstrained Ring Buckling,	
DS.2 - Onconstrained King Ducking,	Levy's Equation (Long Term)
	ncrease the pipe's buckling strength, therefore on will produce a conservative value.
considering an anconstrained condition	Factor of Safety
N := 2.0	
	Poisson's Ratio for PE pipe material, long term (ASTM F 1962, 8.2.4.2)

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$E_{long} = 28200 \ psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}} \right)$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \left(\frac{f_d}{dR_1-1}\right)^3$	$\frac{D_{a}long}{N} = 31.1 \ psi$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ ps$	si	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := \mathbf{if} \left(P_{UC_long} \right)$	$>P_{net},$ "okay", "no	ot okay") = "okay"
(



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill



Champlain Hudson Power Express - Package 6 Crossing #98- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

ining Parameters of Horizontal Directi	
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_1 = 2.375 \text{ in}$	Pipe 2 outer diameter
$D_{2i} = 2.516$ in $D_{rod} = 3.5$ in	Assumed drill rod diameter
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepath	pipeentry
drill rig 8	
p D	A
H	
CI	B
pipeexit	
• •	
L L L	· · · · · · · · · · · · · · · · · · ·
Illustration 1 - Schematic of	Drive Cross-section
$\alpha \coloneqq 10^{\circ}$ $\alpha_{in} \coloneqq \alpha = 0.1745 \ rad$	
	Borehole entry angle (degrees, radians)
	Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$\begin{array}{l} \beta \coloneqq 14 \ ^{\circ} \qquad \beta_{exit} \coloneqq \beta \equiv 0.2443 \ rad \\ D_r \coloneqq 18 \cdot in \\ H_{max} \coloneqq 48.4 \ ft \end{array}$	Borehole exit angle (degrees, radians) Final reamed bore diameter
$\begin{array}{c} \beta \coloneqq 14 & \beta_{exit} \coloneqq \beta \equiv 0.2443 \ rad \\ D_r \coloneqq 18 \cdot in \end{array}$	Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
$\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 48.4 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 49.15 \ ft$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
$\begin{array}{l} \beta \coloneqq 14 \circ & \beta_{exit} \coloneqq \beta \equiv 0.2443 \ rad \\ D_r \coloneqq 18 \cdot in \\ H_{max} \coloneqq 48.4 \ ft \end{array}$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
$\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 48.4 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 49.15 \text{ ft}$ $L_{total} := 883.2 \text{ ft}$ $L_1 := 150 \text{ ft}$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bordiameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 48.4 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 49.15 \ ft$ $L_{total} := 883.2 \ ft$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
$\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 48.4 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 49.15 \text{ ft}$ $L_{total} := 883.2 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 433.7 \text{ ft}$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bordiameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 48.4 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 49.15 \text{ ft}$ $L_{total} := 883.2 \text{ ft}$ $L_1 := 150 \text{ ft}$	 Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bordiameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -

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$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ ho_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b \! \coloneqq \! \frac{\gamma_m}{\rho_w} \! = \! 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
<u>A - Axial Bending Stress</u>	<u>.</u>	
$R_{avg._in}$:=1000 ft		Radius of curvature at the entry, provided by Contractor
$R_{avg_out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$ \qquad \qquad$	$\frac{dt}{dt} = 1000 \; ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 35$	0 ft	ASTM F 1962-99, Equation 1, p7
$\underline{Check}\!\coloneqq\!\mathbf{if}\left(\!R_{avg._in}\!\!>\!$	r _{rod} , "okay", "not	(vokay") = "okay"
$Check \coloneqq \mathbf{if} \left(R_{avg_out} > \right)$	≻r _{rod} , "okay", "no	tokay") = "okay"

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
E _{12hr} := 57500 • psi	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \coloneqq e_a \cdot E_{12hr} = 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



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Checked by: NW Date	e: 4/15/23
Site Specific Analyses: Pullback Force:	
<u>1 - Empty Pipe</u>	
B1.1 - Effective Weight of Empty Pipe:	
$w_a := \frac{\pi}{4} \left(\left(D_1^{2} - \left(D_1 - T_{p1} \right)^2 \right) + \left(D_2^{2} - \left(D_2 - T_{p1} \right)^2 \right) \right)$	$\left.T_{p2}\right\rangle^{2}\left)\left)\cdot ho_{w}\cdot\gamma_{a}\!=\!8.3 \; plf$
B1.2 - Upward Buoyant Force:	Effective weight
$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2 \ pl_{s}$	f Upward buoyant force of empty pipe
B1.3 - Hydrokinetic Pressure:	
$\Delta T := \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ low{l}$	bf Hydrokinetic force
B1.4 - Pullback Force Point A:	
$T = v_a \cdot \alpha_m \left(\cdot $	0.11.6
$T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 94$	2 <i>lof</i> Pullback force when pipe enters the ground
B1.5 - Pullback Force Point B:	
$T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot \left w_{b} \right \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \right)$	
	Pullback force increase with depth
B1.6 - Pullback Force Point C:	
$T_c \coloneqq T_b + \left(v_b \cdot w_b \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{\left(v_b \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{\left(v_b \cdot \alpha_{in} \right)} \right)$	$e^{(v_a \cdot \alpha_{in})} = 11456 \ lbf$
B1.7 - Pullback Force at D:	
$T_d \coloneqq e^{\left(v_b \cdot \beta_{exit}\right)} \cdot \left(T_c + v_b \cdot \left w_b\right \cdot L_4 - w_b \cdot H_{max} - \frac{1}{2} \left(T_c + v_b \cdot \left w_b\right + \frac{1}{2} \left(T_c +$	$e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 16676 \ lbf$
B1.8 - Maximum Pullback Force - Empty Pipe	<u>e:</u>
$P_{max_empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 174$	472 <i>lbf</i>
max_empty = (a, b, c, a).	Maximum Pullback Force
2 - Filled Pipe with Water	
B2.1 - Upward Buoyant Force:	2)
$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \cdot \boldsymbol{D}_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)\right)$	$\left(\frac{1}{1}\right)^{2} - w_{a} = 24.6 \ plf$
	Upward buoyant force of pipe filled with wa
	opriara babyane force of pipe finea with we

$T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 942 \ lbf \qquad \text{Pullback force enter ground}$							
	$T_{afilled}$:	$= e^{v_a \cdot \alpha_{in}} \cdot ($	$(v_a \cdot w_a \cdot (L$	$_1 + L_2 + L_3 + L_4$	$) = 942 \ lbf$	Pullback force enter	ground



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot \left w_{bfilled} \right \cdot L_2 + \frac{1}{2} + \frac{1}$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 6014 \ lbf$ Pullback force increase and decrease with depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3\right) - e^{\left(v_b \cdot \alpha\right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 6561 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot (T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_{dfilled})$	$_{4} - e^{\left(v_{a} \cdot lpha_{in} ight)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{\left(v_{a} \cdot lpha_{in} ight)} ight) = 10221 \; lbf$
B2.6 - Maximum Pullback Force - Filled Pip	be with Water:
$P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$	$_{d}) = 10221 \ lbf$ Maximum Pullback Force
<u> B3 - Safe Pull Strength / Ultimate Tensi</u>	le Load Check:
B3.1 Safe Pullback Check	
$A_{1} := \frac{\pi}{4} \left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) = 19 \ in^{2}$	Cross-sectional area of Pipe 1
$A_2 := rac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 ight) = 0.8 \; in^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 16794 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 678 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 9825 \ lbf$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 397 \ lbf$	Pullback forces acting on Pipe 2 (Ballast)
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
<i>P</i> _{<i>SPF</i>2} :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$= \frac{check := \mathbf{if}(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''})}{(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''})}$	
$= check := if(P_{SPF2} > P_{21}, "okay", "not okay$	
$check := if (P_{SPF1} > P_{12}, "okay", "not okay")$	
$check \coloneqq if(P_{SPF2} > P_{22}, "okay", "not okay")$	/ / - UKay



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<u>C - Allowable Mud Pressures:</u>

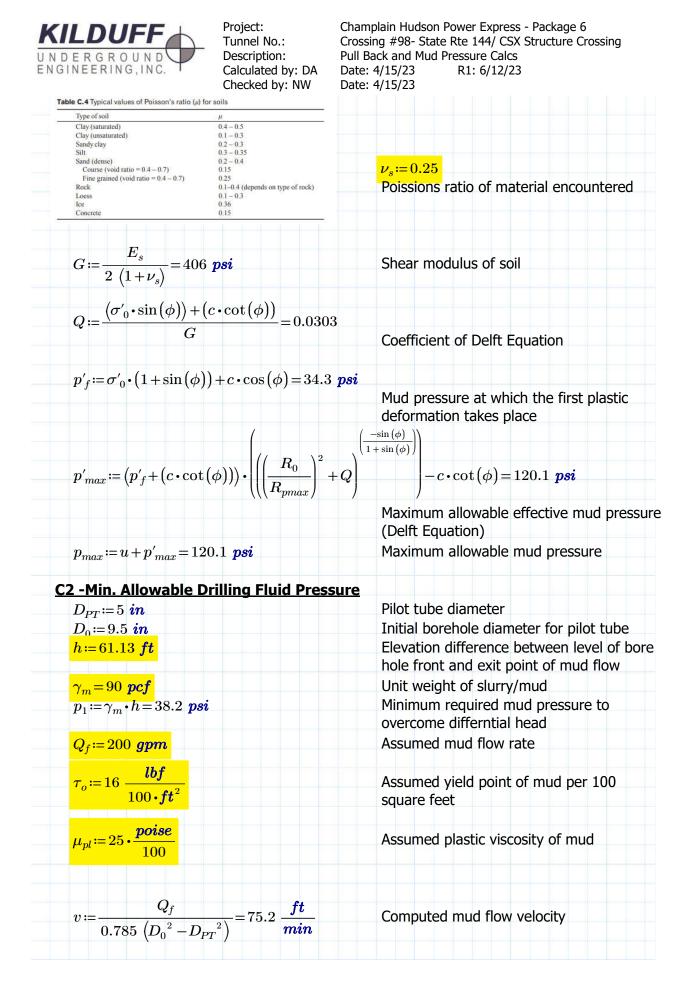
<u>C1 -</u>	Max.	Allowable	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

 elevation Vertical separation distance between critical structure and pipe (Stream S-28, ~3+88) Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia Initial radius of the borehole
structure and pipe (Stream S-28, ~3+88) Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia
Assumed unit weight very soft clay Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia
Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia
Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia
Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered materia
Assumed friction Angle Assumed cohesion of encountered materia
Assumed friction Angle Assumed cohesion of encountered materia
Initial radius of the borehole
Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$E_s \coloneqq 7 \frac{N}{mm^2} \equiv 1015 \ psi$
116116
Assumed modulus of elasticity



KILDUFF UNDERGROUND ENGINEERING, INC.	Tunnel No.:CrosDescription:PullCalculated by: DADate	nplain Hudson Power Express - Package 6 sing #98- State Rte 144/ CSX Structure Crossing Back and Mud Pressure Calcs : 4/15/23 R1: 6/12/23 : 4/15/23
$L_{structure} \coloneqq 388 \; ft$ $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_1}{(D_0 - D_0)} \right) \right)$	$v \rightarrow (\tau_o)$	Length to sturcture
$p_2 \coloneqq L_{structure} \bullet \left[\left \frac{1}{(D_0 - D_0)} \right \right]$	$\left[-D_{PT}\right]^2 + \left[\overline{\left(D_0 - D_{PT}\right)}\right]^2$	$\left \right = 1.2 psi$
		Minimum required mud pressure to create flow inside the borehole
$p_{min.} \coloneqq p_1 + p_2 = 39.4$	psi	Minimum required mud pressure
$check \coloneqq \mathbf{if}\left(p_{max} > p_{min}\right)$	$_{n.},$ "okay", "not okay")	="okay"



