

Champlain Hudson Power Express - Package 6 Crossing #102- Stream S-34 & Coxsackie Creek (S-35) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

Defining Parameters of Horizontal Directional Drilling : $D_1 := 10.75$ in $D_2 := 2.375$ inPipe 1 outer diameter Pipe 2 outer diameter $D_{cin} := 3.5$ in $D_{R_1} := 9$ Dimension ratio of Pipe 1 $DR_1 := 9$ Dimension ratio of Pipe 2 $T_{p1} := \frac{D_1}{DR_1} = 1.194$ in $T_{p2} := \frac{D_2}{DR_2} = 0.216$ in $C_2 := \pi \cdot D_2 = 7.5$ inThickness of Pipe 1 $T_{p2} := \frac{D_2}{DR_2} = 0.216$ in $C_2 := \pi \cdot D_2 = 7.5$ inPipe circumference of pipe 1 Pipe circumference of pipe 2dill rig pipeesit p L_4 L_3 L_4 L_3 L_2 L_4 dill rig pipeesit $\beta_{cat} := \alpha = 0.1745$ rad $\beta_{cat} := \beta = 0.2094$ radBorehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter $m_{max} := H_{max} + \frac{D_r}{2} = 42.35$ ftMax depth to bore hole to final reamed bore dilustration 1 $H_{max} := 266.8$ ft $H_{mix} := 1362.5$ ftTotal length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8$ ft $H_{11} := 1362.5$ ftStraight horizontal section, before curve	Checked by:	NW Date: 4/17/23
$\begin{array}{c} D_1 \coloneqq 10.75 \ in \\ D_2 \coloneqq 2.375 \ in \\ D_{rod} \coloneqq 3.5 \ in \\ D_{rod} \equiv 1.194 \ in \\ T_{p1} \coloneqq \frac{D_1}{DR_1} = 1.194 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 7.5 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 7.5 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 7.5 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 1.194 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 1.194 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 7.5 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 7.5 \ in \\ D_{rod} \simeq 10^{+} \ c_{2} = 1.12^{+} \ c_{2} = 1.1$	Defining Parameters of Horizontal Direct	<u>ional Drilling :</u>
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$\begin{array}{c} D_{rod} \coloneqq 3.5 \ in \\ DR_1 \coloneqq 9 \\ DR_2 \coloneqq 11 \\ \hline \\ DR_2 \coloneqq 11 \\ \hline \\ T_{p1} \coloneqq \frac{D_1}{BR_1} = 1.194 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ \hline \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ \hline \\ C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in \\ C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in \\ \hline \\ \hline \\ bree fright prime from the state of $	$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$\begin{array}{c c} DR_1 \coloneqq 9 \\ DR_2 \coloneqq 11 \\ DR_2 \coloneqq 11 \\ DR_2 \coloneqq 11 \\ T_{p1} \coloneqq \frac{D_1}{DR_1} = 1.194 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.226 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.276 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.276 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.276 \ in \\ T_{p3} \coloneqq \frac{D_2}{DR_2} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ in \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \coloneqq 10^{-2} \ M_{p3} = 0.276 \ max \\ T_{p3} \equiv 10^{-2} \ M_{p3} \equiv 10^{-$	$D_{rod} \coloneqq 3.5 \ in$	Assumed drill rod diameter
$\begin{array}{c} DR_2 \coloneqq 11 \\ DR_1 \coloneqq 194 \ in \\ T_{p1} \coloneqq \frac{D_1}{DR_1} = 1.194 \ in \\ T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \ in \\ C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in \\ C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in \\ \end{array}$ $\begin{array}{c} \text{Pipe circumference of pipe 1} \\ \text{Pipe circumference of pipe 2} \\ Pipe circumference of$	$DR_1 := 9$	Dimension ratio of Pipe 1
$T_{p1} := \frac{D_1}{DR_1} = 1.194 \text{ in}$ $T_{p2} := \frac{D_2}{DR_2} = 0.216 \text{ in}$ $Pipe circumference of pipe 1$ $Pipe circumference of pipe 2$ $Pipe c$	$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$T_{p2} := \frac{L_2}{DR_2} = 0.216 \text{ in}$ Thickness of Pipe 2 $C_1 := \pi \cdot D_1 = 33.8 \text{ in}$ Pipe circumference of pipe 1 Pipe circumference of pipe 2 $C_2 := \pi \cdot D_2 = 7.5 \text{ in}$ Pipe circumference of pipe 2 $Illustration 1 - Schematic of Drive Cross-section$ $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ Borehole entry angle (degrees, radians) $\beta := 12^{\circ} \qquad \beta_{ext} := \beta = 0.2094 \text{ rad}$ Dr_:= 18 · in $H_{max} := H_{max} + \frac{D_r}{2} = 42.35 \text{ ft}$ $L_2 := 256.8 \text{ ft}$ Thickness of Pipe 2 Pipe circumference of pipe 1 Pipe circumference of pipe 2 Pipe circumference of pipe circumfer	$T_{p1} := \frac{D_1}{DR_1} = 1.194 \ in$	Thickness of Pipe 1
C1:= $\pi \cdot D_1$ = 33.8 in C2:= $\pi \cdot D_2$ = 7.5 inPipe circumference of pipe 1 Pipe circumference of pipe 2Distribution of the pipe pathPipe circumference of pipe 2Distribution of the pipe pathPipe circumference of pipe 2Distribution of pipe pathPipe circumference of pipe 2 </th <th>$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$</th> <th>Thickness of Pipe 2</th>	$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$\begin{array}{c} C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in \\ \hline \\ C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in \\ \hline \\ Pipe circumference of pipe 2 \\ \hline \\ pipe circumferenc$	$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$C_2 \coloneqq \pi \cdot D_2 = 7.5 \text{ in}$	Pipe circumference of pipe 2
$\begin{array}{c c} \text{drill rig} & p \\ pipe exit \\ \hline \\ Illustration 1 - Schematic of Drive Cross-section \\ \hline \\ \alpha := 10 \circ \\ \beta_{exit} := \alpha = 0.1745 \text{ rad} \\ \beta_{i=12} \circ \\ \beta_{exit} := \beta = 0.2094 \text{ rad} \\ \hline \\ D_{r} := 18 \cdot in \\ H_{max} := 41.6 \text{ ft} \\ H_{max} := H_{max} + \frac{D_{r}}{2} = 42.35 \text{ ft} \\ Illustration 1 - Schematic of Drive Cross-section \\ \hline \\ D_{r} := 130 \text{ ft} \\ H_{max} := 2441 \text{ ft} \\ L_{1} := 150 \text{ ft} \\ L_{2} := 256.8 \text{ ft} \\ I_{3} := 1362.5 \text{ ft} \\ \hline \\ \end{array}$	bore/pipepath	pipe entry
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		
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pipe exit $\begin{array}{c} \mathbf{u}_{4} \\ \mathbf{u}_{4} \\ \mathbf{u}_{4} \\ \mathbf{u}_{5} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}_{2} \\ \mathbf{u}_{6} \\ \mathbf{u}_{6} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}_{2} \\ \mathbf{u}_{6} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}_{2} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}_{2} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}_{2} \\ \mathbf{u}_{6} \\ \mathbf{u}_{1} \\ \mathbf{u}$		
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Illustration 1 - Schematic of Drive Cross-section $\alpha := 10^{\circ}$ $\beta_{exit} := \alpha = 0.1745 rad\beta_{exit} := \beta = 0.2094 radBorehole entry angle (degrees, radians)Borehole exit angle (degrees, radians)Borehole exit angle (degrees, radians)Har angle (degrees, radians)Final reamed bore diameterD_r := 18 \cdot inH_{max} := 41.6 ftH_{max1} := H_{max} + \frac{D_r}{2} = 42.35 ftBorehole entry angle (degrees, radians)Borehole exit angle (degrees, radians)Final reamed bore hole to final reamed borediameterH_{max1} := H_{max} + \frac{D_r}{2} = 42.35 ftMax depth of bore hole to final reamed borediameterL_{total} := 2441 ftL_1 := 150 ftMax depth of HDD crossingAssumed pipe drag on surface, SeeIllustration 1Horizontal length to achieve depth -provided by Contractor, See Illustration 1Straight horizontal section, before curve$	pipeexit	в
L_{tors} Illustration 1 - Schematic of Drive Cross-section $\begin{array}{l} \alpha \coloneqq 10 \ ^{\circ} \qquad \alpha_{in} \coloneqq \alpha = 0.1745 \ rad \\ \beta \Subset 12 \ ^{\circ} \qquad \beta_{exit} \coloneqq \beta = 0.2094 \ rad \\ D_r \coloneqq 18 \cdot in \\ H_{max} \coloneqq 41.6 \ ft \\ H_{max} = H_{max} + \frac{D_r}{2} = 42.35 \ ft \\ L_{total} \coloneqq 2441 \ ft \\ L_1 \coloneqq 150 \ ft \\ L_2 \coloneqq 256.8 \ ft \\ L_3 \ 1 \coloneqq 1362.5 \ ft \\ L_3 \ 1 \coloneqq 1362.5 \ ft \\ \end{array}$ Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Boreho	La La	
L _{tors} Illustration 1 - Schematic of Drive Cross-section $\alpha := 10^{\circ}$ $\beta := 12^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta_{exit} := \beta = 0.2094 \ rad$ Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter $D_r := 18 \cdot in$ $H_{max} := 41.6 \ ft$ $H_{max} := 41.6 \ ft$ $H_{max} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter $H_{max} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth of bore hole to final reamed bore diameter $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} := 2441 \ ft$ $L_1 := 150 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8 \ ft$ $H_{max} := 1362.5 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3,1} := 1362.5 \ ft$ Straight horizontal section, before curve		
The section $\alpha := 10^{\circ}$ $\beta := 12^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta_{exit} := \beta = 0.2094 \ rad$ Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter $D_r := 18 \cdot in$ $H_{max} := 41.6 \ ft$ Borehole exit angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter $H_{max} := 41.6 \ ft$ $H_{max} := 41.6 \ ft$ Max depth of bore hole to final reamed bore diameter $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} := 2441 \ ft$ $L_1 := 150 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8 \ ft$ $L_3 := 1362.5 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1	• In	
Illustration 1 - Schematic of Drive Cross-section $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ Borehole entry angle (degrees, radians) $\beta := 12^{\circ}$ $\beta_{exit} := \beta = 0.2094 \ rad$ Borehole exit angle (degrees, radians) $D_r := 18 \cdot in$ Final reamed bore diameter $H_{max} := 41.6 \ ft$ Max depth of bore hole to final reamed bore $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} := 2441 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3 \ 1} := 1362.5 \ ft$ Straight horizontal section, before curve		
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$\alpha := 10^{\circ}$ $\beta := 12^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ rad $\beta_{exit} := \beta = 0.2094$ radBorehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) $Borehole exit angle (degrees, radians)Horehole exit angle (degrees, radians)Final reamed bore diameterD_r := 18 \cdot inHarrow in the second secon$	Illustration 1 - Schematic of	Drive Cross-section
$\beta := 12 \circ \beta_{exit} := \beta = 0.2094 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 41.6 \text{ ft}$ $H_{max} := 41.6 \text{ ft}$ $H_{max} := H_{max} + \frac{D_r}{2} = 42.35 \text{ ft}$ $L_{total} := 2441 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 256.8 \text{ ft}$ $L_{3,1} := 1362.5 \text{ ft}$ $D_r := 1362.5 ft$	$\alpha := 10^{\circ}$ $\alpha := \alpha = 0.1745$ rad	Borehole entry angle (degrees, radians)
$D_r := 18 \cdot in$ Final reamed bore diameter $H_{max} := 41.6 \ ft$ Final reamed bore diameter $H_{max} := 41.6 \ ft$ Max depth of bore hole to final reamed bore diameter $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} := 2441 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3,1} := 1362.5 \ ft$ Straight horizontal section, before curve	$\beta := 12^{\circ}$ $\beta_{mi} := \beta = 0.2094$ rad	Borehole exit angle (degrees, radians)
$H_{max} := 41.6 \ ft$ Max depth of bore hole to final reamed bore diameter $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth of bore hole springline from ground surface $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} := 2441 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 := 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3-1} := 1362.5 \ ft$ Straight horizontal section, before curve	$D := 18 \cdot in$	Final reamed bore diameter
$H_{max} = H_{max} + \frac{D_r}{2} = 42.35 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 42.35 \text{ ft}$ $H_{max1} := 2441 \text{ ft}$ $L_{total} := 2441 \text{ ft}$ $L_{1} := 150 \text{ ft}$ $L_{2} := 256.8 \text{ ft}$ $H_{max1} := 1362.5 \text{ ft}$ $H_{max2} := 1362.5 \text{ ft}$	$H_{\text{max}} \coloneqq 41.6 \text{ ft}$	Max depth of bore hole to final reamed bore
$H_{max1} \coloneqq H_{max} + \frac{D_r}{2} = 42.35 \ ft$ Max depth to bore hole springline from ground surface $L_{total} \coloneqq 2441 \ ft$ Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 $L_2 \coloneqq 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3_1} \coloneqq 1362.5 \ ft$ Straight horizontal section, before curve		diameter
$\begin{array}{c} L_{total} \coloneqq 2441 \ ft \\ L_1 \coloneqq 150 \ ft \\ \end{array} \qquad \qquad$	$H_{max1} \coloneqq H_{max} + \frac{D_r}{2} = 42.35 \ ft$	Max depth to bore hole springline from ground surface
$L_1 \coloneqq 150 \ ft$ Assumed pipe drag on surface, See $L_2 \coloneqq 256.8 \ ft$ Illustration 1 $L_2 \coloneqq 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3_1} \coloneqq 1362.5 \ ft$ Straight horizontal section, before curve	$L_{total} \coloneqq 2441 \ \mathbf{ft}$	Total length of HDD crossing
$L_2 \coloneqq 256.8 \ ft$ Horizontal length to achieve depth - provided by Contractor, See Illustration 1 $L_{3_1} \coloneqq 1362.5 \ ft$ Straight horizontal section, before curve	$L_1 \coloneqq 150 \ ft$	Assumed pipe drag on surface, See Illustration 1
$L_{3_1} = 1362.5 \ ft$ Straight horizontal section, before curve	$L_2 := 256.8 \ ft$	Horizontal length to achieve depth - provided by Contractor, See Illustration 1
	L_{3_1} ≔ 1362.5 ft	Straight horizontal section, before curve
$L_{3_2} \coloneqq 332.6 \ ft$ Curve Length	$L_{3_2} := 332.6 \ ft$	Curve Length
$L_{3_3} = 193.1 \ ft$ Straight horizontal section, after curve	$L_{3_{-3}} := 193.1 \ ft$	Straight horizontal section, after curve

Project: Tunnel No.:

Description: Calculated by: DA

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #102- Stream S-34 & Coxsackie Creek (S-3 Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
$L_4 := 289.6 \ ft$		Horizontal distance to rise to surface, See Illustration 1
<i>H</i> ≔ 39.9 <i>ft</i>		Elevation difference between the lowest point in borehole and slurry pump elevation (entry or exit pit), See Illustration 1
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$\rho_{\rm eff} := 62.4 \ pcf$		Unit weight of water
$\gamma_a^w = 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 67 \ pcf = 9 \ \frac{lbf}{gal}$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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
A - Axial Bending Stress:		
$R_{avg._in} \coloneqq 1000 \; ft$		Radius of curvature at the entry, provided by Contractor
$\frac{R_{avg._out}}{=}1000 \; ft$		Radius of curvature at the exit, provided
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1000$	ft	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg_in} > r_{rod}, \mathbf{``ok} \right)$	ay", "not okay")="okay"
$Check := if (R_{ava}, out > r_{rod}, "o$	kay", "not okav	") = "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)
$S_a \coloneqq e_a \cdot E_{12hr} = 25.8 \ psi$	Axial bending stress within the casing pipe



Champlain Hudson Power Express - Package 6 Crossing #102- Stream S-34 & Coxsackie Creek (S-35) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

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 $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{\Lambda}\right) \rho_w \cdot \gamma_b - w_a = 36 \ plf \qquad \text{Upward buoyant force of empty pipe}$ 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: $T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 2180 \ \textit{lbf}$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 6570 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C1: $T_{c_1} := T_b + (v_b \cdot w_b \cdot L_{3_1}) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})}) = 20076 \ lbf$ B1.7 - Pullback Force Point C2: $\alpha_{curve} \coloneqq 19.1$ ° $\frac{\alpha_{curve} - 10.1}{T_{c_2} := e^{v_b \cdot \alpha_{curve}}} \left(T_{c_1} + v_b \cdot |w_b| \cdot L_{3_2} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 27498 \ lbf$ $\begin{array}{l} \underline{B1.8} - \underline{Pullback \ Force \ Point \ C3:} \\ T_{c \ 3} \coloneqq T_{c_{-2}} + (v_b \cdot w_b \cdot L_{3_{-3}}) - e^{(v_b \cdot \alpha_{curve})} \cdot (v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{(v_a \cdot \alpha_{curve})}) = 29401 \ \textit{lbf} \end{array}$ B1.9 - Pullback Force at D: $T_{d} := e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c}_{3} + v_{b} \cdot |w_{b}| \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) = 32778 \ lbf$ B1.10 - Maximum Pullback Force - Empty Pipe: $P_{max_empty} \! \coloneqq \! \max \left(\! T_a, T_b, T_{c_1}, T_{c_2}, T_{c_3}, T_d \! \right) \! + \! \Delta T \! = \! 33575 \ \textit{lbf}$ Maximum Pullback Force

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Checked by: NW

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<u>B2 -</u>	Filled	Pipe	with	Water

B2.1 - Upward Buoyant Force:

$$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} \boldsymbol{D}_{1}^{-2} \right)}{4} \right) \boldsymbol{\cdot} \rho_{w} \boldsymbol{\cdot} \left(\gamma_{b} - \gamma_{c} \boldsymbol{\cdot} \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 10.2 \ \boldsymbol{plf}$$

Upward buoyant force of pipe filled with water

B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 2180 \ \textit{lbf}$ Pullback force enter ground

B2.3 - Pullback Force Point B:

 $T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot |w_{bfilled}| \cdot L_2 + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 3794 \ lbf$ Pullback force increase and decrease with depth

 $T_{c1_filled} \coloneqq T_{bfilled} + \left(v_b \cdot \left| w_{bfilled} \right| \cdot L_{3_1} \right) - e^{(v_b \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})} \right) = 6732 \ lbf$

B2.5 - Pullback Force Point C2:

 $\alpha_{curve} = 19.1$ °

 $T_{c2_filled} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c1_filled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_{3_2} + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_{3_2} \cdot e^{\left(v_a \cdot \alpha_{curve}\right)} \right) = 9341 \ \textit{lbf}$

B2.6 - Pullback Force Point C3:

 $T_{c3_filled} \coloneqq T_{c2_filled} + \left(v_b \cdot \left| w_{bfilled} \right| \cdot L_{3_3} \right) - e^{\left(v_b \cdot \alpha_{curve} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 8639 \ \textit{lbf}$

B2.7 - Pullback Force at D:

 $T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c3_filled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) \right) = 9873 \ lbf$

<u>B2.8 - Maximum Pullback Force - Filled Pipe with Water:</u> $P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{c1_filled}, T_{c2_filled}, T_{c3_filled}, T_{dfilled} \right) = 9873 \ lbf$

Maximum Pullback Force

B3 - Safe Pull Strength / Ultimate Tensile Load Check:

B3.1 Safe Pullback Check

$A_1 \! \coloneqq \! rac{\pi}{4} \left({D_1}^2 - \left({D_1 - T_{p1}} ight)^2 ight) \! = \! 19 \; {oldsymbol in}^2$	Cross-sectional area of Pipe 1
$A_2 \! \coloneqq \! rac{\pi}{4} \left({D_2}^2 \! - \! \left(\! D_2 \! - \! T_{p2} \! ight)^2 ight) \! = \! 0.8 {\it in}^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 32272 \ lbf$	Pullback forces acting on Pipe 1 (Empty)
$A_1 + A_2$	

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$P_{21} \! \coloneqq \! \frac{A_2 \! \cdot \! P_{max_empty}}{A_1 \! + \! A_2} \! = \! 130$	3 lbf	Pullback forces a	acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 9490 \ lbf$		Pullback forces a	acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 383 \ lbf$		Pullback forces a	acting on Pipe 2 (Ballast)
$P_{SPF1} \! \coloneqq \! 41214 \textit{lbf}$		Safe pullback fo p. 448, PPI)	rces Pipe 1 (Table %,
$P_{SPF2} \coloneqq 1683 \ lbf$		Safe pullback fo p. 448, PPI)	rces Pipe 2 (Table %,
$check := \mathbf{if} (P_{SPF1} > P_{11}, \text{``ok})$ $check := \mathbf{if} (P_{SPF2} > P_{21}, \text{``ok})$ $check := \mathbf{if} (P_{SPF1} > P_{12}, \text{``ok})$ $check := \mathbf{if} (P_{SPF2} > P_{22}, \text{``ok})$	xay", "not okay") = xay", "not okay") = xay", "not okay") = xay" "not okay") =	= "okay" = "okay" = "okay" = "okay"	
	(dy , 110 t olday) -		



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C - Allowable Mud Pressures:

<u>C1 -</u>	Max.	Allowa	able D	riling	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	$= 17.7 \cdot ft$		Depth of the bore below groundwater elevation
H _c	≔17.7 <i>ft</i>		Vertical separation distance between critical structure and pipe (Coaxsackie Creek controls ~15+50)
$\gamma =$	= 100 pcf		Assumed unit weight soft to clay/silt
			(zero blow count material)
γ	= 62.4 ncf		Unit weight of water
γ^{w}	$-\alpha - \alpha - 37.6$ m	of	Effective unit weight
y .	$\gamma = \gamma_w = 31.0 \text{ pc}$	-]	
	$=\gamma_w \cdot H_w = 8 psi$		
<mark>φ</mark> ።	=0 deg		Assumed friction Angle
			(B K-210.1 %-200=66%)
<u>c</u> :=	:450 psf =3.13 <u>1</u>	<mark>psi</mark>	Assumed cohesion of encountered materia (KIE suggests Su=300-350 psf)
B.	$=\frac{D_{rod}}{1.75}$ in		Initial radius of the borehole
10	2		
R _{pr}	$_{max} \coloneqq \frac{1}{2} \cdot H_c = 9 f$	^f t	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
σ'_0	$\coloneqq \left(\left(\gamma \boldsymbol{\cdot} \left(H_c - H_w \right) \right) \right)$	$\left(\gamma' \cdot H_w \right) = 5 \ psi$	Initial effective stress
Table C 2 T	unical values of modulus of elastic	ity (E.) for different types of soils	
Table C.2 1	Type of Soil	$F_{\rm c}$ (N/mm ²)	
	Clay	ny (mana y	
	Very soft Soft	2-15 5-25	
	Medium	15-50	
	Hard Sandy	50–100 25–250	$E_s := 5 - \frac{2}{2} = 725 \ psi$
	Glacial till		
	Dense	144-720	Assumed modulus of elasticity
	Very dense	478-1,440	
	Loess Sand	14-57	
	Silty	7-21	
	Loose	10-24	
	Sand and gravel	40-01	
	Loose	48148	
	Dense	96-192	
	Silt	2-20	

N D E R G R O U N D NGINEERING, INC.	Description: Calculated by: DA Checked by: NW	Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
Table C.4 Typical values of Poisson's ratio (μ) for soils		
Type of soil µ		
Clay (unsaturated) $0.4 - 0.3$ 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 Fine grained (void ratio = $0.4 - 0.7$) 0.25		$\nu_s \coloneqq 0.4$
Rock 0.1-0.4 (dependence) Loess 0.1 - 0.3 Ice 0.36 Concrete 0.15	ds on type of rock)	Poissions ratio of material encountered
C_{i-} E_s -250 mai		Shear modulus of soil
$G = \frac{2}{2 \left(1 + \nu_s\right)} = 259 \text{ pst}$		
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + (c \cdot 0)}{\widetilde{\alpha}} = 0$)	
G		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$s(\phi) = 7.7 \ psi$	
		deformation takes place
	$\left(\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}\right)$	_))
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left\ \left(\frac{R_0}{R_{pmo}} \right) \right\ \right) + \left\ \left\ \left(\frac{R_0}{R_{pmo}} \right) \right\ \right\ \right\ \right)$	$\left(\frac{1}{ax}\right) + Q$	$-c \cdot 0 = 7.7 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} \equiv 15.4 $ psi		Maximum allowable mud pressure
C2 -Min. Allowable Drilling F	luid Pressure	
$D_{PT} \coloneqq 5 \ in$		Pilot tube diameter
$D_0 = 9.5 \ in$		Initial borehole diameter for pilot tube
$h \coloneqq 38.9 \ \mathbf{ft}$		Elevation difference between level of bore
		hole front and exit point of mud flow
$\gamma_m = 67 pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 18.1 \ psi$		Minimum required mud pressure to overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
$\tau_o \coloneqq 16 - \frac{lbf}{lbf}$		Assumed yield point of mud per 100
$100 \cdot ft^2$		square feet
$\mu_{nl} \coloneqq 25 \cdot \frac{poise}{2}$		Assumed plastic viscosity of mud
100		. ,

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$v \coloneqq \frac{Q_f}{0.785 \left(D_0^2 - D_{PT}^2\right)} = 75$	$5.2 \frac{ft}{min}$	Computed mud flow velocity
$L_{total} = 2441 \; ft$		Total length of HDD crossing
$p_2 \coloneqq L_{total} \cdot \left(\left(rac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} ight)^2} ight) + ight)$	$\left(\frac{\boldsymbol{\tau}_o}{\left(\boldsymbol{D}_0 - \boldsymbol{D}_{PT} \right)} \right) = \boldsymbol{T}_{o}$	7.3 <i>psi</i>
		Minimum required mud pressure to create
$p_{min.} \! \coloneqq \! p_1 \! + \! p_2 \! = \! 25.4 {\it psi}$		Minimum required mud pressure