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Mobilized)	ormed Borehole with Arching Mobili:		<u>- Ring Deflection (Sho</u> D1.1 - Overburden Pressu
	Depth of cover		$H_c \coloneqq H_{max} = 48.4 \ ft$
	Friction angle of soil		$\phi = 34 \ deg$
lue =	"Silo" width, conservative value = reamed hole diameter		$B \coloneqq D_r = 18 $ <i>in</i>
	Earth pressure coefficient		$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$
	Unit weight of soil, assumed		$\gamma = 125 \ pcf$
		$\cdot H_c$ $\cdot \tan\left(\frac{\phi}{2}\right)$	$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{\ldots} \cdot \right)$
PPI)	Arching factor (Eq. 6, p.432, PPI)	$\frac{B}{\cdots} \tan\left(\frac{\phi}{2}\right) = 0.066$	$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot 1\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(-\frac{K \cdot H_c}{B} \cdot 1\right)}$
re	Effective overburden pressure		
		eflection (Short Term)	D1.2 Earth Load Deflection
ty for	Apparent modulus of elasticity for		
of 73 deg.	PE4710, Base Temperature of 73 Fahrenheit at 10 hrs of sustained (Table X1.1 ASTM F 1962)		E _{short} := 57500 • psi
tion equation	Variable in earth load deflection e	$(-1)^{3} = 9.36 \ psi$	$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} =$
as per	Pipe deflection to diameter as per		$\Delta y_{ELD_short} \coloneqq rac{0.0125 \cdot P_E}{k_{short}}$
PPI Handboo	PPI Equ. 10 (Chp 12, p 437, PPI H		
		eflection (Long Term)	D1.3 Earth Load Deflection
renheit at 50	Apparent modulus of elasticity for Base Temperature of 73 Fahrenhe years of sustained loading (Table ASTM F 1962)		$E_{long} \coloneqq 28200 \cdot psi$
tion equation	Variable in earth load deflection e	-=4.6 <i>psi</i>	$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6$
	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)		
		$\frac{25 \cdot P_E}{k} = 0.4\%$	$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k}$



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D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in	Thickness of casing pipe
<i>p</i> 1	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$	Assumed unit weight of fluid in
	borehole (Slurry unit weight)
$I := \frac{t^3}{1} = 0.14 \frac{in^4}{1}$	Moment of inertia of pipe wall cross
12 in $(D)^4$	section
$0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{d_1}\right)$	Pipe ring deflection to buoyant force
$\Delta u_{1} = \frac{1}{2} = 0.1\%$	ASTM F 1962 (Eq. X2.6, p.6)
$\gamma_m = 90 \text{ pcf}$ $I \coloneqq \frac{t^3}{12} = 0.14 \frac{in^4}{in}$ $\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\%$	·····
D2.1 Buoyant Deflection (Long Term)	
Please note that long term buoyant deflectio	
assumed to be cured after a 1-week period f	from installation/pumping.
3 - Reissner Effect Deflection (Short Ter	m)
	-
D3.1 - Reissner Effect Deflection (Short Tern	-
D3.1 - Reissner Effect Deflection (Short Tern	<u>n)</u>
	n) Poisson's Ratio for PE pipe material
$\mu_{short} = 0.35$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} = 0.35$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendir
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisr Effect
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term) $\mu_{long} := 0.45$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term})$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendin Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2)



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$\Delta y_{lim} = 7.5\%$	Deflection limit for DR 9 non pressuriz
D4.1 - Net Short Term	pipe (Table 2 , p. 437, PPI Handbook)
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y$	$R_{R_short} = 0.2\%$ Percent ring deflection in sho term analysis
$Check \coloneqq \mathbf{if} \left(\Delta y_{short_net} {<} \Delta y_{lim}, \text{``okay''}, \text{``} \right)$	"not okay") = "okay"
D4.2 - Net Long Term	
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{R_long} = 0.4\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``n} \right)$	not okay") = "okay"



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	g, Levy's Equation (Short Term-During Pull)
	increase the pipe's buckling strength, therefore ition will produce a conservative value.
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
E _{short} =57500 рsi % DELГЕСТЮИ	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
0.0 0.2 0 0 0 2 4 6 8 10	42
2	Ovality compensation factor, Figure
fo 6	3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o_short} \coloneqq 0.98$
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{s}}\right) \cdot \left(\frac{1}{DB_{s} - 1}\right)$	$\int_{0-1}^{3} \cdot \frac{f_{o_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
$H = 61.13 \; ft$	Elevation difference between the lowest point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 38.21 \ psi$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 38.21 \ psi$	Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_short} > P_{net}, \text{``okay''} \right)$	', "not okay") = "okay"
D5.2 - Unconstrained Ring Buckling	<u>, Levy's Equation (Long Term)</u>
	l increase the pipe's buckling strength, therefore
Note that constraining the pipe will considering an unconstrained cond $N := 2.0$	Factor of Safety

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #98- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23
$E_{long} = 28200 \; psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right)$	$\left \cdot\left(\frac{1}{DR_1-1} ight)^3\cdot \frac{f_c}{d} ight $	$\frac{D_{a}long}{N} = 31.1 \ psi$ Allowable unconstrained buckling pressure
$P_{GW} := \gamma_w \cdot H_w = 0 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_long} > \right.$	P_{net} , "okay", "no	ot okay") = "okay"
(00_00.09		



Champlain Hudson Power Express - Package 6 Crossing #98- State Rte 144/ CSX Structure Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill



Champlain Hudson Power Express - Package 6 Crossing #99- CSX Tracks Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

fining Parameters of Horizontal Directi			
$D_1 := 10.75 \ in$	Pipe 1 outer diameter		
$D_2 := 2.375 in$	Pipe 2 outer diameter		
$D_{rod} \approx 3.5 \ in$	Assumed drill rod diameter		
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1		
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2		
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1		
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2		
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1		
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2		
bora/ninanath			
bore/pipepath	pipeentry		
drill rig B	\ /a		
PD			
Н			
CI	B		
pipe exit			
La La			
L ₄ L ₃			
• L _{bore}			
Illustration 1 - Schematic of	Drive Cross-section		
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ rad			
L_{bore} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)		
$\mathbf{\alpha} := 10 \circ \mathbf{\alpha}_{in} := \alpha = 0.1745 \ \mathbf{rad}$ $\beta := 14 \circ \mathbf{\beta}_{exit} := \beta = 0.2443 \ \mathbf{rad}$ $D_r := 18 \cdot \mathbf{in}$ $H_{max} := 23.6 \ \mathbf{ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo		
$\mathbf{L}_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter		
$\begin{array}{c} & \qquad \qquad \mathbf{L}_{bose} \\ & \qquad \qquad \mathbf{Illustration \ 1 - Schematic \ of} \\ & \alpha_{in} \coloneqq \alpha = 0.1745 \ \textbf{rad} \\ & \beta_{exit} \coloneqq \beta = 0.2443 \ \textbf{rad} \\ & D_r \coloneqq 18 \cdot \textbf{in} \end{array}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from		
L_{toos} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter		
L_{total} $Illustration 1 - Schematic of$ $\alpha := 10 \circ \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14 \circ \qquad \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \ ft$ $L_{total} := 1608.5 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing		
L_{tors} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 1608.5 \text{ ft}$ $L_1 := 150 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface		
L_{tors} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad \\ \beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 23.6 \ ft \\ H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \ ft \\ L_{total} := 1608.5 \ ft \\ L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1		
L_{total} $Illustration 1 - Schematic of$ $\alpha := 10 \circ \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14 \circ \qquad \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \ ft$ $L_{total} := 1608.5 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -		
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L_{total} $Illustration 1 - Schematic of$ $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \ ft$ $L_{total} := 1608.5 \ ft$ $L_1 := 150 \ ft$ $L_2 := 531.4 \ ft$ $L_3 := 748.7 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section		
L_{tors} Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.35 \text{ ft}$ $L_{total} := 1608.5 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 531.4 \text{ ft}$ $L_3 := 748.7 \text{ ft}$ $L_4 := 328.4 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1		
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DERGROUND GINEERING, INC.	oject: Innel No.: escription: Iculated by: DA Iecked by: NW	Champlain Hudson Power Express - Package 6 Crossing #99- CSX Tracks Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w := 62.4 \ pcf $		Unit weight of water
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
Axial Bending Stress:		
$R_{avg._in} \coloneqq 1000 \; ft$		Radius of curvature at the entry, provided by Contractor
$R_{avg.out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1$	1000 ft	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \ ft$	t	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left\langle R_{avg._in} \! > \! r_{rod} \right.$,"okay","not	okay") = "okay"
$Check \coloneqq \mathbf{if} \left(R_{avg_out} > r_{rot} \right)$. "okay", "no	t okay") = "okay"

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \coloneqq e_a \cdot E_{12hr} = 25.8 \ psi$	Axial bending stress within the casing pipe



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B - Site Specific Analyses: Pullback Force:
B1 - Empty Pipe
B1.1 - Effective Weight of Empty Pipe:

$$w_{a} := \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right), \rho_{u} \cdot \gamma_{a} = 8.3 \text{ plf}$$
B1.2 - Upward Buoyant Force:
Effective weight

$$w_{b} := \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2 \text{ plf}$$
Upward buoyant force of empty pipe
B1.3 - Hydrokinetic Pressure:

$$\Delta T := \Delta P \cdot \left(\frac{\pi}{8} \right) \left(D_{r}^{2} - \left(D_{1}^{2} + D_{2}^{2} \right) \right) = 796 \text{ lbf}$$
Hydrokinetic force
B1.4 - Pullback Force Point A:

$$T_{a} := e^{v_{a} \cdot a_{w}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3} + L_{4} \right) \right) = 1483 \text{ lbf}$$
Pullback force when pipe enters the ground
B1.5 - Pullback Force Point B:

$$T_{b} := e^{v_{a} \cdot a_{w}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot a_{w})} \right) = 10966 \text{ lbf}$$
Pullback force point C:

$$T_{c} := T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3} \right) - e^{(v_{a} \cdot a_{w})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot a_{w})} \right) = 27286 \text{ lbf}$$
B1.8 - Maximum Pullback Force a D:

$$T_{d} := e^{(v_{a} \cdot a_{w})} \cdot \left(T_{c} + v_{b} \cdot |w_{b}| \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot a_{w})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot a_{w})} \right) \right) = 27286 \text{ lbf}$$
B1.8 - Maximum Pullback Force - Empty Pipe:

$$P_{max,cmpty} := \max \left(T_{a}, T_{b}, T_{c}, T_{d} \right) + \Delta T = 28083 \text{ lbf}$$
Maximum Pullback Force
B2.1 - Upward Buoyant Force:

$$w_{bfitted} := \left(\frac{\left(\left(\tau \cdot D_{r}^{2} \right)}{4} \right) \cdot \rho_{w} \cdot \left(\tau_{a} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 24.6 \text{ plf}$$
Upward buoyant force of pipe filled with water
B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1483 \ \textit{lbf} \quad \text{Pullback force enter ground}$



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$T \rightarrow e^{v_b \cdot \alpha_{in}} (T \rightarrow u) = u$	$+ w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot lpha_{in})} = 6788$
$I \ bfilled \leftarrow \mathcal{E} \qquad (I \ afilled \leftarrow \mathcal{V}_b \bullet \mathcal{W}_b filled \bullet \mathcal{L}_2 \neg$	Pullback force increase and decrease
B2.4 - Pullback Force Point C:	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 \right) - e^{\left(v_b \cdot v_b \right)}$	$(\alpha_{an}) \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 11659 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} := e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot \left w_{bfilled} \right \cdot I_{cfilled} \right)$	$\left(v_{a} \cdot a_{in}\right) \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{\left(v_{a} \cdot a_{in}\right)}\right) = 14855 \ l$
<u>B2.6 - Maximum Pullback Force - Filled Pi</u>	pe with Water:
$P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfill} \right)$	$(ad) = 14855 \ lbf$
mux (ujuicu > ojuicu > cjiiicu > ujui	Maximum Pullback Force
<u> 3 - Safe Pull Strength / Ultimate Tens</u>	ile Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 := \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 26993 \ lbf$	Pullback forces acting on Pipe 1 (Emp
$P_{21} \coloneqq \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 1090 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Emp
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 14279 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ball
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 576 \ lbf$	Pullback forces acting on Pipe 2 (Ball
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table % p. 448, PPI)
<i>P</i> _{<i>SPF</i>2} :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq if(P_{SPF1} > P_{11}, "okay", "not oka$	
$check := if(P_{SPF2} > P_{21}, "okay", "not oka$	
$\begin{aligned} check &\coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ check &\coloneqq \mathbf{if} \left(P_{SPF2} > P_{22}, \text{``okay''}, \text{``not okay} \right) \end{aligned}$	