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1- Ring Deflection (Short & Long Term):	
D1.1 - Overburden Pressure (Considering De	eformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 41.6 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18$ in	"Silo" width, conservative value =
$\left(\begin{array}{c} \phi \end{array} \right)^2$	reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\varphi}{2}\right)$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{R}\right)\right)$	
$k \coloneqq \frac{\left(\begin{array}{c}B\\2\end{array}\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 11 \ psi \ P_E = 1564 \ p$	osf 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)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$	Variable in earth load deflection equation
$0.0125 \cdot P_E$	
$\Delta y_{ELD_short} = \frac{1}{k} = 1.5\%$	Pipe deflection to diameter as per
[™] short	PPI Equ. 10 (Chp 12, p 437, PPI Handbook
D1.3 Earth Load Deflection (Long Term)	
H 00000	Apparent modulus of elasticity for PE4/10, Base Temperature of 72 Eabraphoit at E0
$E_{long} \coloneqq 28200 \cdot psi$	vears of sustained loading (Table X1.1
	ASTM F 1962)
$E_{long} = 4.6$ mai	Variable in earth lead deflection equation
$n = \frac{12}{12} \left(DP = 1 \right)^3 = 4.0 \text{ psi}$	
$12 \cdot (DR_1 - 1)$	Dine deflection to diameter as nor
$A_{4} = -\frac{0.0125 \cdot P_E}{-3.0\%}$	PPI Fau, 10 (Chp 12, p 437)
$\Delta g_{ELD_long} = \frac{1}{k}$	

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection (<u>(Short Term)</u>	
$D_1 \!=\! 10.75 \; in$		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)
$\gamma_m = 67 pcf$		Assumed unit weight of fluid in
+ ³ im ⁴		borehole (Slurry unit weight)
$I := \frac{l}{12} = 0.14 \frac{m}{12}$		Moment of inertia of pipe wall cross
12 in ($(D_1)^4$	section
$0.1169 \cdot \gamma_m \cdot $		Pipe ring deflection to buoyant force
$\Delta y_{boundart} :=($	$\frac{2}{2}$ = 0.0	ASTM F 1962 (Eq. X2.6, p.6)
$E_{short} \cdot I$		
D2.1 Buoyant Deflection (Long Term)	
assumed to be cured afte	ection (Short Term)
assumed to be cured afte D3 - Reissner Effect Defle D3.1 - Reissner Effect Def μ_{short} :=0.35	ection (Short Term)) Poisson's Ratio for PE pipe material at
assumed to be cured afte D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	ection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
assumed to be cured afte D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ R = 1000 ft	ection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - z)^2$	$\frac{t}{t} = 0.0000033$	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
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_1\right)$ $16 \cdot t^2 \cdot R^2$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$\frac{t}{t} = 0.0000033$	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 Reisnner Effect
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \approx \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right) \left(D_1 - z \approx \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_1 = \frac{2}{3} \cdot z + $	$\frac{t}{t}^{4} = 0.0000033$ $\frac{t}{t}^{2} = 0.0002\%$ 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
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) + \left(\frac{1}{135}\right) + \frac{3}{16} \cdot t^2 \cdot R^2$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ D3.2 - Reissner Effect Defle $\mu_{long} \coloneqq 0.45$	$\frac{t}{t}^{4} = 0.0000033$	 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 Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_1 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_2 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_3 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_3 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_3 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_3 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_4 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$ $D_5 = \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z \equiv \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \right)$	$\frac{t}{t}^{4} = 0.0000033$	 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 Reisnner Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
assumed to be cured after D3 - Reissner Effect Defle D3.1 - Reissner Effect Defle $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - z_1^2\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ $D3.2 - \text{Reissner Effect Defl}$ $\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1 - z_1^2\right)$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1 - z_1^2\right)$	$\frac{t}{t}^{4} = 0.0000033$ $\frac{t}{t}^{4} = 0.0000033$ $\frac{t}{t}^{4} = 0.0002\%$ Flection (Long Term) $\frac{t}{t}^{4} = 0.000003$	 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 Reisnner 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

N D E R G R O U N D NGINEERING, INC.	Tunnel No.: Description: Calculated by: DA Checked by: NW	Crossing #102- Stream S-34 & Coxsackie Creek (S-35) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
D4 - Net Ring Deflection		
Δy_{lim} := 7.5%		Deflection limit for DR 9 non pressurized
D4.1 - Net Short Term		pipe (Table 2 , p. 437, PPI Handbook)
Δy_{short_net} := Δy_{ELD_short} +	- $\Delta y_{bouyant}$ + Δy_{R_short}	$t_t = 1.5\%$ Percent ring deflection in short term analysis
$Check \coloneqq$ if $(\Delta y_{short_net} < \Delta y_{short_net} > \Delta y_{short_net} < \Delta y_{short_net} < \Delta y_{short_net$	∆y _{lim} , "okay", "not c	okay") = "okay"
D4.2 - Net Long Term		
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{ELD_long}$	$\Delta y_{R_long} = 3.0\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq$ if $\left(\Delta y_{long_net} \! < \! \Delta \right)$	$y_{lim}, \mathrm{``okay''}, \mathrm{``not}\mathrm{ob}$	kay") = "okay"



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Note that constraining the pipe will	increase the pipe's buckling strength, therefore
considering an unconstrained condit	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)
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	Eahrenheit at 10 hrs of sustained loading
€ DEFLECTION	(Table X1.1 ASTM F 1962)
0 2 4 6 8 10	12
0.0	
2	Ovality compensation factor Figure
	- 3 (PPI Chp. 12). Calculated
f ₀	deflection limit in section D4.1
6	
8	$f_{o_short} \coloneqq 0.88$
1.0	
$\left(2 \cdot L_{short} \right) \left(1 \right)$	³ fo short
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$	${}^{3} \cdot \frac{f_{o_short}}{N} = 112.6 \text{ psi}$ Allowable unconstrained buckling pressure
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$	$ \frac{f_{o_short}}{N} = 112.6 \text{ psi} $ Allowable unconstrained buckling pressure Elevation difference between the lowest
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$	³ • $\frac{f_{o_short}}{N}$ = 112.6 <i>psi</i> Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 18.56 \ psi$	$\frac{f_{o_short}}{N} = 112.6 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$	$\frac{f_{o_short}}{N}$ = 112.6 <i>psi</i> Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq \text{if } \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$	³ $\cdot \frac{f_{o_short}}{N} = 112.6 \text{ psi}$ Allowable unconstrained buckling pressure 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"
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$ $D5.2 - Unconstrained Ring Buckling$	 ³ • <u>fo_short</u> = 112.6 <i>psi</i> Allowable unconstrained buckling pressure 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" , Levy's Equation (Long Term)
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_{m} \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$ $D5.2 - \text{Unconstrained Ring Buckling},$	³ • <u>f_{o_short}</u> = 112.6 psi Allowable unconstrained buckling pressure 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" , Levy's Equation (Long Term)
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_{m} \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$ D5.2 - Unconstrained Ring Buckling, Note that constraining the pipe will considering an unconstrained conditional statements and the statements are statements and the statements and the statements are statements are statements and the statements are statements	 ³ • <u>fo_short</u> = 112.6 <i>psi</i> Allowable unconstrained buckling pressure 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" , Levy's Equation (Long Term) increase the pipe's buckling strength, therefore tion will produce a conservative value.
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_{m} \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$ $D5.2 - \text{Unconstrained Ring Buckling},$ Note that constraining the pipe will considering an unconstrained condit $N \coloneqq 2.0$	 ³ • <u>fo_short</u> = 112.6 <i>psi</i> Allowable unconstrained buckling pressure 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" , Levy's Equation (Long Term) increase the pipe's buckling strength, therefore tion will produce a conservative value. Factor of Safety
$P_{UC_short} \coloneqq \left(\frac{2 \cdot L_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)$ $H = 39.9 \ ft$ $P_{mud} \coloneqq \gamma_{m} \cdot H = 18.56 \ psi$ $P_{net} \coloneqq P_{mud} = 18.56 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}\right)$ $D5.2 - \text{Unconstrained Ring Buckling},$ Note that constraining the pipe will considering an unconstrained condit $N \coloneqq 2.0$ $\mu_{long} \coloneqq 0.45$	 ³ • <u>fo_short</u> = 112.6 <i>psi</i> Allowable unconstrained buckling pressure 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" , Levy's Equation (Long Term) increase the pipe's buckling strength, therefore tion will produce a conservative value. Factor of Safety Poisson's Ratio for PE pipe material,

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #102- Stream S-34 & Coxsackie Creek (S-35) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 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· E_{long}) ($(1)^3 f_{o long}$	
$P_{UC_long} \coloneqq \left(\frac{1-\mu_{long}^2}{1-\mu_{long}^2}\right) \cdot \left(\frac{1}{L}\right)$	$\overline{DR_1-1}$ \cdot N =	31.1 <i>psi</i> Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 7.67 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq if \left< P_{UC_long} > P_{net} \right>$	<mark>, "okay", "not okay</mark>	")="okay"



Champlain Hudson Power Express - Package 6 Crossing #102- Stream S-34 & Coxsackie Creek (S-35) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

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Champlain Hudson Power Express - Package 6 Crossing #103&104-C1- CSX Tracks & Mansion St Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23

Checked b	y: NW Date: 4/17/23
Defining Parameters of Horizontal Direct	ctional 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
$DR_2 := 11$	Dimension ratio of Pipe 2
$T_{p1} := \frac{D_1}{DR_1} = 1.194 \ in$	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/pinepat	b nineentar
	pipeenty
drill rig B	A a
	- Condesenant from and and
H H	
pipe exit C	В
• I	*• <u> </u>
L4 . L3	. L ₂ L ₁
-	0019
Illustration 1 - Schematic o	of Drive Cross-section
$\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396$ rad	Borehole entry angle (degrees, radians)
$\beta \coloneqq 10^{\circ}$ $\beta_{exit} \coloneqq \beta = 0.1745 \ rad$	Borehole exit angle (degrees, radians)
$D_r := 18 \cdot in$	Final reamed bore diameter
$H_{max} \coloneqq 36 \ ft$	Max depth of bore hole to final reamed bore diameter
$H_{max1} := H_{max} + \frac{D_r}{2} = 36.75 \ ft$	Max depth to bore hole springline from ground surface
$L_{total} \coloneqq 1994.3 \ \boldsymbol{ft}$	Total length of HDD crossing
$L_1 := 150 \ ft$	Assumed pipe drag on surface, See Illustration 1
$L_2 := 325.6 \ ft$	Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{3_{-1}} := 1001 \ ft$	Straight horizontal section, before curve
$L_{3_2} := 104.6 \ ft$	Curve Length
$L_{3_3} := 65.3 \ ft$	Straight horizontal section, after curve

Project: Tunnel No.:

Description: Calculated by: SA

	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #103&104-C1- CSX Tracks & Mansion St Cross Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23		
$L_4 \coloneqq 232.5 \ ft$		Horizontal distance to rise to surface, See Illustration 1		
<i>H</i> ≔ 25.5 <i>ft</i>		Elevation difference between the lowest point in borehole and slurry pump elevation (entry or exit pit), See Illustration 1		
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)		
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)		
$\rho_{aa} \coloneqq 62.4 \ pcf$		Unit weight of water		
$\gamma_a := 0.965$		Specific gravity of pipe		
$\gamma_m \coloneqq 67 \ pcf = 9 \ \frac{lbf}{gal}$		Assumed unit weight of slurry		
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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:				
$R_{avg._in}$:=1000 ft		Radius of curvature at the entry, provided by Contractor		
$R_{avg._out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided		
$R \coloneqq \frac{R_{avg._in} + R_{avg._out}}{2} = 1000$	ft	Average radius of curvature at entry		
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7		
$Check \coloneqq \mathbf{if} \left(R_{avg,_in} > r_{rod}, \mathbf{``ok} \right)$	ay", "not okay")	="okay"		
$Check := \mathbf{if}(B \longrightarrow r \longrightarrow "o$	kay" "not okay"	= "okay"		

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

$e_a := \frac{D_1}{2 \cdot R} = 0.0004$	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



Champlain Hudson Power Express - Package 6 Crossing #103&104-C1- CSX Tracks & Mansion St Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23

$\begin{split} 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) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ \textit{plf} \\ \hline \textbf{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} = 36 \ \textit{plf} \\ \textbf{Upward buoyant force of en } \\ \hline \textbf{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 \ \textit{lbf} \\ \textbf{Hydrokinetic force } \\ \hline \textbf{B1.4 - Pullback Force Point A:} \\ T_{a} &:= e^{v_{a} \cdot c_{m}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3,1} + L_{3,2} + L_{3,3} + L_{4} \right) \right) = 1579 \ \textit{lbf} \\ \textbf{Pullback force when pipe enter.} \\ \hline \textbf{B1.5 - Pullback Force Point B:} \\ T_{b} &:= e^{v_{b} \cdot c_{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^{\left(v_{a} \cdot c_{m} \right)} \right) = 6380 \ \textit{lbf} \\ \textbf{Pullback force increase with} \\ \hline \textbf{B1.6 - Pullback Force Point C1:} \\ T_{c_{-1}} &:= T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3,1} \right) - e^{\left(v_{b} \cdot c_{m} \right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3,1} \cdot e^{\left(v_{a} \cdot c_{m} \right)} \right) = 16315 \ \textit{lbf} \\ \hline \textbf{B1.7 - Pullback Force Point C2:} \\ \alpha_{curve} &:= 6.9 \cdot s_{T} \\ T_{c_{-2}} &:= e^{v_{b} \cdot v_{min}} \left(T_{c_{-1}} + v_{b} \cdot w_{b} \cdot L_{3,2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3,2} \cdot e^{\left(v_{a} \cdot c_{min} \right)} \right) = 1988 \ \textit{lbf} \\ \hline \textbf{B1.9 - Pullback Force at D:} \\ T_{d} &:= e^{\left(v_{b} \cdot \beta_{min} \cdot V_{3,3} \right) - e^{\left(v_{b} \cdot \alpha_{min} \cdot V_{3,3} \right) - e^{\left(v_{a} \cdot \alpha_{min} \cdot V_{3,3} \right$	
$\begin{array}{llllllllllllllllllllllllllllllllllll$	
$\begin{split} w_{b} &\coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2}\right)}{4}\right) \rho_{w} \cdot \gamma_{b} - w_{a} = 36 \ \textit{plf} \qquad \text{Upward buoyant force of ent} \\ \hline \textbf{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 \ \textit{lbf} \ \text{Hydrokinetic force} \\ \hline \textbf{B1.4 - Pullback Force Point A:} \\ T_{a} &\coloneqq e^{v_{a} \cdot \alpha_{in}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3,1} + L_{3,2} + L_{3,3} + L_{4}\right)\right) = 1579 \ \textit{lbf} \\ Pullback force Point A: \\ 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^{\left(v_{a} \cdot \alpha_{in}\right)}\right) = 6380 \ \textit{lbf} \\ Pullback force Point B: \\ T_{c_{-1}} &\coloneqq T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3,1}\right) - e^{\left(v_{b} \cdot \alpha_{in}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3,1} \cdot e^{\left(v_{a} \cdot \alpha_{in}\right)}\right) = 16315 \ \textit{lbf} \\ \hline \textbf{B1.7 - Pullback Force Point C1:} \\ T_{c_{-2}} &\coloneqq e^{v_{b} \cdot \alpha_{carre}} \left(T_{c_{-1}} + v_{b} \cdot w_{b} \cdot L_{3,2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3,2} \cdot e^{\left(v_{a} \cdot \alpha_{carre}\right)}\right) = 19 \\ \hline \textbf{B1.8 - Pullback Force Point C3:} \\ T_{c_{-3}} &\coloneqq T_{c_{-2}} + \left(v_{b} \cdot w_{b} \cdot L_{3,3}\right) - e^{\left(v_{b} \cdot \alpha_{carre}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3,3} \cdot e^{\left(v_{a} \cdot \alpha_{carre}\right)}\right) = 19988 \ \textit{lbf} \\ \hline \textbf{B1.9 - Pullback Force at D:} \\ T_{d} &\coloneqq e^{\left(v_{b} \cdot \beta_{oxt}\right)} \cdot \left(T_{c_{-3}} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{\left(v_{a} \cdot \alpha_{on}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{\left(v_{a} \cdot \alpha_{on}\right)}\right)\right) \\ \hline \textbf{B1.10 - Maximum Pullback Force - Empty Pipe: \\ \hline \end{tabular}$	
$\begin{array}{l} \underline{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 \ \ \mbox{Hydrokinetic force} \\ \underline{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_1} + L_{3_2} + L_{3_3} + L_{4}\right)\right) = 1579 \ \ \mbox{lbf} \\ Pullback force when pipe enters. \\ \underline{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^{\left(v_{a} \cdot \alpha_{m}\right)}\right) = 6380 \ \ \mbox{lbf} \\ Pullback force increase with \\ \underline{B1.6 - Pullback Force Point C1:} \\ T_{c_1} := T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3_1}\right) - e^{\left(v_{b} \cdot \alpha_{m}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_1} \cdot e^{\left(v_{a} \cdot \alpha_{m}\right)}\right) = 16315 \ \ \mbox{lbf} \\ \underline{B1.7 - Pullback Force Point C2:} \\ \alpha_{curve} := 6.9 \ \ T_{c_2} := e^{v_{b} \cdot \alpha_{avec}} \left(T_{c_1} + v_{b} \cdot w_{b} \cdot L_{3_2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3_2} \cdot e^{\left(v_{a} \cdot \alpha_{curve}\right)}\right) = 19 \\ \underline{B1.8 - Pullback Force Point C3:} \\ T_{c_3} := T_{c_2} + \left(v_{b} \cdot w_{b} \cdot L_{3_3}\right) - e^{\left(v_{b} \cdot \alpha_{curve}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_3} \cdot e^{\left(v_{a} \cdot \alpha_{curve}\right)}\right) = 19988 \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$	mpty pipe
$\begin{split} \Delta T &:= \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^{-2} - \left(D_1^{-2} + D_2^{-2}\right)\right) = 796 \ \textit{lbf} \ \text{Hydrokinetic force} \\ & \texttt{B1.4 - Pullback Force Point A:} \\ T_a &:= e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4\right)\right) = 1579 \ \textit{lbf} \\ & \text{Pullback force when pipe enters} \\ & \texttt{B1.5 - Pullback Force Point B:} \\ T_b &:= e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})}\right) = 6380 \ \textit{lbf} \\ & \text{Pullback force increase with} \\ & \texttt{B1.6 - Pullback Force Point C1:} \\ & T_{c_1} &:= T_b + \left(v_b \cdot w_b \cdot L_{3_1}\right) - e^{(v_b \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})}\right) = 16315 \ \textit{lbf} \\ & \texttt{B1.7 - Pullback Force Point C2:} \\ & \alpha_{curre} &:= 6.9 \\ & T_{c_2} &:= e^{v_b \cdot \alpha_{curre}} \left(T_{c_1} + v_b \cdot w_b \cdot L_{3_2} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curre})}\right) = 19 \\ & \texttt{B1.8 - Pullback Force Point C3:} \\ & T_{c_3} &:= T_{c_2} + \left(v_b \cdot w_b \cdot L_{3_3}\right) - e^{(v_b \cdot \alpha_{curre})} \cdot \left(v_a \cdot w_a \cdot L_{3_3} \cdot e^{(v_a \cdot \alpha_{curre})}\right) = 19988 \ \textit{lbf} \\ & \texttt{B1.9 - Pullback Force at D:} \\ & T_d &:= e^{(v_b \cdot \beta_{cxi})} \cdot \left(T_{c_3} + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) \\ & \texttt{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{aligned}$	
$\begin{array}{l} \textbf{B1.4 - Pullback Force Point A:} \\ T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 1579 \ \textit{lbf} \\ & \text{Pullback force when pipe enter} \\ \textbf{B1.5 - Pullback Force Point B:} \\ T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot w_b \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 6380 \ \textit{lbf} \\ & \text{Pullback force increase with} \\ \textbf{B1.6 - Pullback Force Point C1:} \\ T_{c_1} \coloneqq T_b + \left(v_b \cdot w_b \cdot L_{3_1} \right) - e^{(v_b \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})} \right) = 16315 \ \textit{lbf} \\ \textbf{B1.7 - Pullback Force Point C2:} \\ & \alpha_{curve} \coloneqq 6.9 \ \ T_{c_2} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c_1} + v_b \cdot w_b \cdot L_{3_2} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 19 \\ \textbf{B1.8 - Pullback Force Point C3:} \\ & T_{c_3} \coloneqq T_{c_2} + \left(v_b \cdot w_b \cdot L_{3_3} \right) - e^{(v_b \cdot \alpha_{curve})} \cdot \left(v_a \cdot w_a \cdot L_{3_3} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 19988 \ \textit{lbf} \\ \textbf{B1.9 - Pullback Force at D:} \\ & T_d \coloneqq e^{(v_b \cdot \beta_{curve})} \cdot \left(T_{c_3} + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) \right) \\ \textbf{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{aligned}$	
$\begin{split} T_{a} &:= e^{v_{a} \cdot \alpha_{in}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3_1} + L_{3_2} + L_{3_3} + L_{4}\right)\right) = 1579 \ \textit{lbf} \\ & \text{Pullback force when pipe enter} \\ \hline B1.5 - Pullback Force Point B: \\ T_{b} &:= e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 6380 \ \textit{lbf} \\ & \text{Pullback force increase with} \\ \hline B1.6 - Pullback Force Point C1: \\ T_{c_1} &:= T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3_1}\right) - e^{\left(v_{b} \cdot \alpha_{in}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_1} \cdot e^{\left(v_{a} \cdot \alpha_{in}\right)}\right) = 16315 \ \textit{lbf} \\ \hline B1.7 - Pullback Force Point C2: \\ \alpha_{curve} &:= 6.9 \ ^{\circ} \\ T_{c_2} &:= e^{v_{b} \cdot \alpha_{curve}} \left(T_{c_1} + v_{b} \cdot w_{b} \cdot L_{3_2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3_2} \cdot e^{\left(v_{a} \cdot \alpha_{curve}\right)}\right) = 19 \\ \hline B1.8 - Pullback Force Point C3: \\ T_{c_3} &:= T_{c_2} + \left(v_{b} \cdot w_{b} \cdot L_{3_3}\right) - e^{\left(v_{b} \cdot \alpha_{curve}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_3} \cdot e^{\left(v_{a} \cdot \alpha_{curve}\right)}\right) = 19988 \ \textit{lbf} \\ \hline B1.9 - Pullback Force at D: \\ T_{d} &:= e^{\left(v_{b} \cdot \beta_{exil}\right)} \cdot \left(T_{c_3} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{\left(v_{a} \cdot \alpha_{m}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{\left(v_{a} \cdot \alpha_{m}\right)}\right)\right) \\ \hline B1.10 - Maximum Pullback Force - Empty Pipe: \end{split}$	
$\begin{aligned} & \mathbf{r}_{a} \cdots \mathbf{r}_{a} \cdots \mathbf{r}_{a} (\mathbf{r}_{a} + \mathbf{r}_{b} + \mathbf{r}_{b}) = \mathbf{r}_{a} = \mathbf{r}_$	
$\begin{array}{l} \textbf{B1.5 - Pullback Force Point B:} \\ T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 6380 \ \textit{lbf} \\ \textbf{Pullback force increase with} \\ \textbf{B1.6 - Pullback Force Point C1:} \\ T_{c_{-1}} \coloneqq T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3_{-1}}\right) - e^{(v_{b} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_{-1}} \cdot e^{(v_{a} \cdot \alpha_{in})}\right) = 16315 \ \textit{lbf} \\ \textbf{B1.7 - Pullback Force Point C2:} \\ \alpha_{curve} \coloneqq 6.9 \ ^{\circ} \\ T_{c_{-2}} \coloneqq e^{v_{b} \cdot \alpha_{curve}} \left(T_{c_{-1}} + v_{b} \cdot w_{b} \cdot L_{3_{-2}} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3_{-2}} \cdot e^{(v_{a} \cdot \alpha_{curve})}\right) = 19 \\ \textbf{B1.8 - Pullback Force Point C3:} \\ T_{c_{-3}} \coloneqq T_{c_{-2}} + \left(v_{b} \cdot w_{b} \cdot L_{3_{-3}}\right) - e^{(v_{b} \cdot \alpha_{curve})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_{-3}} \cdot e^{(v_{a} \cdot \alpha_{curve})}\right) = 19988 \ \textit{lbf} \\ \textbf{B1.9 - Pullback Force at D:} \\ T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exil})} \cdot \left(T_{c_{-3}} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) \\ \textbf{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{array}$	ers the gro
$\begin{split} T_{b} &\coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot w_{b} \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 6380 \ lbf \\ & \text{Pullback force increase with} \\ \hline \textbf{B1.6 - Pullback Force Point C1:} \\ T_{c_{-1}} &\coloneqq T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3_{-1}} \right) - e^{(v_{b} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_{-1}} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 16315 \ lbf \\ \hline \textbf{B1.7 - Pullback Force Point C2:} \\ \hline \alpha_{curve} &\coloneqq \textbf{6.9}^{\circ} \\ T_{c_{-2}} &\coloneqq e^{v_{b} \cdot \alpha_{curve}} \left(T_{c_{-1}} + v_{b} \cdot w_{b} \cdot L_{3_{-2}} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3_{-2}} \cdot e^{(v_{a} \cdot \alpha_{curve})} \right) = 19 \\ \hline \textbf{B1.8 - Pullback Force Point C3:} \\ T_{c_{-3}} &\coloneqq T_{c_{-2}} + \left(v_{b} \cdot w_{b} \cdot L_{3_{-3}} \right) - e^{(v_{b} \cdot \alpha_{curve})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3_{-3}} \cdot e^{(v_{a} \cdot \alpha_{curve})} \right) = 19988 \ lbf \\ \hline \textbf{B1.9 - Pullback Force at D:} \\ T_{d} &\coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c_{-3}} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) \right) \\ \hline \textbf{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{split}$	
$\begin{aligned} & \text{Pullback force increase with} \\ & \text{B1.6 - Pullback Force Point C1:} \\ & T_{c_{-1}} \coloneqq T_b + (v_b \cdot w_b \cdot L_{3_{-1}}) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_{3_{-1}} \cdot e^{(v_a \cdot \alpha_{in})}) = 16315 \ \textit{lbf} \\ & \text{B1.7 - Pullback Force Point C2:} \\ & \alpha_{curve} \coloneqq 6.9 \ ^{\circ} \\ & T_{c_{-2}} \coloneqq e^{v_b \cdot \alpha_{curve}} \ (T_{c_{-1}} + v_b \cdot w_b \cdot L_{3_{-2}} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_{-2}} \cdot e^{(v_a \cdot \alpha_{curve})}) = 19 \\ & \text{B1.8 - Pullback Force Point C3:} \\ & T_{c_{-3}} \coloneqq T_{c_{-2}} + (v_b \cdot w_b \cdot L_{3_{-3}}) - e^{(v_b \cdot \alpha_{curve})} \cdot (v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{(v_a \cdot \alpha_{curve})}) = 19988 \ \textit{lbf} \\ & \text{B1.9 - Pullback Force at D:} \\ & T_d \coloneqq e^{(v_b \cdot \beta_{exil})} \cdot (T_{c_{-3}} + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) \\ & \text{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{aligned}$	
$\begin{array}{l} \textbf{B1.6 - Pullback Force Point C1:} \\ T_{c_{-1}} \coloneqq T_b + \left(v_b \cdot w_b \cdot L_{3_{-1}}\right) - e^{\left(v_b \cdot \alpha_{in}\right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-1}} \cdot e^{\left(v_a \cdot \alpha_{in}\right)}\right) = 16315 \ \textit{lbf} \\ \hline \textbf{B1.7 - Pullback Force Point C2:} \\ \hline \alpha_{curve} \coloneqq \textbf{6.9}^{\circ} \\ T_{c_{-2}} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c_{-1}} + v_b \cdot w_b \cdot L_{3_{-2}} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_{-2}} \cdot e^{\left(v_a \cdot \alpha_{curve}\right)}\right) = 19 \\ \hline \textbf{B1.8 - Pullback Force Point C3:} \\ T_{c_{-3}} \coloneqq T_{c_{-2}} + \left(v_b \cdot w_b \cdot L_{3_{-3}}\right) - e^{\left(v_b \cdot \alpha_{curve}\right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{\left(v_a \cdot \alpha_{curve}\right)}\right) = 19988 \ \textit{lbf} \\ \hline \textbf{B1.9 - Pullback Force at D:} \\ T_d \coloneqq e^{\left(v_b \cdot \beta_{exit}\right)} \cdot \left(T_{c_{-3}} + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{\left(v_a \cdot \alpha_{in}\right)} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{\left(v_a \cdot \alpha_{in}\right)}\right)\right) \\ \hline \textbf{B1.10 - Maximum Pullback Force - Empty Pipe:} \end{array}$	h depth
$\begin{split} T_{c_{-1}} &:= T_b + \left(v_b \cdot w_b \cdot L_{3_{-1}} \right) - e^{\left(v_b \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-1}} \cdot e^{\left(v_a \cdot \alpha_{in} \right)} \right) = 16315 \ \textit{lbf} \\ \hline \\ \underline{B1.7 - Pullback \ Force \ Point \ C2:} \\ \alpha_{curve} &:= 6.9 \\ T_{c_{-2}} &:= e^{v_b \cdot \alpha_{curve}} \ \left(T_{c_{-1}} + v_b \cdot \left w_b \right \cdot L_{3_{-2}} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_{-2}} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 19 \\ \hline \\ \underline{B1.8 - Pullback \ Force \ Point \ C3:} \\ T_{c_{-3}} &:= T_{c_{-2}} + \left(v_b \cdot w_b \cdot L_{3_{-3}} \right) - e^{\left(v_b \cdot \alpha_{curve} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 19988 \ \textit{lbf} \\ \hline \\ \\ \hline \\ \underline{B1.9 - Pullback \ Force \ at \ D:} \\ T_d &:= e^{\left(v_b \cdot \beta_{cxil} \right)} \cdot \left(T_{c_{-3}} + v_b \cdot \left w_b \right \cdot L_4 - w_b \cdot H_{max} - e^{\left(v_a \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{\left(v_a \cdot \alpha_{in} \right)} \right)) \\ \hline \\ \\ \hline \\ \\ \hline \\ B1.10 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe: \end{split}$	
$\begin{array}{l} \underline{B1.7 - Pullback \ Force \ Point \ C2:} \\ \alpha_{curve} \coloneqq 6.9 \ \circ \\ T_{c_2} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c_1} + v_b \cdot \left w_b \right \cdot L_{3_2} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 19 \\ \underline{B1.8 - Pullback \ Force \ Point \ C3:} \\ T_{c_3} \coloneqq T_{c_2} + \left(v_b \cdot w_b \cdot L_{3_3} \right) - e^{(v_b \cdot \alpha_{curve})} \cdot \left(v_a \cdot w_a \cdot L_{3_3} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 19988 \ lbf \\ \underline{B1.9 - Pullback \ Force \ at \ D:} \\ T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c_3} + v_b \cdot \left w_b \right \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) \right) \\ \underline{B1.10 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \end{array}$	
$\begin{split} & \alpha_{curve} \coloneqq 6.9 \ ^{\circ} \\ & T_{c_{-2}} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c_{-1}} + v_b \cdot \left w_b \right \cdot L_{3_{-2}} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_{-2}} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 19 \\ & \underline{B1.8 - \text{Pullback Force Point C3:}} \\ & T_{c_{-3}} \coloneqq T_{c_{-2}} + \left(v_b \cdot w_b \cdot L_{3_{-3}} \right) - e^{\left(v_b \cdot \alpha_{curve} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 19988 \ \textit{lbf} \\ & \underline{B1.9 - \text{Pullback Force at D:}} \\ & T_d \coloneqq e^{\left(v_b \cdot \beta_{exil} \right)} \cdot \left(T_{c_{-3}} + v_b \cdot \left w_b \right \cdot L_4 - w_b \cdot H_{max} - e^{\left(v_a \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{\left(v_a \cdot \alpha_{in} \right)} \right) \right) \\ & \underline{B1.10 - \text{Maximum Pullback Force - Empty Pipe:}} \end{split}$	
$\begin{split} I_{c_{-2}} &:= e^{ v \cdot v_{and}} \left(I_{c_{-1}} + v_b \cdot w_b \cdot L_{3_{-2}} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_{-2}} \cdot e^{(v_a \cdot v_{and})} \right) = 19 \\ \\ & \underline{B1.8 - Pullback \ Force \ Point \ C3:} \\ & T_{c_{-3}} &:= T_{c_{-2}} + \left(v_b \cdot w_b \cdot L_{3_{-3}} \right) - e^{(v_b \cdot \alpha_{curve})} \cdot \left(v_a \cdot w_a \cdot L_{3_{-3}} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 19988 \ lbf \\ \\ & \underline{B1.9 - Pullback \ Force \ at \ D:} \\ & T_d &:= e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c_{-3}} + v_b \cdot w_b \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) \right) \\ \\ & \underline{B1.10 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \end{split}$	0220 # 6
$\begin{split} & \underbrace{\text{B1.8 - Pullback Force Point C3:}}_{T_{c_3}:=T_{c_2}+(v_b\cdot w_b\cdot L_{3_3})-e^{(v_b\cdot \alpha_{curve})}\cdot (v_a\cdot w_a\cdot L_{3_3}\cdot e^{(v_a\cdot \alpha_{curve})}) = 19988 \ \textit{lbf} \\ & \\ & \\ & \\ & \\ & \\ & \\ & \\ & \\ & \\ $.9339 lof
$\begin{split} T_{c_3} &\coloneqq T_{c_2} + \left(v_b \cdot w_b \cdot L_{3_3} \right) - e^{\left(v_b \cdot \alpha_{curve} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_3} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 19988 \ \textit{lbf} \\ \\ \underline{B1.9 - Pullback \ Force \ at \ D:} \\ T_d &\coloneqq e^{\left(v_b \cdot \beta_{exit} \right)} \cdot \left(T_{c_3} + v_b \cdot \left w_b \right \cdot L_4 - w_b \cdot H_{max} - e^{\left(v_a \cdot \alpha_{in} \right)} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{\left(v_a \cdot \alpha_{in} \right)} \right) \right) \\ \\ \underline{B1.10 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \end{split}$	
$\begin{array}{l} \underline{B1.9 - Pullback \ Force \ at \ D:} \\ T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c_3} + v_b \cdot \left w_b\right \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) \\ \underline{B1.10 - Maximum \ Pullback \ Force \ - \ Empty \ Pipe:} \end{array}$	
$T_{d} \coloneqq e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c_{a}} + v_{b} \cdot w_{b} \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right)$ B1.10 - Maximum Pullback Force - Empty Pipe:	
$\underline{B1.10 - Maximum Pullback Force - Empty Pipe:}$) = 22134
B1.10 - Maximum Pullback Force - Empty Pipe:) - 22101
$P_{max empt_d} := \max (T_a, T_b, T_{c_1}, T_{c_2}, T_{c_3}, T_d) + \Delta T = 22930 \ lbf$	
Maximum Pullback Force	



Champlain Hudson Power Express - Package 6 Crossing #103&104-C1- CSX Tracks & Mansion St Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23

B2.1 - Upward Buoyant Force:

$$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} \boldsymbol{D}_{1}^{\ 2} \right)}{4} \right) \boldsymbol{\cdot} \rho_{w} \boldsymbol{\cdot} \left(\gamma_{b} - \gamma_{c} \boldsymbol{\cdot} \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 10.2 \ \boldsymbol{plf}$$

Upward buoyant force of pipe filled with water

B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 1579 \ \textit{lbf}$ Pullback force enter ground

B2.3 - Pullback Force Point B:

 $T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot |w_{bfilled}| \cdot L_2 + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 3347 \ lbf$ Pullback force increase and decrease with depth

 $T_{c1_filled} \coloneqq T_{bfilled} + \left(v_b \cdot \left|w_{bfilled}\right| \cdot L_{3_1}\right) - e^{\left(v_b \cdot \alpha_{in}\right)} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{\left(v_a \cdot \alpha_{in}\right)}\right) = 5518 \ \textit{lbf}$

B2.5 - Pullback Force Point C2:

 $\alpha_{curve} = 6.9$ °

 $T_{c2_filled} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c1_filled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_{3_2} + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_{3_2} \cdot e^{\left(v_a \cdot \alpha_{curve}\right)} \right) = 6521 \ \textit{lbf}$

B2.6 - Pullback Force Point C3:

$$T_{c3_filled} \coloneqq T_{c2_filled} + \left(v_b \cdot \left| w_{bfilled} \right| \cdot L_{3_3} \right) - e^{\left(v_b \cdot \alpha_{curve} \right)} \cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{\left(v_a \cdot \alpha_{curve} \right)} \right) = 5849 \ \textit{lbf}$$

B2.7 - Pullback Force at D:

$$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c3_filled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 6701 \ lbf$$

B2.8 - Maximum Pullback Force - Filled Pipe with Water:

 $P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{c1_filled}, T_{c2_filled}, T_{c3_filled}, T_{dfilled} \right) = 6701 \ \textit{lbf}$ Maximum Pullback Force

B3 - Safe Pull Strength / Ultimate Tensile Load Check: B3.1 Safe Pullback Check

$$A_{1} \coloneqq \frac{\pi}{4} \left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) = 19 \ \textbf{in}^{2}$$

$$A_{2} \coloneqq \frac{\pi}{4} \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ \textbf{in}^{2}$$

$$P_{11} \coloneqq \frac{A_{1} \cdot P_{max_empty}}{A_{1} + A_{2}} = 22041 \ \textbf{lbf}$$

$$Pullback forces acting on Pipe 1 (Empty)$$

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudso Crossing #103&1 Pull Back and Mu Date: 4/13/23 Date: 4/17/23	n Power Express - Package 6 04-C1- CSX Tracks & Mansion St Crossing d Pressure Calcs R2: 9/18/23
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 890 \ ll$	of	Pullback forces	acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 6441 \ \textit{lbf}$		Pullback forces	acting on Pipe 1 (Ballast)
$P_{22} \coloneqq \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 260 \ \textit{lbf}$		Pullback forces	acting on Pipe 2 (Ballast)
$P_{SPF1}\!\coloneqq\!41214~\textit{lbf}$		Safe pullback fo p. 448, PPI)	prces Pipe 1 (Table %,
$P_{SPF2} \coloneqq 1683 \ \textit{lbf}$		Safe pullback fo p. 448, PPI)	prces Pipe 2 (Table %,
$\underline{\qquad} check \coloneqq \mathbf{if} \left(P_{SPF1} > P_{11}, \text{``okay} \right)$	y", "not okay") =	="okay"	
$\underline{\qquad} check \coloneqq \mathbf{if} (P_{SPF2} > P_{21}, \text{``okay})$	y", "not okay") =	= "okay"	
$= check := if (P_{SPF1} > P_{12}, "okay")$	y", "not okay") =	= "okay"	
$Check \coloneqq \Pi(P_{SPF2} > P_{22}, "OKAy")$	y", "not okay") =	= Okay	



Champlain Hudson Power Express - Package 6 Crossing #103&104-C1- CSX Tracks & Mansion St Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23

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

<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.

$H_c := 15 \ ft$ Vertical separation distance between critistructure and pipe (~11+50) $\gamma := 100 \ pcf$ Assumed unit weight soft to clay/silt (zero blow count material) $\gamma_w := 62.4 \ pcf$ Unit weight of water Effective unit weight $u := \gamma_w \cdot H_w = 7 \ psi$ $\gamma := \gamma - \gamma_w = 37.6 \ pcf$ Unit weight of water Effective unit weight Initial pore water pressure $\phi := 15 \ deg$ $c := 450 \ psf = 3.13 \ psi$ Assumed friction Angle Assumed cohesion of encountered mate $R_0 := \frac{D_{rod}}{2} = 1.75 \ in$ Initial radius of the borehole $R_{pmax} := \frac{1}{2} \cdot H_c = 8 \ ft$ Initial radius of plastic zone (H/2 in clays & $2/3 \ H \ in sands)$ $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4 \ psi$ Initial effective stress $the C3 \ Typical value of modulus of elasticity (\mathcal{L}_{S} for different types of sold\frac{D_{opt} \ different types of sold\frac{D_{opt} \ different types of sold\frac{L(Nuw)}{Vog sold} \ \frac{L(Nuw)}{Vog sold} \ \frac{L(Nuw)}$	$H_w \coloneqq 15 \cdot ft$	Depth of the bore below groundwater elevation
$\gamma := 100 \ pcf$ Assumed unit weight soft to clay/silt (zero blow count material) $\gamma_w := 62.4 \ pcf$ Unit weight of water Effective unit weight Initial pore water pressure $\gamma' := \gamma - \gamma_w = 37.6 \ pcf$ Initial pore water pressure $\psi := 15 \ deg$ $c := 450 \ psf = 3.13 \ psi$ Assumed friction Angle Assumed cohesion of encountered mate $\phi := 15 \ deg$ $c := 450 \ psf = 3.13 \ psi$ Assumed friction Angle Assumed cohesion of encountered mate $R_0 := \frac{D_{rod}}{2} = 1.75 \ in$ Initial radius of the borehole $R_{pmax} := \frac{1}{2} \cdot H_c = 8 \ ft$ $2^{\circ} := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4 \ psi$ Radius of plastic zone (H/2 in clays & $2/3 \ H \text{ in sands})$ $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4 \ psi$ Initial effective stress $be c.2 \ Typical values of modulus of elasticity (E) for different types of soilsE_s := 5 \ \frac{N}{mm^2} = 725 \ psiradia uitDomeNo y demoNo y demo$	<i>H_c</i> := 15 <i>ft</i>	Vertical separation distance between critical structure and pipe (\sim 11+50)
$\begin{aligned} \gamma_w &:= 62.4 \ pcf \\ \gamma' := \gamma - \gamma_w = 37.6 \ pcf \\ u := \gamma_w \cdot H_w = 7 \ psi \end{aligned} \qquad Unit weight of water Effective unit weight Initial pore water pressure \\ \hline \phi := 15 \ deg \\ c := 450 \ psf = 3.13 \ psi \end{aligned} \qquad Assumed friction Angle \\ Assumed cohesion of encountered mater \\ R_0 := \frac{D_{rod}}{2} = 1.75 \ in \end{aligned} \qquad Initial radius of the borehole \\ \hline R_{pmax} := \frac{1}{2} \cdot H_c = 8 \ ft \\ \sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4 \ psi \end{aligned} \qquad Initial effective stress \\ \hline bt c.2 \ Typical values of mediates of ideaticity \ c_1 \ yry dense \ 144.750 \\ New \ 10.255 \\ Stat \ 162.55 \\ Sta$	γ≔100 pcf	Assumed unit weight soft to clay/silt (zero blow count material)
$\gamma' := \gamma - \gamma_w = 37.6 \ pcf$ $u := \gamma_w \cdot H_w = 7 \ psi$ Effective unit weight Initial pore water pressure $\phi := 15 \ deg$ $c := 450 \ psf = 3.13 \ psi$ Assumed friction Angle Assumed cohesion of encountered mate $R_{0} := \frac{D_{rod}}{2} = 1.75 \ in$ Initial radius of the borehole $R_{pmax} := \frac{1}{2} \cdot H_c = 8 \ ft$ $\sigma'_{0} := \left(\gamma \cdot (H_c - H_w)\right) + \gamma' \cdot H_w = 4 \ psi$ Initial effective stress $\sigma'_{0} := \left(\gamma \cdot (H_c - H_w)\right) + \gamma' \cdot H_w = 4 \ psi$ Initial effective stress $bc C.2 \ Tpictar values of modulus of elasticity (E) for different types of sols \frac{V_{ey} \ soli \qquad 2-15 \ soli \qquad 2-550 \ Mad \qquad 5-50 \ Mad \qquad $	$\gamma_{\text{m}} \coloneqq 62.4 \text{ pcf}$	Unit weight of water
$\begin{aligned} u := \gamma_w \cdot H_w = 7 \text{ psi} \\ \text{Initial pore water pressure} \\ \phi := 15 \text{ deg} \\ c := 450 \text{ psf} = 3.13 \text{ psi} \\ \text{Assumed friction Angle} \\ c := 450 \text{ psf} = 3.13 \text{ psi} \\ \text{Assumed cohesion of encountered mate} \\ R_0 := \frac{D_{rod}}{2} = 1.75 \text{ in} \\ \text{Initial radius of the borehole} \\ R_{pmax} := \frac{1}{2} \cdot H_c = 8 \text{ ft} \\ \sigma'_0 := \left(\gamma \cdot (H_c - H_w)\right) + \gamma' \cdot H_w = 4 \text{ psi} \\ \text{Initial effective stress} \\ Initial$	$\gamma_w^{\prime} = \gamma - \gamma - 37.6 \text{ mcf}$	Effective unit weight
	$u \coloneqq \gamma_w \cdot H_w = 7 \ psi$	Initial pore water pressure
c:=450 psf =3.13 psi Assumed cohesion of encountered mate $R_0 := \frac{D_{rod}}{2} = 1.75$ in Initial radius of the borehole $R_{pmax} := \frac{1}{2} \cdot H_c = 8$ ft Radius of plastic zone (H/2 in clays & 2/3 H in sands) $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $\sigma'_0 := (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4$ psi Initial effective stress $P_{very ofn}$ 2-15 Sold 5-25 Medium 15-30 Hard 50-100 Smady 25-250 Glacati till Loose Loose 10-14 Drawe 48-81 Stad 7-21 Stad 96-12 Shale 14-14,000	$\phi \coloneqq 15 \text{ deg}$	Assumed friction Angle
$R_{0} := \frac{D_{rod}}{2} = 1.75 \text{ in}$ Initial radius of the borehole $R_{pmax} := \frac{1}{2} \cdot H_{c} = 8 \text{ ft}$ Radius of plastic zone (H/2 in clays & 2/3 H in sands) $\sigma'_{0} := \left(\gamma \cdot (H_{c} - H_{w})\right) + \gamma' \cdot H_{w} = 4 \text{ psi}$ Initial effective stress c.2 Typical values of modulus of elasticity (E_{b}) for different types of soils $\frac{Type of Soil}{Clay} \frac{E_{i}(Nmn^{2})}{Clay}$ Nery soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 14-477 Sand Sitty 7-21 Loose 10-24 Dense 48-81 Sand and gravet Loose 48-14 Conse 48-1	<u>c := 450 psf = 3.13 psi</u>	Assumed cohesion of encountered material
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 8 ft$ $R_{adius of plastic zone (H/2 in clays & 2/3 H in sands)$ $T'_{0} \coloneqq (\gamma \cdot (H_c - H_w)) + \gamma' \cdot H_w = 4 psi$ Initial effective stress $Typical values of modulus of elasticity (E_{s}) for different types of soils$ $Type of Soil E_{t} (Nima2)$ $Radius of plastic zone (H/2 in clays & 2/3 H in sands)$ Initial effective stress $E_{s} \coloneqq 5 \frac{N}{mm^{2}} = 725 psi$ Redum 15-50 Redum 14-72 Sond 50-100 Sondy 25-250 Glaciat till Loose 10-153 Dense 144-72 Sand Sindy 7-21 Loose 10-24 Dense 48-145 Sand sity 7-21 Loose 10-24 Dense 48-145 Sand sity 7-21 Loose 10-24 Dense 48-145 Sand sity 144-14,400	$R_0 := \frac{D_{rod}}{2} = 1.75 \ in$	Initial radius of the borehole
$\sigma'_{0} := \left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w} = 4 \text{ psi}$ Initial effective stress c.2 Typical values of modulus of elasticity (Eg) for different types of soils $\frac{\overline{Type of Soil} E_{c}(N(mn^{2}))}{Clay}$ 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 Loose 144-77 Sand Sity 7-21 Loose 14-57 Sand Sity 7-21 Loose 10-24 Dense 48-148 Dense 96-192 Shale 144-14,400	$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 8 ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
c C.2 Typical values of modulus of elasticity (<i>E</i> ₀) for different types of soils Type of Soil <i>E</i> ₁ (N/mm ³) Clay Very soft Very soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till 0-153 Dense 144-720 Very dense 478-1,440 Loess 14-57 Sand 5 Sitty 7-21 Loose 10-24 Dense 48-81 Sand gravel 10-24 Dense 48-148 Dense 96-192 Shale 144-14,400	$\sigma'_{0} \coloneqq \left(\gamma \cdot \left(H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} = 4 \ psi$	Initial effective stress
Type of Soil $E_s(N/mn^3)$ Clay 2-15 Nets 2-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glaciat till $E_s:=5 \frac{N}{mm^2} = 725 psi$ Loose 10-153 Dense 144-720 Very dense 478-1,440 Loess 14-57 Sand Sity Sity 7-21 Loose 10-24 Dense 48-148 Dense 48-148 Dense 96-192 Shale 144-14,400	C.2 Typical values of modulus of elasticity (<i>E</i> ₅) for different types of soils	
Vary soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till $E_s := 5 \frac{N}{mm^2} = 725 psi$ Loose 10-153 Dense 144-720 Very dense 478-1,440 Loes 14-57 Sand	Type of Soil E _s (N/mm ²)	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Very soft 2–15	
Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till mm^2 = 725 psi Loose 10-153 Dense 144-720 Very dense 478-1,440 Looss 14-57 Sand Sand Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose 48-148 Dense 96-192 Shale 144-14,400 Loose 144-14,400	Soft 5-25	AT.
Sandy 25-250 Glaciat till 120 pc0 Loss 10-153 Dense 144-720 Very dense 478-1,440 Loss 14-57 Sand 14-57 Sand 10-24 Dense 10-24 Dense 48-81 Sand and gravel 10-24 Dense 48-148 Dense 96-192 Shale 144-14,400	Hard 50–100	$E_{\rm c} \coloneqq 5 \xrightarrow{N} = 725 \text{ nsi}$
Loose 10-153 Dense 144-720 Very dense 478-1,440 Loess 14-57 Sand	Sandy 25–250	mm^2 = 120 per
Dense 144-720 Assumed modulus of elasticity Very dense 478-1,440 Loess 14-57 Sand 14-57 Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel 1 Loose 48-148 Dense 96-192 Shale 144-14,400	Loose 10–153	
Very ende 4/5-1/440 Loess 1/4-57 Sand	Dense 144–720	Assumed modulus of elasticity
Sand Silty 7–21 Silty 10–24 10–24 Dense 48–81 10 Sand and gravel 10–24 10 Loose 48–148 10 Dense 96–192 144–14,400	Loess 14-57	
Sity 7-21 Loose 10-24 Dense 48-81 Sand and gravel 1000000000000000000000000000000000000	Sand	
Loose 48–81 Loose 48–148 Dense 96–192 Shale 144–14,400	Silty 7–21 Loose 10–24	
Sand and gravel Lose 48148 Dense 96-192 Shale 144-14,400	Dense 48–81	
Loose 40-146 Dense 96-192 Shale 144-14,400	Sand and gravel	
Shale 144-14,400	Loose 48–148 Dense 96–192	
	Shale 144–14,400	
Silt 2-20	Silt 2-20	

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ble C.4 Typical values of Poisson's ratio (μ) for soils		
Type of soil µ		
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		$\nu_s \coloneqq 0.4$
Fine grained (void ratio = 0.4 – 0.7) 0.25 Rock 0.1–0.4 (depends on	type of rock)	
Loes 0.1-0.3 lee 0.36 Concrete 0.15		Poissions ratio of material encountered
$G := \frac{E_s}{259}$ nsi		Shear modulus of soil
$C = \frac{1}{2} (1 + \nu_s)^{-260} por$		
$Q \coloneqq \frac{\left(\sigma'_0 \cdot \sin(\phi)\right) + (c \cdot 0)}{\tilde{c}} = 0.0$	039	
G		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$\phi) \!=\! 7.9 psi$	
		Mud pressure at which the first plastic deformation takes place
	$(\frac{-\sin(\phi)}{1+\sin(\phi)})$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) \right) = \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) = \left(\left(\frac{R_0}{R_{pmax}} \right) \right) = \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) \right) = \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) = \left(\left(\frac{R_0}{R_{pmax}} \right) \right) = \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) = \left(\left(\frac{R_0}{R_{pmax}} \right) = \left(R$	+Q	$-c \cdot 0 = 24.4 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 30.9 \ psi$		Maximum allowable mud pressure
2 -Min. Allowable Drilling Flu	iid Pressure	
$D_{PT} = 5 in$		Pilot tube diameter
$D_0 := 9.5 in$		Initial borehole diameter for pilot tube
$h \coloneqq 45 \ ft$		Elevation difference between level of bore
		hole front and exit point of mud flow
$\gamma_m = 67 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 20.9 \; psi$		Minimum required mud pressure to
		overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
$\tau_o \coloneqq 16 \frac{lbf}{lbf}$		Assumed yield point of mud per 100
$100 \cdot ft^2$		square feet
$\mu_{\mu} := 25 \cdot \frac{poise}{25}$		Assumed plastic viscosity of mud
100		

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$v \coloneqq \frac{Q_f}{0.785 \left(D_0^2 - D_{PT}^2\right)} = 75$	$5.2 \frac{ft}{min}$	Computed mud flow velocity
$L_{structure} \coloneqq 1150 \; ft$		Length to structure
$p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D - D \right)^2} \right)^2 \right)$	$- + \left(\frac{ au_o}{(D_0 - D_{PT})} \right)$	= 3.4 <i>psi</i>
$((D_0 - D_{PT}))$) (())	/ Minimum required mud pressure to create flow inside the borehole
$p_{min.} \coloneqq p_1 + p_2 = 24.4 \ psi$		Minimum required mud pressure
$check \coloneqq \mathbf{if} \left(p_{max} > p_{min.}, \text{``oka'} \right)$	y", "not okay") =	="okay"

Preventative measures should be taken to limit the potential of inadvertent returns.