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<u>C</u> - Allowable Mud Pressures:

<u>C1 -</u>	Max.	Allow	able	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

<i>H_w</i> := 26.7 • <i>ft</i>		Depth of the bore below groundwater elevation
$H_c \coloneqq 26.7 \ ft$		Vertical separation distance between critica structure and pipe (Ravine, Sta 13+50)
$\gamma \coloneqq 120 \ pcf$		Assumed unit weight stiff clay
$\gamma_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 57.6 \ \mu$	ocf	Effective unit weight
	-	
$u \coloneqq \gamma_w \cdot H_w = 12 \ ps$		Initial pore water pressure
$\phi \coloneqq 0 \ deg$		Assumed friction Angle
$c := 1200 \ psf = 8.33$		Assumed cohesion of encountered material (Comment W7, Wei Tu suggests 400-500p for med. stiff silt)
$R_0 \coloneqq \frac{D_{rod}}{2} = 1.75 \ in$	n	Initial radius of the borehole
1		
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 13$	3 ft	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 13$ $\sigma'_0 \coloneqq \left(\left(\gamma \cdot \left(H_c - H_u \right) \right) \right)$	$\beta ft \\ (b) + \gamma' \cdot H_w = 11 psi$	
$\sigma'_{0} \coloneqq (\langle \gamma ullet \langle H_{c} - H_{u} ullet$ le C.2 Typical values of modulus of el	$(y_{s}) + \gamma' ullet H_w) = 11 psi$ lasticity (E_s) for different types of soils	2/3 H in sands)
$\sigma'_0 \coloneqq (\langle \gamma \cdot (H_c - H_u) \rangle)$	$\left(, \right) \left(+ \gamma' \boldsymbol{\cdot} H_w \right) = 11 \boldsymbol{psi}$	2/3 H in sands)
$\sigma'_{0} \coloneqq \left(\left(\gamma \cdot \left(H_{c} - H_{u} \right) \right) \right)$	$(\gamma_{s}) + \gamma' \cdot H_w = 11 \text{ psi}$ $(E_s) \text{ for different types of soils}$ $(E_s (N/mm^2))$ $(2-15)$	2/3 H in sands)
$\sigma'_{0} \coloneqq \left(\left(\gamma \cdot \left(H_{c} - H_{u} \right) \right) \right)$ $ = C.2 \text{ Typical values of modulus of elements} $ $ = \frac{Type \text{ of Soil}}{Clay} \\ \text{Very soft} \\ \text{Soft} $	$(y_{s}) + \gamma' \cdot H_w = 11 \text{ psi}$ $(E_s) \text{ for different types of soils}$ $(E_s) = 11 \text{ psi}$ $(E_s) = 11 \text{ psi}$ $(E_s) = 11 \text{ psi}$	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \left(\left(\gamma \cdot \left(H_{c} - H_{u} \right) \right) \right)$	$(\gamma_{s}) + \gamma' \cdot H_w = 11 \text{ psi}$ $(E_s) \text{ for different types of soils}$ $(E_s (N/mm^2))$ $(2-15)$	2/3 H in sands) Initial effective stress
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left(H_{c} - H_{u} \right) \right\rangle \right)$ He C.2 Typical values of modulus of elements of modulus of elements of Soil $\frac{\text{Type of Soil}}{\text{Clay}}$ Very soft Soft Medium Hard Sandy	$(y_{s}) + \gamma' \cdot H_w) = 11 \ psi$ $(E_s) \text{ for different types of soils}$ $(E_s, (N/mm^2))$ $(2-15)$ $(S-25)$ $(1-1)$	2/3 H in sands)
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right\rangle \right. \right.$ If C.2 Typical values of modulus of elements of Soil $\boxed{\text{Clay}} \\ \text{Very soft} \\ \text{Soft} \\ \text{Medium} \\ \text{Hard} \\ \text{Sandy} \\ \text{Glacial till}$	$\gamma' \cdot H_w = 11 \ psi$ $ $	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{u} \right) \right) \right)$ $= C.2 \text{ Typical values of modulus of elements}$ $= C.2 Typical value of elements of elements$	$\gamma(\mathbf{y}) + \gamma' \cdot H_w = 11 \ psi$ $\underline{\text{lasticity } (E_s) \text{ for different types of soils}}_{E_y (N/mm^2)}$ $\frac{2-15}{5-25}$ $15-50$ $50-100$ $25-250$ $10-153$	2/3 H in sands) Initial effective stress
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right\rangle \right. \right. \\ \left. \frac{Type of Soil}{Clay} \right _{Very soft} \\ \left. \frac{Soft}{Medium} \right _{Hard} \\ \left. \frac{Sandy}{Glacial till} \right _{Sandy} \\ \left. \frac{Glacial till}{Soft} \right _{Soft} \\ \left. \frac{Soft}{Soft} \right $	$\gamma' \cdot H_w = 11 \ psi$ $ $	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \langle \langle \gamma \cdot \langle H_{c} - H_{u} \rangle \rangle$ If C .2 Typical values of modulus of elements of modulus of elements of the formula	$\gamma(\mathbf{v},\mathbf{h}) + \gamma' \cdot \mathbf{h}_w) = 11 \ \mathbf{psi}$ $\underline{\mathbf{asticity}} \ (E_s) \text{ for different types of soils}$ $\underline{E_i (N/mn^2)}$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right\rangle \right. \right.$ If C.2 Typical values of modulus of elements of soil Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand	$\gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \frac{1}{12} + \frac{1}{$	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \langle \langle \gamma \cdot \langle H_{c} - H_{u} \rangle \rangle$ If C .2 Typical values of modulus of elements of modulus of elements of the formula	$\gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{2-15}$ $\frac{1}{5-25}$ $\frac{1}{5-50}$ $\frac{1}{5-25}$ $\frac{1}{5-50}$ $\frac{1}{50-100}$ $\frac{1}{25-250}$ $10-153$ $144-720$ $478-1,440$	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{u} \right) \right) \right)$ $rac{Type of Soil}{Clay}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty	$y_{s}(y_{s}) + \gamma' \cdot H_{w} = 11 \text{ psi}$ $(E_{s}) \text{ for different types of soils}$ $E_{x} (N/mm^{2})$ $2-15$ $5-25$ $15-50$ $50-100$ $25-250$ $10-153$ $144-720$ $478-1,440$ $14-57$ $7-21$	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right\rangle \right. \right.$ In the C.2 Typical values of modulus of elements of the form of the soft of t	$\gamma' \cdot H_w = 11 \text{ psi}$ lasticity (E _s) for different types of soils $E_* (N/mm^2)$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57 7-21 10-24 48-81	2/3 H in sands) Initial effective stress $E_s := 50 \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right. \right. \right. \right.$ If c.2 Typical values of modulus of elements of soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel Loose Sand and gravel Loose Sand and gravel Loose Sand and gravel Loose Sand Silty Sonse Sand and gravel Loose Sand and gravel Loose Sand Silty Sand and gravel Loose Sand and gravel Loose Sand Sand Sand Sand Sand Sand Sand Sand	$\gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$ $\frac{1}{12} + \gamma' \cdot H_w = 11 \text{ psi}$	2/3 H in sands) Initial effective stress $E_s := 50 \ \frac{N}{mm^2} = 7252 \ psi$
$\sigma'_{0} := \left(\left\langle \gamma \cdot \left\langle H_{c} - H_{u} \right\rangle \right. \right.$ In the C.2 Typical values of modulus of elements of the form of the soft of t	$\gamma' \cdot H_w = 11 \text{ psi}$ lasticity (E _s) for different types of soils $E_* (N/mm^2)$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57 7-21 10-24 48-81	2/3 H in sands) Initial effective stress $E_s := 50 \frac{N}{mm^2} = 7252 \ psi$

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Table C.4 Typical values of Poisson's ratio (µ)	for soils			
Type of soil	μ			
Clay (saturated)	0.4 - 0.5			
Clay (unsaturated) Sandy clay	0.1 - 0.3 0.2 - 0.3			
Silt Sand (dense)	0.3 - 0.35 0.2 - 0.4			
Course (void ratio = $0.4 - 0.7$)	0.15	$\nu_s = 0.3$		
Fine grained (void ratio = $0.4 - 0.7$) Rock	0.25 0.1-0.4 (depends on type of rock)	Poissions ratio of material encountered		
Loess	0.1-0.3 0.36			
Concrete	0.15			
$G \coloneqq \frac{E_s}{2 (1 + \nu_s)} = 278$	89 <i>psi</i>	Shear modulus of soil		
$Q \coloneqq \frac{(\sigma'_0 \cdot \sin(\phi)) + C}{C}$	$\frac{(c \cdot 0)}{c} = 0$			
G		Coefficient of Delft Equation		
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi))$	$))+c\cdot\cos(\phi)=19$	psi		
		Mud pressure at which the first plastic deformation takes place		
	($-\sin(\phi)$		
	$\left \left(1 - 1 \right)^{1} \right\rangle$	$1 + \sin(\phi)$		
$p'_{max} \coloneqq \left(p'_f \! + \! \left(c \! \cdot \! 0 ight) ight)$	$\cdot \left(\left(\left(\frac{R_0}{R_{pmax}} \right)^2 + Q \right) \right)$	$ \left. \begin{array}{c} -\sin\left(\phi\right) \\ 1+\sin\left(\phi\right) \end{array} \right) - c \cdot 0 = 19 \ psi $		
		Maximum allowable effective mud pressur (Delft Equation)		
$p_{max} \coloneqq u + p'_{max} \equiv 30$	0.6 psi	Maximum allowable mud pressure		
<u>C2 -Min. Allowable [</u>	Drilling Fluid Pres	<u>sure</u>		
$D_{PT} = 5 in$		Pilot tube diameter		
$D_0 := 9.5 in$		Initial borehole diameter for pilot tube		
$h \coloneqq 41.4 \ ft$		Elevation difference between level of bore hole front and exit point of mud flow		
$\gamma_m = 90 \ pcf$		Unit weight of slurry/mud		
$p_1 \coloneqq \gamma_m \cdot h = 25.9 \ ps$	<i>vi</i>	Minimum required mud pressure to overcome differntial head		
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate		
		Assumed yield point of mud per 100		
$\tau_o \coloneqq 16 \ \frac{lbf}{100 \cdot ft^2}$		square feet		
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud		
$\mu_{pl} = 25 \cdot \frac{100}{100}$		Assumed plastic viscosity of mud		

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$v \coloneqq rac{Q_f}{0.785 (D_0^2 - D_f)}$	$\left(\frac{ft}{p_T}\right) = 75.2 \frac{ft}{min}$	Computed mud flow velocity
$\frac{L_{structure} \coloneqq 1350 \ ft}{\prime \prime}$		Length to sturcture
$p_2 \! \coloneqq \! L_{structure} \! \cdot \! \left(\! \left(\! \frac{1}{(D_0)} \right) \! \right) \! \cdot \! \left(\! \frac{1}{(D_0)} \right) \! \cdot \! \left($	$\left(\frac{\mu_{pl} \cdot v}{\left(p - D_{PT} \right)^2} \right) + \left(\frac{\tau}{\left(D_0 - v \right)^2} \right)$	$\left \frac{\sigma}{D_{PT}} \right\rangle = 4 \ psi$
$p_{min.} \coloneqq p_1 + p_2 = 29.9$) nei	 Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure
$p_{min} - p_1 + p_2 - 23.$, psi	
$check := if(p_{max} > p_r)$	_{nin.} , "okay" , "not o	kay") = "okay"



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D1.1 - Overburden Pressure (Considering	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 23.6 \ ft$	Depth of cover
$\phi = 0 \ deg$	Friction angle of soil
$B := D_r = 18$ in	"Silo" width, conservative value =
$\left(\right)^{2}$	reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 120 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 9 \ psi \qquad P_E = 135$	
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
$\frac{12}{0.0125 \cdot P_E}$	
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.3\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handbool
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \! \coloneqq \! \frac{0.0125 \cdot P_E}{k} \! = \! 2.6\%$	PPI Equ. 10 (Chp 12, p 437)