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Former of Developer state Analysis a Mahilimad)
formed Borenole with Arching Mobilized)
Depth of cover
Friction angle of soil
"Silo" width, conservative value = reamed hole diameter
Earth pressure coefficient
Unit weight of soil, assumed
Arching factor (Eq. 6, p.432, PPI)
sf Effective overburden pressure
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
Dina deflection to diamater as per
PPI Equ. 10 (Chp 12, p 437, PPI Handbook
Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit at 50 years 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)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection	(Short Term)	
$D_1 = 10.75 \ in$		Outside diameter of casing pipe
$t := T_{n1} = 1.194$ in		Thickness of casing pipe
P-		Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$		PE4710, Base Temperature of 73
		Fahrenheit (Table B.1.1)
$\gamma_m = 67 \ pcf$		Assumed unit weight of fluid in
4 ³ ∴ ⁴		borehole (Slurry unit weight)
$I \coloneqq \frac{t}{1} = 0.14 \frac{in}{1}$		Moment of inertia of pipe wall cross
12 in	$(D_1)^4$	section
$0.1169 \cdot \gamma_m \cdot$	$\left \frac{D_1}{2}\right $	Pipe ring deflection to buoyant force
$\Delta y_{bounant} \coloneqq$	$\frac{(2)}{2} = 0.0$	ASTM F 1962 (Eq. X2.6, p.6)
$E_{short}ullet$	1	
D2.1 Buoyant Deflection	(Long Term)	
assumed to be cured aft	er a 1-week period in	om installation/pumping.
please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$	lection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	er a 1-week period fro lection (Short Term) eflection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1 - 2) (D_1 - 2) = \frac{3}{16 \cdot t^2 \cdot R^2}$	$\frac{\text{lection (Short Term})}{\text{eflection (Short Term)}}$ $= 0.0000033$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \frac{3}{16} \cdot t^2 \cdot R^2\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$\frac{1 - t}{2}^{4} = 0.000033$	 point installation/pumping. 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
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \frac{3}{16 \cdot t^2} \cdot R^2\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ D3.2 - Reissner Effect Definition	$\frac{1 - t}{2}^{4} = 0.0000033$ $\frac{1 - t}{5} \cdot z^{2} = 0.0002\%$ eflection (Long Term)	 point installation/pumping. 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
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R \equiv 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \mu_{short}^2\right)$ $Z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right)$ $Z \vdash \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right)$	$\frac{1 - t}{2}^{4} = 0.0000033$ $\frac{1 - t}{5} \cdot z^{2} = 0.0002\%$ eflection (Long Term)	 point installation/pumping. 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)
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{3}{2} \cdot (1 - \mu_{short}^2) \ (D_1 - 2t)^2$ $z := \frac{3}{2} \cdot (1 - \mu_{short}^2) \ (D_1 - 2t)^2$ $\Delta y_{R_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)^2$ D3.2 - Reissner Effect Define $\mu_{long} := 0.45$ $R = 1000 \ ft$	$\frac{1 - t}{2}^{4} = 0.0000033$ $\frac{1 - t}{2} \cdot z^{2} = 0.0002\%$ eflection (Long Term)	 point installation/pumping. 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) Radius of curvature
Please note that long ter assumed to be cured aft D3 - Reissner Effect Defi D3.1 - Reissner Effect Defi $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \frac{3}{16 \cdot t^2} \cdot R^2\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$ $D3.2 - \text{Reissner Effect Definition}$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1 - \frac{3}{16 \cdot t^2} \cdot R^2\right)$	$\frac{-t}{2}^{4} = 0.000033$ $\frac{-t}{2}^{4} = 0.000033$	 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) Radius of curvature Deflection due to longitudinal bending

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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		
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{ELD_short}$	$\Delta y_{bouyant} + \Delta y_{R_shor}$	$_{t}$ = 1.3% Percent ring deflection in short term analysis
$Check \coloneqq \mathbf{if} \left(\Delta y_{short_net} < \Delta y_{short_net} \right)$	$y_{lim}, \mathrm{``okay''}, \mathrm{``not}\mathrm{o}$	kay") = "okay"
D4.2 - Net Long Term		
Δy_{long_net} := Δy_{ELD_long} + Δ	$y_{R_long} = 2.6\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y \right)$	l _{lim} , "okay", "not ol	kay") = "okay"



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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)
<i>f_{o_long}</i> := 0.45		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1}{D}\right)$	$\frac{1}{2R_1 - 1} \bigg)^3 \cdot \frac{f_{o_long}}{N} =$	31.1 <i>psi</i> Allowable unconstrained buckling
$P_{GW} \coloneqq \gamma_w \cdot H_w = 6.5 \; psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := if (P_{UC \ long} > P_{net})$,"okay", "not okay	") = "okay"



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Champlain Hudson Power Express - Package 6 Crossing #105- CSX RR (~MP 211.8) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

Defining Parameters of Horizontal Direct	ional Drilling :
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 = 2.375 \ in$	Pipe 2 outer diameter
$\tilde{D_{rod}} \coloneqq 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 := 11$	Dimension ratio of Pipe 2
$T_{p1} := \frac{D_1}{DR_1} = 1.194 \ in$	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	nine entry
	pipeonity
drill rig B	A a
	- manana mananananananananananananananana
H	
nine exit C	B
p.p.c.	
L_4 L_3	L ₂ L ₁
Lbos	
Illustration 1 - Schematic of	Drive Cross-section
$\alpha \coloneqq 10^{\circ} \qquad \alpha_{in} \coloneqq \alpha \equiv 0.1745 \text{ rad}$	Borehole entry angle (degrees, radians)
$\beta = 10^{\circ}$ $\beta_{exit} = \beta = 0.1745 \text{ rad}$	Borehole exit angle (degrees, radians)
$D_r := 18 \cdot in$	Final reamed bore diameter
$H_{max} \coloneqq 21.40 \ ft$	Max depth of bore hole to final reamed bore diameter
$H_{max1} := H_{max} + \frac{D_r}{2} = 22.15 \ ft$	Max depth to bore hole springline from ground surface
$L_{total} \coloneqq 531.7 \ ft$	Total length of HDD crossing
$L_1 \coloneqq 150 \ ft$	Assumed pipe drag on surface, See Illustration 1
$\frac{L_2 \coloneqq 211.7 \ \boldsymbol{ft}}{\boldsymbol{ft}}$	Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_3 := 104.3 \ ft$	Straight horizontal section
$L_4 \coloneqq 215.7 \ ft$	Horizontal distance to rise to surface, See Illustration 1
$H := 21.66 \ ft$	Elevation difference between the lowest point in borehole and slurry pump elevation

Project: Tunnel No.:

Description: Calculated by: DA

Checked by: NW

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		(entry or exit pit), See Illustration 1
$v_a := 0.1$		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
$\gamma_m \coloneqq 70 \ pcf = 9.4 \ \frac{lbf}{gal}$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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
$R \coloneqq \frac{R_{avg._in} + R_{avg._out}}{2} = 1000$	0 ft	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} > r_{rod}, \text{``o'} \right)$	kay", "not okay"	() = (okay)
$Check \coloneqq \mathbf{if} \left(R_{avg. out} > r_{rod}, "contents of the second secon$	okay", "not okay	") = "okay"

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

$e_a := \frac{D_1}{2 \cdot R} = 0.0004$	Strain within the casing pipe
$E_{12hr} \!\coloneqq\! 57500 \boldsymbol{\cdot psi}$	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



Champlain Hudson Power Express - Package 6 Crossing #105- CSX RR (~MP 211.8) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

B - Site Specific Analyses: Pullback Force (C1 controls):
B1 - Empty Pipe
B1.1 - Effective Weight of Empty Pipe:

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

$$\text{Effective weight}$$

$$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2} \right)}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 38 \text{ plf}$$
Upward buoyant force of empty pipe
B1.3 - Hydrokinetic Pressure:

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

$$T_{a} \coloneqq e^{v_{a} \cdot v_{a}} \cdot \left(v_{a} \cdot w_{a} \cdot \left(L_{1} + L_{2} + L_{3} + L_{4} \right) \right) = 575 \text{ lbf}$$
Pullback force when pipe enters the ground
B1.5 - Pullback Force Point B:

$$T_{b} \coloneqq e^{v_{a} \cdot v_{a}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot v_{a})} \right) = 3817 \text{ lbf}$$
Pullback force increase with depth
B1.6 - Pullback Force Point C:

$$T_{c} \coloneqq T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3} \right) - e^{(v_{a} \cdot v_{a})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot v_{a})} \right) = 4912 \text{ lbf}$$
B1.7 - Pullback Force at D:

$$T_{d} \coloneqq e^{(v_{a} \cdot v_{a})} \cdot \left(T_{c} + v_{b} \cdot |w_{b} | \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot v_{a})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot v_{a})} \right) \right) = 6715 \text{ lbf}$$
B1.8 - Maximum Pullback Force - Empty Pipe:

$$P_{max_{a} \text{ cmpty}} \coloneqq \max \left(T_{a}, T_{b}, T_{c}, T_{d} \right) + \Delta T = 7512 \text{ lbf}$$
Maximum Pullback Force
B2.1 - Upward Buoyant Force:

$$w_{by \text{tited}} \coloneqq \left(\frac{\left(\pi \cdot D_{1}^{2} \right)}{4} \right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{c}} \right) \right)^{2} \right) - w_{a} = 12 \text{ plf}$$
Upward buoyant force of pipe filled with water

<u>B2.2 - Pullback Force Point A:</u> $T_{afilled} := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 575$ *lbf* Pullback force enter ground



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot lpha_{in}} \left(T_{afilled} + v_b \cdot \left w_{bfilled} \right \cdot L_2 + B2.4 - Pullback Force Point C:$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 1871 \ lbf$ Pullback force increase and decrease with depth
${T}_{cfilled} \! \coloneqq \! {T}_{bfilled} \! + \! \left({v}_{b} \! \cdot \! \left {w}_{bfilled} \! \right \! \cdot \! L_3 ight) \! - \! {e}^{\left({v}_{b} \cdot {v}_{c} ight)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot lpha_{in})}) = 2155 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot eta_{exit})} ullet \left(T_{cfilled} + v_b ullet \left w_{bfilled} ight ullet L$	$(v_4 - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 2897 \ lbf$
<u> B2.6 - Maximum Pullback Force - Filled Pi</u>	pe with Water:
$\mathcal{P}_{max} \! \coloneqq \! \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$	$(ad) = 2897 \ lbf$ Maximum Pullback Force
- Safe Pull Strength / Ultimate Tensi B3.1 Safe Pullback Check	ile Load 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
${}_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 7220 \ lbf$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 291 \ lbf$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 2785 \ lbf$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} \coloneqq \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 112 \ lbf$	Pullback forces acting on Pipe 2 (Ballast)
$P_{SPF1} \coloneqq 41214 \ lbf$	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)
$\begin{aligned} & heck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \coloneqq \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > P_{12}, \text{``okay} \right) \\ & eheck \vdash \mathbf{if} \left(P_{SPF1} > $	y") = "okay" y") = "okay" y") = "okay"



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

<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.

	$H_w \coloneqq 10.2 \cdot ft$		Depth of the bore below groundwater elevation			
	<i>H_c</i> :=21.29 <i>ft</i>		Vertical separation distance between critical structure and pipe (CSX, MP 211.8)			
	$\gamma \coloneqq 100 \ pcf$		Assumed unit weight soft to clay/silt			
			(zero blow count material)			
	$\gamma_{\text{m}} \coloneqq 62.4 \text{ pcf}$		Unit weight of water			
	$\gamma_w^{\prime} = \gamma_{-} - \gamma_{-} - 37.6 \text{ m}$	of	Effective unit weight			
	$\gamma = \gamma - \gamma_w = 51.0 \text{ pc}$	-J				
	$u \coloneqq \gamma_w \cdot H_w = 4 psi$		Initial pore water pressure			
	$\phi \coloneqq 0 \ deg$		Assumed friction Angle			
	$c \coloneqq 450 \ psf = 3.13 \ p$	psi	Assumed cohesion of encountered materia (KIE suggests Su=300-350 psf)			
	$R_0 := \frac{D_{rod}}{2} = 1.75$ in	ı	Initial radius of the borehole			
	$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 11$	ft	Radius of plastic zone (H/2 in clays & 2/3 H in sands)			
	$\sigma'_0 \! \coloneqq \! \left(\left\langle \gamma \boldsymbol{\cdot} \left(H_c \! - \! H_w \right) \right. \right. \right)$	$\left(\gamma\right) + \gamma' \cdot H_w = 10 \ ps$	<i>i</i> Initial effective stress			
Tab	e C.2 Typical values of modulus of elastic	ity (E_r) for different types of soils				
	Type of Soil	E, (N/mm ²)				
	Clay					
	Very soft Soft	2-15 5-25				
	Medium	15-50				
	Hard Sandy	25-250	$E_s = 2 - 290 \text{ psi}$			
	Glacial till		mm			
	Dense	10-153	Assumed modulus of elasticity			
	Very dense	478-1,440				
	Loess	14-57				
	Sand	7-21				
	Loose	1024				
	Dense	48-81				
	Loose	48-148				
	Dense	96-192				
	Shale	144-14,400				
	<u></u>	2-20				

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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) 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 Fine grained (void ratio = $0.4 - 0.7$) 0.25		$\nu_s = 0.4$
Rock 0.1-0.4 (dependence) Loess 0.1-0.3	ends on type of rock)	Poissions ratio of material encountered
Concrete 0.15		
$G \coloneqq \frac{E_s}{2 (1+\nu_s)} = 104 \ psi$		Shear modulus of soil
$(\sigma', sin(\phi)) + (c, 0)$		
$Q \coloneqq \frac{(\circ 0 \circ \sin(\phi)) + (\circ \circ 0)}{G} = 0$	0	Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot co$	$\cos(\phi) = 13.5 \ psi$	
		deformation takes place
	$\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pm}}\right)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pm}}\right)\right) + \left(\left(\frac{R_0}{R_{pm}}\right)\right)\right) + \left(\left(\left(\frac{R_0}{R_{pm}}\right)\right) + \left(\left(\left(\frac{R_0}{R_{pm}}\right) + \left(\left(\frac{R_0}{R_{pm}}\right)\right) + \left(\left(\left(\frac{R_0}{R_{pm}}\right) + \left(\left(\frac{R_0}{R_{pm}}\right) + \left(\left(\frac{R_0}{$	$\left(\frac{1}{100}\right)^2 + Q$	$-c \cdot 0 = 13.5 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 17.9 \ \textbf{psi}$		Maximum allowable mud pressure
C2 -Min. Allowable Drilling I	<u>Fluid Pressure</u>	
$D_{PT} \coloneqq 5$ in		Pilot tube diameter
$D_0 = 9.5 \ in$		Initial borehole diameter for pilot tube
$h \coloneqq 21.4 \ ft$		Elevation difference between level of bore hole front and exit point of mud flow
$\gamma_m = 70 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h \equiv 10.4 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v \coloneqq \frac{Q_f}{0.785 (D_0^2 - D_{PT}^2)} = 78$	$5.2 \frac{ft}{min}$	Computed mud flow velocity
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--	--	---
$L_{structure} \coloneqq 225 \ ft$ $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{p_{pl} \cdot v} \right)^2 \right)$	$- + \left(\frac{\tau_o}{(D_0 - D_{PT})}\right)$	Length to sturcture $= 0.7 \ psi$
$p_{min} := p_1 + p_2 = 11.1 \ psi$) ((//////////////////////////////////	Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure
$check \coloneqq \mathbf{if} (p_{max} > p_{min}, \text{``oka})$	y", "not okay") =	- "okay"



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- Ring Deflection (Short & Long Term):	
D1.1 - Overburden Pressure (Considering De	formed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 21.4 \ ft$	Depth of cover
$\phi = 0 \ deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{K \cdot H_c}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_L \coloneqq 300 \ psf$	Live loading for E80 (RR at 20-feet depth)
$P_E \coloneqq \left(k \cdot (\gamma - \gamma_w) \cdot (H_c)\right) + P_L \equiv 8 \ psi$ $P_E \equiv 1105 \ psf$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
$E_{short} \coloneqq 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{3} = 9.36 \ psi$	Variable in earth load deflection equation
$12 \cdot (DR_1 - 1)$	
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.0\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handbo
D1.3 Earth Load Deflection (Long Term)	
$E_{long} := 28200 \cdot psi$	Apparent modulus of elasticity for PE471 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{D_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$0.0125 \cdot P_{-}$	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \coloneqq \frac{0.0120 \ T_E}{k} = 2.1\%$	PPI Equ. 10 (Chp 12, p 437)

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D2 - Buovant Deflection
D2.1 Buoyant Deflection (Short Term)
$D_1 = 10.75 \ in$
$t \coloneqq T_{p1} = 1.194$ in
$E_{short}\!=\!57500~{\it psi}$
$\gamma_m = 70 \ pcf$
$I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$
$\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)}{E_{short} \cdot I} = 0.0$

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.

<u>D3 -</u>	Reissner	Effect D	eflection	(Short Term)

D3.1 - Reissner Effect Deflection (Short Term)

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

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	$z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term
<u> D4 - Net Ring Deflection</u>		
Δy_{lim} := 7.5%		Deflection limit for DR 9 non pressurized pipe (Table 2 , p. 437, PPI Handbook)
D4.1 - Net Short Term		
Δy_{short_net} := Δy_{ELD_short} + 2	$\Delta y_{bouyant} + \Delta y_{R_shor}$	$_{t} = 1.1\%$ Percent ring deflection in short term analysis
$Check \coloneqq ext{if} \left(\Delta y_{short_net} < \Delta y_{short_net} \right)$	J _{lim} , "okay", "not o	kay") = "okay"
D4.2 - Net Long Term		
$\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \Delta$	$y_{R_long} = 2.1\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} < \Delta y \right)$	_{lim} , "okay", "not ol	kay") = "okay"



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D3.1 Onconstrained King Dacking, Levy 3 L	
Note that constraining the pipe will increase considering an unconstrained condition will p	the pipe's buckling strength, therefore 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
$E_{short} \!=\! 57500 \mathbf{psi}$	PE4710, Base Temperature of 73 deg.
	(Table X1.1 ASTM F 1962)
0 2 4 6 8 10 12	
0.0	
2	Ovality compensation factor. Figure
	3 (PPI Chp. 12). Calculated
t, b	deflection limit in section D4.1
	$f \rightarrow -0.88$
8	Jo_short - 0.00
1.0	
$P_{UC \text{ short}} \coloneqq \left(\underbrace{2 \cdot E_{short}}_{0} \right) \cdot \left(\underbrace{1}_{0} \right)^{3} \cdot \frac{f_{o_short}}{0}$	t = 112.6 psi Allowable unconstrained
$\left(1-\mu_{short}^{2}\right)\left(DR_{1}-1\right) \qquad N$	buckling pressure
$H = 21.66 \ ft$	Elevation difference between the lowest
	point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 10.53 \ psi$	Pressure of drilling slurry
$P_{net} := P_{mud} = 10.53 \ psi$	Net external loading with open borehole
$Check := if(P_{UC \ short} > P_{net}, "okay", "not okay")$	ay") = "okay"
D5.2 - Unconstrained Ring Buckling, Levy's E	quation (Long Term)
D5.2 - Unconstrained Ring Buckling, Levy's E Note that constraining the pipe will increase	quation (Long Term) the pipe's buckling strength, therefore
D5.2 - Unconstrained Ring Buckling, Levy's E Note that constraining the pipe will increase considering an unconstrained condition will p	the pipe's buckling strength, therefore produce a conservative value.
D5.2 - Unconstrained Ring Buckling, Levy's E Note that constraining the pipe will increase considering an unconstrained condition will p N := 2.0	the pipe's buckling strength, therefore produce a conservative value. Factor of Safety Poisson's Ratio for PE pipe material

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #105- CSX RR (~MP 211.8) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 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
$P \qquad -\left(\begin{array}{c} 2 \cdot E_{long} \end{array}\right)$	$(1)^3 f_{o_long}$	21.1 mai
$T_{UC_long} = \left(\frac{1-\mu_{long}^2}{1-\mu_{long}^2}\right)^{\bullet}$	$\left(\overline{DR_1-1}\right)$ \cdot N $-$	Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 4.42 \text{ ps}$	i	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq if \left(P_{UC_long} > P_{n} \right)$	_{vet} , "okay" , "not okay	")="okay"



Champlain Hudson Power Express - Package 6 Crossing #105- CSX RR (~MP 211.8) 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

107.A



Champlain Hudson Power Express - Package 6 Crossing #107.A - CSX Tracks and Flint Mine Rd Pull Back and Mud Pressure Calcs Date: 9/18/23 Date: 9/18/23

Defining Parameters of Horizontal Directi	onal Drilling :		
$D_1 := 10.75 \ in$	Pipe 1 outer diameter		
$D_2 := 2.375 \ in$	Pipe 2 outer diameter Assumed drill rod diameter Dimension ratio of Pipe 1 Dimension ratio of Pipe 2		
$D_{rod} = 3.5 \ in$			
$DR_1 \coloneqq 9$			
$DR_2^{'} \coloneqq 11$			
$T_{p1} := \frac{D_1}{DR_1} = 1.194 \ in$	Thickness of Pipe 1		
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2		
$C_1 \coloneqq \pi \cdot D_2 = 33.8 \text{ in}$	Pipe circumference of pipe 1		
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2		
bore/ninenath	ninemter		
	pipeenty		
drill rig B			
D	- running and the second		
H			
nine wit C1	B		
pipecan			
L ₄ L ₃	L ₂ L ₁		
- Lton			
0.05			
Illustration 1 - Schematic of	Drive Cross-section		
$\alpha_{1} = 10^{\circ}$ $\alpha_{1} = \alpha_{2} = 0.1745$ mad	Borehole entry angle (degrees, radians)		
$\begin{array}{c} \alpha \coloneqq 10 \\ \alpha_{in} \coloneqq \alpha \equiv 0.1745 \ \text{full} \\ \alpha_{in} \coloneqq \alpha \equiv 0.1745 \ \text{mad} \\ \alpha_{in} \equiv \alpha_{in} \equiv \alpha_{in} = \alpha_{in} = \alpha_{in} = \alpha_{in} = \alpha_{in} = \alpha_{in} = \alpha_{i$	Borehole evit angle (degrees, radians)		
$p_{exit} = p = 0.1745 \ rua$	Einel reamed here diameter		
$D_r \coloneqq 18 \cdot in$	Final reamed bore diameter		
$H_{max} \approx 30 \ ft$	diameter		
$H_{max1} := H_{max} + \frac{D_r}{2} = 30.75 \ ft$	Max depth to bore hole springline from		
	Total length of UDD crossing		
$L_{total} \coloneqq 819 ft$			
$L_1 \coloneqq 150 \ ft$	Assumed pipe drag on surface, See Illustration 1		
$L_2 := 269 \ ft$	Horizontal length to achieve depth - provided by Contractor, See Illustration 1		
$L_2 \coloneqq 314 \ ft$	Straight horizontal section		
$L_4 \coloneqq 236 \ ft$	Horizontal distance to rise to surface, See		
$H \coloneqq 29 \ ft$	Elevation difference between the lowest point in borehole and slurry pump elevation (entry or exit pit). See Illustration 1		

Project: Tunnel No.:

Description: Calculated by: SA

Checked by: NW

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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
$\gamma_m \! \coloneqq \! 67 pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1000$) <i>ft</i>	Average radius of curvature at entry
$r_{rod} \! \coloneqq \! 1200 \cdot D_{rod} \! = \! 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} \! > \! r_{rod}, \text{``ok'} \right)$	xay", "not okay")="okay"
$Check \coloneqq \mathrm{if} \left(R_{avg._out} \! > \! r_{rod}, \mathrm{``o} \right)$	kay" , "not okay	")="okay"

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

$e_a := \frac{D_1}{2 \cdot R} = 0.0004$	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:
B - Empty Pipe
B 1.1 - Effective Weight of Empty Pipe:

$$w_{a} := \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \text{ plf}$$
B 1.2 - Upward Buoyant Force:

$$w_{b} := \left(\frac{\pi \cdot (D_{1}^{2} + D_{2}^{2})}{4} \right) \rho_{w} \cdot \gamma_{b} - w_{a} = 36 \text{ plf}$$
Upward buoyant force of empty pipe
B 1.3 - 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
B 1.4 - Pullback Force Point A:

$$T_{a} := e^{v_{a} \cdot a_{a}} \cdot \left(v_{a} \cdot w_{a} \cdot (L_{1} + L_{2} + L_{3} + L_{4}) \right) = 817 \text{ lbf}$$
Pullback force when pipe enters the ground
B 1.5 - Pullback Force Point B:

$$T_{b} := e^{v_{a} \cdot a_{a}} \cdot \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot a_{a})} \right) = 4822 \text{ lbf}$$
Pullback force Point C:

$$T_{c} := T_{b} + \left(v_{b} \cdot w_{b} \cdot L_{3} \right) - e^{(v_{a} \cdot a_{a})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot a_{a})} \right) = 7934 \text{ lbf}$$
B 1.7 - Pullback Force a D:

$$T_{d} := e^{(v_{a} \cdot a_{a})} \cdot \left(T_{c} + v_{b} \cdot |w_{b}| \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot a_{a})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot a_{a})} \right) \right) = 9695 \text{ lbf}$$
B 1.8 - Maximum Pullback Force - Empty Pipe:

$$P_{max_{a} compty} := \max \left(T_{a}, T_{b}, T_{c}, T_{d} \right) + \Delta T = 10492 \text{ lbf}$$
Maximum Pullback Force
B 2. - Filled Pipe with Water
B 2.1 - Upward Buoyant Force:

$$w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2} \right)}{4} \right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{2} \right) - w_{a} = 10.2 \text{ plf}$$
Upward buoyant force of pipe filled with water
B 2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 817 \ lbf \qquad \text{Pullback force enter ground}$



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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 + v_b \cdot \left B_2 \cdot 4 - Pullback Force Point C: \right $	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})}) = 2284 \ lbf$ Pullback force increase and decrease with depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled}\right \cdot L_3 ight) - e^{\left(v_b \cdot lpha_{in} ight)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 2961 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{\left(v_b \cdot \beta_{exit}\right)} \cdot \left(T_{cfilled} + v_b \cdot \left w_{bfilled}\right \cdot L_4\right)$	$-e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 3664 \ lbf$
<u> B2.6 - Maximum Pullback Force - Filled Pipe</u>	e with Water:
$P_{max} \! \coloneqq \! \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$)=3664 <i>lbf</i> Maximum Pullback Force
B3 - Safe Pull Strength / Ultimate Tensile	e Load 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
$A_2\!\coloneqq\!$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 10085 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 407 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 3522 \ lbf$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 142 \ lbf$	Pullback forces acting on Pipe 2 (Ballast)
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
$P_{SPF2} \coloneqq 1683 \ lbf$	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$\begin{aligned} check &\coloneqq \mathbf{if} \ (P_{SPF1} > P_{11}, \text{``okay''}, \text{``not okay''} \\ check &\coloneqq \mathbf{if} \ (P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay''} \\ check &\coloneqq \mathbf{if} \ (P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay''} \\ check &\coloneqq \mathbf{if} \ (P_{SPF2} > P_{22}, \text{``okay''}, \text{``not okay''} \end{aligned}$	') = "okay" ') = "okay" ') = "okay" ') = "okay"



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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.

$H_{\text{out}} := 0 \cdot ft$	
	Depth of the bore below groundwater
$H_c \coloneqq 30 \ ft$	Vertical separation distance between critical
	structure and pipe (CSX Tracks)
v:= 140 ncf	Assumed unit weight of bedrock(no geotech
	available)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 77.6 \ pcf$	Effective unit weight
$\mu = \gamma \cdot H = 0$ nsi	Initial pore water pressure
$\frac{1}{10} - \frac{1}{10} = 0$	Accumed friction Angle (no gestach available
)≔ 35 aeg	Assumed inclion Angle (no geolech available
:=450 psf =3.13 psi	Assumed cohesion of encountered material
D_{rod} .	
$R_0 := \frac{n_0 a}{2} = 1.75 \ in$	Initial radius of the borehole
$K_{pmax} \coloneqq - H_c = 15 ft$	Radius of plastic zone (H/2 in clays &
2	2/3 H in sands)
$\gamma'_{\circ} := ((\gamma \cdot (H - H)) + \gamma' \cdot H) = 29 $ nsi	Initial effective stress
C.2 Typical values of modulus of elasticity (E_{c}) for different types of soils	
2 Typical values of modulus of elasticity (<i>E</i> ₅) for different types of soils Type of Soil <i>E</i> _ (N/mm ²)	
2 Typical values of modulus of elasticity (<i>E</i> ₅) for different types of soils Type of Soil <i>E</i> _s (N/mm ²) Clay Clay	
2 Typical values of modulus of elasticity (<i>E</i> ₃) for different types of soils Type of Soil <i>E</i> _y (N/mm ²) Clay Very soft 2–15 Soft 5–25 5–25	
Typical values of modulus of elasticity (E _s) for different types of soils Type of Soil E _s (N/mm ²) Clay -15 Soft 5–25 Medium 15–50	N
Typical values of modulus of elasticity (E _s) for different types of soils Type of Soil E _y (N/mm ²) Clay Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100	$E_{s} = 28 \frac{N}{2} = 4061 \ psi$
Typical values of modulus of elasticity (E _s) for different types of soils Type of Soil E _x (N/mm ²) Clay Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Glacial till	$E_s := 28 \frac{N}{mm^2} = 4061 \ psi$
Typical values of modulus of elasticity (E _s) for different types of soils Type of Soil E _s (N/mm ²) Clay 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till Loose Loose 10–153	$E_s \coloneqq 28 \frac{N}{mm^2} = 4061 \text{ psi}$
Z Typical values of modulus of elasticity (E _s) for different types of soils Type of Soil E _s (N/mm ²) Clay -15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till	$\frac{E_s \coloneqq 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
.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 Lower 14–77	$\frac{E_s \coloneqq 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_y (N/mm²) Clay -15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till	$\frac{E_s = 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
$\begin{array}{c c} \textbf{2.2 Typical values of modulus of elasticity (E_{s}) for different types of soils \hline Type of Soil & E_{s} (N/mm^{2}) \\ \hline Type of Soil & E_{s} (N/mm^{2}) \\ \hline Clay & \\ Very soft & 2-15 \\ Soft & 5-25 \\ Medium & 15-50 \\ Hard & 50-100 \\ Sandy & 25-250 \\ \hline Glacial till & \\ Loose & 10-153 \\ Dense & 144-720 \\ Very dense & 478-1,440 \\ Loess & 14-57 \\ Sand \\ Silty & 7-21 \\ \hline \end{array}$	$\frac{E_s = 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft Very soft 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 Silty 7–21 Loose 10–24 Dense 10–24	$\frac{E_s = 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft Very soft 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 Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel 5	$\frac{E_s = 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (N/mm ²) Clay Very soft Very soft 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 Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel Loose Loose 48–148	$\frac{E_s = 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (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 Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose Loose 48-148 Dense 96-192	$\frac{E_s := 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (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 Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose Loose 96-192 Shale 144-14,400 Sit 2-70	$\frac{E_s := 28}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
2.2 Typical values of modulus of elasticity (E_s) for different types of soils Type of Soil E_s (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 Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose Loose 96-192 Shale 144-14,400 Silt 2-20	$\frac{E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}}{\text{Assumed modulus of elasticity}}$
Clay Very soft 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 Loes 10-24 Dense 48-81 Sand Silty Silty 7-21 Loose 10-24 Dense 48-81 Sand Silty Silt 2-20	$\frac{E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}}{\text{Assumed modulus of elasticity}}$
2.2 Typical values of modulus of elasticity (E_3) for different types of soils Type of Soil E_i (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 Silty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose Loose 96-192 Shale 144-14,400 Silt 2-20	$\frac{E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}}{\text{Assumed modulus of elasticity}}$
2.2 Typical values of modulus of elasticity (E_S) for different types of soils Type of Soil E_s (N/mm²) Clay -15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till	$\frac{E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}}{\text{Assumed modulus of elasticity}}$
2.2 Typical values of modulus of elasticity (E_S) for different types of soils Type of Soil E_s (N/mm ²) Clay 2-15 Noft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till 10 Loose 10-153 Dense 144-720 Very dense 478-1,440 Loose 10-24 Dense 48-81 Sand and gravel 10-024 Dense 48-148 Dense 96-192 Shale 144-14,400 Silt 2-20	$\frac{E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}}{\text{Assumed modulus of elasticity}}$
2.2 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 Loose 10–153 Dense 144–720 Very dense 478–1,440 Loose 14–57 Sand Sand Silty 7–21 Loose 10–24 Dense 48–81 Sand and gravel Loose Loose 96–192 Shale 144–14,400 Silt 2–20	$E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity
Clay E_g (N/mm ²) Clay 2-15 Noft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till 100 Loose 10-153 Dense 144-720 Very dense 478-1,440 Loose 10-24 Dense 14-57 Sand 50-100 Silty 7-21 Loose 10-24 Dense 48-148 Dense 96-192 Shale 144-14,400 Silt 2-20	$E_s := 28 \frac{N}{mm^2} = 4061 \text{ psi}$ Assumed modulus of elasticity

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Table C.4 Typical values of Poisson's ratio (μ) for soils		
Clay (unsaturated) 0.1 – 0.3 Sandy clay 0.2 – 0.3		
Silt 0.3 - 0.35 Sand (dense) 0.2 - 0.4		$\nu_s := 0.4$
Course (void ratio = $0.4 - 0.7$) 0.15 Fine grained (void ratio = $0.4 - 0.7$) 0.25 Particle 20 0.1 0.4 (decord of the second		
Loes 0.1-0.3 (depends of 0.1-0.3 (depends of 0.1-0.3)	on type of rock)	Poissions ratio of material encountered
Concrete 0.15		
$G \coloneqq \frac{E_s}{2 \ \left(1 + \nu_s\right)} = 1450 \ \mathbf{psi}$		Shear modulus of soil
$(\sigma'_0 \cdot \sin(\phi)) + (c \cdot 0)$		
$Q \coloneqq \frac{\langle \cdot \rangle}{C} = \frac{\langle \cdot \rangle}{C}$	=0.0115	
G		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot c$	$\cos(\phi) = 48.5 \ psi$	
		Mud pressure at which the first plastic
($(-\sin(\phi))$) deformation takes place
	$\sqrt{1+\sin(\phi)}$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left\ \left(\frac{P_f}{R_p} \right) \right\ _{2} \right) + \left\ \left\ \left(\frac{P_f}{R_p} \right) \right\ _{2} \right\ _{2} \right\ _{2} + \left\ \left(\frac{P_f}{R_p} \right) \right\ _{2} + \left\ \left(P$	$\left(\frac{R_0}{pmax}\right)^2 + Q$	$-c \cdot 0 = 245.7 \ psi$
		Maximum allowable effective mud pressur (Delft Equation)
$p_{max} := u + p'_{max} = 245.7$ ps	ri	Maximum allowable mud pressure
C2 -Min. Allowable Drilling	<u>g Fluid Pressure</u>	
$D_{PT} \coloneqq 5 in$		Pilot tube diameter
$D_0 = 9.5 in$		Initial borehole diameter for pilot tube
h := 29 ft		Elevation difference between level of bore
1025 JV		bole front and exit point of mud flow
07		Light weight of clump (roud
$\gamma_m = 67 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 13.5 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
Q_f	ft	Computed mud flow valacity
$v := \frac{1}{0.785 (D_0^2 - D_{PT}^2)} =$	$\frac{10.2}{\text{min}}$	

KILDUF Champlain Hudson Power Express - Package 6 Project: Crossing #107.A - CSX Tracks and Flint Mine Rd Tunnel No.: Description: Pull Back and Mud Pressure Calcs UNDERGROUND ENGINEERING, INC. Calculated by: SA Date: 9/18/23 Checked by: NW Date: 9/18/23 $L_{structure} \coloneqq 300 \ ft$ Length to sturcture $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)} \right)$ =0.9 **psi** Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure $p_{min.} \coloneqq p_1 + p_2 = 14.4 \ psi$ $check := if(p_{max} > p_{min.}, "okay", "not okay") = "okay"$



Champlain Hudson Power Express - Package 6 Crossing #107.A - CSX Tracks and Flint Mine Rd Pull Back and Mud Pressure Calcs Date: 9/18/23 Date: 9/18/23

1- Ring Deflection (Short & Long Term):	
D1.1 - Overburden Pressure (Considering Def	ormed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 30 \ ft$	Depth of cover
$\phi = 35 \ deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$\gamma = 140 \ pcf \tag{(4)}$	Unit weight of soil, assumed
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{\mathbf{n} \cdot \mathbf{n}_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{B} = 0.106$	Arching factor (Eg. 6, p.432, PPI)
$2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)$	
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 2 psi$ $P_E = 248 psf$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ \textbf{psi}$	Variable in earth load deflection equation
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{I} = 0.2\%$	Pipe deflection to diameter as per
κ_{short} D1.3 Earth Load Deflection (Long Term)	PPI Equ. 10 (Chp 12, p 437, PPI Handbook
	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 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$0.0125 \cdot P_{\pi}$	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \coloneqq \frac{0.012011E}{k} = 0.5\%$	PPI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection (<u>(Short Term)</u>	
$D_1 = 10.75 \ in$		Outside diameter of casing pipe
$t := T_{n1} = 1.194$ in		Thickness of casing pipe
F-		Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$		PE4710, Base Temperature of 73
		Fahrenheit (Table B.1.1)
$\gamma_m = 67 \ pcf$		Assumed unit weight of fluid in
-3 - 1		borehole (Slurry unit weight)
$I \coloneqq \frac{t^{\circ}}{1} = 0.14 \frac{in^{+}}{1}$		Moment of inertia of pipe wall cross
12 in	D $)^4$	section
$0.1169 \cdot \gamma_m \cdot [$	$\underline{D_1}$	Pipe ring deflection to buoyant force
Δy_{1}	$\frac{2}{2}$ = 0.0	ASTM F 1962 (Eq. X2.6, p.6)
$E_{short} \cdot I$		
D2.1 Buovant Deflection (Long Term)	
Please note that long tern assumed to be cured afte D3 - Reissner Effect Defle D3.1 - Reissner Effect Def	n buoyant deflection r a 1-week period fro ection (Short Term) flection (Short Term)	was assumed negibile, since grout is om installation/pumping.
	•	
$\mu_{short} \coloneqq 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature
3 () (. 4	
$z \coloneqq \frac{\frac{\partial}{\partial t} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - \frac{\partial}{\partial t}\right)}{16 \cdot t^2 \cdot R^2}$	t) = 0.0000033	Deflection due to longitudinal bending
$\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$ ight) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect Def	flection (Long Term)	
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at
		long term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature
3 (1 2) (5	4	
$-\frac{1}{2} \cdot (1 - \mu_{long}) (D_1 - \mu_{long})$	t)	Deflection due to longitudinal bending
$z \coloneqq \frac{1}{2}$	= 0.000003	
$10 \cdot t \cdot \kappa$		
$\Delta y_{R_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$\cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term

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Champlain Hudson Power Express - Package 6 Crossing #107.A - CSX Tracks and Flint Mine Rd Pull Back and Mud Pressure Calcs Calculated by: SA Date: 9/18/23 Date: 9/18/23

	Dute: 5/10/25
4 - Net Ring Deflection	
$\Delta y_{lim} \coloneqq 7.5\%$	Deflection limit for DR 9 non pressuriz
D4.1 - Net Short Term	
$\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_sh}$	$_{ort} = 0.3\%$ Percent ring deflection in sho term analysis
$Check \coloneqq \mathbf{if} \left(\Delta y_{short_net} \! < \! \Delta y_{lim}, \text{``okay''}, \text{``not} \right)$	okay") = "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)
$Check \coloneqq if \left(\Delta y_{long_net} < \Delta y_{lim}, \text{``okay''}, \text{``not''} \right)$	okay'') = "okay"

Project: Tunnel No.: Description:



Champlain Hudson Power Express - Package 6 Crossing #107.A - CSX Tracks and Flint Mine Rd Pull Back and Mud Pressure Calcs Date: 9/18/23 Date: 9/18/23



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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
$P \cdots \left(\begin{array}{c} 2 \cdot E_{long} \end{array} \right) \left(\begin{array}{c} \end{array} \right)$	1 $\int_{a}^{3} f_{o_long}$	21.1 nei
$I UC_{long} = \left(\frac{1 - \mu_{long}^2}{1 - \mu_{long}^2} \right) \cdot \left(\frac{1}{D} \right)$	$\overline{R_1-1}$) N	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
$Check \coloneqq \mathbf{if} \left(P_{UC_long} > P_{net}, \right.$	"okay", "not okay	'') = "okay"



Champlain Hudson Power Express - Package 6 Crossing #107.A - CSX Tracks and Flint Mine Rd Pull Back and Mud Pressure Calcs Date: 9/18/23 Date: 9/18/23

References

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- 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.
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- 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 #108- Flats Rd & Murderers Creek Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23

$D_1 := 10.75$ <i>in</i> 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	
$T_{p1} \coloneqq \frac{D_1}{DR_1} = 1.194 \text{ in}$ Thickness of Pipe 1	
$T_{p2} \coloneqq \frac{D_2}{DR_2} = 0.216 \text{ in}$ Thickness of Pipe 2	
$C_1 := \pi \cdot D_1 = 33.8$ in Pipe circumference of pipe 1	
$C_2 := \pi \cdot D_2 = 7.5$ in Pipe circumference of pipe 2	
bore/pipepath pipeentry	
drill rig β D	
H	
pipe exit C B	
* <u>, *** , *** , *** , *</u> *	
\mathbf{L}_4 \mathbf{L}_3 \mathbf{L}_2 \mathbf{L}_1	
· · · · · · · · · · · · · · · · · · ·	
Lbore	
Illustration 1 - Schematic of Drive Cross-section	
$\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094$ rad Borehole entry angle (degrees, r	adians)
$\beta := 8$ $\beta_{\text{cmit}} := \beta = 0.1396$ rad Borehole exit angle (degrees, rad	dians)
$D_{r} = 18 \cdot in$ Final reamed bore diameter	,
H := 45 ft Max depth of bore hole to final r	eamed bore
diameter	
$H_{max1} \coloneqq H_{max} + \frac{D_r}{45.75} ft$ Max depth to bore hole springlin	e from
ground surface	
$L_{total} = 2553.5 \ ft$ Total length of HDD crossing	
$L_1 := 150 \text{ ft}$ Assumed pipe drag on surface, S	See
Illustration 1	
$L_2 = 285.7 \text{ ft}$ Horizontal length to achieve dep	th -
provided by Contractor. See Illus	stration 1
$L_{2,1} \coloneqq 48 \ ft$ Straight horizontal section, before	e curve
$L_{3_1} = 48 \ ft$ Straight horizontal section, before	e curve
$L_{3_{-1}} \coloneqq 48 \ ft$ $L_{3_{-2}} \coloneqq 273.4 \ ft$ Curve Length	e curve
$L_{3_1} \coloneqq 48 \ ft$ Straight horizontal section, befor $L_{3_2} \coloneqq 273.4 \ ft$ Curve Length	e curve

Project: Tunnel No.:

Description: Calculated by: DA

Checked by: NW

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$L_4 \coloneqq 286.9 \cdot ft$		Horizontal distance to rise to surface, See Illustration 1
<i>H</i> ≔38.71 <i>ft</i>		Elevation difference between the lowest point in borehole and slurry pump elevation (entry or exit pit), See Illustration 1
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$\rho_{m} := 62.4 \ pcf$		Unit weight of water
$\gamma_{a} := 0.965$		Specific gravity of pipe
$\gamma_m^{\prime u} \coloneqq 70 \ pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		Specific gravity of slurry, assumed unit weight
$\begin{array}{l} \gamma_c \coloneqq 1.0 \\ \Delta P \coloneqq 10 \ \textbf{psi} \end{array}$		Specific gravity of water to fill the pipe 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
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1000$) <i>ft</i>	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} \! > \! r_{rod}, \text{``ok} \right)$	xay", "not okay")="okay"
$Check \coloneqq \mathbf{if} \left(R_{avg._out} \! > \! r_{rod} , \text{``o'} \right)$	kay", "not okay	") = "okay"
Radius of curvature should exceed	40 times the pipe	e outside diameter to prevent ring collapse.

$e_a := \frac{D_1}{2 \cdot R} = 0.0004$	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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B1.1 - Effective Weight of Empty Pipe:	
$w_{a}\!\coloneqq\!\!\frac{\pi}{4}\left(\!\left(\!D_{1}^{2}-\!\left(\!D_{1}\!-\!T_{p1}^{}\!\right)^{2}\right)\!+\!\left(\!D_{2}^{2}-\!\left(\!D_{1}^{}\!-\!T_{p1}^{}\!\right)^{2}\right)\!+\!\left(\!D_{2}^{2}-\!\left(\!D_{2}^{2}-\!T_{p1}^{}\!\right)^{2}\right)\!+\!\left(\!D_{2}^{2}-\!T_{p1}^{}\!\right)^{2}\right)$	$\left(D_2 - T_{p2}\right)^2 \left) \cdot \rho_w \cdot \gamma_a = 8.3 \ plf$
B1.2 - Upward Buoyant Force:	Effective weight
$w_{b} \coloneqq \left(\frac{\pi \cdot \left(D_{1}^{2} + D_{2}^{2}\right)}{4}\right) \rho_{w} \cdot \gamma_{b} - w_{a} = 3$	8 <i>plf</i> 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 <i>lbf</i> Hydrokinetic force
B1.4 - Pullback Force Point A:	
$T := e^{v_a \cdot \alpha_{in}} (q, q_{in}) (I + I + I) + I$	(+L,+L) - 1786 lbf
$\mathbf{L}_a \cdots \mathbf{C} \qquad \cdot (\mathbf{U}_a \cdot \mathbf{W}_a \cdot (\mathbf{L}_1 + \mathbf{L}_2 + \mathbf{L}_{3_1} + \mathbf{L}_3))$	$\mu_{3,2} + \mu_{3,3} + \mu_{4/2} = 1700$ iog Pullback force when pipe enters the grou
B1.5 - Pullback Force Point B:	
$T_{i} := e^{v_{b} \cdot \alpha_{in}} \left(T_{i} + v_{i} \cdot u_{i} \cdot L_{i} + u_{i} \cdot H \right)$	$-v \cdot w \cdot L_{\alpha} \cdot e^{(v_a \cdot \alpha_{in})} - 6932$ lbf
$1 b = c \qquad (1 a + cb + w_b + L_2 + w_b + H_{mo})$	Pullback force increase with depth
B1.6 - Pullback Force Point C1:	
$\boldsymbol{T}_{c_1} \coloneqq \boldsymbol{T}_b + \left(\boldsymbol{v}_b \boldsymbol{\cdot} \boldsymbol{w}_b \boldsymbol{\cdot} \boldsymbol{L}_{3_1}\right) - \boldsymbol{e}^{\left(\boldsymbol{v}_b \boldsymbol{\cdot} \boldsymbol{\alpha}_{in}\right)} \boldsymbol{\cdot} \left(\boldsymbol{v}_a\right)$	$\boldsymbol{\cdot} \boldsymbol{w}_{a} \boldsymbol{\cdot} \boldsymbol{L}_{3_{-1}} \boldsymbol{\cdot} \boldsymbol{e}^{(\boldsymbol{v}_{a} \boldsymbol{\cdot} \boldsymbol{\alpha}_{in})} = 7435 \boldsymbol{lbf}$
B1.7 - Pullback Force Point C2:	
$\alpha_{curve} = 15.4$ °	
$T_{c_{-2}} := e^{v_b \cdot u_{curve}} (T_{c_{-1}} + v_b \cdot w_b \cdot L_{3_{-2}} + u$	$v_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{\langle v_a \cdot u_{curve} \rangle} = 13038 \ lbf$
B1.8 - Pullback Force Point C3:	
$\boldsymbol{T}_{c_3} \coloneqq \boldsymbol{T}_{c_2} + \left(\boldsymbol{v}_b \boldsymbol{\cdot} \boldsymbol{w}_b \boldsymbol{\cdot} \boldsymbol{L}_{3_3}\right) - \boldsymbol{e}^{\left(\boldsymbol{v}_b \boldsymbol{\cdot} \boldsymbol{\alpha}_{curve}\right)} \boldsymbol{\cdot}$	$(v_a \cdot w_a \cdot L_{3_3} \cdot e^{(v_a \cdot lpha_{curve})}) = 24208 \ lbf$
B1.9 - Pullback Force at D:	
$T \leftarrow e^{(v_b \cdot \beta_{exit})} \cdot (T + v_b \cdot w_b \cdot L - w_b \cdot e^{(v_b \cdot \beta_{exit})} \cdot (T + v_b \cdot w_b \cdot L - w_b \cdot e^{(v_b \cdot \beta_{exit})} \cdot (T + v_b \cdot e^{(v_b \cdot \beta_{exit})} \cdot e^{(v_b \cdot \beta_{exi$	$H = e^{\langle v_a \cdot \alpha_{in} \rangle} \cdot \langle v_a \cdot v_b \cdot L \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} \rangle - 26612 L$
$\mathbf{I}_d = \mathbf{C} \mathbf{I}_{c_1} \mathbf{I}_{c_2} \mathbf{I}_{c_3} \mathbf{I}_{c_5} \mathbf{I}_{$	$\prod_{max} c = (c_a \cdot w_a \cdot L_4 \cdot c - f) = 20012 c$
B1.10 - Maximum Pullback Force - Em	pty Pipe:
$P_{\text{max}} = \max\left(T_{\star}, T_{\star}, T_{\star}, T_{\star}, T_{\star}, T_{\star}\right)$	$(2, 2, T_{t}) + \Delta T = 27408 \ lbf$
$- \max_{a, r} max_{a, r$	Maximum Pullback Force



Project: Tunnel No.:

Champlain Hudson Power Express - Package 6 Crossing #108- Flats Rd & Murderers Creek Crossing S

U N E E N G	DERGROUND INEERING, INC.	Description: Calculated by: DA Checked by: NW	Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23
B	<u> 2 - Filled Pipe with Water</u>		
	B2.1 - Upward Buoyant Force	<u>:</u>	
	$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} D_1^{\ 2}\right)}{4}\right) \boldsymbol{\cdot} \rho_w \boldsymbol{\cdot} \left(\gamma_b$	$-\gamma_c \cdot \left(1 - \left(rac{2}{DR_1} ight) ight)^2$	$\left(-w_a=12 \ \boldsymbol{plf}\right)$
		Upwai	rd buoyant force of pipe filled with water
	B2.2 - Pullback Force Point A	<u>:</u>	
	$T = e^{v_a \cdot \alpha_{in}} (a - av_a) (I - av_a)$		$I + I \rangle - 1786 lbf$
	$I_{afilled} - c$ $(v_a, w_a, (L_1))$	$-L_2 + L_{3_1} + L_{3_2} + .$	Pullback force enter ground
	B2.3 - Pullback Force Point B	<u>. </u>	
	$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot \right)$	$w_{bfilled} \cdot L_2 + w_{bfill}$	$_{ed} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot a_{inj})} = 3835 \ lbf$
	B2 4 - Pullback Force Point C	1.	denth
		<u> </u>	
	$T_{c1_filled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfill} \right \right)$	$_{ed}ig ullet L_{3_1}ig) - oldsymbol{e}^{(v_b ullet lpha_{in})}$	$\cdot \left(v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})} \right) = 3965 \ \textit{lbf}$
	B2.5 - Pullback Force Point C	<u>2:</u>	
	$\alpha_{curve} = 15.4$ °		
T_{c2_f}	$r_{illed} \coloneqq e^{v_b \cdot \alpha_{curve}} \left(T_{c1_filled} + v_b \cdot u_{curve} \right)$	$w_{bfilled} ig ullet L_{3_2} + w_{bfil}$	$led \cdot H_{max} + v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} = 6209 \ lbf$
	B2.6 - Pullback Force Point C	<u>3:</u>	
	$T_{c3_filled} \coloneqq T_{c2_filled} + \left(v_b \cdot \middle w_{bf}\right)$	$\left \boldsymbol{\cdot} L_{3_3} \right) - \boldsymbol{e}^{\left(v_b \cdot \boldsymbol{lpha}_c \right)}$	$(v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot lpha_{curve})}) = 10017 \ lbf$
	B2.7 - Pullback Force at D:		
	$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exil})} \cdot (T_{c3_filled} +$	$v_b \! \cdot \! \left w_{bfilled} ight \! \cdot \! L_4 \! - \! \epsilon$	$e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 11267 \ lbf$
	B2.8 - Maximum Pullback	Force - Filled Pipe	with Water:
	$\overline{P_{max}} \coloneqq \max\left(T_{afilled}, T_{bfilled}\right)$	$_{cd}, T_{c1_filled}, T_{c2_fill}$	$\left(T_{c3_filled}, T_{dfilled} ight) = 11267 \ \textit{lbf}$ Maximum Pullback Force
B	<u> 3 - Safe Pull Strength / Ult</u>	<u>imate Tensile Lo</u>	ad Check:
	B3.1 Safe Pullback Check		
	$A_1 := \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) =$	=19 <i>in</i> 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 <i>in</i> ²	Cross-sectional area of Pipe 2
	$P_{11} \! \coloneqq \! \frac{A_1 \! \cdot \! P_{max_empty}}{A_1 \! + \! A_2} \! = \! 26345$	lbf	Pullback forces acting on Pipe 1 (Empty)

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$P_{21} \! \coloneqq \! \frac{A_2 \! \cdot \! P_{max_empty}}{A_1 \! + \! A_2} \! = \! 1063$	lbf	Pullback forces acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 10830 \ \textit{lbf}$		Pullback forces acting on Pipe 1 (Ballast)
$P_{22} \coloneqq \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 437 \ \textit{lbf}$		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> _{SPF2} :=1683 <i>lbf</i>		Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$\underline{\qquad} check \coloneqq \mathbf{if} \left(P_{SPF1} > P_{11}, \text{``oka} \right)$	y", "not okay") =	= "okay"
	y", "not okay") =	= "okay"
$check := if (P_{SPF1} > P_{12}, "oka$	y'', "not okay") =	= "Okay"
$\underline{\qquad} check \coloneqq \mathbf{if} \left(P_{SPF2} > P_{22}, \text{``oka} \right)$	y", "not okay") =	= "okay"



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

<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.