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$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194 \ in$	Thickness of casing pipe
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$	Assumed unit weight of fluid in
4 ³ in ⁴	borehole (Slurry unit weight)
$I \coloneqq \frac{l}{12} = 0.14 \frac{in}{i}$	Moment of inertia of pipe wall cro
$(D_1)^4$	section
$0.1169 \cdot \gamma_m \cdot \left \frac{\Sigma_1}{2} \right $	Pipe ring deflection to buoyant for
$\gamma_m = 90 \text{ pcf}$ $I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$ $\Delta y_{bouyant} := \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\%$	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (Long Term)	

D3 - Reissner Effect Deflection (Short Term)

D3.1 - Reissner Effect Deflection (Short Term)

$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	Deflection due to longitudinal bending
$\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term	Pipe ring deflection due to the Reisnner Effect
$\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{long}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.000003$	Deflection due to longitudinal bending
$\Delta y_{R_long} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term



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D4 - Net Ring Deflection	
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$\Delta y_{lim} = 7.5\%$	Deflection limit for DR 9 non pressurized
	pipe (Table 2 , p. 437, PPI Handbook)

D4.1 - Net Short Term

 $\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short} = 1.3\%$ Percent ring deflection in short term analysis

 $Check \coloneqq if (\Delta y_{short net} < \Delta y_{lim}, "okay", "not okay") = "okay"$

D4.2 - Net Long Term

 $\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \! \Delta y_{R_long} \! = \! 2.6\%$

Percent ring deflection in long term analysis (50 years)

 $Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``not okay''} \right) = \text{``okay''}$



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D.1 Onconstrained King Ducking	, Levy's Equation (Short Term-During Pull)
	increase the pipe's buckling strength, therefore tion will produce a conservative value.
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
E _{short} =57500 psi	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
2	
f ₀ .6	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o_short} \coloneqq 0.88$
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$	$\frac{f_{o_short}}{N} = 112.6 \text{ psi}$ Allowable unconstrained buckling pressure
$H = 4.1 \; ft$	Elevation difference between the lowest
	point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 2.56 \ psi$	Pressure of drilling slurry
$P_{mud} \coloneqq \gamma_m \cdot H = 2.56 \ psi$ $P_{net} \coloneqq P_{mud} = 2.56 \ psi$	
	Net external loading with open borehole
$P_{net} \coloneqq P_{mud} = 2.56 \ psi$	Net external loading with open borehole , "not okay") = "okay"
$P_{net} \coloneqq P_{mud} = 2.56 \ psi$ $Check \coloneqq if (P_{UC_short} > P_{net}, "okay")$ D5.2 - Unconstrained Ring Buckling Note that constraining the pipe will	Net external loading with open borehole , "not okay") = "okay" , Levy's Equation (Long Term) increase the pipe's buckling strength, therefore
$P_{net} \coloneqq P_{mud} = 2.56 \ psi$ $Check \coloneqq if (P_{UC_short} > P_{net}, "okay")$ D5.2 - Unconstrained Ring Buckling Note that constraining the pipe will	Net external loading with open borehole , "not okay") = "okay" , Levy's Equation (Long Term)

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$E_{long} {=} 28200 \; psi$			Apparent modulus of elasticity for PE4710, Base Temperature of 73 de Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)	g.
$f_{o_long} \coloneqq 0.45$			Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2	
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right)$	$- \left(\frac{1}{DR_1 - 1} \right)^3 \cdot \frac{f_c}{dc}$	$\frac{D_long}{N} = 3$	31.1 <i>psi</i> Allowable unconstrained buckling pressure	
$P_{GW} \coloneqq \gamma_w \bullet H_w = 11.5$	7 psi		Groundwater head pressure	
$P_{net} \coloneqq P_{GW}$			Net external loading with open bore	hole
$Check := if (P_{UC_long})$	>P"okay", "no	ot okav	$^{\prime}$ = "okay"	
	net, onay, ne	je onaj) ondy	



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill

99.A



Champlain Hudson Power Express - Package 6 Crossing #99.A- Stream S-28,-29,-30 & NY Thruway Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$D_{rod} = 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 := 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
rillrig B D	A a
	Juning anna ann ann ann
H	
pipe exit C	В
L_4 L_3	
L_4 ! L_3	
L ₄ : L ₃	
• L _{bore}	
Illustration 1 - Schematic of	Drive Cross-section
L_{bore} Illustration 1 - Schematic of $\alpha := 8^{\circ}$ $\alpha_{in} := \alpha = 0.1396 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians)
L_{tore} Illustration 1 - Schematic of $\alpha := 8 \overset{\circ}{} \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \overset{\circ}{} \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
L_{bore} Illustration 1 - Schematic of $\alpha := 8 ^{\circ} \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 ^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
L_{tore} Illustration 1 - Schematic of $\alpha := 8 \overset{\circ}{} \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \overset{\circ}{} \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
\mathbf{L}_{bore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
L_{toore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
L_{bore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
L_{toore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
L_{total} $Illustration 1 - Schematic of$ $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$ $L_{total} := 2724.7 \ ft$ $L_{1} := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
L_{toos} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 87.3 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \text{ ft}$ $L_{total} := 2724.7 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
L_{tore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$ $L_{total} := 2724.7 \ ft$ $L_1 := 150 \ ft$ $L_2 := 566.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
L_{total} $Illustration 1 - Schematic of$ $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \qquad \beta_{exit} := \beta = 0.1396 \ rad \qquad D_r := 18 \cdot in$ $H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$ $L_{total} := 2724.7 \ ft$ $L_1 := 150 \ ft$ $L_2 := 566.6 \ ft$ $L_3 := 1678 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section
L_{tore} Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 87.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 88.05 \ ft$ $L_{total} := 2724.7 \ ft$ $L_1 := 150 \ ft$ $L_2 := 566.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1

KILDUFF INDERGROUND NGINEERING, INC. Project: Tunnel No.: Description: Calculated by Checked by:	
$v_a = 0.1$	Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$	Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w \coloneqq 62.4 \ pcf $	Unit weight of water
$\gamma_a \coloneqq 0.965$	Specific gravity of pipe
$\gamma_m := 90 \ pcf$	Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.4$	Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$	Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$	Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$	Gravitational Constant
- Axial Bending Stress:	
$R_{avg._in} \coloneqq 1000 \; ft$	Radius of curvature at the entry, provided by Contractor
$R_{avg.out} \coloneqq 1000 \ ft$	Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1000 \ ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} > r_{rod}, \text{``okay''} \right)$, "not okay") = "okay"
$Check \coloneqq ext{if} ig (R_{avg.out} \! > \! r_{rod}, ext{``okay'}$	

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \! \coloneqq \! e_a \! \cdot \! E_{12hr} \! = \! 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



Champlain Hudson Power Express - Package 6 Crossing #99.A- Stream S-28,-29,-30 & NY Thruway Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

B - Site Specific Analyses: Pullback Force: **B1 - Empty Pipe** B1.1 - Effective Weight of Empty Pipe: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{\Lambda}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ B1.3 - Hydrokinetic Pressure: $\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf \text{ Hydrokinetic force}$ B1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 2416 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot \left| w_b \right| \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 15761 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 40069 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 44386 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 45182 \ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} \boldsymbol{D}_{1}^{-2} \right)}{4} \right) \boldsymbol{\cdot} \rho_{w} \boldsymbol{\cdot} \left(\gamma_{b} - \gamma_{c} \boldsymbol{\cdot} \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 24.6 \ \boldsymbol{plf}$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

$$T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 2416 \ \textit{lbf} \quad \text{Pullback force enter ground}$$



Champlain Hudson Power Express - Package 6 Crossing #99.A- Stream S-28,-29,-30 & NY Thruway Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

	$-w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 9628 \ ll_{max}$ Pullback force increase and decrease w
4 - Pullback Force Point C:	depth
$= T_{bfilled} + (v_b \cdot w_{bfilled} \cdot L_3) - e^{(v_b \cdot c_b)}$	$(x_{in}) \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 20565 \ lbf$
<u>.5 - Pullback Force at D:</u>	
$\mathcal{U}_{illed} \coloneqq e^{\langle v_b \cdot v_{exil} \rangle} \cdot (T_{cfilled} + v_b \cdot w_{bfilled} \cdot L)$	$(v_4 - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 24720 $ lbf
<u>.6 - Maximum Pullback Force - Filled Pi</u>	pe with Water:
$ax \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$	$_{ed}) = 24720 \ lbf$
	Maximum Pullback Force
<u>Safe Pull Strength / Ultimate Tensi</u>	ile Load Check:
<u>1 Safe Pullback Check</u>	
$= \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$= \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$	Cross-sectional area of Pipe 2
$:=\frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 43429 \ lbf$	Pullback forces acting on Pipe 1 (Empty
$:=\frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 1753 \ lbf$	Pullback forces acting on Pipe 2 (Empty
$A_1 + A_2$	
$\underline{A} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 23761 \ lbf$	Pullback forces acting on Pipe 1 (Ballas
$A_1 + A_2$	
$\underline{A} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 959 \ lbf$	Pullback forces acting on Pipe 2 (Ballas
$A_1 + A_2$ $b_{F1} \coloneqq 41214 \ lbf$	Safe pullback forces Pipe 1 (Table %,
<i>p</i> ₁ − 11211 <i>00</i>	p. 448, PPI)
$_{PF2} := 1683 \ lbf$	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$eck \coloneqq if(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''})$	
$eck \coloneqq \mathbf{if} \left(P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay} \right)$ $eck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right)$	
$eck \coloneqq \mathbf{if} \left(P_{SPF2} > P_{22}, \text{``okay''}, \text{``not okay''} \right)$	



Champlain Hudson Power Express - Package 6 Crossing #99.A- Stream S-28,-29,-30 & NY Thruway Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

<u>C - Al</u>	lowable	e Mud P	ressures:

<u>C1 -</u>	Max.	Allow	able	Driling	Fluid	Pressure	

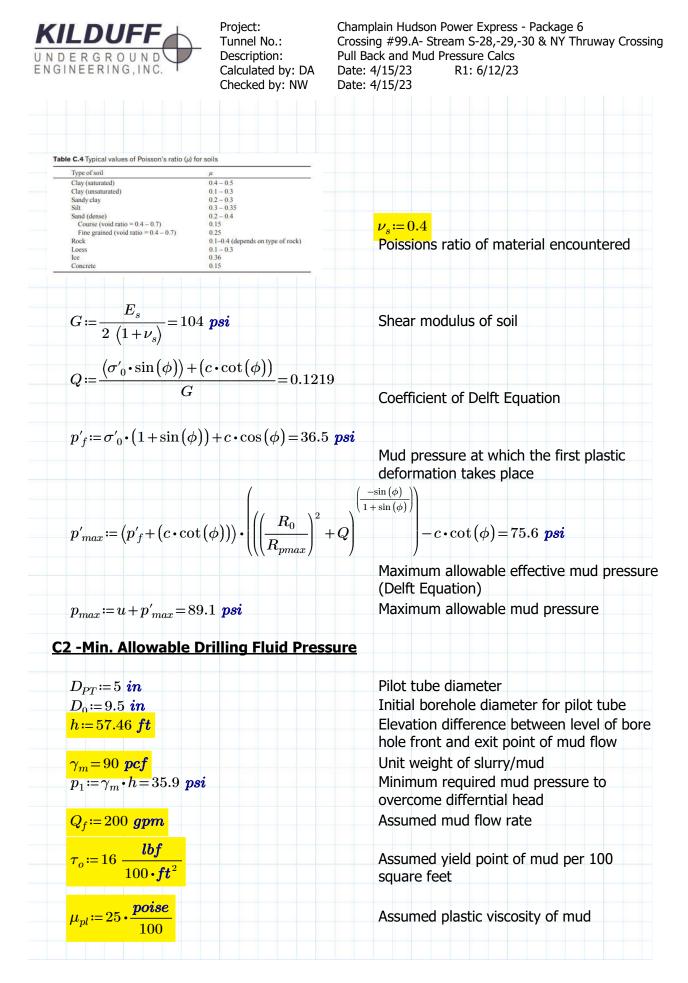
Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