$H_{c} := 25.8 ft$ $\gamma := 100 pcf$ $\gamma_{w} := 62.4 pcf$ $\gamma' := \gamma - \gamma_{w} = 37.6 pcf$ $\gamma' := \gamma_{w} \cdot H_{w} = 11 psi$ $\phi := 0 deg$ $c := 450 psf = 3.13 psi$ $R_{0} := \frac{D_{rod}}{2} = 1.75 in$ $R_{pmax} := \frac{1}{2} \cdot H_{c} = 13 ft$ $\sigma'_{0} := \left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w} = 7 psi$ C.2 Typical values of modulus of elasticity (ε_{3}) for different types of soils $\frac{Type of Soil}{Clay} = \frac{2-15}{Soft} = \frac{1-153}{Soft} = \frac{1-15}{Soft} = 1-15$	 Vertical separation distance between critical structure and pipe (~3+00) Assumed unit weight soft to clay/silt (zero blow count material) Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\gamma := 100 \text{ pcf}$ $\gamma_w := 62.4 \text{ pcf}$ $\gamma' := \gamma - \gamma_w = 37.6 \text{ pcf}$ $\mu := \gamma_w \cdot H_w = 11 \text{ psi}$ $\phi := 0 \text{ deg}$ $c := 450 \text{ psf} = 3.13 \text{ psi}$ $R_0 := \frac{D_{rod}}{2} = 1.75 \text{ in}$ $R_{pmax} := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $\tau'_0 := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \text{ psi}$ C.2 Typical values of modulus of elasticity (E_3) for different types of soils $\overline{T_{ype} \text{ of Soil}} E_v(N/mn^2)$ $\overline{Clay} 2-15$ Soft $5-25$ Medium $15-50$ Hard $50-100$ Sandy $25-250$ Glacial till Loose $10-153$	 Assumed unit weight soft to clay/silt (zero blow count material) Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\gamma_{w} := 62.4 \ pcf$ $\gamma' := \gamma - \gamma_{w} = 37.6 \ pcf$ $\mu := \gamma_{w} \cdot H_{w} = 11 \ psi$ $\phi := 0 \ deg$ $c := 450 \ psf = 3.13 \ psi$ $R_{0} := \frac{D_{rod}}{2} = 1.75 \ in$ $R_{pmax} := \frac{1}{2} \cdot H_{c} = 13 \ ft$ $\tau'_{0} := \left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w} = 7 \ psi$ $c.2 \ Type of Soil \qquad E_{s} (N/mn^{2})$ $Clay \qquad Clay \qquad $	 Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\begin{aligned} &\gamma' := \gamma - \gamma_w = 37.6 \ pcf \\ &\mu := \gamma_w \cdot H_w = 11 \ psi \\ &\phi := 0 \ deg \\ &c := 450 \ psf = 3.13 \ psi \\ &R_0 := \frac{D_{rod}}{2} = 1.75 \ in \\ &R_{pmax} := \frac{1}{2} \cdot H_c = 13 \ ft \\ &\sigma'_0 := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \ psi \\ &C_2 \ Type of Soil & E_s (N/ma^2) \\ &\hline &C_{lay} \\ &Very soft & 2-15 \\ &Soft & 5-25 \\ &Medium & 15-50 \\ &Hard & 50-100 \\ &Sandy & 25-250 \\ &Glacial till \\ &Lcose & 10-153 \end{aligned}$	Effective unit weight Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$y := \gamma = \gamma_w = 31.0 \text{ pcj}$ $u := \gamma_w \cdot H_w = 11 \text{ psi}$ $\phi := 0 \text{ deg}$ $c := 450 \text{ psf} = 3.13 \text{ psi}$ $R_0 := \frac{D_{rod}}{2} = 1.75 \text{ in}$ $R_{pmax} := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $\sigma'_0 := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \text{ psi}$ $c.2 \text{ Typical values of modulus of elasticity (E_3) for different types of soils}$ $\boxed{\frac{\text{Type of Soil} \qquad E_c (N/mm^2)}{\text{Clay}}}$ $\frac{\text{Type of Soil} \qquad E_{-15}}{\text{Sofi} \qquad 5-25}$ $\frac{\text{Medium} \qquad 15-50}{\text{Hard} \qquad 50-100}$ $\frac{\text{Sandy} \qquad 25-250}{\text{Glacial till}}$ $Loose \qquad 10-153$	Initial pore water pressure Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\begin{aligned} \mathbf{u} &:= \gamma_w \cdot \mathbf{H}_w = 11 \ \mathbf{pst} \\ \mathbf{p} &:= 0 \ \mathbf{deg} \\ \mathbf{c} &:= 450 \ \mathbf{psf} = 3.13 \ \mathbf{psi} \\ \mathbf{R}_0 &:= \frac{D_{rod}}{2} = 1.75 \ \mathbf{in} \\ \mathbf{R}_{pmax} &:= \frac{1}{2} \cdot \mathbf{H}_c = 13 \ \mathbf{ft} \\ \mathbf{r}_0' &:= \left(\gamma \cdot \left(\mathbf{H}_c - \mathbf{H}_w\right)\right) + \gamma' \cdot \mathbf{H}_w = 7 \ \mathbf{psi} \\ \mathbf{c.2 \ Typical values of modulus of elasticity (E_3) for different types of soils} \\ \hline \hline \frac{\mathrm{Type of Soil}}{\mathrm{Clay}} \\ \hline \frac{\mathrm{Clay}}{\mathrm{Very \ soft}} \\ \frac{\mathrm{Type of Soil}}{\mathrm{Soft}} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{4} \\ \mathbf{f}_{3} \\ \mathbf{f}_{4} \\ \mathbf{f}_{4} \\ \mathbf{f}_{4} \\ \mathbf{f}_{5} \\ \mathbf{f}_{5} \\ \mathbf{f}_{5} \\ \mathbf{f}_{6} \\ \mathbf{f}$	Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\phi := 0 \ deg$ $c := 450 \ psf = 3.13 \ psi$ $R_0 := \frac{D_{rod}}{2} = 1.75 \ in$ $R_{pmax} := \frac{1}{2} \cdot H_c = 13 \ ft$ $\sigma'_0 := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \ psi$ C.2 Typical values of modulus of elasticity (E ₃) for different types of soils $\frac{Type \text{ of Soil} \qquad E_e(\text{N/mm}^2)}{Clay}$ Very soft $\qquad 2-15$ Soft $\qquad 5-25$ Medium $\qquad 15-50$ Hard $\qquad 50-100$ Sandy $\qquad 25-250$ Glacial till Loose $\qquad 10-153$	 Assumed friction Angle Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$c := 450 \text{ psf} = 3.13 \text{ psi}$ $R_0 := \frac{D_{rod}}{2} = 1.75 \text{ in}$ $R_{pmax} := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $\tau'_0 := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \text{ psi}$ $c.2 \text{ Typical values of modulus of elasticity } (E_3) \text{ for different types of soils}$ $\frac{Type \text{ of Soil} \qquad E_4 (N/mm^2)}{Clay}$ $Clay \qquad Clay \qquad Cl$	Assumed cohesion of encountered material Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$R_{0} \coloneqq \frac{D_{rod}}{2} = 1.75 \text{ in}$ $R_{pmax} \coloneqq \frac{1}{2} \cdot H_{c} = 13 \text{ ft}$ $\tau'_{0} \coloneqq \left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w} = 7 \text{ psi}$ C.2 Typical values of modulus of elasticity (E ₃) for different types of soils $\frac{1}{\frac{\text{Type of Soil}}{\text{Clay}}} = \frac{2.15}{\frac{1}{\text{Soft}}} = \frac{2.15}{\frac{1}{\text{Soft}}} = \frac{2.15}{\frac{1}{\text{Medium}}} = \frac{1}{15-50}$ Hard 50-100 Sandy 25-250 Glacial till Loose 10-153	Initial radius of the borehole Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 13 \ ft$ $F'_0 \coloneqq \left(\gamma \cdot \left(H_c - H_w\right)\right) + \gamma' \cdot H_w = 7 \ psi$ $\frac{1}{Clay} = \frac{1}{Clay} = \frac{1}{$	Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$I'_{0} := \left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w} = 7 \text{ psi}$ 2 Typical values of modulus of elasticity (E _s) for different types of soils $\boxed{\frac{\text{Type of Soil} E_{s} (\text{N/mm}^{2})}{\text{Clay}}}$ Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153	Initial effective stress
C.2 Typical values of modulus of elasticity (E_3) for different types of soils Type 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	
Type of Soil E _g (N/mm ²) Clay 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till 25-250 Loose 10-153	
Clay Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till 25–250	
Soft 5–25 Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till	
Medium 15–50 Hard 50–100 Sandy 25–250 Glacial till	DT.
Sandy 25–250 Glacial till Loose 10–153	$E_{i} := 5 \frac{N}{2} = 725 \text{ nsi}$
Loose 10–153	mm^2
Dense 144–720	Assumed modulus of elasticity
Loess 14-57	
Sand	
Silty 7–21 Loose 10–24	
Dense 48-81	
Sand and gravel	
Dense 96–192	
Shale 144–14,400	
Silt 2-20	

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Table C.4 Typical values of Poisson's ratio (μ) for soils		
Type of soil μ	5	
Clay (sublated) 0.4 - 0. Clay (unsaturated) 0.1 - 0. Sandy clay 0.2 - 0.	.3	
Silt 0.3 - 0. Sand (dense) 0.2 - 0.	.35	
Course (void ratio = $0.4 - 0.7$) 0.15 Fine grained (void ratio = $0.4 - 0.7$) 0.25		$\nu_s = 0.4$
Rock 0.1–0.4 Loess 0.1 – 0.	4 (depends on type of rock)	
Ice 0.36 Concrete 0.15		Poissions ratio of material encountered
$G \coloneqq \frac{E_s}{2(1+\mu)} = 259 \ psi$		Shear modulus of soil
$(\sigma' \cdot \sin(\phi)) + (c \cdot 0)$		
$Q \coloneqq \frac{(v_0 \cdot \sin(\varphi)) + (c \cdot \theta)}{G}$	-=0	Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot$	$\cdot \cos(\phi) = 9.9 \ psi$	
		Mud pressure at which the first plastic deformation takes place
($\left(\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}\right)$	_))
$p'_{max} \coloneqq (p'_f + (c \cdot 0)) \cdot \left(\left(\left(\frac{1}{F} \right) \right) \cdot \left(\left(\frac{1}{F} \right) \right) \right) \cdot \left(\frac{1}{F} \right) \right)$	$\left(\frac{R_0}{R_{pmax}}\right)^2 + Q$	$-c \cdot 0 = 9.9 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} \equiv 21 $ psi		Maximum allowable mud pressure
<u>C2 -Min. Allowable Drillin</u>	ng Fluid Pressure	
$D_{PT} \coloneqq 5 in$		Pilot tube diameter
$D_0 := 9.5 \ in$		Initial borehole diameter for pilot tube
$h \coloneqq 38.6 \ ft$		Elevation difference between level of bore hole front and exit point of mud flow
$\gamma_m = 70 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 18.8 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v := \frac{Q_f}{0.785 (D_0^2 - D_{\rm rec}^2)}$	$=75.2 \frac{ft}{min}$	Computed mud flow velocity

Champlain Hudson Power Express - Package 6 Project: KILDUF Tunnel No.: Crossing #108- Flats Rd & Murderers Creek Crossing Description: Pull Back and Mud Pressure Calcs UNDERGROUND ENGINEERING, INC. Calculated by: DA Date: 4/13/23 R1: 9/18/23 Checked by: NW Date: 4/17/23 $L_{structure} \coloneqq 385 \ ft$ Length to sturcture $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)} \right) \right) = \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)^2} \right)$ =1.2 **psi** Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure $p_{min.} \coloneqq p_1 + p_2 = 19.9 \ psi$ $check \coloneqq if(p_{max} > p_{min.}, "okay", "not okay") = "okay"$



Champlain Hudson Power Express - Package 6 Crossing #108- Flats Rd & Murderers Creek Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23

I- Ring Deflection (Short & Long Term)	
D1.1 - Overburden Pressure (Considering D	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 45 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{(B (2))}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 12 \ psi P_E = 1692$	<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)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot (DR_1 - 1)^3} = 9.36 \ psi$	Variable in earth load deflection equation
$0.0125 \cdot P_E \qquad 1.007$	Dine deflection to diameter as nor
$\Delta y_{ELD_short} \coloneqq \underbrace{k_{short}}_{k_{short}} \equiv 1.0\%$	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)
$k \coloneqq \frac{E_{long}}{12 \cdot (DB_1 - 1)^3} = 4.6 \text{ psi}$	Variable in earth load deflection equation
$\Delta u_{EEE} = \frac{0.0125 \cdot P_E}{2} = 3.2\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)
$\Delta y_{ELD_long} \coloneqq \frac{0.0123 \cdot 1_E}{k} = 3.2\%$	PPI Equ. 10 (Chp 12, p 437)

UNDERGROUND ENGINEERING, INC.	Tunnel No.: Description: Calculated by: DA Checked by: NW	Crossing #108- Flats Rd & Murderers Creek Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23
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
$E_{short} = 57500 \ psi$		PE4710, Base Temperature of 73
		Fahrenneit (Table B.1.1)
$\gamma_m = 70 \ pcf$		Assumed unit weight of fluid in
t^3 in^4		borenole (Slurry unit weight)
$I \coloneqq \frac{1}{12} = 0.14 \frac{1}{in}$		Moment of inertia of pipe wall cross
$0.1169.\gamma$	$\left(\underline{D_1}\right)^4$	Pipe ring deflection to huevant force
$\Delta y_{bouyant} \coloneqq \frac{0.1109^{\circ} f_m}{E_{short}}$	$\left(\begin{array}{c} \hline 2 \end{array} \right) = 0.0$	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection	(Long Term)	
assumed to be cured af		
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$	lection (Short Term)	Poisson's Ratio for PE pipe material at
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Iection (Short Term)	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot (1 - \mu_{short}^2) (D_1$	$\frac{ \text{ection (Short Term}) }{ \text{eflection (Short Term}) }$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 + \frac{3}{16 \cdot t^2 \cdot R^2}\right)$	$\frac{1}{1} \frac{(\text{Short Term})}{(1 + t)^4} = 0.0000033$	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
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 + \frac{3}{16 \cdot t^2} \cdot R^2\right)$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{13}\right)$	$\frac{-t}{5} \cdot z^{2} = 0.0002\%$	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
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1\right)$ $z \coloneqq \frac{3}{16 \cdot t^2 \cdot R^2}$ $\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{13}\right)$ D3.2 - Reissner Effect D	$\frac{-t}{5} \cdot z^{2} = 0.0002\%$	 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
assumed to be cured affinition of the formula of the second determinant of the second determina	$\frac{-t}{5} \cdot z^{2} = 0.0002\%$	 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)
assumed to be cured aff D3 - Reissner Effect Def D3.1 - Reissner Effect D $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1}\right)$ $z \mapsto \frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1}\right)$	$\frac{1}{2} = 0.0000033$ $\frac{1}{5} \cdot z^{2} = 0.0002\%$ eflection (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) Radius of curvature
assumed to be cured affinition of the formula of the second determinant of the second determina	$\frac{-t}{5}^{4} = 0.00002$	 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) Radius of curvature Deflection due to longitudinal bending
assumed to be cured affinition of the expression of the expressio	$\frac{-t)^{4}}{-1} = 0.000033$ $\frac{-t)^{4}}{-1} = 0.000033$	 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) Radius of curvature Deflection due to longitudinal bending

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #108- Flats Rd & Murderers Creek Cr Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23	rossing
D4 - Net Ring Deflection			
Δy_{lim} :=7.5%		Deflection limit for DR 9 non pressurize	ed
D4.1 - Net Short Term			
${\it \Delta} y_{short_net}$:= ${\it \Delta} y_{ELD_short}$ +	- $\Delta y_{bouyant}$ + Δy_{R_short}	$t_t = 1.6\%$ Percent ring deflection in shor term analysis	t
$Check \coloneqq ext{if} \left(\Delta y_{short_net} < \Delta ight)$	$\Delta y_{lim}, \mathrm{``okay''}, \mathrm{``not}\mathrm{ob}$	okay") = "okay"	
D4.2 - Net Long Term			
$\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{ELD_long}$	$\Delta y_{R_long} = 3.2\%$	Percent ring deflection in long term analysis (50 years)	
$Check \coloneqq \mathbf{if} \left(\Delta y_{long_net} \! < \! \Delta \right)$	$y_{lim}, \mathrm{``okay''}, \mathrm{``notok}$	kay") = "okay"	



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Note that constraining the pipe will in considering an unconstrained conditi	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)
$E_{short} \!=\! 57500 \mathbf{psi}$	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 2 4 6 8 10	12
5	Ovality compensation factor, Figure
	3 (PPI Chp. 12). Calculated
f6	deflection limit in section D4.1
8	$f_{o_short} \coloneqq 0.88$
1.0	
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)^{3}$	$f_{o_short} = 112.6 \ psi$ Allowable unconstrained buckling pressure
H=38.71 ft	Elevation difference between the lowest
	Pressure of drilling slurry
$P_{mud} \coloneqq \gamma_m \bullet H = 18.82 \ \textbf{psi}$	· · · · · · · · · · · · · · · · · · ·
$P_{mud} \coloneqq \gamma_m \bullet H = 18.82 \text{ psi}$ $P_{net} \coloneqq P_{mud} = 18.82 \text{ psi}$	Net external loading with open borehole
$\begin{split} P_{mud} &\coloneqq \gamma_m \boldsymbol{\cdot} H \!=\! 18.82 ~ \textbf{psi} \\ P_{net} &\coloneqq P_{mud} \!=\! 18.82 ~ \textbf{psi} \\ Check &\coloneqq & \mathbf{if} \left(P_{UC_short} \! \! > \! P_{net}, \text{``okay''}, \right. \end{split}$	Net external loading with open borehole "not okay") = "okay"
$\begin{split} P_{mud} &\coloneqq \gamma_m \cdot H \!=\! 18.82 \ \textit{psi} \\ P_{net} &\coloneqq P_{mud} \!=\! 18.82 \ \textit{psi} \\ \\ Check &\coloneqq & \text{if} \left(P_{UC_short} \! \! > \! P_{net}, \text{``okay''}, \right. \\ \\ & \text{D5.2 - Unconstrained Ring Buckling,} \end{split}$	Net external loading with open borehole "not okay") = "okay" Levy's Equation (Long Term)
$P_{mud} \coloneqq \gamma_m \cdot H = 18.82 \text{ psi}$ $P_{net} \coloneqq P_{mud} = 18.82 \text{ psi}$ $Check \coloneqq \text{if } (P_{UC_short} > P_{net}, \text{``okay''}, \text{D5.2 - Unconstrained Ring Buckling,}$ Note that constraining the pipe will in considering an unconstrained conditi	Net external loading with open borehole "not okay") = "okay" Levy's Equation (Long Term) ncrease the pipe's buckling strength, therefore
$P_{mud} \coloneqq \gamma_m \cdot H = 18.82 \text{ psi}$ $P_{net} \coloneqq P_{mud} = 18.82 \text{ psi}$ $Check \coloneqq \text{if } \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{D5.2 - Unconstrained Ring Buckling,} \right)$ Note that constraining the pipe will in considering an unconstrained conditi $N = 2.0$	Net external loading with open borehole "not okay") = "okay" Levy's Equation (Long Term) ncrease the pipe's buckling strength, therefore on will produce a conservative value. Eactor of Safety
$P_{mud} \coloneqq \gamma_m \cdot H = 18.82 \ psi$ $P_{net} \coloneqq P_{mud} = 18.82 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{D5.2 - Unconstrained Ring Buckling,} \text{Note that constraining the pipe will in considering an unconstrained conditi}$ $N \coloneqq 2.0$ $\mu_{trav} \coloneqq 0.45$	Net external loading with open borehole "not okay") = "okay" Levy's Equation (Long Term) ncrease the pipe's buckling strength, therefore on will produce a conservative value. Factor of Safety Poisson's Ratio for PE pipe material

	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #108- Flats Rd & Murderers Creek Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23
$E_{long} {=} 28200 \; {\it psi}$		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
$P \sim \left(2 \cdot E_{long} \right)$	1 $)^3 f_{o_long}$	- 21.1 mai
$P_{UC_long} \coloneqq \left(\frac{1 - \mu_{long}^2}{1 - \mu_{long}^2} \right)^{\bullet} \left(\frac{1}{D} \right)$	$\overline{R_1-1}$) \cdot N	Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 11.18 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left(P_{UC_long} > P_{net}, \right.$	"okay", "not oka	y") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #108- Flats Rd & Murderers Creek Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/17/23

References

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- 2. ASTM F 1804-08 Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
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- 6. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill


Project:ChaiTunnel No.:CrosDescription:PullCalculated by: SADateChecked by: DADate