- Geologic conditiosn will vary through alignment

$f_w \coloneqq 31.2 \cdot ft$		Depth of the bore below groundwater elevation
T _c ≔31.2 ft		Vertical separation distance between critica structure and pipe (Stream S-30 ~16+76)
≔110 pcf		Assumed unit weight Med. dense silt
w ≔ 62.4 pcf		Unit weight of water
$\tilde{r} = \gamma - \gamma_w = 47.6 \ \mu$	ocf	Effective unit weight
$= \gamma_w \cdot H_w = 14 ps$	32	Initial pore water pressure
<mark>≔32 deg</mark>		Assumed friction Angle
=0 psf =0 psi		Assumed cohesion of encountered material
$_{0} := \frac{D_{rod}}{2} = 1.75 \ i$	n	Initial radius of the borehole
$_{pmax} \coloneqq \frac{2}{3} \cdot H_c = 21$	1 <i>ft</i>	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$V_0 \coloneqq \gamma \cdot H_c = 24 \ ps$	ri 👘	Initial effective stress
$Y_0 \coloneqq \gamma \cdot H_c = 24 \ ps$	tiasticity (E_{s}) for different types of soils	Initial effective stress
$Y_0 \coloneqq \gamma \cdot H_c = 24 \ ps$		Initial effective stress
${\cal Y}_0\!:=\!\gamma\!ullet\!H_c\!=\!24{\it ps}$ 2 Typical values of modulus of e	elasticity (E_s) for different types of soils	Initial effective stress
$Y_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft	elasticity (E_s) for different types of soils E_i (N/mm ²) 2–15	Initial effective stress
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft	elasticity (E_5) for different types of soils E_i (N/mm ²) 2–15 5–25	Initial effective stress
$Y_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium	elasticity (E_s) for different types of soils $E_s (N/mm^2)$ 2–15 5–25 15–50	Initial effective stress
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard	elasticity (E_S) for different types of soils $ \frac{E_s (N/mm^2)}{2-15} $ 5-25 15-50 50-100	Initial effective stress
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy	elasticity (E_s) for different types of soils $E_s (N/mm^2)$ 2–15 5–25 15–50	Initial effective stress
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard	elasticity (E_S) for different types of soils $ \frac{E_s (N/mm^2)}{2-15} $ 5-25 15-50 50-100	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$
$V_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till	Plasticity (E_s) for different types of soils $E_i (N/mm^2)$ 2–15 5–25 15–50 50–100 25–250	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose	Plasticity (E_s) for different types of soils E_i (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense	Plasticity (E_5) for different types of soils E_4 (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153 144–720	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense	$\frac{E_s(\text{N/mm}^2)}{2-15}$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess	Plasticity (E_5) for different types of soils E_i (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand	Plasticity (E_5) for different types of soils E_i (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21 10–24	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense	Plasticity (E_5) for different types of soils E_i (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$J_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Very dense Loess Sand Silty Loose Dense Sand Silty Sand Silty Loose Dense Sand Silty Loose Dense Sand S	Plasticity (E_5) for different types of soils $E_i (N/mm^2)$ 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21 10–24 48–81	Initial effective stress $E_{s} := 2 \frac{N}{mm^{2}} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand gravel Loose	Plasticity (E_s) for different types of soils E_i (N/mm ²) 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21 10–24 48–81 48–148	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loese Sand Silty Loose Dense Sand Silty Loose Dense Sand and gravel Loose Dense	Plasticity (E_5) for different types of soils $E_i (N/mm^2)$ 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21 10–24 48–81 48–148 96–192	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower
$\gamma_0 := \gamma \cdot H_c = 24 \ ps$ 2 Typical values of modulus of e Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand gravel Loose	Plasticity (E_s) for different types of soils $E_i (N/mm^2)$ 2–15 5–25 15–50 50–100 25–250 10–153 144–720 478–1,440 14–57 7–21 10–24 48–81 48–148	Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity; lower



FUNCTION
Project: No:
Description:
Catalized by: DA
Created by: NW

$$v := \frac{Q_f}{0.785 (D_0^2 - D_{FT}^2)} = 75.2 \frac{ft}{min}$$

Computed mud flow velocity
 $u := \frac{Q_f}{0.785 (D_0^2 - D_{FT}^2)} = 75.2 \frac{ft}{min}$
Computed mud flow velocity
Length to sturcture
 $p_2 := L_{atvacture} \cdot \left(\left(\frac{\mu_{pt} \cdot v}{(D_0 - D_{FT})^2} \right) + \left(\frac{\tau_o}{(D_0 - D_{FT})} \right) \right) = 7.2 \text{ psi}$
Minimum required mud pressure to create flow index mud pressure flow index mud pressure flow index mud pressure to create flow index mud pressure flow index mud pressure to create flow index mud pressure flow



Champlain Hudson Power Express - Package 6 Crossing #99.A- Stream S-28,-29,-30 & NY Thruway Crossing Pull Back and Mud Pressure Calcs Date: 4/15/23 R1: 6/12/23 Date: 4/15/23

D1.1 - Overburden Pressure (Considering Def	ormed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 87.3 \ ft$	Depth of cover
$\phi = 32 \ deg$	Friction angle of soil
$B \coloneqq D_n = 18 in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 110 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.036$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 1 \ psi$ $P_E = 150 \ psf$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.1\%$	Pipe deflection to diameter as per
	PPI Equ. 10 (Chp 12, p 437, PPI Handbook
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 0.3\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)



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D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194 \ in$	Thickness of casing pipe
$E_{short} = 57500 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$	Assumed unit weight of fluid in borehole (Slurry unit weight)
$I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$	Moment of inertia of pipe wall cross section
$\gamma_m = 90 \text{ pcf}$ $I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$ $\Delta y_{bouyant} := \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\%$	Pipe ring deflection to buoyant force ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (Long Term)	
<u>B - Reissner Effect Deflection (Short Ter</u> <u>D3.1 - Reissner Effect Deflection (Short Terr</u>	-
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} \coloneqq 0.35$	<u>n)</u>
3 - Reissner Effect Deflection (Short Ter D3.1 - Reissner Effect Deflection (Short Terr $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material a
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} \approx 0.35$ R = 1000 ft	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2)
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} \coloneqq 0.35$ R = 1000 ft	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\underline{D3.1 - \text{Reissner Effect Deflection (Short Terr}}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$	n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature
<u>D3.1 - Reissner Effect Deflection (Short Terr</u> $\mu_{short} := 0.35$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendir Pipe ring deflection due to the Reisn Effect
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term}$ $\mu_{long} \coloneqq 0.45$	 n) Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendir Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material long term (ASTM F 1962, 8.2.4.2)
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendir Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material a
$D3.1 - \text{Reissner Effect Deflection (Short Terr}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}$ $z \coloneqq \frac{3}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term}$ $\mu_{long} \coloneqq 0.45$	 n) Poisson's Ratio for PE pipe material a short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bendir Pipe ring deflection due to the Reisn Effect n) Poisson's Ratio for PE pipe material a long term (ASTM F 1962, 8.2.4.2)



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$\Delta y_{lim} \coloneqq 7.5\%$	Deflection limit for DR 9 non pressurize pipe (Table 2 , p. 437, PPI Handbook)
D4.1 - Net Short Term	
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_s}$	$_{short} = 0.2\%$ Percent ring deflection in short term analysis
$Check \coloneqq \mathbf{if} \left(\Delta y_{short_net} < \Delta y_{lim}, \text{``okay''}, \text{``no} \right)$	tokay") = "okay"
D4.2 - Net Long Term	
$\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \Delta y_{R_long} \! = \! 0.3\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``not} \right)$	tokay") = "okay"



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Note that constraining the pipe wil	l increase the pipe's buckling strength, therefore
	lition will produce a conservative value.
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
E _{short} =57500 psi	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
2 0.0 0 2 4 6 8 10	12
2	
f ₀ 6	3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o_short} \coloneqq 0.98$
1.0	
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$	$\int_{0}^{3} \cdot \frac{f_{o_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
H=14.3 ft	Elevation difference between the lowest point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 8.94 \ psi$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 8.94 \ psi$	Net external loading with open borehole
$Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''} \right)$	", "not okay") = "okay"
D5.2 - Unconstrained Ring Buckling	<u>g, Levy's Equation (Long Term)</u>
	l increase the pipe's buckling strength, therefore lition will produce a conservative value.
considering an unconstrained cond	
considering an unconstrained cond $N \coloneqq 2.0$ $\mu_{long} \coloneqq 0.45$	Factor of Safety Poisson's Ratio for PE pipe material,

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$E_{long}\!=\!28200~{psi}$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.4$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$(2 \cdot E_{long})$	$(1)^3 f$	
$P_{UC_long} \coloneqq \left(\frac{ung}{1 - \mu_{long}^2}\right)$	$\cdot \left(\frac{1}{DR_1 - 1} \right) \cdot \frac{1}{DR_1 - 1}$	$\frac{p_long}{N} = 27.6 \ psi$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \bullet H_w \!=\! 13.52$	psi	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_long} > \right)$	P _{net} , "okay", "no	ot okay") = "okay"



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill



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fining Parameters of Horizontal Direc	ctional Drilling :
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 \coloneqq 2.375$ in	Pipe 2 outer diameter
$D_{rod} := 3.5 in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepatl	h pipe entry
1	
drill rig B D	A a
pipe exit C	B
• • • • • •	
\mathbf{L}_4 : \mathbf{L}_3	
-	
	boze
-	ecod
	ecod
	ecod
Illustration 1 - Schematic c	bore of Drive Cross-section
Illustration 1 - Schematic c $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$	bore of Drive Cross-section Borehole entry angle (degrees, radians)
$\alpha := 10 \circ \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \text{ ft}$	bore of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
Illustration 1 - Schematic c $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$	bors of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor
Illustration 1 - Schematic c $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 46.55 \ ft$	bose of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface
Illustration 1 - Schematic c $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \text{ ft}$	bose of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
Illustration 1 - Schematic c $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 46.55 \text{ ft}$ $L_{total} := 1125.3 \text{ ft}$	bose of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
Illustration 1 - Schematic c $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 46.55 \ ft$ $L_{total} := 1125.3 \ ft$ $L_1 := 150 \ ft$ $L_2 := 383.0 \ ft$	bose of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
Illustration 1 - Schematic c $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ} \qquad \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 45.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 46.55 \text{ ft}$ $L_{total} := 1125.3 \text{ ft}$ $L_{1} := 150 \text{ ft}$	bose of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -

Project: Tunnel No.:

Description:

Calculated by: DA

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$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w \coloneqq 62.4 \ pcf $		Unit weight of water
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe
$\gamma_m := 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
<u>A - Axial Bending Stress:</u>		
$R_{avg._in}$:=1000 ft		Radius of curvature at the entry, provided by Contractor
$R_{avg._out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 100$	00 <i>ft</i>	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg_in} > r_{rod}, " \right)$	okay", "not okay")="okay"
$Check \coloneqq$ if $(R_{avg_out} > r_{rod}, S_{rod})$		

Radius of curvature should exceed 40 times the pipe outside diameter to prevent ring collapse.

$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$S_a \! \coloneqq \! e_a \! \cdot \! E_{12hr} \! = \! 25.8 \ \textbf{psi}$	Axial bending stress within the casing pipe



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B - Site Specific Analyses: Pullback Force: **B1 - Empty Pipe** B1.1 - Effective Weight of Empty Pipe: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{\Lambda}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ B1.3 - Hydrokinetic Pressure: $\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf \text{ Hydrokinetic force}$ B1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1075 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot \left| w_{b} \right| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 9464 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 15593 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{\langle v_b \cdot \beta_{exil} \rangle} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{\langle v_a \cdot \alpha_{in} \rangle} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} \right) \right) = 19232 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 20029\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)^{2}\right) - w_{a} = 24.6 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} := e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1075 \ lbf$ Pullback force enter ground



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<u>B2.3 - Pullback Force Point B:</u>	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot \left w_{bfilled} \right \cdot L_2 + v_b \cdot \left w_{$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 5647$ Pullback force increase and decrease
B2.4 - Pullback Force Point C:	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled}\right \cdot L_3\right) - e^{\left(v_b \cdot \alpha_{in}\right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 8402 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot (T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_4$	$-\boldsymbol{e}^{(v_a\boldsymbol{\cdot}\alpha_{in})}\boldsymbol{\cdot} \left(v_a\boldsymbol{\cdot}w_a\boldsymbol{\cdot}L_4\boldsymbol{\cdot}\boldsymbol{e}^{(v_a\boldsymbol{\cdot}\alpha_{in})}\right) = 11284 \boldsymbol{l}$
<u> B2.6 - Maximum Pullback Force - Filled Pipe</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$) = 11284 <i>lbf</i> Maximum Pullback Force
3 - Safe Pull Strength / Ultimate Tensil	e Load Check:
B3.1 Safe Pullback Check	
$A_1 \coloneqq \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ \boldsymbol{in}^2$	Cross-sectional area of Pipe 1
$A_{2} \coloneqq \frac{\pi}{4} \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ \boldsymbol{in}^{2}$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 19251 \ lbf$	Pullback forces acting on Pipe 1 (Emp
$P_{21} \coloneqq \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 777 \ lbf$	Pullback forces acting on Pipe 2 (Emp
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 10846 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ball
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 438 \ lbf$	Pullback forces acting on Pipe 2 (Ball
$P_{SPF1} \coloneqq 41214 \ lbf$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
<i>P</i> _{SPF2} :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq \mathbf{if} \left(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''} \right)$	
$check \coloneqq if(P_{SPF2} > P_{21}, "okay", "not okay")$	
$check \coloneqq if (P_{SPF1} > P_{12}, "okay", "not okay")$ $check \coloneqq if (P_{SPF2} > P_{22}, "okay", "not okay")$	



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C - Allowable Mud Pressures:

<u>C1 - Max</u>	Allowable	Driling	Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

$H_w := 0 \cdot ft$	Depth of the bore below groundwater elevation
<i>H_c</i> ≔17 <i>ft</i>	Vertical separation distance between critical structure and pipe
$\gamma \coloneqq 100 \ pcf$	Assumed unit weight soft to clay/silt (zero blow count material)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 37.6 \ pcf$	Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 0 \ psi$	Initial pore water pressure
$\phi \coloneqq 0 \ deg$	Assumed friction Angle
c≔450 psf=3.13 psi	Assumed cohesion of encountered material
$R_0 := \frac{D_{rod}}{2} = 1.75 \ in$	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 8.5 \ ft$	Radius of plastic zone (H/2 in clays &
$\frac{1}{2}$	
$\sigma'_0 \coloneqq \gamma \cdot H_c = 11.8 \ psi$	2/3 H in sands) Initial effective stress
$\sigma'_0 \coloneqq \gamma \cdot H_c = 11.8 \ psi$	2/3 H in sands) Initial effective stress
2	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \gamma \cdot H_{c} = 11.8 \text{ psi}$ C.2 Typical values of modulus of elasticity (<i>E_s</i>) for different types $\frac{Type \text{ of Soil}}{Clay}$	2/3 H in sands) Initial effective stress
$\sigma'_0 := \gamma \cdot H_c = 11.8 \ psi$ C.2 Typical values of modulus of elasticity (<i>E_s</i>) for different types T_{i} (N/mm ²)	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \gamma \bullet H_{c} = 11.8 \text{ psi}$ C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types of Soil <i>E</i> _s (N/mm ²) Clay Very soft 2-15 Soft 5-25 Medium 15-50	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \gamma \bullet H_{c} = 11.8 \text{ psi}$ C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types. $\boxed{\frac{\text{Type of Soil} \qquad E_{s}(\text{N/mm}^{2})}{\text{Clay}}}_{\text{Very soft}}$ Soft 5–25	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \gamma \bullet H_{c} = 11.8 \text{ psi}$ C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types. Type of Soil <i>E</i> _s (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium Hard 50–100 Sandy Glacial till 25–250 Clay	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
$\sigma'_{0} := \gamma \bullet H_{c} = 11.8 \text{ psi}$ c.2 Typical values of modulus of elasticity (<i>E_s</i>) for different types of Soil E_{i} (N/mm ²) Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 144-720	2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \gamma \bullet H_{c} = 11.8 \text{ psi}$ c.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types of Soil <i>E</i> _s (N/mm ²) Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 144-720 Very dense 478-1,440	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
$\sigma'_{0} := \gamma \cdot H_{c} = 11.8 \text{ psi}$ c.2 Typical values of modulus of elasticity (<i>E_s</i>) for different types of the set of the s	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$
	2/3 H in sands) Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \ psi$

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Table C.4 Typical values of Poisson's ratio (µ) for soils		
The complete values of this soft state (μ) for softs		
Clay (saturated) 0.4 - 0.5 Clay (unsaturated) 0.1 - 0.3		
Sandy clay 0.2 - 0.3 Silt 0.3 - 0.35		
Sand (dense) 0.2 - 0.4 Course (void ratio = 0.4 - 0.7) 0.15		$\nu_s := 0.5$
	ends on type of rock)	
Loess 0.1 - 0.3 lce 0.36 Concrete 0.15		Poissions ratio of material encountered
$G = \frac{E_s}{-97}$ nsi		Shear modulus of soil
$G \coloneqq \frac{E_s}{2 (1 + \nu_s)} = 97 \ psi$		
$(\sigma'_0 \cdot \sin(\phi)) + (c \cdot 0)$		
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + (c \cdot 0)}{G} = 0$	0	
G		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$\cos(\phi) = 14.9 \ psi$	
1 9 0 ((,))		Mud pressure at which the first plastic
		deformation takes place
($(-\sin(\phi))$	
11 -	$1 + \sin(\phi)$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pm}} \right) \right) + \left(\left(\left(\frac{R_0}{R_{pm}} \right) + \left(\left(\left(\frac{R_0}{R_{pm}} \right) \right) + \left(\left(\left(\left(\frac{R_0}{R_{pm}} \right) + \left(\left(\left(\left(\frac{R_0}{R_{pm}} \right) + \left($	$\binom{0}{2} + 0$	$-c \cdot 0 - 14.9$ nsi
$P_{max} = (P_f + (C - O)) (((R_{pm})))$	nax ()	
, , , , -		Maximum allowable effective mud pressu
		(Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 14.9 \ psi$		Maximum allowable mud pressure
$p_{max} - a + p_{max} - 14.5$ pst		
C2 -Min. Allowable Drilling	Fluid Pressure	
$D_{PT} \coloneqq 5 in$		Pilot tube diameter
$D_0 \coloneqq 9.5 in$		Initial borehole diameter for pilot tube
$\frac{D_0}{h \coloneqq 34.7 \ \mathbf{ft}}$		Elevation difference between level of bor
10-01.1 JU		hole front and exit point of mud flow
$\gamma_m = 90 \ pcf$		Unit weight of slurry/mud
		Minimum required mud pressure to
$p_1 \coloneqq \gamma_m \cdot h = 21.7 \ psi$		overcome differntial head
0		
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
$\tau_o \coloneqq 16 \ \frac{lbf}{100 \cdot ft^2}$		Assumed yield point of mud per 100
$100 \cdot ft^2$		square feet
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		
$\mu_{pl} \coloneqq 25 \cdot \frac{100}{100}$		Assumed plastic viscosity of mud
100		

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$v \coloneqq rac{Q_f}{0.785 \left({D_0}^2 - {D_{PT}}^2 ight)} = 75$	$5.2 \frac{ft}{min}$	Computed mud flow velocity
$L_{structure} \coloneqq 1125 \; ft$		Length to sturcture
$p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right)^2 \right)$	$\left(\frac{\tau_o}{\left(D_0 - D_{PT}\right)}\right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT}\right)}\right)$	Minimum required mud pressure to create flow inside the borehole
$p_{min.} \coloneqq p_1 + p_2 = 25.1 \ psi$		Minimum required mud pressure
$check \coloneqq \mathbf{if} \left(p_{max} > p_{min.}, \text{``oka} \right)$	ay", "not okay") =	= "not okay"
Crossing will require risk m	itigation of cond	ductor casing &/or relief wells.



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D1.1 - Overburden Pressure (Considering D	Peformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 45.8 \ ft$	Depth of cover
$\phi = 0 \ deg$	Friction angle of soil
$B \coloneqq D_r = 18 in$	"Silo" width, conservative value =
	reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 \exp\left(-\frac{K \cdot H_c}{2} \tan\left(\phi\right)\right)$	
$\frac{1-\exp\left(-2\cdot\frac{1}{B}\cdot\tan\left(\frac{1}{2}\right)\right)}{B}$	Arching factor (Eq. 6, p. 422, DDI)
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 12 \ psi P_E = 1722$	<i>psf</i> Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$\frac{E_{short} \coloneqq 57500 \cdot psi}{2}$	PE4710, Base Temperature of 73 deg.
	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.6\%$	Pipe deflection to diameter as per
k_{short}	PPI Equ. 10 (Chp 12, p 437, PPI Handboo
D1.3 Earth Load Deflection (Long Term)	
	Apparent modulus of elasticity for PE4710
$E_{long} \coloneqq 28200 \cdot psi$	Base Temperature of 73 Fahrenheit at 50
	years of sustained loading (Table X1.1
Elma	ASTM F 1962)
$k \coloneqq \frac{-i \delta h g}{3} = 4.6 \ psi$	Variable in earth load deflection equation
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	
	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 3.3\%$	PPI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection	(Short Term)	
$\overline{D_1 = 10.75 \ in}$		Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
P-		Apparent modulus of elasticity for
$E_{short} \!=\! 57500 {\it psi}$		PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)
$\sim -90 \text{ maf}$		Assumed unit weight of fluid in
$\gamma_m = 30 \ pcj$		borehole (Slurry unit weight)
$I := \frac{t^3}{0.14} = 0.14 \frac{in^4}{10}$		Moment of inertia of pipe wall cross
$\frac{1}{12} = 0.14$ in	$D \setminus 4$	section
$0.1169 \cdot \gamma_m \cdot$	$\frac{D_1}{2}$	Pipe ring deflection to buoyant force
$\gamma_{m} = 90 \text{ pcf}$ $I := \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $0.1169 \cdot \gamma_{m} \cdot \left(\Delta y_{bouyant} := \frac{0.1169 \cdot \gamma_{m} \cdot \left(E_{short} \cdot I \right) \right)}{E_{short} \cdot I}$	$\frac{2}{2}$ = 0.1%	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection	(Long Term)	
assumed to be cured afte		
D3 - Reissner Effect Defle D3.1 - Reissner Effect De	_	ψ
D3 - Reissner Effect Defle D3.1 - Reissner Effect De	_	ψ
<u>D3 - Reissner Effect Defle</u>	_	D Poisson's Ratio for PE pipe material at
D3 - Reissner Effect Defle D3.1 - Reissner Effect De $\mu_{short} := 0.35$ R = 1000 ft	flection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
D3 - Reissner Effect Defle D3.1 - Reissner Effect De	flection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
D3 - Reissner Effect Defle D3.1 - Reissner Effect De $\mu_{short} := 0.35$ R = 1000 ft	$\frac{flection (Short Term)}{t}^{4} = 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle \mu_{short} \coloneqq 0.35 R = 1000 \ ft z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \frac{3}{16 \cdot t^2 \cdot R^2}\right)$	$\frac{f(t)^{4}}{t} = 0.000033$	 Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect
D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \vdash \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \vdash \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \vdash \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$ $z \vdash \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - d_1\right)$	$\frac{f(t)^{4}}{t} = 0.000033$	 Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle \mu_{short} \coloneqq 0.35 R = 1000 \ ft \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_{si}\right) z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) z $	flection (Short Term) $(\cdot t)^4$ = 0.0000033 $(\cdot) \cdot z^2 = 0.0002\%$ flection (Long Term)	 Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at
D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_1 + \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right)\right) \left(D_1 - z_1 + \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right)\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ D3.2 - Reissner Effect De	flection (Short Term) $(\cdot t)^4$ = 0.0000033 $(\cdot) \cdot z^2 = 0.0002\%$ flection (Long Term)	 Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)