Champlain Hudson Power Express - Package 6 Crossing # 109 - Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

fining Parameters of Horizontal Dire	ectional Drilling :
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 3.5 \ in$	Pipe 2 outer diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$T_{n1} := \frac{D_1}{1} = 1.194 \ in$	Thickness of Pipe 1
$\stackrel{p_1}{\longrightarrow} DR_1$	
$T_{n2} := \frac{D_2}{\dots} = 0.318 \ in$	Thickness of Pipe 2
p2 DR_2	
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 := \pi \cdot D_2 = 11$ in	Pipe circumference of pipe 2
bore/pipep	ath pipe entry
1	
drill rig B D	A
	Jannin Kunning Tanananan
H	
pipe exit C	В
4	
L ₄ L ₃	
L ₄ L ₃	
L ₄ L ₃	L ₂ L ₁
L4 L3	L_2 L_1
Illustration 1 - Schematic	L_2 L_1 L_{boxe} c of Drive Cross-section
$L_4 \qquad L_3$ Illustration 1 - Schematic	L ₂ L ₁
$\begin{array}{c} \bullet \\ \mathbf{L}_{4} \\ \bullet \\ \mathbf{L}_{3} \\ \mathbf{L}_{4} \\ \mathbf{L}_{3} \\ \mathbf{L}_{3$	L ₂ L ₁ L _{box} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$\begin{array}{c} \mathbf{L}_{4} & \mathbf{L}_{3} \\ \mathbf{L}_{4} & \mathbf{L}_{3} \\ \mathbf{L}_{4} & \mathbf{L}_{3} \\ \end{array}$ Illustration 1 - Schematic $\begin{array}{c} \alpha := 10 \\ \beta := 8 \\ \beta := 8 \\ \beta := \alpha = 0.1745 \\ \mathbf{rad} \\ \beta := \beta = 0.1396 \\ \mathbf{rad} \\ D := 18 \\ \mathbf{in} \end{array}$	L ₂ L _{bore} C of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed hore diameter
$a := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{rad} := 23.8 \text{ ft}$	L ₂ L _{tore} C of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
$\alpha := 10 \circ \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \text{ ft}$	L ₂ L _{bos} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface
$\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max} := 24.55 \ ft$	L ₂ L _{tore} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface
$\begin{array}{c} \begin{array}{c} & & \\ & & \\ & \\ & \\ \end{array} \end{array} \\ Illustration 1 - Schematic \\ \hline \\ & \\ & \\ \end{array} \\ \begin{array}{c} \alpha_{in} \coloneqq \alpha = 0.1745 \ rad \\ \beta_{i=8} \circ \\ \beta_{exit} \coloneqq \beta = 0.1396 \ rad \\ D_r \coloneqq 18 \cdot in \\ H_{max} \coloneqq 23.8 \ ft \\ H_{max1} \coloneqq H_{max} + \frac{D_r}{2} = 24.55 \ ft \end{array}$	L ₂ L _{tore} C of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface Max depth to bore hole springline from ground surface
Illustration 1 - Schematic $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ rad $\beta := 8^{\circ}$ $\beta_{exit} := \beta = 0.1396$ rad $D_r := 18 \cdot in$ $H_{max} := 23.8$ ft $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55$ ft	L ₂ L _{bos} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface Max depth to bore hole springline from ground surface Tatal length of HDD crossing
$\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$	L ₂ L _{tore} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface Max depth to bore hole springline from ground surface Total length of HDD crossing
$\mathbf{A} := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_1 := 150 \ ft$	L ₂ L ₁ L _{tors} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$\mathbf{A} := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_1 := 150 \ ft$	L ₂ L _{bos} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surfac Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$\mathbf{A} := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_1 := 150 \ ft$ $L_2 := 49.8 \ ft$	L ₂ L ₁ L _{box} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface 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 -
$\mathbf{L}_{4} \qquad \mathbf{L}_{3}$ Illustration 1 - Schematic $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_{r} := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_{r}}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_{1} := 150 \ ft$ $L_{2} := 49.8 \ ft$	L ₂ L ₁ L _{tors} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surfac Max depth to bore hole from ground surfac 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 $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ rad $\beta := 8^{\circ}$ $\beta_{exit} := \beta = 0.1396$ rad $D_r := 18 \cdot in$ $H_{max} := 23.8$ ft $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55$ ft $L_{total} := 556.5$ ft $L_1 := 150$ ft $L_2 := 49.8$ ft $L_3 := 73.2$ ft	L ₂ L ₁ L ₀₀₈ c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surfac 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
$\mathbf{L}_{4} \qquad \mathbf{L}_{3}$ Illustration 1 - Schematic $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_{r} := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_{r}}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_{1} := 150 \ ft$ $L_{2} := 49.8 \ ft$ $L_{3} := 73.2 \ ft$ $L_{4} := 233.9 \ ft$	L ₂ L ₁ L _{tore} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface 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 Horizontal distance to rise to surface, See
$\mathbf{L}_{4} \qquad \mathbf{L}_{3}$ Illustration 1 - Schematic $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_{r} := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_{r}}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_{1} := 150 \ ft$ $L_{2} := 49.8 \ ft$ $L_{3} := 73.2 \ ft$ $L_{4} := 233.9 \ ft$	L ₂ L ₁ L _{tore} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface 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 Horizontal distance to rise to surface, See Illustration 1
Illustration 1 - Schematic $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ}$ $\beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_1 := 150 \ ft$ $L_2 := 49.8 \ ft$ $L_3 := 73.2 \ ft$ $H_{i} := 233.9 \ ft$ $H := 25.2 \ ft$	L ₂ L ₁ L _{tore} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface 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 Horizontal distance to rise to surface, See Illustration 1 Elevation difference between the lowest
Illustration 1 - Schematic $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 8^{\circ}$ $\beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.8 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 24.55 \ ft$ $L_{total} := 556.5 \ ft$ $L_1 := 150 \ ft$ $L_2 := 49.8 \ ft$ $L_3 := 73.2 \ ft$ $H := 25.2 \ ft$	L ₂ L ₁ L ₁ L _{box} c of Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole from ground surface 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 Horizontal distance to rise to surface, See Illustration 1 Elevation difference between the lowest point in borehole and entry or exit pit,

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: SA Checked by: DA	Champlain Hudson Power Express - Package 6 Crossing # 109 - Culvert Crossing 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
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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
$R \coloneqq \frac{R_{avg._in} + R_{avg._out}}{2} = 100$	0 <i>ft</i>	Average radius of curvature at entry
$r := 40 \cdot D_1 = 36 \ ft$		
$Check \coloneqq \mathbf{if} \left(R_{avg_in} > r , \text{``oka} \right)$	y", "not okay")=	= "okay"
$Check \coloneqq \mathbf{if} \left(R_{avg_out} > r, \text{``oka} \right)$	ay", "not okay")	= "okay"

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

$e_a := \frac{D_1}{2 \cdot R} = 0.0004$	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



Champlain Hudson Power Express - Package 6 Crossing # 109 - Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

B - Site Specific Analyses: Pullback Force: B1 - Empty Pipe B1.1 - Effective Weight of Empty Pipe: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.7 \ plf$ B1.2 - Upward Buoyant Force: Effective weight $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{\Lambda}\right) \rho_w \cdot \gamma_b - w_a = 40.1 \ plf \quad \text{Upward buoyant force of empty pipe}$ B1.3 - Hydrokinetic Pressure: $\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 770 \ lbf \text{ Hydrokinetic force}$ B1.4 - Pullback Force Point A: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 447 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_a + v_b \cdot \left| w_b \right| \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 2063 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 2876 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 4721 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max \ empty} := \max(T_a, T_b, T_c, T_d) + \Delta T = 5492 \ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} \coloneqq \left(\frac{\left(\pi \cdot D_1^{\ 2} \right)}{4} \right) \cdot \rho_w \cdot \left(\gamma_b - \gamma_c \cdot \left(1 - \left(\frac{2}{DR_1} \right) \right)^2 \right) - w_a = 11.7 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 447 \ \textit{lbf} \quad \text{Pullback force enter ground}$



Champlain Hudson Power Express - Package 6 Crossing # 109 - Culvert Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

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 + v_b \cdot \left B_2 \cdot 4 - Pullback Force Point C: \right $	$v_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 993 \ lbf$ Pullback force increase and decrease with depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_{in} \right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 1182 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} := e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_4 \cdot $	$-e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 1867 \ lbf$
<u> B2.6 - Maximum Pullback Force - Filled Pipe</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$) = 1867 <i>lbf</i> Maximum Pullback Force
33 - Safe Pull Strength / Ultimate Tensile	e Load Check:
B3.1 Safe Pullback Check	
$A_1 \coloneqq \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 \coloneqq \frac{\pi}{4} \left(D_2^2 - \left(D_2 - T_{p2} \right)^2 \right) = 1.7 \ in^2$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 5049 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} := \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 443 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 1716 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 150 \ lbf$	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> _{SPF2} ≔1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check \coloneqq if (P_{SPF1} > P_{11}, "okay", "not okay")$	") = "okay"
$check \coloneqq if(P_{SPF2} > P_{21}, "okay", "not okay")$	") = "okay"
$check := if (P_{SPF1} > P_{12}, "okay", "not okay")$	() = "okay" () = "okay"
r_{22} , r_{2	/- Okay



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

C1 - Max. Allowable Driling Fluid Pressure

 $H_w \coloneqq 0 \cdot ft$ Depth of the bore below groundwater elevation $H_c \coloneqq 22.5 \ ft$ Vertical separation distance between critical structure and pipe (\sim 2+75) $\gamma \coloneqq 100 \ pcf$ Unit weight of CH (K-216.2 and B-216.1) $\gamma_w \coloneqq 62.4 \ pcf$ 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 $\phi \coloneqq 0 \ deg$ Friction Angle *c* ≔ 450 *psf* Assumed cohesion of encountered material $R_0 \coloneqq \frac{D_r}{2} = 9 \, in$ Initial radius of the borehole $R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 11 \ ft$ Radius of plastic zone (H/2 in clays & 2/3 H in sands) $\sigma'_0 \coloneqq \left(\gamma \boldsymbol{\cdot} \left(H_c \!-\! H_w\right)\right) + \gamma' \boldsymbol{\cdot} H_w \!=\! 16 \hspace{0.1cm} psi$ Initial effective stress (no GWT Table C.2 Typical values of modulus of elasticity (Es) for different types of soils Type of Soil E_s (N/mm²) Clay Very soft 2-15 $E_s := 5 \frac{N}{mm^2} = 725 \ psi$ Soft 5-25 Medium 15-50 Hard 50-100 25-250 Sandy Glacial till Assumed modulus of elasticity of CH 10-153 Loose Dense 144-720 Very dense 478-1 440 Loess 14-57 Sand Silty 7-21 Loose 10-24 48-81 Dense Sand and gravel Loose 48-148 96-192 Dense Shale 144-14,400 Silt 2-20 Table C.4 Typical values of Poisson's ratio (µ) for soils Type of soil μ Clay (saturated) 0.4 - 0.5Clay (unsaturated) 0.1 - 0.3 $\nu_s \coloneqq 0.4$ Sandy clay 02 - 03Silt 0.3 - 0.35Poissions ratio of material encountered Sand (dense) 0.2 - 0.4Course (void ratio = 0.4 - 0.7) 0.15 Fine grained (void ratio = 0.4 - 0.7) 0.25 Rock 0.1-0.4 (depends on type of rock) Loess 0.1 - 0.3Ice 0 36 0.15 Concrete

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$G \coloneqq \frac{E_s}{2 \ (1 + \nu_s)} = 258.996 \ psr$	i	Shear modulus of soil
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + (c \cdot 0)}{G} = 0$	0	Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$s(\phi) = 18.8 \ psi$	
1 j 0 ((<i>i</i>) j		Mud pressure at which the first plastic deformation takes place
	$\left(\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}\right)$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\frac{R_0}{R_{pm}}\right)\right)$	$\left(\frac{1}{2}\right)^2 + Q$	$-c \cdot 0 = 18.8 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 18.8 \ psi$ C2 -Min. Allowable Drilling I	Fluid Pressure	Maximum allowable mud pressure
$D_{PT} \coloneqq 3.5 \ in$		Pilot tube diameter
$D_0 := 9.5 in$		Initial borehole diameter for pilot tube
$h \approx 25.2 \ ft$		hole front and exit point of mud flow
$\gamma_m = 70 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 12.3 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v \coloneqq \frac{Q_f}{0.785 \left(D_0^2 - D_{PT}^2\right)} = 62$	$2.9 \frac{ft}{min}$	Computed mud flow velocity
$L_{total} \!=\! 556.5 \; ft$		Total length of HDD crossing
$p_2 := L_{total} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \right)$	$-\left(\frac{\tau_o}{\left(D_0 - D_{PT}\right)}\right) = 1$	1.2 <i>psi</i>
		Minimum required mud pressure to create flow inside the borehole
$p_{min.} = p_1 + p_2 = 13.5 \ psi$		Minimum required mud pressure



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1- Ring Deflection (Short & Long Term)	
D1.1 - Overburden Pressure (Considering D	eformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 23.8 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18 in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	Arching factor (Eq. (p. 422, DDI)
$k \coloneqq \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right) \equiv \ell k \coloneqq 1$	
$P_E \coloneqq k \cdot (\gamma - \gamma_m) \cdot (H_c) = 5 \ psi$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{3} = 9.36 \ psi$	Variable in earth load deflection equation
$12 \cdot (DR_1 - 1)$	
$\Delta y_{ELD_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.7\%$	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)
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
(125, P)	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \coloneqq \frac{0.0123 \cdot \Gamma_E}{k} = 1.4\%$	PPI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflectio	<u>n</u>	
D2.1 Buoyant Deflectio	n <u>(Short Term)</u>	
$D_1 \!=\! 10.75 in$		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
4 ³ in ⁴		borehole (Slurry unit weight)
$I := \frac{\iota}{\iota} = 0.14 \frac{\iota}{\iota}$		Moment of inertia of pipe wall cross
12 in	$(D_1)^4$	section
$0.1169 \cdot \gamma_m$	$\cdot \left \frac{D_1}{2} \right $	Pipe ring deflection to buoyant force
$\Delta y_{bounant} \coloneqq$	(2) = 0.0	ASTM F 1962 (Eq. X2.6, p.6)
E_{short}	• <i>I</i>	
D2.1 Buoyant Deflectio	n (Long Term)	
D3 - Reissner Effect De	fter a 1-week period fro ffection (Short Term) Deflection (Short Term)	m installation/pumping.
$\mu_{short} \coloneqq 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \; ft$		Radius of curvature
3	4	
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D\right)}{16 \cdot t^2 \cdot R^2}$	(1-t) = 0.0000033	Deflection due to longitudinal bending
$\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{7}{13}\right) \cdot $	$\left(\frac{1}{35}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect I	Deflection (Long Term)	
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$		Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{long} \coloneqq 0.45$ $R = 1000 ft$ $3 (-2) (-2)$	A 4	Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1\right)$	$(-t)^4$	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
$\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$ $z \coloneqq \frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1\right)$	$(-t)^4 = 0.000003$	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
$\mu_{long} := 0.45$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{long}^{2}) \ (D_{1})}{16 \cdot t^{2} \cdot R^{2}}$	$(-t)^4 = 0.000003$	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
$\mu_{long} \coloneqq 0.45$ $R \equiv 1000 \ ft$ $z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{long}^2\right) \left(D_1\right)}{16 \cdot t^2 \cdot R^2}$ $\Delta y_{R_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{7}{13}\right)$	$\frac{(-t)^4}{(-t)^4} = 0.000003$ $\frac{1}{(5)} \cdot z^2 = 0.0002\%$	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 Pipe ring deflection due to the Reisnner Effect, long term

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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	

 $\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short} = 0.7\%$ Percent ring deflection in short term analysis

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

D4.2 - Net Long Term

 $\Delta y_{long_net} \coloneqq \Delta y_{ELD_long} + \Delta y_{R_long} = 1.4\%$

Percent ring deflection in long term analysis (50 years)

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



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Note that constraining the pipe will	increase the pipe's buckling strength, therefore
considering an unconstrained condition	tion will produce a conservative value.
N:=2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material a 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 loa
% DEFLECTION	(Table X1.1 ASTM F 1962)
0.0 2 4 6 8 10	12
2	Ovality compensation factor, Figure
f ₀ ,4,,,,,,,,	- 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
10	
8	$f_{o_short} \coloneqq 0.98$
1.0	
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$	³ $\cdot \frac{f_{o_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
$H = 25.2 \ ft$	Elevation difference between the low
$P_{mud} \coloneqq \gamma_m \cdot H = 12.25 \ psi$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 12.25 \ psi$	Net external loading with open boreh
$Check \coloneqq \mathbf{if} \left(P_{UC_short} > P_{net}, \text{``okay''} \right)$, "not okay") = "okay"
D5.2 - Unconstrained Ring Buckling	, Levy's Equation (Long Term)
Note that constraining the pipe will considering an unconstrained condi	increase the pipe's buckling strength, therefore
$N \coloneqq 2.0$	Factor of Safety
0.45	Poisson's Ratio for PE nine 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)
$f_{o_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right) \cdot \left(\frac{1}{DE}\right)$	$\left(\frac{1}{R_1-1}\right)^3 \cdot \frac{f_{o_long}}{N} =$	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
$Check \coloneqq if (P_{UC_long} > P_{net}, "$	okay", "not 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. Mohammad Najafi, 2013, Trenchless Technology, First Edition, McGraw Hill
- 4. Larry Slavin, 2009, Guidelines for Use of Mini-Horizontal Direction Drilling for Placement of High Density Polyethylene Pipe
- 5. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition





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Defining Parameters of Horizontal Directi	onal Drilling :
$D_1 := 10.75 \ in$	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
D.	
$T_{p1} := \frac{D_1}{DR} = 1.194 \ in$	Thickness of Pipe 1
DR_1 D_2	
$T_{p2} := \frac{-2}{DB} = 0.216 in$	Thickness of Pipe 2
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \text{ in}$	Pipe circumference of pipe 1
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2
bees/ pin a path	
oore/pipepau	pipeentry
drill rig B	
PD	
H	
nine exit C	B
pipean	
L_4 L_3	L ₂ L ₁
Loor	
Illustration 1 - Schematic of	Drive Cross-section
$\alpha \coloneqq 8^{\circ}$ $\alpha_{in} \coloneqq \alpha = 0.1396 \ rad$	Borehole entry angle (degrees, radians)
$\beta \coloneqq 10^{\circ}$ $\beta_{crit} \coloneqq \beta = 0.1745 \ rad$	Borehole exit angle (degrees, radians)
$D_r := 18 \cdot in$	Final reamed bore diameter
$H_{max} \coloneqq 30.9 \ ft$	Max depth of bore hole to final reamed bore
	diameter
$H_{max1} \coloneqq H_{max} + \frac{D_r}{max} = 31.65 \ ft$	Max depth to bore hole springline from
	ground surface
$L_{total} \coloneqq 1155.8 \ ft$	Total length of HDD crossing
$L_1 := 150 \ ft$	Assumed pipe drag on surface, See
	Illustration 1
$L_2 := 337.7 \ ft$	Horizontal length to achieve depth -
	provided by Contractor, See Illustration 1
$L_3 := 668.2 \ ft$	Straight horizontal section
$L_4 := 149.9 \ ft$	Horizontal distance to rise to surface, See
	Illustration 1
$H \coloneqq 25.5 \ ft$	Elevation difference between the lowest
	point in borehole and slurry pump elevation
	(entry or exit pit), See Illustration 1

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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
$\gamma_m \coloneqq 70 \ pcf$		Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.1$		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
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 1000$) <i>ft</i>	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} \! > \! r_{rod}, \text{``ok} \right)$	xay", "not okay")="okay"
$Check \coloneqq \mathbf{if} \left(R_{avg._out} \! > \! r_{rod}, "or the second sec$	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
$E_{12hr} \coloneqq 57500 \cdot psi$	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: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 38 \ plf \qquad \text{Upward buoyant force of empty pipe}$ 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: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1097 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_{b} := e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 6085 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 13115 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 14248 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max \ empty} \coloneqq \max \left(T_a, T_b, T_c, T_d\right) + \Delta T = 15045 \ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \boldsymbol{\cdot} \boldsymbol{D}_{1}^{-2} \right)}{4} \right) \boldsymbol{\cdot} \rho_{w} \boldsymbol{\cdot} \left(\gamma_{b} - \gamma_{c} \boldsymbol{\cdot} \left(1 - \left(\frac{2}{DR_{1}} \right) \right)^{z} \right) - w_{a} = 12 \ \boldsymbol{plf}$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

$$T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1097 \ \textit{lbf} \quad \text{Pullback force enter ground}$$



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left(T_{afilled} + v_b \cdot w_{bfilled} \cdot L_2 + C_2 \right)$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 3100 \ lbf$ Pullback force increase and decrease with
<u>B2.4 - Pullback Force Point C:</u>	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 ight) - e^{\left(v_b \cdot lpha ight)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot lpha_{in})}) = 4928 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot w_{bfilled} \cdot L_{exit}\right)$	$(v_4 - e^{(v_a \cdot lpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot lpha_{in})})) = 5629 \ lbf$
<u>B2.6 - Maximum Pullback Force - Filled Pir</u>	<u>pe with Water:</u>
$P_{max} \! \coloneqq \! \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}, T_{dfilled$	$(d_{cd}) = 5629 \ lbf$ Maximum Pullback Force
B3 - Safe Pull Strength / Ultimate Tensi	ile Load Check:
B3.1 Safe Pullback Check	
$A_1 \coloneqq \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 \! \coloneqq \! rac{\pi}{4} \left({D_2}^2 \! - \! \left(\! D_2 \! - \! T_{p2} \! ight)^2 ight) \! = \! 0.8 \; m{in}^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 14461 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} \coloneqq \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 584 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 5411 \ lbf$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 218 \ lbf$	Pullback forces acting on Pipe 2 (Ballast)
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
$P_{SPF2} \coloneqq 1683 \ lbf$	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check := if(P_{SPF1} > P_{11}, "okay", "not okay")$	$y^{\prime\prime}$) = "okay"
$check := if (P_{SPF2} > P_{21}, "okay", "not okay)$	y'' = ``okay''
$check := if (P_{SPF2} > P_{22}, "okay", "not okay")$	(v) = 0 (v) $(v) = 0$ (v) (



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

<u>C1</u>	- Max.	Allowa	ble D	riling	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.

	$v := 0 \cdot ft$	Dept eleva	h of the bore below groundwater ation
H	:= 25.6 ft	Verti struc	cal separation distance between critical cture and pipe (~3+50)
γ :	= 110 pcf	Assu	med unit weight soft to clay/silt
		(N =	7 to 16; med. stiff clay)
e /	-62 1 maf	Lipit	weight of water
1 w		Offic	
γ'	$=\gamma - \gamma_w = 47.6 \ pcf$	Effec	ctive unit weight
u:	$= \gamma_w \cdot H_w = 0 psi$	Initia	al pore water pressure
<u></u> .	=0 dea	Assu	med friction Angle
φ.	-800 mof -5 EG ma	Accu	mod cohosion of oncountorod material
C	$= 800 \ ps_j = 5.50 \ ps_j$	ASSU	
R_0	$=\frac{D_{rod}}{2}=1.75$ in	Initia	al radius of the borehole
	1		
$ R_p$	$max := \frac{13}{2} \cdot H_c = 13 \text{ ft}$	Radi	us of plastic zone (H/2 in clays &
R_{p}	$max \coloneqq \frac{13}{2} \cdot H_c = 13 ft$	Radi 2/3 I	us of plastic zone (H/2 in clays & H in sands)
$\frac{R_{\mu}}{\sigma_{0}^{\prime}}$ Table C.	$max \coloneqq \frac{1}{2} \cdot H_c = 13 ft$ $\gamma \coloneqq (\gamma \cdot (H_c - H_w)) + 2$ Typical values of modulus of elast	Radi $2/3$ $\gamma' \cdot H_w = 20 \ psi$ Initia	us of plastic zone (H/2 in clays & H in sands) al effective stress
R_p σ_0'	$\begin{array}{l} \underset{max}{\underset{max}{\underset{max}{:=}} \bullet H_c = 13 \ ft}{} \\ \eta := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \\ 2 \\ \hline \end{array}$ Type of Soil	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils <u>E_s (N/mm²)</u>	us of plastic zone (H/2 in clays & H in sands) al effective stress
σ_{0} Table C.	$\begin{array}{l} \underset{max}{\underset{max}{\underset{max}{:=}} \bullet H_c = 13 \ ft}{_{2} \bullet H_c = 13 \ ft} \\ \underset{max}{\underset{max}{:=}} \bullet H_c = 13 \ ft \\ \underset{max}{\overset{max}{\underset{max}{:=}} \bullet H_c = 13 \ ft \\ _{2} \bullet H_c = 13 \ ft \\ _{1} \bullet H_c = 13 \ ft \\ _{2} \bullet H_c = 13 \ ft \\ _{2} \bullet H_c = 13 \ ft \\ _{1} \bullet H_c = 13 \ ft \\ _{2} \bullet H_c = $	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia <u>icity (E_s) for different types of soils</u> <u>E_s (N/mm²)</u>	us of plastic zone (H/2 in clays & H in sands) al effective stress
σ_{L} Table C.	$\begin{array}{l} \underset{max}{\operatorname{max}} \coloneqq \frac{13}{2} \cdot H_c = 13 ft\\ \mathfrak{f} = \left(\gamma \cdot \left(H_c - H_w\right)\right) + \\ \begin{array}{r} \underset{max}{\operatorname{Typical values of modulus of elas}}\\ \end{array}$	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils E_s (N/mm ²) 2-15	us of plastic zone (H/2 in clays & H in sands) al effective stress
σ_{L} Table C.	$\begin{array}{l} \underset{max}{\operatorname{max}} \coloneqq \frac{13}{2} \cdot H_c = 13 ft\\ \gamma \cdot \left(H_c - H_w\right) + 2 \\ \end{array}$ 2 Typical values of modulus of elast $\begin{array}{r} \hline \\ \hline \\ \hline \\ \\ \hline \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils E_s (N/mm ²) 2-15 5-25 15-50	us of plastic zone (H/2 in clays & H in sands) al effective stress
r_{r}	$\begin{array}{l} \underset{max}{\operatorname{max}} \coloneqq \frac{13}{2} \cdot H_c = 13 ft\\ \gamma \cdot \left(H_c - H_w\right) + 2 \\ \begin{array}{r} \\ \underset{max}{\operatorname{Typical values of modulus of elas}} \\ \\ \hline \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils E_s (N/mm ²) 2-15 5-25 15-50 50-100 E_s :=	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 psi$
r_r	$\begin{array}{l} \underset{max}{\underset{l}{\underset{l}{\underset{l}{\underset{l}{\underset{l}{\underset{l}{\underset{l}{$	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils E_s (N/mm ²) 2-15 5-25 15-50 50-100 25-250 $E_s :=$	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \ psi$
r_r	$\begin{array}{l} \underset{max}{\operatorname{max}} \coloneqq \frac{13}{2} \cdot H_c = 13 ft\\ \gamma \cdot \left(H_c - H_w\right) + 2 \\ \begin{array}{r} \\ \begin{array}{r} \\ \end{array} \end{array}$ 2 Typical values of modulus of elas \\ \hline \hline \\ \\ \hline \\ \\ \end{array} \\ \begin{array}{r} \\ \hline \\ \\ \end{array} \\ \begin{array}{r} \\ \\ \end{array} \\ \begin{array}{r} \\ \\ \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \\ \end{array} \\ \begin{array}{r} \\ \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\ \end{array} \\ \end{array} \\ \begin{array}{r} \\ \end{array} \\	Radi 2/3 I $\gamma' \cdot H_w = 20 \ psi$ Initia ticity (E _s) for different types of soils E_s (N/mm ²) 2-15 5-25 15-50 50-100 25-250 Assu	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 psi$ med modulus of elasticity
r_r	$\begin{array}{l} \max \coloneqq \frac{1}{2} \cdot H_c = 13 \ ft\\ \eta \coloneqq \frac{1}{2} \cdot H_c = 13 \ ft\\ \eta \coloneqq \frac{1}{2} \cdot \left(H_c - H_w\right) + \frac{1}{2} \\ 1 \ \text{Typical values of modulus of elas} \\ \hline \frac{1}{2} \ \text{Type of Soil} \\ \hline \frac{1}{2} \ \text{Clay} \\ \text{Very soft} \\ \text{Soft} \\ \text{Medium} \\ \text{Hard} \\ \text{Sandy} \\ \text{Glacial till} \\ \text{Loose} \end{array}$	Radii $\gamma' \cdot H_w = 20$ psiInitiaficity (E_s) for different types of soils E_s (N/mm²)2-155-2515-5050-10025-25010-153	us of plastic zone (H/2 in clays & H in sands) al effective stress $\frac{15}{\frac{N}{mm^2}} = 2176 \text{ psi}$ med modulus of elasticity
r_{r}	$\begin{array}{l} \max \coloneqq \frac{13}{2} \cdot H_c = 13 \ ft\\ \gamma \leftarrow \left(H_c - H_w\right)\right) + \\ \begin{array}{l} \text{2 Typical values of modulus of elax} \\ \hline \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \\ \hline \\ \\ \hline \\$	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_s (N/mm²) 2-15 5-25 15-50 50-100 25-250 10-153 144-720	us of plastic zone (H/2 in clays & H in sands) al effective stress $\frac{15}{mm^2} = 2176 \ psi$ med modulus of elasticity
r_{r}	$\begin{array}{l} \max \coloneqq \frac{13}{2} \cdot H_c = 13 \ ft\\ \gamma \cdot \left(H_c - H_w\right) + \frac{1}{2} \\ \text{Typical values of modulus of elast} \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \\ \hline \\ \\ \hline \\$	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440	us of plastic zone (H/2 in clays & H in sands) al effective stress $\frac{15}{mm^2} = 2176 \ psi$ med modulus of elasticity
r_r	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elast Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Loes Loe	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57	us of plastic zone (H/2 in clays & H in sands) al effective stress $\frac{15}{mm^2} = 2176 \ psi$ med modulus of elasticity
σ_0	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elast Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Situe	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
σ_0	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elast Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57 7-21 10-24	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
σ_0	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elast Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Dense	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) 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 10-24 48-81	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
σ_0	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + 2 \text{ Typical values of modulus of elass}$ 2 Typical values of modulus of elass 2 Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) 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 10-24 48-81	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
σ_0	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + 2 \text{ Typical values of modulus of elast}$ 2 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	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 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	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
r_{T}	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elas 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 Dense Sand and gravel Loose Dense Sand and gravel Loose Dense	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_x (N/mm²) 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	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \text{ psi}$ med modulus of elasticity
r_{T}	$\max := \frac{1}{2} \cdot H_c = 13 \text{ ft}$ $y := \left(\gamma \cdot \left(H_c - H_w\right)\right) + \frac{1}{2}$ Typical values of modulus of elas 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 Dense Sand and gravel Loose Dense Sand and gravel Loose Dense Shale	Radi $\gamma' \cdot H_w = 20$ psi Initia ticity (E_s) for different types of soils E_i (N/mm²) 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 96-192 144-14,400	us of plastic zone (H/2 in clays & H in sands) al effective stress $15 \frac{N}{mm^2} = 2176 \ psi$ med modulus of elasticity

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #110- Wetlands Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
Table C.4 Typical values of Poisson's ratio (μ) for soils		
Type of soil μ 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 Fine grained (void ratio = 0.4 - 0.7) 0.25 Partic	and an trace of early	$\nu_s = 0.5$
Loess 0.1-0.4 (dep Loess 0.1-0.3 Loe	ends on type of tock)	Poissions ratio of material encountered
Concrete 0.15		
$G \coloneqq \frac{E_s}{2(1-s)} = 725 \ psi$		Shear modulus of soil
$2(1+\nu_s)$		
$Q \coloneqq \frac{(\sigma'_0 \cdot \sin(\phi)) + (c \cdot 0)}{G} =$	0	
		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot cc$	$\cos(\phi) = 25.1 \ psi$	
		Mud pressure at which the first plastic deformation takes place
($\left(\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}\right)$	
$((R_{i}))$	$\begin{pmatrix} 2 \\ 0 \end{pmatrix}^2$	
$p'_{max} \coloneqq (p'_f + (c \cdot 0)) \cdot \left(\left \left \frac{R_{pm}}{R_{pm}} \right \right) \right $	$\left \frac{1}{nax} \right + Q$	$-c \cdot 0 = 25.1 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} := u + p'_{max} = 25.1 \ psi$		Maximum allowable mud pressure
C2 -Min. Allowable Drilling	<u>Fluid Pressure</u>	
$D_{PT} := 5$ in		Pilot tube diameter
$D_0 = 9.5 in$		Initial borehole diameter for pilot tube
$h \coloneqq 25.6 \ ft$		Elevation difference between level of bore hole front and exit point of mud flow
$\gamma_m = 70 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 12.4 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v \coloneqq rac{Q_f}{0.785 \left({D_0}^2 - {D_{PT}}^2 ight)} = 7$	$5.2 \ \frac{ft}{min}$	Computed mud flow velocity

Champlain Hudson Power Express - Package 6 Project: KILDUF Tunnel No.: Crossing #110- Wetlands Crossing Description: Pull Back and Mud Pressure Calcs UNDERGROUND ENGINEERING, INC. Calculated by: DA Date: 4/13/23 R1: 6/12/23 Checked by: NW Date: 4/17/23 $L_{structure} \coloneqq 350 \ ft$ Length to sturcture $p_2 \coloneqq L_{structure} \cdot \left(\left(\frac{\mu_{pl} \cdot v}{\left(D_0 - D_{PT} \right)^2} \right) + \left(\frac{\tau_o}{\left(D_0 - D_{PT} \right)} \right)$ =1 **psi** Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure $p_{min.} \coloneqq p_1 + p_2 = 13.5 \ psi$ $check \coloneqq \mathbf{if} \left(p_{max} > p_{min.}, \text{``okay''}, \text{``not okay''} \right) = \text{``okay''}$



Champlain Hudson Power Express - Package 6 Crossing #110- Wetlands Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

D1- Ring Deflection (Short & Long Term)	
D1.1 - Overburden Pressure (Considering D	Peformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 30.9 \ ft$	Depth of cover
$\phi = 0 deg$	Friction angle of soil
$B \coloneqq D_r = 18 \text{ in}$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)$	Earth pressure coefficient
$\gamma = 110 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{k \coloneqq (2)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 10 \ psi \ P_E = 1471$	<i>psf</i> Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{\text{struct}} = 57500 \cdot nsi$	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
$0.0125 \cdot P_E$	
$\Delta y_{ELD_short} \coloneqq \underbrace{k_{short}} = 1.4\%$	PIPE deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handbook
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 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_{\star} - 1)^3} = 4.6 \text{ psi}$	Variable in earth load deflection equation
	Pipe deflection to diameter as per
$\Delta y_{ELD_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 2.8\%$	PPI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection (S	Short Term)	
$D_1 = 10.75 in$		Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
F -		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
43		borehole (Slurry unit weight)
$I \coloneqq \frac{t}{1} = 0.14 \frac{n}{1}$		Moment of inertia of pipe wall cross
12 in (1	D_{1}	section
$0.1169 \cdot \gamma_m \cdot $	$\frac{1}{2}$	Pipe ring deflection to buoyant force
$\Delta y_{bounant} := $	$\frac{2}{2}$ = 0.0	ASTM F 1962 (Eq. X2.6, p.6)
$E_{short} \cdot I$		
D2.1 Buoyant Deflection (I	<u>_ong Term)</u>	
D3 - Reissner Effect Defle	tion (Short Term)	m installation/pumping.
$\mu_{short} \coloneqq 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature
3 (2) (-	× 4	
$z \coloneqq rac{1}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)$	t) = 0.0000033	Deflection due to longitudinal bending
$\Delta y_{R_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right)$	$\cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect Defl	ection (Long Term)	
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at
		long term (ASTM F 1962, 8.2.4.2)
$R = 1000 \; ft$		Radius of curvature
3 (2) (-	4	
$-\frac{1}{2} \cdot (1 - \mu_{long}^{2}) (D_{1} - t)$)	Deflection due to longitudinal bending
$z \coloneqq \frac{z}{10 + t^2 - D^2}$	= 0.000003	
$16 \cdot t^- \cdot R^-$		
$\Delta y_{R_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z = \left(\frac{71}{135}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z = \left(\frac{7}{135}\right) \cdot z = \left(\frac{7}{135$	$\cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term

KILDUFF	4	6	
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 $\Delta y_{lim} = 7.5\%$

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D4	NISL	D :	Deflection
<u>D4 -</u>	net	KING	Deflection

Deflection limit for DR 9 non pressurized
pipe (Table 2 , p. 437, PPI Handbook)

D4.1 - Net Short Term

 $\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short} = 1.4\%$ Percent ring deflection in short term analysis

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

D4.2 - Net Long Term

 $\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \Delta y_{R_long} \! = \! 2.8\%$

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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Note that constraining the pipe will	increase the pipe's buckling strength, therefore
considering an unconstrained condi	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 loadin
% DEFLECTION	(Table XI.I ASTM F 1962)
0.0 2 4 6 8 10	45
5	Ovality compensation factor, Figure
0 4	3 (PPI Chp. 12). Calculated
lt 10	deflection limit in section D4.1
	$f_{-} := 0.87$
8	$J_{o_short} = 0.01$
1.0	
$P = \left(\begin{array}{c} 2 \cdot E_{short} \end{array} \right) \left(\begin{array}{c} 1 \end{array} \right)$	$\int_{a}^{3} f_{o_short} = 111.2$ mei. Allowable unconstrained
$\Gamma_{UC_short} = \left(\frac{1 - \mu_{short}^2}{1 - \mu_{short}^2}\right) \cdot \left(\frac{DR_1 - 1}{DR_1 - 1}\right)$	N = 111.5 psi Allowable unconstrained buckling pressure
H = 25.5 ft	Elevation difference between the lowest
	point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 12.4 \text{ psi}$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 12.4 \ psi$	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	, Levy's Equation (Long Term)
	increase the pipe's buckling strength, therefore
Note that constraining the pipe will	
Note that constraining the pipe will considering an unconstrained condi	tion will produce a conservative value.
Note that constraining the pipe will considering an unconstrained condi N := 2.0	Factor of Safety

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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
$P_{UC_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1}{DE}\right)$	$\frac{1}{R_1-1}\Big)^3 \cdot \frac{f_{o_long}}{N} =$	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
$Check \coloneqq if \left(P_{UC_long} > P_{net}, " \right)$	okay", "not 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



Project:ChanTunnel No.:CrossDescription:Pull ECalculated by: DADateChecked by: NWDate

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Defining Parameters of Horizontal Direction	onal Drilling :
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$\tilde{D_{rod}} = 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$T_{p1} := \frac{D_1}{DR_1} = 1.194 \ in$	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
$C_2 := \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
	piptany
drill rig B	A /a
	runninghanningh
H	
pipe exit C	B
L_4 : L_3 :	L ₂ L ₁
Leore	- 1
Illustration 1 - Schematic of C	Drive Cross-section
$\alpha \coloneqq 8^\circ$ $\alpha_{\pm} \coloneqq \alpha = 0.1396 \ rad$	Borehole entry angle (degrees, radians)
$\beta := 10^{\circ}$ $\beta_{mit} := \beta = 0.1745 rad$	Borehole exit angle (degrees, radians)
$D \coloneqq 18 \cdot in$	Final reamed bore diameter
$H_{max} := 30.9 \ ft$	Max depth of bore hole to final reamed bore diameter
$H_{max1} := H_{max} + \frac{D_r}{2} = 31.65 \ ft$	Max depth to bore hole springline from ground surface
$L_{total} \coloneqq 1132.7 \ ft$	Total length of HDD crossing
$L_1 := 150 \ ft$	Assumed pipe drag on surface, See Illustration 1
$L_2 := 283.7 \ ft$	Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_2 := 617.0 \ ft$	Straight horizontal section
$L_4 \coloneqq 232.8 \ ft$	Horizontal distance to rise to surface, See Illustration 1
$H \coloneqq 25.3 \ \mathbf{ft}$	Elevation difference between the lowest point in borehole and slurry pump elevation (entry or exit pit), See Illustration 1

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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
$R \coloneqq \frac{R_{avg_in} + R_{avg_out}}{2} = 100$	0 <i>ft</i>	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left(R_{avg._in} \! > \! r_{rod}, "o" \right)$	kay", "not okay")="okay"
$Check \coloneqq \mathbf{if} \left(R_{avg._out} \! > \! r_{rod} , ``e_{rod} , ``e_{rod$	okay", "not okay"	")="okay"
Radius of curvature should exceed	40 times the pipe	e outside diameter to prevent ring collapse.
$e_a := \frac{D_1}{2 \cdot R} = 0.0004$		Strain within the casing pipe
$\overline{E_{12hr}} \! \coloneqq \! 57500 \boldsymbol{\cdot} \boldsymbol{psi}$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)

 $S_a := e_a \cdot E_{12hr} = 25.8 \ psi$ 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: $w_{a} \coloneqq \frac{\pi}{4} \left(\left(D_{1}^{2} - \left(D_{1} - T_{p1} \right)^{2} \right) + \left(D_{2}^{2} - \left(D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ 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: $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1079 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B: $T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left(T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 7071 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C: $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 16009 \ lbf$ B1.7 - Pullback Force at D: $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 18762 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe: $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 19558\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force: $w_{bfilled} \coloneqq \left(\frac{\left(\pi \cdot D_1^{\ 2} \right)}{4} \right) \cdot \rho_w \cdot \left(\gamma_b - \gamma_c \cdot \left(1 - \left(\frac{2}{DR_1} \right) \right)^2 \right) - w_a = 24.6 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left(v_a \cdot w_a \cdot \left(L_1 + L_2 + L_3 + L_4 \right) \right) = 1079 \ lbf$ Pullback force enter ground



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot lpha_{in}} \left(T_{afilled} + v_b \cdot \left w_{bfilled} \right \cdot L_2 + C_{afilled} + $	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 4355 \ lbf$ Pullback force increase and decrease with
<u>B2.4 - Pullback Force Point C:</u>	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left w_{bfilled} \right \cdot L_3 \right) - e^{\left(v_b \cdot \alpha_b \right)}$	$^{(m)} \cdot \left(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 8376 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot \left w_{bfilled}\right \cdot L_4\right)$	$_{4} - e^{(v_{a} \cdot lpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot lpha_{in})} ight) = 10432 lbf$
B2.6 - Maximum Pullback Force - Filled Pip	e with Water:
$P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$	$d) = 10432 \ lbf$ Maximum Pullback Force
B3 - Safe Pull Strength / Ultimate Tensil	le Load Check:
B3.1 Safe Pullback Check	
$A_1 \coloneqq \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_2 \! \coloneqq \! rac{\pi}{4} \left({D_2}^2 \! - \! \left({D_2 \! - \! T_{p2}} ight)^2 ight) \! = \! 0.8 \; {\it in}^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max_empty}}{A_1 + A_2} = 18799 \ lbf$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} \coloneqq \frac{A_2 \cdot P_{max_empty}}{A_1 + A_2} = 759 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 10027 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} \coloneqq \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 405 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Ballast)
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	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"
$check := if(P_{SPF2} > P_{21}, "okay", "not okay$	") = "okay"
$cneck := \mathbf{if} (P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay})$	(") = "okay"
$r_{1} r_{1} r_{1} r_{2} r_{22}$, r_{22} , $r_{1} r_{22}$, $r_{1} r_{1} r_{1$	



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

<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.

$H_w := 0 \cdot ft$		Depth of the bore below groundwater elevation		
$H_c := 22.0 \ ft$		Vertical separation distance between critical structure and pipe (Schohaire Tkpe controls		
$\gamma \coloneqq 100 \ pcf$		Assumed unit weight soft to clay/silt		
		(zero blow count material)		
$\gamma_{w} \coloneqq 62.4 \ pcf$		Unit weight of water		
$\gamma' = \gamma - \gamma_{m} = 37.6$	pcf	Effective unit weight		
$u := \gamma \cdot H = 0$ ms	i i	Initial pore water pressure		
$\frac{d}{d} = 0 \frac{d}{d} $	•	Assumed friction Angle		
$\varphi = 0$ ueg) mat	Assumed robosion of ancountered material		
$c \coloneqq 450 \ psj = 3.13$	3 psi	Assumed conesion of encountered material		
$R_0 := \frac{D_{rod}}{2} = 1.75$	in	Initial radius of the borehole		
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 1$	1 ft	Radius of plastic zone (H/2 in clays & 2/3 H in sands)		
Table C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy	Example Contract of the second s	$E_s := 5 \frac{N}{mm^2} = 725 psi$		
Glacial till Loose	10-153			
Dense Very dense Loess Sand	144-720 478-1,440 14-57	Assumed modulus of elasticity		
Silty	7-21			
Dense	48-81			
Loose	48-148			
Dense Shale	96–192 144–14.400			
Silt	2-20			

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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) 0.1 - 0.3 Sandy clay 0.2 - 0.3 Silt 0.3 - 0.55		
Sand (dense) 0.2 - 0.4 Course (void ratio = 0.4 - 0.7) 0.15		$\nu := 0.4$
Fine grained (void ratio = 0.4 - 0.7) 0.25 Rock 0 1-0.4 (dependence)	ds on type of rock)	Poissions ratio of material encountered
Loess 0.1-0.3 Ice 0.36 Concrete 0.15		
$G \coloneqq \frac{E_s}{2 \ \left(1 + \nu_s\right)} = 259 \ psi$		Shear modulus of soil
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + \left(c \cdot 0\right)}{2} = 0$		
↓ G		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$s(\phi) = 18.4 psi$	
		Mud pressure at which the first plastic deformation takes place
	$\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}$	
$p'_{max} \coloneqq \left(p'_f + (c \cdot 0)\right) \cdot \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) \cdot \left(\left(\left(\frac{R_0}{R_{pmax}} \right) \right) \right) \right) = \left(\frac{R_0}{R_{pmax}} \right) \right)$	$\left(\frac{1}{1}\right)^2 + Q$	$-c \cdot 0 = 18.4 \ psi$
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 18.4 $ psi		Maximum allowable mud pressure
<u>C2 -Min. Allowable Drilling F</u>	luid Pressure	
$D_{PT} \coloneqq 5$ in		Pilot tube diameter
$D_0 = 9.5 in$		Initial borehole diameter for pilot tube
$h \coloneqq 18.85 \ ft$		Elevation difference between level of bore
		hole front and exit point of mud flow
$\gamma_{\rm m} = 90 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 11.8 \ psi$		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
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
$v \coloneqq rac{Q_f}{0.785 \left({D_0}^2 - {D_{PT}}^2 ight)} = 75$	$1.2 \frac{ft}{min}$	Computed mud flow velocity

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$egin{aligned} & L_{structure} &\coloneqq 125 \ ft \ & p_2 &\coloneqq L_{structure} \cdot \left(\left(rac{\mu_{pl} \cdot v}{(D_0 - D_{PT})} ight) ight) \end{aligned}$	$\left(\frac{\tau_o}{\left(D_0 - D_{PT}\right)}\right)$	Length to sturcture = $0.4 \ psi$
$p_{min.} \coloneqq p_1 + p_2 = 12.2 \ psi$		Minimum required r flow inside the bore Minimum required r

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Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure

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D1.1 - Overburden Pressure (Considering	Deformed Borehole with Arching Mobilized)	
$H_c \coloneqq H_{max} = 30.9 \ ft$	Depth of cover	
$\phi = 0 deg$	Friction angle of soil	
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value =	
$\left(\begin{array}{c} \phi \end{array} \right)^2$	reamed hole diameter	
$K \coloneqq \tan\left(45 - \frac{\varphi}{2}\right)$	Earth pressure coefficient	
$\gamma = 100 \ pcf$	Unit weight of soil, assumed	
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{R}\right)\right)$		
$k \coloneqq \frac{(B (2))}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = ? k \coloneqq$	1 Arching factor (Eq. 6, p.432, PPI)	
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 8 \ psi \qquad P_E = 1162$	2 <i>psf</i> Effective overburden pressure	
D1.2 Earth Load Deflection (Short Term)		
	Apparent modulus of elasticity for	
$E_{short} := 57500 \cdot psi$	PE4710, Base Temperature of 73 deg.	
F	Fahrenheit at 10 hrs of sustained loading (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	
$\Delta u_{\text{EFD}} := \frac{0.0125 \cdot P_E}{2} = 1.1\%$	Pipe deflection to diameter as per	
$-g_{ELD_short}$ 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	
$k \coloneqq \underbrace{E_{long}}_{3} = 4.6 \ psi$	Variable in earth load deflection equation	
$12 \cdot (DR_1 - 1)^{\circ}$		
$0.0125 \cdot P_{F}$	Pipe deflection to diameter as per	
$\Delta y_{ELD_long} \coloneqq \frac{1}{k} = 2.2\%$	PPI Equ. 10 (Chp 12, p 437)	
K		
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<u>D2 - Buoyant I</u>	Deflection	
D2.1 Buoyant	t Deflection (Short Term)	
$D_1 = 10.75$ in	ε	Outside diameter of casing pipe
$t = T_{p1} = 1.19$	94 <i>in</i>	Thickness of casing pipe
		Apparent modulus of elasticity for
$E_{short} = 57500$	D 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)
$I := \frac{\iota}{12} = 0.14$	<u></u>	Moment of inertia of pipe wall cross
12	$(D_1)^4$	section
0	$0.1169 \cdot \gamma_m \cdot \left \frac{-1}{2} \right $	Pipe ring deflection to buoyant force
	(2) = 0.1%	ASTM F 1962 (Eq. X2.6, p.6)
	$E_{short} \cdot I$	
D2.1 Buoyant	t Deflection (Long Term)	
assumed to b D3 - Reissner D3.1 - Reissn	be cured after a 1-week period fr Effect Deflection (Short Tern her Effect Deflection (Short Term	n)
$\mu_{short} \coloneqq 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu\right)}{16}$	$\frac{2}{3 \cdot t^2 \cdot R^2} \left(D_1 - t \right)^4 = 0.0000033$	Deflection due to longitudinal bending
$\Delta y_{R_short} \coloneqq \left(\frac{2}{3} \right)$	$\left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissn	er Effect Deflection (Long Term))
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu\right)}{16}$	$\frac{1}{1000} \left(D_1 - t \right)^4 = 0.000003$	Deflection due to longitudinal bending
$\Delta y_{R_long} \coloneqq \left(\frac{2}{3}\right)$	$\left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term

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D4 -	Net	Ring	Deflection

Δy_{lim} := 7.5%	Deflection limit for DR 9 non pressurized
	pipe (Table 2, p. 437, PPI Handbook)
D4.1 - Net Short Term	

 $\Delta y_{short_net} \coloneqq \Delta y_{ELD_short} + \Delta y_{bouyant} + \Delta y_{R_short} = 1.1\%$ Percent ring deflection in short term analysis

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

D4.2 - Net Long Term

 $\Delta y_{long_net} \! \coloneqq \! \Delta y_{ELD_long} \! + \Delta y_{R_long} \! = \! 2.2\%$

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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Note that constraining the pipe will in considering an unconstrained conditi	ncrease the pipe's buckling strength, therefore on will produce a conservative value.
$N \coloneqq 2.0$	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.
& DEFECTION	Fahrenheit at 10 hrs of sustained loadii (Table X1.1 ASTM F 1962)
0.0 0 2 4 6 8 10 12	
2	Ovality compensation factor. Figure
fo 4	3 (PPI Chp. 12). Calculated
9	
10	$f_{o_short} \coloneqq 0.92$
$P_{UC_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)^{3}$	f_{\bullet_short} = 117.7 psi Allowable unconstrained buckling pressure
<i>H</i> =25.3 <i>ft</i>	Elevation difference between the lowes
$P_{mud} \coloneqq \gamma_m \cdot H = 15.81 \ psi$	Pressure of drilling slurry
	Net external loading with open borehol
$P_{net} \coloneqq P_{mud} = 15.81 \ psi$	Net external loading with open borenol
$\begin{split} P_{net} &\coloneqq P_{mud} \!=\! 15.81 \ \textit{psi} \\ \\ Check &\coloneqq & \!$	"not okay") = "okay"
$P_{net} \coloneqq P_{mud} = 15.81 \text{ psi}$ $Check \coloneqq \text{if} \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{D5.2 - Unconstrained Ring Buckling,} \right)$	"not okay") = "okay" Levy's Equation (Long Term)
$P_{net} \coloneqq P_{mud} = 15.81 \ psi$ $Check \coloneqq if \left(P_{UC_short} > P_{net}, \text{``okay''}, \text{D5.2 - Unconstrained Ring Buckling,} \right)$ Note that constraining the pipe will in considering an unconstrained conditi	"not okay") = "okay" <u>Levy's Equation (Long Term)</u> ncrease the pipe's buckling strength, therefore on will produce a conservative value
$P_{net} := P_{mud} = 15.81 \ psi$ $Check := if (P_{UC_short} > P_{net}, "okay", 05.2 - Unconstrained Ring Buckling, 05.2 - Unconstrained Ring Buckling, 0.5.2 - Unconstrained Ring Buckling, 0.5.$	"not okay") = "okay" <u>Levy's Equation (Long Term)</u> ncrease the pipe's buckling strength, therefore on will produce a conservative value. Factor of Safety

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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
$\left(\begin{array}{c} 2 \cdot E_{long} \end{array}\right) \left($	$1 \rangle^3 f_{o_long}$	01.1
$P_{UC_long} \coloneqq \left(\frac{1 - \mu_{long}^2}{1 - \mu_{long}^2}\right) \cdot \left(\frac{1}{D_{L}}\right)$	$\overline{R_1-1}$) $\cdot \overline{N} =$	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
$Check \coloneqq if \left(P_{UC_long} > P_{net}, \right.$	"okay", "not okay	'') = "okay"

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