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<u> D4 - Net Ring Deflection</u>			
$\Delta y_{lim} \coloneqq 7.5\%$ D4.1 - Net Short Term			or DR 9 non pressurized . 437, PPI Handbook)
Δy_{short_net} := Δy_{ELD_short} + 2	$\Delta y_{bouyant} + \Delta y_{R_shor}$	=1.7% Percent term ar	ring deflection in short alysis
$Check \coloneqq if \left(\Delta y_{short_net} < \Delta y_{short_net} \right)$	J _{lim} , "okay", "not o	kay") = "okay"	
<u>D4.2 - Net Long Term</u>			
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{ELD_long}$	$y_{R_long} = 3.3\%$	Percent ring defl analysis (50 yea	ection in long term rs)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y_{long_net} \right)$	_{lim} , "okay", "not ol	ay") = "okay"	



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D5.1 - Unconstrained Ring Buckling, Levy'	s Equation (Short Term-During Pull)
Note that constraining the pipe will increase considering an unconstrained condition wi	
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$E_{short} \!=\! 57500 \mathbf{psi}$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
% DEFLECTION	(Table X1.1 ASTM F 1962)
0.0 0 2 4 6 8 10 12	
2	Ovality compensation factor, Figure
fo 6	3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o_short} := 0.85$
1.0	
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)^3 \cdot \frac{f_{o_s}}{N}$	$\frac{1}{N} = 108.8 \ psi$ Allowable unconstrained buckling pressure
H=49.45 ft	Elevation difference between the lowest point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 30.91 \ psi$	Pressure of drilling slurry
$P_{net} := P_{mud} = 30.91 \ psi$	Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{``not} \right)$	okay") = "okay"
D5.2 - Unconstrained Ring Buckling, Levy	s Equation (Long Term)
Note that constraining the pipe will increas considering an unconstrained condition wi	
$N \coloneqq 2.0$	Factor of Safety
$\mu_{long} \coloneqq 0.45$	Poisson's Ratio for PE pipe material, long term (ASTM F 1962, 8.2.4.2)

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$E_{long} = 28200 \ psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1 - \mu_{long}^{2}}{1 - \mu_{long}^{2}}\right)$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_{o_long}}{N} =$	31.1 <i>psi</i> Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := \mathbf{if} \left(P_{UC_long} > P_n \right)$	$\mathbf{x}_{t},$ "okay", "not oka	y") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #101- Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23

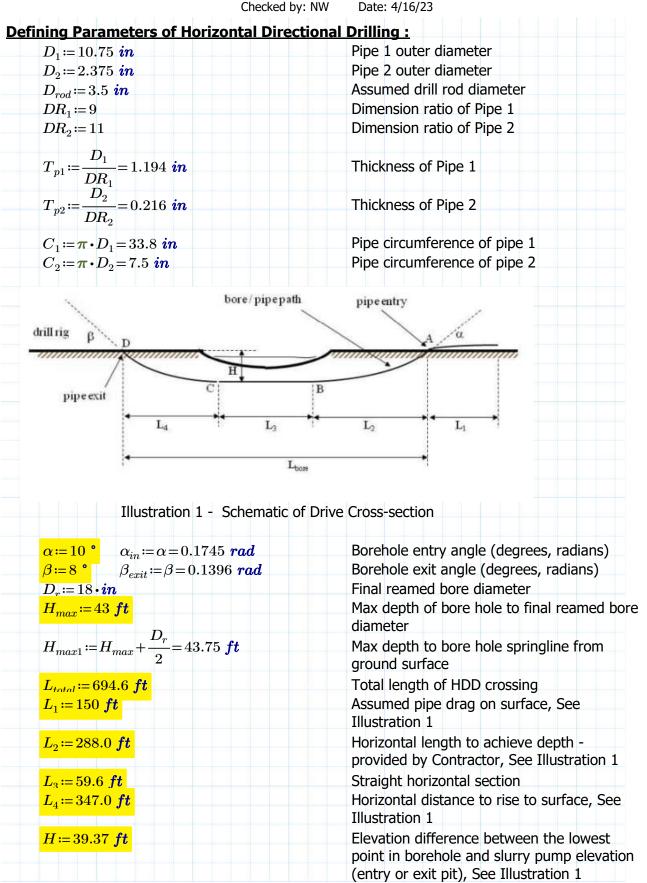
References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill

101.A



Champlain Hudson Power Express - Package 6 Crossing #101.A - Stream S-33 & Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23



Project: Tunnel No.:

Description:

Calculated by: DA

KILDUFF UNDERGROUND ENGINEERING, INC.	Project:Champlain Hudson Power Express - Package 6Tunnel No.:Crossing #101.A - Stream S-33 & Culvert CrossingDescription:Pull Back and Mud Pressure CalcsCalculated by: DADate: 4/16/23Checked by: NWDate: 4/16/23
$v_a = 0.1$	Friction coefficient before pipe enters (rollers assumed)
$v_b = 0.3$	Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w \coloneqq 62.4 \ pcf $	Unit weight of water
γ_a :=0.965	Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$	Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.4$	Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$	Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$	Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$	Gravitational Constant
<u>A - Axial Bending Stress:</u>	
$R_{avg._in} \coloneqq 1000 \; ft$	Radius of curvature at the entry, provided by Contractor
$R_{avg.out} \coloneqq 1000 \ ft$	Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 100$	<i>ft</i> Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} \! > \! r_{rod}, \text{``o'} \right)$	xay", "not okay") = "okay"
$Check \coloneqq \mathrm{if}\left(R_{avg._out} \! > \! r_{rod}, \text{``e}_{rod}, \text{``e}_{rod},$	kay", "not okay") = "okay"
Radius of curvature should exceed	40 times the pipe outside diameter to prevent ring collapse.
$e_a \coloneqq \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$\overline{E_{12hr}} \! \coloneqq \! 57500 \cdot psi$	Apparent modulus of elasticity for PE4710 Base Temperature of 73 deg. Fahrenheit a 10 hrs of sustained loading (Table X1.1 ASTM F 1962)

 $S_a := e_a \cdot E_{12hr} = 25.8 \ psi$ Axial bending stress within the casing pipe



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Site Specific Analyses: Pullback Force	
11 - Empty Pipe	
B1.1 - Effective Weight of Empty Pipe:	
$w_{a} := \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) \right) + \left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right$	$\left(\rho_2 - T_{p2} \right)^2 \right) \cdot \rho_w \cdot \gamma_a = 8.3 \ plf$
B1.2 - Upward Buoyant Force:	Effective weight
$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 51.2$	2 <i>plf</i> Upward buoyant force of empty pipe
B1.3 - Hydrokinetic Pressure:	
(π)	
$\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 79$	06 <i>lbf</i> Hydrokinetic force
B1.4 - Pullback Force Point A:	
$T := c^{v_a \cdot \alpha_{in}} / c_{in} = c_{in} / T = T + T + T + T$	- 712 lbf
$T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) =$	Pullback force when pipe enters the ground
B1.5 - Pullback Force Point B:	i diback force when pipe chers the ground
$T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - \frac{1}{2} \right)$	$-v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 7477 \ lbf$
	["] Pullback force increase with depth
B1.6 - Pullback Force Point C:	
$T_c \coloneqq T_b + \left(v_b \cdot w_b \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_3 \right)$	$L_3 \cdot e^{\langle v_a \cdot v_{mf} \rangle} = 8340 \ lbf$
B1.7 - Pullback Force at D:	
DI.7 TUBBACK FORCE at D.	
$T_d := e^{(v_b \cdot \beta_{exit})} \cdot (T_c + v_b \cdot w_b \cdot L_d - w_b \cdot H_{mu}$	$_{ax} - e^{(v_a \cdot lpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot lpha_{in})})) = 11649 \ lbf$
B1.8 - Maximum Pullback Force - Empty	Pipe:
$P_{max_empty} \coloneqq \max \left(T_a, T_b, T_c, T_d \right) + \Delta T =$	
	Maximum Pullback Force
2 - Filled Pipe with Water	
B2.1 - Upward Buoyant Force:	
· · · · · · · · · · · · · · · · · · ·	(2)
$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \cdot \boldsymbol{D}_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{2}\right)\right)\right)$	$\left(\frac{2}{DR_1}\right)\right) \left(-w_a = 24.6 \ plf\right)$
	Upward buoyant force of pipe filled with wa
B2.2 - Pullback Force Point A:	

m <i>v</i>	······································		Dullha al. favor anter survival	
$T_{afilled} \coloneqq e^{\circ}$	$a \circ \omega_{in} ullet (v_a ullet w_a ullet (L_1 ullet u_a ullet w_a ullet u_a ullet w_a ullet (L_1 ullet u_a ullet w_a ullet w_a ullet w_a ullet (L_1 ullet u_a ullet w_a $	$+L_2+L_3+L_4)) = 712 \ lof$	Pullback force enter ground	



Champlain Hudson Power Express - Package 6 Crossing #101.A - Stream S-33 & Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23

• bfilled • C (* afilled $+ b_b \bullet w_{bfilled} \bullet L_2 +$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} = 4367$ Pullback force increase and decrease
<u>B2.4 - Pullback Force Point C:</u>	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_b \right)}$	$^{\scriptscriptstyle{(n)}}\!\cdot\!\left(\!v_a\!\cdot\!w_a\!\cdot\!L_3\!\cdot\!e^{\left(\!v_a\cdotlpha_{\scriptscriptstyle{(n)}}\! ight)}\! ight)\!=\!4755lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_{d}\right)$	$_{4}-e^{\left(v_{a}\cdotlpha_{in} ight)}\cdot\left(v_{a}\cdot w_{a}\cdot L_{4}\cdot e^{\left(v_{a}\cdotlpha_{in} ight)} ight) ight)=7323$ lbg
<u>B2.6 - Maximum Pullback Force - Filled Pip</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}, T_{$	
	Maximum Pullback Force
<u> 3 - Safe Pull Strength / Ultimate Tensi</u>	le Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 := \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 11962 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Emp
$P_{21} \coloneqq \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 483 \ lbf$	Pullback forces acting on Pipe 2 (Emp
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 7039 \ lbf$	Pullback forces acting on Pipe 1 (Balla
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 284 \ lbf$	Pullback forces acting on Pipe 2 (Balla
$P_{SPF1} \coloneqq 41214 \ lbf$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
$P_{SPF2} \coloneqq 1683 \ \textit{lbf}$	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check \coloneqq if (P_{SPF1} > P_{11}, "okay", "not okay")$	") = "okay" ") = "okay"



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C - Allowable Mud Pressures:

<u>C1 - I</u>	Max.	Allow	able	Driling	g Fluid	Pressure

Assumptions:

-MathCAD calculations are used for a critical structure as identified for each crossing. If the HDD alignment crosses multiple structures the one with least cover was used. Provided hydrofracture graphs use equations, as detailed herein, to identify potential frac-out areas. Typically entry and exit areas are most susceptible to frac-out due to low cover.

-Where applicable, soil properties referenced from Kiewit's Proposed Soil Properties for CHPE Package 1, dated October 12, 2022.

$H_w := 0 \cdot ft$	Depth of the bore below groundwater elevation
$H_c := 22.54 \ ft$	Vertical separation distance between critical structure and pipe (Stream S-33, ~3+50)
$\gamma \coloneqq 110 \ pcf$	Assumed unit weight med. stiff clay
	(no geotechnical borings for crossing)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 47.6 \ pcf$	Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 0 \ psi$	Initial pore water pressure
$\phi := 0 deg$	Assumed friction Angle
$c := 800 \ psf = 5.56 \ psi$	Assumed cohesion of encountered materia
$R_0 := \frac{D_{rod}}{2} = 1.75 \ in$	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{2}{3} \cdot H_c = 15 \ ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\sigma'_{0} \coloneqq \left(\left(\gamma \cdot \left(H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 17.2 \text{ psi}$	Initial effective stress (conservative assume all buoyant)
• C.2 Typical values of modulus of elasticity (<i>E_s</i>) for different types of soils	•
C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types of soils Type of Soil <i>E_y</i> (N/mm ²) Clay	-
C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types of soils Type of Soil <i>E_s</i> (N/mm ²)	assume all buoyant)
e C.2 Typical values of modulus of elasticity (<i>E</i> _s) for different types of soils Type of Soil <i>E</i> _s (N/mm ²) Clay Very soft 2–15	assume all buoyant)
e C.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250	-
e C.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose 10–153	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \ psi$
	assume all buoyant) $E_s := 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \ psi$
e C.2 Typical values of modulus of elasticity (\mathcal{E}_{s}) for different types of soils Type of Soil $\mathcal{E}_{\nu}(N/mm^2)$ Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose Loose 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand Silty	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
a C.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
a C.2 Typical values of modulus of elasticity (\mathcal{E}_{s}) for different types of soils Type of Soil $\mathcal{E}_{s}(Nimn^{3})$ Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand Sitly 7–21 Loose 10–24 Dense 48–81 Sand and gravel	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
a C.2 Typical values of modulus of elasticity (\mathcal{E}_{s}) for different types of soils Type of Soil \mathcal{E}_{s} (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel Loose 48–148 Dense 96–192 Shale 144–14,400	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
	assume all buoyant) $E_s := 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty
a C.2 Typical values of modulus of elasticity (\mathcal{E}_{s}) for different types of soils Type of Soil \mathcal{E}_{s} (N/mm ²) Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose 10–153 Dense 144–720 Very dense 478–1,440 Loess 14–57 Sand Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel Loose 48–148 Dense 96–192 Shale 144–14,400	assume all buoyant) $E_s \coloneqq 15 \frac{N}{mm^2} = 2176 \text{ psi}$ Assumed modulus of elasticity; silty

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Table C.4 Typical values of Poisson's ratio (μ) for soils Type of soil μ	<u> </u>	
Clay (saturated) 0.4 - 0.5 Clay (unsaturated) 0.1 - 0.3		
Sandy clay 0.2 - 0.3 Silt 0.3 - 0.35 Sand (dense) 0.2 - 0.4		$\nu_s \coloneqq 0.4$
Course (void ratio = 0.4 - 0.7) 0.15 Fine grained (void ratio = 0.4 - 0.7) 0.25	14 AC	Poissions ratio of material encountered
Rock 0.1–0.4 (depend Loess 0.1 – 0.3 Ice 0.36	s on type of rock)	
Concrete 0.15		
$G \coloneqq \frac{E_s}{2 (1 + \nu_s)} = 777 \ psi$		Shear modulus of soil
$(\sigma' \cdot \sin(\phi)) + (c \cdot 0)$		
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + (c \cdot 0)}{C} = 0$		
G		Coefficient of Delft Equation
(1, -1, (1, -1, (1)))	(4) 22 2	
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$\phi(\phi) = 22.8 \ psi$	Mud pressure at which the first plastic
		deformation takes place
($(-\sin(\phi))$	
	$1 + \sin(\phi)$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pma}} \right) \right) \cdot \left(\left(\frac{R_0}{R_{pma}} \right) \right) + \left(\left(\frac{R_0}{R_{pma}} \right) \right) \right) + \left(\frac{R_0}{R_{pma}} \right) \right) + \left(\frac{R_0}{R_{pma}} \right) + \left(\frac{R_0}{R_{pma}$	- +Q	$-c \cdot 0 = 22.8 \ psi$
		/
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 22.8 \ psi$		Maximum allowable mud pressure
$p_{max} - a + p_{max} - 22.0$ ps		
<u>C2 -Min. Allowable Drilling F</u>	<u>luid Pressure</u>	
$D_{PT} := 5 $ <i>in</i>		Pilot tube diameter
$D_0 := 9.5 in$		Initial borehole diameter for pilot tube
$h \coloneqq 39.34 \ ft$		Elevation difference between level of bore
$\gamma_m = 90 \ pcf$		hole front and exit point of mud flow Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 24.6 \text{ psi}$		Minimum required mud pressure to
		overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
$\tau_o \coloneqq 16 \ \frac{lbf}{100 \cdot ft^2}$		Assumed yield point of mud per 100 square feet
poise		
$\underline{\qquad } \mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v \coloneqq \frac{Q_f}{0.785 \left(D_0^2 - D_{PT}^2\right)} = 75$.2 <u>ft</u>	Computed mud flow velocity
$0.785 \left({D_0}^2 - {D_{PT}}^2 ight)$	min	

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 $L_{structure} \coloneqq 350 \ ft$

Length to sturcture

$$p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)} \right) \right) = 1 \ psi$$

Minimum required mud pressure to create flow inside the borehole

 $p_{min.} = p_1 + p_2 = 25.6 \ psi$

Minimum required mud pressure

 $check := if(p_{max} > p_{min.}, "okay", "not okay") = "not okay"$

Crossing will require risk mitigation of conductor casing &/or relief wells.



Champlain Hudson Power Express - Package 6 Crossing #101.A - Stream S-33 & Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23

ned Borehole with Arching Mobilized) pepth of cover riction angle of soil Silo" width, conservative value = eamed hole diameter arth pressure coefficient Init weight of soil, assumed rching factor (Eq. 6, p.432, PPI)
riction angle of soil Silo" width, conservative value = eamed hole diameter arth pressure coefficient nit weight of soil, assumed rching factor (Eq. 6, p.432, PPI)
Silo" width, conservative value = eamed hole diameter arth pressure coefficient Init weight of soil, assumed rching factor (Eq. 6, p.432, PPI)
arth pressure coefficient Init weight of soil, assumed rching factor (Eq. 6, p.432, PPI)
rching factor (Eq. 6, p.432, PPI)
ffective overburden pressure
pparent modulus of elasticity for E4710, Base Temperature of 73 deg. ahrenheit at 10 hrs of sustained loading Table X1.1 ASTM F 1962)
ariable in earth load deflection equation
ipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437, PPI Handboo
pparent modulus of elasticity for PE4710 ase Temperature of 73 Fahrenheit at 50 ears of sustained loading (Table X1.1 STM F 1962)
ariable in earth load deflection equation
ipe deflection to diameter as per PI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection	(Short Term)	
$D_1 = 10.75$ in		Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
		Apparent modulus of elasticity for
$E_{short} \!=\! 57500 {\it psi}$		PE4710, Base Temperature of 73
		Fahrenheit (Table B.1.1)
$\gamma_m = 90 pcf$		Assumed unit weight of fluid in
t^3 in^4		borehole (Slurry unit weight)
$\gamma_{m} = 90 \text{ pcf}$ $I := \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $0.1169 \cdot \gamma_{m} \cdot \left(\frac{\Delta y_{bouyant}}{E_{short}} \cdot I\right)$	$(D_1)^4$	Moment of inertia of pipe wall cross section
$0.1169 \cdot \gamma_m \cdot$		Pipe ring deflection to buoyant force
$\Delta y_{bouyant} :=$	=0.1%	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection ((Long Term)	
D3 - Reissner Effect Defle D3.1 - Reissner Effect De		-
D3.1 - Reissner Effect De		-
		Poisson's Ratio for PE pipe material at
$D3.1 - Reissner Effect Det \mu_{short} = 0.35$ $R = 1000 ft$	flection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$D3.1 - Reissner Effect Det \mu_{short} = 0.35$ $R = 1000 ft$	flection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
D3.1 - Reissner Effect De	flection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$D3.1 - \text{Reissner Effect Der}$ $\mu_{short} \coloneqq 0.35$ $R \equiv 1000 \text{ ft}$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_1\right)$ $16 \cdot t^2 \cdot R^2$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$\frac{t}{t}^{4} = 0.0000033$ $) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$D3.1 - \text{Reissner Effect Der}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - t_2)}{16 \cdot t^2 \cdot R^2}$	$\frac{t}{t}^{4} = 0.0000033$ $) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner
$D3.1 - \text{Reissner Effect Der}$ $\mu_{short} \coloneqq 0.35$ $R \equiv 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - \mu_{short}^2)}{16 \cdot t^2 \cdot R^2}$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ $D3.2 - \text{Reissner Effect Der}$ $\mu_{long} \coloneqq 0.45$	$\frac{t}{t}^{4} = 0.0000033$ $) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$D3.1 - \text{Reissner Effect Der}$ $\mu_{short} \coloneqq 0.35$ $R = 1000 \text{ ft}$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_1\right)$ $16 \cdot t^2 \cdot R^2$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ $D3.2 - \text{Reissner Effect Der}$	$\frac{t}{t}^{4} = 0.0000033$ $) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at
$D3.1 - \text{Reissner Effect Der}$ $\mu_{short} \coloneqq 0.35$ $R \equiv 1000 \text{ ft}$ $z \coloneqq \frac{\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - \mu_{short}^2)}{16 \cdot t^2 \cdot R^2}$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ $D3.2 - \text{Reissner Effect Der}$ $\mu_{long} \coloneqq 0.45$	$\frac{t}{t}^{4} = 0.0000033$ $) \cdot z^{2} = 0.0002\%$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)

ALDUFF	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package Crossing #101.A - Stream S-33 & Culvert Cro Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23	
<u> D4 - Net Ring Deflectio</u>	<u>n</u>		
Δy_{lim} := 7.5%		Deflection limit for DR 9 non pressuriz	
D4.1 - Net Short Term		pipe (Table 2 , p. 437, PPI Handbook))
Δy_{short_net} := Δy_{ELD_short}	$_{t}+ \Delta y_{bouyant}+ \Delta y_{R_sho}$	$_{rt} = 2.0\%$ Percent ring deflection in sho term analysis	ort
$Check \coloneqq ext{if} \left(\Delta y_{short_net} < ight)$	$<\!\Delta y_{lim},$ "okay", "not of	okay") = "okay"	
D4.2 - Net Long Term			
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long}$	$+\Delta y_{R_long} = 3.9\%$	Percent ring deflection in long term analysis (50 years)	
$Check \coloneqq ext{if} \left(\Delta y_{long_net} < ight)$	$\Delta y_{lim},$ "okay", "not o	okay") = "okay"	



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D5.1 - Unconstrained Ring Bucklin	ng, Levy's Equation (Short Term-During Pull)
	ill increase the pipe's buckling strength, therefore dition will produce a conservative value.
N:=2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$E_{short} \!=\! 57500 \mathbf{psi}$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loadin (Table X1.1 ASTM F 1962)
0 2 4 6 8 10 12 % DEPLECTION	5
2 0.0 0 2 4 6 8 10 12	
f ₀ 6	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o_short} \coloneqq 0.85$
	$\left(\frac{1}{n}\right)^{3} \cdot \frac{f_{o_short}}{N} = 108.8 \text{ psi}$ Allowable unconstrained buckling pressure
H=39.37 ft	Elevation difference between the lowest
$P \rightarrow \gamma \gamma H = 24.61$ mei	point in borehole and entry or exit pit Pressure of drilling slurry
$m_{mud} = \gamma_m \cdot m - 24.01 \text{ pst}$	
	Net external loading with open borehole
$P_{mud} \coloneqq \gamma_m \cdot H = 24.61 \text{ psi}$ $P_{net} \coloneqq P_{mud} = 24.61 \text{ psi}$ $Check \coloneqq \text{if } (P_{UC_short} > P_{net}, \text{``oka})$	
$P_{net} \coloneqq P_{mud} = 24.61 \ psi$	y", "not okay") = "okay"
$P_{net} := P_{mud} = 24.61 \ psi$ $Check := if (P_{UC_short} > P_{net}, "okay)$ D5.2 - Unconstrained Ring Buckling Note that constraining the pipe w	y", "not okay") = "okay" ng, Levy's Equation (Long Term) ill increase the pipe's buckling strength, therefore
$P_{net} := P_{mud} = 24.61 \ psi$ $Check := if (P_{UC_short} > P_{net}, "okay)$ D5.2 - Unconstrained Ring Buckling Note that constraining the pipe w	ng, Levy's Equation (Long Term)

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #101.A - Stream S-33 & Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/16/23 R1: 6/12/23 Date: 4/16/23
$E_{long} = 28200 \; psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1 - \mu_{long}^{2}}{1 - \mu_{long}^{2}}\right) \cdot \left(1 - \mu_$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_{o_long}}{N} =$	31.1 <i>psi</i> Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_long} > P_{net}, \text{``okay''}, \text{``not okay''} \right) = \text{``okay''}$		
$Check := \Pi \left(P_{UC_long} > P_n \right)$	_{et} , "okay", "not okay	$('') = \operatorname{Okay}^{*}$



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References

- 1. ASTM F 1962 -05 Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings
- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- 3. Proposed Soil Properties for CHPE Package 1 HDDs, Kiewit, October 12, 2022.
- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
- 5. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill